Dietrich Borchardt · Janos J. Bogardi
Ralf B. Ibisch *Editors*

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Foreword

2015 was a pivotal year for water in development generally, and for Integrated Water Resources Management (IWRM) in particular. It started with the launch of the report "Global Risks 2015" at the World Economic Forum that identified "water crises" at the top global risk in terms of impacts (eighth in terms of likelihood). In September the UN General Assembly adopted the 17 Sustainable Development Goals (the SDGs), with 169 specific targets, to guide the world's development agenda through 2030. One of the goals is to "Ensure availability and sustainable management of water and sanitation for all", and one of the six targets to be achieved under this is "By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". And 2015 ended with a new global climate agreement at COP 21 in Paris in which the critical role of water for adaptation and resilience building is highlighted.

Hence the book "Integrated Water Resources Management: Concept, Research and Implementation" addresses the right topic at the right time.

As explained in the book IWRM has developed and matured since early thoughts the 1950s through the world conferences at Mar del Plata in 1977 and Dublin in 1992, and the World Summits in Rio in 1992, in Johannesburg in 2002 and Rio in 2012, to being adopted as a global target for sustainable development in 2015. Highlights on this journey have been the four "Dublin principles" in 1992, the adoption of IWRM in Agenda 21 in 1992, the target in the Implementation Plan from Johannesburg in 2002 for "all countries to develop IWRM and Water Efficiency Plans" to the UN report to Rio+20 in 2012 reporting that 80 % of all countries were making good progress, including IWRM in national policies and legislation, while half are in an "advanced state of implementation". In a historical perspective this rapid advance of a development concept that cuts across sensitive political, cultural, economic, social and environmental dimensions is indeed remarkable.

But obviously there are questions and doubts. The IWRM concept lends itself to many interpretations, and therefore also doubts as to its apparent "success". Some critics, mainly academics, have seen IWRM as a set of principles—even brand—that does not provide a clear methodology to support actual problem solving, while most policy makers and practitioners view IWRM as a philosophy and process that provides an integrated approach to complex issues that need to be reconciled across sectors, across levels and across stakeholder interests, taking a problem-driven approach embedded in integrated thinking.

However, we have no choice. With the world having adopted the SDG target on IWRM we need to look forward, reconcile views and form alliances across civil society, public, private and academic actors towards a commonly agreed approach and set of actions that can be monitored.

So what is the main challenge and key way forward for IWRM?

At the World Water Forum in Korea in April 2015 IWRM was one of the key thematic areas and the subject of a high-level panel. The discussion up to, during and after the forum converged on a view that the implementation of IWRM invariably being a "messy, noisy process in which stakeholders are trialling solutions, negotiating choices and moving upwards and downwards between levels and sectors", picturing IWRM as a process in messy "bazaar", rather than religion in a "cathedral". This view is consistent with the "integration" in IWRM being a difficult combination of the horizontal integration between sectors and stakeholders at all levels, and the vertical integration from the local village or catchment level through basin and de-central administrative structures to the national and the regional levels. The future focus in IWRM implementation must take its point of departure in pragmatic solutions to actual problems, reconciling IWRM processes with pragmatic problem solving, from high-level policy and strategy development, through proper operating mechanisms to bridge strategy and problem solution, to monitoring of progress.

However, the world is changing and future IWRM implementation needs to adapt to new vectors such as climate change, demographic change, the water–energy–food security nexus and greening growth. The "water sector" may not be in the lead in many cases, rather, as has been recognized in the nexus debates, we need to think "beyond the water box" and include a much wider set of stakeholders and actors. The SDG on water is one of 17 goals, likely to galvanize revitalization of IWRM implementation; but most of the other 16 goals—e.g. on gender, health, food, energy, cities, ecosystems, oceans and so on—cannot be achieved without proper development and management of our scarce, vulnerable and variable water resources and we need to think and act across them. IWRM provides a vehicle for doing so.

This book provides support for that way forward. As stated in the first chapter "translation into practical implementation has been demonstrated in the various studies in this book". By addressing 10 key topics of IWRM implementation in 28 chapters the book clearly identifies the duality between "philosophy" on the one hand and "methodology" on the other, it rightly emphasizes about the adaptive management in a changing world. It also makes a clear case of the role of research and the need for future research into methodologies for implementation under different settings that can support a pragmatic approach.

For the "IWRM community", but also for a lot of people outside it, this book is an important contribution to our continued journey towards achieving the post-2015 development agenda by moving the IWRM agenda forward.

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World Water Week in Stockholm
Chief Water Policy Adviser, DHI Group
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Part I
Introduction

Chapter 1
Integrated Water Resources Management: Concept, Research and Implementation

Ralf B. Ibisch, Janos J. Bogardi and Dietrich Borchardt

Abstract This chapter reviews the concept, contemporary research efforts and the implementation of Integrated Water Resources Management (IWRM) which has evolved as the guiding water management paradigm over the last three decades. After analyzing the starting points and historical developments of the IWRM concept this chapter expands on relations with recently upcoming concepts emphasizing adaptive water management and the land-water-food-energy nexus. Although being practically adopted worldwide, IWRM is still a major research topic in water sciences and its implementation is a great challenge for many countries. We have selected fourteen comprehensive IWRM research projects with worldwide coverage for a meta-analysis of motivations, settings, approaches and implementation. Aiming to be an up-to-date interdisciplinary scientific reference, this chapter provides a comprehensive theoretical and empirical analysis of contemporary IWRM research, examples of science based implementations and a synthesis of the lessons learnt. The chapter concludes with some major future challenges, the solving of which will further strengthen the IWRM concept.

Keywords Sustainable development · IWRM · Adaptive management · Nexus approach · Global change

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1.1 Origins and Development of the Integrated Water Resources Management (IWRM) Concept

Very few ideas and recommendations have been embraced in the “water world” as quickly, enthusiastically and universally as IWRM. Hardly any major international event with relevance to water and water management, and the associated declarations have missed to endorse IWRM as the way to tackle and to solve water problems irrespective of scale and scope. Probably the most prominent among these events was the World Summit on Sustainable Development held in Johannesburg in 2002. The Johannesburg Plan of Implementation (JPoI) (United Nations 2002) stipulates that within five years all countries should have IWRM and water efficiency plans. While this appeal triggered the compilation of national IWRM plans the implementation of this resolution was much less than universal. With this resolution the JPoI placed IWRM at the national level. Other models are also promoted however. The European Water Framework Directive (EC 2000/60/EC) defines the basin and “water body” scale as appropriate for water resources management whereas other sources promote small scale, stakeholder involved IWRM (Burton 2003).

Clearly there are substantial uncertainties, if not outright differences in the interpretation of what IWRM is supposed to be. When did the concept of IWRM emerge and what were its original attributes? Report No. 7. of the EU funded NeWater Project (2005) claims that IWRM is a “Dublin-Rio” principle by referring to the respective water conference and UN Conference on Environment and Development, which both took place in 1992. This report also mentions the UN Conference in Mar del Plata 1977 as an origin and refers to UN efforts to introduce IWRM as early as the 1950s. Irrespective of these historical traces it is fair to identify the emergence of IWRM when it began occurring in laws, official government guidelines, or similar administrative documents as instructions for administration and technical services for the implementation of water resources management in a new “integrated” way. One comprehensive example of these guidelines is the Derde Nota Waterhuishouding “Water vor nu en later” (Water for Now and Later) issued by The Netherlands government (Rijkswaterstaat 1989). It is obvious that the political will and the concept of IWRM predate the Dublin Conference (Bogardi 1990). This conclusion does not aim to mitigate the significance of major international events which endorsed and scaled up IWRM. If we assume that IWRM implementation began in the late 1980s this should enable us to look back on almost three decades of experience. Yet conferences continue to issue appeals to use IWRM rather than being able to showcase many encouraging experiences and improvements gained through the application of IWRM. In this context it is worth mentioning the critical evaluation of IWRM (Biswas 2004, 2008) highlighting the meager accomplishments in applying IWRM worldwide. More than a decade after this review IWRM still looks like a cherished birthday cake, none of the guests daring to cut and savor.

The above-mentioned enthusiasm—at least verbally—for IWRM is accompanied by fairly broad interpretations (see review by Martínez-Santos et al. 2014). This might be acceptable as far as a concept or philosophy is concerned. However this "plurality" (in order to just avoid calling it "cacophony") could become a real handicap if IWRM were considered a method to be encapsulated in practical guidelines and manuals for implementation in practice.

This basically unresolved duality of IWRM being interpreted either as a philosophy, or a methodology (tool) can be seen as the main reason for its popularity and frequent endorsement, whereby being simultaneously hampered in becoming a day to day tool in water related institutions.

One core dilemma already highlighted by Bogardi (1990) is the question of what is to be integrated? This question has been reoccurring in the debate ever since (Biswas 2004; Molle 2008; Hering and Ingold 2012). There is an inherent contradiction. Integration should be as comprehensive as possible. Thus it provides an excellent concept for sketching the complexity of the problem and for drawing intricate flow charts displaying complex feedback loops and other interconnectedness. In the meantime engineering, applied science and administrative actions have been and are focusing on the main (actionable) components of a problem to be solved. No doubt this frequently implies simplification rather than expanding the integration.

By reviewing the early definitions of IWRM the different aims and aspirations of the different protagonists can be analyzed. It is worth juxtaposing some of the most prominent definitions of IWRM in order to trace the above-mentioned duality and highlight the diverging interpretations.

The Derde Nota Waterhuishouding (Rijkswaterstaat 1989) defines IWRM as

> Interrelated water resources policy making and management by government agencies responsible for the strategical and management tasks, executed on the basis of the systems concept under consideration of the internal functional relationships between quality and quantity aspects of both surface- and groundwater, as well as the external interactions between the water resources management and management of other fields like environmental protection, regional planning, nature conservation etc.

This definition is a clear example of a political/administrative guideline with clear limitations and degrees of consideration of what and how to be integrated. With the reference to systems concept even a hint of methodological prescription is given. Clearly this definition was formulated with IWRM as a practical tool in mind.

While NeWater calls IWRM a "Dublin-Rio principle" the four Dublin principles (the outcome of the Dublin Conference 1992) do not use explicitly the term "IWRM". Rather Principle 2

> Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels

refers to a participatory approach involving all stakeholders at all levels. Thus it calls for a kind of vertical integration in the sociopolitical sphere rather than emphasizing the need for the topical (horizontal) integration. It is a substantial addendum (or difference) compared to the definition by Rijkswaterstaat (1989).

Within the promulgation of the new water law of the Republic of South Africa in the late 1990s the Department of Water Affairs and Forestry (DWAF) formulated the following definition (Görgens et al. 1998)

> IWRM is a philosophy, a process and a management strategy to achieve sustainable use of the resources by all stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and integrity of water resources at the catchment scale within agreed limits.

This definition shows remarkable differences compared with the example from The Netherlands (Rijkswaterstaat 1989), regardless of the fact that in both cases the definitions are formulated by a ministry of a national government. The South African definition gives different attributes to IWRM, thus implicitly acknowledging its duality. It emphasizes the "background" and philosophical characteristics and calls it a strategic approach instead of specifying how it should be implemented. One can see that experiences made in the 1990s with attempted implementations of IWRM are already mirrored in this definition. It repeats the multistakeholder view of the Dublin principle and boasts the basin scale approach. The term "agreed limits" reflects the negotiations-based decision making process involved. Compared to the definition in the Derde Nota Waterhuishouding (Rijkswaterstaat 1989) the DWAF definition involves all levels of the jurisdictional hierarchy including the international level. It is a logical extension should the basin scale principle be consequently pursued.

The definition of the Global Water Partnership (GWP 2000)

> IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

calls IWRM a process and explicitly refers to the necessity of coordinated land and water management, a recommendation which has been repeatedly been called for (Bogardi et al. 2012). While this definition is much less prescriptive than that of the Derde Nota it explicitly links the elements of sustainable development to IWRM.

Needless to say that these three definitions are only examples—albeit the most important ones—of the broad spectrum of interpretations of IWRM. This "liberal" use of definitions was not and is not really conducive for the breakthrough of IWRM as a practical and commonly deployed tool. The critical evaluation by Biswas from 2004

> The definition of IWRM continues to be amorphous, and there is no agreement on fundamental issues like what aspect should be integrated, how by whom, or even if such integration in a wider sense is possible … in the real world, the concept will be exceedingly difficult to be made operational.

unfortunately has not lost its actuality during the last decade.

As the popularity of IWRM seems to continue unabatedly, at least as a slogan in the international water discourse, the calls for IWRM continue. The call for implementation of IWRM on all levels even appears in the recently adopted Sustainable Development Goals (SDGs) of the United Nations (Goal 6, Target 6.5), including transboundary cooperative setups by 2030. Compared to the "deadline" set out in the Johannesburg Plan of Implementation in 2002 (5 years) (United Nations 2002) at least the world gives itself 15 years to comply this time. Whether it means that the inherent obstacles are adequately assessed is yet to be seen. After the unrealistic resolution in 2002 in Johannesburg the elevation of IWRM to be part of an SDG is an opportunity, but not without risks. The credibility of the professional community, but also that of the concept is at stake. This forthcoming challenge, to be encapsulated in an intergovernmental binding resolution, underlines the importance of this book in providing a broad review of the state-of-the-art of IWRM and its various components.

After almost 30 years of less than satisfactory IWRM implementation the impression is emerging that stakeholder and other non-water professional interest groups increasingly attempt to equate IWRM with the concept of multi-stakeholder involvement (with integration thus mainly in the sociopolitical domain). While this is a fundamental requirement of planning in a pluralistic society, not only for IWRM, it can by no means be equated with IWRM. While multi-stakeholder involvement has its merits in reaching sustainable consensus solutions, reducing IWRM to a "simple" integration of various interest groups in the decision making process remains a long way from the originally high aims of IWRM as reflected for example in the Derde Nota definition in 1989.

1.2 IWRM in the Context of Adaptive Management and the Nexus Approach

IWRM gained momentum with the adoption of the Dublin principles at the World Summit in Rio de Janeiro in 1992 (Savenije and Van der Zaag 2008). The IWRM principles comprise three elements (i) the integration of different sectors and different uses and users of water, (ii) the balancing of three pillars—economic, social and environmental sustainability and (iii) the participation of stakeholders in decision-making and the strengthening of the role of women. IWRM clearly takes into account the importance of governance and management systems as well as water infrastructures and technological approaches. Emphasis is given to demand management and to some extent, the perspectives of blue and green water management are included. Nevertheless, implementation of the IWRM concept in the real world has been slow and unsatisfying and has not induced major transformations in the management of freshwater resources (Jeffrey and Gearey 2006; Mukhtarov 2008). A United Nations status report on IWRM prepared for the Rio +20 Conference documents progress in the inclusion of IWRM in national policies and legislation but also states that only half of the countries with IWRM plans report an "advanced state of implementation" (UN-Water 2012). Similarly, at the 2011 Dresden International Conference on IWRM, experts concluded that "the actual implementation of IWRM is lagging behind". They urged that "the implementation of IWRM and the realization of the respective programs have to be accelerated" (Borchardt et al. 2013). It seems that several barriers to implementation impede progress.

Recently the concept of “adaptive management” has appeared as a response to increasing uncertainty und instability (Walters 1986; Pahl-Wostl 2007). The implications of climate change and the expected increase in uncertainties have triggered a debate about how to better capture real-world water dynamics. The adaptive management approach to natural resource management emphasizes learning and is based on the assumptions that our knowledge is always incomplete (Allen et al. 2011). The adaptive decision-making process is well structured and includes careful consideration of goals, identification of alternative management objectives and knowledge of causal connections, implementation, monitoring and evaluation followed by reiteration. Hence, although adaptive management can reduce uncertainty in decision making, it is primarily a means for enabling decision making despite uncertainty (Allen et al. 2011; Pahl-Wostl 2007). Adaptive management recognizes people and ecosystems as inherently complex, unpredictable and difficult to control, and encourages ongoing learning as the key to coping with complexity and uncertainty (Schoeman et al. 2014). The concept has been widely promoted as a solution to complex natural resource management problems and a supporting approach to integration. However, the concept runs the same risk of vagueness as IWRM and it remains more an ideal than a reality (Allen and Gunderson 2011).

The question remains, in which way are the two concepts of IWRM and adaptive management different or parallel developments. A recent review by Schoemann et al. (2014) points out that each approach has its own strengths to contribute to improved water management. While IWRM provides a political platform for broad stakeholder participation and a process for consensus solutions in the range of hydrological boundaries, the adaptive management approach sets a norm for learning by the application of experimentation and ‘learning-by-doing’ principles which can improve responsiveness to biophysical feedbacks. It is clear that the IWRM concept in the 1990s did not explicitly tackle the newly arising challenges of interconnected social-ecological systems and global environmental change. Water governance must deal with these new risks and uncertainty and there is a strong call for the development of flexible institutions and policies that facilitate learning, adaptation and the ability to transform (Pahl-Wostl et al. 2011).

The Bonn 2011 Conference, The Water, Energy and Food Security Nexus: Solutions for the Green Economy (see also Hoff 2011) triggered an unprecedented series of international conferences and events dedicated to exploring this widened integrative framework of problem formulation and searching for sustainable solutions. This integrative view on the linkages between water, energy, land and food was promoted during the 2013 Bonn conference on *Water in the Anthropocene: Challenges for Science and Practice* (Gupta et al. 2013; Ringler et al. 2013). The nexus approach, which grew out of systems analysis, recognizes that water, energy and food are closely linked through global and local water, carbon and energy cycles or chains. Water, land and energy are also essential resources, but billions of people have limited access to them and all three are under pressure from supply constraints and rapidly growing demand.

Compared to the IWRM paradigm the nexus approach clearly steps ‘out of the water box’ and focuses on water’s central role in linking the conceptual domains of energy systems, aquatic and terrestrial ecosystems and food production. While the nexus approach accentuates the interlinkages of different domains and economic sectors, the IWRM concept has concentrated predominantly on the water sector although the need for cross-sectoral views have already been addressed in the first definitions of IWRM (GWP 2000). When translating IWRM into projects the connections easily become obvious, for example during the development of concepts for the use of treated wastewater in agricultural production (see Liehr et al., Chap. 26). Thus, we do not see a contradiction between the two concepts and rather see that the possibility of linking integrated management plans prepared for different sectors through the nexus approach.

IWRM is obviously neither a unique, nor lonely concept in the field of resource management. Its ultimate value could be proven by its documented contribution to solving multilevel, multisectoral, multiple-stakeholder resource allocation and other problems. In this jigsaw puzzle IWRM, the nexus concept and adaptive management have their potential role. However, without fitting the pieces together all of these concepts and methods will lose credibility.

1.3 Concept of the IWRM Projects

This edited volume on IWRM intends to provide a multidisciplinary perspective on problem-driven analyses of water-related challenges as well as the development and implementation of practical solutions. The sources of this rather diverse collection of studies and projects on IWRM were two large research programs; GLOWA (Global Change and the Hydrological Cycle—GLOWA) and IWRM (Integrated Water Resources Management) which were both funded by the German Federal Ministry of Education and Research (BMBF).

The GLOWA program was initiated in 2000 with the overall goal of developing solutions for the extraordinary challenges presented by the regional impacts of global environmental change on the users and managers of water resources (von Witsch 2008; Klepper 2011). The GLOWA program ran until 2012 working in five different regions of the world (Upper Danube River, West Africa region, Volta River basin, Jordan River basin, Elbe River basin). The five projects focused on the development of water management tools that enabled the analysis of both natural and human impacts on the water cycle at the river basin level. A characteristic approach of GLOWA was the development of integrated simulation (modelling) tools for decision-makers to treat complex scenarios of how determining factors in the water cycle will change in the future. The GLOWA program included intensive multi-stakeholder-dialogues and knowledge-transfer activities in order to ensure the practical application and further development of the available management models. While the results of some GLOWA projects have already been published elsewhere (like Speth et al. 2010) the results of the GLOWA Jordan River project are presented in this edited volume (Tielbörger et al., Chap. 27).

In the following years, under the BMBF program ‘IWRM’ the focus was widened to a larger variety of water related problem-settings, the development of integrated solutions and their real-world implementation. The program started in 2006 with the aim “to develop new approaches and concepts for Integrated Water Resources Management in suitable model regions of manageable size outside the European Union” (Ibisch et al. 2013). The funding program also aimed at improving the local population’s access to clean drinking water and reliable sanitation. With this objective on the agenda the program was rooted in the research domain but simultaneously targeted towards social and economic development in the particular regions. Within this program seventeen projects were funded altogether, three of which were still running in 2015. In adherence with the German government’s funding scheme, the projects within this IWRM initiative included German universities, research facilities and private sector companies together with partners from the case study regions. The projects were complemented by (minor) co-funding from the governments of the specific countries.

The present volume contains a unique compilation of both original data and synthesis papers on the different topics of IWRM research in fourteen different regions and river basins around the world (Table 1.1). The studies presented here were conducted under completely different natural, cultural and socio-economic conditions including extreme arid environments (such as the upper mega aquifer system in the Arabian Peninsula, Siebert et al., Chap. 4), the outer tropics (such as Central Brazil, Lorz et al., Chap. 21), sparsely populated regions in Mongolia (Karthe et al., Chap. 25) and the densely inhabited Mekong Delta (Kuenzer et al., Chap. 15) (Table 1.1). We aimed at identifying general lessons learnt from the two programs GLOWA and IWRM while looking at the diverse conditions in the different case study basins at the same time. It becomes evident that there are inherent difficulties in integrating the results of a large number of independent and methodologically diverse studies, but this could be approached by identifying joint topics and thematic areas (Table 1.2) and framing these with a comprehensive structure (Fig. 1.1).

In the following section, we present a review of the different topics addressed by the studies (Table 1.1) which will help to gain an overview and an integrative picture of state-of-the-art IWRM research. The following dimensions of IWRM are considered in more detail (Table 1.2):

1. Water quantity
2. Water quality
3. Water demand
4. Climate change
5. Water governance
6. Public information and participation
7. Capacity Development
8. Decision support
9. Integrated land and water management
10. Pathways to sustainable water management

Table 1.1 Regional coverage of this volume: drainage basins and selected characteristics

Basin	Countries	Area (km^2)	Population (million)	Mean annual precipitation (mm/a)	References in this volume
Khorezm region	Uzbekistan	6,800	1.5	95	Kim and Hornidge (Chap. 9), Hornidge et al. (Chap. 22)
Western Bug basin	Poland, Belarus, Ukraine	40,000	0.950	700	Bernhofer et al. (Chap. 8)
Al-Batinah region	Oman	12,500	0.760	125	Bernhofer et al. (Chap. 8)
Upper Mega Aquifer, Arabian Peninsula	Saudi Arabia	1.8×10^6	ca. 15–20	<100	Siebert et al. (Chap. 4)
Zayandeh Rud basin	Iran	26,000	4.5	80–1,500	Mohajeri et al. (Chap. 23)
Brasília region	Brazil	5,790	2.5	1,300–1,700	Bernhofer et al. (Chap. 8), Lorz et al. (Chap. 21)
Jordan River basin	Israel, Jordan, Lebanon, Palestine, Syria	18,285	7.18	100–1,400	Tielbörger et al. (Chap. 27), Schacht et al. (Chap. 18), Onigkeit et al. (Chap. 12), Bonzi et al. (Chap. 16); Upper Jordan River: Reichmann et al. (Chap. 6); Lake Kinneret basin: Sade et al. (Chap. 2); Lower Jordan River: Klinger et al. (Chap. 28), Chen & Weisbrod (Chap. 3)
Dead Sea	Israel, Jordan, Palestine	43.223	0.680	50–800	Siebert et al. (Chap. 5)

(continued)

Table 1.1 (continued)

Basin	Countries	Area (km^2)	Population (million)	Mean annual precipitation (mm/a)	References in this volume
Mekong Delta	Vietnam	40,000[a]	17.2	1,900	Kuenzer et al. (Chap. 15)
Guanting basin	China	43,600	8.1	350–450	Otto et al. (Chap. 10)
Miyun basin	China	15,654	0.381	500	Meissner et al. (Chap. 20)
Huangshui River basin	China	1,560	0.620	550	Kaden & Geiger (Chap. 24)
Kharaa River basin	Mongolia	15,000	0.147	250–300	Hofmann et al. (Chap. 19), Karthe et al. (Chap. 25)
Cuvelai-Etosha basin	Namibia	84,589	0.844	300–600	Liehr et al. (Chap. 26)

[a]Surface area of the Mekong Delta

Table 1.2 Topics covered in this volume

Topic	Sub-topics and contributions to this volume
Water quantity	Water availability within the Lake Kinneret watershed, Israel (Sade et al., Chap. 2) Environmental flows and indicators of hydrologic alteration in the Lower Jordan River (Chen and Weisbrod, Chap. 3) Quantification of water fluxes in an extremely arid environment, Upper Mega Aquifer System on the Arabian Peninsula (Siebert et al., Chap. 4) Water budget of the Dead Sea basin (Siebert et al., Chap. 5)
Water quality	Impact of rainfall-runoff events on water quality of the Upper Catchment of the Jordan River (Reichmann et al., Chap. 6)
Water demand	Water use efficiency along the supply chain of agricultural products in Uzbekistan (Bekchanov et al., Chap. 7)
Climate change	Adequate climate information for Integrated Water Resources Management (Bernhofer et al., Chap. 8)

(continued)

Table 1.2 (continued)

Topic	Sub-topics and contributions to this volume
Water governance	Water policies and institutions in the Region Khorezm, Uzbekistan (Kim and Hornidge, Chap. 9) Institutional responses to water scarcity, Guanting Basin, North China (Otto et al., Chap. 10) Handbook for context-specific institutional analysis (Monsees et al., Chap. 11)
Public information and participation	Participative scenario development as a method to integrate science and IWRM (Onigkeit et al., Chap. 12) Benefits and challenges of participation in applied IWRM research (Kirschke et al., Chap. 13)
Capacity Development	Lessons learned from a series of applied IWRM research projects (Ibisch et al., Chap. 14)
Decision support	Water related information system for the Mekong Delta (Kuenzer et al., Chap. 15) Application of a transboundary water resources simulation and planning tool for decision making in the Jordan River basin (Bonzi et al., Chap. 16) Approaches and functions of decision support systems in IWRM research projects (Stärz et al., Chap. 17)
Integrated land and water management	The use of treated wastewater for irrigation, evaluating site-specific soil suitability for the Jordan River basin (Schacht et al., Chap. 18) Water, land and fertilizer management in the Kharaa River basin, Mongolia (Hofmann et al., Chap. 19) Monitoring and modelling of water and solute fluxes in the Miyun basin, China (Meissner et al., Chap. 20) Dynamic land use change as challenge for IWRM, Central Brazil (Lorz et al., Chap. 21)
Pathways to sustainable water management	Reconceptualising Water Management in Khorezm, Uzbekistan (Hornidge et al., Chap. 22) Integrated Water Resource Management in the Zayandeh Rud basin, Iran (Mohajeri et al., Chap. 23) Measures for sustainable water resources management in the coastal area of Shandong Province, PR China (Kaden and Geiger, Chap. 24) Integrated urban water management in the Kharaa River Basin, Mongolia (Karthe et al., Chap. 25) Integrated Water Resources Management in Northern Namibia (Liehr et al., Chap. 26) Strategies and guidelines for sustainable water and land management under global change in the Jordan River basin (Tielbörger et al., Chap. 27) Challenges of implementing IWRM in the Lower Jordan Valley (Klinger et al., Chap. 28)

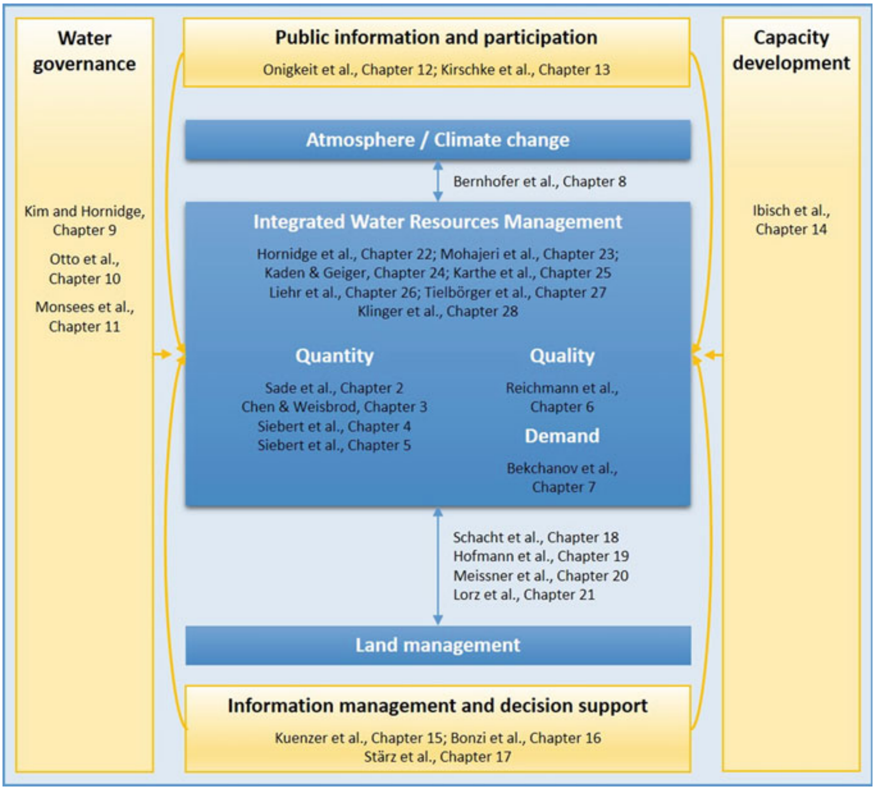

Fig. 1.1 Structural representation of the core elements of IWRM and contributions from the chapters of this volume (figure adapted from Kalbus et al. 2012)

1.3.1 Water Quantity

Precise knowledge of the quantities of available water resources within a region is an indispensable prerequisite for any management attempt. This includes an in-depth understanding of the components of the hydrological cycle and the variability over time and space within the individual region to be managed. All case studies presented in this book have been implemented in data-scarce regions. Monitoring networks were underdeveloped or entirely absent due to harsh conditions and large environmental gradients in the regions.

Siebert and colleagues emphasize the importance of combining different tools when analysing the water budget of the Dead Sea basin (Siebert et al., Chap. 5) or, in a different study when quantifying the water budget of the aquifer system in the Arabian Peninsula (Siebert et al., Chap. 4). They link four methodological approaches for the quantification of surface and groundwater influx to the Dead Sea: (i) direct and non-direct measurements and hydrological modelling to quantify surface runoff, (ii) chemical fingerprinting to characterize groundwater origin, flow, and evolution between recharge and discharge areas, (iii) thermal remote sensing to precisely identify the location and abundance of groundwater discharge and (iv) groundwater modelling to quantify discharge volumes. The authors showed that the combination of methods reduced data uncertainty when quantifying the different components of the water cycle.

In the same vein, Sade et al. (Chap. 2) claim that complex hydrogeological conditions in different areas of a catchment require the application of different statistical and modelling approaches. In their study on Lake Kinneret, Israel, two built-in catchment modules in the Water Evaluation and Planning (WEAP) tool, a model of karst hydrology (HYMKE), lake water balance calculations and artificial rain series based on a stochastic rainfall generation tool were used in order to assess water availability in the region.

Chen and Weisbrod (Chap. 3) look at the alteration and regulation of river flows in order to supply human needs. The concept of environmental flow assessments (Tharme 2003) was applied in the Lower Jordan River basin to determine the quality and quantity of water required for ecosystem conservation. The authors point out that the variability of natural stream flow quantity and timing is critical in determining water quality, temperature, habitat diversity and channel geomorphology. Thus, altering hydrological variability in rivers is ecologically harmful, and has chain reaction effects (Pahl-Wostl et al. 2013). Since there was no information available on ecological biodiversity and ecosystem services in the Lower Jordan River (Chen and Weisbrod, Chap. 3), the ecological flow requirements could be used as a precautionary principle in order to protect the river's ecosystem until relevant findings could be incorporated into an integrated restoration plan.

1.3.2 Water Quality

Water quality is a global concern as deterioration risks translate directly into social and economic impacts including human health and food security. As the water quality situation on a global scale is poorly understood, an important step is to develop a world water quality assessment framework to reduce the information gap and support decision-making and management processes (Bärlund et al. 2014). As agriculture accounts for about 70 % of global water use the potential risk of water quality impacts from agricultural return flows is significant (UNESCO 2012). Agricultural practices cause nutrient contamination, and the sector is the major driver of eutrophication, except in areas with high urban concentrations. Nutrient enrichment has become one of the planet's most widespread water quality problems (UNESCO 2009).

The impacts of flood events on the water quality in the Upper Jordan River was examined in the paper by Reichmann et al. (Chap. 6) in order to understand the spatial and temporal behaviour of nutrient transport in an agro-catchment. The understanding of nutrient sources, transport and retention was crucial in translating the result into the land and water management concepts presented by Tielbörger et al. (Chap. 27) for the Jordan River basin.

1.3.3 Water Demand

Integrated concepts for reducing water demand and using water more efficiently are especially needed in water scarce regions. Water scarcity threatens the livelihoods of billions of people as well as the functioning of ecosystems and valuable service provision by these ecosystems, particularly in arid and semi-arid regions (Rosegrant et al. 2002). The contribution by Bekchanov et al. (Chap. 7) takes a look at such a dry region, namely the irrigated drylands of Uzbekistan in Central Asia and analyses the direct and indirect water uses along the supply chain of agricultural products. The comprehensive analysis of efficient water use was conducted through an environmentally extended input-output model. Several options for increasing water productivity are discussed from a production and consumption perspective. The point is made here that a diversified strategy could enhance water productivity in Uzbekistan, not only during production, but also during the processing, consumption, and trading of commodities.

1.3.4 Climate Change

Which climate change information is needed and adequate for future water management decisions? This question is raised by Bernhofer and colleagues (Chap. 8) and analysed in three different river basins in Eastern Europe (Western Bug basin), the Arabian Peninsula and the region of Brasília (Brazil). Climate change was an IWRM relevant problem in all three regions, leading to increasing evaporation in irrigated agriculture in the Middle East, changing soil erosion and its accumulation in drinking water reservoirs in central Brazil or runoff in the basin of River Bug. The authors present a scheme for replacing measured data by climate model output and assessed model performance of global circulation models in the example regions. Finally, they conclude that there is no unique answer to the question of adequate climate change information, this depends on the specific IWRM problem setting.

1.3.5 Water Governance

Integrated water resources management is inherently complex and since the early 2000s the topic of water governance came into the global water discourse as a key issue (Mollinga 2008). Governance, in a broad sense, can be understood as "the art of governing" and embraces the full complexity of regulatory processes and their interaction. This is reflected in the United Nations Development Programme (UNDP) definition of water governance: "The term water governance encompasses the political, economic and social processes and institutions by which governments, civil society, and the private sector make decisions about how best to use, develop and manage water resources" (UNDP 2004).

The implementation of IWRM must be seen as both highly ambitious and very challenging to those involved in implementation (Mitchell 2005). The lack of progress in implementing IWRM projects is striking, especially in developing and transition countries and there is criticism on failing to adequately address the prevailing political and institutional circumstances at local, regional, national and transnational scales (Biswas 2004; Molle 2008; Butterworth et al. 2010). Monsees and colleagues present in Chap. 11 a methodological guideline, the IRS handbook (IRS is the acronym of the author´s institution Leibniz-Institute for Regional Development and Structural Planning), for analyzing political and institutional environments which was developed within this context and in order to give practical support on the ground to help tune management measures to fit the institutional contexts of implementation. "The IRS Handbook provides an analytical framework for refining projects in both planning and implementation phases, a methodological guide for utilization, an appendix of useful resources and general advice on the often difficult task of finding the necessary information for identifying relevant political processes and institutional arrangements" (Monsees et al., Chap. 11).

The paper by Kim and Hornidge (Chap. 9) describes how IWRM in contemporary Uzbekistan is locally operationalized and implemented in irrigation governance. The authors used a method of inquiry and analysis called "institutional ethnography" and discovered important points of misfit between the formal promises of IWRM-motivated policies and the actual outcomes of the policies for marginalized water users. Based on their analyses the authors could identify and formulate recommendations for suitable policy changes in existing documents which frame the organization of the national water management system.

In the study presented by Otto et al. (Chap. 10) a link is created between climate change adaptations in Northern China and existing institutional arrangements. The authors present the results of interviews with stakeholders from the Guanting Basin on the perceptions of climate change and adaptation needs. As in other studies, the authors observed weak coordination of water management across various government units and levels.

1.3.6 Public Information and Participation

Participation is an intensely discussed topic for developing and implementing Integrated Water Resources Management and both researchers (Mostert 2003; Pahl-Wostl et al. 2007; Özerol and Newig 2008) and practitioners (BMZ 1999; GWP 2000; The World Bank 2006) have underlined the importance of participation. Generally speaking, participation comprises all forms of influence pertaining to the design of collectively binding agreements on the part of individuals and organizations not routinely involved in these tasks (Renn 2006). Specific design principles for successful participatory processes have been developed by committed advocates (von Korff et al. 2010; Kirschke et al., Chap. 13) while others emphasize the limits and negative effects of participation (Cooke and Kothari 2001).

In the contribution to this volume by Kirschke et al. (Chap. 13) the BMBF funding programme 'IWRM' was taken as an empirical basis in order to discover the specific benefits and challenges of conducting participation in applied IWRM research. The authors conducted quantitative and qualitative interviews within fifteen research projects in emerging and developing countries and compared the findings with hypotheses in the literature. In general the findings confirmed the positive and essential role of participatory processes in IWRM research and their different functions and specific design principles. But the authors also point at the framework conditions in these regions; the political, cultural and social influences which were of greatest importance for successful participatory processes. As an example for a participatory methodology Onigkeit et al. (Chap. 12) elaborate on the "story and simulation" (SAS) approach (Alcamo 2008) which was applied in a case study in the Jordan River basin. This approach required participation of a variety of stakeholders in order to gain a broad perspective on water management issues, and the involvement of scientists from a variety of disciplines in order to quantify the relevant aspects of IWRM. The authors conclude that the process required the opportunity and willingness of interaction between the scientists and stakeholders so that the parties involved could profit from the process and its outcomes.

In a related study conducted in the Jordan River Basin, Bonzi and colleagues (Chap. 16) built the bridge between participation, modelling and decision support by integrating socio-economic scenarios and water management strategies resulting from the stakeholder process described by Onigkeit et al. (Chap. 12). The authors applied the spatially-explicit water evaluation and planning system (WEAP) in order to support decision making in this transboundary setting. By doing this, it was possible to model the effects and spatial response patterns of water management strategies under different future development pathways. Bonzi et al. (Chap. 16) point out that the approach facilitated an open, creative and at the same time well-structured discussion between stakeholders and scientists on water management options, responses and the consequences. This might be a general lesson learnt for the development of river basin management strategies.

1.3.7 Decision Support

The development of tools for facilitating water resources management decisions was at the core of the IWRM studies summarized in this volume. IWRM typically deals with highly complex decision situations with many actors involved in the decision making process, and many people affected by the resulting decisions (Ganoulis 2005). Decision making in IWRM also takes place under high uncertainty because on the one hand environmental problems are regarded as complex and require a long-term perspective, and on the other hand the knowledge available to practitioners and policy makers is often fragmentary and not systemized (Sigel et al. 2010). Scientists or political advisers are often consulted in order to bring their expertise to the table. Decision Support Systems (DSS) become relevant here as computer-based tools which give structure and provide interactive support to the decision-making process (Giupponi et al. 2004). Nevertheless, when summarizing the IWRM studies in this volume it becomes clear that there were multiple ways to support the decision-making process in IWRM such as the structured collection and management of water knowledge, the development and implementation of knowledge management tools and (graphical) information systems, the application of numerical models and computer-based decision support systems. It seems that the type of decision-support ultimately developed depends strongly on the specific environment and stakeholders needs. The decision-making tools in IWRM studies are discussed and classified in the contribution by Stärz et al. (Chap. 17). Based on a survey across thirteen IWRM studies the authors summarize the different approaches, methods and functions of the different decision support tools. They conclude that only those systems which have a clear client/user interface, real-world and continuous problem contents, durable software concepts and stable data basis, and guaranteed long-term operation and maintenance will be successfully implemented.

Two examples of advanced decision support tools are presented by Kuenzer et al. (Chap. 15) and Kaden and Geiger (Chap. 24). An environmental information system was developed within an IWRM project conducted in the Mekong Delta in Vietnam in order to fill the numerous knowledge gaps existing for the region (Kuenzer et al., Chap. 15). During the project the knowledge on water related issues in the region was significantly increased and all the findings were made available to decision makers and stakeholders through an information system. The paper discusses information system design and components, the training measures which were undertaken, and general experiences during the realization of the project. A multi-level decision support system for the Huangshui River basin and Longkou City, China was developed and described in the contribution by Kaden and Geiger (Chap. 24). The DSS contained a catalogue of water management measures roughly categorized with regard to application sector, cost-efficiencies, impact on management objectives and peoples' acceptance. The contribution discusses the DSS concept and the efforts made towards an IWRM approach in the region. The authors indicate that the decision support system itself does not solve environmental problems but helps to identify the most socioeconomically viable compromise for achieving sustainable water management.

1.3.8 Capacity Development

Nowadays, it is increasingly recognized that major constraints for improved water resources management arise from inadequate governance structures, and especially the gap between existing and required capacities, rather than technical shortcomings (Alaerts 2009). Capacity development was defined by the UNDP as an integral process for the mediation, strengthening, preservation and further development of individual, organizational and societal capabilities, in order to (i) realize functions, (ii) solve problems and (iii) set and achieve sustainable goals (UNDP 2009). The multi-level approach in Capacity Development as described by van Hofwegen (2004) and Alaerts (2009), with a focus on the three levels of individuals, organisational structures and the enabling environment was taken as a theoretical framework in the contribution by Ibisch et al. (Chap. 14), in order to bundle and conceptualize the experiences made in capacity development activities in IWRM research projects. The authors argue that capacity development should be established as a cyclic process and harmonized with IWRM implementation as much as possible.

1.3.9 Integrated Land and Water Management

Land-water interactions are discussed in four contributions to this volume, each of them highlighting another topic. The contribution by Hofmann et al. (Chap. 19) emphasizes the importance of understanding nutrient fluxes between land and water, especially in catchments dominated by agriculture. The case study was conducted in the sparsely populated regions of Northern Mongolia, a country that faces extreme water-related challenges and at the same time significant transformations with regard to urbanization and the expansion of arable land. Surprisingly, the authors report a significant negative balance for nitrogen and phosphorus in Mongolia's agricultural system which might be caused by nutrient losses and the absence of chemical fertilizer use. Several options are discussed in this paper for integrated nutrient-cycling strategies and linkages between cities as nutrient surplus regions and agricultural deficit regions.

The importance of monitoring and modelling water and solute fluxes on the catchment scale is emphasized in a study conducted in the Miyun basin in China (Meissner et al., Chap. 20). The Miyun reservoir, one of the main surface water supply sources for the city of Bejing, suffers from increasing water quantity and quality problems. The paper discusses the establishment of a sophisticated monitoring network and the application of STOFFBILANZ, a WebGIS-based water and solute balance model as a basis for developing management strategies for the reservoir. Different scenarios were calculated by using the model as a decision-support tool for stakeholders, in order to demonstrate how different management measures could reduce water pollution in the reservoir.

The use of treated wastewater as a non-conventional water resource in water-scarce regions is discussed in the paper by Schacht et al. (Chap. 18). Treated wastewater can be utilized for various purposes, such as irrigation, conservation, groundwater recharge or domestic and industrial uses. The paper evaluates the regional risks associated with treated wastewater irrigation in the Jordan River basin and defines sensitive and non-sensitive regions for the application. The implementation of a regional decision support system for water allocation and the extension of irrigation infrastructures is discussed.

The effects of expanding agriculture and urbanization on water resources in the Distrito Federal, Western Central Brazil were assessed in another paper in this volume (Lorz et al., Chap. 21). Major effects identified during the project were (i) decreasing base flow during the dry season and (ii) sediment generation and the siltation of reservoirs. The paper describes an IWRM strategy by identifying the causes of problems and possible solutions for maintaining sustainable water supply for the region. The study was able to show that a long-term cost efficient management and the protection of water resources could only be achieved if complex land-water interactions were an integrated part of IWRM. The authors underline the challenge of interdisciplinary cooperation and close collaboration between applied science and practice (Lorz et al., Chap. 21).

1.3.10 Pathways to Sustainable Water Management

Both the scientific and the management community agree that the framework and concept of IWRM lacks clear methodologies (Stålnacke and Gooch 2010). Several comprehensive contributions to this volume address the status of IWRM in the respective model regions and describe pathways to a more sustainable management of the water resources under pressure.

In the article by Hornidge et al. (Chap. 22) the focus was to provide a detailed assessment of the current status of IWRM within a case study in Khorezm region, Uzbekistan, and also to give recommendations for its further development. The paper concludes that elements of IWRM such as transparency, accountability, participation, and technical efficiency are as relevant to improving water management in Khorezm as elsewhere.

In the contribution to this volume by Mohajeri et al. (Chap. 23) the Zayandeh Rud catchment in central Iran is taken as a model for initiating and locally adapting an IWRM process which integrates organisational, participative and technical measures. The article describes the developed tools which serve as instruments for understanding water management processes and provide the authorities with a decision support tool. The authors urge the need for institutional and organizational reforms at the national and provincial level in order to establish IWRM in the region in the long term.

A comprehensive IWRM research project is presented by Kaden and Geiger (Chap. 24) for the Huangshui River basin, China. The paper introduces socio-economic analyses, a multi-level decision support system, monitoring concepts and instruments, and concepts for water-saving and reuse, including pilot projects.

An integrated urban water resources management concept for the Kharaa River basin in Mongolia is presented by Karthe et al. (Chap. 25). The authors present several pilot projects that have been successfully implemented for improving water supply and sanitation, and explore linkages to the urban surroundings. The paper discusses how solutions were adapted to local situations, taking both sustainable resource utilization and local acceptance into consideration.

An IWRM approach is presented by Liehr et al. (Chap. 26) for the arid regions in central northern Namibia, the Cuvelai-Etosha basin. The authors describe how different water sources (rainwater, floodwater, groundwater and wastewater) were used for various purposes and implemented as pilot plants. The paper emphasizes the integration of research, technology and societal aspects by linking scientific knowledge from natural, engineering and social sciences with the everyday practices and know-how of the stakeholders involved.

Finally, two studies address pathways to sustainable water management for the Jordan River basin, a region that is confronted with extreme water scarcity and a delicate political and transboundary setting (Tielbörger et al., Chap. 27; Klinger et al., Chap. 28). The project presented by Tielbörger et al. (Chap. 27) developed strategies and guidelines for sustainable water and land management under global change. A transdisciplinary approach was realized by developing several scenarios of the water situation and potential adaptation strategies in cooperation with stakeholders, as well as by establishing the use of the WEAP tool together with regional stakeholders. The integration of disciplinary knowledge and the active transboundary dialogue between science and stakeholders is highlighted in this paper.

The project presented by Klinger et al. (Chap. 28) developed a comprehensive IWRM approach for the region. In addition to naturally available freshwater, unconventional sources such as treated waste water, artificially recharged groundwater and desalinated brackish groundwater were considered as water sources. This contribution describes the strategies developed as well the challenges of implementation.

1.4 Lessons Learnt

Most of the research projects summarized in this volume took the most prominent definition of IWRM from the Global Water Parthership (GWP 2000) as a starting point for their work. The conceptual definition was then translated into the context of the study regions (see for example Liehr et al. for Namibia) and, not surprisingly, the outcomes were extremely heterogeneous. There is an obvious need of context-specific adaptations of the general IWRM concept, and successful projects operationalized their approaches to the regional or problem-specific settings. It became obvious that research projects could then provide a substantial scientific basis for the efforts of IWRM implementation (science based IWRM).

However, while considerable progress has been made in including IWRM in national policies, strategies and laws worldwide, the actual implementation of IWRM is lagging behind (Borchardt et al. 2013). Success factors for effective approaches and their implementations can be summarized as follows: (i) working horizontally across sectors such as economy, energy, agriculture, environment, science, and vertically from international to national, regional, basin and local levels; (ii) working with an intense dialogue between governmental institutions, science, NGOs and society; (iii) targeted and coordinated capacity development on different levels (in particular academic, administrative, technical, stakeholder); (iv) addressing the key role of economics in effective water resources management with water services treated as part of the economy to be paid for, while considering water as such in human rights (UN 2010) and (v) implementing infrastructures that serve multi-purpose schemes (e.g. wastewater management for protecting the environment and human health, water storage schemes for producing energy or food and the mitigation of extreme events such as floods and droughts).

1.4.1 Research Plays a Key Role for Data, Information and Information Management

In order for informed decisions to be made in IWRM, reliable and timely information must be available for all aspects of the target area. Information is used at different stages of the IWRM process and in different forms by the various authorities and stakeholders, whether in the form of quantitative measured data values, written or orally disseminated local wisdom (GWP 2003) or analysed or modelled results. The studies summarized here could provide valuable support in establishing and using current and historical data in order to characterize the baseline conditions of the model regions, thus gaining an understanding of the state and dynamics of the various aspects of the environments. For many regions this stage involved developing new monitoring networks (e.g. Kaden and Geiger, Chap. 24; Klinger et al., Chap. 28) and establishing some type of information system, usually involving databases linked to a GIS; storing and managing the data (see for example WISDOM information system for the Mekong Delta, Kuenzer et al., Chap. 15). Problem solving, developing priorities, defining management options, and establishing decision criteria may only tackled with this deepened understanding of the model region. Even under difficult political (transboundary) settings, the involved research institutions were able to play a politically neutral role as information broker and helped establish a transboundary data- and information system, which is now publicly available (e.g. Siebert et al., Chap. 5, for the Dead Sea basin).

It is needless to say that the number of decision-support tools developed over the past decades by scientists and consulting firms is close to endless. Kuenzer et al. (Chap. 15) summarize some lessons learned for future projects with regard to the long-term implementation of such systems. They highlight critical points such the use of an open source technology-based approach, the provision of all systems parts and resources such as guidelines in the local language, inclusion of potential user rights from the beginning, and the development of an implementation concept including the financing concept right from the start of the project, or even earlier.

1.4.2 Capacities Needing Development

Capacity development is a key factor for Integrated Water Resources Management. The studies presented in this volume show how research, training and advisory services can be linked in a multi-level approach. All of the studies confirm the need for adequate capacities in individuals and society in order to address and solve water problems. Liehr and colleagues (Chap. 26) summarize that capacity development measures play a key role in sustainably anchoring scientific project results locally, beyond the duration of the research project conducted in Namibia. Klinger et al. (Chap. 28) show how impulses for the careful use of water were created in schools in Jordan and Palestine by the development of comprehensive teaching and learning materials on water issues, and the organization of classes for students and teachers. Nevertheless, capacity development activities within the projects presented here also experienced significant setbacks. People-related challenges and other administrative and staff changes on both project partner sides, "brain drain" (trained experts leaving their home country to look for jobs abroad) and intercultural challenges. Some general "lessons learnt" for overcoming these challenges are summarized in the contribution by Ibisch et al. (Chap. 14).

As a matter of fact, capacity development is not a new concept in water management (Blokland et al. 2009). However it is often regarded as only one piece of the puzzle and not as an integral and inherent part of IWRM. At its best, it is regarded as a supplementary process accompanying developments in the water sector. Harmonizing the concepts of IWRM (at the river basin level) and capacity development is important in supporting the implementation of improved water resources management (Leidel et al. 2012).

1.4.3 Stakeholder Involvement Supports Sustainable Consensus Solutions

The broad participation of stakeholders in decision-making supports the formulation of sustainable consensus solutions. The positive benefits of multi-stakeholder involvement comprise several participatory functions such as information exchange, learning, acceptance, legitimation, ownership and the balancing of interests (Özerol and Newig 2008; Kirschke et al., Chap. 13). There is evidence that stakeholder participation can enhance the quality of decisions by considering more comprehensive information inputs. However, the quality of decisions made through stakeholder participation is strongly dependant on the nature of the process leading to them (Reed 2008). In the context of this book "participation" was often understood as the collaboration of scientists and stakeholders working together in a specific project framework. Cooperation in this case, for example cooperation of scientists with national authorities and agencies of international cooperation, was a decisive factor in creating synergies and ultimately supporting the sustainability of such projects at the interface of research and development.

As a typical project pitfall, several projects experienced significant staff turnover on the local and on the German side of the project which can be a substantial step backwards in achieving the project objectives. Kaden and Geiger (Chap. 24) state that "what we learned is that, even for our small study area, [Huangshui River basin and Longkou City, China] it was difficult to get and to keep all stakeholders on board. The more complex the processes are and the more stakeholders are involved, the more difficult the development and implementation of IWRM methods become" (Kaden and Geiger, Chap. 24).

1.4.4 Institutional Fragmentation Is Still a Major Barrier for IWRM Implementation

Institutional barriers to sectoral integration are still a major obstacle for the implementation of IWRM (UN-Water 2012). IWRM was proposed to ideally work within catchment boundaries. Administrative borders seldom coincide with these, therefore leading to a potential disconnection of spatial planning and water management. An analytical approach for the assessment of the institutional and political context of IWRM is presented in this volume (Monsees et al., Chap. 11) which will help to elucidate such disconnections. The implementation of IWRM principles has often triggered the establishment of new administrative units (such as river basin organisations), but their legitimation and power is often weak (Dombrowsky et al. 2014). Broader sectoral integration is not necessarily facilitated by the basin principle. As the fit with hydrological boundaries is increased, the interplay with other sectors governed by existing administrative boundaries might be weakened (Moss 2007).

1.4.5 IWRM Based Infrastructures Typically Serve Multi-purpose Schemes

Water infrastructures which are implemented under IWRM typically serve multi purposes (multi-purpose infrastructures) and connect different domains. An example is described by Karthe et al. (Chap. 25) in this volume for the case study in Mongolia. A decentralized and willow-based wastewater treatment system was set up as a pilot plant that treats (or purifies) the wastewater of small communities, and produces wood and biomass at the same time. The system incorporates local economic and environmental benefits as it provides both wastewater and sludge treatment and represents an alternative fuel source for the local population at the same time. Financial returns from wood sales could generate local income and could in turn reduce the logging of local forests and riparian vegetation with accepted benefits for the highly-stressed land resources (Karthe et al., Chap. 25). Another example was described by Liehr et al. (Chap. 26) for the study in Namibia. In a pilot study, rain- und floodwater was collected on impermeable surfaces, and stored in local reservoirs for the irrigation of vegetable gardens. The sales of vegetables also generated local income. Although there are relatively high associated investment costs, there are multiple positive effects generated in income, nutrition, resources efficiency and the local economy.

1.5 Summary and Conclusion

A large number of research projects dealing with different aspects of IWRM are summarized in the present volume. Although IWRM might be regarded as an elusive concept (Jeffrey and Geary 2006) and a philosophy, its translation into practical implementation has been demonstrated in the various studies summarized in this book. The duality of the IWRM concept (philosophy and methodology), bears both risk and opportunity. On the one hand there is a risk that IWRM may be captured by “traditionalists” which follow traditional schemes, in particular dealing with clearly defined problems and providing technical, end-of-pipe solutions. However, the approaches presented here have given evidence that the implementation of technical solutions can only be effective if embedded in an integrated systems approach recognizing social, cultural and institutional environments and accompanying capacity development measures. On the other hand, the vagueness of the IWRM concept opens space for the specific adaptation and integration of domains, disciplines and societal stakeholders across sectors and hierarchical levels. The term ‘IWRM’ might be seen as strategic anchor on a higher level that can and needs to be filled with life and practical management solutions on the ground. The procedural character of the IWRM concept (GWP 2000) gives room for adaptation, refinement and a variety of adapted solutions.

We propose that the lessons learnt presented above should be treated as priority fields for strengthening the IWRM concept and should be included in the design and implementation of future IWRM programs. This includes: (i) the development of adequate governance structures; (ii) the need for international data archives and metadata for IWRM; (iii) long term service and updating of decision support systems; (iv) different participation models under different social and political systems and (v) capacity development concepts harmonized with IWRM implementation.

Major future research efforts should be made to develop clear methodologies for IWRM implementation under different settings. IWRM is accepted internationally and this warrants a concerted effort to overcome barriers to implementation. More pragmatic approaches that take the specific social, cultural and institutional environment into account will support ways for sustainable water resources management. We propose a shift away from IWRM as a normative concept and argue for realism and action by giving attention to the critical needs of people and the environment as the core dimensions of integration.

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Part II
Water Resources Assessments

Chapter 2
Water Management in a Complex Hydrological Basin—Application of Water Evaluation and Planning Tool (WEAP) to the Lake Kinneret Watershed, Israel

Rotem Sade, Alon Rimmer, Rana Samuels, Yigal Salingar, Michael Denisyuk and Pinhas Alpert

Abstract Sustainability of fresh water ecosystems and human activities in Mediterranean watersheds under future climate change can be supported with integrated hydrological modeling. The Lake Kinneret Watershed (LKW), which spans over 2730 km^2, is divided between three Mediterranean countries, Israel, Lebanon, and Syria; and incorporates four different hydrogeological units: Mt. Hermon in the north, the Golan Heights in the east, the eastern Galilee Mountains in the west, and the Hula Valley in the central part of the watershed. In this study, we used several modeling tools together with a detailed observed database to assemble, test, calibrate and predict simultaneously the water availability within the entire LKW. The hydrological tools that we used compounded of two built-in catchment modules in the Water Evaluation and Planning (WEAP) tool, a model of karst hydrology (HYMKE), lake water balance calculations and artificial rain series based on a stochastic rainfall generation tool. With this setup we defined the “coverage” parameter for water availability and identified vulnerable partial areas inside the watershed, which are more sensitive to extreme draught conditions. The heterogeneity of the LKW water system and the tools we operated enabled the

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separation of the watershed into regions affected by "climate change" scenarios (mainly reduced amounts of annual rainfall) compared to regions impacted mainly by operational decisions.

Keywords Lake Kinneret watershed · Mount Hermon · Golan Heights · Water evaluation and planning · Integrated water resources management · Climatic scenarios · Lake water balance

2.1 Introduction

Increasing demand of water for irrigation and domestic usage are threatening rivers in general, and specifically those situated in semi-arid or Mediterranean climates. Future sustainability of such fresh water ecosystems given the human activities that surround them can be supported by improvements of regional water management (Grantham et al. 2012). Logically, such improvements require a better understanding of the hydrological system behavior under current and future climatic scenarios as well as under various human activities. Modeling both the natural processes and human demands of the hydrological system requires the use of an integrated approach in order to understand how climate change may impact the entire water system.

Integrated hydrological models using the Water Evaluation and Planning (WEAP) platform (Yates et al. 2005a, b), have been used by some researchers to assess the potential effects of climate change in basins with significant agricultural activity. A case study for the Sacramento River basin suggested that improvement in irrigation efficiency and change in cropping pattern have the potential to reduce the effect of climate change on water demand in the agricultural sector (Purkey et al. 2008). Similar conclusions were found in a work done on a smaller basin in California (Mehta et al. 2013). Vicuña et al. (2011a) suggested that reservoir and groundwater storage were key factors for water management under future climate change in the semi-arid climate in Chile. Joyce et al. (2011) concluded that the increasing demand for agriculture in California's central valley under future climate change may result in over-exploitation of groundwater. However, they concluded that while changing operation rules could lead to better water allocation, it could not mitigate all the reduction in water availability.

By dividing a basin into smaller sub-basins, an integrated hydrological modeling approach has the ability to identify sub-basins which are more vulnerable to climate change (Joyce et al. 2011; Vicuña et al. 2011a). The concept of vulnerability was defined by Vicuña et al. (2011b) as the ability to sustain a given level of agricultural activities as a consequence of climatic change. In the dry region of the Middle-East, with limited amount of water, this is an important characteristic of the watershed.

The northern part of Israel, like other Middle East semi-arid regions, is susceptible to climate change due to generally dry conditions and limited water availability. The IPCC global circulation models (IPCC 2007) as well as runs of four different global climate models (20 km mesh) agree on a drying scenario in the Middle East before the end of the 21st century (IPCC 2007; Krichak et al. 2011). Models also predict higher incidence of extremely wet and extremely dry events (Krichak et al. 2007; Samuels et al. 2009). A former work on water availability in the region predicted a 15 % decrease in water availability, together with increasing of 6 % in water demand for agriculture in Lebanon (Bou-Zeid and El-Fadel 2002). The potential decrease in water sources and steadily growing freshwater demands already impose great amounts of pressure on all available water resources in the region in general, and in Israel in particular.

Located in the northern part of the Jordan Valley (Northern Israel), the Lake Kinneret watershed (LKW), including the northern part of the Jordan River (JR), is the most important surface water source in Israel. Despite the large variety of hydrological studies of LKW (*see review in* Rimmer and Givati 2014), modeling of water resources and consumption in the entire LKW and along the course of the JR for managing purposes has never been done. This task, however, is not trivial because of the following reasons:

a. The LKW includes four different hydrological units with large differences in their precipitation to stream flow and groundwater recharge relations, as well as in the quantity of local water consumption (Fig. 2.1): (1) The Jurassic mountainous karst of Mt. Hermon; (2) The basalt plateau of the Golan Heights; (3) The Cenomanian-Turonian carbonaceous karst of the Eastern Galilee Mountains; and (4) The flat alluvial Hula Valley (for details see Sect. 2.2).
b. Simultaneous prediction of precipitation-stream flow relations for the three main tributaries of the JR (Dan, Snir and Hermon) is feasible only by using a hydrological modeling approach, suitable for karstic regions (Rimmer and Salingar 2006).
c. The continuously changing water consumption and groundwater extraction at the Hula Valley, the Eastern Galilee, and the Golan Heights, complicates significantly the calculations of water balances along the JR.
d. The annual precipitation in the entire LKW ranges from >1300 mm annually at the top of the Hermon Mountain to ~400 mm (~ is used instead of "about") annually at the Lake Kinneret, only 50 km south of the Hermon.

The complexity and unknowns of the hydrological and water supply systems increased the need of a basin scale water balance and modeling tool. Such a model can integrate between various data bases, four sub-basins and lake water balance in order to help decision makers in managing the water system in the region. In this case study, we simulate the complex hydrological system of LKW, focusing on two main objectives: (1) Incorporating the main hydrological components of the LKW into an integrated water resources management (IWRM) tool for a large heterogeneous watershed, and (2) Identifying vulnerable areas inside LKW which are more sensitive to climate change. The complexity of LKW required the integration of several modeling tools, constructed on the basis of one central platform (WEAP).

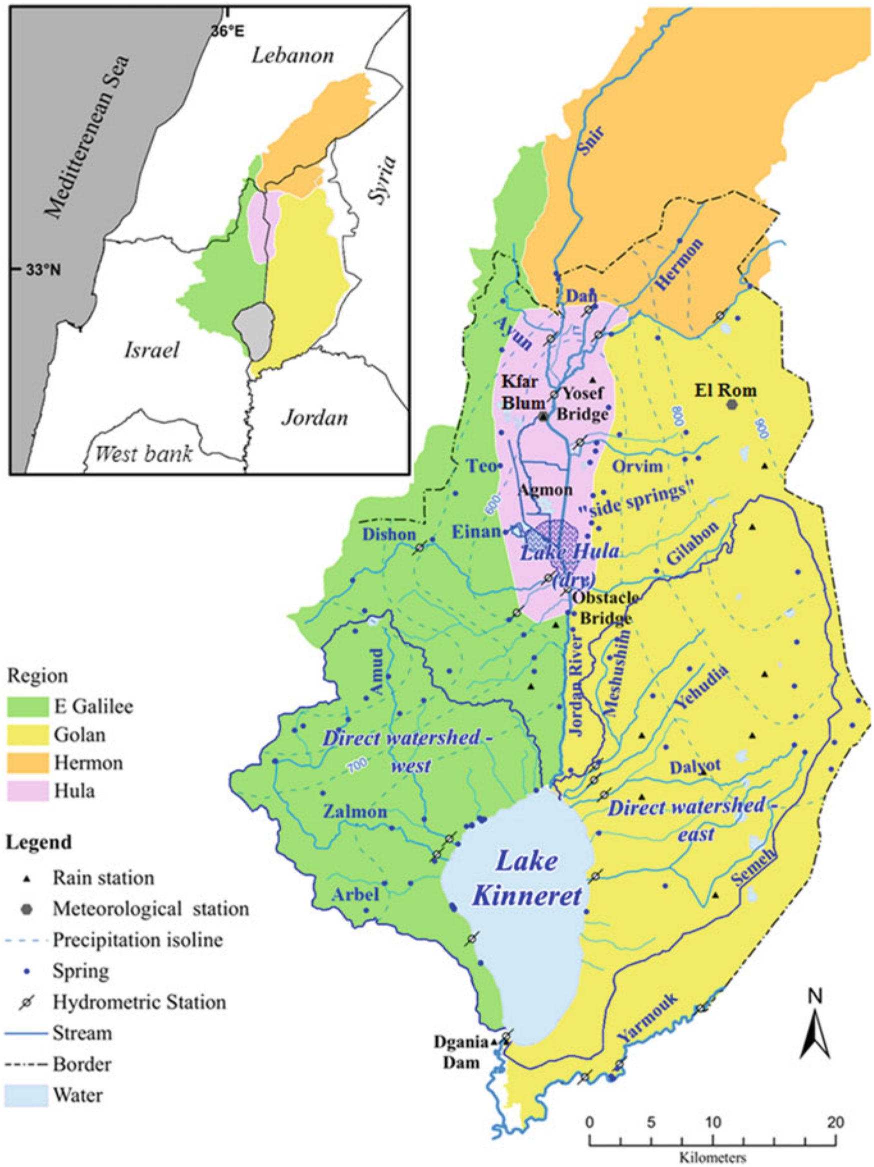

Fig. 2.1 General map of Lake Kinneret Watershed

2.2 Study Site—The Lake Kinneret Watershed

Approximately 35 % of Israel's natural fresh water resources originate from the watershed of Lake Kinneret (Sea of Galilee). The area of the LKW is ~2,730 km^2, of which ~780 km^2 are in Syria and Lebanon. This area holds some of Israel's most important fresh water ecosystems. Agricultural use of ~150 × 10^6 m^3 annually for irrigation is the main water consumer in the entire LKW. Water supply comes from various sources: The Jordan River, groundwater and effluent. The expected future reduction of available water in the watershed due to climate change will create great challenges for the water management in this region. Future climate is predicted to cause reduction of groundwater recharge, which in turn may reduce the inflows into Lake Kinneret by an average rate of ~3 × 10^6 m^3 $year^{-1}$. An increase of ~0.4 × 10^6 m^3 $year^{-1}$ in evaporation from the lake is also expected (Rimmer et al. 2011).

2.2.1 *The Hermon Mountain*

The Hermon Mountain range (Fig. 2.1) is an elongated anticline of mostly karstic limestone of Jurassic age with thickness greater than 2000 m. The Hermon high regions (above 1000 m a.s.l.) receive precipitation above 1300 mm/a, restricted to the wet season from October to April. The Hermon basin recharges the main tributaries of the JR: Dan, Snir (Hatzbani), and Hermon (Banias).

The karstic nature of the Hermon basins is evident when the annual flow of each stream is introduced compared to its attributed surface area. The Dan stream that emerges from a small topographic catchment of only 24 km^2 is the largest spring in the region (255 × 10^6 m^3 annually). The annual flow of the Snir stream, which exhibits the largest topographic drainage area (612 km^2) is 118 × 10^6 m^3, originated mainly by the Wazani and Hazbaya springs located near the Israel-Lebanon border. The Hermon stream (annual flow of 107 × 10^6 m^3; drainage area 147 km^2) receives most of its water from the Banias Spring (~67 × 10^6 m^3) and the rest from other springs and small runoff components. By using HYMKE (Rimmer and Salingar 2006), Samuels et al. (2010) estimated that snowfall amounts on the Hermon basin for 1970–2000 were 2.4 (1978/9) to 202.8 (1991/2) × 10^6 m^3 with an average of 41 ± 40 × 10^6 m^3 $year^{-1}$, and Samuels et al. (2009) assessed that evaporation is ~20 % of the total annual precipitation.

2.2.2 *The Hula Valley*

The Dan, Hermon and Snir streams join together near the Yosef Bridge (Fig. 2.1) to form the JR, which for the next 21 km flows through the Hula Valley (Hula, Fig. 2.1). The valley covers 177 km^2 (25 km long by 6–8 km wide), and serves as a drainage basin to streams and groundwater from the surrounding aquifers. The valley is filled with sedimentary materials of low permeability. An early study of the Hula groundwater (Neuman and Dasberg 1977) claimed that due to the surrounding hydraulic heads there is a significant contribution of deep groundwater flux to the valley. However, based on groundwater measurements in the local aquifer, Litaor et al. (2008) and Sade et al. (2010) found that the shallow water table in the valley is strongly affected by the water level in the JR canals through significant lateral flow in macropores. Litaor et al. (2008) suggested that the component of vertical flow upward is fairly mild. The origin of water in the valley is therefore mainly from the JR, from springs at the margins of the valley, and streams that drain the surrounding mountain. Annual rainfall in the Hula valley varies greatly between ~400 mm in the south, up to 800 mm in the north, and the contribution to the flow in the JR is considered minor.

2.2.3 The Golan Heights

The Golan Heights (Golan, Fig. 2.1) is a 1,160 km^2 upland region. Its boundaries are the slopes of Mt. Hermon in the north-west, the Rokad River in the east, the Hula Valley and the JR in the west, and the Yarmouk River in the south. It is a basalt-covered plateau, sliced off by deep canyons at its edges. The plateau slopes gently from north to south, descending from 1200 m a.s.l. on its northern edge to 300 m a.s.l. at its southern rim. Average annual rainfall ranges from 1200 mm at the north to less than 500 mm at the southern part. The Golan area may be divided into two hydrological regions: northern (between Sa'ar-Hermon and Gilabun; Fig. 2.1), that drain to the JR, and southern (between Meshushim and Yarmouk Valley; Dafny et al. 2003), that drain directly to Lake Kinneret.

2.2.4 The Eastern Galilee Mountains

The water sources originating from this region are the groundwater and stream flows from all sub-basins west of the JR, the Hula Valley, and Lake Kinneret. It includes the surface water basins of the Ayun stream ($\sim 6\times10^6$ m^3 $year^{-1}$) in the north, Dishon ($\sim 4.5 \times 10^6$ m^3 $year^{-1}$), Hatzor ($\sim 0.4 \times 10^6$ m^3 $year^{-1}$), and down to the Amud ($\sim 1\times10^6$ m^3 $year^{-1}$) and Zalmon streams that drain directly into Lake Kinneret (Fig. 2.1). The main groundwater resources of this region are the Einan Springs, located South-West of the Hula Valley, and the Tao spring, about 5 km north of Einan. The annual contribution of all the springs in this region today is only $\sim 6 \times 10^6$ m^3 $year^{-1}$. The average annual precipitation in this region is between 400 mm at the Hula Valley (~60 m a.s.l) and 740 mm on Mt. Knaan (900 m a.s.l.).

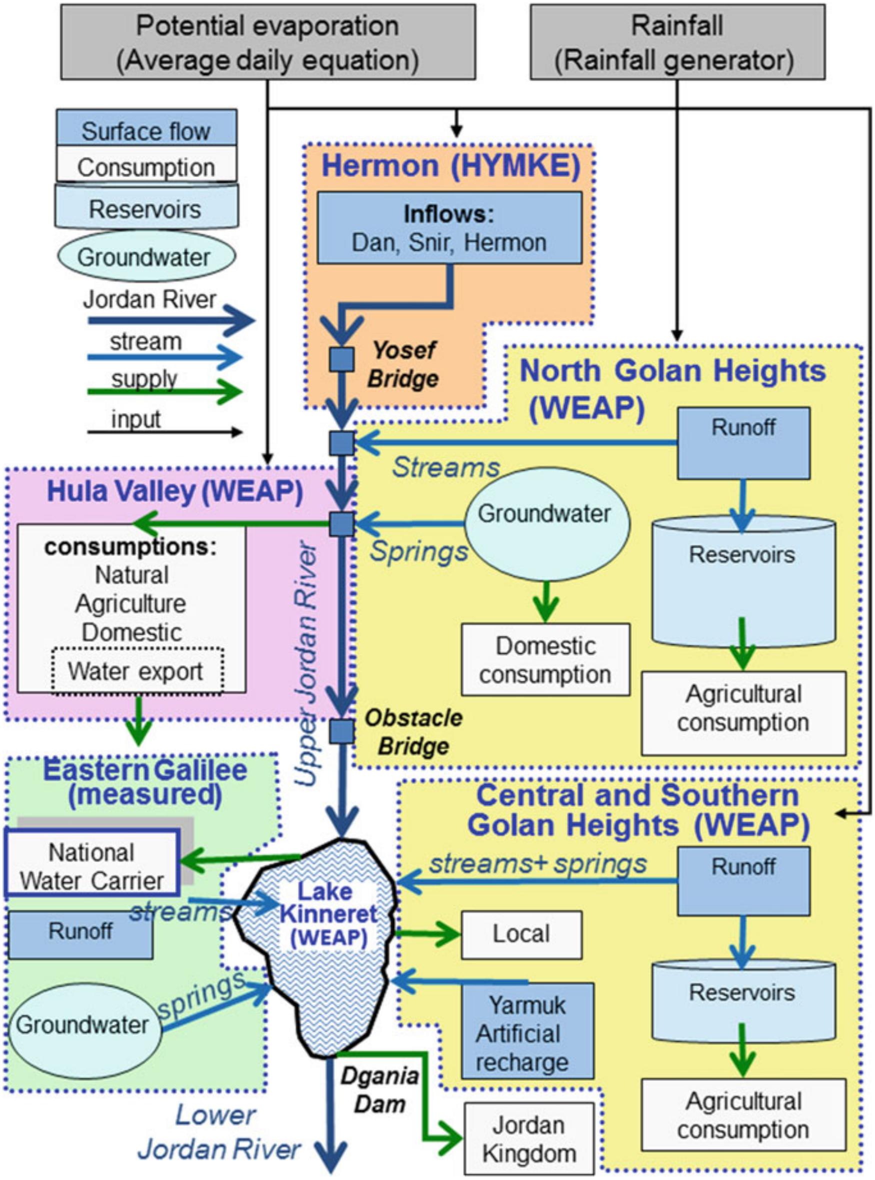

Fig. 2.2 Schematic presentation of the water system in Lake Kinneret watershed, and how it was integrated into the entire IWRM system

2.2.5 The Water System in Lake Kinneret Watershed

The structure of the water system in the LKW (Fig. 2.2) includes fresh water sources (springs, surface streams and wells); the surface runoff reservoir systems (mainly on the Golan Heights); main water supply projects of the "Mekorot" Water Company and local associations (Upper Galilee and Mei Golan); and several reservoirs of treated effluent for agricultural reuse, originating from the sewage of urban and rural communities in the watershed. Some 60×10^6 m^3 year^{-1} is consumed annually for agricultural activity in the Hula Valley, mainly from the northern part of the JR. Additional 23×10^6 m^3 year^{-1}, originating from the Jordan River and local effluent sources is exported from the JR by the Zemer project for agricultural use in the Eastern Galilee Mountains. The Golan Heights with local reservoir volume of 32×10^6 m^3 year^{-1}, consume 34×10^6 m^3 year^{-1}, mostly for agriculture. Direct pumping from the Lake Kinneret (LK) for local consumption is $\sim 75 \times 10^6$ m^3 year^{-1}. Finally, the largest water consumer in the LKW is the National Water Carrier (NWC), which exports on average $\sim 300 \times 10^6$ m^3 year^{-1} from Lake Kinneret to the central and southern parts of Israel.

2.3 Methodology

The heterogeneous hydrological characteristics of LKW require the application of different modeling approaches to different areas of the catchment. The choice of modeling approach is subjective and depends on its goal and the features of the modeled area. In this case, we divided the catchment into the above four regions, namely Mt. Hermon, Hula Valley, Golan Heights and Eastern Galilee. Each region was simulated and calibrated separately using a suitable modeling tool, and then the calibrated units were unified into WEAP to create the simulation for the entire LKW. Short description of WEAP, the modeling procedure of each region, and how they were incorporated together, is explained in the following sections.

2.3.1 WEAP21 General Description and Applications

The Water Evaluation and Planning (WEAP) is an IWRM simulation tool that has been designed to bridge the gap between water management and watershed hydrology. WEAP integrates natural watershed processes together with agricultural, municipal, and industrial water demands. The entire simulation components are set into a sources-sinks network to define an allocation problem. For solving this problem, WEAP supplies the water demands according to priorities and quantities.

Different strategies for representing water sources and water demands are available in WEAP. Water sources can be represented by either time series of flow data or by a more complex quasi-physical approach that represents rainfall-runoff processes and groundwater-surface-water interactions. Water demands can be assigned as a time series of monitored data. Alternatively, it can be calculated as a function of evapotranspiration and crop coefficients (Kc) for modeling agricultural water demands, or for modeling watershed scale evaporative demands as part of the rain runoff module.

Other simulation capabilities of WEAP include simple in-stream water quality, surface reservoir, hydropower stations, snow temperature index melt model and financial planning. WEAP is by no means an optimization tool, but a simulation tool to calculate regional water balances and support decision making (Yates et al. 2005a, b).

In recent years, WEAP has been applied for various problems including snow-melt modeling under climate change in the hydrological system of California's Sierra Nevada (Young et al. 2009); modeling of transboundary water resources in South Africa (Juízo and Lidén 2008); hydrologic model for the Rio Conchos Basin (Eusebio and Daene 2009) and hydrological modeling and water resources modeling of the Sacramento Basin under climate change.

2.3.2 Simulating Mt. Hermon Streams

This mountainous region (Figs. 2.1 and 2.2) is the source of most of the water in the catchment. On one hand, the "two buckets" conceptual structure of the WEAP groundwater model (see Golan Heights simulations below) is not suitable for modeling the complex karst hydrology of Mt. Hermon. On the other hand, there is fairly small local water consumption in the Mt. Hermon region. Therefore, rainfall-runoff procedure on this area were modeled and calibrated separately with the Hydrological Model for Karst Environment (HYMKE; Rimmer and Salingar 2006). The input to HYMKE is two time series: a. equivalent rainfall on Mt. Hermon, and b. predetermined daily potential evaporation (ET; see Fig. 2.2). The daily output of the calibrated model (i.e., the discharge of the Dan, Hermon and Snir streams) formed the calculated discharge of the JR, and was introduced as monthly input to the WEAP model of the Hula Valley. Local consumption in the Hermon is relevant only to the Snir River in Lebanon, where consumption data are not available to us. Therefore the model was calibrated with monthly flows of the Dan, Hermon and Snir River measured at a gauging station located on the Israel–Lebanon border.

2.3.3 Simulating the Hula Valley

The Hula Valley is mainly an agricultural area. The water balance of the valley was calculated using simple mass balance equation because: (1) the local rainfall- runoff in the Hula Valley is negligible compared to the external inflows-outflows; (2) large inflows and outflows of the JR are measured directly; (3) on a monthly scale it is assumed that no significant storage change is available in the valley; (4) it is assumed that most of the Hula direct rainfall seeps into the upper soil layer, and later evaporates with very little contribution to the groundwater discharge or surface flow, and thus this component could be omitted. We therefore define the monthly water balance (m^3 $month^{-1}$) equation for the valley as:

$$Q_{out} = Q_{in} + Q_{sp} + Q_{ro} - Q_{ET} - Q_{zemer} \tag{2.1}$$

where Q_{ET} is the evapotranspiration (ET), attributed mainly to water "import" into the valley for irrigation; Q_{in} is the JR natural inflow to the valley (calculated using HYMKE) including the volumes allocated for agriculture; Q_{sp} is the local Hula Valley springs discharge; Q_{ro} is the runoff (unmeasured flow into the valley), Q_{out} is the JR outflow at the obstacle bridge, and Q_{zemer} is the water exported from the valley for agricultural use in the Eastern Galilee (Zemer Project). The Q_{ET} in Eq. 2.1 includes evaporation from open water surface, as well as ET from land following irrigation and from riparian vegetation (Fig. 2.2).

Most of the water (95 %) consumed in the valley is used for agriculture. Only the agricultural consumption was simulated using the FAO crop evaporation method (Allen et al. 1998) which is available within WEAP "Irrigation Demands Only" Method. It allows simulating changes in water demands by man-induced alterations using the "crop coefficient" Kc. The Kc incorporates crop characteristics and averaged effects of evaporation from the soil (Allen et al. 1998). Climate-driven changes are simulated by changing the values of potential input ET (Fig. 2.2).

The information on the land-use in the Hula Valley was extracted from maps generated by the Survey of Israel and by the Crop Ecology Laboratory, Migal (Israel). The former was validated and updated with an orthophoto before seven categories of land-use were defined (Table 2.1; Fig. 2.3). For calculation of water demands within the valley, only consumers which directly receive water from the JR were used, i.e., field crops, fruits, water bodies and riparian vegetation. The last two categories, although not irrigated, do receive water directly from the JR and thus they were aggregated into the non-irrigated category.

The land-use changes within a year were estimated with maps that elaborate only part of the area (the Hula Project, a reclamation project conducted over 4000 ha in the south Hula Valley area) between the years 2004 and 2006. These maps are being updated twice a year (March and August) and therefore, could represent general management trends within a year. For the purpose of this work we assumed no land-use changes between years.

The reference ET and the Kc value determine the actual ET (Allen et al. 1997). For the WEAP simulations, we used reference ET from the Israeli Meteorological Service, which was calculated by the Penman Monteith equation using data from the Kefar Blum meteorological station (Fig. 2.1). The crop factors, i.e. Kc values, (Table 2.1) were based on the National Engineering Handbook (NEH 1993).

Table 2.1 Land use area and Kc values used for the Hula Valley and the Golan basins

	Type	Area (km^2)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Golan	Citrus	3.73	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	Olives	3.03	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Orchard	27.62	0.7	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.9	1.0	1.0	1.0
	Palm	0.41	0.6	0.5	0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.6
	Subtropics	5.19	1.1	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.1
	Vineyards	9.00	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.9	0.9	0.8
	Field crops	58.49	0.1	0.2	0.9	0.9	0.9	0.2	0.1	0.2	0.5	0.6	0.3	0.1
	Open area	958.06	–	–	–	–	–	–	–	–	–	–	–	–
	Elev < 600 m	–	0.5	0.7	0.8	1.0	1.0	1.1	1.0	0.4	0.2	0.2	0.2	0.5
	Elev > 600 m	–	0.5	0.5	0.6	1.0	1.0	1.2	1.0	0.6	0.2	0.2	0.2	0.5
Hula	Field crops	96.46	0.1	0.2	0.9	0.9	0.9	0.2	0.1	0.2	0.5	0.6	0.3	0.1
	Fruits	29.78	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	Water bodies	11.30	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Riparian vegetation	3.20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

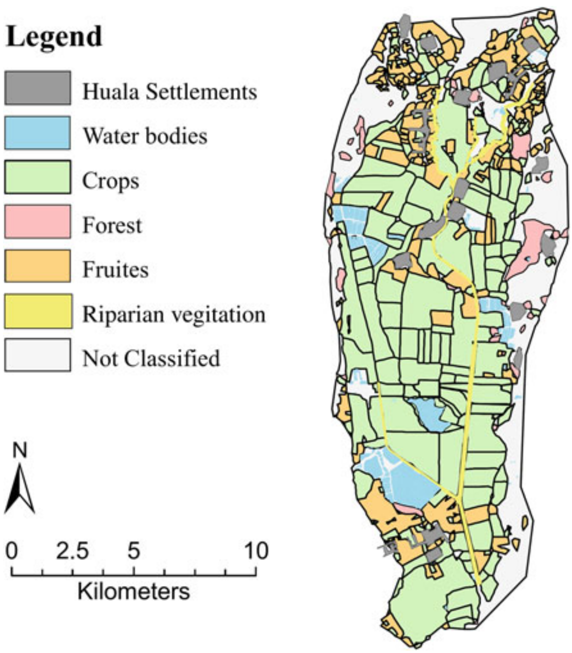

Fig. 2.3 Land use map of the Hula Valley

The FAO crop evaporation does not account for domestic water-use. This part of the simulation was evaluated by per capita calculation. The population size (8300 capita) was taken from the Israeli statistical bureau, and water consumption was assumed to be 250 m^3/(capita × year). The springs and the runoff flow (i.e. Ayun and the Eastern Galilee streams) were used directly as time series data measured by the Israeli Hydrological Service (IHS).

Calibration of the Hula area was performed by comparing the calculated flow at the Obstacle Bridge (Fig. 2.2) to the measured flow (Fig. 2.4c). We calibrated the model by adjustment of the irrigated portion out of the total field crops area for each month. The calibration resulted in an irrigated portion that reached the maximum of 90 % at late spring and early summer, and decreased to 50 % at the end of summer (August, September). This reflects general trends of decreased irrigation towards the end of the summer crop season.

2.3.4 Simulating the Golan Heights

The Golan area consists mainly of non-cultivated open areas (i.e. grazing land, nature reserve, army fire zone). Direct rainfall over the area is the main water source; thus the total water input can be estimated by interpolation of rain records over the Golan. In order to estimate the available water for the region, one must also

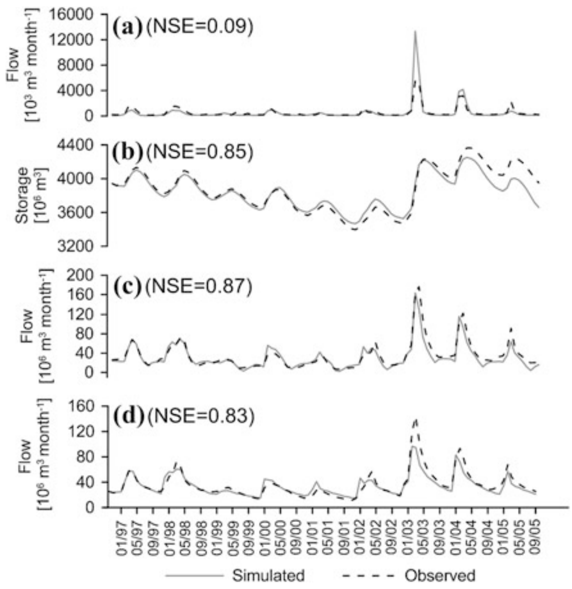

Fig. 2.4 The observed and the simulated **a** the Orvim Stream monthly flow; **b** Lake Kinneret storage; **c** the Obstacle Bridge monthly flow; and **d** the JR sources monthly flow. The Nash-Sutcliffe Efficiency (NSE) is shown for each simulation

know the total output of water. This component includes the ET, surface flow and groundwater flow all of which are difficult to estimate. The ET was estimated with the Penman Monteith equation similar to the Hula Valley. The surface water flows through about 15 streams running from east to west into the JR in the north and into the Lake Kinneret in the south (Fig. 2.1), but only five streams are equipped with flow gauges. Moreover, some of the precipitations infiltrate into the basalt aquifer which feeds many small springs located in the large streams and at the western slopes of the Golan (Dafny et al. 2003). Here again, not all springs have flow records. Evidently, no direct measurements of the total input and output in the Golan are available and consequently, the water balance of this area could not be simply completed.

The Golan area was therefore simulated with the rain runoff module (RRM) inside WEAP (Fig. 2.2). In this modeling approach, the hydrological system is treated as a "two bucket system" (Sieber and Purkey 2002). Meteorological records are the forcing variables for the modeled hydrological system. The main watersheds of the Golan area were delineated from a digital elevation model (DEM) (50 m pixel) using ArcMap (ESRI). Since meteorological parameters such as precipitation and temperature are strongly correlated with elevation (Rimmer and Salingar 2006), each watershed was segregated into elevation belts (<0, 0–300, 300–600, 600–900, >900 m. a.s.l.) and meteorological parameters were calculated as a linear function of the mean elevation of each elevation belt.

Since precipitation data show high variability between years, and precipitation is correlated with geographic elevation, we used the monthly time series data of 14 rain gauges (partly shown on Fig. 2.1) to generate the spatial distribution of rain on the Golan. The other meteorological parameters used to force the RRM were air temperature, relative humidity and wind speed. Their values were based on the monthly averages records from two meteorological stations, one in Kfar Blum (Israeli Meteorological Service) at the elevation of 75 m, and the other in El-Rom (Ministry of Agriculture and Rural Development) at the elevation of 900 m (Fig. 2.1).

The RRM was calibrated for five watersheds with flow gauges at their outlet: Orvim (Fig. 2.4a), Meshushim, Yehudia, Dalyot and Samah. Parameters for calibration were the soil hydraulic parameters (Sieber and Purkey 2002) and the seasonal changes of Kc (Table 2.1) which in this case represent the growing stage of the natural grass that cover most of the open areas on the Golan Heights. The calibrated parameters were then used to run the RRM for the rest of the Golan Heights watersheds.

Using the RRM we evaluated the inflow into the reservoirs on the Golan Heights. The watersheds which include a reservoir were divided into two parts; one part included only the watershed upstream the reservoir and the other part included the watershed downstream. The reservoir overflow was linked to the main stream of each watershed so that the total flow from each watershed was the sum from both parts excluding the reservoir storage.

The agricultural water demands were simulated similarly to the Hula area. Land maps from the local water company (Mei Golan) were used together with Kc (Table 2.1) and ET values as the input for the FAO crop evaporation method inside WEAP.

2.3.5 Simulating the Eastern Galilee

The Eastern Galilee (Fig. 2.1) has minor influence on the catchment water budget because the large springs in the area are pumped into the local water system and runoff occurs only after large rainstorms. Since we have only little information about the consumption in this area, we decided to represent it by monthly time series of the measured flow from all stream gauges at the Eastern Galilee (average of 15×10^6 m^3 $year^{-1}$; Fig. 2.2). The flow is either to the JR or directly to Lake Kinneret.

2.3.6 Simulating Lake Kinneret Water Balance

When measured variables of the water balances are separated from the unknowns the water balance equation of Lake Kinneret is:

$$Q_s - Q_e = \Delta V_L + \sum Q_{out} - \sum Q_{in} \tag{2.2}$$

where the monthly measured quantities (m^3) at the right hand side of Eq. (2.2) are the change in water volume of the lake (ΔV_L, positive if inflows larger than outflows); the outflows (Q_{out}), including water released to the lower Jordan River through the Degania Dam (Fig. 2.1), the withdrawal of water by pumping to the National Water Carrier (NWC) and by private consumers. The inflows (Q_{in}) include the flow from the upper JR, the runoff from the direct watershed, water diverted to the lake from the Yarmouk River, direct rainfall, and discharge from several gauged saline springs. The monthly-unknown quantities (m^3) at the left hand side of Eq. (2.2) are evaporation loss (Q_e), and the unmonitored contribution of saline springs (Q_s).

The Lake is simulated in WEAP as a reservoir on the JR, and as such, uncertainties in the water balance (Rimmer and Gal 2003) were not taken into account. Following Eq. 2.2, inflows (Q_{in}) were calculated from the cumulative models of the upstream units- the JR and the direct watersheds. The JR includes the Hermon, the northern parts of the Golan Heights (see Sect. 2.2.3) and the Western Galilee, and the Hula Valley. Direct watersheds are the southern parts of the Golan Height and the Western Galilee. The pumped outflows (one part of Q_{out}) were set as monthly measured time series of pumping to the NWC and to private consumers. In Eq. 2.2 both the evaporative loss (Q_e) and the contribution of the saline springs (Q_s) are unknowns of the water balance which are not possible to evaluate with the WEAP built in modules. These unknowns were introduced as calculated time series, based on the long term solution of the water-solute-energy balances (Assouline 1993). The change in water volume of the lake (ΔV_L in Eq. 2.2) was determined by the WEAP simulations, using the Israeli official hypsographic curve (volume-elevation and volume-storage capacity curves) of the lake (Mekorot 2003). Comparison between the simulated and the observed lake storage is presented in Fig. 2.4b.

2.3.7 Scenarios

In this part of the study, we have generated artificial rainfall and ET scenarios in order to evaluate the effects of the changes in precipitation and ET on the water availability in the entire LKW. Note that by combining the four units into the general WEAP-LKW scenario, the priorities of water allocations could be re-examined. For example, the system allows testing how allocations should be determined for both local water consumers and NWC consumers, together with the considerations of maintaining the required water level in Lake Kinneret. The main purpose of this part was to test the performance of the complete WEAP-LKW under various forces, and it is by no means a prediction of climate change scenarios.

Four scenarios (SC) were determined in WEAP: SC1 real daily rain time series in the years 1996–2005 and average monthly ET; SC2—based on SC1, but the rain reduced by a factor of 0.8, and the ET increased by a factor of 1.05; SC3—artificial rain series (see Samuels et al. 2009 base scenario) and average monthly ET.

The SC3 time series represent hypothetical precipitation (no real meaning to dates) with an averaging monthly rainfall as in SC1, but daily and monthly precipitation vary stochastically; SC4—based on SC3, but the rain reduced by a factor of 0.8, and ET increased by a factor of 1.05.

In SC1 we verified that the HYMKE results and the entire LKW inflows and outflows were consistent with the real water system, while SC2 was used to detect the effect of extreme reduction in precipitation and increase in ET. These scenarios served as references for the SC3 and SC4, respectively, used for simulating the same long-term conditions as in SC1 and SC2, but with random climate conditions for each year (Samuels et al. 2009). These four scenarios are used for (1) verifying that the WEAP LKW system is reliable under general trends of climatic forcing, and (2) compare between the results of two scenarios—business as usual (SC1, SC3) and severe drought (SC2, SC4).

2.4 Results

The calibrations of the different parts of the model were good (Fig. 2.4) with Nash-Sutcliffe Efficiency (NSE) values of 0.09, 0.85, 0.87 and 0.83 for the Orvim stream, Kinneret water storage, JR at the obstacle bridge and the sources of the JR, respectively. Moriasi et al. (2007) suggested that a model performance was satisfying if the NSE is greater than 0.5. The NSEs here are well inside this range except for the NSE of the Orvim stream which is low even compared to the NSE of other streams in the Golan, i.e. NSE of 0.58, 0.87, 0.75 and 0.79 for the Meshushim, Yehudia, Dalyot and Semeh, respectively. Thus, overall performance of the model is satisfying for the purpose of this work.

In some cases the non-satisfying WEAP performance in modeling rain-runoff processes and especially peak floods, could be attributed to the time step in the model (Yates et al. 2009). This should be at least as long as the longest resident time in the system (Purkey et al. 2008). Like many others, a monthly time step was used here because only monthly consumption data is available. This choice inherently scales the soil parameters to monthly values (Purkey et al. 2008) and puts a limitation on modeling the rain-runoff process which occurs on shorter time scales, i.e. hours to days. Despite this limitation, the Rain-Runoff method inside WEAP gives good results for the needs of the integrated hydrological system, as it is evident here and in other works (Purkey et al. 2008; Yates et al. 2009; Joyce et al. 2011; Vicuña et al. 2011a, b; Mehta et al. 2013).

Results of the scenarios are focused mainly on the ability of WEAP to examine the differences between “business as usual” SC3 and drought SC4. Available water in the Golan, in the Hula and in LK is presented and discussed as the difference between SC3 and SC4. The flow from the Golan was aggregated into two components, the flow to the JR in the Hula Valley (north) and the direct flow to LK (south). The decrease in the flows (SC4 compared to SC3) is presented in Fig. 2.5a as the percentage of the accumulated flow of SC3. As expected, SC4 generated less flow. The decrease is sharper in the direct flow to Lake Kinneret (southern Golan) where it reaches ~25 %, compared to only ~15 % decrease in the northern Golan. The larger decrease in the southern part is explained by the higher storage volume in this area compared to the north of the Golan Heights, which causes larger percentage of the water to be stored in local reservoirs. The decrease in the available water from SC4 compared to SC3 is seen not only in the discharge but also in the reservoir storage and the unmet demands (the monthly volume of water needed which could not be supplied by the present water system; Fig. 2.5b). The calculated maximal storage in each year is reduced by ~4–8 × 10^6 m^3. The very close similarity between the decrease in storage volume and the increase in unmet demands is due to the high reliance on reservoir storage for irrigation in the Golan.

The results from the simulation of the Hula area are presented in Fig. 2.6. The simulated JR accumulated flow at the Obstacle Bridge under SC4 was reduced by about 30 % with respect to the simulated flow in SC3 (Fig. 2.6a). Most of it is attributed to reduction of stream flow in the JR sources. Although the simulation showed significant reduction in the available water, most of the demand for irrigation in the Hula Valley could still be met (Fig. 2.6b). The reduction in available water in the Hula is reflected in the reduction of the water export through the Zemer project (Fig. 2.6b). In this case the simulation showed 6 summer month of unmet demand. Unlike the local reservoir system on the Golan Height, the water supply to the Zemer project is supported by the entire JR system, and therefore unmet demands occurred only during extreme cases of draught, in the middle of the summer, when large amount of water is needed.

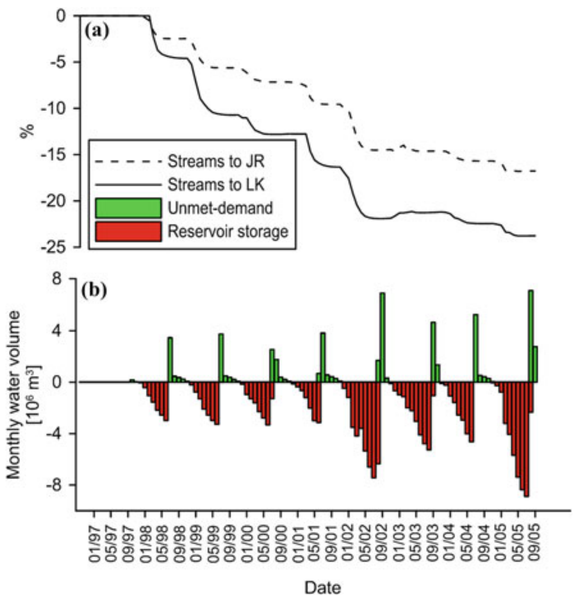

Fig. 2.5 Available fresh water in the Golan. **a** The change in accumulated flow from the Golan in SC4 as percentage of accumulated flow in SC3. **b** The change in storage volume and unmet demands in SC4 compared to SC3

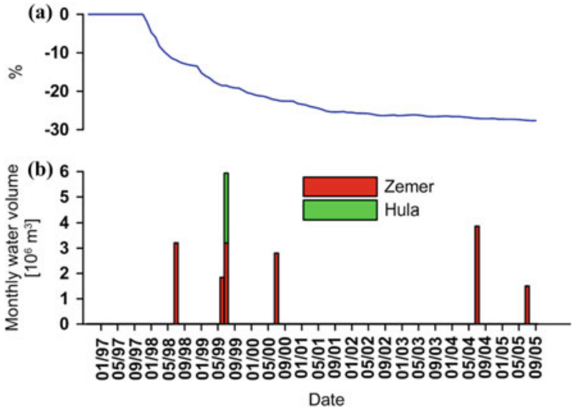

Fig. 2.6 Available fresh water in the Hula. **a** The change in accumulated flow at the Obstacle Bridge in SC4 as percentage of accumulated flow in SC3. **b** Unmet demands of the Zemer Project and of the Hula agricultural area

The storage volume in LK is influenced greatly by the decrease in precipitation (Fig. 2.7a). Similarity can be observed between the steady water storage in SC1 and SC3, compared to the severe reduction in lake storage in SC2 and SC4. These reductions were caused since lake deployment was considered the same for both the regular (SC1, SC3) and drought (SC2, SC4) scenarios. When the operation of the lake is unrestricted, no unmet demands are expected in the NWC (as long as there is water in the lake). However, realistically, the operation of the lake is restricted between the upper red line (flood risk) and the lower red line (operational and environmental risks). Therefore, practically pumping from the lake should not continue when water level is under the lower red line. When SC3 and SC4 were modified to meet the red line restriction (i.e. minimum lake storage of 3660×10^6 m^3) the restrictions created unmet demands in the NWC (Fig. 2.7b), which was given lower priority. Unmet demands were observed in three out of nine years in SC3 but increased to six out of nine years in SC4. The unmet demands reached a maximum of about 50×10^6 m^3 a month, and a total of 148×10^6 m^3 and 649×10^6 m^3 in SC3 and SC4, respectively.

The “coverage” was suggested to be a good estimation of the vulnerability of agricultural area (Vicuña et al. 2011a, b) to changes in available water. It is defined as the ratio between the water demand and water supply. Since all scenarios had the same land use, the changes in coverage reflect the ability of a watershed to sustain current agricultural activity under climatic/operational changes.

The change in monthly average coverage in the SC4 simulation with respect to the SC3 simulation is presented in Fig. 2.8a. In the Golan, during most of the summer and the autumn month, the simulations showed a reduction of the monthly average coverage. This reduction reached to about 20 % in July and September. In the Hula area the reduction in coverage was evident only in July. Thus, we see that

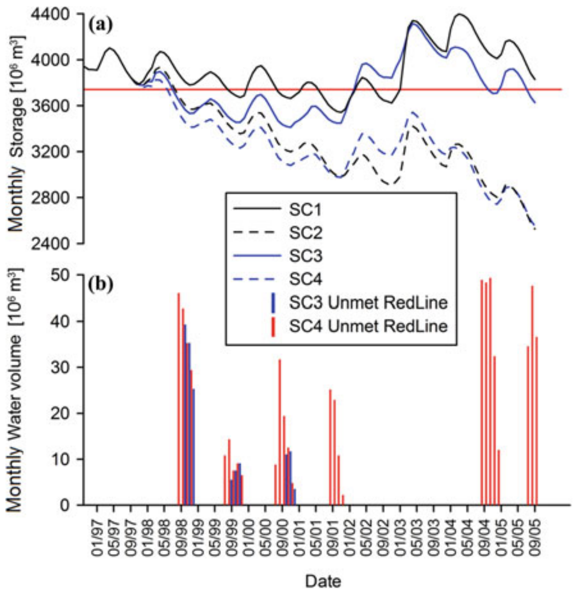

Fig. 2.7 **a** Simulated storage volume in LK in SC1–4; **b** The unmet demands in the National Water Carrier in SC3 and SC4 when storage volume is restrict to above 3660×10^6 m^3

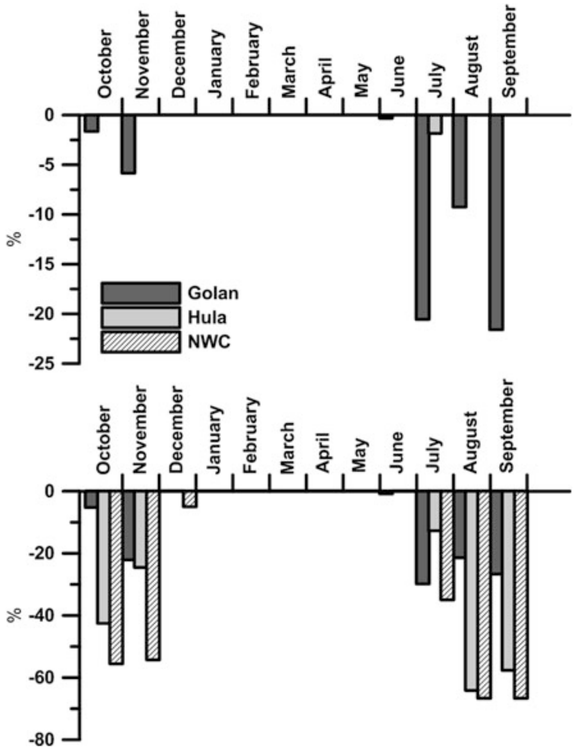

Fig. 2.8 **a** Changes (%) in coverage calculated for SC4 relative to SC3. **b** Changes (%) in coverage calculated for SC4 *Red Line* relative to SC3. The coverage is defined as the ratio between the water demand and water supply. The negative values indicate decrease in coverage

the agriculture in Golan area is more vulnerable to “climate change” then the agriculture in the Hula.

The comparison between the two areas is interesting since they represent two different kinds of water production strategies. The Golan area relies on local reservoir which is nearly fully exploited every year, i.e., there is no long term storage. The Hula area irrigation relies on the supply of water from direct pumping from the JR. The low vulnerability of the Hula area is due to the large volume of water flow in the JR with respect to total water demand in this area.

The regional picture becomes more complicated when we analyze the coverage if the water authorities will change operation rules in the lake, so that the water level is restricted above the red line (Scenario SC4 Red-Line, Fig. 2.8b). In this case the coverage of the Hula area and the NWC is significantly reduced. The reduction of the coverage in the Golan is kept similar to the original SC4. These results imply that the NWC and the Hula area are more vulnerable to the lake operation rules, then to “climate change”. The Golan is operated almost autonomously, thus is less vulnerable to the operation rules of the lake.

2.5 Summary

According to the Global Water Partnership (GWP) website (http://www.gwp.org), Integrated Water Resources Management (IWRM) is a “…process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.”

In this study, emphasize was set on one of the IWRM basis: the quantification of finite natural water resources which have many different uses, under scenarios of reduced available water. The integrated model tested how irrigation demands in two locations, are met together with ecological management of Lake Kinneret and its tributaries. Some aspects of IWRM such as economic and social welfare, including trans-boundary water sources and the touristic significance of the Lake Kinneret Watershed, were not included in this project. However, the quantification basis set by this study may lead to farther enhancement of these aspects as well.

Here we used several modeling tools together with detailed databases of monitoring to assemble, test, calibrate and predict simultaneously the water availability within the entire LKW. The system is now in the required form, capable for integrated water resources management in the LKW. Two main aspects of water management were demonstrated in this study:

The first aspect is from a watershed modeling technical point of view - how to incorporate and integrate the main hydrological components of a complicated hydrological system into an IWRM using various, independent models. The central modeling tool was WEAP however, although it was designed to integrate natural watershed processes with various types of water demands, application of this tool alone to complex watersheds such as the LKW was not the preferred choice.

The hydrogeological structures that we tested required an operation of several complimentary modeling tools: (i) HYMKE (Rimmer and Salingar 2006) for the hydrology of the karst Mt. Hermon springs; (ii) Input of monthly time series (lake evaporation and offshore springs discharge) originating from an independent lake water balance calculations (Assouline 1993); (iii) the usage of two different WEAP built in catchment modules- one ("Irrigation Demands Only" Method) for the Hula and one ("Rain Run Off, Soil Moisture" Method) for the Golan Heights; and (iv) Artificial rain series based on stochastic rainfall generation tool (Samuels et al. 2009). It is suggested that in complicated hydrological problems the approach of integrating several independent models and analytical tools into a single modeling system might be more accurate and easier to produce than using a single modeling tool.

The second aspect is from a practical water management point of view. We defined the coverage as a parameter of water availability; we show how to identify vulnerable partial areas inside the watershed, which are more sensitive to extreme conditions; and exemplified how to separate between the effect of "climate change" and the effect of operational decisions on water availability. It is the heterogeneity of the LKW water system that made it possible to demonstrate various types of hydrological approaches and water availability considerations within a single case study.

Acknowledgment This article is dedicated to the memory of our colleague and friend Dr. Rana Samuels, an excellent climate researcher who died at the age of 42. Dr. Samuels had a significant contribution to the climate modeling of the Eastern Mediterranean in general, and the climate—hydrology modeling of the Lake Kinneret basin in particular. The study was funded by the German Federal Ministry of Science and Education (BMBF) within the GLOWA Jordan River Project.

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Chapter 3
Assessment of Anthropogenic Impact on the Environmental Flows of Semi-arid Watersheds: The Case Study of the Lower Jordan River

Assaf Chen and Noam Weisbrod

Abstract The escalation in hydrological alteration of rivers on a global scale, potentially causing environmental degradation, initiated the establishment of the Environmental Flow Assessment science where the quality and quantity of water required for ecosystem conservation is determined and taken into consideration. The Lower Jordan River (LJR) Basin has gone through massive exploitation of its scarce water resources in the last half century: man-made stream regulations and diversions have drastically affected the LJR's natural flow regime and degraded its water quality. This research aims to investigate the continuous degradation of water flow in the LJR, by looking into its past natural temporal and spatial flow variability. River flow data were obtained for years 1921–2011. Both natural and regulated flow regimes were examined. The software tool 'Indicators of Hydrologic Alteration' (IHA) was used for daily flows' comparisons. The IHA tool results show significant changes in rates of base flows and frequency and magnitude of extreme flow events, between pre-impact and post-impact periods. According to our results, in order to mitigate these flow alterations, a relocation of 100 MCM/year of fresh water to the LJR river system is needed, which will be used to: fortify its depleted base flow; generate two yearly flood events; and introduce four additional high flow pulses. This reallocation would enable a mimicking of the LJR's natural variability of flow at a relatively minimal amount of water. This research constitutes a first step towards understanding the LJR's hydrological natural conditions. Its findings could be very useful when weighing different rehabilitation options for the LJR and other anthropogenic impacted semi-arid basins.

Keywords Environmental flows · Jordan River · Hydrology · River management and rehabilitation · Indicators of hydrologic alteration

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List of Acronyms

CMS	Cubic Meter per Second
EFA	Environmental Flow Assessment
EFC	Environmental Flow Components
EFR	Environmental Flow Requirements
IHA	Indicators of Hydrologic Alteration
IHS	Israeli Hydrological Service
IMS	Israeli Meteorological Service
IWA	Israeli Water Authority
KAC	King Abdullah Canal
LJR	Lower Jordan River
LJRB	Lower Jordan River Basin
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
NWC	National Water Carrier
SOG	Sea of Galilee
SWC	Saline Water Carrier
UJR	Upper Jordan River
UJRC	Upper Jordan River Catchment
WWTP	Waste Water Treatment Plant
YR	Yarmouk River

3.1 Introduction

Humans can't survive without rivers. From the dawn of time, rivers have been providing food, drink and habitation sites. People have relied on rivers for cleaning, waste removal, decomposition, transportation, commerce, power generation and recreation. Humans have been thus altering and regulating natural rivers' flows to meet these needs. Rivers won't be able to continue to meet the full array of humanity's needs if people continue to look at river management from a purely economic and exploitative point of view. The flow of rivers is part of the planet's water cycle and breaking it would harm not only the rivers' flow but also the entire web of life (Karr and Chu 2000).

The alteration and regulation of rivers flows in order to supply human needs comes at the great cost of damaging the rivers' integrity. Variability of natural stream flow quantity and timing is critical in determining water quality, temperature, habitat diversity and channel geomorphology. Thus, altering hydrological variability in rivers is ecologically harmful, and has chain reaction effects (Poff et al. 1997).

Unregulated river flow is dynamic and can be measured at different scales. Flow regime consists of five main components, which regulate ecological processes and directly and indirectly influence the river's integrity. These components are: magnitude of flow, frequency of a flow event (or aggregated events within a time period), its duration, timing (predictability) and rate of change (how quickly flow changes amplitude) (Arthington and Pusey 2003; Dyson et al. 2003; Poff and Ward 1989; Poff et al. 1997; Richter et al. 1996, 1997; Smakhtin et al. 2004; Tharme 2003). These components help to explain different hydrological phenomena such as floods and low flows (droughts), and can be used to measure human impacts.

The escalation in hydrological alteration of rivers on a global scale, causing environmental degradation, initiated the establishment of the science of Environmental Flow Assessment (EFA) where the quality and the quantity of water required for ecosystem conservation is determined and taken into consideration (Tharme 2003). Therefore, Environmental Flow Requirements (EFR) is a compromise between human development plans exploiting the ecosystem's resources and aquatic system maintenance (Smakhtin 2008).

Arid and semi-arid watersheds are especially vulnerable to increasing demands on freshwater resources, due to the scarcity of water resources. In particular, shared water resources within semi-arid to arid regions, such as the Middle East, are a source for dispute. The control over water and its allocation has been a root cause and reason for exacerbated political tensions in this area (Mimi and Sawalhi 2003).

Shallow groundwater often supports the base flow of many arid streams and river tributaries (Arthington and Pusey 2003). Consequently, overpumping for irrigation or domestic purposes, combined with water diversions, result in groundwater depletion and stream dewatering (Stromberg et al. 1996). Such extreme changes in flow conditions pose considerable implications on riparian plant and animal species (Poff et al. 1997). Arid watersheds' temporal variability of flow is inherently high. According to climate change forecasts, this variability is expected to rise, along with an overall decrease in the amount of available precipitation, in semi-arid to arid zones (Givati and Rosenfeld 2007; Abdulla et al. 2009; Iglesias et al. 2007). Therefore it is probable that these environmental conditions will continue to deteriorate without having firm rehabilitation strategies in place.

3.2 Lower Jordan River Hydro-System

The Jordan River, located in the Middle East region, is considered to be a sacred river according to the Jewish and Christian religions. Its total drainage area is 18,000 km^2. Its total length from the Hermon Mountain in the north to the Dead Sea in the south, along the Syrian-African Rift system, is around 250 km in aerial distance (Fig. 3.1). The LJR extends for a 105 km distance from the Sea Of Galilee (SOG) in the north to the Dead Sea in the south. Its total length, due to meandering, is almost double (Farber et al. 2007; Klein 1985). The LJR constitutes the border between the Hashemite Kingdom of Jordan (to the east) and Israel and the

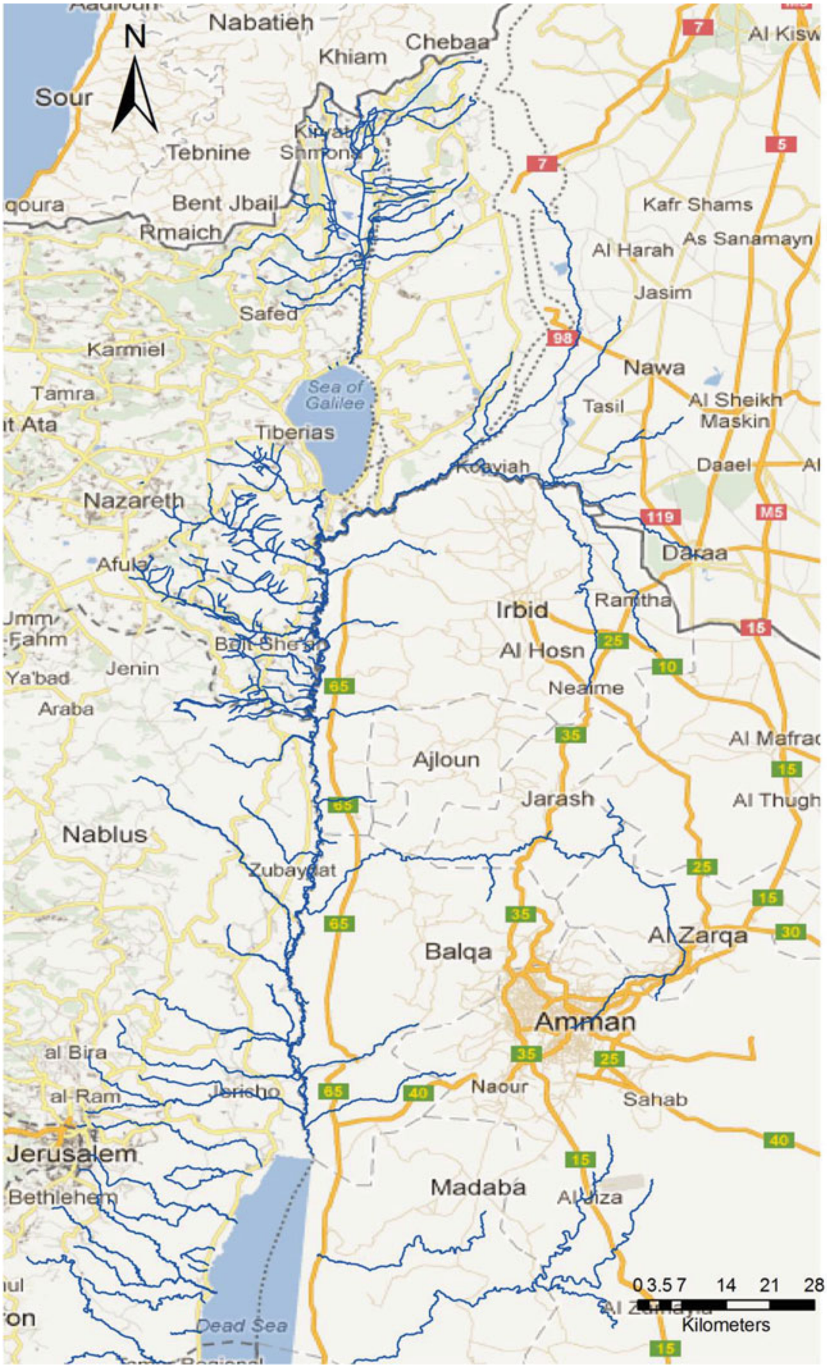

Fig. 3.1 The Jordan River Basin

Palestinian Authority (to the west). Access to the river is limited due to imposed military restrictions on both sides. Precipitation in the Jordan river basin varies from 1,400 mm/a in the north (Mount Hermon, including snow) to 250 mm south of the SOG, further diminishing to around 100 mm/a near the Dead Sea, averaging at less than 200 mm/a on both sides of the Jordan River (Lowi 1993; Klein 2005). Therefore, much of the basin is semi-arid to arid, requiring irrigation for agricultural development.

For thousands of years the Jordan River flowed freely. During the last century up until fifty years ago, the LJR carried an amount of 1,300 MCM of fresh water annually, to the Dead Sea. The river contained healthy, balanced and sustainable ecosystems rich with fauna and flora (Orthofer et al. 2001; Farber et al. 2005; Lynch 1853).

The LJR has two main water sources: (1) the starting point of the LJR at the outlet of the SOG (currently at Degania Dam), which is fed by the Upper Jordan River (UJR); and (2) the Yarmouk River (YR) which originates in Syria, travels through the Hashemite Kingdom of Jordan and confluences with the LJR at Naharayim, 7.5 km south of the origin of the LJR at the SOG. Currently, the majority of the other tributaries contribute water to the LJR only during extreme high flow events during the winter season, while most of the steady springs' contribution is exploited mainly for agriculture needs (Klein 2005).

The LJR was flowing naturally without any interruptions until the construction of the Degania Dam in 1932, blocking the natural starting point of the LJR at the outlet of the SOG. The dam was functioning to produce electricity between the years 1932–1948. In 1964, the Israeli NWC was inaugurated, diverting water away from the SOG to the southern parts of Israel, thus reducing greatly the amount of water available for the LJR. Another two more recent, artificial man-made sources originating at the starting point of the LJR are: an effluent of the Bitania Waste Water Treatment Plant (WWTP) and saline water from the Saline Water Carrier (SWC), which diverts saline springs' water from entering the SOG. Currently, the only source of water at the outlet of the SOG is effluent, which flows at a relatively constant rate of 23 MCM/y, from the SWC and Bitania WWTP. This is less than 4 % of the SOG's historical mean annual runoff to the LJR (Chen 2011).

The flow of the YR into the LJR was uninterrupted until the inauguration of the King Abdullah Canal (KAC) at 1964. During the 1980s, Syria had constructed a series of dams along the tributaries of the YR in its territory, further diminishing the amount of water available for the YR (Hassan and Klein 2002). The recently joint Syrian-Jordanian construction of the Unity Dam (El Wahdeh dam) which has recently been inaugurated (in 2011), and can hold up to 110 MCM, is going to further impound the natural flow of the YR (Klein 1985; Shub and Anisfeld 2009). Due to these diversions and regulations, the LJR contributes approximately only 120 MCM/y out of the original amount of 1,300 MCM/y of water flow into the Dead Sea, with the majority of the water being effluents, agricultural runoff and drainage of poor water quality (Orthofer et al. 2001; Shaham 2007; Venot et al. 2008; Holtzman et al. 2005; Farber et al. 2004, 2005; Chen 2011). Due to massive decline in inflow, the Dead Sea level has dropped more than 25 m within the last 30 years (Ali 2011; Lensky et al. 2005; Hersh 2005; Abu Ghazleh et al. 2009).

It is a great challenge to design and implement an ecologically sustainable water management program which can satisfy both human needs, such as storing and diverting water for human consumption, without degrading or simplifying the affected ecosystem, culminating in the loss of species' biodiversity and services for society (Richter et al. 2003). EFR should be prescribed in a way which would mimic important features of natural ecosystem flow regime to the fullest extent possible (Poff et al. 1997; Richter et al. 2003; Arthington and Pusey 2003; Arthington and Zalucki 1998). A river basin is considered "closed" when all its river flow is allocated for uses other than the maintenance of its aquatic ecosystem services (Smakhtin 2008). Since the structure and function of every river is determined by temporal and spatial variability of flow, it is important to find out the historical natural flow regime of the LJR before its basin was "closed". For that purpose, examining historical data regarding past flow patterns of the LJR is necessary in finding out natural flow trends of the river and in suggesting solutions that would mimic this natural behavior and will restore the river's ecological integrity (Poff et al. 1997).

The overall objective of this research was to investigate the continuous degradation of water flow in the LJR and to prescribe a rehabilitation plan for the river. This was done by comparing the LJR's past natural uninterrupted flow regime with contemporary anthropogenic regulated flow. Looking into the river's natural flow helped determining the natural uninterrupted temporal and spatial flow variability of the LJR, and facilitated in constructing EFR for the river.

3.3 Methods

River flow was measured by the British mandate authorities, and later by the Israeli Water Authority (IWA) within the time periods of 1921–2010 at different scales, including: daily, monthly, seasonally, and yearly. In this research, emphasis was given to: (1) differences between distinctive magnitudes of flow—base flows versus extreme flow events (floods and droughts); (2) frequency, duration and timing of extreme flow events; and (3) rate of change in flow amplitude. Comparisons were conducted in three different locations as described in Table 3.1: (1) the outflow of the LJR from the SOG; (2) the YR tributary, before its confluence with the LJR; and (3) the point of confluence of the LJR and the YR (Naharayim and Gesher) (Fig. 3.2). Hydrological data was obtained courtesy of the Israeli Hydrological Service (IHS), from eight different monitoring stations (Table 3.2).

As can be seen in Table 3.2, these monitoring stations were in operation for different periods of time, where the period of record at most stations is broken and not continuous. Therefore there was a need to rely on all possible available data in order to get a continuous flow data. For example: the two adjacent monitoring stations on the YR—Yarmouk-gate 121 and Yarmouk-below gate 121 are only a

Table 3.1 Compared pre and post impact periods on the LJR, with the corresponding hydrometric stations and flow data resolution

Location	Pre-impact period	Post-impact period	Resolution
Degania (I in Fig. 3.2)	1921–1931	1933–2008	Monthly
Yarmouk (II)	1934–1948 (Dec–Apr)	1989–2010 (Dec–Apr)	Daily
Yarmouk (III)	1926–1964	1989–2010	Monthly
Gesher/Naharayim (IV)	1927–1931	1933–1946, 1978–1999	Monthly

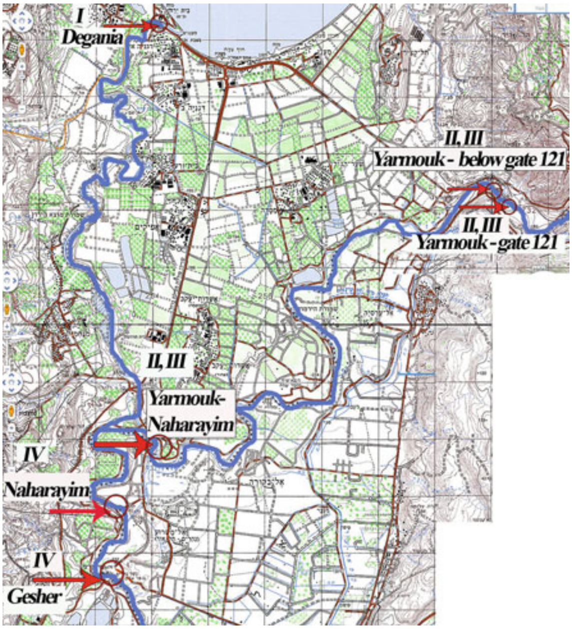

Fig. 3.2 Locations of hydrometric monitoring stations on the LJR and YR, used in this study

few hundred meters apart (Fig. 3.2) and would provide the same flow data. Therefore, theoretically there would be a need for only one of the station's data. Nevertheless, since their operation was interrupted, it was necessary to use both stations in order to get a continuous flow data. The same goes with the two monitoring stations on the LJR main stem—Gesher and Naharayim (Fig. 3.2): both stations were in operation only part of the explored time period, so data from both stations had to be combined. Since the distance between Gesher and Naharayim is only 2 km, and there are no other tributaries joining the LJR in between, these two points were considered as a single point of reference for measuring water flow. Yarmouk-Power-Company and Yarmouk-Naharayim monitoring stations may refer to the same location, whereas the former was used only during the British mandate and there is no mention to its exact location. Degania monitoring station has been in operation almost uninterruptedly since the inauguration of the Degania dam. However, when the NWC was constructed, and saline spring water was diverted

Table 3.2 Available data on the LJR: location, timing and resolution

Hydrological station name	Hydrological station number	Latitude/longitude	Years	Resolution
Degania	31,198	32.71153/ 35.57300	10/1921–8/22, 10/25–9/32, 10/33–4/48, 5/49–9/08	Monthly
Gesher (Jisr el Majami)	None	32.62463/35.56460	10/26–9/46	Monthly
Naharayim	34,185	32.63516/35.56550	1/78–4/2000	Monthly
Yarmouk–gate 121	34,159	32.68280/35.6395	10/95–2/99	Monthly
Yarmouk–gate 121	34,159	32.68280/35.6395	10/88–9/91	Daily
Yarmouk- below gate 121	34,160	32.68498/35.6364	10/91–2/99, 1–9/2000, 1/01–9/10	Daily, Monthly
Yarmouk—Power-Company[a]	None	–	Dec–Apr/34–48	Daily
Yarmouk–Naharayim	34,180	32.64482/35.5729	5/26–9/95	Monthly
SWC at Alumot	None	32.70217/35.5630	1/65–9/2008	Monthly

[a]There is no specific location information. It is assumed to be in the vicinity of station number 34,180

away from the SOG via the SWC into the LJR, it was necessary to monitor and include this additional amount of water to the LJR water budget, therefore adding the monitoring of the flow of the SWC at Alumot dam was also included in our study. The fact that the river is marking an international border, which until 1994 was an antagonistic border between enemy countries, might explain the lack of cooperation between the countries in maintaining and constructing hydrometric monitoring stations along the river in order to monitor its flow.

Meteorological data containing monthly and annual precipitation information from seven rain gauging stations within the catchment area of the UJR and LJR were obtained courtesy of the Israeli Meteorological Service (IMS), for the years 1921–2010. Precipitation measured in the K. Gilady rain gauging station, which is located in the upper Galilee area, was found to correlate best to the uninterrupted flow discharge of the LJR, thus was chosen for this study. A comparison between the multi-annual precipitation patterns of pre- and post-impacted years was conducted in order to find out if there were different trends in precipitation during the two periods, in order to estimate what the contribution of climatic changes (if any) was to the alteration of the LJR flow regime, besides the anthropogenic impact that was discussed already in the introduction.

With such ample daily scale hydrological data, it was possible to use the "Indicators of Hydrologic Alteration" (IHA) software tool for statistical analysis of temporal flow variability regimes, comparing the daily flows of the YR during the pre-impact period of 1935–1948 and post-impact period of 1989–2010 (Richter et al. 1996). IHA works best with daily scale mean flows, providing 32 hydrologic parameters for each data series along with 34 additional parameters representing the Environmental Flow Components (EFC) analysis which are also available within the IHA tool (Mathews and Richter 2007). These parameters were calculated for each period and compared in order to measure alteration in flow. These statistical capabilities proved to be very advantageous in pinpointing and identifying the major differences between the different flow regimes (Richter et al. 2003, 1996). Since access to the LJR is restricted due to military restrictions, there are no substantial records of botanical or zoological data comparing between pre and post impact eras. This lack of information provided another incentive to use the IHA tool, which can provide flow recommendation "standards", based only on hydrologic alteration.

3.3.1 IHA Parameters and Statistics Analysis Characteristics

The following 32 IHA parameters, which correlate to the different aspects of flow variability were analyzed and are described in Table 3.3, according to their characteristics.

Reversal events are calculated by first dividing the hydrological year into periods in which flow discharge magnitude is either rising or falling. A reversal event is an occurrence of alternation from a "rising" period to a "falling" period or vice versa. A change in the sign of the difference between 2 consecutive couple of days will be regarded as a reversal event (The Nature Conservancy 2009).

A two period parametric and nonparametric statistics analysis was created in IHA comparing the daily flows of the YR during the pre-impact period of 1935–1948 and post-impact period of 1989–2010. Means and standard deviation were used in the parametric analysis in order to measure averaged flows and providing thresholds of high and low flows using ±1 standard deviation from the mean, respectively. Median, 75 and 25 percentiles were used in the nonparametric analysis for the same purposes. The uninterrupted YR flow distribution is a positively skewed distribution due to extreme scattered high flow events (flood events) which drastically increase the mean and standard deviation values, creating a narrow positive tail. Since flood events are a crucially important component of measuring flow variability, these values could not be ignored, in order to obtain a normal distribution. Even though the flow distribution is not a normal distribution, parametric analysis was used in cases such as measuring monthly flow volumes and flood frequencies, where mean values gave a better affinity to reality than median values. A shortened water year including only the winter months of December–April were compared for two reasons: (1) for the years 1935–1948—there was availability of daily flow data only for these months; and (2) the principal variability of flow in the YR occurs during the rainy season, thus is more interesting to analyze.

Table 3.3 Summary of hydrological parameters used in IHA, and their characteristics (Richter et al. 1996, 1997)

IHA statistic group	Regime characteristics	Hydrologic parameters
Group 1: Magnitude of monthly water conditions	Magnitude timing	Mean monthly flow discharge magnitudes (December to April)
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude duration	Annual minima 1-day means
		Annual maxima 1-day means
		Annual minima 3-day means
		Annual maxima 3-day means
		Annual minima 7-day means
		Annual maxima 7-day means
		Annual minima 30-day means
		Annual maxima 30-day means
		Annual minima 90-day means
		Annual maxima 90-day means
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1-day maximum
		Julian date of each annual 1-day minimum
Group 4: Frequency and duration of high/low pulses	Frequency duration	Number of high pulses each year
		Number of low pulses each year
		Mean duration of high pulses within each year (in days)
		Mean duration of low pulses within each year (in days)
Group 5: Rate/frequency of water condition changes	Rates of change frequency	Means of all positive differences between consecutive daily values
		Means of all negative differences between consecutive daily values
		Number of rises (reversals)
		Number of falls (reversals)

3.3.2 *Classifying Environmental Flow Components (EFC)*

Whereas the basic 32 IHA parameters enable conducting specific inter-annual assessment of variability changes, they lack in providing concrete recommendation towards riparian environmental flow needs and targets. The additional 34 EFC parameters describe five major components of flow which are ecologically important when describing hydro climatic regions. These five components are: (1) Extreme low flows; (2) Low flows; (3) High flow pulses; (4) Small floods; and (5) Large floods. These components can be accounted for the way an organism experiences flow variability, and are especially of importance in semi-arid to arid zones, where variability of flow is high and extreme flow events are commonplace pattern. Even though the IHA doesn't provide an answer to how much alteration of the EFC parameters might be too much, their great advantage over the basic IHA parameters is that it is fairly feasible to construct EFR based upon the EFC. Even though these two parameter types are slightly redundant, they complement each other and enable to perceive the "big picture" of flow alteration. That is why both types of parameters were chosen for this study (Mathews and Richter 2007).

For both analysis types (parametric and non-parametric), a daily flow is classified as a **high flow** or **low flow** occurrence if it exceeds 15.9 Cubic Meter per Second (CMS) which is at the 66.6 percentile of daily flow for the uninterrupted period or is below 12 CMS—the median flow for the uninterrupted period, respectively. These numbers were chosen after examining the pre-impact data, concluding that most of the winter flows of the YR (the winter base flows) were within the threshold of these numbers. In between these two thresholds, a high flow will begin if flow discharge increases by more than 40 % per day, and will end when flow decreases in less than 25 % per day. A **small flood event** and a **large flood event** are defined by initial flows greater than a flow magnitude with 1.1 and 3.5 years return interval, 84 and 405 CMS, respectively. An **extreme low flow** is defined as an initial low flow below the 10 percentile of daily flow (7.19 CMS) for the uninterrupted period. These values for the five different types of EFC were introduced as a result of a thorough calibration which took into consideration the nature of the existing pre-impact flow regime. The following EFC parameters were analyzed: Small and large floods' frequency, duration, peak flow, timing and rise and fall rates.

3.4 Results

3.4.1 Meteorological Data Comparison

The correlation between K. Gilady annual rainfall, and the YR annual discharge flow for the uninterrupted period of 1926–1964 (as measured at Yarmouk-Naharayim monitoring station) is very high, with correlation coefficient of 0.81 and Eta-Square of 0.66 (Fig. 3.3a), confirming that rainfall pattern in the Upper Jordan River Catchment (UJRC), correlates with the discharge flow pattern of the YR, thus enabling a comparison of annual rainfall changes between pre impact and post impact years, and correlates it to the YR discharge flow changes in these years. In years with extremely high annual rainfall (above 900 mm/a), lower correlation between rainfall in the UJRC and YR discharge is exhibited. The frequency of such years, however, is relatively rare.

Both periods of 1935–1948 and 1989–2010 experience a decreasing trend in annual rainfall, according to the annual rainfall trend in K. Gilady gauging station (Fig. 3.3b). It is also evident that overall, pre impact period years are located slightly higher on the graph then the post impact period. Supporting this

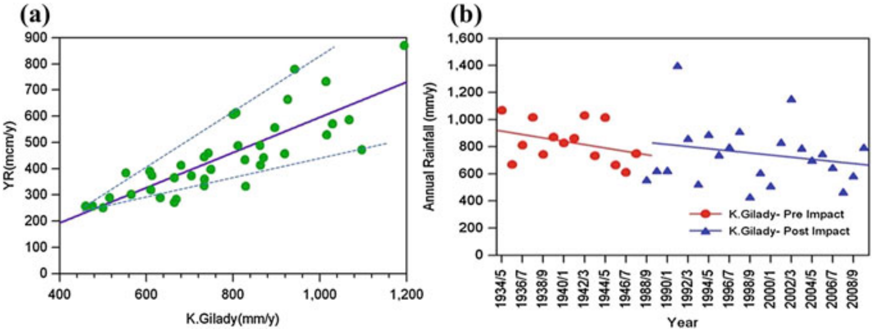

Fig. 3.3 **a** K. Gilady annual rainfall and YR annual flow correlation (as measured at Yarmouk-Naharayim monitoring station) for the years 1926–1964 with linear regression correlation coefficient R^2 = 0.81; Eta^2 = 0.66; STD = 86.6, **b** K. Gilady annual rainfall trend for YR comparison of pre (1935–1948) and post impact (1989–2010) years with linear regression correlation coefficient R^2 = 0.35; Eta^2 = 0.12; STD = 135.6

observation is the fact that the average rainfall amount for the pre impact years is 833 ± 150 mm/a, whereas the average rainfall amount for the post impact years is only 736 ± 228 mm/a. Whereas the difference in precipitation between pre and post impact periods is almost 12 %, the differences in discharge flow on the YR are evidently higher, suggesting that as expected, anthropogenic activities are the main reason for such an impact. However, this trend of diminishing precipitation might have been another factor that is responsible for a decline in base flow on the LJR (as can be seen in Sect. 3.4.2).

3.4.2 Monthly Flow Comparisons

3.4.2.1 Degania: Pre-impact 1921–1931 and Post-impact 1933–2008 Time Periods

During the period before the construction of the Degania dam (1921–1931) the peak flow occurred in April and had reached almost 60 ± 6 CMS, sharply decreasing till reaching the minimum monthly flow during November (2.7 ± 0.6 CMS), at the end of the dry season. March and May had noticeably higher flows than the rest of the year. During the period of electricity production (1933–1948), the flow trend has changed: the regime flow has been smoothed out and was lowered artificially during the winter months, relying on flow from the YR tributary during the wet season, peaking during the dry season in order to provide enough flow for electricity production during this period. During 1948–1964, the trend of smoothing out differences in flow has been intensified. Since the inauguration of the

NWC in 1964, there is a sharp decline in water flow, reaching a grave situation during 2000–2008 where the peak flow occurred during August and stood at 0.48 ± 0.12 CMS (which is 5 times lower than the lowest natural discharge flow), indicating constancy of flow and river desiccation conditions. Pre-impact flow was measured at Degania monitoring station; whereas post-impact flow was measured at both Degania monitoring station and at the SWC at Alumot (Table 3.2). These data are described in Fig. 3.4a.

3.4.2.2 Yarmouk: Pre-impact 1926–1964 and Post-impact 1989–2010 Time Periods

Trends for months of peak and low flows haven't changed from pre to post impact periods; only the amount of water flowing has reduced significantly. Yearly peak of flow occurs in February, with an average flow of 74 ± 14 and 12.8 ± 6.5 CMS for the pre and post impact periods respectively. Average flow during the summer and fall months is 7–9 ± 1 and 1 ± 0.08 CMS during the pre and post impact periods respectively (Fig. 3.4b). Pre-impact flow was measured at Yarmouk-Naharayim monitoring station; whereas post-impact flow was measured at both Yarmouk-Naharayim and Yarmouk- below gate 121 monitoring stations (Table 3.2).

3.4.2.3 Gesher/Naharayim: Pre-impact 1927–1931 and Post-impact 1933–1999 Time Periods

During the pre-impact period, peak flow was during the months of February, March and April, amounting to 99 ± 15, 85 ± 12 and 59 ± 9 CMS, respectively, dropping gradually to a minimum flow in October (11.2 ± 2.6 CMS). This trend is altered during the period of electricity production, 1933–1946, where rate of flow is flattened and ranges between 24–30 ± 2.5 CMS during most months of the year. The following time period still shows flow differences between summer and winter months, but with a massive decline in flow rate due to water diversions. The flow at Gesher and Naharayim is currently directly influenced by the flow of the YR and the effluents from the SWC and Bitania WWTP—being the main water sources upstream reaching this point in the river, with an average of 1 ± 0.1 CMS flow rate during the summer months (June–October) indicating the river's main stem desiccation during low flow years (Fig. 3.4c). Pre-impact flow was measured at Gesher monitoring station; whereas post-impact flow was measured at both Gesher and Naharayim monitoring stations (Table 3.2).

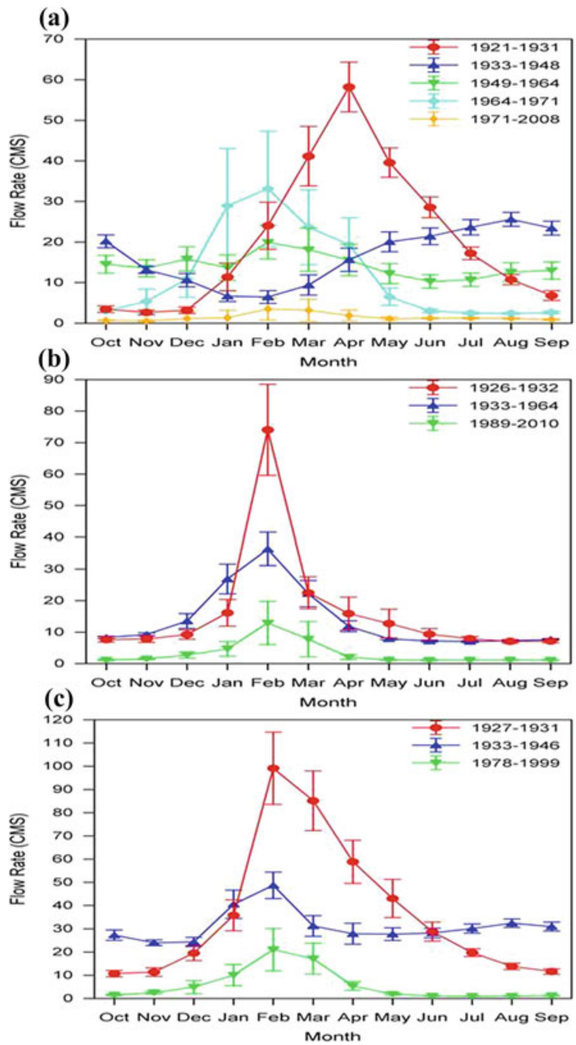

Fig. 3.4 Mean and ± 1 standard error of the mean (standard deviation divided by the square root of the sample size) of monthly flow: out of the Sea of Galilee (Degania dam), 1921–2008; YR to the LJR, 1926–2010; and on the LJR main stem at Gesher/Naharayim, 1927–1999, labels **a–c**, respectively. Degania's pre-impact flow data are based on Degania monitoring station; whereas post-impact flow data are based on Degania and SWC at Alumot monitoring stations. YR pre-impact flow data are based on Yarmouk-Naharayim monitoring station; whereas post-impact flow data are based on Yarmouk-Naharayim, Yarmouk-gate 121 and Yarmouk- below gate 121 monitoring stations. LJR main stem at Gesher/Naharayim pre-impact flow data are based on Gesher monitoring station; whereas post-impact flow data are based on Gesher and Naharayim monitoring stations (Table 3.2)

3.4.3 YR Daily Flow Comparisons for the Time Periods December–April/1934–1948 and December–April/1989–2010

IHA tool was used in order to compare historical (pre-impact) and contemporary (post-impact) discharge flow on the YR in daily resolution. Pre-impact flow was measured at Yarmouk-Power-Company monitoring station; whereas post-impact flow was measured at both Yarmouk-gate 121 and Yarmouk-below gate 121 monitoring stations (Table 3.2).

3.4.3.1 Daily Flow Data with Environmental Flow Components (EFC)

During the pre-impact period (1935–1948), except for the winter of 1935–1936, every year had at least one or more flood events (Fig. 3.5a, zoomed in Fig. 3.5b). The periods with extreme low flows are rare. During the post-impact period (1989–2010), the extreme low flow type is the most notable flow. Flood events and high flow pulses are scarcely distributed (Fig. 3.5a, zoomed in Fig. 3.5c).

3.4.3.2 Dates of Minimum and Maximum Flows

Almost 80 % of pre-impact period's maximum flows occurred between Julian days 30–58, during the month of February. As for the post impact period, there is no significant trend, with most events appear later in the hydrological year, suggesting that maximum annual flows dates have been altered. For the pre-impact period, roughly 70 % of the minimal flows occurred during December, and the other 30 % occurred during April. As for the post-impact period, minimum flow dates are more scattered: 40 % fall within February, 23 % in March, while the rest are distributed between December, January and April equally.

3.4.3.3 High Pulse Count and Duration

During most years of the pre-impact period there were at least 6 high flow pulses annually, most of them lasted between 3 to 5 days, with one exceptionally high pulse duration of 22 days during 1938. On the other hand, more than 50 % of post-impact years had zero high flow pulses, with the rest ranging mostly between 1 and 2 pulses a year.

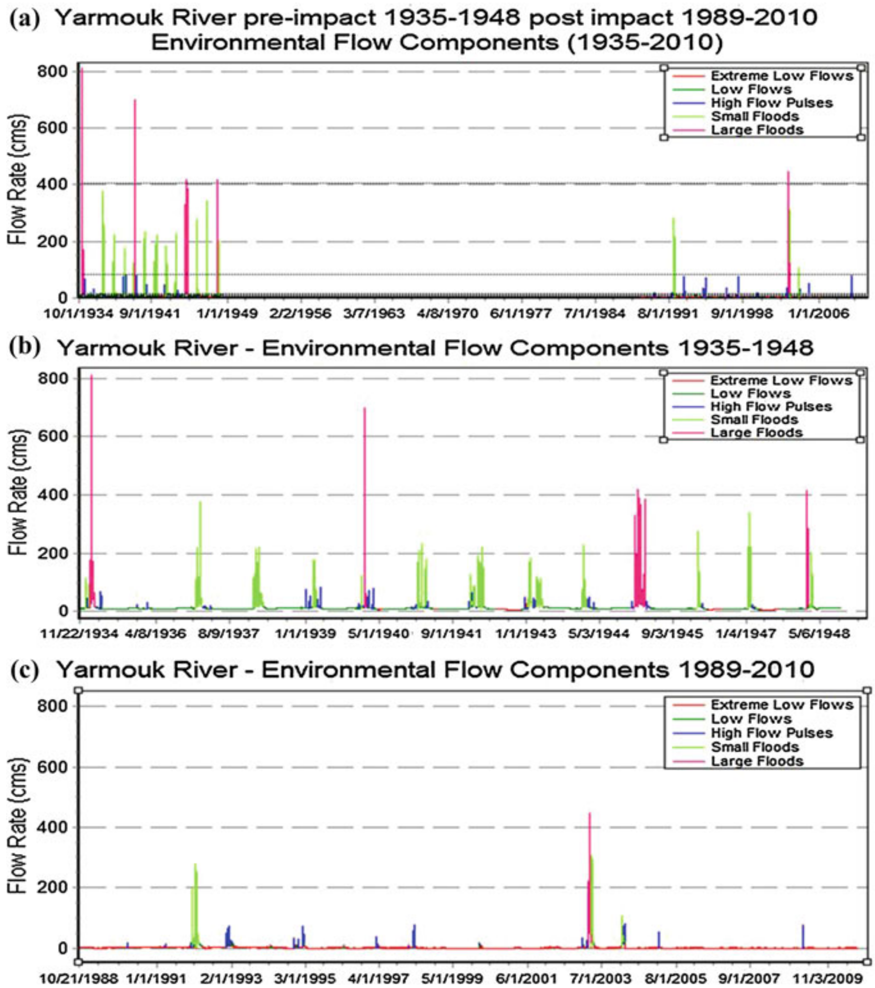

Fig. 3.5 YR daily flows hydrograph with EFC for: 1935–1948 and 1989–2010; zoom on 1935–1948; and zoom on 1989–2010, labels **a**–**c**, respectively. Pre-impact flow was measured at Yarmouk-Power-Company monitoring station; whereas post-impact flow was measured at both Yarmouk-gate 121 and Yarmouk-below gate 121 monitoring stations (Table 3.2)

3.4.3.4 Reversals Count

Pre-impact average amount of annual reversal events is 70 ± 9, whereas the average post-impact amount is only 48 ± 20. Pre-impact reversal events are within a narrow range between 60 and 80. Most post-impact annual reversal counts are below 70, with several years with less than 20 reversal events, indicating constancy of flow magnitude. Even though statistically reversal events count have dropped on average during the post-impact period only by 30 %, which is a high rate by itself, one should look at the amplitude of change as well. Due to the rarity of extremely high flow events during the post-impact period, a change from low flow to lower flow and vice versa, is still considered statistically as a reversal event, but actually does not have the same effect as alternation between high and low flows, as naturally occurred during the pre-impact period.

3.4.3.5 Small Floods

For the pre-impact years, small floods' peak ranges between 150–250 CMS. Whereas on average 2 annual small flood events occurred during pre-impact years, only 3 post-impact years had small flood events. Duration of small flood events for pre-impact years is ranging from 4 to 27 days, averaging 16 ± 8, and the floods' timing is equally spread between the months of January and February. These data are described in Fig. 3.6.

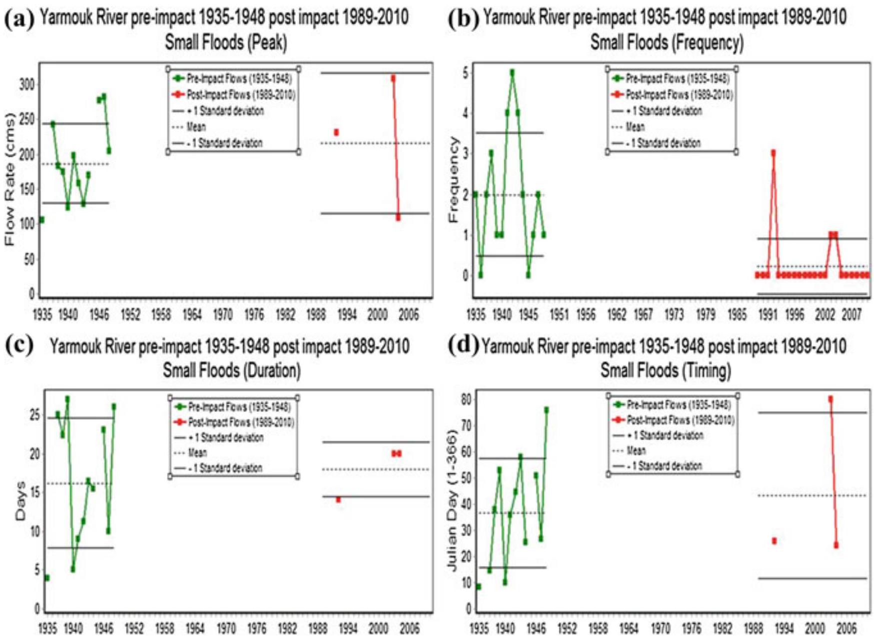

Fig. 3.6 YR pre-impact (1935–1948) and post-impact (1989–2010) small floods mean annual peak, frequency, duration and timing, labels **a–d**, respectively. Pre-impact flow was measured at Yarmouk-Power-Company monitoring station; whereas post-impact flow was measured at both Yarmouk-gate 121 and Yarmouk-below gate 121 monitoring stations (Table 3.2)

3.4.3.6 Large Floods

For the pre-impact years, large floods' peak ranges between 400–800 CMS. Whereas 4 large flood events occurred during the 14 of pre-impact years, on average one large flood event every 3.5 years, only one large flood event (in 2003) occurred during 22 post-impact years. Duration of large flood events for pre-impact years is ranging from 13 to 81 days, averaging 36 ± 31, with a median duration of 26.5 days. Duration for the 2003 large flood event was 26 days. Large flood events' timing for the pre-impact years is from the end of January till mid-February.

3.4.3.7 Flow Duration Curves

The flow magnitude exceeding probability for the pre and post impact time periods, was calculated for the months December–April (Fig. 3.7). The Y-axis represents the flow rate in CMS, whereas the X-axis represents the percentage of total flow, which is higher than the corresponding flow rate. The area under the graph represents the Mean Annual Runoff (MAR). For example—the median flow can be located at the 50 percentile and is equal to 12 and 1.5 CMS, for the pre-impact and post-impact periods respectively. The area under the graph beyond the threshold of the median may approximate the annual base flow (Smakhtin et al. 2004), which suggests that the pre-impact annual base flow is approximately 10 times bigger than the contemporary annual base flow. While the lowest flow recorded during pre-impact period is 4 CMS, more than 85 % of total post-impact flow magnitude is lower than 4 CMS, pointing to severe flattening of the amplitude of variability of flow. The portion of flood events flow (above 85 CMS) out of the total flow has dropped from

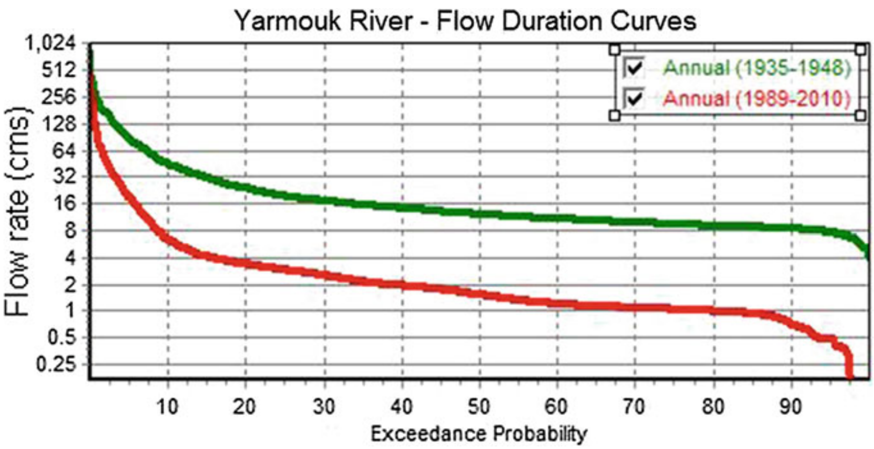

Fig. 3.7 YR pre-impact (1935–1948) and post-impact (1989–2010) flow duration curves, measured in daily scale. Pre-impact flow was measured at Yarmouk-Power-Company monitoring station; whereas post-impact flow was measured at both Yarmouk-gate 121 and Yarmouk-below gate 121 monitoring stations (Table 3.2)

5 % in pre-impact period to less than 1 % in the post-impact period. Looking on the other end of the scale, 21 % of total flow during post-impact period is less than 1 CMS, and 7 % of total flow is below the flow rate of 0.5 CMS, which indicates river's desiccation—even during the rainy season.

3.5 Discussion

Hassan and Klein (2002) have analyzed discharge flow data on the LJR in Gesher for the years 1934–1945. During that period, the Degania dam was already active and flow rate from the SOG to the LJR was approximately 10 CMS during the winter season (Fig. 3.4a). Therefore, the majority of the winter flow came from the YR. This study's finding is in agreement with Hassan and Klein's when examining the frequency of large floods (400–800 CMS); however, there is discrepancy between the two studies when the recurrence interval is lower than 3 years. According to this study, peak flows with magnitudes 150–250 occurred on an average of twice a year whereas a peak event with magnitude 175 CMS would occur according to Hassan and Klein (2002) only once every 1.2 years. The reason for this discrepancy stems from the fact that Hassan and Klein have used monthly flow resolution from which they extracted for each hydrological year the maximum annual discharge and used that amount for their statistics (Micha Klein, personal communication, November 22, 2011), whereas in this research, daily flow resolution was used and every flood event was recorded and taken into consideration. Therefore, Hassan and Klein's findings show the maximal annual peak flows whereas in this research minor flood events with higher frequencies were also taken into consideration.

During the last four decades the effect of the massive diversion of water out of the LJRB has an intensifying trend. Currently, the only source of water at the beginning of the LJR is the SWC and Bitania WWTP effluents, not including increasingly rare occasions when the Degania dam is opened. The last occurrence of such an opening happened during the month of February 1995 (as of September 2013). The natural discharge flow out of SOG, prior to the inauguration of the Degania dam, had a MAR of 640 ± 134 MCM, compared to a contemporary MAR of 18 ± 2.4 MCM. According to Smakhtin et al. (2004), this amount of flow describes a critically modified and degraded river, with diminished habitat diversity and extensive exploitation of water resources. Without the additional flow of sewer and saline effluents, the stretch of river initiating from the Degania dam till the confluence with the Yarmouk at Naharayim would have completely dried out.

YR post impact (1989–2010) variability of flow has been severely altered compared to pre-impact (1935–1948) natural uninterrupted flow (Fig. 3.5). Frequency and magnitude of contemporary flood events and high flow events on the YR have been significantly reduced: frequency of small floods has been reduced by an order of magnitude from an average of 2 floods a season (December–April) to merely one flood in 5 years (Fig. 3.6); frequency of large floods has been reduced

Table 3.4 YR flow regime components during the pre-impact (December–April/1934–1948) and post-impact (December–April/1989–2010) periods, measured in daily scale. Pre-impact flow was measured at Yarmouk-Power-Company monitoring station; whereas post-impact flow was measured at both Yarmouk-gate 121 and Yarmouk-below gate 121 monitoring stations (Table 3.2)

Event	Magnitude (CMS)		Frequency (per year)		Timing (Julian day)		Duration (days)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Small flood	150–250	100–300	2	0.23	37	43	16	18
Large flood	400–800	450	0.29	0.05	33	53	36	26
High flow pulse	31	36	6.5	0.7	44	40	2.5	2.1
December mean flow	12.4	2.59	–	–	–	–	–	–
January mean flow	34.5	4.66	–	–	–	–	–	–
February mean flow	42.85	12.43	–	–	–	–	–	–
March mean flow	24.34	6.52	–	–	–	–	–	–
April mean flow	11.8	2.15	–	–	–	–	–	–
1-day minimum flow	6.95	0.85	–	–	116	Scattered	–	–
30-day minimum flow	8.9	1.07	–	–	–	–	–	–
90-day minimum flow	22.24	2.17	–	–	–	–	–	–
1-day maximum flow	330	60	–	–	38	50	–	–
7-day maximum flow	131	33.7	–	–	–	–	–	–
Rise rate	14.5	3.8	–	–	–	–	–	–
Fall rate	–10	–1.7	–	–	–	–	–	–
Reversals	–	–	70	48	–	–	–	–

from an average of one flood in 3.5 years to only one large flood recorded during the 22 years of post-impact data; high flow pulse frequency have been reduced from an average of 6.5 ± 2.2 pulses a season to less than one pulse a season (Table 3.4).

The decline in the frequency and magnitude of high flow pulses and flood events could be one of the factors contributing to the reduction of the LJR's sinuosity. According to Klein (1985) the LJR's sinuosity has been dropping since 1932. Whereas in 1920s the thalweg (meandering pattern) length of the LJR was 220 km, it was reduced to 199 by 1975. The current thalweg length of the LJR is only 179 km. Sinuosity is the ratio between the thalweg and the aerial lengths of a river. Therefore, whereas sinuosity of the LJR was 2.1 in the 1920s, it had dropped to 1.9 by 1975, and had further declined to a current level of 1.7. This sharp decline in sinuosity is an indicator of the river's reduced ability to carry sediments due to diminished base flow discharge and high flow pulses which is the main contributor to sedimentation deposition. With such a meager discharge there is a threat that the LJR will further abandon its meandering nature and will become braided (Klein 1985). Changes in river sinuosity have a dominant impact on the formation of riparian vegetation spatial patterns (Perucca et al. 2006). Changes in sedimentation loads and fluvial migration affect the nature and texture of riparian soils, changing the soil moisture balance, which in turn affects the riparian plants' population (Rodriguez-Iturbe et al. 1999; Nanson and Beach 1977 in Perucca et al. 2006).

It must be noted that some of our findings are based on relatively short pre-impact periods of record, due to limited data availability. Whereas Richter et al. (1996) have recommended at least 20 years of flow data, some of our conclusions are based on only 10–15 years. However, due to the cardinal differences between the pre and post periods, and the consistent flow patterns within each period, we estimate the vulnerability of our conclusions to be minor.

3.6 Preliminary Flow Recommendations Within an Adaptive Management Framework

Estimation of ecosystem flow requirements is a complicated task. Arthington et al. (2006) suggested that in order to protect and maintain the goods and the services provided by a riparian ecosystem along with its biodiversity, components of natural flow such as magnitude, frequency, duration, timing and rate of change of flow should be mimicked. This research has shown a massive alteration and interruption of all the above-mentioned components. The most apparent alteration in the LJR's natural flow is the lack of contemporary flood events and high flow events, and the drastic reduction in base flow discharge. Consequently, the transition between high and low flows has also been dramatically flattened, as can be seen in the lower amounts of contemporary reversal events and diminished rise and fall rates.

Since different types of flow variability support different species of wildlife and plants, these species are probably exhibiting stress due to the current situation in which the natural variability has been severely altered. This stress is intensified with flow magnitude dropping to desiccation levels on the tributaries of the LJR as well as on the river's main stem during low flow years.

According to our research, if one would consider supporting and rehabilitating the natural ecosystem of the LJR, it is crucial to reallocate water back to the LJR system according to its natural flow patterns. We prescribe two flood events per year, with peak magnitude of 100 CMS (for 12 h), and an average magnitude of 30 CMS (with duration of seven days), one during the month of February, and the other during the month of January or March. If possible, it is probably preferable that one of the floods will originate from the Degania dam (the starting point of the LJR at the outlet of the SOG), while the other from the El-Wahdeh dam (damming the YR tributaries). Such an operation will require additional allocation of 45 MCM per year (22.5 MCM per flood event). In addition, four high flow pulses, with magnitude of 30 CMS, and duration of 24 h, with a frequency of once a month during the rainy season (December–April), to be incorporated with the prescribed flood events. This operation will require additional 10 MCM per year (2.5 MCM per high flow pulse). Furthermore, an additional allocation of 45 MCM/y, to be divided equally in order to increase the LJR's base flow by 1.5 CMS, which would almost triple the current base flow discharge of the LJR and bring it above 2.5 CMS (Fig. 3.4c), hopefully enabling adequate plant and animal habitat conditions along the river banks.

Once every 3–4 years, the two flood events will be combined, using the same amount of water (45 MCM) to create a large flood event, with peak magnitude of 325 CMS (12 h), and an average magnitude of 30 CMS, with duration of twelve days, during the month of February. In total, an additional 100 MCM/y of fresh water is needed in order to facilitate this flow alteration, mimicking the natural uninterrupted flow of the LJR.

Reallocating 100 MCM/y of fresh water for environmental restoration might seem an unrealistic amount, especially given the region's natural water resources scarcity. Both Jordan and Israel, the two major riparian on the LJR are experiencing an increase in water demands due to population growth (both natural and in the case of Jordan supplemented by massive immigration waves from neighboring countries such as Syria and Iraq), and increase in affluence. On the other hand, natural water resources potential in these countries has been reduced according to reported studies (Givati and Rosenfeld 2007; Abdulla et al. 2009; Iglesias et al. 2007; Vörösmarty et al. 2000). Israel's way to deal with this situation is to develop and increase the use of marginal water: wastewater treatment and reclamation, and desalination of both sea water and deep brines, for agricultural and domestic use, respectively. With desalination production prices continually dropping, "physical scarcity" is no longer an issue in Israel, turning water allocation issues into a matter of price (Chen et al. 2015; Dreizin et al. 2008; Elimelech and Phillip 2011; Garb 2010). Since most desalinated water production is located in the coastal area, where the vast majority of Israel's population resides, transporting water from the SOG via the NWC becomes superfluous. Instead, water can be released from the SOG via the Degania dam to the LJR uninterruptedly. A scenario of releasing 50 MCM/y unilaterally by Israel, even without cost sharing of the other riparian states, have proved to be economically beneficial to Israel, according to a Contingent Valuation survey (Chen et al. 2015). The recent agreement signed by Israel, Jordan and the Palestinian Authority (in December 2013), in which Jordan will pump 200 MCM/y from the Red Sea, out of which 80 MCM will be desalinated, and the rest will flow via a conduit to the Dead Sea in order to replenish its' massive water loss, might be used as another incentive to rehabilitate the LJR. According to this agreement, Israel will receive 50 MCM/y from Jordan, for local domestic use in its' southern part, and will return this amount to Jordan from the SOG, for domestic use in Amman (Barnea 2013; Sherwood 2013). These 50 MCM/y could theoretically flow in the LJR and be extracted for domestic use (after treatment) 30–40 km north of the mouth of the Dead Sea in order to avoid hyper saline springs' infiltration into the fresh water (Farber et al. 2004). This solution can only be viable provided that major pollutants are removed from the river. The combination of the two above mentioned solutions will provide 100 MCM/y of fresh water that will flow from the SOG to the LJR with economic viability.

In order to fully understand the mechanisms at work within the LJR ecosystem, inputs from an interdisciplinary group of scientists should be sought for, in order to provide a full picture of the hydrologic, geomorphic and biogeochemical processes which together will create desirable habitat conditions on the LJR (Richter et al. 2003). An adaptive and iterative process assessing the LJR's ecosystem's ecological responses to the reregulation of the LJR should take place thus enabling fine tuning of the water allocations in order to reach the most desirable results. This case study of the LJR can be used as an example for the implementation of rehabilitation programs in other watersheds located in arid and semi-arid regions, based on available historical hydrographs and other botanical and zoological data.

To the best of our knowledge, this is the first time that daily resolution flow data are being used in order to determine the temporal and spatial variability of the LJR's natural uninterrupted historical flow regime. This research's findings constitute a first step towards understanding the LJR's hydrological natural hydrological conditions, from which EFR could be extracted, after being incorporated with botanical and zoological studies' findings. Since currently, due to restrictions in access to the river, there are no substantial research findings regarding the LJR ecological biodiversity and services provided by the river. This research's findings can be very useful if adopted as a precautionary principle in order to protect the river's ecosystem in the meantime, until further relevant findings could be incorporated into an integrated restoration plan. Creative thinking and thorough investigation of ecosystem needs in relation to available resources should be combined in order to satisfy both human and ecosystem requirements.

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Chapter 4
New Tools for Coherent Information Base for IWRM in Arid Regions: The Upper Mega Aquifer System on the Arabian Peninsula

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Abstract In arid regions like the Arabian Peninsula, available water resources are essentially restricted to groundwater, requiring a detailed understanding of the local and regional hydrogeological conditions and water budgets. In the framework of the IWAS initiative, the 1.8×10^6 km^2 large sedimentary Upper Mega Aquifer of the Arabian Peninsula was chosen as a model region to develop concepts and methodologies to quantify water fluxes in such an arid environment. Field and laboratory studies were conducted to analyse (i) precipitation patterns, (ii) groundwater recharge, (iii) the hydrochemical evolution of groundwater and (iv) evaporation particularly from Sabkhas in detail. Results were used as input parameters for a 3D groundwater model for the central part of the Peninsula, which was later

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extended to the full dimension of the Upper Mega Aquifer. It could be shown that in such a region different components of the water cycle have to be quantified with great care and several methods should be applied to reduce data uncertainty. It was not possible to make use out of satellite products to receive reliable actual precipitation patterns for the peninsula. It was observable; recharge estimations based on average annual precipitation are not applicable but should be based on singular precipitation events. A threshold of 6 mm/event was derived, below of which no recharge in sand seas occurs. The loss of water from UMA, due to sabkha evaporation reaches about 40 mm/a under the given recent climatic conditions.

Keywords Groundwater modelling · Rare earth elements · Hydrochemistry · Time domain reflectometry · Soil moisture · Paleo-climate · Recharge · Sabkha evaporation

4.1 Introduction

The hydrogeology of arid regions is controlled by specific climatic conditions where the potential evaporation by far exceeds the precipitation limiting e.g. groundwater recharge. Due to the resulting scarcity of utilizable young, near surface groundwater and surface water, water demand is predominantly covered by deep groundwater resources that date back to more humid periods in the late Pleistocene to early Holocene. ‘Groundwater mining’ is consequently a fact in many arid regions leading to an irreversible depletion of these resources. Their smart management is therefore of overriding importance. This is especially important considering the heterogeneity of regional aquifer systems in terms of water quality. Quality limitations may have natural reasons, e.g. long circulation in deep aquifers leading to an increase in salinity, as does seawater intrusion at the coastlines. High evaporation of groundwater in discharge areas (sabkhas) results in salt deposits and highly saline shallow aquifers. In addition, radioactivity might be a problem especially considering the large sandstone aquifers typical for Arabian Peninsula and northern Africa (Michelsen et al. 2012). As a further problem, the occurrence of low quality water might be random.

These problems are likely intensified by over-pumping aquifers, leading e.g. to hydraulic shortcuts between layered aquifers or to intrusion of highly mineralized waters out of low permeability zones due to the drastic loss in hydraulic heads. Not considering these factors can lead to early water quality deterioration, e.g. at well fields, and to a further decrease of the utilizable amount of water. Hence, only a well-calibrated numerical groundwater flow model in combination with a sound hydrogeochemical database may be tools to evaluate natural and anthropogenic impacts on the scarce resources and enable the establishment of a smart integrated water resources management concept.

However, particularly at the Arabian Peninsula, the scattered occurrence of boreholes leads to an incoherent information base. To overcome the problem of

Fig. 4.1 Impressions from Saudi Arabian dessert, where agriculture is only possible due to active center pivot irrigation (*green* area)

data scarcity and to feed a numerical model with sound facts of the local and regional hydrogeological conditions, available resources and water budgets an interdisciplinary methodological approach was pursued.

In the framework of the IWAS initiative, the Arabian Peninsula was chosen as a model region to develop concepts and methodologies for the characterization of large-scale aquifer systems and for the quantification of water fluxes in an arid to hyper-arid environment (Fig. 4.1). Profound mathematical optimization concepts considering the particularities of arid regions are scarce, particularly on a regional scale. Also optimization criteria are difficult to define due to diverging interests as stakeholders from agriculture, industry and the public sector compete for priority ranking. However, groundwater models considering these necessities can be used to predict the effects of groundwater abstraction varying in space and time and support decisions leading to optimized management strategies.

Consequently, the main goal was to implement all information in a comprehensive groundwater flow model for the Upper Mega Aquifer (UMA) as a base for an eventually smart and integrated water resources management concept.

4.2 Study Area

The Arabian Peninsula can be subdivided into the predominantly Precambrian igneous and metamorphic Arabian Shield in the west and the Arabian Platform in the east, covered by basin sediments with a thickness sometimes exceeding 10,000 m (Margat 2007) (Fig. 4.2) and forming one of the largest aquifer systems in the world.

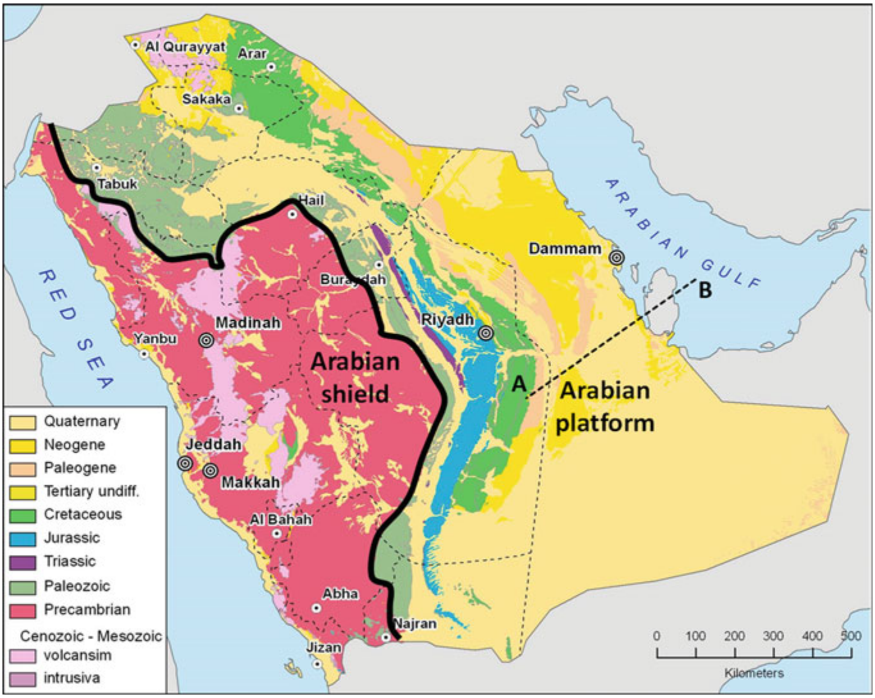


Fig. 4.2 Geological map of the Kingdom of Saudi Arabia. The Peninsula is divided into a magmato-metamorphic complex (*left* of the *bold black line*) and a sedimentary succession, with the *Upper* Mega Aquifer containing the strata from Cretaceous to Neogene and the *Lower* Mega Aquifer below. *Dashed line* indicates the location of the cross-section shown in Fig. 4.3

The whole sedimentary succession is split into an Upper Mega Aquifer (UMA) and a Lower Mega Aquifer (LMA). The former covers an area of about 1.8×10^6 km^2 and consists of sediments from Cretaceous to Tertiary age, with mainly sandstones in the lower part and carbonates in the upper part. Except in the north and very south it is hydraulically separated from the LMA by anhydrites of the Upper Jurassic Hith formation.

Main subaquifers in the UMA are the Cretaceous Wasia-Biyadh and the Tertiary Umm Er Radhuma and Dammam, while the Aruma and Neogene aquifers have a lower yield and can be classified as secondary aquifers (Fig. 4.3). Aquifers are separated by several aquitards, e.g. the Rus aquitard is separating the Umm Er Radhuma from the Dammam aquifer. Groundwater flow in general follows the dipping of the sedimentary layers (ca. 1° ENE), which is only interrupted by north-south striking anticlines and synclines. Main discharge areas are the Euphrates/Tigris Basin in the north, the Arabian Gulf, and inland sabkhas and coastal sabkhas along the Gulf.

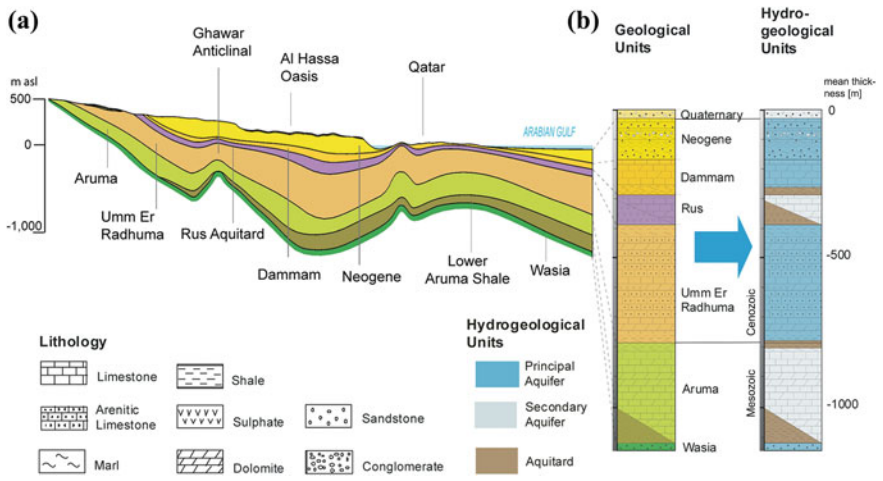


Fig. 4.3 Cross section of the Upper Cretaceous to Tertiary part of the UMA on the Arabian platform with hydrostratigraphic interpretation. Location of the cross section indicated in Fig. 4.2 (Engelhardt et al. 2013a, b)

4.3 Precipitation

The Arabian Peninsula is defined as a semi- to hyper-arid region with occasional convective rainfall events, which seldom exceed 100 mm/a, while potential evapotranspiration easily reaches 3,500 mm/a (Dincer et al. 1974). Precipitation data from the region are scarce and the low amounts of rainfall result in relatively high uncertainties of both measured and estimated rainfall data. Given the low density of station data and the large surface area satellite-derived rainfall estimates often pose the only applicable source of data for large-scale groundwater modelling. Therefore and within this study, different available satellite data products were evaluated. The data used were (i) station data from the Global Surface Summary of the Day (GSOD) dataset (NCDC 2012), (ii) interpolated station data from the Climatic Research Unit (CRU) TS (time-series) dataset 3.0 (Mitchell and Jones 2005), (iii) satellite rainfall estimates from the Tropical Rainfall Measuring Mission (TRMM, product 3B42), (iv) from NOAA CPC Morphing Technique (CMORPH) at a resolution of 25 km and (v) CMORPH data at a resolution of 8 km (Joyce et al. 2004; Huffman et al. 2007).

When visually comparing long-term averages of annual rainfall both interpolated station data (Fig. 4.4a) and estimated rainfall from satellite data (Fig. 4.4b) seem to capture the large scale orographic pattern in the SW' corner of the Arabian Peninsula or the Euphrates/Tigris basin in Iraq equally well. However, looking at comparisons between station and satellite data the resulting goodness of fit values (r^2) can be considered meaningless (Fig. 4.4c).

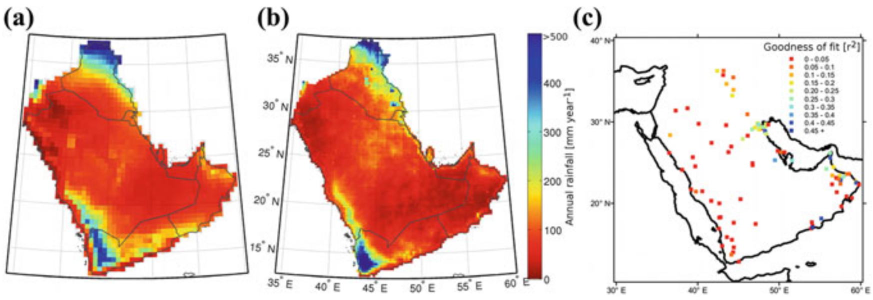


Fig. 4.4 Annual rainfall based on **a** CRU 1901–2006 and **b** TRMM 3B42 1998–2008. The color scale plate **c** shows goodness of fit of TRMM versus GSOD stations

In general the goodness of fit increases when increasing the temporal average periods from daily to decadal to monthly level. However, with $r^2 < 0.5$ even an improvement does not show meaningful correlations. Besides increasing the averaging time periods we also checked whether correlation would improve when averaging different spatial windows around the stations. No clear trend could be seen when averaging one pixel versus four pixels around the stations.

A method to confirm rainfall occurrence of satellite-derived rainfall events was developed (Friesen et al. 2010) using vegetation response as validation of single rainfall events. Confirmation of single rainfall events as detected by satellite is possible. However, to derive rainfall amounts from satellite data, a reliable calibration is required but impossible due to the poor comparability of station versus satellite data. Different tools were developed to assess satellite data, however, the reliability of the station data could not be fully assessed. With more reliable station data a sound calibration of satellite data may be possible in the future.

However, precipitation is the key value for the replenishment of groundwater resources and hence a prerequisite for recharge estimations. It is assumed that the UMA system was filled up at least partially during the early Holocene under more humid conditions and runs empty since then. To account for that and to drive the groundwater flow model for such a long period, we set up a spatio-temporal precipitation model for the last 10 ka. The model is based on spatial rainfall information from TRMM (3B42.V6) datasets. Based on these and in combination with a simulation of the evolution of the northern Africa climate-ecosystem (Liu et al. 2007), paleo-datasets were derived. Additionally, temporal information about precipitation distribution from isotopic investigation of stalagmites in Oman (Fleitmann et al. 2003) were applied.

The resulting paleo-precipitation model provides annual precipitation rates for the last 10 ka (Fig. 4.5). It shows maximum precipitation rates at about 9 and 7 ka before present, respectively. After the last maximum the aridification of the region began and ceased at 2.5 ka ago when recent dry climate was established. Our model results for the entire peninsula are in good agreement with present reports about paleo-precipitation rates in local areas on the Arabian Peninsula (Wood and Imes 1995; Engel et al. 2012; Radies et al. 2005).

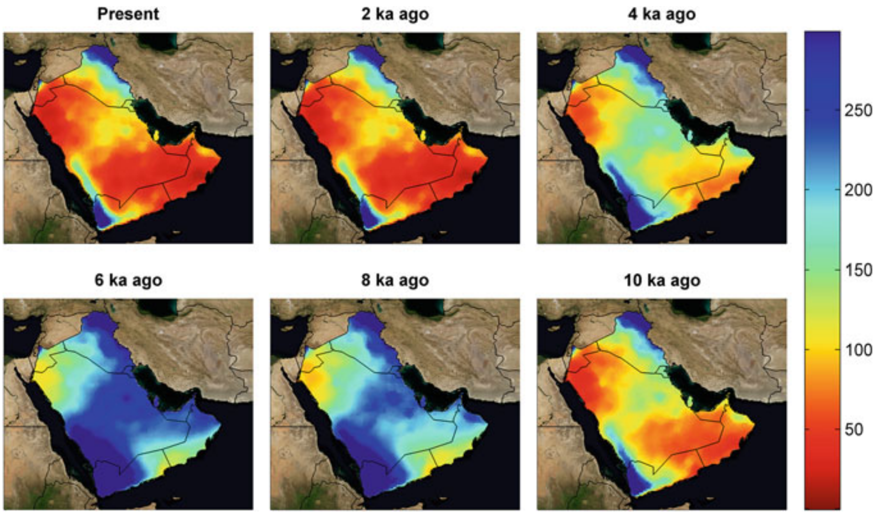


Fig. 4.5 Rainfall distribution in 2 ka time steps for the Arabian Peninsula according to the paleo-precipitation model (legend gives precipitation rate in mm/a)

4.4 Groundwater Recharge

Although the amount of actual precipitation is still an open question, a profound knowledge about infiltration rates eventually leading to groundwater recharge is the major parameter for groundwater flow models and the base for every resources management. Unfortunately, in arid areas, the rate of recharge due to infiltration is one of the most difficult values to derive with sufficient accuracy.

It starts with precipitation, which is limited and as shown above highly variable in space, time and intensity. Additionally, the typically thick vadose zone complicates recharge estimations. Elsewhere, water fluxes measured below just the root-zone are assumed to reflect groundwater recharge. In arid areas recharge may not be similar in magnitude or even in direction compared to the water flux just below a possible existing root zone.

Generally, groundwater recharge mechanisms can be defined as direct/diffuse recharge from precipitation through the unsaturated zone, indirect recharge through the beds of surface watercourses, and localized recharge of water concentrated in local depressions.

As aridity increases, direct recharge is likely to decrease while indirect and localized recharge may dominate. Former studies reported large discrepancies on recharge amounts, depending on the recharge mechanisms. Based on isotopic studies in sand dunes of Saudi Arabia, Dincer et al. (1974) proposed a recharge of at least 20 mm/a, when precipitation is >50 mm/a. Contrastingly, Bazuhair and Wood (1996) calculate only 3.7 mm/a in Saudi alluvial aquifers and Subyani (2004) come up with 6.1–20 mm/a in ephemeral streams of the peninsula. Scanlon et al. (2006) found recharge even to be negligible at all when precipitation is less than 200 mm/a.

However, considering the large outcrop area of the UMA, also very low direct recharge rates of a few millimetres per year could significantly add to the water resources.

The UMA outcrop area is predominantly characterised by sandy and rocky desserts, where sparse vegetation of small trees, scrubs, forbes and gras, representing a fragile ecosystem (Al-Gaadi et al. 2011). Moreover, sand dunes of Ad-Dahna, Rub al Khali, An'Nafud cover about 60 % of that area (Shahin 2007; own analyses of recent Landsat images) and are missing any vegetation. Moreover, field studies at the Arabian Pensinsula showed, well-sorted dune sands effectively enable infiltration of precipitation (Dincer et al. 1974; Cook et al. 1989; Sophocleous 1992; Fayer et al. 1996; Gaye and Edmunds 1996; Keese et al. 2005).

Both, the remarkable coverage and good infiltration potential made the sand seas to the focus areas in our study. In 2010 a 3D monitoring site was erected to continuously measure soil moisture with high spatial and temporal resolution within a sand-dune belt SW of Riyadh (Fig. 4.6). At the site, one 45°-sloped and six vertical drillings were deepened down to max. 13 m below ground and each is equipped with (i) continuous Time Domain Reflectometry (TDR) sensors: Taupe- (sloped drilling)

Fig. 4.6 Impressions from construction the moisture observation site SW' of Riyadh with vertical and sloped drillings for TDR sensor mounting

and tube-(vertical drilling) sensors as well as (ii) discrete temperature sensors to allow continuous vertical moisture monitoring and tracking of possible infiltration fronts. Both sensors types were tested on field scale in Darmstadt (Germany) and finally deepened in Saudi Arabia by using direct push. The combination of the chosen sensors and the technology to deepen them by applying Geoprobe guaranteed two major advantages: minimal invasiveness and continuous measurements.

By using TDR, the water content of a material surrounding the sensor is indirectly measured by its relative dielectric permittivity. A variety of approaches exist to measure and analyse TDR data (Schmugge et al. 1980; Charlesworth 2000; Robinson et al. 2003; Topp 2003; Walker et al. 2004; Hübner et al. 2005; Schlaeger et al. 2006), of which the Topp equation (Topp et al. 1980) was used to calibrate and convert the raw signals from sensor into volumetric water contents (VWC) in a resolution of about 1 vol.-%.

Unfortunately, the sensitivity of the tube-sensors significantly declined at depths larger than 2–3 m, prohibiting any interpretation of data deeper than that. In contrast the Taupe sensors enable soil moisture analyses until a depth of 9 m. To calibrate TDR data, the actual soil-moisture contents in the upper 8 m of the dune were derived from drilling core samples. Additionally, by applying a Hydrus-1D model (Madi 2012), the plausibility of the TDR-measurements was tested. The simulation confirms the monitored soil moisture distribution along the TDR tube-sensors (Fig. 4.7).

The moisture in the shallow parts of the dune ranged from 0−10.3 vol.–% and quickly reacts on seasonal climatic impacts within the uppermost 2 m. Below moisture persists at around 1.5 vol.–%.

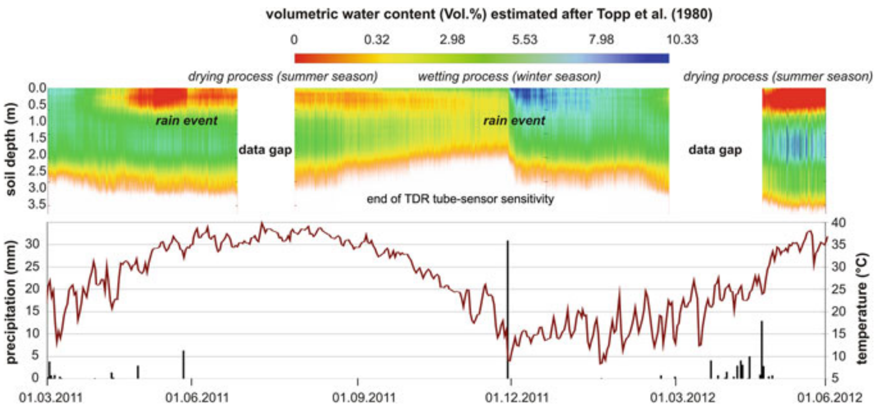


Fig. 4.7 Precipitation and air temperature (*lower part*) and the corresponding moisture distribution (*upper part*) in sand dunes SW of Riyadh between March 2011 and June 2012

Precipitation events with rates less than 6 mm/d do not alter the moisture contents in the dune sands, while those exceeding 6 mm/d induce increasing moisture in the uppermost 1.5 m of about 1.5 vol.-%. That indicates a threshold for effective precipitation of 6 mm/d below of which no remarkable infiltration occurs. Moreover, in November 2011 a single precipitation event of 30 mm/d induced a change of the moisture content of about 2-7 vol.-% along the infiltration front until a final depth of ca. 7 m. In April 2012 a precipitation event of 12.9 mm was also traceable until a depth of 1.5 m.

If sufficient rain events occur, they lead to uniform infiltration fronts in the soil profile, indicating absence of recharge dominating preferential flow. That is supported by the fact, that grain-size distribution in the dune sands is quite homogenous. Hence, matrix flow controls the infiltration process and consequently the amount of groundwater recharge in dune sands.

During the first observation period (Mar 2011–Nov 2012), we derived from the observed precipitation events and the depth of the resulting infiltration fronts, that the infiltration process is driven by the amount of a singular precipitation event. For the observed time period annual infiltration amounts between <3 mm (2012) and 30 mm (2011) were calculated on the base of daily precipitation data. The remarkable annual infiltration amount of 30 mm is related on the extreme event in Nov 2011. As a consequence, recharge estimations for sand seas based on annual or monthly precipitation data are not applicable for the region.

4.5 Evaporation from Sabkhas

Sabkhas are salt flats with a shallow saline water table, where capillary up rise causes evaporation at its surface. They are predominantly located in the Rub' al Khali desert and at the Arabian Gulf coast (Al-Saafin 1996). Besides the discharge of groundwater into the Arabian Gulf, sabkhas are considered as the major natural outflow component of the UMA system (Al-Saafin 1996; Shehata and Lotfi 1993; GDC 1980a). In order to estimate the total groundwater loss by evaporation from sabkhas for the UMA system a combined approach (remote sensing, hydrochemical/isotopic investigations and column experiment analysis) is carried out.

First, spectral information from 39 Landsat satellite images and the terrain information extracted from the DEM were analysed to map the total sabkha area. To enhance accuracy and reliability of the supervised classification, more than 800 ground-truth points were recorded in November 2012. As a result, we could conclude that about 36,000 km^2 of the UMA system is covered by sabkhas.

To identify the source of evaporating water of each sabkha, water samples from the Gulf, from sabkhas and from up-gradient groundwater wells were analysed for major ion ratios (Cl/Br, K/Br) and isotopic signatures of $\delta^{34}S$ (SO_4) (Fig. 4.8).

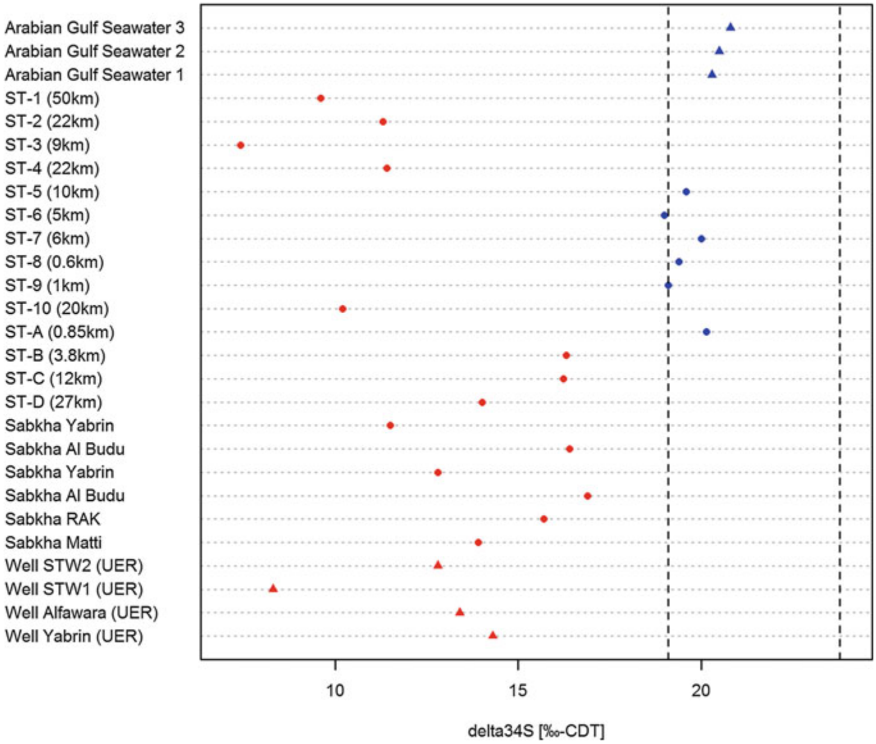


Fig. 4.8 Plots ^{34}S signatures of porewater from sabkhas and for comparison (i) well waters in the up gradient sections of the aquifers, which crop out in the respective sabkhas and (ii) from Arabian Gulf, close to the sabkha areas. In *blue*, the seawater-evaporating sabkhas (and Gulf water) are presented, while groundwater-fed sabkhas (and groundwaters from wells) are shown in *red*

The results allow delimiting seawater-fed sabkhas, which occur up to 6 km (on average) from the coastline, from those sabkhas, which solely evaporate groundwater from UMA (Fig. 4.9).

And finally, to evaluate the amount of actual evaporation in active groundwater evaporating sabkhas, a column experiment with sediment cores from Al-Budu, Yabrin, Matti and a Rub-al-Khali inter-dune sabkha, respectively, was set up. We chose a setup that allowed variations of boundary conditions: surface temperature and humidity and water level. Simultaneously, these parameters were monitored in the field site Al-Budu, where surface temperature and humidity were collected and a 3.5 m deep well was drilled and equipped with groundwater data logger. Results are showing an average evaporation rate for the sabkhas on the Arabian Peninsula of about 40 mm/a.

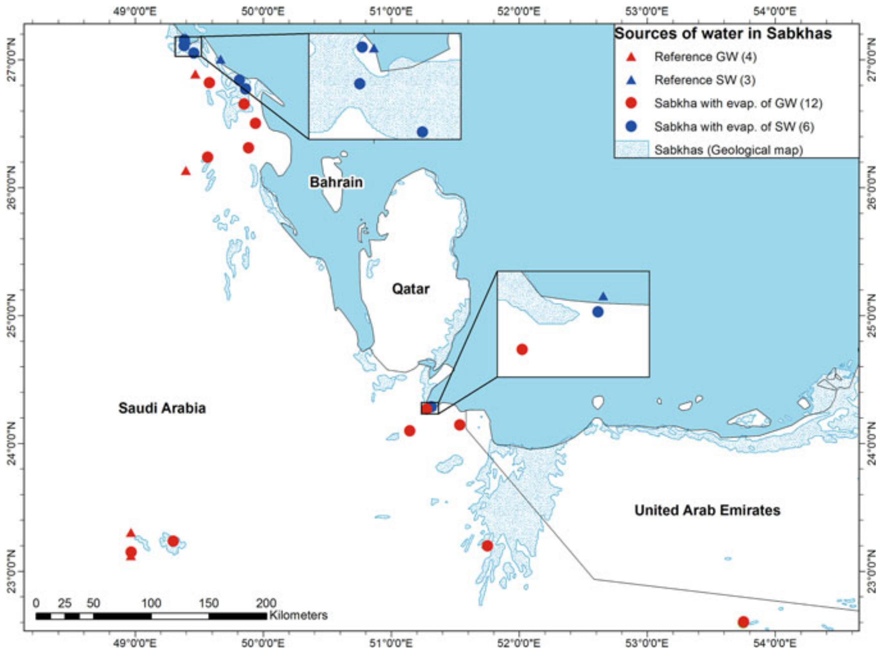


Fig. 4.9 Location map of investigated Sabkhas and their connection to the sea (*blue* indication) and groundwater (*red* indication)

4.6 Hydrochemistry

In data scarce regions, where consistent information on groundwater residence times, characteristics of flow-paths and possible inter-aquifer flow are missing, hydro-geochemical methods may be applied to at least partially answer these questions.

The chemical composition of the groundwater percolating within the UMA varies between the sub-aquifers and within these also laterally. While outcrop areas usually host freshwater, groundwater becomes more saline along the flow-path and even briny towards the Arabian Gulf. Simultaneously, the major ion and particular anion compositions of the waters change, which is exemplarily shown in Fig. 4.10, a Piper plot depicting the hydrochemistry of the Cretaceous Wasia aquifer. While freshwaters in the unconfined parts of the aquifer are often dominated by HCO_3, the brackish waters show SO_4-dominance at the expense of HCO_3. Further along the flow-path, with increasing salinities, the sulphate proportion decreases and chloride plays the most important role in the encountered brines–a hydrochemical evolution often referred to as Chebotarev-sequence (Chebotarev 1955).

As several of the aquifers exhibit this chemical evolution, their major ion chemistries often do not differ strongly, thus hampering the identification of hydrochemical fingerprints. Recent investigations suggest that the ratio of the

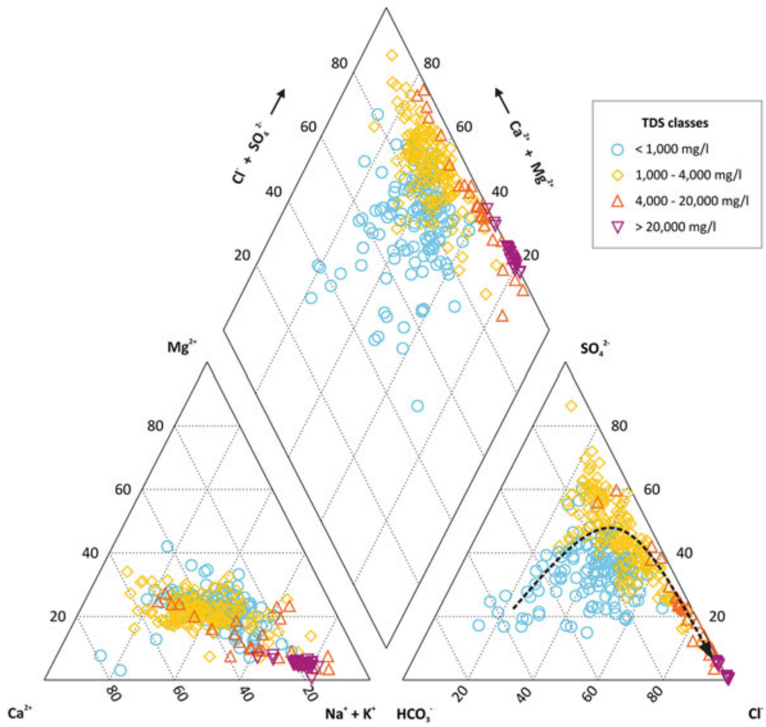


Fig. 4.10 Piper plot showing the hydrochemical development in the Wasia aquifer (*arrow*). While the fresh waters show a significant bicarbonate contribution, more saline waters are governed by sulphate. The final stage of the evolution is represented by chloride-dominated brines (*Data sources* BRGM 1976; GDC 1980a, b; Italconsult 1969; SMMP 1975; Saudi ARAMCO, unpublished data; own analyses)

radionuclides ^{226}Ra and ^{228}Ra might represent a useful fingerprinting tool. Yet, its application is limited to relatively simple cases, e.g. if it has to be clarified whether a borehole with unknown depth, well design, etc. taps a sandstone or a limestone aquifer (Michelsen et al. 2012). However, in more complicated cases, for instance if cross-formational flow is suspected, more sophisticated methods have to be applied, e.g. relying on rare earth elements (REE).

REE including Yttrium (i.e. REY) are a powerful tool to understand large scale, low-temperature hydrogeological systems (Smedley 1991; Siebert et al. 2011). REY are involved in any redox- or pH-driven process, adsorb on mineral surfaces and amorphous precipitates and complex with major anions (e.g. Bau 1999). REY-patterns in groundwater rarely coincide with the patterns of their corresponding rocks, due to the considerable release of REY from accessory minerals e.g. phosphates (Möller 2002), which differ in their REY patterns from the rock-forming minerals.

During first water-rock (w/r) interactions, infiltrating water dissolves REY-bearing minerals and gets immediately saturated in respect to REY. Due to their affinity to strongly adsorb on mineral surfaces (Johannesson et al. 1999), aquifer walls are immediately in chemical equilibrium with the REY-pattern of through-flowing groundwater. Is the water intruding into a different lithology (inter-aquifer flow), over time the solids surfaces in the new aquifer are again in equilibrium with the approaching water and its REY-fingerprint, which was acquired by the first w/r interaction (Möller 2002). Consequently, while major element characteristic may change, REY-fingerprints remain and refer to the aquifer of origin.

REY are commonly presented as standardised patterns, e.g. to C1-chondrite (Anders and Grevesse 1989) to smooth the abundance differences of even and odd elements. If the normalised abundance of an element, e.g. Ce, Eu or Gd deviate from its expected value (derived from interpolation of its neighbours) an anomaly is identified. The amplitude and orientation (negative/positive) of anomalies in different water samples give characteristic information about geochemical processes in the aquifer and to identify relationships between water samples.

During the study, a sampling-transect was conducted from Riyadh via Hofuf Oasis to Dammam with the aim (i) to identify original REY-fingerprints of the aquifers in their outcrops and (ii) to reveal possible aquifer-interactions along the average flow path towards the Gulf.

The observed groundwaters can be divided into 3 major types (Fig. 4.11), according to their REY-pattern. ***Group 1*** waters are characterised by patterns, which decrease from La to Lu and show negative Eu- and pronounced Y-anomalies. Such patterns are typical in carbonate-controlled groundwaters (Siebert et al. 2012). In contrast, waters of ***Group 2*** are characterised by arched patterns with declining abundances towards Lu. In combination with positive Gd- and Y-anomalies, negative Eu- and variable Ce-anomalies these patterns are typical for waters from sandstones (Möller et al. 2003). While group 2 represents waters from Biyadh Sandstone, ***Group 3*** shows increasing patterns with negative Eu- and positive Y-anomalies and is typical for Wasia Sandstones.

The groundwater samples presented in Fig. 4.11 were taken along the entire transect. Within each group, the major chemical composition changes considerable, while REY-patterns persist. Hence, REY-patterns allow distinguishing between groundwaters infiltrated into Aruma or Umm er Rhaduma formations and those originally infiltrated into the Wasia and Biyadh sandstones formations.

Although we could not extend sampling to the full UMA-dimensions, it was possible to identify by chemical and isotopic data, patterns and fingerprints interaction of groundwater bodies due to hydraulic shortcuts between aquifers or inversion of pressure conditions as result of intense abstraction. We also identified variety of sources of salinization, which are either long-term storage in deep aquifers, seawater intrusion or mixing of groundwater bodies as described before.

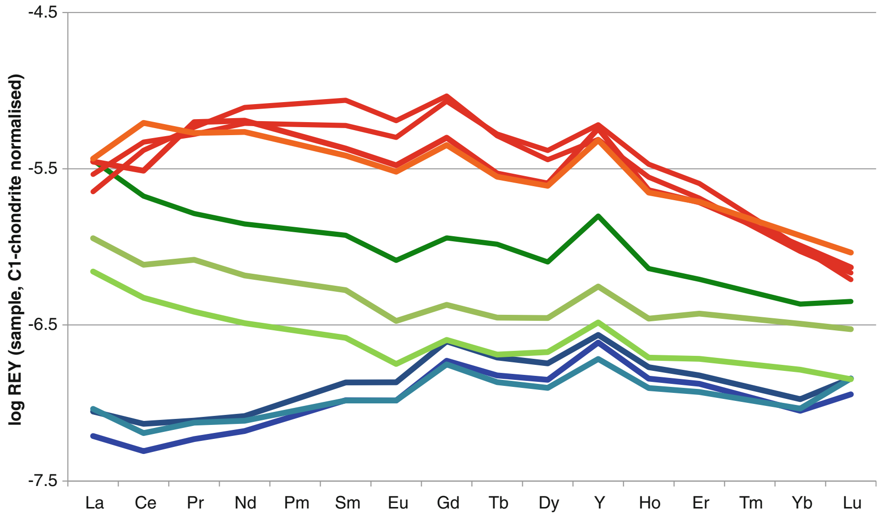


Fig. 4.11 REY-patterns of selected water samples representing REY-groups: group 1 (*greenish*), water from limestone aquifers; group 2 (*reddish*), water from Biyadh sandstones and group 3 (*bluish*) water from Wasia sandstone (Siebert et al. 2012)

4.7 Groundwater Flow Model

In a first step, a 3D groundwater model for the central part of the Arabian Peninsula was developed using Modflow-2000 (Fig. 4.12). Hydraulic conductivities and storage coefficients were obtained from Balkiewicz et al. (1982) and GDC (1980b) and are based on pumping tests. Due to the high uncertainties in actual data and the assumption, that the UMA is naturally flowing out since chiliads, the model was designed to simulate long-term variabilities of the UMA resource before large-scale abstraction schemes for agriculture were established in Saudi Arabia (Engelhardt et al. 2013a, b). Hence, all available information on the paleo-climate of the Arabian Peninsula, which was as stated above distinctly different 7–10 ka before present (BP), were compiled. Estimates on past precipitation on the Arabian Peninsula, as the only input parameter in the water balance, were based on different approaches, including climate models (e.g. Braconnot et al. 2008), sedimentological investigations of lake sediments (Edgell 2006), stable isotope analyses (e.g. Fleitmann et al. 2003), and interpretations of pollen data and faunal remains (e.g. Hoelzmann et al. 2000). 9–10 ka BP, precipitation is assumed to reach about 250 mm/a in the central part and declined steadily to values ranging between 100 and 125 mm/a in the north and 25–50 mm/a towards the south (Fig. 4.5). Modern recharge was calculated by applying the hydrological model HEC-HMS accounting for current precipitation, temperature, wind, soil types, and geomorphology and using empirical equations valid for semi-arid and arid settings (Scanlon et al. 2006;

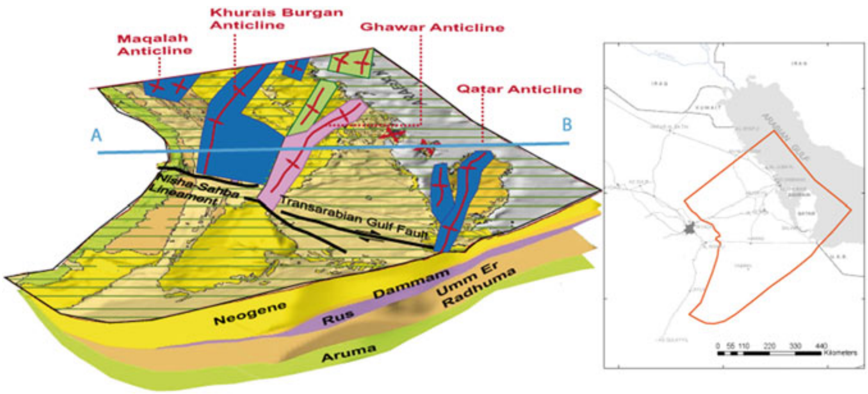


Fig. 4.12 Sub-model of the central part of the Arabian Peninsula with the hydrostratigraphic units of the Upper Mega Aquifer and the main tectonic features. *Line A–B* indicates the location of cross section in Fig. 4.2 (details are given in Engelhardt et al. 2013b)

Green et al. 2012). Recharge for the last 10 ka was then calculated using the precipitation estimates and the same empirical equations.

Further inflow into the groundwater system results from surface water infiltration in wadi beds, while natural outflow from the groundwater system occurs by discharge to the Gulf, evaporation from sabkhas, and spring discharge. Before 1950, artesian springs discharged about 12 m^3/s within the main oases in the E part of the Arabian Peninsula (Hötzl and Zötl 1984; Vidal 1951). Backward predictions were verified by sedimentological observations of paleo-river systems and lakes indicating that during wetter climatic conditions, groundwater levels reached at least temporarily the surface. Furthermore, information concerning fluctuations of the Arabian Gulf were considered: 10 ka BP, it was about 30 m lower than today and reached its current level only 6 ka before present (Purser 1973; Siddall et al. 2003). For details of the model development see Engelhardt et al. (2013a, b).

Figure 4.13 shows the overall water balance of the UMA in the model area over the last 10 ka. In general, in- and outflow volumes displayed sensitively Mid- and Late-Holocene changes in climate. Inflow volumes are groundwater recharge and subsurface inflow from wadi beds. Outflow occurred by evaporation from sabkhas, spring discharge and discharge to the Arabian Gulf that was by far the largest outflow component. The volumetric balance showed that between 10–3 ka before present inflow exceeded outflow and groundwater storage took place. At 3 ka BP a natural depletion of the groundwater system developed that reached a maximum at 1.7 ka BP, when the climate was drier than today.

In a second step, the numerical subset model was extended using Open GeoSys to the full dimension of the UMA to enable long-term balancing of the aquifer system. The UMA represents the upper part of a huge sedimentation basin, comprising the whole sedimentary part of the Arabian Platform (Fig. 4.2) hence, hydraulic heterogeneities due to (gradual) facies-changes had to be implemented

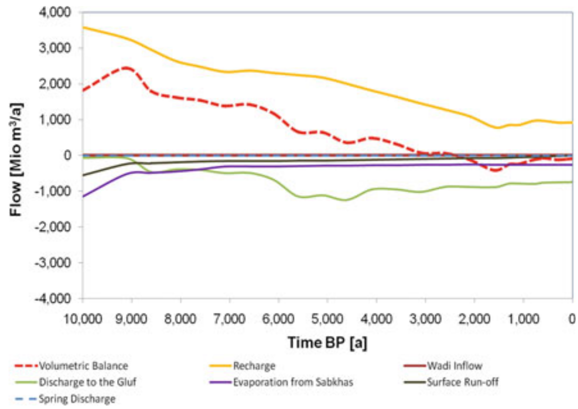
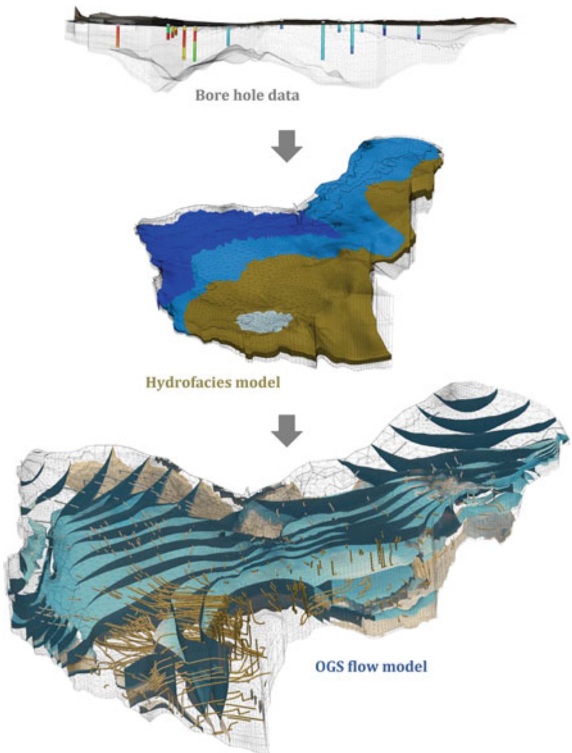


Fig. 4.13 Calculated groundwater budget over the last 10,000 years for the sub-model shown in Fig. 4.12, negative values show outflow, positive values give inflow into the aquifer system (Engelhardt et al. 2013b)

Fig. 4.14 Simplified workflow for the set up of the model for the entire UMA: from borehole data (stratigraphic data and hydraulic properties) to hydrofacies model and finally to the numerical simulations



into the model. Beside the basin structure and related sedimentary facies-changes, (ii) tectonic processes and (iii) different expositions of strata over longer time periods, cause varying hydraulic properties within each hydrogeological unit. To consider that, these units are separated into hydrofacies zones according to Ziegler (2001). Afterwards these hydrofacies zones are parameterised by pumping test data and are projected on each hydrogeological unit in the geometric model. A simplified workflow for the model set up and a first simulation is shown in Fig. 4.14.

Based on that new approach to spatially define hydraulic properties of substrata in an aquifer model, the implementation of hydrochemical information to better outline hydraulic properties and boundary conditions was applied to build up a comprehensive groundwater flow model for UMA that may serve as planning tool for future resources managing stakeholders.

4.8 Conclusions

A sustainable use of groundwater resources at the Arabian Peninsula might be unrealistic due to (i) limited and extremely varying infiltration amounts at least in the predominant sand seas, which may lead to groundwater recharge and (ii) the growing water demand for agricultural irrigation, domestic supply and industry. Therefore, a management concept based on 'safe yield' is desirable, but not achievable. Instead, 'smart mining' concepts have to be developed with the aim to use the resources in the most efficient way (Sophocleous 2000).

This requires a sound understanding of the aquifer as a dynamic system responding to interferences caused by natural factors, such as variations in climate affecting the water balance as well as the anthropogenic water abstraction. For the Arabian Peninsula and the UMA we could show, that under the arid and data scarce conditions different components of the water cycle have to be quantified with great care and several methods should be applied to reduce data uncertainty. However, the key for appropriate water management concepts are numerical groundwater models allowing an evaluation of how future scenarios will influence the spatial availability and quality of groundwater. Good estimates on natural and anthropogenic inputs and outputs and an on-going monitoring program for a constant update of the database are crucial to adapt and further refine these models.

Further on, to enable smart water resources management strategies in Saudi Arabia, at least for the UMA, the aquifer package must be taken as a unity. The implementation of an IWRM for just sub-aquifers would exclude (i) strong interactions along faults, folds and fractures, (ii) hydraulic bypasses through boreholes in well fields and (iii) the locally extreme depletion of sub-aquifer levels changing gradients and flow directions.

Hence, in the here presented IWAS-project we followed that holistic approach. The central aim was to develop a best possible numerical flow model, including reliable boundary conditions (recharge, discharge, etc.) and well-indicated internal information (structures, inter-aquifer-flow, aquifer properties, etc.). Due to the complexity of that mission, and although we already integrated the Ministry of Water and Electricity (MoWE) as full project partner, neither socio-economic issues nor a water distribution framework were aimed to be established. These must be the next steps in the implementation of an IWRM in Saudi Arabia.

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Chapter 5
Multidisciplinary Investigations of the Transboundary Dead Sea Basin and Its Water Resources

Christian Siebert, Tino Rödiger, Stefan Geyer, Johnathan B. Laronne, Noa Hillel, Martin Sauter and Ulf Mallast

Abstract Israel, the Palestinian Authorities and Jordan exploit the transboundary water resources of the Dead Sea basin. Our aim was to add reliable numbers to the water budget of the lake, despite the complicated integrative work and data acquisition due to the tense political situation. We here outline four parts of the project that generally concern surface and groundwater influx to the Dead Sea: (i) direct and non-direct measurements and hydrological modelling to quantify surface runoff, (ii) chemical fingerprinting to characterize groundwater origin, flow, and evolution between recharge and discharge areas, (iii) thermal remote sensing approaches to precisely identify location and abundance of groundwater discharge and (iv) groundwater modelling to quantify discharge volumes. The major outcomes are: (i) total mean annual runoff volumes from side wadis (except the Jordan River) entering the Dead Sea amounts to approximately $58{-}66 \times 10^6$ m^3 a^{-1}, (ii) area normalised recharge amounts differ on both sides being $\sim$45 mm/a at the western side and $\sim$32 mm/a at the eastern side, (iii) modelled groundwater discharge volumes from Upper Cretaceous aquifers from both sides are in order of magnitude of 177×10^6 m^3 a^{-1}.

Keywords Jordan river · Flash floods · Groundwater · Springs · SUMAR

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5.1 Introduction

The Dead Sea basin, situated within the Dead Sea Tranform (DST), is an endorheic basin that comprises a surface drainage area of 43.223 km^2, calculated from SRTM 2.1 datasets (USGS 2009). Politically, Israel, the Palestinian Authorities and Jordan have a stake on the Dead Sea basin and its water resources (Fig. 5.1), underlining the complexity of the transboundary case the Dead Sea basin constitutes. It is exacerbated by climatic conditions on the one hand that vary from Mediterranean to hyper-arid conditions and in turn mirror natural water (surface and groundwater) availability. On the other hand, tremendously increasing anthropogenic water needs led to a significant overexploitation of water resources during the last 60 years (Weinberger et al. 2012). The effect is visible at the Dead Sea, a terminal lake that is mainly fed by surface runoff of the Jordan river and groundwater discharging from Cretaceous (Kurnub-, Ajloun-, Belqa-, Judea Groups) and older formations (e.g. Zarqa-, Kreim- and Ram Groups).

Although fluctuating before, the lake's water level strongly and continuously decreased from mid 1960s until today (EXACT 1998). This decrease can be allocated to a large fraction to water management projects, which followed the

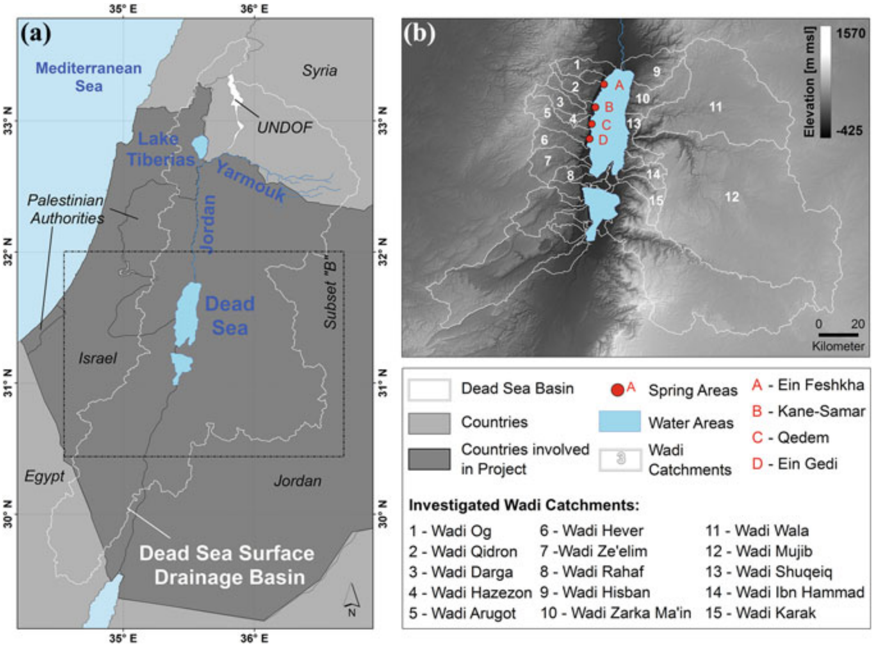

Fig. 5.1 General overview of the SUMAR project area. **a** Indicating the entire surface drainage basin of the Dead Sea and its major water bodies. **b** Subset in Fig. **a**, indicating surface drainage basins (investigated and others) directly discharging to the DS. Background: DEM calculated from SRTM data

suggestions of the Johnston Water Plan (Murakami 1996) and severely changed the hydrology of the Jordan River. These are among others:

- The embankment of Lake Tiberias in 1964 at Degania to supply the National Water Carrier of Israel resulting in the reduction of lake effluents (Lower Jordan) to a minimum (10 % of the amount before),
- The construction of the East Ghor Main canal between 1955−1964 in Jordan diverting ca. 25 % of the Yarmouk River to the King Abdulah Canal and
- The construction of the Al-Wuheda (Maqarin) dam and several small-scale schemes at Yarmouk's tributaries in Syria that additionally reduced the Yarmouk's runoff.

The remaining Lower Jordan River, still the main contributor to the lake, is no longer a river with a yearly discharge of >1,000 × 10^6 m^3, but merely a runlet (Table 5.1). Apart from the severe human impact on the Jordan outflow the steadily increasing population in the riparian states (Israel: 1.6 %, Palestinian Authority's 3.2 %, Jordan: 2.6 % (UN population database) forced an enhanced groundwater abstraction from the connected Upper Cretaceous aquifers to currently about 105 −140 × 10^6 m^3 a^{-1} (SWITCH 2006; Al-Raggad 2009; El-Naqa and Al-Shayeb 2009; PWA 2010; PHG 2012; Mekorot 2012). Fluctuating recharge amounts in combination with the increased groundwater abstraction has depleted aquifer reservoir volumes and led to the drying out of wells particularly in elevated areas (Weinberger et al. 2012). In Jordan, which in recent times received large flows of refugees from Iraq and Syria, the situation even exacerbated.

The postulated consequence was the observable acceleration of volume reduction in the lake, accompanied by secondary effects like falling water tables in the mountain aquifers since they are hydraulically connected to the lake level. Moreover, the generation of subrosion structures (sinkholes) in the dry-fallen lakebed sediments are widely observable (a.o. Abelson et al. 2006; Arkin and Gilat 2000; Filin et al. 2011). Although being the basement of every possible integrated water resources management concept, the fractions of surface runoff and groundwater flow on the balance of the Dead Sea are still inadequately quantified. Hence, the overall aim of the here presented study was to qualify and quantify the amount

Table 5.1 Estimated flow rates of the Jordan River entering the Dead Sea over the last century

Year	Volume (10^6 m^3 a^{-1})	Source
1920s	1,870	Al-Weshah (2000)
before 1967	1,370	Salameh (1996)
1996	250–300	Salameh (1996)
2000	100	Al-Weshah (2000)
2000/2001	16–35	Holtzman et al. (2005)
2002	400	Asmar and Ergenzinger (2002)
2004	50–20	Farber et al. (2004)
1931–1995	88–669	Salameh and El-Naser (2000)
<2005?	60–150	Lensky et al. (2005)

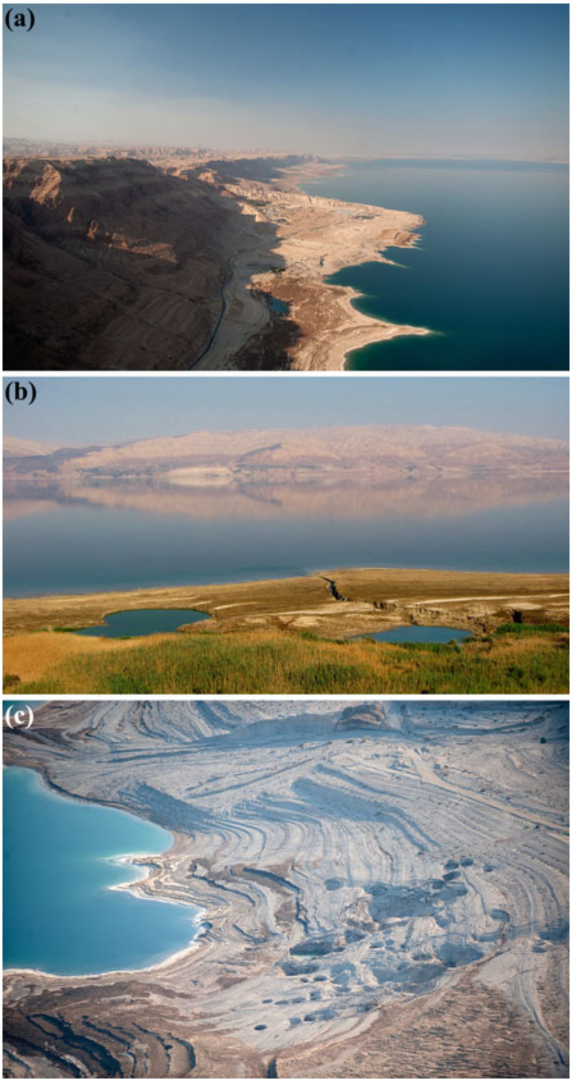

Fig. 5.2 Scenic impressions from the Dead Sea. **a** bird's eye view from the western Grabenflank with outcropping Upper Cretaceous limestones forming the mountains and the Dead Sea Group sediments between the cliff and the Dead Sea shoreline. **b** View across the lake towards the Jordanian mountains in the background. The dissolution of the through-flown Dead Sea Group sediments mostly forms springs, sinkhole structures and channels towards the lake, mostly surrounded by reet and other salt-tolerant plants. **c** The stepwise dropping of the lake terraces its bed, which is left behind and falls dry. Due to the following groundwater table, springs and sinkholes follow the shoreline. In the background an incising wadi is observable from that bird's eye view. (copyright **a**, **c**: Künzelmann A. 2009 (UFZ); **b**: Siebert 2010 (UFZ))

of water flushing into the Dead Sea. Due to the tense political situation in the area, the amount of direct measurements was restricted, why we used a variety of methods including numerical simulations as workarounds to receive reliable numbers for surface- and subsurface flow to the lake.

The aim of the work presented here is to introduce the approaches pursued during the SUMAR project ("SUstainable Managment of water in semi-arid and Arid Regions") which included (1) the measurement and modelling of surface runoff characteristics to estimate its contribution to the lake balance, (2) chemical fingerprinting, age determination and microbial investigations of groundwater to reproduce flow-paths, their development and water evolution, (3) remote sensing approaches to localise areas of enhanced discharge to the lake and finally (4) the development of numerical groundwater flow models under the co-consideration of chemical fingerprinting and remote sensing results to quantify subsurface discharge from the mountain ranges (Fig. 5.2). All these information are aimed to refine the still large differing estimates of total inflows into the lake: <475 × 10^6 m^3 a^{-1} (Lensky et al. 2005) to 617 × 10^6 m^3 a^{-1} (Salameh and El-Nasser 1999).

5.2 Surface Runoff

Surface water is a very limited water resource in the semi-arid to arid drainage basin of the Dead Sea. It includes mainly the discharge of the perennial Jordan River and the temporary flushing of the tributaries (wadis) on the western and eastern side of the Dead Sea. In contrast to humid areas, the Dead Sea area is characterized by an infrequent, high intensity flood regime with steep, short-lived hydrographs (Cohen and Laronne 2005; Storz-Peretz 2012).

To quantify those sporadic, highly turbulent and sediment-rich flash floods, an ingenious and/or robust monitoring technique is necessary. To date this challenge results in sparsely equipped wadis and largely incomplete time series on surface runoff.

To overcome both and to receive a deeper knowledge about the generation of flash floods, several sites have been chosen to either maintain or modify existing stations or to install additional, deliberated and robust stations to condense the regional runoff gauges network (Fig. 5.3a).

The stations were planned and constructed to be almost immune to damage by the high-energetic flash floods, given by the fact, that each important instrument (controllers, data logger, energy supply, automatic samplers and GSM-modems) was positioned outside the stream channel in deep funded concrete caves (Fig. 5.3b). Inside the river bed just collecting tubes and sensors were deployed in a slotted steel pipe to minimize contact surface to passing floods (Fig. 5.3c, d). Within these pipes EC-, T-, turbidity and pressure sensors are installed to record respective data during flash floods. The to date received short time-series of these data are not appropriate for quantification purposes. Instead these continuous and precise measurements will provide exact numbers of flash flood volumes and represent an adequate data basis for future quantification approaches. In the same context of future quantification of single flash flood events in unequipped wadis it was of interest to develop a remote method that enables us in a repeatable and easy-to-use manner to obtain runoff volume approximations by surface velocity radar (SVR). It is based on the velocity area method that exploits the relationship between surface velocity and runoff volume given calibration parameters describing stream increment area (area of vertical sections that virtually divide the stream) and average velocity within the increment. To derive and optimize the calibration parameters an Acoustic Doppler Current Profiling was used providing average flow velocities at

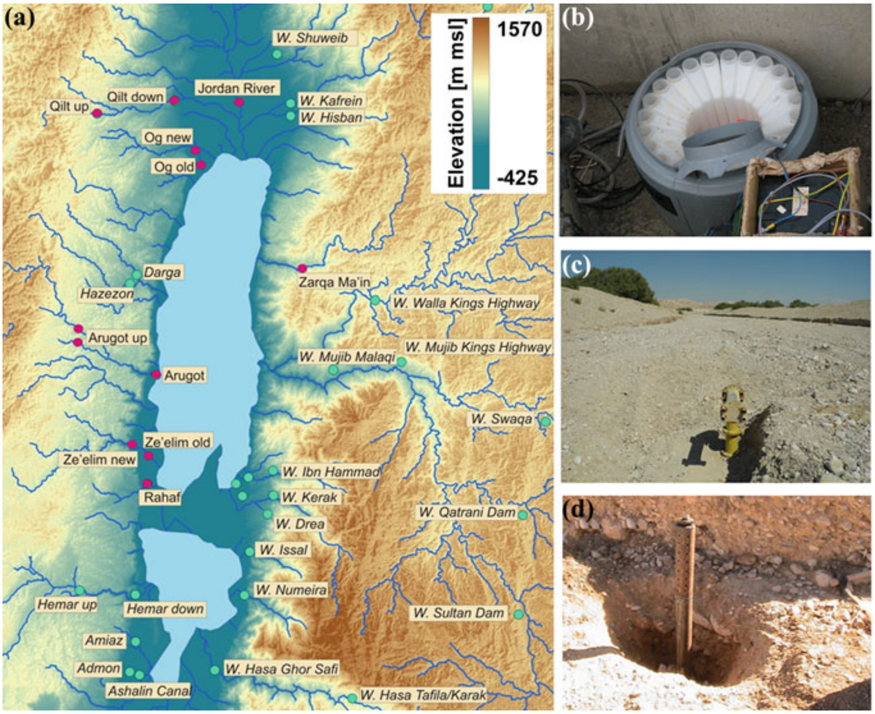

Fig. 5.3 **a** Overview of the locations of wadi runoff-gauging stations—SUMAR sharing partner stations are displayed in red, stations from local authorities (Israel Hydrological Service of Israel, Jordan: Water Authority/Ministry of Water and Irrigation) are shown in *green*, **b** Part of the interior of the Wadi Arugot downstream station including modem and autosampler, **c** sensor-pipe installed in Wadi Og, **d** sensor pipe installation in the headwater of Wadi Arugot

defined increment width/area that enabled to calculate the total runoff volume. Due to these calibration parameters it is possible to obtain surface runoff volumes with a thoroughly reliable degree of accuracy at water levels >0.3 m and low-medium roughness of streambed based on surface velocities measurements only that can easily be derived using a SVR (Zamler 2013). Based on these promising results it is intended to equip and train local scientists, technicians and rangers on the usage of the low-price and mobile SVR to subsequently obtain flash-flood volume measurements at ungauged wadis.

Since these aforementioned studies will provide applicable time-series of minimum legth only in the near future, it was important to develop models to estimate regional surface runoff volumes fur current budget estimations (Table 5.2). In a first approach, Israeli Partners prepared an empirical multiple regression model (Greenman 2009), valid for all major wadis (area >5 km^2) along the western Dead Sea flank. The model was developed including data from 8 watersheds where runoff data for calibration purposes were available from Israel Hydrological Service (IHS). It identifies significant correlation between independent variables such as watershed

Table 5.2 Area, modeled runoff and runoff/area ratio per observed drainage basin

Surface drainage basin (SDB)	Reference	Area (A) (km^2)	Runoff (Q_S) (10^6 m^3 a^{-1})	Q_S/A ratio (mm/a)
Western SDB	Greenman (2009)	1,443	2.7	1.9
Western SDB	Sachse et al. (in prep.)	1,443	15.4	10.7
Eastern SDB	Alkhoury (2011)	6,277	51	8.1
Eastern SDB (outcrop A7/B2 only)	Al-Raggad (2009)	3,427	25	7.3

area, latitude and meridian at the top of the main channel (the latitude is related to rainfall characteristics that affect the number of events in the marginal sub-seasons), topography, mean annual precipitation, mean number of runoff events in a year (related to the precipitation), top elevation of the watershed that influence the expected surface runoff volume. Within the multiple-regression highest correlation was achieved integrating the drainage area and the meridian (longitudinal location) that in part is related to the topographic height of the water divide. Applying the so obtained multiple-regression equation at all wadis of the western drainage basin (1,962 km^2) resulted in an expected yearly surface runoff volume of 2.7×10^6 m^3 a^{-1} for the western drainage basin. Although calibrated at a surface runoff time series of 30 years returning a most likely long-term average value the simplicity of the model might evoke some inaccuracies. For validation purposes and additionally to obtain surface runoff magnitudes on the eastern flank of the Dead Sea at which runoff data was insufficiently available, a suite of process-based (JAMS) and physically-based (TRAIN-ZIN) hydrological models was applied for the western and eastern Dead Sea catchments, respectively.

JAMS (Krause et al. 2010) accounts for morphology, land cover, soil parameters and climatic data that were either available or obtained through remote sensing approaches (Rödiger et al. 2014). The calibration was pursued at catchments with available hydrographs and subsequently regionalised to the entire western drainage basin (1,443 km^2), resulting in a mean annual surface runoff volume of 15.4×10^6 m^3 a^{-1} for the period of 1977−2010. The considerable differences between both models, applied in the western drainage basin document the importance of long-term precipitation datasets (Siebert et al. 2014a).

Within the eastern drainage basin, Jordanian partners developed an analogous JAMS model for the outcrop area of the pivotal A7/B2 aquifer (3,427 km^2). The resulting mean annual surface runoff approaches 25×10^6 m^3 a^{-1} (Al-Raggad 2009). To spatially extend the approach of Al-Raggad (2009) to the entire eastern drainage area (6,277 km^2), a TRAIN-ZIN model (Menzel et al. 2007) was set up and forced by precipitation data from 1966−2006 with the result of 51×10^6 m^3 a^{-1} of mean annual surface runoff (Alkhoury 2011). Existing dam structures (Mujib, Tannur and Wala) comprise a total capacity of ca. 56×10^6 m^3 (Ijam and

Al-Mahamid 2012; Ijam and Tarawneh 2012; JVA 2013) and partially refrain surface runoff from entering the Dead Sea.

Our results give a total long-term runoff-rate of 66.8 × 10^6 m^3 a^{-1} for the drainage basins on both sides, which is much above the given values by Asmar and Ergenzinger (2002), Lensky et al. (2005) and references therin, which assume surface runoff through flash floods to be 8.96−10 × 10^6 m^3 a^{-1}. However, Salameh and El-Nasser (1999) calculate the total surface runoff to be 160 × 10^6 m^3 a^{-1}. As a proof of our calculations, excluding Greenman's calculations, for which rainfall data from exceptional dry years were taken, our calculated runoff/area ratios (Table 5.2) revealed comparable numbers for both sides. However, although the absolute amount is less, area-normalised runoff (10.7 mm/a) is larger in the west than in the east (7.3−8.1 mm/a), an assumed result of declining precipitation amounts eastwards.

The Lower Jordan River (LJR) is not included in any of the aforementioned numbers. Although its annual runoff volume declined during the last decades (Table 5.1) it is still the most important surface runoff component for the total Dead Sea water budget. The current estimated LJR discharge volume by far exceeds runoff contributions from flash floods and is still above the discharge contribution from groundwater (see Sect. 5.4). However, all existing LJR runoff values are highly uncertain approximations, since reliable in situ data are missing. This is the result of the tense political situation due to the LJR's role as high-security border between Israel/Palestine Authorities and the Kingdom of Jordan, allowing very restricted access to install or maintain hydrometric instrumentations.

Hence, one of the most important aims of the multilateral SUMAR project was to install such a station for the first time as close as possible to the river's mouth. Since 2010, on-site-parameters (e.g. water level, turbidity, EC) are telemetrically transferred to a web interface (http://www.bacsoft.com/webclient/) to provide online data access (Fig. 5.4). As yet, political obstacles hindered us to survey the streambed morphology and to measure cross-sectional velocities, respectively. Both are required to develop a discharge function to infer absolute discharge quantities.

In addition to telemetrically transferred on-site parameters, every 6 h water samples were automatically taken, conserved and sent for analysis. Since the LJR is the sum of a plenty of contributors, e.g. the Yarmouk River, the Sea of Galilee, saline/brackish springs and artificial ponds, the results from hydrochemical analysis are promising to reveal their chemical variety and discharge dynamics. Moreover, it enabled us to investigate quality variability in high temporal resolution, crucial for evaluating the compositional effects the LJR may has on the Dead Sea. Detailed looks revealed the expected inverse relation between discharge and salinity, but likewise, occasionally, an unexpected non-inverse behaviour showing increased percentage of saline spring water in the River (Fig. 5.4). Hence, EC varied between 1.01−7.77 mS/cm for the presented period and can rise up to 40 mS/cm.

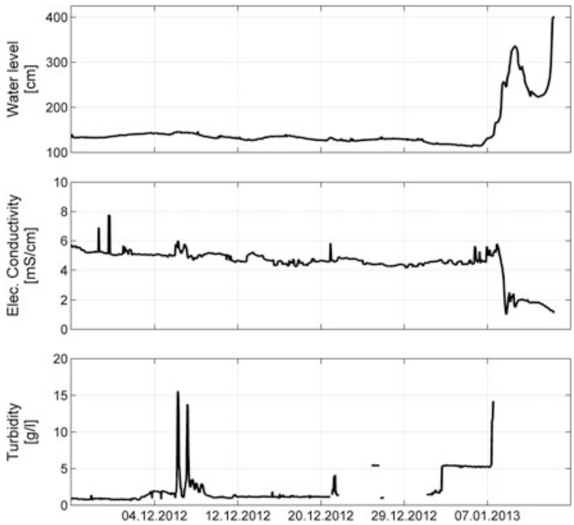

Fig. 5.4 Water level, electrical conductivity and turbidity of the Jordan River station exemplary shown for the period 25.11.2012–15.01.2013

5.3 Chemical Fingerprinting

The contribution of groundwater to the balance of the Dead Sea is discussed since decades (Lensky et al. 2005; Salameh and El-Naser 2000) as well as its origin (e.g. Mazor et al. 1969; Salameh and Hammouri 2008; Yechieli et al. 1996) and geochemical evolution (Katz and Starinsky 2009; Gavrieli et al. 2001; Möller et al. 2003). Neither distinct attribution of randomly emerging springs to particular aquifers nor the isolation of recharge areas for these springs were yet geochemically and comprehensively investigated along the Dead Sea. However, particularly these information are required to correlate specific discharge locations and amounts to the conjectural feeding aquifers and hence may be important calibration factors for numerical groundwater flow simulations. Moreover, a sound understanding of the complex structural and hydrogeological flow system (Laronne Ben-Itzhak and Gvirtzman 2005) is essential to suggest management strategies.

Within the study, we broadly investigated groundwaters within the proposed catchments and in outlets all along the shoreline. However, due to the considerable catchment sizes and the number of contributing aquifers, we had to focus and left springs alongside the eastern shore as subject to further investigations.

The intense sampling campaigns in the west were executed over 3 hydrological years (2009−2012) at groundwater wells in the hinterland and the known shoreline spring areas of Ein Feshkha, Kane-Samar, Mizpe Shalem, Qedem and Ein Gedi (Fig. 5.1) as well as at newly discovered discharge locations (see Sect. 5.4), both on land and submarine.

The shoreline springs originate from at least three aquifers of Lower and Upper Cretaceous age, each assigning typical chemical fingerprints on the passing waters. Based on these signals and in combination with isotope signatures, it was possible to infer groundwater origin for the springs, which emerge from nowadays-exposed lacustrine Dead Sea Group (DSG) sediments (Fig. 5.2) hosting halite-saturated interstitial brines and associated minerals.

The combined interpretation of stable isotope analyses ($\delta^{18}O$, $\delta^{2}H$), radiogenic information (^{3}H), major- and minor elements and rare earth elements (REE) including Yttrium (combined to REY) show evidences of different recharge areas within the western mountain range going from the area of Ramallah in the north, down to the Negev dessert. Adapted from studies in the Lower Jordan Valley, where the application of REY-patterns allowed to successful differentiate between waters from different Upper Cretaceous lime- and dolostone sub-aquifers could be shown (Siebert 2006; Siebert et al. 2009, 2012), REY patterns show distinct features from which both Judea Group aquifers and the Kurnub Aquifer (Siebert et al. 2014b) can be outlined as sources for the springs (Fig. 5.5).

Consequently, except hot springs in Qedem and Mizpe Shalem, which are fed by ascending brines, the chemical composition of encountered groundwaters show that the terrestrial and submarine springs are the result of (i) mixing of the interstitial brines with fresh groundwaters from the mountain aquifers and (ii) the microbial accelerated dissolution of evaporates which are abundant in the DSG sediments (Ionescu et al. 2012).

The hydrochemical data show waters partly flow through the unconsolidated DSG within well-developed open cracks with notably low water/rock interaction (Fig. 5.5a, b). Such waters discharge up to 110 m distance from the coast in water depths down to 30 m with occasionally remarkable low salinity, expressed by electrical conductivities down to 5 mS/cm (Figs. 5.6 and 5.9b). We suggest, although the origin of these open fissures is still debatable, their development is connected to the abundant microbial life detected in all terrestrial and submarine springs (Ionescu et al. 2012). Their particular metabolism, such as sulphate reduction, degradation of organic matter and accompanied (by-) products like H_2S and H_2SO_4 proved microbial activity to be a major force in the karstification of the carbonate- and sulphate-rich DSG-sediments.

A second type of flow within the DSG occurs through small fissures that probably represent the early stage of the above-described open cracks. These fissures allow the arriving fresh-water to slowly migrate and to intensely interact with DSG minerals and interstitial brines (Fig. 5.5c). This is supported by the similarity of their "patelliform" -like REY pattern to that of the Qedem brine, for which the intense contact with DSG sediments was shown by Gavrieli et al. (2001). Nevertheless the degree at which originally fresh groundwater is affected by the DSG passage depends on numerous processes. These include interaction with clay minerals, fine clastics and FeOOH complexes, dissolution or precipitation of different types of evaporates (e.g., aragonite, gypsum, anhydrite, halite, celestite, barite), microbial degradation of organic matter, sulphate- and iron reduction, anaerobe oxidation and mixing with interstitial and ascending brines in the DSG sediment.

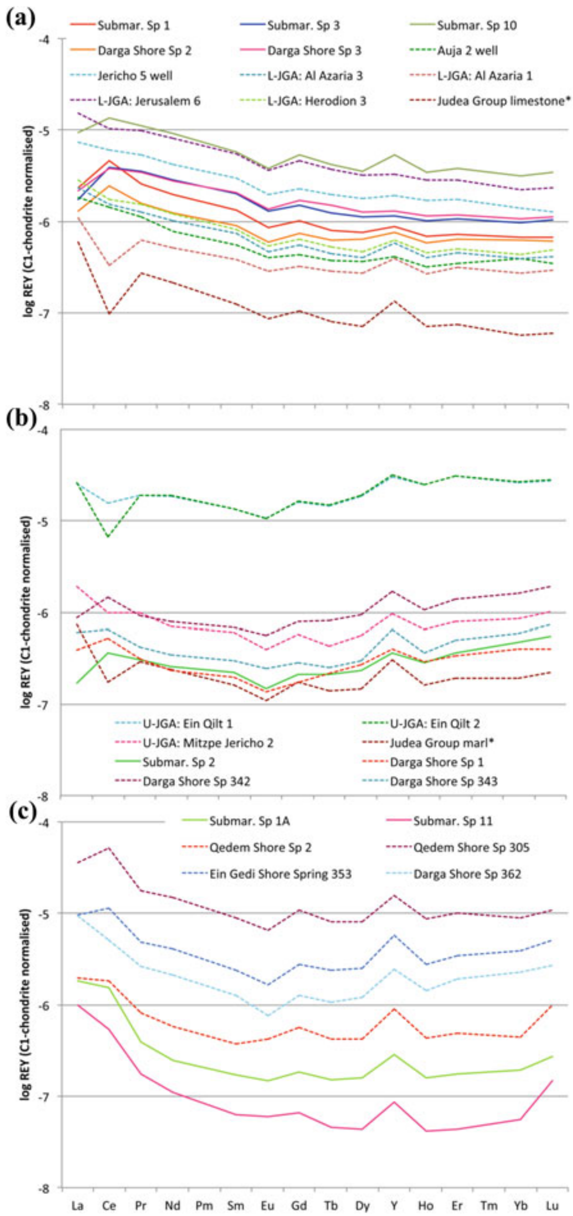

Fig. 5.5 REY-patterns of terrestrial and submarine springs and wells along the Dead Sea shore representing waters from *Lower* Judea Group (**a**), *Upper* Judea Group (**b**) limestone aquifers and of Qedem brine type (**c**)

The understanding and the geochemical modelling of these processes allowed us to disclose groundwater evolution and flow between identified sources and discharge locations. Conceptualized, these information supported the calibration of the groundwater flow model (see Sect. 5.5).

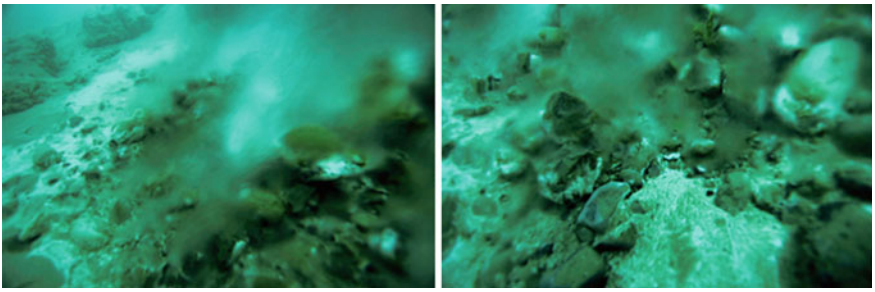

Fig. 5.6 Submarine fresh-water springs at the Dead Sea bottom (Ionescu et al. 2012)

5.4 Remote Sensing

The hydrochemical fingerprinting results prove the effectiveness to qualitatively allocate terrestrial and submarine springs to sources in terms of aquifer and recharge area. Unknown remains the exact abundance, location of those springs that as yet are not identified. These include mainly submarine springs that have been increasingly mentioned lately although their exact locations are not reported.

To identify these locations along the entire coast of the Dead Sea in the first stage of the remote sensing approach we exploit sea surface temperature (SST) contrasts evoked through spatio-temporal and temperature stable (25−30 °C/41−43 °C) continuous influx of groundwater and the season-variable SST of the Dead Sea (22−33 °C) (Hact and Gertman 2003). The resulting SST contrasts as consequence of temporal variability allow drawing conclusions on groundwater discharge locations and their relative importance over large spatial scales (Mallast et al. 2014). The developed approach is based on multi-temporal thermal Landsat ETM + data and includes the conversion from radiances to SSTs, the exclusion of images influenced by surface runoff, and the calculation of ΔSST per pixel of several SST images from different times as a function of SST variability. At sites where groundwater influx with stable temperatures is present the SST temperature is stabilized and comprises low ΔSST values. All other not-influenced areas are dominated by seasonal varying air temperatures that result in high ΔSST values.

Figure 5.7 shows the result for the western coast where it is visible that continuous low ΔSST values agglomerate to groups (termed groundwater affected areas —GAA) differing in extents parallel and orthogonal to the coast. For certain sites the Israel Hydrological Service (IHS) provided an independent in situ observation data set that spatially matches and hence, distinctively validates the multi-temporal thermal satellite results. In total, we could identify 37 GAAs along the entire coast (note that the eastern coast is presented in Mallast et al. 2013). The visually identifiable extent thereby directly mirrors groundwater discharge volumes at the respective location why GAAs were subsequently classified in “large”, “small” and “diffuse/assumed” based on their coast-parallel extents in order to distinguish discharge magnitudes per GAA.

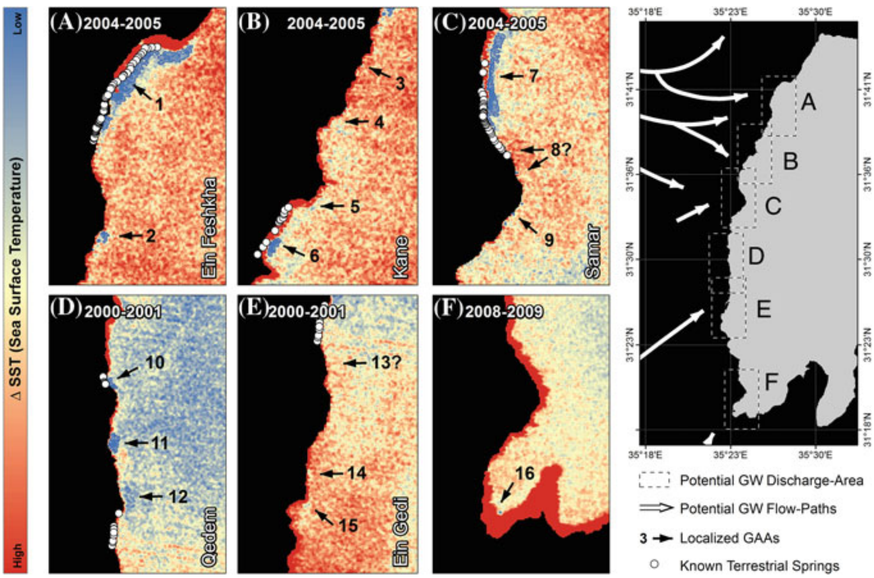

Fig. 5.7 Identification of inflow locations along the western DS coast for potential groundwater discharge zones **A**–**F**—colours indicate ΔSST values per pixel for biennial periods for which *blue* represents small ΔSST values indicating stable groundwater inflow while red indicates high ΔSST values caused by external forces (e.g. seasonal air temperature course) (Mallast et al. 2013)

Two of the identified locations represent large GAAs (1 and 7 in Fig. 5.7) with ΔSST values of 6.3−8.5 °C and a continuous area of ~3.4 km (2 km) length parallel to the coast. The location of both GAAs correspond to the largest known spring areas of Ein Feshkha and Samar with measured discharge volumes of 82−94 × 10^6 m^3 a^{-1} (Ein Feshkha) and 19−35 × 10^6 m^3 a^{-1} (Samar) (note that the numbers originate from the IHS measurements and represent the minimum and maximum numbers between 2004−2011, respectively) (Guttman 2000; Laronne Ben-Itzhak and Gvirtzman 2005; IHS 2012; Mallast et al. 2013).

Small GAA, such as 5, 6, 10 and 11 in Fig. 5.7, possess similar ΔSST as the previously mentioned values of 6.4−8.5 °C but with smaller coast parallel lengths (<400 m). GAA 5 and 6 corresponds to the Kane spring area with 6−9 × 10^6 m^3 a^{-1} (IHS 2012—for the years 2004−2005); and 10/11 correspond to the Qedem spring area with a discharge volume of ~10 × 10^6 m^3 a^{-1} (Shalev et al. 2007—given for the year 2005). This discharge volume reflects only a minimum since several field observations exhibited at least 3 submarine springs with an estimated sea surface diameter of ~10 m that probably significantly contribute to the thermally indicated extent of site 6. Further small GAAs are located at sites 2, 14, 15 and 16. Except GAA 2 that characterises similar extents and hence discharge magnitude as GAA 10, all remaining most likely feature discharge volumes that are lower by an order of magnitude.

In parallel, these 4 sites represent concrete indications for hitherto unreported discharge sites. In total we could outline 15 unknown sites along the entire coast that include GAAs 2, 3, 4, 9, 12, and 13 on the western coast also. From their thermal characteristics all except GAA 12 are characterised by extents <4 pixel (pixel size: 30 × 30 m) and ΔSST values of 8.9−9.5 °C. The slightly higher ΔSST values might indicate low groundwater discharge and less than the before mentioned sites. These characteristics and the fact that all require a ground-truth validation lead the allocation of these sites to class “assumed/diffuse”.

As pointed out before the GAA extents provide an indication of discharge magnitudes. The following step included a differentiation in biennial investigation periods for each coast with the intention to investigate and estimate the temporal

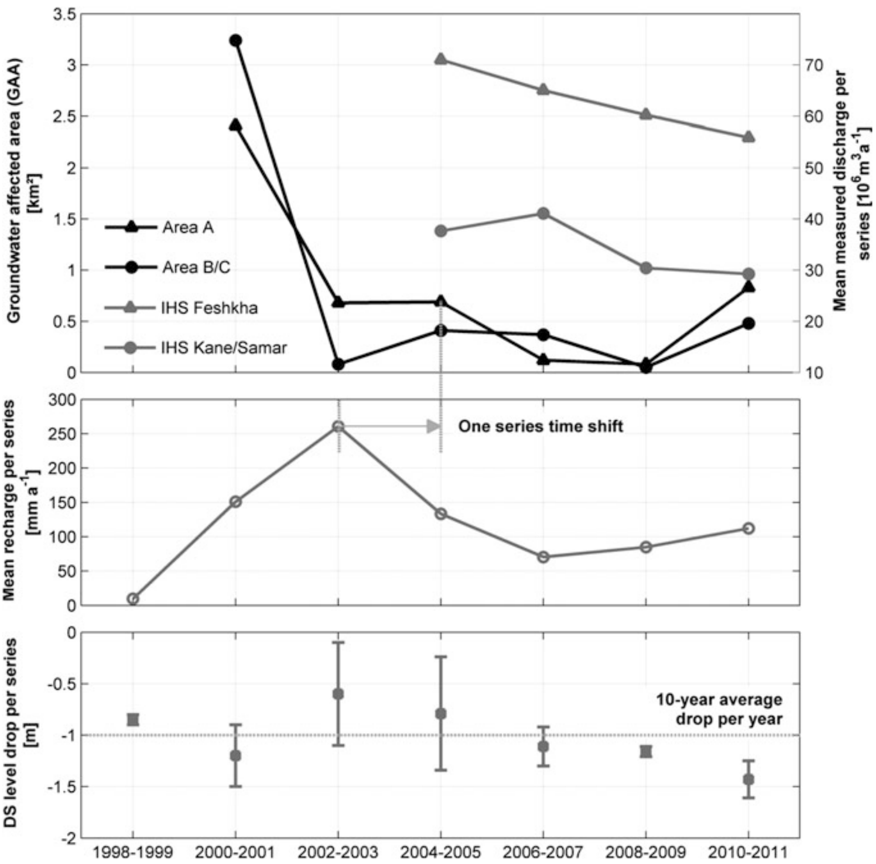

Fig. 5.8 Comparison of GAA per identified areas **a** (equivalent to Ein Feshkha) and **b/c** (equivalent to Kane/Samar) against the mean recharge amount calculated using rainfall information [mm/a] of Jerusalem station and the empirical equation from Guttman (2000) and the mean, maximum and minimum DS level drop per biennial investigation period (Mallast et al. 2013)

discharge behaviour for the years 2000−2011. Figure 5.8 presents the result in comparison to recharge and the Dead Sea level drop per period. It becomes obvious that for the shown potential groundwater discharge zones A and B/C the GAA extents vary over time from 3.24 (2.41) km^2 to 0.08 (0.05) km^2.

Most interesting are two facts. First, the calculated recharge reveals a similar curve progression as the GAA curve with a delayed response time of less than two years while, in contrast to both curves, the measured spring discharge (IHS 2012) decreases almost linearly. The reason is most likely related to submarine spring discharge that is not contained in the in situ measured spring discharge that due to measurement feasibility focuses on terrestrial springs only. At two non-conform investigation periods to the measured spring discharge (2000−2001 and 2010−2011) we observe an above average drop of the Dead Sea level (Fig. 5.8). For this situation Kiro et al. (2008) and Yechieli and Sivan (2011) propose an increased discharge (flushing) of old brines temporarily stored in void spaces of the recently exposed DSG sediment. The discharge then occurs over large continuous areas rather than at discrete points that the thermal results confirm.

Both so far inconsiderable facts, natural occurring submarine discharge and increased submarine discharge trough the flushing effect, are mirrored by the multi-temporal satellite based approach and hence provides further insights to the groundwater discharge situation influencing and contributing to the Dead Sea.

At a second stage of the remote sensing approach we conducted an airborne thermal campaign. The high spatial resolution of 0.5 m ground sampling distance even allows providing a differentiated single spring inventory. Only for the NW' coast of the Dead Sea we could outline a total of 72 discharge sites from which 42

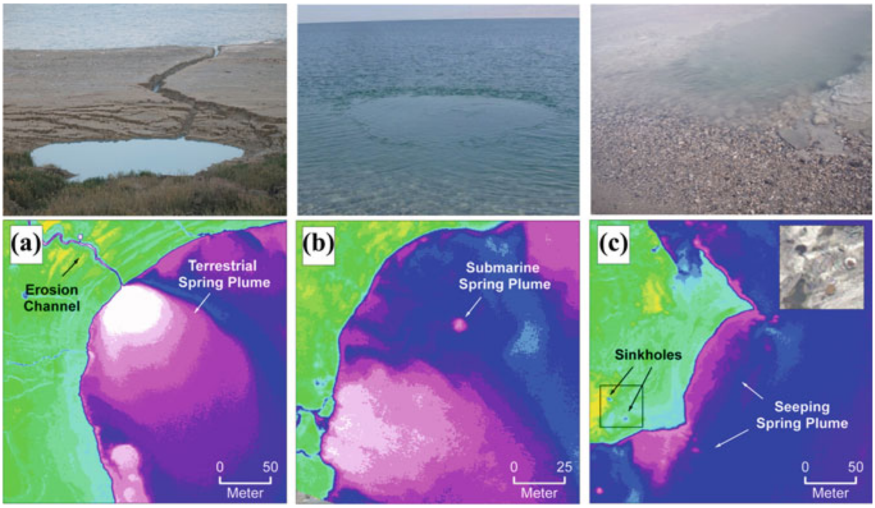

Fig. 5.9 Classes of thermal plumes from different types of springs—terrestrial spring (**a**), submarine spring (**b**), and from diffuse seeps (**c**). For orientation, the *Upper Left* coordinates for thermal images **a**–**c** are: 31.701°N/35.453°E (**a**); 31.692°N/35.449°E (**b**); 31.694°N/35.450°E (**c**)

belong to the terrestrial type (Fig. 5.9a), 6 are of submarine origin (Fig. 5.9b), and 24 belong to a hitherto unreported type of seeping springs (Fig. 5.9c). Type respective abundance numbers allow the conclusion that major groundwater contribution (~60 %) originates from terrestrial springs, while submarine springs represent only a minor fraction of <10 %. A most likely smaller but still considerable amount derives from seeping springs that in turn deserve future research in order to obtain a reliable total discharge volume that contributes to the Dead Sea.

5.5 Groundwater Modelling

Exploitable groundwater resources are of central focus since the beginning of intense colonisation of the semi-arid Levant. Estimations concerning groundwater discharge into the endorheic Dead Sea basin vary widely from 140 × 10^6 m^3 a^{-1} (Salameh and El-Naser 1999) to ca. 300 × 10^6 m^3 a^{-1} (Lensky et al. 2005), probably due to the non-quantified subsurface flow described above. Most to date available groundwater estimations are based on volume- or mass-balances being vulnerable to measurement and calculation errors of e.g. water level, volume, evaporation, etc. A further approach to gain more accurate estimations on groundwater discharge is to develop well-calibrated and verified transient groundwater models. The positive aspects of these models concern the revealing of system understanding as it provides spatially discretized groundwater flow paths and temporal discharge behaviour. Those positive aspects outweigh inherited uncertainties (spatial distribution of physical parameters, e.g. hydraulic conductivity or storage capacity and spatio-temporal recharge calculations), particularly when combined with further independent information such as from hydrochemistry and remote sensing.

To evaluate groundwater discharge and under constraining consideration of previous hydrochemical findings and results from remote sensing two transient numerical flow models for the Upper Cretaceous Aquifers (Judea Group on the western side (Gräbe et al. 2013) and A7/B2 on the eastern side (Al-Raggad 2009) were developed. Both models are based on finite elements including all hydrogeological and geomorphological drainage basin conditions such as outcropping layers, valley incision along wadis, fault and fold structures. Available water levels from well data are insufficient for proper model calibration requiring a multi-component analysis as described in Rödiger et al. (2014).

For the eastern side the results show a natural loss of groundwater from A7/B2 aquifer to the Dead Sea of 109 × 10^6 m^3 a^{-1}. This value is based on the hydraulic equilibrium between recharge and discharge excluding abstraction rates. Available data on abstraction rates reveal an approximate maximum value of 55 × 10^6 m^3 a^{-1} from the A7/B2 (Al-Raggad 2009) leaving a direct groundwater discharge to the

Dead Sea of 54 × 10^6 m^3 a^{-1} (note that this number represent discharge from A7/B2 only, not including the Lower Aquifer), which is nearly half the amount (90 × 10^6 m^3 a^{-1}) given by Salameh and El-Naser (1999).

Based on our results it is furthermore to expect that from hydraulic equilibrium perspectives 173 × 10^6 m^3 a^{-1} of groundwater discharge from the Upper Cretaceous Aquifers in the west to the Dead Sea. Accounting for approximate maximum abstraction rates from the Judea Group Aquifers of 50 × 10^6 m^3 a^{-1} (SWITCH 2006; PWA 2010; PHG 2012; Mekorot 2012) reveals a long-term mean discharge volume of 123 × 10^6 m^3 a^{-1} contributing from the west to the Dead Sea. This modelled number matches measured discharge volumes ~112−145 × 10^6 m^3 a^{-1} from terrestrial springs of the areas of Ein Feshkha, Kane/Samar, and Ein Gedi in the period 2004−2011 (IHS 2012). Assuming the abstraction from the Judea Group Aquifer not to be constant over time about 10−20 % of the total amount may discharge submarine and through seeps, which matches remote sensing findings described above.

Scenario analysis according to prognostic changes of 20−30 % less annual mean precipitation in the Levant (Christensen et al. 2007—based on MMD-A1B simulations) will have different impacts on eastern and western sides of the Dead Sea. While mean annual recharge contributing to available groundwater resources will reduce from currently ~44 mm/a to 22−13 mm/a on the western side, the amounts will reduce from ~32 mm/a to 15−12 mm/a on the eastern side (Siebert et al. 2014a). Since already today the regional available groundwater resources by far not cover the demand, the prognosticated decrease in precipitation and resulting recharge and groundwater availability will have tremendous socio-economic and ecological impacts on the region that even more require a sustainable groundwater management.

5.6 Conclusion

The information- and database within the Dead Sea basin is yet unsatisfying, although the outcomes of the SUMAR project add a significant amount of knowledge on the existing knowledge. However, the harsh conditions and large gradients in that arid to semiarid study area merely impede a sufficient monitoring network for hydrological parameters such as precipitation, surface runoff or groundwater flow.

As a consequence, alternative methods like remote sensing, geochemical fingerprinting and numerical modelling may reduce uncertainties due to their integral character.

Although having not enough gauging stations in side wadis along the Dead Sea, the application of hydrological models allow the reliable calculation of recharge and runoff numbers as long as climatic time-series are representative. Taking short-term series may lead to extreme under- or overestimation, as observable in the results for the western surface drainage basin.

For groundwater, the situation is even more complicated. In such data scarce regions, where groundwater wells and derived hydraulic data are, if at all, only clustered available, numerical groundwater flow models are extremely difficult to calibrate. Only by adding spatial and temporal integrating information i.e. travel times, existing inter-aquifer shortcuts, specific recharge locations, flow path evolution, maturity of karstification, discharge locations and discharge dynamics from hydrogeochemical and remote sensing investigations one may overcome that problem.

Flash-flood discharge (66.8×10^6 m^3 a^{-1}) contributes only a third of the modelled groundwater discharge (177×10^6 m^3 a^{-1}) to the budget of the Dead Sea, but contributes much more then estimated by Lensky et al. (2005). Since Salameh and El-Nasser (1999) combined groundwater-bearing base flow and flash-floods to surface runoff comparing the numbers is not possible. Completing surface runoff by the actual Jordan River (ca. 100×10^6 m^3 a^{-1}), our calculated contribution from surface- and groundwater equals. However, to develop an IWRM for the region, one has to consider still not answered but crucial questions, which need to be solved previously:

- How large is the contribution of the Lower Aquifer along the Jordanian shoreline?
- Where are additional monitoring stations necessary to refine the spatial and temporal knowledge of surface- and subsurface water flows?
- Is the hitherto unknown contribution of submarine groundwater discharge negligible or important for the budgets of the Dead Sea and surrounding groundwater resources?

The calculated effects on runoff- and recharge amounts under the forecasted drying of the region do send alarming signals to stakeholders and the scientific community and do not allow postponing the answers.

One important step towards an IWRM was done in the SUMAR project as well: the establishing of a transboundary data- and information system, which is publically available under www.ufz.de/daisy. DAISY is intended to simplify the cooperation in possible future transboundary projects by providing scientists and stakeholders with alphanumerical, vector- and raster-based datasets of hydrological and societal relevance.

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Chapter 6
The Impact of Rainfall-Runoff Events on the Water Quality of the Upper Catchment of the Jordan River, Israel

Oren Reichmann, Yona Chen and Iggy M. Litaor

Abstract This study examined the influence of rainfall-runoff events on water quality of the Upper Catchment of the Jordan River (UCJR) with a special emphasize on P fate and transport. We sampled 60 locations across the catchment to test the hypothesis that under Mediterranean climate conditions, most of the nutrient losses from the fields to waterways will occur in few major events while the actual contributing areas will be limited to critical source areas (CSA). Water analyses included nutrients (SRP, TP, TSS, NO_3, & NH_4), fecal indicators (Fecal Coliforms, E-Coli and Enterococcus) and EC & pH. Spatial analysis was conducted to identify CSA. In general, the results demonstrated the influence of runoff events on the water quality in the UCJR and the high heterogeneity of these events in space and time. The study showed that the levels of SRP, TP, TSS as well as indicators of fecal contamination were primarily transported with surface runoff and increased significantly in the stream during these events. Phosphorous concentrations in some sub-catchments reached extremely high concentrations (19 mg/l) during runoff compared with an average of 1.9 mg/l for the entire watershed. The medium to high correlation between the fecal indicators, total P and TSS suggest that during runoff events, P and bacteria attached to soil particles were mobilized to the stream from CSA. Water sampling along the streams flow paths together with the spatial analysis, identified CSA where an elevated nutrient concentration has been identified. Autocorrelation test identified CSA where an external pollution source influences the water nutrients content. The study provides watershed management science-based remediation options to reduce the potential of water pollution during major rainfall-runoff events.

Keywords Runoff events · Phosphorus · Moran I · Jordan river · Agro-catchment

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6.1 Introduction

Water quality in lakes is strongly influenced from factors and processes occurring upstream. Nutrient transport, especially N & P, from farm fields to water body may increase the primary productivity which in-turn will affect the aquatic system by reducing its ability to provide ecological services (Sharpley and Rekolainen 1997; Howarth et al. 2000). Nutrient transport in farm fields is highly affected by numerous components changing in space and time. Therefore, understanding the spatiotemporal behavior of nutrients in agro-catchments is crucial for the selection of best management practices to achieve maximum reduction in nutrient transport. Moreover, different nutrients exhibit a dissimilar spatiotemporal pattern within a given watershed, hence the transport mechanism of each nutrient must be evaluated. For example, Pionke et al. (1999) found that during the winter months, nitrate and dissolved phosphorus losses represent about 60 % of the yearly load in a Pennsylvanian watershed, but high-flow events were responsible for about 44 % of the nitrate load but more than 66 % of the annual phosphorus load. Similar results were reported by Udawatta et al. (2004) in an agricultural area in Missouri (USA), where the five largest runoff cases out of 66 events in seven years, accounted for 27 % of total phosphorus (TP) loss. Edelmann et al. (2002) found that NH_4 and P levels increase during flood events while the levels of $NO_3 + NO_2$ decreased in a mountain watershed in Colorado. These authors suggested that biological processes may enhance the transition of NH_4 to $NO_3 + NO_2$ during base flow. In a study conducted in the Pampean basin, Argentina, P concentration loss was mainly associated with surface runoff and was correlated with rain amounts, while the NO_3 apparently moves with groundwater during the dry season (Feijoo et al. 1999). They concluded that the nature of the change in nutrient concentrations can indicate the origin and flow-path of a given ion. Similarly, Houser et al. (2006) reported that SO_4 concentration increased with the decreasing of flow rate after high-flow events, a behavior they suggested originated from ground water movement.

The rainfall-runoff ratio also has an influence on the losses of nutrients from agro-catchments to waterways. This ratio is affected by rain properties (i.e., amount, intensity, event's time and the interval period with preceding rain event), soil surface permeability, antecedent soil moisture, degree of stoniness and the steepness of the slope (McDowell and Sharpley 2002; Little et al. 2005; Udawatta et al. 2004). Other parameters such as cultivation method, surface coverage and vegetation type, also exert an imported role in determining the rainfall-runoff ratio (Udawatta et al. 2004; Murphy et al. 2006).

Identifying the contributing areas is an essential task in watershed management. Source areas identification is difficult because of the heterogeneity of and the disparity between sub-basins. In fact, each basin has unique characteristics arising from the combination of factors that defines the water quality of the stream. Land-use, soil conservation and management, topography (basin size and slopes) and the amount and spatial distribution of rainfall, are all factors involved in determining the nutrient load across the sub-catchment (Eghball and Gilley 1999;

Gburek et al. 2000; Withers et al. 2009). In the case of P loss from land to waterways, Edwards and Withers (1998) emphasized the importance of soil properties, agricultural activities and watershed level. They pointed out that in pasture zone, grazing density and organic deposits are the dominant factors, while in cultivated field, crop growing method is the significant factor in P fate and transport. Franklin et al. (2002) examined the spatial distribution of N and P concentrations and their relationship in Oconee River basin, Georgia (USA). They employed autocorrelation analysis between points along streams using the assumption that downstream concentrations, depend on upstream conditions (river continuum concept). These authors demonstrated that the watershed physical characteristics and land-use practices are responsible to the stream nutrient concentrations. In a comparative study using data collected from different catchments across the USA (agro-, industrial- & urban areas) Preston et al. (2011) showed that catchment characteristics as well as atmospheric deposition and background concentrations, have a major impact on surface water quality. They also adapted the river continuum concept via the SPARROW model (SPAtially Referenced Regressions On Watershed attributes) to assess the nutrient concentrations in the river.

The current study was conducted within the framework of the Jordan River (JR) GLOWA project that assessed the influence of climate change on the JR's discharge (Tielbörger et al. 2016). Climate change projections show that the number of extreme rainfall events will rise in this region (Alpert et al. 2002; Yosef et al. 2009; Samuels et al. 2011). Hence, the objective of the present work was to examine the impact of flood events on the water quality in the Upper Catchment of the Jordan River. We hypothesized that under Eastern Mediterranean climate conditions typified by hot and dry summers and relatively short rainy winter, most of the nutrient losses from the fields to waterways will be confined to few major rainfall-runoff events while the actual contributing areas will be limited to specific land-use practices. Better understanding of such processes will facilitate science-based watershed management practices.

6.2 Methods

6.2.1 Study Area

The watershed of the Jordan River (JR) covers approximately 1600 km^2, with altitudes ranging from about 210 m below sea level (Lake Kinneret) to about 1000 m above sea level (a.s.l.) on the Golan Heights and more than 2800 m a.s.l. on top of Mount Hermon (Fig. 6.1). The JR is fed by three main perennial tributaries, emerging from the southern flank of the karstic Hermon Mountain, and by additional small, predominantly intermittent rivulets draining the basaltic Golan Heights plateau in the east and the karstic Eastern Galilee escarpment to the west. The combined discharge of all the major tributaries that formed the JR is about

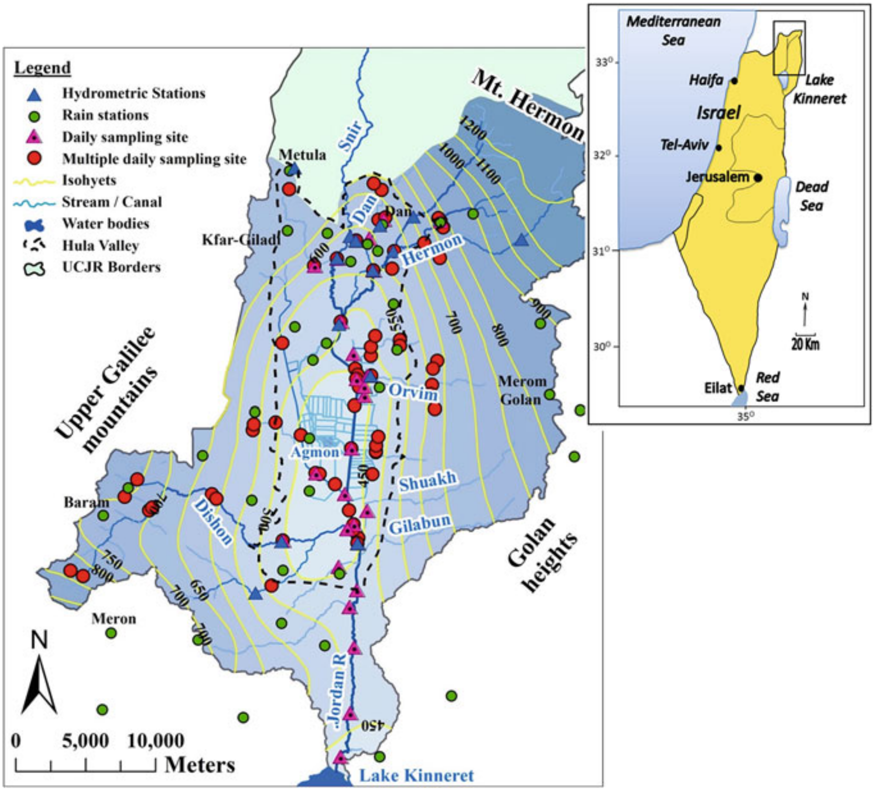


Fig. 6.1 The Upper Catchment of Jordan River (UCJR) study area. The *pink triangles* represent the single daily sampling station and the *red circles* represent the multiple daily sampling stations

455 Mm^3, which is roughly 70 % of the water entering Lake Kineret. The study area is characterized by hot and dry summers, cool and wet winters and short transitional periods that are often overlapped by the two prevailing seasons. The mean annual precipitation in the main recharge areas of the JR, range from more than 1600 mm in the upper Mount Hermon area (Gilad and Schwartz 1978; Simpson and Carmi 1983) to 900 mm in the upper Golan area, steadily decreasing to 450 mm at the southern tip of the watershed.

6.3 Water Sampling & Analysis

Water samples were collected from over 60 sites located along the main stream and in all major sub-catchments (Fig. 6.1). The exact location was determined based on the ability to assess discharge in pre-determined cross-section during high- and low-flow and accessibility. We conducted two types of water campaigns: (1) occasional single daily sampling in 20–30 stations during high-flow and during the summer of low base flow condition, and (2) multiple daily sampling in 60 sites across the entire watershed during a strong rainfall-runoff event. Most of the water sampling was conducted manually except in two rain events (02/2003 & 02/2004) when an automated portable sampler (ISCO, NE, USA) was used in two locations, collecting 500 mL water sample every hour for 36 h period. Water discharge was measured in 14 stations (Fig. 6.1) by the Israeli Hydrological Service. In all the other sampling points, the discharge was measured using a portable flow meter (FP201, Global water, USA) in a pre-determined cross-section with known width while the water gauge was determined with measuring stick. In few locations, the cross-section was estimated using a photograph with measuring device from which the area was computed with a special tool in ArcView 9.3. Rain data was gleaned from a wide array of meteorological stations scattered throughout the watershed (Fig. 6.1).

Electrical conductivity and temperature were measured with a WTW Cond340i handheld conductivity meter connected to a WTW Tetracon®325 standard conductivity cell (Weilheim, Germany) while the pH was measured using a WTW glass electrode Model 420A, (Orion, USA). Ions (Cl, NO_3, SO_4,) were analyzed by ion chromatography (Dionex, model DX 600, Sunnyvale, CA, USA). Total suspended solids (TSS) and suspended organic matter (SOM) was determined gravimetrically while NH_4 was determined using the Phenate method (APHA, AWWA, WEF, 1998). Dissolved P was analyzed using the Ascorbic acid method while the total P was determined using a standard procedure (APHA, AWWA, WEF 1998). Water samples for fecal indicators (*Fecal coliform, E-coli, Enterococci*) were collected into 1 L sterile bottles and were determined using the standard procedure (APHA, AWWA, WEF 1998). Samples for hormones analysis were collected into acid-washed polyethylene 250 mL bottles, immediately acidified with HCl and kept in a cooler. Samples were analyzed for Testosterone, Estrogen, Ethinylestradiol and Estriol as described by Shore et al. (2004).

6.4 Statistical Analyses

We used non-parametric test (Mann-Witney) to test the difference between various parameters in high- versus low- flow. We run Spearman's Rank Correlation to ascertain the relationships among the different chemical constituents in the water. These statistical analyses were performed using SPSS version 19 (IBM Corp. Released 2010, Armonk, NY, USA). The spatial relationships between topographic attributes such as aerial cover, slope steepness, and length of the stream beds and the nutrient loads were conducted using GIS (ArcView 9.3, ESRI, Redlands, CA). The Moran I test embedded in Geoda algorithm (Anselin 2003) was employed to assess the autocorrelation of the nutrients along the stream flow and to identify the spatial connection among the sampling sites. The Moran I test is computed using the following equation:

$$I = \frac{N\Sigma_i\Sigma_j W_{i,j}\left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\left(\Sigma_i\Sigma_j W_{i,j}\right)\sum_i\left(X_i - \overline{X}\right)^2}$$

Where N is the number of observations, Xi is the nutrient value in a defined location i, Xj is the nutrient value at location j adjacent to i, $\overline{X}$ is the mean nutrient value, Wij is the weight given to a distance parameter between values. The Moran I test provides an overall view of the spatial dependency along the stream flow. However, when a catchment is characterized with zone breaks in the autocorrelation pattern, the test would fail and a local version of the Moran I test is required as described by Anselin (1995) and Brody et al. (2005). The Local Indicator of Spatial Autocorrelation (LISA) is given by the following equation:

$$I_i = Z_i \sum_j W_{i,j} Z_j$$

where Z_i and Z_j are the observations in deviations from the mean, $W_{i,j}$ is a distance weight for the interaction between observations i and j, and Σ is the sum of only adjacent observations affecting each other. Examples of the use of LISA and Moran I test to ascertain the spatial dependency and autocorrelation among sampling points along a river are given in Brody et al. (2005) and Franklin et al. (2002; 2013). In essence, a break in the autocorrelation of a given water quality parameter along the river flow suggests the existence of another source of pollution outside the main course of the flow. Local conditions can also affect the autocorrelation values of the different elements, for example, rapid change in flow velocity or channel slope will affect the chemical constituents concentrations in the river.

6.5 Results

General Characteristics

The concentrations of the various water quality parameters in the UCJR are characterized by a wide range of values (Table 6.1). For example, TP varies between 0.006 to 19 mg/l while NO_3 extends between 0.3 to 230 mg/l. The low values were found mostly at the headwater sources that receive little or no runoff contributions because of the small catchment area. The highest TP value was measured at the Snir headwater tributary which has a large catchment area. These extreme TP values were recorded during a major rainfall-runoff event in December, 2002. The origin of this elevated value is probably from Lebanon where sewage from villages drained directly to the stream a phenomenon that increased with runoff. In support of this assessment is the fact that the TP was correlated with high value of TSS (12,300 mg/l). The highest NO_3 concentration was observed in the Dishon Creek that joins the JR at midstream (Fig. 6.1) during base flow episode that was characterized by high SO_4 (>100 mg/l) and Cl (160 mg/l). These interrelationships

Table 6.1 General characteristics of water quality parameters of the UCJR

Parameter	Units	n	Minimum	Maximum	Median	Mean	S.D
EC	$\mu S\ cm^{-1}$	1148	160	1876	382	427	197
pH		1079	7.0	8.7	8.0	8.0	0.3
TP	mg/l	915	0.006	19.07	0.38	0.84	1.75
SRP		1166	0.003	6.24	0.10	0.21	0.39
NO_3		1104	0.3	230.2	8.8	12.1	16.3
NH_4		605	<0.01	7.7	0.1	0.2	0.5
Cl		1109	1.1	490	15	22	26
SO_4		1109	2.5	760	17	26	40
T.S.S		944	<1	12,350	77	324	1003
SOM		578	<1	1340	16	41	85
DOC		274	0.4	46	5	6	4
Alkalinity	mmol L^{-1}	396	1.4	7.0	3.6	3.6	0.8
F. Col.	No. in 100 mL	209	3	8.3E + 05	5.4E + 03	2.1E + 04	6.7E + 04
E. Coli		179	0	1.4E + 05	2.3E + 03	7.1E + 03	1.5E + 04
Entro.		188	0	1.7E + 05	1.3E + 03	4.0E + 03	1.3E + 04
Testosterone	$\mu g\ L^{-1}$	383	0.01	10.49	0.69	1.20	1.31
Estrogen		367	N.D	9.40	0.30	0.51	0.83
Ethinyl		224	N.D	9.58	0.50	0.74	1.03
Estriol		167	N.D	7.79	0.10	0.39	1.00

imply to an existence of a local source of pollution outside the main course of the JR most likely cowsheds located upstream from the sampling point in Dishon basin.

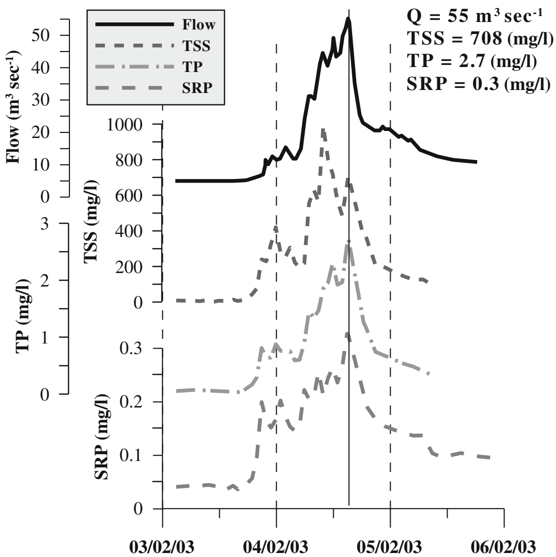
Pearson correlation analysis using more than 1000 water samples showed that the TP is highly correlated with TSS ($r = 0.83$, $P < 0.001$) and SOM ($r = 0.72$, $P < 0.001$) while the TSS was also highly correlated with SOM ($r = 0.9$, $P < 0.001$). EC is correlated as expected with Cl and SO_4 ($r = 0.79, 0.77$, $P < 0.001$, respectively) while during high-flow EC was also correlated with NO_3 ($r = 0.45$, $P < 0.001$). Spatiotemporal assessment of P and other constituents and their interrelationships with TSS and SOM during high- and low flow strongly suggests that rainfall events that generate runoff elevate the P concentrations in most sub-catchments while more conservative ions such as Cl, SO_4 and NO_3 are unaffected or even exhibited a reduction in concentrations because of dilution effect.

Analysis of a Single Extreme Rain Event

The winter of the hydrologic year 2002–2003 exhibited rainfall amounts significantly above average (1153 mm in Kfar-Giladi compared to annual mean of 790 mm, based on the Israel Meteorological Service data). On February 2nd in a course of one single rain event that lasted 38 h, about 90 mm were measured in a meteorological station located at the headwaters. The discharge in the Hermon tributary rose from 5 to 55 $m^3 s^{-1}$ while the hydrograph at a nearby Snir tributary reached 70 $m^3 s^{-1}$. During this event, we conducted a continuous water sampling campaign in the Hermon stream and the water samples were analyzed for TP, SRP and TSS (Fig. 6.2). The TP load in the Hermon stream reached 4.5 ton per event compared with annual mean of 70 ton yr^{-1} reaching Lake Kinneret. The TP load was coupled with 700 kg of dissolved P and 1450 ton of TSS. Such a high load in a short time may have a significant impact downstream. Similar nutrient pattern in other sub-catchments was observed during other extreme events (not shown).

Watershed Characteristics and Contributing Areas
Spatial variations in rain intensity, duration and frequency strongly affect the total P concentration across the watershed (Fig. 6.3). In particular, strong local rain intensity falling locally will elevate P concentrations downstream. Some of these variations also originate from deviations in topography of sub-basins. Low slope canals draining the center of the Hula valley can mobilize relatively little particulate matter, while steep riverbed characterized by turbulent flow may transport high volumes of particles containing P downstream. Changes in various constituents in the stream are also affected by the locations of hot spots along the river or by in-stream processes such as dilution and sedimentation. For example, a significant correlation ($r = 0.7$, $P < 0.01$) between the conservative Cl ion and the reactive P were found during baseflow conditions, while in rain events the trends of these two constituents were vastly different (Fig. 6.4). This pattern is strongly indicative of the existence of local processes that operate mostly during high flow conditions. An autocorrelation analysis was conducted to test the spatial pattern of TP, SRP and

Fig. 6.2 The discharge and concentrations of TP, SRP and TSS during a single extreme rainfall-runoff event



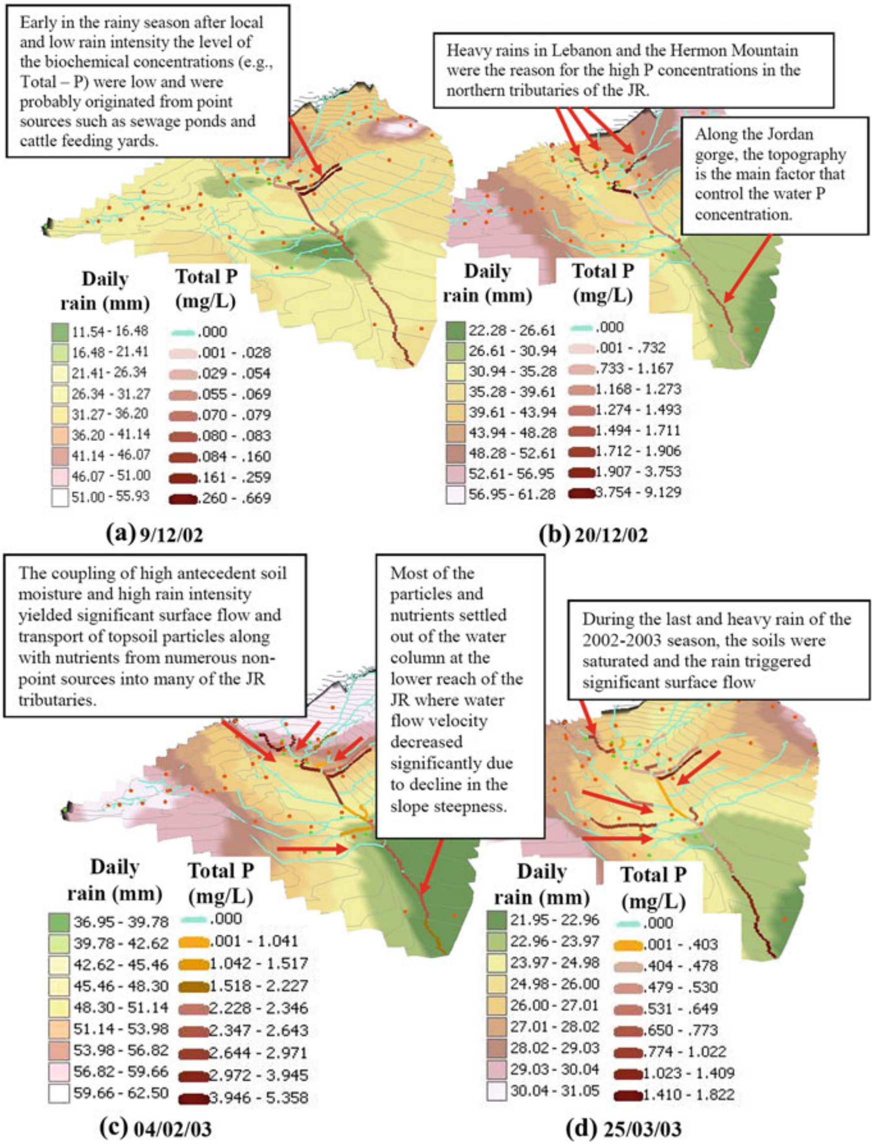


Fig. 6.3 The interrelationships between rain events, topography and phosphorus concentrations in the stream are depicted for the 2002–2003 rainy season

TSS across the watershed (Fig. 6.5). Sampling points denoted with light color exhibited no significant spatial correlation while colored points have a variable degree of spatial autocorrelation. The highest autocorrelation was found along the JR itself which mean that the P load at a given sampling point is influenced by the P loading at a point upstream. On the other hand, sampling locations in smaller

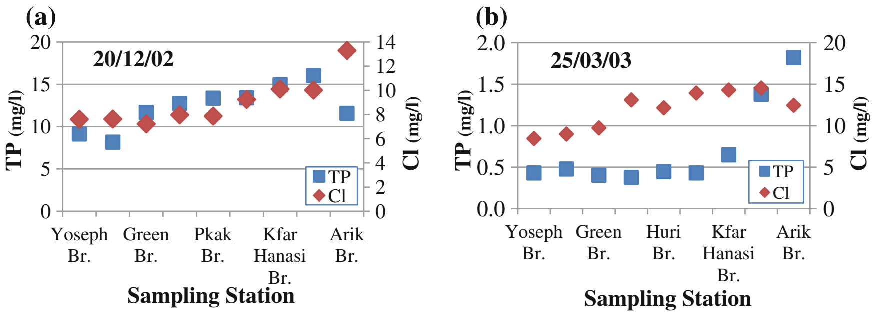


Fig. 6.4 Changes in Total P and Cl concentrations along the Jordan in two different rain events

sub-catchments of the Golan Heights or Eastern Galilee showed little autocorrelation, which means that the P loads at a particular sampling site, is not affected from contributing areas upstream. A striking example of this phenomenon was observed in Dishon Creek (Insert in Fig. 6.5) where the increase in TP concentrations at the lower end of the stream originated from external source rather than a gradual increase along the main-stream flow.

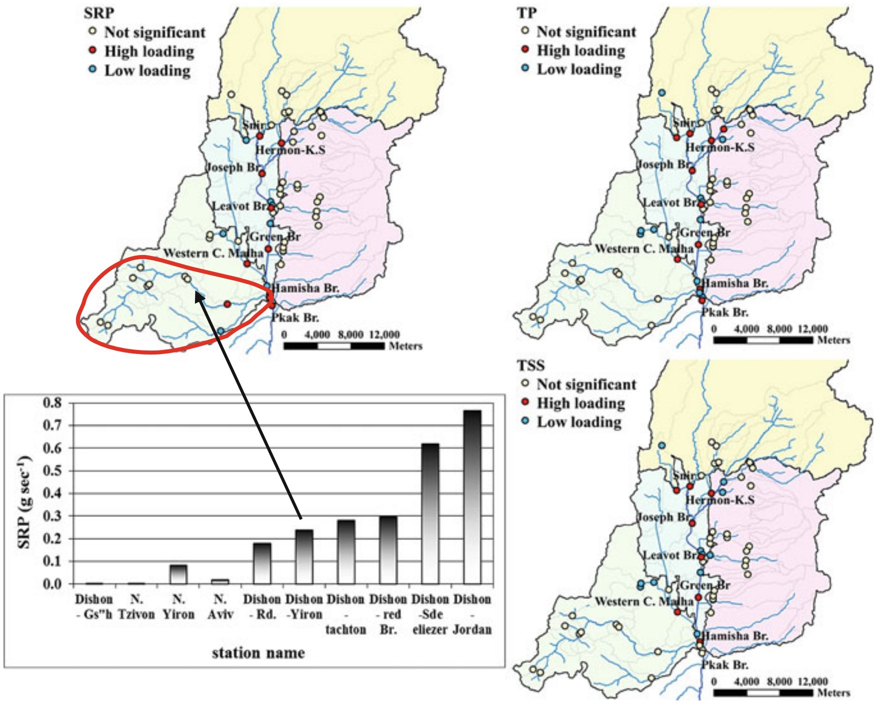


Fig. 6.5 Moran I test of *TP, SRP and TSS loads* for contributing areas along the JR watershed. The change in Moran I value in the lower end of Dishon stream is depicted in the insert figure

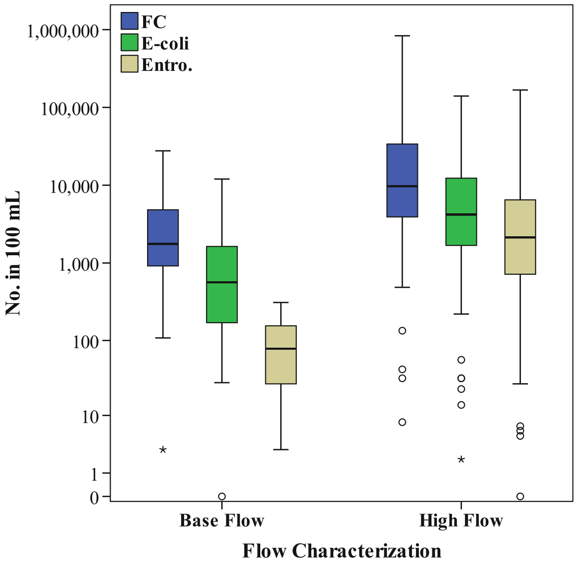


Fig. 6.6 Comparison between the 3 fecal indicators measured during base flow versus high flow. The low levels were found only in the headwater springs. Flooding events elevated considerably the number of bacteria in the water compared with normal flow conditions

Fecal Indicators

We analyzed selected water samples for fecal indicators that provide a good assessment of human, cattle and poultry contribution in terms of E-coli, FC (*Fecal Coliforms*), Entro. (*Enterococcus*) and certain hormones. Usually the levels of bacteria varied between few 100 s to over 250,000 in 100 mL solution. The lowest values were recorded in the headwater springs and tributaries while the highest values were found during rainfall-runoff events (Fig. 6.6). There is a high correlation among the 3 fecal indicators ($r = 0.8$–0.9, $P < 0.01$) as well as between the indicators and TSS ($r = 0.7$, $P < 0.01$). There was also a high correlation between the fecal indicators and TP ($r = 0.7$, $P < 0.01$) which suggests that both contaminants have originated from the same source, and they mostly transport in the river as suspended solids, however, in few instances the TSS level did not correlate with the fecal indicators. A closer look on the correlation matrices showed that the correlation coefficient between *Enterococcus* and TSS and TP was only 0.5 during base flow but increased dramatically during runoff ($r = 0.73$, $P < 0.01$). A medium to high correlations ($r = 0.5$–0.7, $P < 0.01$) was found between the 3 fecal indicators and Estrogen only during base flow, however.

6.6 Discussion

The results clearly demonstrated the importance of major rainfall-runoff events on the water quality of the JR. Since P is a limiting factor in eutrophication of Lake Kinneret (Berman et al. 1998; Hadas et al. 2002), a closer examination of the P behavior during runoff events is important in terms of the state of the lake health. The clear spatiotemporal heterogeneity in P concentrations resulted from the differences in rain intensity, rain spatial distribution and its timing within the season, sub-catchment size, slope steepness and land-use. Phosphorous concentrations in some sub-catchments reached extremely high concentrations (19 mg/l) during runoff compared with an average of 1.9 mg/l for the entire watershed. Peak values during base-flow were significantly lower (0.15 mg/l) while mean value of base-flow is several orders of magnitude lower (0.056 mg/l) than P concentrations during runoff. The influence of watershed size and land-use on P concentrations during runoff was also pointed out by Tarkalson and Mikkelsen (2004) for pediment soils and Torrent et al. (2007) for agro-catchments in Southern Europe.

In the UCJR, the foremost P transport mechanisms during major runoff events are surface erosion of contributing areas and re-suspension of sediments in the stream channel. Support for this explanation is found in the high correlation coefficient between TP and TSS in the JR as well as in other watersheds in the USA and Europe (Svendsen et al. 1995; Kronvang et al. 1997; Sharpley et al. 2008). Kronvang et al. (1997) showed that TSS levels increased with the hydrograph in Danish agro-catchment while Withers and Lord (2002) demonstrated that the concentrations of TP, dissolved P and TSS have similar loading characteristics during increased discharge in the Nadder River in South England. Bowes et al. (2005) performed graphic analysis and showed that hysteresis loop best described the change in TP in relation to discharge, sampling location and the distance of the source area, to the stream. The hysteresis is characterized by higher TP concentrations in early rainfall-runoff events while at later runoff occurrences, the TP fraction is more stable and is less susceptible to movement. According to this concept, during early rainfall events, most of the transportable TP in a catchment is originated from adjacent sites along the stream and from re-suspension of P that was accumulated during the preceding season. Later in the season, during large rainfall events, the level of TP in the stream is also affected from more distant locations in the watershed. We found similar spatiotemporal pattern of TP transport in the headwater stream of the JR.

The medium to high correlation between the fecal indicators, total P and TSS suggests that during runoff events in the upper catchment of the JR, P and bacteria attached to soil particles were mobilized to the stream from cattle feeding zones, poorly maintained sewage holding ponds and animal manure that were spread improperly across farm fields. Similar results were reported for other agro-catchments during runoff events in New Zealand (McDowell et al. 2005) and Scotland (Oliver et al. 2005). Tyrrel and Quinton (2003) suggested that bacteria can be transported to the stream attached to soil particles, embedded in sludge and as free cells. They also indicated that intense rain may extricate the bacteria from the particles and release them to the water column while Fries et al. (2006) noted that bacteria attached to soil particles are less mobile and settled fairly rapidly to the stream bottom This process is accompanied by increased numbers of bacteria in stream sediments, as describe by Stephenson and Rychert (1982) and Burton et al. (1987). Stephenson and Rychert (1982) reported that in Idaho (USA), *E. coli* concentrations in stream bottom sediments were 2–760 times greater than the concentration of the overlying water, while Burton et al. (1987) found that pathogens can survive in sediment for months, in contrast to faster mortality rates in the water column. Resuspension of bacteria in sediments may occur during critical flow conditions, which disturb the cohesiveness of the streambed. It appears that the number of bacteria is highest during the rising limb of the storm hydrograph and become reduced during the event after the depletions of suspendable microorganisms (Jamieson et al. 2005). This attachment-detachment-re-suspension mechanism may explain the findings that in several runoff events, we found only medium correlation between the fecal indicators and TSS.

Unlike the P spatiotemporal behavior, the NH_4 concentrations did not exhibit a consistent pattern in time or space, while NO_3 did not show significant difference between base flow and runoff. Ammonium is normally exposed to oxygen during base flow, thus it commonly exhibits low values in the stream waters (Edelmann et al. 2002). During a major runoff event, the transport of NH_4 is faster with less exposure to oxygen, which translates to higher values of this compound in the stream. Nitrate transport is occurring mostly in the subsurface contrary to P that moves via accelerated surface transport, so the nitrate reaches the stream well behind the peak discharge. In fact, Pionke et al. (1996) noted that most of the nitrate is moving during elevated base flow, which refer to water seeping out of the soil after the rain. However, if contributing areas are close to the stream, the transport time is shorter and it may affect the spatiotemporal pattern. Support to this assessment we found in the nitrate pattern at the Dan headwater tributary and in a contiguous stream that exhibited higher NO_3 concentrations. This elevated concentrations originated from adjacent orchards and nearby cattle feeding site that contributed high levels of nitrate even during base flow.

Nutrient transport from the fields to waterways within the catchment during rainfall that creates a significant runoff followed by substantial rise of the hydrograph is mostly originated from non-point source areas (Withers and Jarvie 2008). These areas are difficult to identify, quantify and treat adequately. The JR watershed is heterogeneous in terms of lithology, soil types, relief and land-use, which make the identification of non-point areas, especially challenging. For example, the Hula Valley which is mostly flat, relatively wide soilscape with a high percentage of peat and enriched organic layers of the formerly Hula Lake and swamps, is usually characterized by base-flow with very little runoff. Most of the nutrient loads from the Hula Valley were generated by dual flow and reverse hydraulic head mechanisms described by Litaor et al. (2008) and Sade et al. (2010). The contribution of the Hula Valley to the overall P, TSS and biological loadings to the JR is probably minor compared with side streams from small but steep sub-catchments that are contributing nutrients such as TP, TSS and fecal indicators during major rainfall-runoff events. These critical source areas are greatly affecting the water quality of the JR and leading to occasional extremely high values of P in the water. Franklin et al. (2013) found that spatial attributes such as hydrology, drainage density and soil organic matter, were good predictors of P in an agro-catchment in Oklahoma, USA. The spatial heterogeneity of the UCJR described above, precludes the use of landscape attributes as P predictor for the entire watershed. Hence, we used autocorrelation analysis (Moran I) to identify the river confluences where the directional autocorrelation break down. This lack of autocorrelation was explained by the existence of small cattle feeding areas adjacent to stream beds in the upper reaches of these sub-catchments that contribute high levels of P, TSS and fecal indicators during rainfall-runoff events. Similar results were reported in other agro-catchments in North America (McDowell et al. 2005) and Europe (Quinn and Stroud 2002; Kurz et al. 2006). An alternative technique for the identification of critical source area is the P-index tool describe by Lemunyon and Gilbert (1993), Gburek et al. (2000) and Heathwaite et al. (2003). Recently, Reichmann et al. (2013) demonstrated the use of the P-index tool with certain modification to fit a watershed in a Mediterranean climate zone. However, this approach required ample of spatial data of various types that often are not available in the catchment. Regardless of the technique used to identify critical source areas the present study clearly illustrated the importance of relocation of the cattle feeding zones away from the streams as was recommended by James et al. (2007) in the Cannonsville Watershed (New York). In addition, better soil conservation practices were advocated by Carpenter et al. (1998) in a review article and by Udawatta et al. (2004) in northeastern Missouri, to curtail the level of nutrients reaching the stream. Some or all of these remedial actions should be adapted for the JR in order to reduce the potential runoff transport of nutrients and fecal indicators from the non-point source areas to the waterways.

Summary

In the beginning of this study, we hypothesized that under Eastern Mediterranean climate conditions most of the nutrient losses from the fields to waterways will be limited to a few major rainfall-runoff events, while the actual contributing areas will be limited to specific land-use practices. We found that although different nutrients have distinctive transport mechanism or hydro-geochemical characteristics, high-flow events affect them all. The magnitude, time and direction of this influence may change from one constituent to another. Phosphorus loss from basin areas is occurred mostly by overland flow in the form of dissolved or particulate matter, as reflected in the rapid increase of P concentration in the stream. Nitrate transport time is longer than P due to its movement through soil profile, resulting in a delay of nitrate arrival to the stream. Pollution sources far away from the waterways are characterized by a longer transport time to streams, as well as a significant delay in their influence on the hydro-geochemical attributes during peak events. Sampling at the peak of the hydrograph will yield elevated P concentration coupled with a decrease in the NO_3 concentration due to a dilution effect caused by rain water. Land-use adjacent to stream flows that are characterized by a high level of nutrient's effluxes, may have a great impact on the water quality during flood events. Rain distribution as well as stream channel topography may also affect the stream's nutrient levels. Spatial autocorrelation demonstrated that "hot spot" areas, such as cattle feeding zones, contribute a significant amount of nutrients to the stream. This analysis provides watershed managers with crucial information about a few contributing areas rather than searching the entire basin. On the basis of this work, and after considering various remedial options (see Schoumans et al. 2011) we recommended that several key drainage canals in the Hula Valley be transformed into vegetated agricultural drainage ditches (VADD). This technique should be able to reduce the P loads in the waterways to acceptable levels that will minimize the potential of eutrophication downstream. This recommendation has been adapted recently by the JNF, and a comprehensive study is underway in the vicinity of the confluence of the eastern and western canals (see Fig. 6.1) intended to evaluate the preferred macrophytes and type of treatment wetland required to attain this goal.

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Chapter 7
Input-Output Model-Based Water Footprint Indicators to Support IWRM in the Irrigated Drylands of Uzbekistan, Central Asia

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Abstract Water scarcity due to increasing water demand triggered by population growth and irrigation expansion versus a limited and increasingly variable water supply as a consequence of climate change is presently one of the global challenges. This is exemplified in Uzbekistan, Central Asia, where irrigated agriculture is the primary source of the livelihoods of the rural population that makes more than 60 % of all inhabitants. Yet, socio-economic and ecological challenges keep growing, also due to the inefficient management of water resources. Therefore, options to increase water use efficiency were analyzed while considering the entire supply chain of products including the production, processing, consumption and trade stages and processes. These options were analyzed through an elaborated environmentally extended input-output model. The options examined throughout the entire supply chain included: (i) implementing advanced field-level water saving technologies, (ii) increasing crop diversity through expanding fruits and vegetables

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production and reducing the area of current dominant crops (cotton and paddy rice in downstream), (iii) fostering the further development of less-water demanding agricultural processing industries, (iv) upgrading production value chains by expanding the production of the commodities with higher values added, (v) reducing production and consumption losses, and (vi) diversifying exports by replacing the current cotton fiber exports with cotton commodities of higher values added. The findings may spur decision-makers to formulating strategic priorities at national level and coordinating water uses considering comprehensively technical, economic and ecological aspects along the entire supply chain, which is a key element of IWRM concepts. However, it is argued that increasing water use efficiency through technological and economic transformation reforms necessitates the empowerment of water users, raising their awareness for, and providing the institutional and market infrastructure, which is in-line with IWRM principles as well.

Keywords Water use efficiency · Supply chain · Economic transformation · Empowerment of water users

7.1 Introduction

Water scarcity challenges the livelihoods of billions of people as well as the functioning of and valuable service provision by ecosystems particularly in arid and semi-arid regions (Rosegrant et al. 2002). While presently about one fifth of the world population lives in areas troubled by permanent water scarcity, it is expected that more than one third will be confronted with either physical or economic water scarcity by 2025 (UN WATER 2007). Climate change impacts are expected to aggravate these challenges (Wheeler and von Braun 2013). A growing severity of water scarcity challenges is exemplified in the case of Central Asia, where the tremendous expansion of irrigated agriculture to produce cotton between 1950–1990 turned this region into one of the largest irrigation regions of the world. Although Uzbekistan is not the largest country in Central Asia, it hosts more than half of the population in the region and hosts more than 50 % of the irrigated croplands (Fig. 7.1). However, inefficient use of (irrigation) water resources led to water overuse in some parts and water scarcity in other parts of the region as well as reduced environmental flows which also contributed to the desiccation of the Aral Sea (Micklin 2007). To overcome current and future challenges, improving one single water management measure is not sufficient. Rather a combination of several options geared towards water use reduction along the entire production supply chains should be implemented concurrently addressing all relevant economic sectors.

The concept of Integrated Water Resources Management (IWRM) is recurrently advocated as a suitable approach for improving the coordination of water allocation and use and in turn dealing with water scarcity (GWP 2000). Therefore, IWRM is recognized as a “process which promotes the coordinated development and

Fig. 7.1 Map of Uzbekistan

management of land, water, and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment (GWP 2000)". Experts from Central Asia emphasize especially the social and equitability aspects of water use and interpret IWRM as a "management system supported by governance arrangements to consider all types of water resources (surface, ground-, and return waters) within hydrological units; which links the interests of different economic sectors and hierarchical levels of water use; involves stakeholders in decision-making; and promotes effective use of water, land and other natural resources in order to ensure stable water supply for the environmental and societal needs (Dukhovny et al. 2013)". Although the bottom-line of both perceptions is to increase overall water use efficiency and productivity, both deal with direct water uses across the economic sectors. However, when considering merely direct water use, only a part of the entire picture is addressed. Here, we present therefore a more comprehensive approach to support IWRM by not only striving for a holistic coordination of direct uses of water and related resources, but also by considering indirect water uses throughout the entire supply chain since these indirect uses can be considerable. This approach joins in addition all water users such as water ministries, water managers and irrigators, producers, and consumers, within one water system. According to this extended concept of IWRM, increasing water productivity from a production perspective may be gained for instance through the adoption of water conservation technologies, improvement of irrigation efficiency or the selection of intermediate inputs that require less water. However, from a consumption perspective, increasing water productivity could be reached for instance through dietary changes, purchasing foods with low virtual water content, implementing export diversification or importing commodities with a high water footprint. The comprehensive analysis of efficient water use was done here through an environmentally extended input-output model (IOM) that (i) assesses the water footprints of commodities manufactured in different economic sectors, (ii) accounts for intersectoral virtual water flow matrixes needed to determine 'hot-spots' (defined here as part of the chain with large water content) in the entire production value chain, and (iii) determines potential areas for intervention. This approach for identifying options for water use reduction addresses thus not only direct water uses at field and network level, but also water embedded in semi-final and final goods produced at different stages of the supply chain. The objective of this study is to derive a framework for coordinating water management activities under an extended IWRM approach by prioritizing sectors with low water consumption per economic value generated and identifying 'hot spots' of intersectoral water flows.

7.2 Study Area

Uzbekistan is the homeland for more than 28 million people of which more than 60 % live in rural areas (UzStat 2008). The majority of the population, directly or indirectly, relies on irrigated agricultural production that is practiced over 4 million ha of irrigated lands (FAO 2000). Although the share of agriculture in GDP reduced from over 40 % in the 1990s to less than 20 % at present, mainly due to the expansion of the fossil fuel industry, metallurgy, and machinery in urban centers, the share of agriculture remained substantially high across the majority of administrate districts (Bekchanov and Bhaduri 2013) (Fig. 7.2).

Irrigated agriculture clearly dominates the demand-side while accounting for over 90 % of total water withdrawal, which amounts to about 62 km^3 annually (UNDP 2007). The high dependence of the national economy on the water resources is challenging since irrigation water availability largely depends on runoff generated in the mountains and water releases from reservoirs located at the territories of the upstream countries Kyrgyzstan and Tajikistan (Sutton et al. 2008).

Despite the high dependency on external water sources, water use efficiency is very low in Uzbekistan, which is evidenced by having one of the highest water use per capita and per ha among countries worldwide (WWF 2002). Water-demanding crops such as cotton dominate the irrigation crop portfolio while paddy rice is mainly produced in downstream regions and this remained as such despite reduced water access in the last decades (Müller 2006). Cotton production is scrutinized by government organizations to maintain export revenues (Rudenko et al. 2013). The national economy is based on raw products while processing industries are much less-developed (Bobojonov and Lamers 2008). Market prices of agricultural commodities are strongly depending on the season and the dynamics used to show all

Fig. 7.2 Rice planting in Uzbekistan [Photo: Ihtiyor Bobojonov]

year-lows during harvesting periods (in summer and autumn) but spikes during non-harvesting periods (in winter and spring) due to a lack of sufficient processing and storage facilities (Bekchanov and Bhaduri 2013).

7.3 Methods

7.3.1 Supply Chain, Economic Sectors and Input−Output Model

The supply chain of a product or service comprises a system of activities involved in creating and moving the product or service from producers over suppliers to customers. Main components of a supply chain are production, processing, consumption and trade. Water is used directly by each product, semi-product or economic sector at the production stage. At the processing stage, economic sectors also use water indirectly through demanding intermediate inputs that in turn depend on some direct and indirect water use. At the last stage, final products can be either exported or sold in the internal market for consumption and investment needs. Consumption goods and exportable commodities contain water also which is embedded at different production stages also through the use of intermediate inputs.

Input-output models (IOMs) gained relevance in studies aiming at estimating direct and indirect consumption of water resources (Lenzen and Foran 2001; Lenzen 2003). In contrast to the bottom-up approach of evaluating water footprints, which is based on value chains of individual commodities (Hoekstra and Chapagain 2004, 2007), the advantage of an IOM lays in its ability to capture all direct and indirect input uses in the production of a commodity in the entire value chain of a product. Another advantage is its special structure that allows considering the production sectors of the entire economy and their relationships with each other in an integrated manner and within a single analytical framework. Although IOM was developed initially to analyze intersectoral trade flows (Leontief 1951), it was extended with environmental factors such as carbon-emissions, energy, water, etc. (Lenzen 2003). These improvements permitted to use IOMs for evaluating not only the direct use of natural resources across economic sectors, but also the indirect water consumption by these economic sectors (Lenzen 2003). Therefore, IOM can be considered a relevant tool for IWRM since it can link socio-economic and hydrological aspects of water use and can include a wide range of water users (ministries, regional water managers, farmers, industrial entities, and consumers). In this sense, IOM was used here to assess efficient water use throughout the entire supply chain of products in Uzbekistan.

Since industrial and services sectors presently do not demand much water at aggregated level, a high level disaggregation of these sectors was not relevant in this study. In contrast, as agriculture is the main consumer of water resources in Uzbekistan, this sector was disaggregated while considering the six main crops (cotton, winter wheat, rice, fruits-vegetables, fodder, other crops) and one livestock sector. In total, 20 sectors—7 agricultural and 13 industrial and services sectors (power production, oil, metallurgy, chemical engineering, machinery, cotton processing, light industry, food processing, other industries, construction, trade, transport-communication, and other services) were considered.

Water consumption by industrial and services sectors were considered as the difference between water uses and return flows since these return flows pass through basic purification before they are returned into the water system. Since irrigation return flows are not treated before being discharged by the drainage system into tail-end depressions, their availability for secondary use is low because of a decrease in quality. Consequently, irrigation water consumptions were estimated based on gross irrigation requirements rather than crop evapotranspiration.

7.3.2 Leontief Model, Intersectoral Water Flow Matrix and Water Footprint Indicators

The Leontief model is an initial step in evaluating direct and indirect water consumption by sectors. According to this approach (Leontief 1951), the total output of sector i (X_i) consists of the sum of intermediate inputs (x_{ij}) delivered by this sector (i) to other sectors (j) and the final consumption (Y_i):

$$X_i = \sum\nolimits_j x_{ij} + Y_i \tag{7.1}$$

Considering the technical production coefficients (a_{ij}) as ratio of intermediate input by sector i (x_{ij}) to the total output of sector j (X_j), this model (7.1) can be formulated as:

$$X_i = \sum\nolimits_j a_{ij} X_j + Y_i \tag{7.2}$$

Solving this system of Eq. (7.2) for unknown variables of X_i, a relationship between total sectoral output (X_i) and final demand (Y_j) can be derived as (Leontief 1951):

$$X_i = \sum\nolimits_j l_{ij} Y_j \tag{7.3}$$

where l_{ij} is the element of the Leontief inverse matrix defined as the requirements for total input from sector i to provide an unit of the final demand for the commodities of sector j.

In matrix format, Eq. 7.2 can be written as:

$$\mathbf{X} = \mathbf{AX} + \mathbf{Y} \tag{7.2'}$$

where $\mathbf{X}$ is a $nx1$ column vector of production by sectors, A is nxn matrix of technical production coefficients, and production coefficients, and $\mathbf{Y}$ is a $nx1$ column vector of final demand by sectors.

With some transformations, we derive the relationship between total production and final demand that is the matrix form of the Eq. 7.3:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} = \mathbf{LY} \tag{7.3'}$$

where $\mathbf{I}$ is an nxn identity matrix and $\mathbf{L}$ is nxn matrix of total input requirements in the Leontief model.

In follow-up steps, the estimation of total (direct and indirect) water consumption by sectors and their integration into the IOM is considered. Direct water consumption per economic output by sector i (dw_i) is calculated as a ratio of total direct water consumption (W_i) to total economic output (X_i):

$$dw_i = W_i / X_i \tag{7.4}$$

Based on direct water consumption (dw_i) and Leontief model coefficients (l_{ij}), total (direct and indirect) water consumption per economic output of sector j(twc_j) is determined according to Dietzenbacher and Velazquez (2007) as:

$$twc_j = \sum_i dw_i \, l_{ij} \tag{7.5}$$

Indirect water consumption per economic output of sector i (idw_i) that indicates the amount of water embedded in intermediate inputs delivered to sector i from other sectors, is calculated as the difference between total (direct and indirect) water consumption (twc_i) and direct water consumption per economic output (dw_i):

$$idw_i = twc_i - dw_i \tag{7.6}$$

Based on total water consumption per economic output, water embedded in exports of the sector i (WE_i) is estimated according to Dietzenbacher and Velazquez (2007):

$$WE_i = twc_i \, E_i \tag{7.7}$$

where E_i is total exports of sector i.

Similarly, alternative water content of the imports of the sector i(WM_i) is estimated as follows:

$$WM_i = twc_i \, M_i \tag{7.8}$$

where M_i is total imports of sector i.

Combining IOM and water consumption by sectors, the matrix of intersectoral water flows was evaluated. Values of the matrix of intersectoral water flows from one sector i to another j (WF_{ij}) are calculated as follows (Velazquez 2006):

$$WF_{ij} = W_i \, x_{ij} \, / \, X_i \tag{7.9}$$

WF_{ij} indicates the total direct water consumption embedded in inputs delivered from sector i to sector j.

Technical water consumption coefficients (tc_{ij}) and distribution coefficients (dc_{ij}) can be estimated based on the matrix of intersectoral water flows (MIWF). Technical coefficients (tc_{ij}) of the MIWF indicate the ratio of direct water consumption embedded in inputs delivered from sector i to sector j (W_{ij}) to total direct water consumption by sector j (W_j):

$$tc_{ij} = WF_{ij}/W_j \tag{7.10}$$

Meanwhile, the distribution coefficients (dc_{ij}) of the MIWF show the allocation of water embedded in intermediate inputs delivered by sector i among the economic sectors. Distribution coefficients are calculated as the ratio of direct water consumption embedded in inputs delivered from sector i to sector j (W_{ij}) to total water consumption by sector i (W_i):

$$dc_{ij} = WF_{ij} / W_i \tag{7.11}$$

The technical and distribution coefficients of the MIWF are used to determine the 'hot-spots' in the supply chains indicating thus the intersectoral trade flows with high direct or indirect water content and explaining the enormous indirect water uses in some sectors that rely on inputs of the water intensive sectors.

7.3.3 Data

The IOM with disaggregated agricultural accounts is based on previous IOMs developed for Uzbekistan by UNDP (2006) and Müller (2006). Further details of evaluating accounts with IOM are described in an earlier study (Bekchanov et al. 2012). The accounts of the IOM are converted into USD values using the average exchange rate of 1128 UZS per USD (CEEP 2006). Direct water uses across the sectors of the economy are based on UNDP (2007) and disaggregated when necessary while considering normative water consumption per output (State Construction Office 1978; CRIIWRM 1980; Müller 2006) as presented by Bekchanov et al. (2012).

7.4 Results

Cotton is grown not only on the majority of the irrigated croplands in Uzbekistan, but it also consumes ca. 37 % of all water resources (Table 7.1). Among the industrial sectors, power generation also requires considerable amounts of direct water, e.g. for cooling the generators or for turning the turbines. Despite the high water consumption in irrigated agriculture, the entire sector's share to total economic output is lower than the outputs of the industrial and services sectors. Therefore, direct water consumption per economic output is higher in most crop production sectors compared to the direct water consumption per economic output across industrial and services sectors. With 43.8 m^3 per USD, the rice production sub-sector consumes the highest amount of water per economic output among all crops since water requirement per unit area of rice is by far the highest among all crops despite rice production provides substantial benefits. The most water demanding crops per economic output aside from rice turned out to be the state order crops cotton and winter wheat, with values of 23 and 22.9 m^3 per USD, respectively (Table 7.1).

Total (direct plus indirect) water consumption rate was very high for the cotton processing sector (16.6 m^3 per USD) compared to its direct water consumption per unit of output since raw cotton is the main input for the entire cotton processing industry. Total water consumption rates were also high for the food and light

Table 7.1 Direct and indirect water consumption indicators for the economic sectors in Uzbekistan for 2005

No.	Sectors	Total direct water consumption by sectors (mln m^3)	Water consumption share (%)	Economic output (mln USD)	Economic output share (%)	Direct water consumption per economic output (m^3 per USD)	Total water consumption per economic output (m^3 per USD)	Indirect water consumption per economic output (m^3 per USD)
1	Cotton	23087	**37.2**	1006	3.0	**23.0**	**23.4**	0.5
2	Winter wheat	19226	**31.0**	841	2.5	**22.9**	**23.5**	0.7
3	Rice	2501.4	4.0	57	0.2	**43.8**	**45.0**	1.1
4	Fruits-vegetables	5926.5	**9.6**	524	1.6	11.3	12.0	0.7
5	Fodder crops	4002.7	6.5	310	0.9	12.9	13.6	0.7
6	Other crops	523.71	0.8	481	1.4	1.1	1.2	0.1
7	Livestock	1393.3	2.2	2508	7.5	0.6	3.2	**2.7**
8	Power production	4073	6.6	1202	3.6	3.4	3.7	0.3
9	Oil	28.425	0.0	3562	**10.6**	0.0	0.2	0.2
10	Metallurgy	103.97	0.2	2448	7.3	0.0	0.5	0.4
11	Chemical engineering	48.091	0.1	1072	3.2	0.0	0.7	0.7
12	Machinery	189.78	0.3	3264	**9.7**	0.1	0.2	0.1
13	Cotton processing	15.167	0.0	1796	5.4	0.0	16.6	**16.6**
14	Light industry	397.37	0.6	850	2.5	0.5	3.5	**3.0**
15	Food processing	396.6	0.6	1231	3.7	0.3	6.5	**6.1**
16	Other industries	22.606	0.0	1617	4.8	0.0	0.5	0.5
17	Construction	6.5925	0.0	2064	6.2	0.0	0.3	0.3
18	Trade	44.696	0.1	1881	5.6	0.0	0.2	0.2
19	Transport-communication	19.368	0.0	3227	**9.6**	0.0	0.3	0.3
20	Other services	31.343	0.1	3566	**10.6**	0.0	0.3	0.3
	Total	**62038**	**100.0**	**33507**	**100.0**	**1.9**		

Source Authors' calculation

industry and livestock rearing sectors (6.5, 3.5, and 3.2 m^3 per USD, respectively) compared to their direct water consumption requirements, obviously while these sectors heavily depend on inputs from water-intensive activities such as crop and fodder production.

The matrix of intersectoral flows, which is similar to input-output tables in content but with accounts measured in water rather than monetary values, allows determining exactly those agricultural activities that triggered high total (direct and indirect) water consumption in the processing industries and in livestock rearing (Table 7.2). As shown by the raw sums of the matrix, total direct water consumption embedded in intermediate inputs delivered to the economic sectors is the highest for agricultural commodities such as cotton (23.1 km^3) and winter wheat (6.7 km^3). Fodder crops and energy commodities that are further used as intermediate inputs by the sectors also carry substantial amount of water.

A comparison of the column sums of the matrix (Table 7.2) revealed that large amounts of water are embedded in intermediate inputs demanded by the cotton-processing (23.3 km^3) and food-processing sectors (5.9 km^3). Water embedded in raw cotton, which is an input of the cotton-processing sector, amounted to 23.1 km^3 while water embedded in wheat commodities used as intermediate inputs amounted to only 6.7 km^3, of which 4.5 km^3 was supplied to the food processing and 1.7 km^3 to the livestock sector. The livestock production also demanded fodder crops that contained 3.3 km^3 water.

A closer look at the matrix and the intersectoral relationships based on technical water consumption coefficients, revealed that water embedded in intermediate inputs demanded by the livestock rearing and delivered by the winter wheat and fodder crops production were respectively 1.2 and 2.4 times higher than the direct water use in the livestock sector (Fig. 7.3). In the cotton processing sector, direct water consumption, as embedded in raw cotton that delivered as input to the cotton processing sector, was more than 1500 times higher than the direct water consumption of the entire cotton processing. Energy is the main input to most of the non-agricultural production and processing activities such as the oil industry, metallurgy, chemical engineering, other industries, construction, trade, transport-communications, and other services. Therefore, water embedded in energy commodities that were delivered to these sectors showed to be several times higher than the direct water consumptions by these sectors.

According to the distribution coefficients, almost all water virtually comprised in raw cotton production was transferred to the cotton-processing sector through intermediate inputs (Fig. 7.4). Equally, large shares of water embedded in winter wheat (23.5 % of water consumed for total production of this commodity) and rice (32 %) were delivered to the food processing industries. About 82 % of the water embedded in the total production of fodder crops was supplied to the livestock rearing sector.

The analysis of water embedded in the exports and imports revealed that Uzbekistan was a net exporter of water, which is predominantly caused by the more

Table 7.2 Matrix of intersectoral water consumption flows (mln m^3) in Uzbekistan for 2005

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum
1	0	0	0	0	0	0	0	0	0	0	0	0	**23,087**	0	0	0	0	0	0	0	23,087
2	0	401	0	0	0	0	**1717**	0	0	0	0	0	0	0	**4513**	0	0	41	0	65	6738
3	0	0	59	0	0	0	0	0	0	0	0	0	0	0	**800**	0	0	21	0	20	899
4	0	0	0	256	0	0	0	0	0	0	0	0	0	0	327	0	0	39	0	52	673
5	0	0	0	0	166	0	**3280**	0	0	0	0	0	0	0	0	0	0	0	0	0	3446
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	53
7	0	0	0	0	0	0	17	0	0	0	0	0	0	17	49	0	0	0	0	1	83
8	81	80	0	53	0	0	249	172	520	494	526	134	165	29	31	343	76	153	429	403	3937
9	1	1	0	1	0	0	2	5	5	1	0	0	0	0	0	1	1	0	2	2	23
10	0	0	0	0	0	0	0	0	0	30	4	7	0	0	0	2	4	0	0	0	47
11	4	4	0	3	1	3	0	2	1	5	10	2	1	2	0	5	4	0	2	3	52
12	1	1	0	1	0	1	2	4	4	19	2	72	3	1	0	6	8	1	16	13	155
13	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	4
14	0	0	0	0	0	0	1	0	0	3	1	4	4	120	39	4	0	0	0	0	177
15	0	0	0	0	0	0	65	0	0	0	0	0	0	0	52	1	0	0	0	0	117
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	12	1	2	2	22
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	1	0	1	0	1	3	2	4	5	2	7	4	2	2	5	3	0	1	6	50
19	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	2	1	4	2	13
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	2	8
Sum	88	489	59	314	169	4	5336	185	537	557	546	228	23,267	171	5866	370	110	259	458	572	39,584

Note Ordered numbers in the column and raw headings stands for the economic sectors: *1* Cotton, *2* Winter wheat, *3* Rice, *4* Fruits and vegetables, *5* Fodder crops, *6* Other crops, *7* Livestock, *8* Power production, *9* Oil, *10* Metallurgy, *11* Chemical engineering, *12* Machinery, *13* Cotton processing, *14* Light industry, *15* Food processing, *16* Other industries, *17* Construction, *18* Trade, *19* Transport-Communication, *20* Other services
Source Authors' calculation

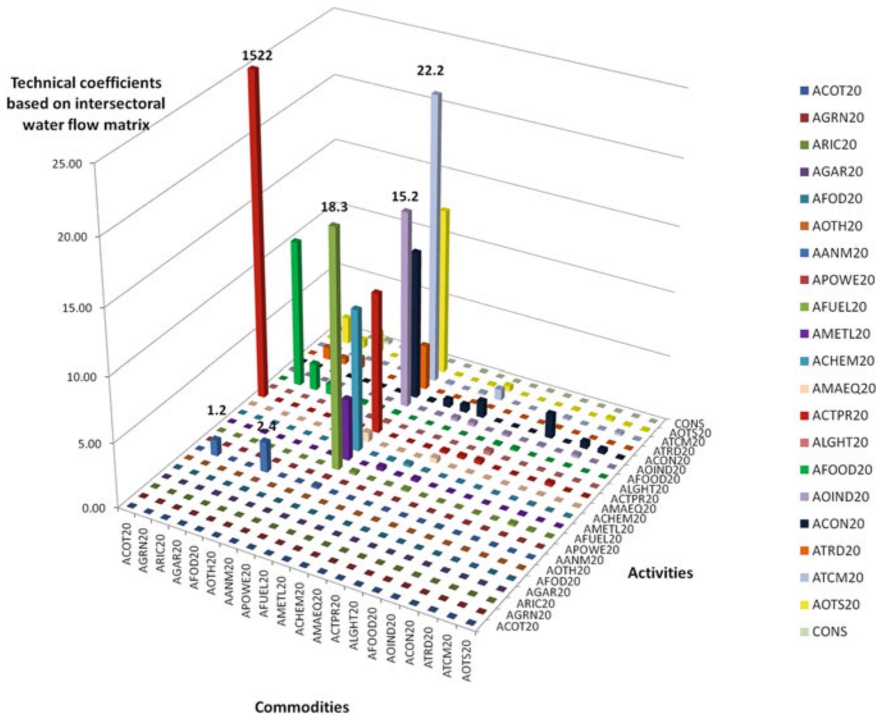

Fig. 7.3 Technical coefficients of water consumption based on the intersectoral flow matrix of Uzbekistan for 2005 *Note* Ordered numbers in the column and raw headings stand for the economic sectors: *ACOT20* Cotton, *AGRN20* Winter wheat, *ARIC20* Rice, *AGAR20* Fruits and vegetables, *AFOD20* Fodder crops, *AOTH20* Other crops, *AANM20* Livestock, *APOWE20* Power production, *AFUEL20* Oil, *AMETL20* Metallurgy, *ACHEM20* Chemical engineering, *AMAEQ20* Machinery, *ACTPR20* Cotton processing, *ALGHT20* Light industry, *AFOOD20* Food processing, *AOIND20* Other industries, *ACON20* Construction, *ATRD20* Trade, *ATCM20* Transport-Communication, *AOTS20* Other services *Source* Authors' calculation

than 22.8 km^3 water embedded in the export of cotton fiber (Table 7.3). In addition, over 3.6 km^3 of water is virtually exported annually through processed food commodities. Water embedded in the exports of all other sectors was much lower. Given that only 10–12 km^3 of water originates within the territory of Uzbekistan, and the remaining 50–55 km^3 water stem from sources outside the country, it can be argued that the risks of water scarcity and in turn income destabilization of the rural population are substantial and an implementation of a series of measures to increase water use efficiency is of utmost importance.

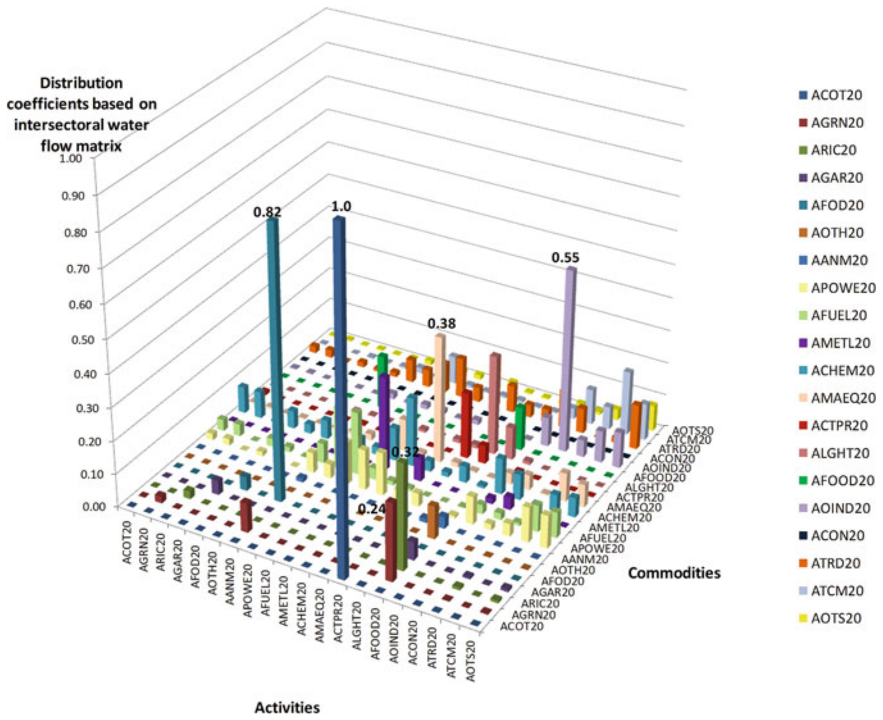

Fig. 7.4 Distribution coefficients based on the intersectoral flow matrix of Uzbekistan for 2005 *Note* Ordered numbers in the column and raw headings stand for the economic sectors: *ACOT20* Cotton, *AGRN20* Winter wheat, *ARIC20* Rice, *AGAR20* Fruits and vegetables, *AFOD20* Fodder crops, *AOTH20* Other crops, *AANM20* Livestock, *APOWE20* Power production, *AFUEL20* Oil, *AMETL20* Metallurgy, *ACHEM20* Chemical engineering, *AMAEQ20* Machinery, *ACTPR20* Cotton processing, *ALGHT20* Light industry, *AFOOD20* Food processing, *AOIND20* Other industries, *ACON20* Construction, *ATRD20* Trade, *ATCM20* Transport-Communication, *AOTS20* Other services *Source* Authors' calculation

7.5 Discussion

The comprehensive analysis of the entire commodity value chains which made an effort in integrating water use and economic output by economic sectors in Uzbekistan, indicated the need for adopting a series of options resulting in water-saving at different stages of the production chain. These options are:

(i) improving efficiency of direct water uses by sectors;
(ii) a sectoral transformation by prioritizing the sectors that require less water consumption per economic output;
(iii) improving productivity of water embedded in intermediate inputs;
(iv) enhancing water use reduction strategies at the consumption and trade stages.

Table 7.3 Water embedded in exports and imports during 2005 in Uzbekistan

No.	Sectors	Exports (mln USD)	Exports share (%)	Imports (mln USD)	Imports share (%)	Water embedded in exports (mln m^3)	Alternative value of water embedded in imports (mln m^3)	Net virtual water trade (mln m^3)
1	Cotton	0	0	0	0	0	0	0
2	Winter wheat	0	0.0	63	1.3	0	**1479**	**–1479**
3	Rice	0	0.0	0	0.0	0	0	0
4	Fruits-vegetables	77	1.2	0	0.0	**933**	0	933
5	Fodder crops	0	0.0	0	0.0	0	0	0
6	Other crops	12	0.2	0	0.0	14	0	14
7	Livestock	0	0.0	0	0.0	0	0	0
8	Power production	22	0.4	24	0.5	84	91	–7
9	Oil	712	**11.4**	102	2.1	178	25	152
10	Metallurgy	1736	**27.8**	472	9.5	783	213	570
11	Chemical engineering	338	5.4	452	9.1	253	338	–85
12	Machinery	536	8.6	1976	**39.9**	109	401	–292
13	Cotton processing	1375	**22.0**	0	0.0	**22,787**	0	**22,787**
14	Light industry	0	0.0	119	2.4	0	**416**	–416
15	Food processing	562	9.0	338	6.8	**3635**	**2187**	**1448**
16	Other industries	180	2.9	520	**10.5**	97	281	–183
17	Construction	0	0.0	14	0.3	0	5	–5

(continued)

Table 7.3 (continued)

No.	Sectors	Exports (mln USD)	Exports share (%)	Imports (mln USD)	Imports share (%)	Water embedded in exports (mln m^3)	Alternative value of water embedded in imports (mln m^3)	Net virtual water trade (mln m^3)
18	Trade	0	0.0	231	4.7	0	53	–53
19	Transport-Communication	611	9.8	526	**10.6**	157	136	22
20	Other services	77	1.2	121	2.4	22	34	–12
	Total	6238	100.0	4958	100.0	29,051	5658	23,393

Note Ordered numbers in the column and raw headings stand for the economic sectors: *1* Cotton, *2* Winter wheat, *3* Rice, *4* Fruits and vegetables, *5* Fodder crops, *6* Other crops, *7* Livestock, *8* Power production, *9* Oil, *10* Metallurgy, *11* Chemical engineering, *12* Machinery, *13* Cotton processing, *14* Light industry, *15* Food processing, *16* Other industries, *17* Construction, *18* Trade, *19* Transport-Communication, *20* Other services
Source Authors' calculation

Considering higher direct water consumption during crop production activities (at field level) compared to the remaining economic sectors, the introduction of improved irrigation water use technologies could substantially increase water use efficiency. Especially drip irrigation and laser-guided land leveling have been postulated as technically and financial feasible in this environment (Bekchanov et al. 2010). Laser-guided land leveling enhances water productivity of rice, cotton, and winter wheat since precise leveling of croplands (i) allows a uniform distribution of the applied water, (ii) enables higher water application efficiency and (iii) enhances yields (Bekchanov et al. 2010). It was furthermore argued that governmental or private initiatives aiming at cost-sharing of laser-guided land leveling equipment has a high potential to facilitate an increased access to this equipment given the present low farm capital of the entrepreneurs (Bekchanov et al. 2010). Drip irrigation on the other hand seems beneficial mainly for vegetable and fruit productions that usually have high returns (Bekchanov et al. 2010). An implementation of incentive-based water management mechanisms such as water pricing or water rights trading can enhance increased water use efficiency despite such mechanisms should be flanked with legal conditions conducive to their adoption (Bekchanov et al. 2013). Moreover, a promotion of the understanding of the real value of water and increased consciousness of water users towards an efficient use of water plays a key role in these reforms (Bekchanov et al. 2013). Improving conveyance efficiencies through lining canals, especially in areas with sandy soils, improves overall irrigation water productivity yet necessitates investments and active promotion by the government. Improved irrigation scheduling also raises water productivity due to closer matching of site-specific and time-dependent demand (Tischbein et al. 2013). Institutional re-arrangements enhancing better coordination of irrigation activities between irrigation field and network level would substantially lower operational losses in the system (Awan et al. 2011).

Given the huge water use by crop production sectors, guiding overall economic development through a targeted expansion of less-water demanding, but higher-income generating sectors such as industrial and services sectors is a promising option for reducing the present water demand. Nevertheless, within the agricultural sector, a crop diversification by increasing the share of fruits and vegetables in the crop portfolio and at the expense of the much higher water demanding crops such as cotton and rice seems to be feasible. Such a targeted crop diversification bears a high potential to enhance overall crop water productivity. Yet, increasing the share of fruits and vegetable in the production scheme must be supported simultaneously by the development of the appropriate infrastructural facilities for storage and trade of the increased outputs to fully explore these opportunities (Bobojonov and Lamers 2008). On the other hand, this option bears financial fruits in the medium and long-term only. Yet, the expansion of fruit and vegetable production may also have a favorable, immediate impact by stabilizing food prices throughout the year. This in turn thus may lead to increased food security for low-income classes of the population.

The analyses showed that water productivity can be boosted also inside the commodity chains through for instance increasing the efficient use of intermediate inputs, and by upgrading the chain for instance through an expansion of the production of semi-final and final goods rather than relying on the production and sale of the raw commodities alone. For example, increasing the production of ready-made garments and clothes by further upgrading the cotton production chain would largely increase water productivity in the cotton sector (Rudenko et al. 2013). Lowering production losses at different stages of the crop production chain also bears options for enhancing water productivity. For example, reducing harvest and storage losses of food commodities (fruits, vegetables, winter wheat, rice) would in turn lessen indirect water uses of the food processing sector and thus increase water productivity of the entire economy. Similar effects can be reached in the livestock sector by reducing harvest and post-harvest losses during fodder production and storage.

At the consumption level, water productivity can be improved also through reducing the wastage of commodities. Since at present the storage systems and agro-processing sector are underdeveloped (Bobojonov and Lamers 2008), expanding these infrastructures has the potential to decreasing storage losses and providing a stable food supply throughout the year. Furthermore, export diversification through a reduction of cotton fiber export in favor of the export of products with higher value-added such as ready-made garments and clothes would not only lead to increased incomes and additional job creation but also enhanced water productivity for the entire economy (Rudenko et al. 2013). Additionally, it can be argued that such strategies may lower the currently high burden on the environment.

The findings of the IOM approach overall provided useful insights to enhance water, food, and income security in Uzbekistan as it is based on a comprehensive analysis of the entire production system and sectoral water uses. However, the implementation of various strategies towards reducing water use at different levels of the supply chain requires a unanimous support and cooperation of the representatives of both the private and public sectors. Particularly, governmental support is essential through coordinating the activities of the different actors, providing access to the necessary technologies, establishing the needed infrastructure, and making investments available for the technological, institutional, and economic reforms. The highly needed investments for changes can be fulfilled in part by foreign investments also. Crop diversification and irrigation efficiency improvements can be enhanced through enabling policies that allow more freedom to agricultural producers who however would concurrently need to increase their managerial ability, knowledge and creativeness about the production technologies (and eventual innovations). The development of industrial and services sectors can be enhanced by various means including an increasing of the access to credit, through reducing administrative barriers for small-scale enterprises, and maintaining governmental investments in infrastructure and industrial production. In the meantime, raising the awareness of all actors participating in the supply chain including water managers, farmers, representatives of the industrial sector, and consumers, is essential to start a conscious movement for a more efficient water use, through improving efficiency of intermediate input uses and reducing the food wastage and harvest and storage losses, in the entire society. Recent experiments with empowering water users while concurrently raising their awareness on efficient water use and supporting them in water distribution in the Ferghana Valley (Uzbekistan, Kyrgyzstan, and Tajikistan) enabled farmers and water managers to improve irrigation performance in terms of irrigation efficiency, delivery equity and water productivity (Dukhovny et al. 2013). In addition, these actions reduced conflicts between water users during water scarce periods. This is an example that underlines that efforts to motivate users towards cooperating as a tool for improving the efficiency of scarce natural resources do not stay fruitless, although they might require some time to unfold their impact.

Since the suggestions extracted from the findings of this study were purely seen from a water quantity perspective, including in future analyses also quality aspects of water management and its impacts on production, environment and society would improve the arguments for policy implications even more.

7.6 Conclusion

The IOM based approach of evaluating direct and indirect water consumptions along the supply chains supports decision-makers to select priorities at national level and provides an overall framework for coordinating water uses, which is as a key element of IWRM concepts. Given the dominance of high-water demanding crops such as cotton and rice and the substantial water losses in the irrigation systems, several options can enhance water productivity in Uzbekistan not only during production, but also during processing, consumption, and trading of commodities. Water use could be reduced through strategies such as: (i) the implementation of advanced irrigation technologies, (ii) reduction of the cropped area of current dominant crops (cotton, rice) in favor of expanding fruits and vegetables production, (iii) development of industrial and services sectors, (iv) upgrade of production value chains by expanding the production of the commodities with higher values added, (v) reduction of the wastage of commodities at production and consumption levels, and (vi) diversification of exports, e.g. by replacing cotton fiber exports by commodities with higher values added such as ready-made garments and clothes. To realize these options, the initiatives from both the public and private sector are essential. In particular, the government is challenged by creating an enabling environment with respect to infrastructural and technological resources as well as the relevant institutional rearrangements. The success of technological and economic transformation reforms can be additionally fostered by the empowerment of water users, raising their awareness for, and providing support to introducing strategies and technologies towards a more effective water use. Furthermore, governmental organizations should be encouraged to play a key role for sustaining efficient water use and long-term prosperity in the region through investing in human capital, ensuring the rule of law, providing long-term planning reliability for farmers necessary for investments in water saving at farm level, and creating an enabling environment to unfold farmers' creativity towards innovations. The implementation of incentive-based water management mechanisms such as water pricing concurrently providing a legal basis for this option can enhance the understanding of the real value of water which is in turn a basis towards an efficient use of water by water users. Although, flanking measures are concurrently needed, such as the development of infrastructural facilities, industrial enterprises, and institutional changes, yet, it is very likely that the impact on the ground takes time and requires thus endurance of the reformers. Nevertheless, changes are direly needed, especially while taking into account (i) the consequences of climate change on the variability and temporal availability of water resources, (ii) the dependency of Uzbekistan on water runoff generated in upstream countries, and (iii) a sharpening competition between water users within and between countries. Measures of improving water use efficiency should be implemented to cushion the enormous water risks even though most benefits are not immediate but expected to be gained in the long future.

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Part III
Climate Change

Chapter 8
Climate Change Information for IWRM

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Abstract Integrated Water Resources Management often needs specific climate data, e.g. for water use assessment in agriculture or reservoir design for drinking water supply and flood retention. Needed data are often missing. Climate Change aggravates this problem, as in contrast to the past, measured data only are probably insufficient to be used in IWRM studies for future impact. A scheme is presented to replace measured data by climate model output. Model performance assessment is done for General Circulation Models (GCMs) with the example regions of Eastern Europe (Western Bug catchment), the Arabian Peninsula and the region of Brasília (Brazil). The ranking of GCMs was sensitive to region, performance measure and reference data. However, HADCM3 (Hadley Centre) and MPEH5 (MPI Hamburg) show a good resemblance with two differing references for two out of three regions. Regional downscaling is demonstrated with two examples: dynamical with the mesoscale CCLM for the Western Bug, statistical with the SDSM for Brasília. Both approaches differ in observational data requirements (lower for dynamical downscaling) and need for bias correction (more for dynamical downscaling). Impact modelling based on

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climate model output shows significant changes in SWAT simulations of runoff in the Western Bug catchment for the B1 and A2 scenarios at the end of the 21st century. Climate change is an IWRM relevant problem in all three regions, increasing evaporation of irrigated agriculture in the Middle East, changing soil erosion into drinking water reservoirs in central Brazil or the Bug runoff. Which climate information is adequate depends on many factors, primarily the specific IWRM problem.

Keywords IWRM · Climate change · Western Bug · Arabian peninsula · Brasília

8.1 Introduction

Global Change—summarizing aspects of changing environmental and socio-economical systems—exerts pressure on water availability and quality. An approach to deal with these problems is Integrated Water Resources Management (IWRM). An important question is to what extent climate change alters or amplifies the existing problems or creates new problems not seen before in a specific region. Water problems vary, e.g. due to political aspects (governance), competition for limited water resources or technical reasons (e.g. out-dated techniques for waste water treatment). Climate change is only one part of the overall problem (Dessai et al. 2009), but use of measured climate information only becomes critical for IWRM assessment. To cope with the processes leading to water problems and quantify their importance, a common approach is to simulate processes relevant for IWRM for current conditions and for projections of the future. This involves a chain of model simulations with uncertainty at each level, often starting with climate modeling and ending with impact models of a specific subsystem relevant for IWRM. The uncertainty of individual model simulations varies and modeling the climate shows often more skill than modeling of the other system components (Dessai et al. 2009).

Nevertheless, the question remains if, how and to which extent the climate system can and has to be modeled. There might be IWRM problems, where climate change amplifies the problems but other subsystems are the relevant drivers. In other problems several (or even all) subsystems contribute to the problem but the main driver is climate change. Often it is not clear which kind of problem it is because uncertainties of subsystem models blur the influence on the overall problem and there might be feedbacks from changes in the other subsystems to the climate (Daron et al. 2014). So, if climate change cannot be excluded from the IWRM problem related processes, some climate change information is needed. Thus the question arises which information is needed within the context of IWRM related problems. In general there are two points of view; the first one states that it is more appropriate not to reduce uncertainty in the modelling chain but to confront impact modellers with the extremes of possible scenarios to allow for so called 'robust decision making' (Dessai et al. 2009) or 'robust adaption' (Wilby and

Dessai 2010) with strategies tailored to the different scenarios. The other point of view relies on the reduction of uncertainty in the climate modeling process and narrowing the range of climate projections. The aim is to provide the most probable climate projection for predefined scenarios of climate drivers (as the SRES, Nakicenovic et al. 2000) including measures of uncertainty. This serves requests of impact modellers for 'probable numbers' concerning climate data (Hallegatte 2009).

Here, we focus on the second strategy along a guidance scheme for climate change assessment in the IWRM context (Fig. 8.1). Because IWRM problems are quite specific (e.g. scale dependent) nearly all parts of the scheme are still topic of research and limitations for each IWRM problem might exist. Figure 8.1 is not a framework with definite decision rules. The scheme and this chapter are to a minor extent targeted to the climate specialist rather to all scientists involved in planning and carrying out IWRM projects.

The scheme consists of four main parts: (retrospective) climate analysis, GCM analysis, regional downscaling and impact models. These parts also form the backbone of our paper outline.

In order to illustrate different parts of the scheme, we provide examples from different regions of the International Water Research Alliance Saxony (IWAS)

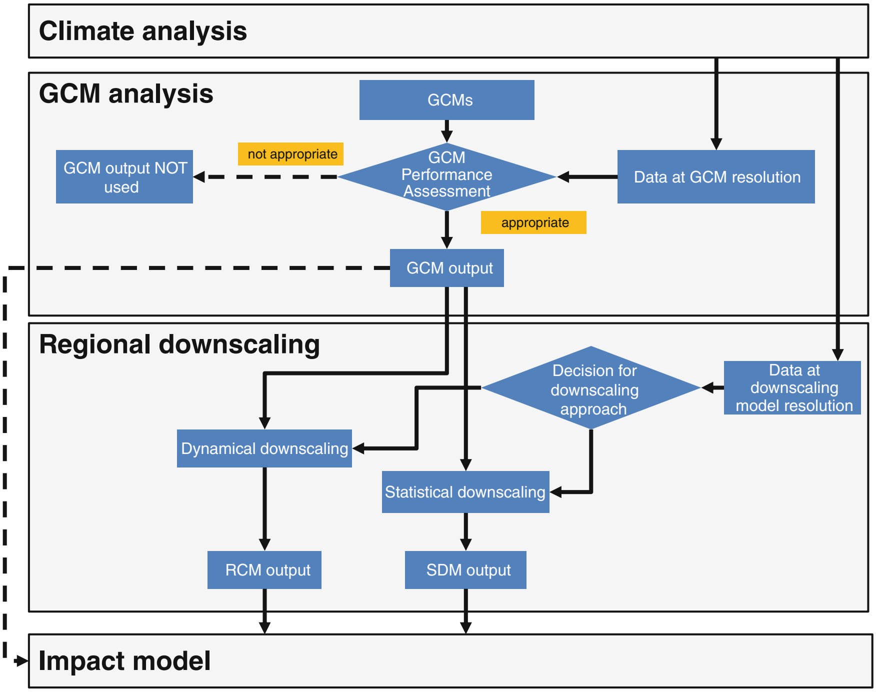

Fig. 8.1 Different levels and steps for generating climate change information for IWRM

IWRM project (Kalbus et al. 2012). These examples are already published in detail in different peer-reviewed articles (cf. Pavlik et al. 2012; Barfus and Bernhofer 2014a, b; Borges et al. 2014a; Fischer et al. 2014; Pavlik et al. 2014). IWAS was a joint project, mainly of the Helmholtz Centre for Environmental Research—UFZ, the Technische Universität Dresden and the Stadtentwässerung Dresden (member of German Water Partnership—GWP). IWAS aimed to contribute to IWRM in hydrologically sensitive regions by developing specific system solutions as a response to water-related problems worldwide. The given examples may not provide a comprehensive view, but an attempt towards IWRM under conditions of limited resources.

8.2 Description of Regions

The IWAS project focused on five regions facing different problems related to water availability and quality (Eastern Europe, Middle East, Mongolia, Vietnam and Brazil). Climate was not identified as a relevant driver for the case study in Vietnam where use of groundwater causing severe surface subsidence was investigated for the city of Hanoi; Mongolia was not tackled due to limited resources. Instead, we focus on three regions with contrasting climate from arid to humid displayed in Fig. 8.2. Figure 8.3 provides some impressions from the regions.

The IWAS region 'Eastern Europe—Ukraine' covers the Western Bug basin situated in the border area of Poland, Belarus and Ukraine. The main problem here is the low water quality influenced by sewage disposal from domestic and industrial areas as well as from diffuse sources from agricultural areas. High environmental loads occur due to out-dated or malfunctioning sewage treatment plants, nutrient leaching, mining activities and pesticide deposits (European Union 2006; Ertel et al. 2012). The second region 'Middle East—Oman & Saudi Arabia' deals with the Arabian Peninsula with a focus on the coastal regions of Oman.

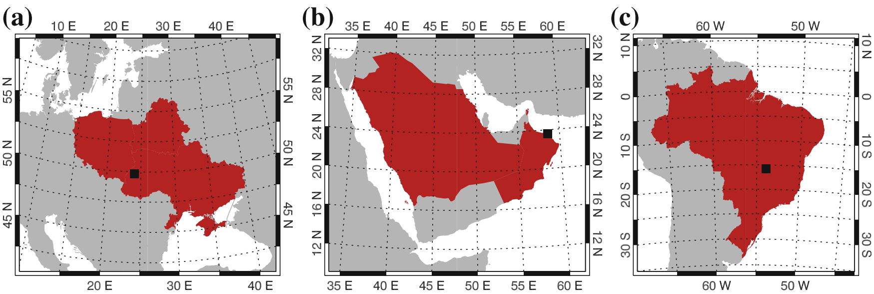

Fig. 8.2 IWAS focus regions for which results of climate change assessments are presented. **a** Ukraine, Poland, and Belarus with the Western Bug catchment and Lviv (*black rectangle*) **b** Saudi Arabia and Oman with focus region near Muscat (*black rectangle*), and **c** Brazil with the Federal District of Brasília (*black rectangle*)

Fig. 8.3 IWAS focus regions: (*upper left*) waste water treatment in Ukraine, (*upper right*) IWAS lab course with Ukrainian and German students at the climate station of the University of Lviv, (*lower left*) installation of a drip irrigation system on a research farm in Oman and (*lower right*) land-use change at Brasília which is intensified by urbanisation from official and informal settlements in the vicinity of Brazil's capital

Here the main problem is the overuse of groundwater for irrigation leading to an advancing of the seawater front and consequently groundwater salinity problems (Grundmann et al. 2012). The third regional study 'Latin America—Brazil' examines water problems of Brasília. More than 75 % of the drinking water of Brazil's capital is extracted from two surface reservoirs. In order to guarantee the actual and future demand, two more reservoirs are planned to be integrated into the drinking water system (GDF 2012). The impacts of climate change on reservoirs and their tributaries are, therefore, of great interest to the local water supplier (Lorz et al. 2012).

8.3 Climate Analysis

Our scheme starts with the Climate Analysis for the region of interest. This analysis includes the compilation of climate data (measurements, reanalysis and remote sensing data) and of results from existing studies. The purpose of this step is to

(i) analyse past and present climate including internal variability and already on-going climate change, (ii) to determine the most critical processes and variables of the regional climate system, and (iii) to provide reference data for model evaluation and calibration.

There are several institutions, like the National Climate Data Center of NOAA or KNMI (Royal Netherlands Meteorological Institute) with the 'Climate Explorer' providing easy accessible measurement data from all over the world. Nevertheless, regions exist, where measurement data are sparse, have never been fed into databases accessible to the international community or are questionable with respect to their quality. There are initiatives, e.g. from the World Meteorological Organisation (WMO) to equip researchers of countries with less tradition in climate data collection and related research with mature methods to analyse their data (e.g. homogeneity tests) and make data or results, e.g. in form of reviewed scientific publications available to the public (e.g. AlSarmi and Washington 2011; Donat et al. 2013 for the Arabian Peninsula). Here, it has to be noted that methods are continuously developed further (e.g. Venema et al. (2012) for homogenization algorithms) with significant impacts on subsequent results. If data are not available from a central database, time consuming collection and processing is necessary (like in all of our three focus regions). However, the three focus regions differed in availability of measurement data: incomplete and spatially sparse data for the Middle East, only monthly data (at least for a sufficient period) for the Ukraine and daily data for a moderate period for the region of Brasília. Details of the analysis in each of the IWAS regions are presented briefly in the following subsection.

Study Cases of the IWAS regions

As a country of the former Soviet Union, the meteorological station network of the Ukraine suffers from a strong decline in the number of stations. After 1990 the number of meteorological stations with available data was reduced to the level of the 1960s resulting in a station density not meeting the requirements of the WMO (Pluntke et al. 2014). Time series of daily data contain non-negligible gaps and data errors (Pavlik et al. 2012; Pluntke et al. 2014) with meta-data often not available. Observed climatic change of the last decades shows increasing annual mean temperatures with larger increase in winter than in summer (EEA 2012). Spatial precipitation patterns show no clear annual trends for Eastern Europe (Schönwiese and Janoschitz 2008), but for some parts a decline in summer and an increase in winter months (Anders et al. 2014).

In case of the IWAS region 'Middle East—Oman & Saudi Arabia' climate analysis from measurements is limited by the data situation (Donat et al. 2013). Time series of measurements are short, have large gaps and are only available for a small proportion of the respective land surface. Precipitation is rare (e.g. in most parts of Oman less than 15 rainy days per year) with large year-to-year variability (Kwarteng et al. 2009) acting on small scales. Consequently, e.g. reanalysis data available for this region are mainly a model product and only to a small degree driven by measurements. Nevertheless, there are some efforts to analyse regional aspects of global climate change on the Arabian Peninsula by means of observations starting with the study of Nasrallah and Balling (1996). Especially in the last years several studies (e.g. Kwarteng et al. 2009; Donat et al. 2013; AlSarmi and Washington 2013) have been published analyzing not only average climatic conditions but also indices of climate extremes. All authors found an increase in mean temperature and temperature related climate extreme indices. Magnitudes are larger in the northern part (~0.6 K per decade between 1980 and 2008) which is less influenced by Monsoon circulations whereas data from the southern Arabian Peninsula show a less significant warming (AlSarmi and Washington 2011). Some stations showed decreasing precipitation but changes are not significant and without spatial coherence. Consequently, signals derived from extreme indices related to precipitation are weak. Results from multi-model projections suggest that increase of temperature related extreme indices will continue whereas indices related to precipitation do not provide a clear picture (Sillmann et al. 2013).

The region around Brasília is characterized by a moderate observation network density starting from the 1960's (Borges et al. 2014b). All accessible daily data were compiled in a database after checking for suspicious values and tests for homogeneity, by a customized approach based on experience in Germany within CLISAX (Bernhofer et al. 2008), adopted for Brazilian data (e.g. combining tests described by Craddock 1956; Buishand 1982; Alexandersson 1986; Dahmen and Hall 1990; Herzog and Müller-Westermeier 1998). Data reveal that the region is already subject of a recent warming, with a highly significant annual trend of +1.1 °C for the 1971–2010's period (Borges et al. 2014a). For precipitation, decreases were observed mostly in winter and spring (dry season), while the summer faced an increase in precipitation amounts (wet season).

8.4 GCM Analysis

Our scheme continues with the GCM analysis. General Circulation Models (GCMs) are the main tool for simulating the global climate response to predefined boundary conditions by either applying the primitive equations or in case of unresolved processes by parameterizations. A comprehensive description of these models can be found by Trenberth (1993) or more collapsed by Neelin (2010). Boundary conditions are defined as scenarios of likely greenhouse gas concentrations in the atmosphere according to growing population, economic development, as well as the energy mix on a global scale (Nakicenovic et al. 2000) or as radiative forcings not immediately linked to socio-economical development (Moss et al. 2010).

GCM data are applied in our scheme in two ways: (i) to determine the climate change signal ('GCM output') which might be used directly or modified by ensemble approaches in 'impact models' and (ii) to act as input data for regional climate models ('regional downscaling'). Projections of the future climate by different GCMs might vary due to different physics, parameterizations and resolutions as well as different forcings in sign and magnitude (Tebaldi and Knutti 2007). Furthermore, differences arise due to the internal climate variability in the models mainly blurring the climate signal in the close-by decades (Hawkins and Sutton 2009; Maraun 2013). Whereas the influence of the other agents seems to be reducible, influence of internal climate variability is not (Deser et al. 2012). The differences depend on the regions of interest as well as the desired parameters (Meehl et al. 2007) but also on the applied reference dataset (Barfus and Bernhofer 2014a). Differences require the assessment of individual GCM performances to select or weigh model projections for subsequent tasks like determination of the GCM climate signal or applying GCMs for downscaling. Examples for the IWAS regions are presented below.

8.4.1 GCM Performance Assessment

Though it is not guaranteed that models which simulate the current climate appropriately, also project the future climate well, it is common sense that projections of these models are at least more reliable (Gleckler et al. 2008). Consequently, it is of importance to assess climate model performance for the region of interest, either to select a reasonable number of models or to assess model diversity in ensemble approaches. There is no consensus in the scientific community how model performance should be evaluated (Knutti et al. 2010). Approaches analyse individual variables of interest (often temperature and precipitation), the nearly complete set of variables (Barfus and Bernhofer 2014a) or recently more often the representation of atmospheric processes and its precursors as well as feedbacks (e.g. Brown et al. 2013; Roehrig et al. 2013; Barfus and Bernhofer 2014b). Assessment is done by scalar metrics like the RMSE or the Model Performance Index (MPI) (Reichler and Kim 2008) or by graphical tools like the Taylor diagram (Taylor 2001). A lively discussion centers around the question, whether the model bias should be the target of the performance assessment (e.g. Ehret et al. 2012) since often only the climate change signal (compared to some reference period being simulated as well) is of interest.

Results for the IWAS regions

In the IWAS regions we mainly applied the Model Performance Index (MPI) suggested by Reichler and Kim (2008), appealing by its ability to combine results for different climate variables as well as the ability to cope with missing data. Basis for the MPI is the mean squared error for each variable normalized with the variance of the reference data and, thus, the MPI accounts for the model bias. Monthly data of 22 GCMs applied in the Climate Model Intercomparison Project 3 (CMIP3) (Meehl et al. 2007) with up to three runs were analysed. The MPI has been calculated for several model variables representing temperature, humidity, and wind in different levels of the troposphere as well as precipitation, radiation, and several geopotential heights. Calculations have been performed with respect to

Table 8.1 Ranking of GCMs according to the Model Performance Index (Reference ERA40 and GPCP data) in regions with different climate and with different hydrological sensitivity (temperate, tropical arid and semi-arid)

Ranking	Ukraine	Arabian Peninsula	Brazil
1	MPEH5	HADCM3	HADCM3
2	HADGEM	MPEH5	NCCCSM
3	MIHR	NCCCSM	CSMK3
4	HADCM3	MIHR	FGOALS
5	GFCM21	MRCGCM	CGMR

different reference datasets consisting mainly of reanalysis data (ERA40[1] (Uppala et al. 2005) and NCEP[2] (Kalnay et al. 1996)) but for precipitation also of merged satellite products like GPCP[3] (Adler et al. 2003) and CMAP[4] (Xie and Arkin 1997). Independent of the reference, the best model for the Arabian Peninsula is HADCM3 from the Hadley Centre/UK. How the ranking continues depends on the reference dataset; if ERA40 serves as the reference, the German model ECHAM5/MPI-OM and the US model NCAR-CCSM3 follow whereas with NCEP as reference the Japanese models CCSR-MIROC3.2 (high resolution) and MRI-CGCM2.3.2 are ranked second and third. Table 8.1 compares the GCM ranking for three IWAS regions.

8.4.2 GCM Climate Signal

Some studies have shown (e.g. Remesan et al. 2014), that it is may be sufficient to feed the GCM climate signal directly into the impact model. But even if this is not the case, the analysis of the climate change signal from GCM data is recommended (van der Linden and Mitchell 2009) to get a first picture of the climate change signal, to analyse the uncertainties of the boundary conditions for regional climate modeling or to identify situations where spurious differences between GCM and RCM signal suggest improper downscaling. Uncertainty due to differences of GCM projections may be reduced by applying ensemble approaches (Tebaldi and Knutti 2007) but there is no agreement how to generate model ensembles or how many models to apply (Pennel and Reichler 2011). Techniques include approaches

[1]ERA40—Reanalysis data set of the European Centre for Medium-Range Weather Forecasts (ECMWF).

[2]NCEP—Reanalysis data set of the National Centers for Environmental Prediction (USA).

[3]GPCP—Global Precipitation Climatology Project, the GPCP combined precipitation data were developed and computed by the NASA/Goddard Space Flight Center's Laboratory for Atmospheres as a contribution to the GEWEX Global Precipitation Climatology Project.

[4]CMAP—Climate Prediction Center (CPC) Merged Analysis of Precipitation.

weighting all members equally (e.g. Peng et al. 2002; Whetton et al. 2012) but it is recommended also to weight models by their ability to simulate the current climate (Tebaldi and Knutti 2007). There are several approaches generating weights by different methods, e.g. the 'Reliable Ensemble Averaging' proposed by Giorgi and Mearns (2002), where weights for the individual models are derived by combining model's ability to simulate the current climate and model's distance from the final ensemble mean. Recent approaches are trying to incorporate information from model's performance to simulate an individual variable for the current climate in future estimates of the variable by ensemble regression (Bracegirdle and Stephenson 2012). Or they even apply ensemble regression to weight models by their ability to simulate processes relevant for the evolution of the variable of interest (Karpechko et al. 2013).

GCM climate signal—Results from IWAS

Within the IWAS project GCM ensembles were analysed by two approaches. The first one applies the Model Performance Index derived for all variables to weight the ensemble members when calculating the ensemble mean. The rationale of this approach is that even the projection for an individual variable is more reliable when the model is able to reproduce properly the current climate situation characterized by coherent states of the climate system. The second approach applies the 'Reliable Ensemble Averaging' (Giorgi and Mearns 2002) where weighting of the ensemble members relies solely on models performance to reproduce the variable of interest. Model performance was derived with respect to ERA40 as well as NCEP reanalysis data.

Ensemble averages have been calculated from GCM output for variables where ensemble members agree in trend direction and for which the trend is significant at least for a subset of the members. This applies to temperatures on different levels as well as the closely linked geopotential heights. All other variables (including precipitation) are characterized by a disagreement between ensemble members concerning the trend direction for all focus regions.

Results for the Arabian Peninsula are shown as an example. They indicate that temperature will increase in all seasons (Fig. 8.4); the greatest magnitude was found in the upper troposphere. This is consistent over all scenarios (A2, A1B and B1). Comparison of the different ensemble averaging approaches shows little effect on the result as long as ensemble members agree in sign. Increase in mean annual near surface temperature ranges between 1.5 and 1.6 K (B1) and between 1.8 and 1.9 K (A2) until 2040–2060. The maximum increase is found for the average of March to May. For the period from 2080 to 2100 magnitudes of the annual near surface temperature increase range between 2.2 and 2.3 K for the B1 scenario and between 3.7 and 4.1 K for the A2 scenario, both with the maximum increase in autumn (September to November).

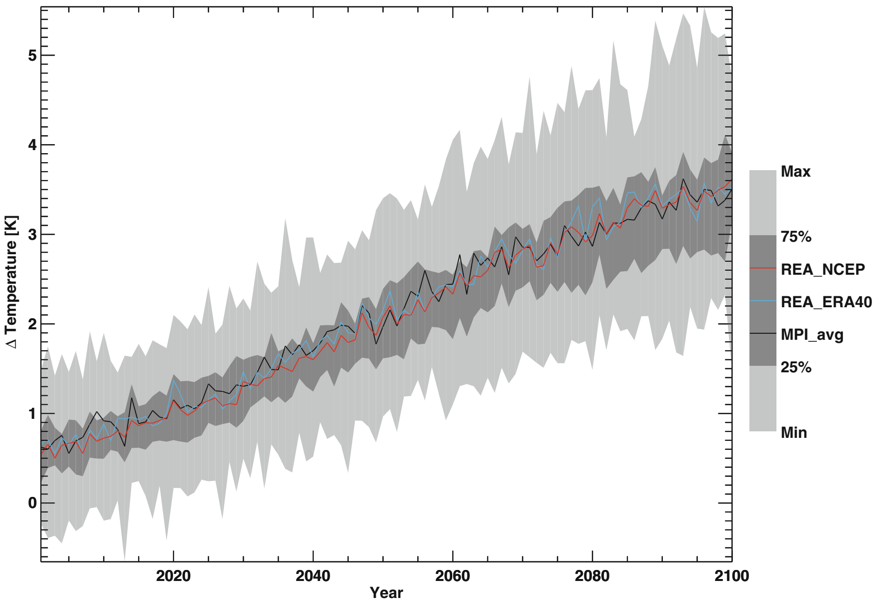

Fig. 8.4 Ensemble averages of changes of yearly mean near surface temperature (compared to control run 1961–1990) for Muscat/Oman (A1B scenario). REA_ERA40 and REA_NCEP indicate ensemble averaging by the 'Reliable Ensemble Averaging' approach with ERA40 and NCEP re-analysis data as reference. MPI_avg indicates ensemble averaging by weighting with the MPI (*source* Barfus and Bernhofer 2014a)

8.5 Regional Downscaling

IWRM acts in most cases at the regional or catchment scale and so IWRM strategies require in the majority of cases climate information at this scale. Today's GCM resolutions are too coarse and thus data have to be downscaled especially for regions with strong influences of small scale topography and surface heterogeneity (Wilby et al. 2002). Several initiatives existed carrying out downscaling experiments for certain regions and providing data to the scientific community like PRUDENCE (Christensen et al. 2007a) and ENSEMBLES (Hewitt and Griggs 2004) for Europe or NARCCAP (Mearns et al. 2013) with the focus on North America. A framework for the synchronization of the experiments is provided by the CORDEX initiative (Giorgi et al. 2009). However, often suitable downscaled data are not available for the region of interest. Then, according to our scheme, downscaling has to be performed ('regional downscaling') either by 'Dynamical Downscaling' or by 'Statistical Downscaling'.

Dynamical downscaling is based on the subsequent modeling of meteorological processes for a specific geographical region using GCM results as atmospheric boundary conditions. The principles of regional climate models (RCM) and GCMs are the same and though RCMs resolve more small scale processes, several processes still have to be parameterized (Christensen et al. 2007b). A survey of the state of art of dynamical downscaling can be found in Rummukainen (2010).

Statistical downscaling produces station-scale time series by using empirical relationships of local-scale predictands from measurements with large-scale predictor variables from models (Wilby et al. 2002). The fundamental assumption is that large scale predictors are simulated properly by the GCM and that the relationship holds in future times. Consequently, statistical downscaling approaches depend strongly on the choice of the predictors but do not require knowledge of the governing physics (Wilby et al. 2002; Mehrotra et al. 2014). Nevertheless, we should try to interpret statistical relationships in physical terms to ensure that the relationship allows an application under future climate conditions (Sauter and Venema 2011). More detailed information about principles, methods and state of the art of statistical downscaling may be found, e.g. in Benestad et al. (2008) and Maraun et al. (2010).

Both main downscaling approaches have advantages and disadvantages, and there is no general or commonly accepted advice available how to make a proper choice. Consequently, it is a topic of current research and we provide here only some non-comprehensive assistance for decision. Decision for one of both approaches depends on data availability, principle limitations of each approach, relevance of dynamical boundary condition and the objectives of the investigations as well as the available resources.

(i) Data availability: Establishing a robust relationship between large scale predictors and small scale predictands for statistical downscaling requires measurements on station scale for a time period covering the whole range of meteorological situations like major temperature and precipitation events, 11-years solar cycles and phases of large scale phenomena affecting the region, such as El Niño Southern Oscillation (ENSO) (Grimm and Natori 2006; Winkler et al. 1997). If data do not meet this requirement, statistical downscaling is not possible and dynamical downscaling is recommended (Wilby et al. 2002; Goodess 2005; Fowler et al. 2007).

(ii) Principle limitations of each approach: It is expected that statistical downscaling simulates at least for the training period point processes more appropriately. Dynamical downscaling attempts to simulate all processes relevant for the local climate in their three-dimensional characteristics. Consequently, it is more appropriate for heterogeneous regions where synoptic processes shape the local climate than statistical downscaling representing most often only point-scale processes (Fowler et al. 2007), though, e.g. Sauter and Venema (2011) try to incorporate situation dependent 2d predictor domains into statistical downscaling. Statistical downscaling is e.g. only able to properly capture effects of orographic forcing and rain shadowing when the station network reflects these gradients. On the other hand, dynamical downscaling is also expected to resolve processes not adequately represented by GCMs like Monsoon effects (Pierce et al. 2013). The underlying physical principles result in consistent information with respect to different variables. Thus, e.g.

Goodess (2005) recommends dynamical downscaling for hydrological impact studies.

(iii) Relevance of dynamical boundary conditions: Some limitations for statistical downscaling are imposed by the stationarity of the predictor-predictand relationship (Casanueva et al. 2013). There is no restriction, if changes of local boundary conditions are negligible (Fowler et al. 2007). If relevant land-surface feedbacks or unprecedented changes in the atmospheric circulation may occur, dynamical downscaling is preferred (Wilby et al. 2004). On the other hand, also dynamical downscaling may suffer from stationarity issues due to parameterizations which are not necessarily appropriate for future climate conditions (Casanueva et al. 2013; Flaounas et al. 2013). It is obvious that the chance to be affected by increases with time horizon of the simulation making statistical downscaling a less attractive choice for a time span of 50 years or more (Bernhofer et al. 2011).

(iv) Objectives of the investigations: Related to the principles and limitations of both approaches are the objectives of the investigations and their specific requirements. If only data for an individual location is needed, statistical downscaling might be suitable (Wilby et al. 2002; Mehrotra et al. 2014). For spatial averages or proper spatial correlations (especially for occurrence and amount of precipitation) Mehrotra et al. (2014) and Chen et al. (2012) recommend dynamical downscaling. There is no agreement of the scientific community about the best approach for extreme values. Whereas Wilby et al. (2002) favour statistical downscaling for extreme events, Fowler et al. (2007) argue that statistical downscaling does not represent extremes properly and Casanueva et al. (2013) hypothesize that stationarity of the relationship in statistical downscaling might be especially a problem for extreme events.

(v) Available resources: If time or computer resources are limited, statistical downscaling is recommended due to the rapid establishment and execution of the model (Wilby et al. 2004). Also the generation of ensembles is less time consuming with statistical downscaling (Fowler et al. 2007; Mehrotra et al. 2014). If human resources are limited, statistical downscaling is also recommended due to the time needed for researchers to familiarize with the more complex regional climate models and their operation.

It becomes clear that there are no distinct rules for the decision between statistical and dynamical downscaling and often there is no option to compare both approaches for the specific problem. If possible, the use of both approaches is recommended for a wider range ensemble of model outputs (e.g. Wang et al. 2014).

On the other hand, the application of downscaling in IWRM projects is typically impact model oriented. Often, due to regional biases in the global fields of GCM outputs (Pierce et al. 2013) deviations of individual simulated variables (especially precipitation) from reference data are not random but systematic. This bias prevents the direct use of the data in impact models. A pragmatic approach is to post-process the model results with an appropriate bias correction method (Christensen et al. 2008; Maraun et al. 2010; Themeßl et al. 2010; Piani et al. 2010). Bias correction methods derive transfer functions, which are based on statistical relationships between observed and modeled data. It is assumed that the statistical relationships, and hence the bias, are also valid for future periods. In contrast, Maraun (2012) showed that this assumption of bias-stationarity seems not to be true in general. Though bias correction is currently an issue discussed intensely in the scientific community (e.g. Ehret et al. 2012), it is the tool of choice when driving impact models with climate model data. For climate change detection itself the analysis of the climate change signal (the difference between future simulation and control run) might be the more appropriate way.

8.5.1 Dynamical Downscaling Example: Eastern Europe–Ukraine

In case of the IWAS Region Eastern Europe—Ukraine downscaling was performed with the regional climate model CCLM (Rockel et al. 2008) due to the lack of sufficient meteorological station data to apply a robust statistical downscaling approach. In principle no observations are needed for processing dynamical downscaling, but observations are needed as reference data to evaluate the model-performance or to perform a bias correction for the use in impact models. For Ukraine, the performance assessment was done with spatially interpolated monthly time series, for which the observation data were sufficient (Pavlik et al. 2012).

Climate data of the GCM with a resolution of 200 km were downscaled to the scale of 7 km. In order to bridge the large scale ratio, a double-nesting was applied. In the first step, output from a global model was downscaled for a central part of Europe with 0.44° (approx. 50 km). Afterwards, the output from the first nesting was downscaled for the region covering Belarus, Poland, the Western-Ukraine, and the Carpathian Mountains to 0.0625 degrees horizontal resolution (approx. 7 km).

Four different model runs were processed: (i) an evaluation run driven by ERA40 reanalysis data for the reference period 1961–1990, (ii) a control run driven by GCM data from ECHAM5/MPI-OM (run 1) (Roeckner et al. 2003) also for the period 1961–1990, (iii) and (iv) two future scenario runs driven by ECHAM5/MPI-OM SRES-scenarios B1 and A2 for the period 2010–2100. Each scenario run was analysed for two 30 year time slices from 2021 to 2050 (period 1) and 2071 to 2100 (period 2).

In a first step evaluation run as well as control run were evaluated with monthly observations of 2 m temperature and precipitation (Pavlik et al. 2012, 2014). Due to limited available observations, the evaluation was restricted to the time period from 1973 to 1990 which slightly limits the evaluation of precipitation output (Pavlik et al. 2012).

Four measures were used to quantify differences between model results and observations (Pavlik et al. 2012): bias (BIAS, Eq. 8.1), spatial root mean square error (SRMSE, Eq. 8.2), pattern correlation (PCOR, Eq. 8.3), and ratio of spatial variances (RSV, Eq. 8.4).

$$BIAS = \bar{m} - \bar{r} \tag{8.1}$$

$$SRMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(m_i - r_i)^2} \tag{8.2}$$

$$PCOR = \frac{1}{(n-1)}\sum_{i=1}^{n}\frac{(m_i - \bar{m})(r_i - \bar{r})}{\delta_m \delta_r} \tag{8.3}$$

$$RSV = \frac{\delta_m^2}{\delta_r^2} \tag{8.4}$$

where m is the model value at a single point in a two dimensional data field, r the reference value at a single point in a two-dimensional data field, $\bar{m}$ the mean of model values, $\bar{r}$ the mean of reference values, δ_r the standard deviation of reference values, δ_m the standard deviation of model values, and n the number of values.

On the 7 km scale, temperature is reproduced very well by the evaluation run, the control run slightly underestimates it with a bias of −0.19 K (Table 8.2). The SRMSE of temperature for the control run of 0.44 K is marginally higher than the SRMSE of 0.40 K for the evaluation run. Spatial variability of temperature is higher for the control run than for the evaluation run. However, the control run reproduces the spatial pattern slightly better than the evaluation run. In summary, the model performance of both historical runs for temperature is acceptable for regional climate change studies and impact modelling.

The long-term mean precipitation sums of both CCLM historical runs are higher compared to interpolated station data. The evaluation run has a bias of about +52 mm/a, which means a relative difference of 7 %. The control run produces a bias of +264 mm/a. Thus, the driving data from the GCM ECHAM5 account for an additional precipitation bias of about +212 mm/a. The SRMSE of 278 mm/a supports this result. Both historical runs reproduce the spatial patterns of precipitation less appropriate than the patterns of temperature. This might also be due to limited data availability, but results indicate that before application of precipitation data in impact models some post-processing is necessary.

After model performance analysis climate change signals were derived as differences between scenario runs and control run.

In the projections the Western Bug basin faces increased temperatures for both emission scenarios, in all months, and for both future time periods (Fig. 8.5a, b). Winter months show the highest temperature increases with highest variability. Warming in the first period ranges from +0.4 to +2.3 K (B1) and from +0.4 K to

Table 8.2 Statistical quality measures for long-term yearly means, 1973–1990 (adopted and modified from Pavlik et al. 2014)

	Evaluation run (driven by reanalysis)		Control run (driven by ECHAM5)	
	Precipitation	Temperature	Precipitation	Temperature
BIAS	52 mm (7 %)	0.00 K	264 mm (34 %)	–0.19 K
SRMSE	99 mm	0.40 K	278 mm	0.44 K
RSV	0.62	1.63	1.13	1.99
PCOR	0.28	0.43	0.37	0.45

+3.6 K (A2). In the second period warming is remarkably more intense with values from +1.3 K to +4.4 K (B1) and +1.6 K to +5.3 K (A2).

Changes of monthly mean precipitation in the first period have no uniform pattern (Fig. 8.5c). In the second period a clear structure of wetter months in autumn and winter and a strong drying of summer months is visible (Fig. 8.5d). The median monthly changes for scenario B1 are between –36 mm to +17 mm and for A2 between –44 mm to +21 mm. Summer months show a drying and winter months a wetting. Thereby, precipitation changes have a greater variability in the second period. This indicates the occurrence of more extreme events (heavy rainfall

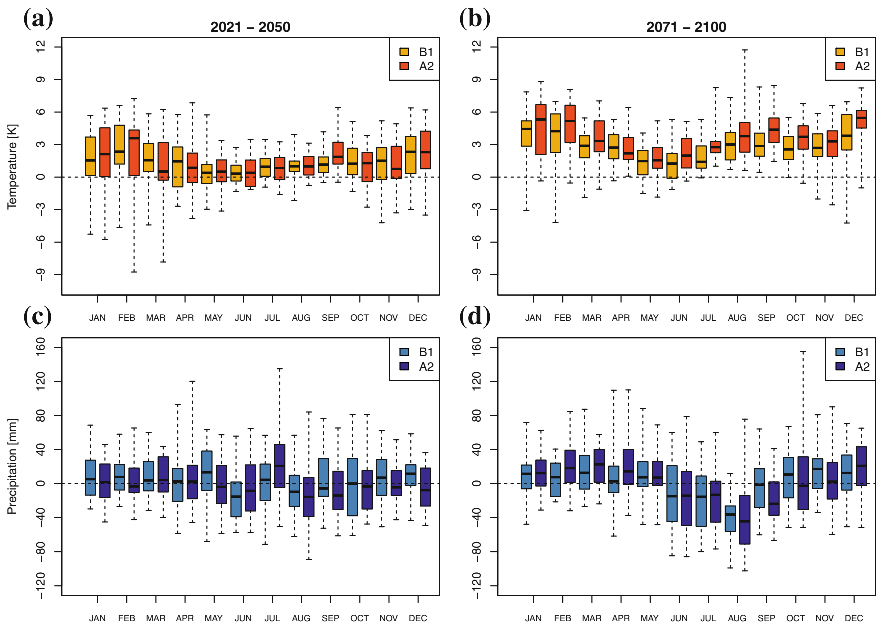

Fig. 8.5 Long-term area mean monthly temperature changes (**a**, **b**) and long-term area mean monthly precipitation changes (**c**, **d**) for the Western Bug basin for SRES scenarios A2 and B1 (compared to control run 1961–1990) (*source* Pavlik et al. 2014)

and droughts) in the second period. Up to the end of the century, long-term annual mean precipitation stays nearly constant, but the inter-annual precipitation distribution changes clearly.

8.5.2 *Statistical Downscaling Example: Latin America—Brazil*

Due to the availability of sufficient daily data for the IWAS region Latin America—Brazil (Borges et al. 2014a) and limited time resources the Statistical DownScaling Model (SDSM) (Wilby et al. 2002) was applied. Despite its simplicity, comparison studies demonstrate that SDSM satisfactorily simulates mean surface air temperatures, the annual precipitation cycle, seasonal and annual precipitation totals, in regions characterized by high seasonal climate variability as Brasília (Wilby and Dawson 2012). SDSM is a hybrid of a regression-based approach and a stochastic weather generator (Wilby et al. 2002). In a first step a multiple linear regression is fitted between large-scale predictors and station scale predictands. Second, assuming that the residuals between regression derived predictands and observations are normally distributed, the standard error is used to stochastically reproduce the distribution of model residuals. This residual is added to the deterministic part on each day in order to add white noise to the downscaled time-series and, therefore, better agree with the variance of the observation (Wilby et al. 2002).

Here, the use of SDSM is documented to downscale the station Brasília-INMET. Large-scale predictors have been derived from NCEP reanalysis data. Sea level pressure, meridional wind speed and specific humidity at 500 hPa as well as near surface temperature itself have been selected as predictors due to their skill to predict near surface temperature. Precipitation is better explained by zonal velocity and specific humidity at 500 hPa and specific humidity at 850 hPa. SDSM was calibrated for the period 1971–2000.

Concerning the validation period of 2001–2010, the downscaled NCEP data replicates the observed 10-year ensemble average of temperature of Brasilia very well with a bias of less than 0.5 °C in June, July, August and September. In general, results demonstrate a high level of correlation (Pearson's $r > 0.97$) between observed and simulated data and low errors (Root Mean Square Error <0.6 °C). Precipitation is only to a minor extent explained by the regression part and, thus, the stochastic component superimposes the deterministic. This is expected for precipitation, especially in regions influenced by convective systems, in which local aspects affect the amount of rainfall (Wilby and Dawson 2012). On the other hand, the occurrence and annual distribution of precipitation is fairly well simulated. Most notorious differences are found for April and November, known as offset and onset months of the rainy season, when the high inter-annual variance is not well explained by the model. As expected, the estimation of frequency of extreme precipitation amounts is limited.

In a next step, reanalysis derived predictor-predictand relationships were applied to downscale projections of 18 GCMs available from the CMIP3 archive. In order to avoid massive amounts of data and to serve the interest of impact modelers in representative projections and spread of the full ensemble set, the results have been categorised. This is done according to temperature and precipitation changes in hot/dry, hot/wet, cold/dry, cold/wet and central. Figure 8.6 shows a scatter plot between precipitation change and mean surface air temperature change projections (i.e., 1961–1990 to 2046–2065). Each cross represents a combination of GCM, emissions scenario, initial conditions (i.e., run) and ensemble member generated by SDSM. Ten members of the ensemble were selected for each category according to median and 10 % and 90 % percentile, respectively. Individual projections (members of the SDSM ensemble) have been identified which come closest to these percentiles. Table 8.3 shows these five 'most representative' climate change projections for the station of Brasília. Projections range from +0.6 to +1.2 K for temperature, while +13.0 to +45.3 % for precipitation. The central tendency is simulated by the BCCR-BCM2.0 model under the A1B SRES scenario, which shows changes of about +0.9 K and +29.1 %, for mean surface air temperature and precipitation, respectively. The projected annual increase in precipitation is large and would have considerable impact on the IWRM in the region of Brasília. However, scatter is high and the seasonal behaviour still needs to be evaluated in more detail.

In order to minimize the random impact of internal variability from one single projection, a larger subset (i.e., 10 members) is recommended for impact analysis (Reclamation 2008). The selection of the most representative projections for each percentile category allows the quantification of uncertainty in the estimation of climate change impacts in the context of IWRM. Some shortcomings of statistical downscaling (here SDSM) have been identified for the case of Brasília, like the lack

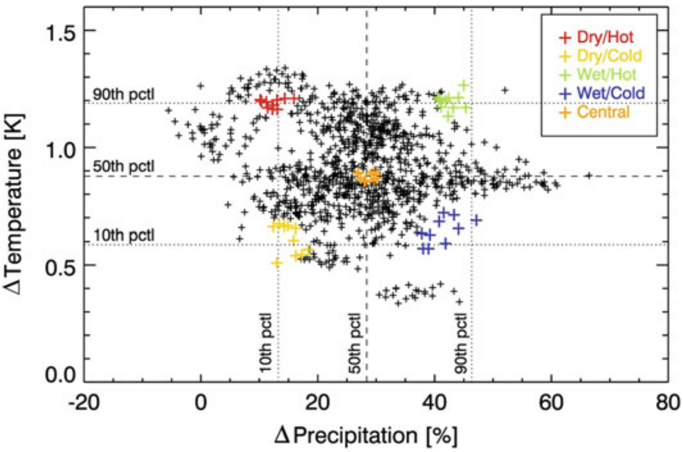

Fig. 8.6 Scatter plot of annual precipitation change versus annual mean surface air temperature change (1961–1990 to 2046–2065) for each projection member. *Colours* illustrate the subsets (i.e., 10 members) of representative projections. *Dotted lines* are 10th and 90th percentiles and *dashed line* the 50th percentile

Table 8.3 Most representative projections to inform about climate change scenario

Scenario	Change precipitation (%)/temperature (K)	GCM acronym	SRES	Run	SDSM member
Dry/Hot	+13.0/+1.2	GFDL-CM2.1[a]	A1B	1	7
Dry/Cold	+15.9/+0.6	FGOALS-g1.0[b]	B1	3	19
Wet/Hot	+45.3/+1.2	CCSR-MIROC3.2-hires[c]	A1B	1	19
Wet/Cold	+41.9/+0.6	CNRM-CM3[d]	B1	1	17
Central Tendency	+29.1/+0.9	BCCR-BCM2.0[e]	A1B	1	8

[a]Geophysical Fluid Dynamics Laboratory, USA (GFDL 2005)
[b]Institute of Atmospheric Physics, China (Yu 2005, 2007)
[c]National Institute for Environmental Studies, Japan (Emori 2005)
[d]Centre National de Recherches Meteorologique, France (Salas 2005)
[e]Bjerknes Center for Climate Research, Norway (BCCR 2005, 2006)

of capacity in simulating the inter-annual climate variability for certain months and the frequency of extreme precipitation. This tendency towards smoothing by statistical downscaling models needs to be known to avoid misinterpretation of impact modeling outputs.

8.6 Impact Models Analysis

It is not the scope of this paper to discuss the influence of climate change information in impact models. Therefore, as an example we just provide some ideas from impact modeling for the Ukrainian focus region.

Results from IWAS

Time-series of the dynamical downscaling procedure served as drivers for water and matter budget studies in the Western Bug river basin. Here, we present exemplary results from water balance investigations. The climatic water balance (CWB) is a suitable integrative variable for a first assessment of the potential water availability in the basin (Olesen et al. 2007). CWB is derived from the difference between precipitation P and potential evaporation ETP (Eq. 8.5).

$$CWB = P - ETP \tag{8.5}$$

ETP was calculated from the regional climate model results by the combination approach after Penman (1948) with modifications after Wendling et al. (1991) and DVWK (1996). It is important to note that only temperature and precipitation but not the other parameters have been validated against observational or reanalysis data. In the first period changes of potential evaporation do not show a clear pattern for any scenario (Fig. 8.7a). Figure 8.7b reveals a clearer pattern for the second period with stagnant or slightly decreasing ETP for March to July but markedly increasing median and variability for August to October. CWB changes show more

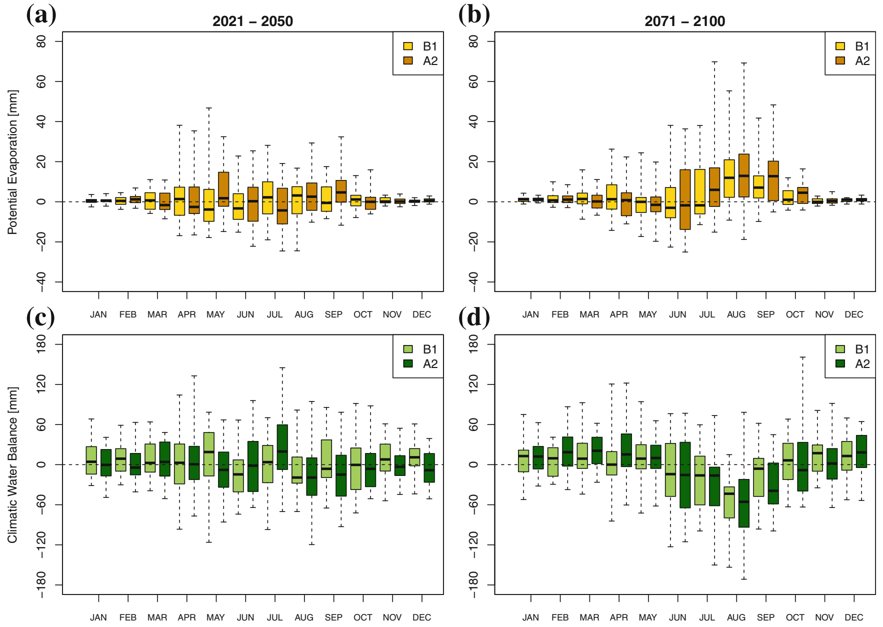

Fig. 8.7 Changes of potential evaporation (**a**, **b**) and changes of the climatic water balance (**c**, **d**) SRES scenarios A2 and B1 (compared to control run 1961–1990) (*source* Pavlik et al. 2014)

distinct patterns for both periods (Fig. 8.7c, d) due to an increase in winter P and a decrease in summer P. In June to September CWB becomes considerable negative at the end of the 21st century.

Summarizing, projections indicate that the projected future climate change leads to an intensification of the already existing pattern, where wet months get wetter and dry months get drier, with potential implications for hydrological and agricultural systems.

The water balance study was carried out with the Soil and Water Assessment Tool (SWAT, Arnold et al. 1998) driven by CCLM data for a sub-basin of the Western Bug (Fischer et al. 2014). Runoff and soil water storage were analysed for the scenarios B1 and A2. The model results show for the first period only small long-term monthly runoff changes without a clear pattern. For the distant future runoff decreases from February to November and increases from December to January for both scenarios. Runoff and soil water content are interdependent, thus, the annual course of the soil water storage usually decreases during the summer half-year and increases during the winter half-year. The projected change in soil water content is linked to the climatic water balance and thus drastically decreases in summer and fall. For the period 2071–2100, the annual course of the changing signal is constantly negative. A decreasing soil water content limits percolation into deeper saturated soil layers, which together with decreasing precipitation leads to a reduced annual groundwater recharge.

Under future climate conditions the river discharge will be reduced by nearly 30 % in summer months. Soil water content decreases in comparison to the reference period and also the groundwater retention will be reduced too. This may result in a change of the hydrological pattern with increase in winter discharge, decrease in summer discharge, and increases in the frequency and the height of peak flows as well as longer and more frequent periods of low flow in summer (cf. Middelkoop et al. 2001). Thus, "a relatively small and insignificant change in precipitation in combination with a more significant increase in temperatures can result in severe and significant changes in hydrological variables, in particular in river flow and groundwater recharge" (Hatterman et al. 2008). A change of the hydrological pattern of the Western Bug river will have manifold consequences for water management, ecology, human health and other water related sectors (cf. Fischer et al. 2014).

8.7 Conclusions

In the previous sections we have shown that the way how to generate climate change information depends on the specific region and the typically regionally specific IWRM problem. As in most IWRM projects, also in IWAS resources have been limited and there was no climate model result available at the start of the project. Consequently, decisions had to be made without a priori assessing performances of individual approaches. Typically, pragmatic solutions like the choice of downscaling technique depending on the available data or about the application of bias corrections are needed, even when their drawbacks are known. Decisions are often caused by the immediate need for data of the impact modelers. On the other hand collaboration with and meeting the demands of impact modelers and IWRM decision makers is a prerequisite to produce adequate climate information for IWRM. Which climate information is adequate depends on many factors, including the specific IWRM problem.

Nearly all steps of our framework are topics of ongoing research, e.g. the discussion which dowscaling approach to apply may change due to advancements in modeling. At this point of time, a pragmatic choice might be statistical downscaling when, (i) enough high quality daily data are available, (ii) the time frame is short enough (e.g., 50 yrs) to apply stationary relationships, and (iii) internal feedbacks are weak or at least relatively constant. In all other cases dynamical downscaling seems to be the better choice. For most tasks like quality assessment of climate data, model performance assessment as well as ensemble approaches, no standard methods exist yet or if existing are rarely applied. Some parts of the dynamic modeling chain especially important at the regional/catchment scale are expected to see some rapid development in near future like vegetation feedbacks or the treatment of snow in climate models. On the other hand some expectations related to future development (e.g. narrowing the range of projections from CMIP3 to CMIP5) might not be met.

However, the proposed scheme is motivated from our experience in the IWAS project. It may not be exclusive and provide distinct decision rules but may help IWRM projects to plan and structure their climate change related component and is flexible enough to be adjusted with respect to future scientific developments. It expresses our point of view that IWRM problem understanding and finally IWRM solutions will benefit from conducting the whole suite of analyses, including the assessment of potential climate change effects.

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Part IV
Water Governance

Chapter 9
IWRM in Uzbekistan: A Global Concept with Local Consequences

Elena Arsenievna Kim and Anna-Katharina Hornidge

Abstract The chapter discusses research findings generated within the framework of the BMBF-funded project entitled “Economic and Ecological Restructuring of Land and Water Use in the Region Khorezm (Uzbekistan): A Pilot Project in Development Research” and implemented in 2001–2011. The authors look at the processes of how IWRM as a globalized concept for irrigation governance is locally operationalized and expressed in the implementation practices within specific conditions of contemporary Uzbekistan. The chapter begins with an overview of the processes which describe the variability of how IWRM principles have been incorporated in Uzbekistan at the level of official institutional policies. It then moves to a discussion of how these policies infiltrate into less formal work practices. We begin with an analysis of a “micro-level” water governance demonstrating important linkages between the officially endorsed IWRM agenda and historically and culturally-embedded systems of informal water management in Uzbekistan. Using an innovative method of inquiry and analysis called “institutional ethnography” (Smith 1987), we discover important points of disjuncture between the formal promises of IWRM-motivated policies and the actual outcomes of the pertinent policies for the marginalized water users. We attempt to explain this inconsistency and put forward an argument which elucidates how benevolent and well-intended policies under the IWRM framework become occluded by the organizational and political-economic administrative apparatus of state-led agricultural marketing in Uzbekistan. Our analysis offers an explicated account of IWRM as a practiced activity, opening up institutional issues that require informed and empirically-based reflection.

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9.1 Introduction

At the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002, the global community made a call for all countries to "develop integrated water resource management and water efficiency plans by 2005, with support to developing countries" (Jonch-Clausen 2004). Many governments in the global South have responded to this call and started national IWRM planning processes. Practitioners around the world have deemed IWRM as a holistic framework to combine the contributions from users, planners, sciences and policy makers (Medema et al. 2008) into the process of enabling the societies to continue to benefit from the utilization of water resources while maintaining the environment and the resource base to meet the needs of future generations (Matondo 2002). In Uzbekistan a lot is hoped to be gained from adopting IWRM. Scholars including ourselves argue that IWRM promises to significantly contribute to solving some of Central Asia's water management problems (Manthrithilake et al. 2008; Hornidge et al. 2011a). Some observers demand effective measures to reduce the emerging threats related to water shortages in the region and minimize detrimental consequences by effectively addressing them (Islamov et al. 2009). They believe that such tasks require mainstreaming of IWRM approaches to all the policies aimed at sustainable development of the country.

At the same time there is growing criticism of IWRM. Scholars point out that while IWRM has been present in various discussions for several decades already, it has not been sufficiently, "objectively, comprehensively and critically" evaluated in relation to what exactly this concept means in operational terms (Biswas 2008). The ambiguity of the term prevents IWRM from being effectively implemented, claims Biswas (2008). He continues by emphasizing that IWRM amid all of its good intentions lacks the required capacities to handle water problems which have already become "far too complex, interconnected and large" (Biswas 2001 in Biswas 2008). So far, he concludes, the actual results of applying IWRM have left much to be desired. Indeed, there has been a serious and growing concern that the gap between IWRM as a theory and IWRM as practice appears to be unfixable (Shah and Koppen 2006; Rahaman and Varis 2005). Some authors questioning the feasibility of IWRM point out that the mere idea of integrated management of one resource is absurd considering its interconnections with all other natural resources and all aspects of human activities (Medema et al. 2008). While there is no consensus among scholars and practitioners concerning how to best understand and implement IWRM, developers, governments and international organizations have coincided in foreseeing the problems that can occur through a lack of integration between water and other policy sectors. They also have recognized that there is an urgent need for strategies to address the prevalence of water insecurity on a global scale (Samuels et al. 2006).

This chapter investigates the implementation of IWRM-informed policies in Uzbekistan and its effects on small-scale subsistence farmers and water users by conducting an institutional ethnography (Smith 1987, 2005). Previous research conducted in this tradition has been able to produce findings described as "epistemologically insightful" (Mueller 1991) and provide new knowledge about "old" phenomena. The inquiry presented here is based on empirical research conducted in spring and summer of 2011 on the level of local water users—the most "on-the-ground" level of IWRM (Abdullaev et al. 2008a). Whereas Biswas (2008) talks about the macro and meso-levels of IWRM programs, this paper attempts to embrace the institutional scope of IWRM practices by carefully and knowingly attending to the integration into such analysis of the actual people's experiences and knowledge. This appears especially important in the light of the raised concern that while some scarce research on IWRM in Uzbekistan has now become available, it lays its focus predominantly on the level of national regional basin and main canals with little attention paid to the IWRM processes at the grass-root level (Abdullaev et al. 2008a).

Our findings reveal that particular groups of water users, i.e., peasants who comprise the majority of the rural population in contemporary Uzbekistan, experience a systematic failure to access water for irrigation. A lack of reliable access to water endangers their food security and livelihoods. This happens despite the fact that a local water management organization (Water User Association or WUA) has been established and mandated specifically to oversee the equitable distribution of irrigation in the village and facilitate decentralized participatory water governance. The WUA serves as the final instance in the water management organization for putting in place the participatory policies inherent to the idea of IWRM. We carefully examined the work of the WUA and discovered an operation of a competing institutional discourse, e.g., the discourse of a state-led agricultural economy. Tracking how this discourse actually displaced the participatory inspirations of IWRM we argue that in the practical implementation of IWRM-inspired practices, its fundamental principles become profoundly transformed. We claim that this transformation generates, in invisible and implicit ways, unintended but malign effects for the local water users. Asking how exactly good intentions achieve reactionary outcomes, we inquired into the daily work of the WUA. On the basis of our findings we offer an analysis which explicates that IWRM has become co-opted by the state-controlled agricultural planning and administration for large-scale cotton and wheat export. We argue that as a result of such co-optation, inherent to IWRM principles such as participation, pro-poor empowerment, food security, etc., become undermined while gender inequality in accessing water is perpetuated. The chapter ends with suggestions on how to overcome the contradictions we discover.

Although the discussion in this chapter focuses on one particular setting in Uzbekistan, the developments with which it engages and the institutional linkages it explores are applicable elsewhere. While taking on particular policy configurations in different locales, IWRM broadly understood has become widespread not only as the national water policy but also as an epitome of global water governance and "good governance". Consequently, the policies, practices and discourses advanced in the specific locale we have chosen are also present in other situations. Therefore, the recommendations we formulate bear the potential to inform decisions in the locations outside the one we analyze in this chapter.

9.2 Methodology

Our inquiry is framed within the traditions of an approach called *institutional ethnography* (Smith 1987, 2005). In line with institutional ethnography's principles our analysis is based on empirical data which was collected within the framework of the BMBF[1]-funded project entitled "Economic and Ecological Restructuring of Land and Water Use in the Region Khorezm (Uzbekistan): A Pilot Project in Development Research" (2001–2011). During the project's final phase, one of the authors, Kim, conducted a five-month (from April to August 2011) ethnographic fieldwork in Khorezm province. She used three major methods of data collection including in-depth and semi-structured interviews; participant observation; and documentary analysis. In total, the data pool was comprised of 40 in-depth interviews and 173 semi-structured interviews with various participants in water management, daily fieldnotes about the daily water use and management practices and associated textual materials. The analysis of these data proceeded from ethnographic descriptions of everyday irrigation activities to identification of a problematic and analytic mapping of the processes, actors and practices which together shaped local experiences and explain how the identified problematic emerges. The research followed all the required ethical requirements applied to research involving human subjects. The collected materials comply with the rules of confidentiality, anonymity and data protection.

9.3 Key Characteristics of the Research Location

Uzbekistan or, officially, Republic of Uzbekistan is located in post-socialist Central Asia and borders with Kazakhstan, Kyrgyzstan, Tajikistan and Afghanistan. Uzbekistan's territory is estimated as 450 million ha or 450,000 square km. Its population is approximately 28 million people, 63 % of whom are rural population. Unemployment rates are high, and about 28 % of the population lives below the poverty line (1 US$ per day) (Mueller 2007). Uzbekistan is the fourth largest cotton producer in the world (Asian Development Bank 2001). Cotton production contributes to 40 % of the export revenues, while wheat production is a key component

[1]BMBF is an abbreviation for Germany's Federal Ministry of Education and Research.

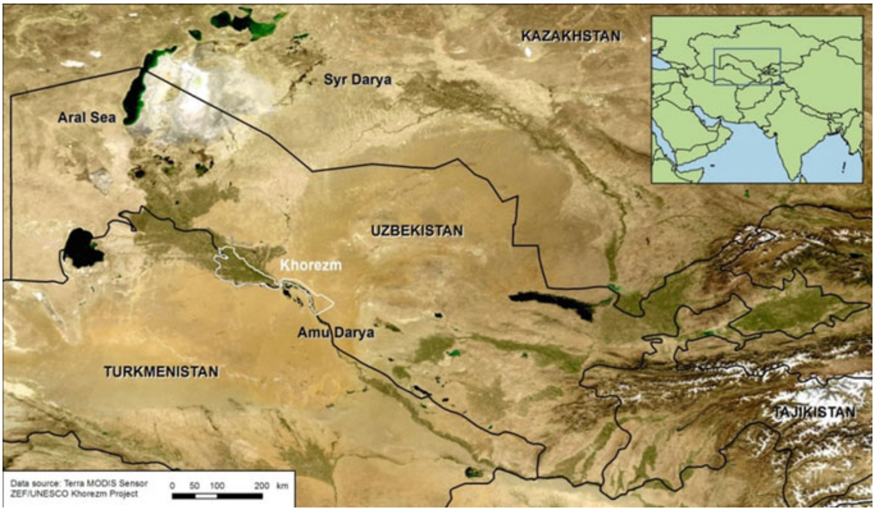

Fig. 9.1 Location of Khorezm Province. *Source* ZEF/UNESCO-Project GIS Laboratory

of the national food security strategy. The government currently procures all the cotton production and 50 % of the wheat produce (UNEP 2006), all of which are currently produced by 'private' farmers (*fermers*). The irrigated land area in Uzbekistan increased from 2.5 million ha to 4.22 million between 1960 and the 1980s and raw cotton production increased from 2.95 to 5.37 million ton annually during this period (UNDP 2007). However, the productivity of arable land declined due to environmental impacts, high water tables, inappropriate irrigation and poorly managed drainage systems. At the same time water scarcity limits the further expansion of irrigated lands.[2]

Currently, 32 % of the inter-farm and main canals and more than 42 % of the on-farm irrigation network require reconstruction and 23.5 % are in need of repair (Islamov et al. 2009). Pumping stations that supply water to 50 % of irrigated area need to be replaced, as well as 40 % of the country's reservoirs (UNDP 2007). Water losses from distribution systems are estimated at 12.9 cubical km per year (World Bank 2003). Yet the water sector is poorly funded by the state budget with a decline from 22.6 to 7.5 % of the GDP at the time when the operation and maintenance costs of the nation's irrigation system more than tripled (Islamov 2009).

Khorezm province is situated in North-western Uzbekistan, in the irrigated lowlands of the Amu Darya river (Fig. 9.1). It encompasses an area of 5,060 km^2 and was inhabited by 1,517,500 people as of 2008 (UzStat 2009). The majority of

[2]The reduction in the resource base has been estimated to cost about $ 1 billion annually (UNEP 2006). Yet according to the World Bank (2003), rehabilitating the irrigation and drainage systems is less expensive than cash transfers equivalent to the value of the lost income from irrigation and the social disruptions that would derive from a decision to no longer invest into these systems.

the Khorezmian population live in villages and work in agriculture, either as *fermers* (leasing, not owning, large tracts of land), peasants (*dehqons*) operating on a smaller scale, workers on fermers' farms, or a combination of the latter two (Veldwisch and Spoor 2008). Due to the arid climate the agricultural systems in Khorezm depend entirely on irrigation to provide adequate soil moisture. The irrigation system consists of earthen canals and hydraulic structures are largely missing or dysfunctional (Abdullaev et al. 2008a). Drainage is realized by a network of open ditches and collectors. Irrigation water in the field is applied mainly by furrow and basins. Annually, about 3.5 km^3 of water are diverted to Khorezm from the Amu Darya River and about 95 % of supplied water is used for agricultural purposes (Conrad et al. 2007).

The village Urto-Yop, where the fieldwork took place is located at the tail-end (more than 60 km from the water source) of the irrigation canals. The village receives less than 70 % of the demanded water share for about 9000 ha land area (2000 of which are used for irrigated agriculture) and a population comprising approximately eleven thousand people. Irrigated agriculture represents the predominant employment of the Urto-Yop inhabitants. But due to the remoteness from the main irrigation sources, water shortages and the declined agricultural productivity, the village is among the poorest in the province (Abdullaev et al. 2008a). The problem of water scarcity is so intense that it became the reason for nearly 200 ha of irrigated, previously fertile land, being rendered unsuitable for agriculture by farmers and eventually abandoned (Abdullaev et al. 2008a). The water to this village is delivered via three other villages situated along the canal which has created additional competition for water and contributed to the lack of sustainability and reliability of accessing water for Urto-Yop. Following a series of land reforms in 2006, 2008 and 2010 twenty-one fermers' farms and more than two thousand peasant households were created (Eichholz et al. 2012; Djanibekov et al. 2012). Many men who previously were engaged in household farming now leave home for long periods of time, making up the considerable labor migration of male Uzbeks to Russia, Kazakhstan and urban areas of Uzbekistan, while their wives run the subsistence farms at home.

9.4 IWRM in Uzbekistan

With independence in 1991, Uzbekistan's economy and society entered a process of transition and active restructuring of its agricultural sector. In 1996, the formerly separate ministries, the Ministry of Agriculture and the Ministry of Melioration and Water Management of Uzbekistan were consolidated into a single organization—the Ministry of Agriculture and Water Resources (MAWR) (Yalcin and Mollinga 2007; Wegerich 2005). Subsequently, reforms in the agricultural sector bespoke changes in the national system of irrigation management. Traces of IWRM are evident in all levels of the new water governance policies: The idea of decentralization and delegation of decision-making, for instance, is overtly prominent in the new water policies and practices in Uzbekistan. To illustrate, the major policy changes occurred in 2003 when water governance in Uzbekistan was fundamentally re-organized from the district-based administrative system into an irrigation basin water management system based on the principles of hydrological boundaries. Accordingly, basin management authorities replaced the regional water resource departments (viloyat) of MAWR in Tashkent and assumed direct responsibilities for water resources management (Yalcin and Mollinga 2007). Not only this reform reflected decentralization rhetoric of IWRM, the idea of restructuring the national system to integrate basin-based hydrological units appears to significantly conform to IWRM's commitment to treat basins as a practical unit for water resources management wherein the basin is a "common reference frame" for planning, management, controlling, data organization, monitoring and water allocation (Global Water Partnership 2000).

IWRM has also become present in the national legislative and administrative frameworks on water use and management. To illustrate, one of the core water-related laws, the "Law on water and water use" (issued May 06 1993) emphasizes IWRM principles, processes and the need for "comprehensive, rational, and efficient use of water resources" (UNEP 2006). While this document still does not contain explicit reference to IWRM in Uzbekistan, the idea of decentralization has been increasingly gaining prominence and entered other legal frameworks which regulate, directly and indirectly, various aspects of water.[3] As one expression of decentralization the notion of Water User Associations (WUA)[4] gained popularity and prevalence among the decision-makers in Uzbekistan in the late 1990s (Yalcin and Mollinga 2007). By the mid 2000s the total number of WUAs created in the country accounted to 1,654 with 170,000 members and a service area of 3.8 million ha (World Bank 2012). A relevant legislative framework has been put in place for WUAs and it was expected that the introduction of WUAs as a policy reform would contribute to the overall national agricultural development strategy which ultimately will facilitate poverty reduction and provide "social assistance to the most vulnerable groups" (ADB 2001).

Critical observers agree that in contrast to IWRM's inherent idea of the WUA as a grass-root organization owned by water users who use the principles of equity and efficiency in the distribution of water and use of irrigation and drainage systems (USAID 2004), Uzbek WUAs were rather state-initiated establishments, founded,

[3]Among them are the Decrees of the President of the Republic of Uzbekistan "On the most important directions for deepening reforms in agriculture" (issued March 24, 2003) and "On the improvement of the system of economic management" (issued December 22, 2003), as well as the Resolutions of the Cabinet of Ministers of the Republic of Uzbekistan "On the improvement of the organization of water resource management" (No. 320 of July 21, 2003) and "On the improvement of activities of the Ministry of Agriculture and Water Resources of the Republic of Uzbekistan" (No. 290 of June 28, 2003).

[4]In 2009 Water User Association (WUA) were renamed into Water Consumer Association (WCA) (Law of Republic of Uzbekistan, Article 18-2). In this chapter we use WUA and WCA interchangeably and synonymously.

maintained, controlled and monitored by state organizations. Such an enforced nature of WUAs, these authors argue, undermined the sense of ownership among the water users, prevented them from full participation in the operation of WUAs, created reluctance and inconsistency in payment of membership fees and, ultimately, led to malfunctioning of WUAs (Hornidge et al. 2011a, b). Nevertheless, WUAs continue to attract attention and considerable funds from developers, policy-makers and practitioners. Since 1999 international donor organizations such as the European Technical Assistance to the Commonwealth of Independent States (TACIS), the Asian Development Bank (ADB), the United States Agency for International Development (USAID), the Japan International Cooperation Agency (JICA), and the Swiss Agency for Development and Cooperation (SDS) have been making their funding and expertise available to specifically support the national government of Uzbekistan to expand WUAs in the country (Yalcin and Mollinga 2007; Zavgorodnaya 2006). This level of responsiveness suggests that the creation of WUAs remains an important policy concept and administrative technology for sustainable, efficient and effective water governance.

The promotion of this concept in Uzbekistan and strengthening its role in local water management is recurrent in the project in focus. In 2008, during the final phase of the BMBF-funded project in Uzbekistan, it engaged with (among others) infusing IWRM principles into the work of the local WUAs which at that time suffered failing operation, poor management and were generally weak (Hornidge and Ul Hassan 2010). An approach called SMID, i.e., Social Mobilization and Institutional Development, was used to enhance the WUAs' capacities to deliver water to its water users in an equitable, reliable and timely manner on the basis of IWRM's public participation principles for the water management process. The improved operation of the WUA was envisioned to ultimately result in improvements in the "livelihoods of the rural inhabitants and enhancing productivity of the irrigated agriculture through better water management" (Abdullaev et al. 2008b). The analysis presented in this chapter is drawn upon an ethnographic study carried out within one of these WUAs.

9.5 Ethnography of the Everyday Water Use: Questions Arising from the "Ground"

Our study was conceptually (and methodologically) inspired by an innovative sociology of knowledge approach called "institutional ethnography" (Smith 1987, 2005). This approach explored the organizational processes and relations of power in which people conducted their lives and the institutions wherein these processes and ruling relations emerged and operated. Institutions were viewed as functional complexes such as markets, policy, law, etc., which were comprised of institutional processes that transformed local actions into standard forms of organizational action thereby generalizing in the local setting the institutional policies and purposes. Institutional forms of organization made actions accountable in terms of generalized categories and the concrete experiences of individuals were structured by these generalizing relations. Conforming to this theoretical perspective we began by taking the standpoint of some actual people in the setting (here small-scale subsistence farmers and water users) in order to track empirically how these people's experiences were organized institutionally. Drawing on this perspective we understood that people enacted what actually happened. Describing the actualities of their work ethnographically was used for further analysis where in these actualities traces of their actual, material and social organization were recovered. We mapped the social/institutional organization, processes and links which shaped the experiences of water use and water management that we discovered. Our data offered instances of the texts such as report forms, guidelines, etc., which informed and instructed water managers to undertake particular activities. We showed how these managerial activities played out in the experiences of the water users. Our analysis was of what actually happened as water managers worked with standardized organizational texts to bring into being the purposively organized institution of water management and what particular people experience (or failed to experience) as water managers worked. We saw ruling relations and disjunctures that people experienced and we analyzed them by tracking them in texts. We identified how local happenings and the ruling discourses and practices were connected to each other through institutional texts which institutional actors used to carry out at their work. This kind of analysis made visible the social organization, e.g., the social processes through which decisions were made, priorities were set and resources were made available that institutional participants typically took for granted.

Our inquiry began from talking to and observing the everyday work of the peasants, most of whom were women. It was learned that their subsistence was predominantly dependent on the produce from their small plots of land (approximately 0,12 ha) disbursed to them by the Uzbek government in 1991. Main staple crops were wheat, potatoes and rice for home consumption. Furthermore, harvested cattle feed allowed to avoid cash spending on it. Petty trade of local produce was common and allowed for some cash earnings.

Irrigated household agriculture formed the main income base of the rural population. However, data revealed systematic difficulties which subsistence farmers in Khorezm faced in assuring that irrigation water reached their fields. Informants indicated their consistent failure to irrigate their fields during the season. To illustrate specifically, one of the respondents complained that she missed the once-in-two-weeks opportunity to irrigate her land because she was unaware about the water's arrival to her part of the village and was not home soon enough to "catch" it (Interview, July 2011). On another occasion, she was staying with her niece at a hospital and when she returned home she learnt that she had missed the water again. Another peasant described that she "must open her ditch upon hearing about the arrival of the water. The water can arrive at any moment during a day or night. If a person is not at home, the water bypasses this person's land" (Interview, July 2011). The problem here did not end in women not having consistent and reliable information. One woman complained that "even if we know that the water is there, the water is scarce and there is no guarantee that it will reach us…"

(Interview, May 2011). We heard stories that peasants "did not manage to irrigate their kitchen garden and field because after the fermer had used the water, nothing was left for them" (Interview, April 2011). Consistent with Kim (2014), what these women-smallholders spoke about indicated that they experienced difficulties with accessing the irrigation water and suffered a great degree of uncertainty about not only "when" but also about "whether" they would be able to irrigate their field. Failure to access the irrigation endangered their abilities to feed their families.

What we discovered from methodically and systematically investigating the everyday actualities of water use among peasants in Urto-Yop contradicted several IWRM principles (see Fig. 9.2) as well as national and local level promises made to them. With regard to the IWRM-principles formulated in Dublin in 2000 (see Fig. 9.2), our specific case illustrated that the principles 2 and 3 were overlooked. Neither was water managed in a participatory manner, involving all relevant stakeholders, nor was the role of women (here subsistence farmers) in this process locally respected. Regarding promises made at the national and local-level, it contradicted the first the goal of the government policy in 1991 to counter poverty and promote self-sufficiency among the rural population by disbursing previously state-owned land to rural households, formalizing the owners of these plots as "household farms" and granting them the permanent and inheritable right to access it (Veldwisch 2008; Zavgorodnaya 2006). It seemed apparent that without proper irrigation, this additional land was infertile. Second, it contradicted the national water management policy reform which envisioned WUAs as facilitating poverty reduction and providing "social assistance to the most vulnerable groups" (Asian Development Bank 2001). Third, it undermined the goal of the BMBF-funded IWRM-informed sub-project to "improve the livelihoods of rural inhabitants" through the improved operation of the local WUA. In consequence, our findings were at odds with foundational principles of IWRM such as public participation, subsidiarity, pro-poor empowerment, and, as we detail later, recognition of gender in water management and use.

Puzzled by these ostensible contradictions we focused our investigation on how the discovered exclusion was institutionally organized. Knowing that water

1. Water is a finite, vulnerable and essential resource which should be managed in an integrated manner
2. Water resources development and management should be based on a participatory approach, involving all relevant stakeholders
3. Women play a central role in the provision, management and safeguarding of water
4. Water has an economic value and should be recognized as an economic good, taking into account affordability and equity criteria (GWP 2000).

Fig. 9.2 IWRM—The Dublin Principles

distribution was the mandate of the local WUA we examined the work of the WUA. Here we discovered a powerful operation of another institutional discourse, i.e., the state-led agricultural export. We tracked how in the institutional processes of international crops marketing participatory aspirations of IWRM becomes displaced. We found that the staff of the WUA, working properly within their institutional mandate, routinely perpetuated work practices which in their effect excluded peasants from equitable and fair use of water for their subsistence. How, we asked, did it happen that the WUA, established to distribute water efficiently and equitably and supported by the foreign funded sources and expertise to do this work even better in order to ultimately "improve the rural livelihoods", failed to do so?

9.6 Social Organization of Water Distribution: Whose Irrigation Is "Worthwhile"?

An inquiry into the work processes of the local WUA provided some answers to the questions we ask. We studied the everyday activities of the WUA staff paying special attention to the institutional texts they used to manage water resources. Studying the institutional texts we tracked how WUA's activities were part of the wider processes of the national agricultural production. On the basis of what we found, we argue that peasants' exclusion from the IWRM process was socially organized by the institutional practices working to serve the goals of state export of marketable crops. Participatory and decentralized water management, we discovered, were subsumed under the government administration for agricultural marketing of cotton. The principle of participation in these conditions became selective and attuned to those stakeholders who directly contributed to the market goals pursued by Uzbekistan's government. We explain our findings below.

In the conditions of predominant water scarcity, irrigation in Urto-Yop, as elsewhere in rural Uzbekistan, was managed on the basis of the sequential principle of water delivery. The definitive schedule was multi-level, i.e., inter-regional, inter-provincial, among villages and within villages. Thus, the villages located along one irrigation canal received water in accordance with the schedule established by the state water management organizations and local government. The daily decisions on water distribution were made in the office of the provincial governor. Conforming to this schedule, Urto-Yop received water every 10–14 days and the WUA had three days to address its irrigation needs with the water available. Distribution of water among the water users was accomplished by the WUA staff and their work was conducted as they used specific textual forms that guided their activities. We focused on the actual work that the WUA in Urto-Yop carried out.

Water masters, also called hydraulic engineers, performed the delivery of water to those water users who had been assigned to them by the WUA chairman. After the water masters distributed water they reported to the WUA accountant who consolidated reports and sent them to the provincial department of water management. As illustrated in details in Kim (2014), water masters used standardized reporting forms which contained information on the particular segments of fields identified in numbers (called contours), how much water was received for these fields, how much of a particular field was irrigated, etc. Water masters used this text to guide how and where the water was delivered. One of the water masters said that as he "controls the number of the watered hectares [he] looks at the [reporting form] […], marks which land has been watered and informs the WUA" (Interview, July 2011). Investigating the use of the reporting forms we foud out peculiar aspects of this text-mediated work. We understood that this text expressed relevancy to one category of water users, i.e., the fermers under state-plan for cotton and wheat. For instance, according to the WUA chairman the reporting forms "define the fermers' land only" (Interview, July 2011). Consequently, as Kim (2014) argued, water masters did not consider informing the peasants about the expected arrival of water as their "work", let alone facilitating their physical access to it. One water master explicitly claimed that working with peasants was "not worthwhile" (Interview, July 2011). The analysis showed that being "worthwhile" was textually organized and priorities being assigned to only particular water users were endorsed in institutional texts.

Because the reporting forms served as a basis for further decision making, being ruled out from them meant being cast outside of the institutionally accountable processes (Kim 2014). The smallholders and their use of water became completely invisible to those responsible for water management at the upper levels. The work of the water masters informed the sequence of other actions by the water management administration of higher levels. The WUA accountant pointed out that the report she consolidated from the water masters would be further used by the provincial department of water management (DWRD) for making particular decisions, such as prolonging the irrigation days for the village. The experience of our informant who complained about her failure to irrigate during the last time Urto-Yop received water because "after the farmer had used the water nothing was left for us" (Interview, April 2011) became more understandable. Kim (2014) developed the idea that when the conditions of the smallholders' land and their irrigation needs were institutionally ignored at the WUA scale, their textual invisibility made their particularities unknown to the higher levels of the water delivery system. Indeed, when the WUA staff organized their work around the reporting form, they used it as "instructions" for their work, attuning their activities with its categories. In institutional terms, the work they did was entirely proper, however, it ultimately resulted in a routine and unwitting overlooking of peasants. Needs of peasants remained largely obscured by the local administrative practices of the WUA, the only village institution through which the water could be accessed. This was how women-smallholders' experiences of uncertainty were organized and their agriculture was being constructed as "unworthy" of irrigation. Their subsistence-relevant water needs were taken less serious than the needs of the fermers, in charge of cotton production for the state. The outcome threatened the livelihoods of the smallholders and demonstrated that the IWRM-inspired policy for water management when implemented routinely worked in an inequitable manner.

9.7 Tracking the Ruling Relations

What happens in Urto-Yop in the practices of the WUA happens not in isolation from a larger complex of institutional relations comprising national water governance. We understand that the national irrigation management is subordinated to the institution of the state-led agricultural economy for cotton and wheat. The latter, we see as embedded in the ruling relations whereby people's actions are coordinated by the "institutional discourses that are systematically developed to provide categories and concepts expressing the relationship of local courses of action to the institutional function" (Smith 2005).

Uzbekistan's water management program is composed of standardized practices and institutional texts, and our analysis shows the text-mediated work in which the water policy takes shape "on the ground" in the actions of the WUA and its staff. These actions are coordinated through work done elsewhere, over time, but maintain their constancy through the constancy of the texts organizing the work. In line with previous findings (Kim 2014), one element of our analysis shows how textual coordination maintains the primacy of the ruling focus on irrigating the farmers' marketable crops, even though participatory management is talked about in various and conflicting ways. Texts, generated in the state bureaucracy, "instruct" the WUA work that maintains the institutionally proper delivery of water. Eligibility to receive irrigation, for instance, is a text-mediated process and we describe this process below. In so doing, we discover what provides support for Kim's (2014) argument that the organizing principle of eligibility is the market-orientation of the crops grown by a prospective member and this organization of eligibility works systematically to exclude peasants from equal and reliable access to irrigation.

The ruling relations that the WUA staff enact are traceable in the WUA's institutional documents which link the local settings to the extralocal. People engaged in water management take up those texts, reading them, and treating them as instructions for their work. As Kim (2014) describes in greater detail, the delivery of water follows a process that begins with the agricultural reform in 2002 which reorganized agricultural enterprises into private (fermers') farming entities expressed in the Cabinet of Ministers Decree No. 8 "On measures of reorganization of agricultural enterprises into farming entities", adopted on 5 January 2002. The policy promised "economic development of smallholder and private farming".[5] An appendix to the decree established water user associations to "rationally manage and use water resources".[6] It stipulated definitions and model documents for establishing WUAs such as a charter, agreements, schedules, calculation matrices, etc. The Ministry of Agriculture and Water Resources oversaw the creation of

[5]Paragraph 9 of the Cabinet of Ministers Decree No. 8 "On measures of reorganization of agricultural enterprises into farming entities" (adopted 5th of January 2002), p. 2.

[6]Appendix 7 of the Cabinet of Ministers Decree No. 8 "On measures of reorganization of agricultural enterprises into farming entities" (adopted 5th of January 2002), p. 15.

WUAs around the country and circulated the model policy texts. WUA Urto-Yop received this package from the provincial department of water management (DWRD) and used it since its establishment in 2005. The package included a number of documents, two of which, the charter and the agreement between the water user and the WUA, we analyze below.

WUA Urto-Yop's charter has been argued to be the key text in establishing the legitimacy for certain land to be irrigated and the way that irrigation is to be managed (Kim 2014). The document lists the WUA's main tasks such as scheduling water and delivering it from the state irrigation systems and its distribution between WUA members, as well as maintaining of the on-farm irrigation system.[7] From this text it becomes clear that the legitimate recipients of water delivery services are "WUA members" and those related to the "on-farm" irrigation systems. The latter does not require explanation as its emphasis on farmers is explicit. We look at the category of "WUA members" and find that the definition of this concept is similarly and remarkably farmer-oriented. Kim (2014) explains that the membership is achieved through an agreement between the water user, WUA and the District Water Resource Department. It is registered by being stamped by a water user, WUA chairman and the chairperson of the DWRD.[8] In the interview with the WUA chairman he emphasizes the fundamental meaning of the agreement for the legitimate claims for water by asserting that "agreement is the most important; if there is an agreement, there is water; no agreement means "no water"" (Interview, July 2011). However, certain groups are not eligible for signing an agreement. The WUA accountant explains that "an agreement between (WUA and non-private farmers) cannot be signed because they [peasants] do not have a stamp, while [cotton and wheat] fermers [under state contract] have the contract with the state. They have cotton and wheat…, while they [peasants] do not have a stamp" (Interview, July 2011). Anybody not possessing a stamp, i.e., a smallholder, is ineligible to join the WUA as a member with full rights to access water. Fermers who were initially registered as independent juridical entities have stamps from the moment they were created. Having a stamp was important for entering a land lease contract with the Ministry of Agriculture and Water Resources, obligating them to annual submission of their entire cotton yield and the larger part of wheat produce to the state at a fixed (and much below the market) price, the so-called "state order quotas", in exchange for subsidized land tenure (Kim 2014). Signing this contract was a defining step in becoming a fermer. Smallholders, on the other hand, were a different category, created as "home consumption" farmers and were formalized as "physical entities" which were not expected to contribute to the state agricultural export from what they produce in their fields.

WUA's "membership" category not only legitimizes the receipt of water for irrigation but is a key textual instrument for assigning the "worthiness" status to certain categories of people (Kim 2014). Water masters' report forms are the ruling

[7]WUA Urto-Yop, Charter, p. 1.

[8]Paragraph 9.1 of the "Agreement between water user and WUA Urto-Yop", p. 4.

texts carrying the authority of the charter and the agreement into the work done at the local level. The water masters focus their work on water delivery and distribution exactly between their customers, i.e., members who are fermers. The agreement between the WUA and water user specifies the details of how the water delivery services are administered and these details "instruct" the tasks of the WUA staff in determining proper water consumption. The appendices of the agreement such as "Plan of Water Use" and the "Limits of Water Use" (described fully in Kim 2014) define the amount of water to be received by a signatory to the agreement based on the norms established for irrigating particular crops. These numbers appear in the text of the report form of each fermer. When water masters irrigate they determine the needed amount of water based on the calculated volumes specified in the form. Any difference between these numbers and how much has been really received must be indicated in the report form and is further used for determining the "quality" of irrigation, i.e., another article the water masters mark in the text.[9] Water masters systematically inform the *fermers*, in advance, about the upcoming irrigation time and this contributes to the quality because it allows the farmers to prepare for more efficient irrigation by cleaning the ditches, checking the water pumps, etc. Information about the quality informs decisions made at the higher levels of water management. Kim (2014) explains that at the end of the irrigation period the report form is also signed by the farmer, WUA chairman, DWRD and the land surveyor. This document becomes the evidential basis for fining a farmer if he fails to produce the minimum (contracted to the state under the state quota system) amount of cotton and wheat, as long as the irrigation water supplied was adequate. In cases of low harvest of cotton or wheat due to the lack of irrigation water, the report form can also be used to waive a farmer's payment of the fine for low productivity. In all these ways, the local farmers are linked into the state agriculture apparatus. Of course, the small-holders not participating in the system as the farmers do, are being ruled out by the same text-mediated practices. As it has been shown, not being registered farmers and thus water users, they cannot enter into agreements with the WUA, and cannot access an agreement's benefits. The textually organized work of water planning, allocation and reporting renders them irrelevant or "unworthy" to the work of the water masters, WUA and DWRD.

In Uzbekistan, as mentioned earlier, agricultural production (with cotton and wheat as strategic commodities for export) accounts for 60 % of export revenues and 30 % of its gross domestic product (Asian Development Bank 2001). The state authoritarian control over its agrarian sector to ensure its economic interest from agricultural export subordinates public water management policies. The IWRM participatory and decentralized principles epitomized in the policy concept of WUA have become subsumed under the strongly hierarchical institutional system of land and water resource management in Uzbekistan. The agenda and goals as well as textual technologies of the state agricultural development program are part of the institutional order in which the state's crop export system provides the ruling terms

[9]From interview with a representative of DWRD.

under which the work in the local setting becomes institutionally organized. The everyday work of the WUA, despite its democratic and inclusive promises, generalizes the institutional rule through enacting the standardized institutional texts that had been introduced to improve the farmers' performance in growing contracted crops. The WUA texts "carry" the ruling relations constituting the coordination of the local sites with the extralocal institution and its goals. The institutionally-ruled, locally implemented, water practices entail specific consequences for the household farmers (smallholders) who are not recognized as institutional actors. It turns out that the water policy is being implemented at the historical moment that people in the category of household farmers and smallholders are mainly women. Neglecting women's needs and roles in water use and management explicitly contradicts the principle of participation and decentralization inherent in IWRM and also neglects its pronounced necessity to attend to the genderedness of water resource management.[10]

All the text-based practices identified here construct smallholders as ineligible for membership, thus officially excluded in terms of legitimate water use. As Kim (2014) also reveals, institutional order and its local implementation has the practical effects of making the peasants understood as insignificant to the water management program. In order to grow crops for state markets, the new system of agricultural production and its related water management policies seem to have turned its back officially on smallholders and subsistence production. Our data show that these peasants strive very hard to accommodate their work to this skewed system. They often do it at the expense of their time, work, energy and health, indeed of their livelihoods (Kim 2014). In this sense, women-smallholders absorb the costs produced in supporting the state's marketing of agricultural products as a financial strategy. This outcome is unjust and works to create gender inequality in accessing water for irrigation. We have shown how it happens so that the disjuncture between the official benign intentions and the reactionary, indeed, discriminatory outcomes, are achieved.

Our analysis partly agrees with Biswas (2008) that IWRM, being a mainstream initiative endorsed at high level institutional arrangement and with resources being made available by the international donors, has not prevented many institutions from continuing what they have previously been doing only under an aegis of popular and fashionable paradigm. However, we have gone beyond his observations. We have mapped out exactly how the perpetuation of particular practices actually happens in people's activities, institutional practices and associated texts working as one social organization. By doing so we were able to identify where exactly policy actions must be taken in order to improve the lives and work of the peasants. We believe that paying attention to how and what we have identified as institutional "spots" to be targeted will contribute to an increased understanding about the usability and implementability of IWRM, which has been of concern to many IWRM critics.

[10]Here we refer to the Dublin Principle N 3 on "Recognition of women's central role in the provision, management and safeguarding the water".

9.8 Identifying Suitable Policy Change: Recommendations

On the basis of our findings we further suggest ideas about addressing the troubles identified in the actual practices of water resource management in Uzbekistan. The analysis presented in this chapter points to an overriding categorization and subsequent operationalization that erases all peasants from the institutionally organized irrigation practices and associated texts. We have shown that this entails far-reaching consequences. When water management workers carry out their work activities and make proper use of these texts, this work ultimately rules out peasants and their farming-related needs. As suggested earlier (Kim 2014), we encourage prospective programming to develop rural areas should address this problematic feature of water governance and challenge it. To create space for the peasants to benefit from enhanced water management mechanisms, changes must be introduced in the current definition of eligibility to receive irrigation that will explicitly express them as legitimate water users. We have identified places in the institutional organization of water management where insertion of the category of peasants has the capacity to change matters. What appears necessary is a re-examination of the documents which frame the organization of the national water management system in the Ministry of Agriculture and Water Resources. It is the language of institutional texts that defines water use in a manner in which peasants are not deemed eligible. Tackling these texts and reformulating the concept of water users so that it unambiguously establishes the peasants' rights to claim irrigation services is one first step and would need to be addressed by project (research) staff as a precursor to setting up WUAs. Subsequent work will entail making relevant changes in the institutional texts such as the report forms and WUA charters to be activated in the everyday work of the institutional participants in water management. This recommendation implies a considerable expansion of the work of the water managers, and would create positions for peasants to fill. It requires everybody to be informed and motivated to extend their services to a larger pool of water users. Only if peasants as a category become legitimate water users can the smallholders be seen and accepted as eligible participants in water management. It is our contention that this is the first and necessary step to facilitate meaningful improvements in their lives and their families' lives.

From a methodological, or rather, an ontological perspective we recommend that if all those individuals using water for their agriculture are to benefit from the "improved" policies, in a more genuine participatory manner the starting point of developing a policy-based practice must begin from careful knowing about what people actually do, how they do it, and how they understand their work. This knowledge must form the entry point into how local problems can be effectively addressed by projects. Knowledge generated otherwise will necessarily fail to capture the actual needs, concerns and interests of particular people and will continue to promote the goals of the institution rather than those whose lives are directly affected by it.

One last suggestion we propose is transdisciplinary in nature and appears to be feasible within the reach of researchers who conduct the kind of research that starts from actual people and their local experiences and moves into the exploration of how these experiences are organized. There is a strong commitment on our side to the usefulness of inviting practitioners and institutional players to analyze their own work to recognize its being coordinated by extralocal sources and to encourage them to find areas where it is possible for them to make changes. We believe that the changes they begin to see will serve the interests of the marginalized beneficiaries rather than those of the ruling institution.

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Chapter 10
Water Scarcity Impacts and Challenges of Water Governance in the Guanting Basin, North China. Evidence from Interviews with Local Stakeholders

Ilona M. Otto, Frank Wechsung, Xiaoxi Wang, Jacob Möhring and Rong Tan

Abstract The chapter presents results of an IWRM Project "Sustainable Water and Agricultural Land Use in the Guanting Watershed under Limited Water Availability" and focuses on institutional responses to water scarcity. We present results of interviews with stakeholders from the Guanting Basin on the perceptions of climate change and adaptation needs. The stakeholders interviewed were deeply aware of water shortages and their impacts in the study area. The examples of adaptation implemented on the ground mainly include supply driven measures. We observe weak coordination of water management across various government units and levels. Most of the interviewees believed that taking adaptation action was not within their competency, thinking that the central government or a different administrative unit would be responsible for such measures. The interviewees were aware of potentially promising concepts in water management such as compensation schemes, trade of water rights and weather insurance. Nevertheless, they recognized that these schemes would require larger institutional changes such as the introduction of water rights and fully recognized land property rights.

Keywords Droughts · Water governance · Adaptation · China

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10.1 Introduction

While mitigation of climate change is a known and acknowledged concept in Chinese politics, there is little known about the potential of adaptation to expected climate change impacts. China's National Climate Change Programme established in 2007 indicates that the central government is aware of the severe challenges faced by the country and declares that China will take practical measures to enhance its capacity to adapt to climate change via key projects for ecosystem protection, disaster prevention and other key infrastructure construction (NDRC 2007). In 2008 China released a white paper called "China's Policies and Actions for Addressing Climate Change" which presents policies and actions to adapt to climate change. Local adaptation plans are expected to follow the central strategies (Gemmer et al. 2011). By 2009 all 34 provinces had produced a climate change plan, and the need to adapt is mentioned in the 12th Five-Year Plan for National Economic and Social Development (2011). However, as pointed out by Gemmer et al. (2011), most proposals only exist on paper and their function greatly depends on local governments. The shortcomings are particularly visible in water management. None of the river basin management plans explicitly consider the projected impacts of climate change (Gemmer et al. 2011).

In the chapter we ask how the impact of water extremes and adaptation needs are recognized and perceived by Chinese water experts and representatives of local and regional Chinese administration. The research is framed within the Integrated Water Resource Management concept, which requires a sustainable approach to water management, recognizing (i) its multidimensional character—considering both time and space, (ii) different knowledge fields and disciplines and (iii) perceptions of different stakeholders (Thomas and Durham 2003; Hooper 2003).

Geographically we focus on the Guanting basin which is a sub-catchment of the Haihe River and is located in North China (Fig. 10.1). The most urgent problem in the Guanting basin is the severe and steadily increasing shortage of water resources, accompanied by a low quality of water, an overexploitation of groundwater resources, and soil erosion (Liu and Xia 2004; Hofmann 2010; Mischke et al. 2011). Interregional and intersectoral water competition and water conflicts have arisen in the area in recent years. From the early 1950s the dominant practice in water resource management was the development of engineering facilities to catch and redistribute water. However, it has been recognized that with reduced potential for engineering left within the region today attention has turned to economic concepts and water demand management (Cai 2008). The new concepts require more participatory approaches that take into account the attitudes and perceptions of local actors (c.f. Dinar and Mody 2004; Wang et al. 2007; McEvoy et al. 2010; Otto-Banaszak et al. 2011). In the chapter we present results of in depth interviews with key stakeholders involved in the Guanting Basin management. We investigate their perceptions of climate change and adaptation, adaptation potential, and adaptation barriers and opportunities. We are also interested in the extent to which the different stakeholders are aware of and acknowledge the need for Integrated Water Resource Management in the water scarcity context.

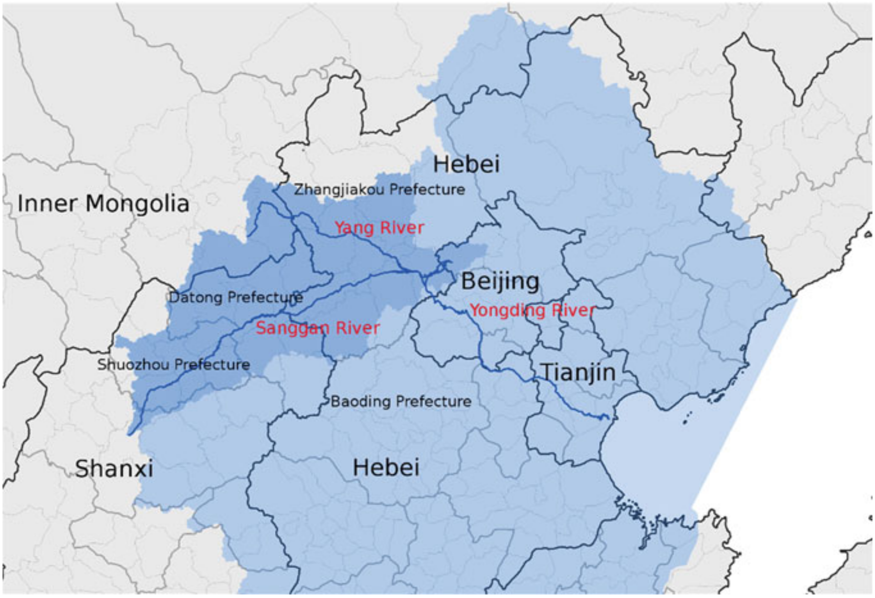

Fig. 10.1 Location of the Guanting basin (*dark blue*) and the Haihe river basin (*light blue*)

The chapter is structured as follows. Section 10.2 presents an overview of the socio-economic situation and water management in the Guanting basin. Section 10.3 outlines the research approach. Sections 10.4 and 10.5 present the research results and finally Sect. 10.6 concludes and discusses policy implications of the findings.

10.2 Introducing the Guanting Basin

10.2.1 Geographical and Socio-economic Situation

The Guanting basin is located North-West of Beijing and covers 43,600 km^2 (Fig. 10.1). The area is inhabited by 8.1 million people (excluding Beijing) of which approximately 54 % is male and 53 % live in rural areas. The basin includes 15 county level administrative districts that belong to the Shanxi province, 13 county level administrative districts that belong to the Hebei province, 2 from Inner Mongolia, and the Yanqing county in Beijing municipality.

The Regional GDP per capita in the basin equated to 3.973 USD in 2009 which was 59 % of the average GDP per capita in China. Agriculture contributes 9 % of the GDP, industrial production 50 % and services 41 %. According to the last available census data from 2000, 63 % of all employees worked in agriculture, 16 % worked in the industrial sector, and 21 % in the service sector. Despite its low share of GDP, the agricultural sector utilizes the largest proportion of water in all prefectures of the Guanting basin, at an average of 71.6 %. The industrial sector and domestic use account for an average of 18.6 and 9.8 % of water use respectively. It is worth pointing out that the agriculture sector mainly depends on surface water with a supplement of groundwater, while domestic use and the industrial sector rely on groundwater which is heavily overexploited (Wang et al. 2013). Surface water is characterized by low quality due to pollution and nutrient emissions from point and diffuse sources.

The name of the Basin comes from the Guanting Reservoir that was build in 1954 approximately 100 km from Beijing. The reservoir covers 253 km^2, encapsulating about 2.3 billion m^3 of fresh water. The original purpose of the reservoir was to protect the land from flooding. It was subsequently used to provide water for domestic use, industries and agriculture in the Beijing Municipality. However, since then, due to continuous droughts at the beginning of twentyfirst century and problems with the quality of the water, the reservoir has served mainly as a source of water for industry (He et al. 2008). The discharge from the reservoir was originally planned to be 44 m^3/s, but the current mean discharge rate is only about 5 m^3/s; there is often hardly any discharge at all. The whole Haihe River Basin itself has been substantially modified with 1879 reservoirs, 6170 water diversion projects, 9000 km of established embankments, over 50 flood drainage channels and 29 flood storage facilities (HWCC 2012; Otto and Wechsung 2014).

10.2.2 Climate and Hydrological Situation and Projections

The Guanting basin is characterized by a semi-humid to semi-arid monsoon climate, resulting in strong seasonally and annually varying rainfalls. Water availability during dry seasons is therefore naturally low. The average surface water availability is 251 m^3/y/cap., which is comparable to the world's driest regions (e.g. Israel's water availability is 300 m^3/y/cap). In the Northern China plain, as a result of the imbalance between surface water supply and the demand for water by the increasing population and agricultural production, ground water resources are depleted to world record breaking levels (Werner et al. 2013).

The average annual mean temperature ranges between 6–7 °C with lowest temperatures in January. Cold winters are associated with with strong and dry winds (Congbin et al. 2008). Over 60 % of the annual precipitation falls between June and August, with the total annual precipitation oscillating between 350 mm and 450 mm (Yihui and Chan 2005). In the last 100 years a rough 50-year periodicity in the fluctuation of precipitation can be detected. At the beginning of the century to the 1940s the climate was dry, turning wet after the mid 1940s and dry again after mid 1980s (Ren et al. 2011). Within this long term periodicity there is a shorter term, 10 year, cycle between wet and dry periods (Jun and Yongyong 2008). In the years 1951–2007 the mean annual temperature increased in the Haihe River Basin by 0.32 °C (Li and Ding 2012). The annual precipitation in the Haihe River

Basin has decreased by more than 100 mm in the last 50 years and the precipitation decrease was most severe during summer (Ren et al. 2011).

Depending on the scenario and the model configuration, future projections show a temperature increase of an average of 2° by 2050. Precipitation is projected to decrease although the resulting trend varies substantially across different climate models. According to the model STARS the summer precipitation will decrease while the spring and autumn rainfall will slightly increase, leading to a blurring of the seasonal precipitation cycle. The large inter-annual variability has a stronger effect on the overall water variability than the seasonal cycle (Wechsung et al. 2014). Surprisingly, the IPCC climate models show an increase in summer precipitation in northern China of 7 ± 7 % above 2000–2006 levels by 2100, under the A1B scenario. The IPCC model ensemble, however, had a very strong variability leading to a low significance of the precipitation simulation results (Piao et al. 2010).

10.2.3 Governance of Water Resources

Water management in the Guanting Basin has been affected by all major societal phases of the People's Republic. After its foundation, there was a major expansion of reservoirs and irrigation districts. The first large scale water engineering projects such as construction of the Guanting Reservoir were inspired by targets for the expansion of the power generation, irrigation and flood control. Self-sufficiency in major agricultural goods production is a long standing principle that has prompted development of the irrigation and drainage networks. After 1978 China launched a series of reforms that triggered economic growth and increased water consumption. At the same time, water pollution exacerbated the problem of water scarcity. Over time the authority for water management transferred downwards from central to provincial and regional authorities. However, the new water law launched in 2002 acknowledged the demand for an integrated river basin management and resulted in the establishment of River Basin Commissions. These act as authorities to balance the needs and interests of water enterprises, municipalities and provinces against the water supply within river basins (Cheng and Hu 2012).

Currently on a regional level, the main actors in water governance are the central government (the State Council), the Ministry of Water Resources, the Ministry of Environmental Protection, and the lower level authorities, such as the departments on the provincial level, and the Haihe River Conservancy Commissions. The Ministry of Water Resources (MWR) is primarily responsible for water policy formulations and implementation at the national level. Water resource bureaus (WRB) in each administrative level are responsible for the implementation and enforcement of water policy. Local agencies also have the authority to issue specific policy measures to adapt to local situations based on the general policy designed by the MWR. In addition, considering the importance of water for the agriculture sector, other agencies besides the WRBs also look after water policy. For instance,

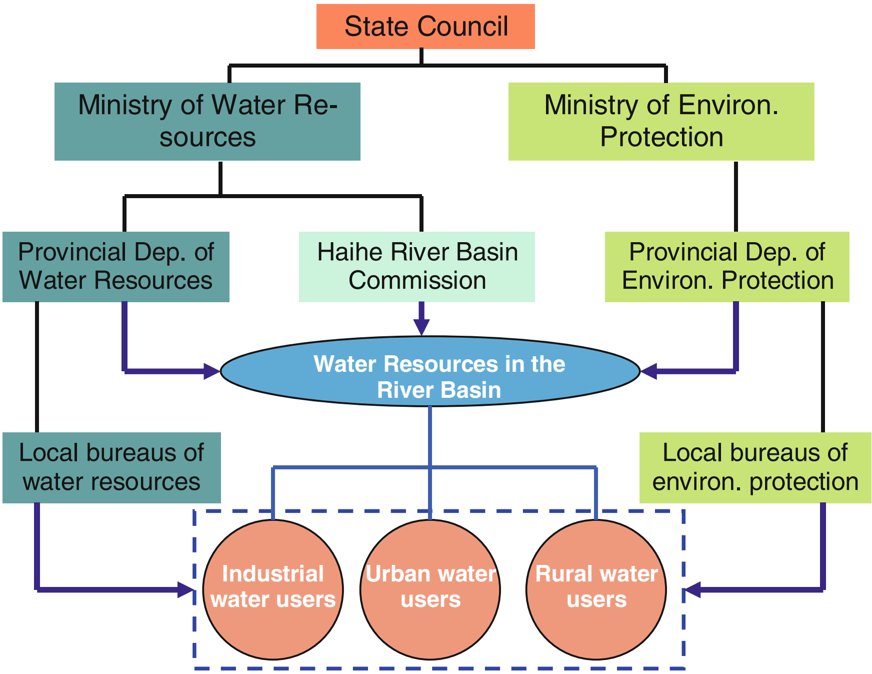

Fig. 10.2 Water agencies in the research area

the water price of surface irrigation is set by the Provincial Price Bureaus, which determines the price an irrigation district commission (IDC) can charge for one cubic meter of surface irrigation water. The Haihe River Basin Commission is a cross-administrative organization, in charge of approving and enforcing provincial water withdrawal plans with respect to cross-region rivers within rivers under the Commission's administration (Fig. 10.2).

Regarding allocation of water abstraction permits, water resources bureaus at or above county level submit water plans to the administrative departments at the next highest level. In cases where rivers run across provinces, river basin plans are devised by the relevant river basin authorities. The Haihe River Conservancy Commissions regulate the amount of surface water transferred to downstream provinces dependent on the degree of water scarcity (Chinese Central Government 2007). These regulations do not function very well in practice. Möhring and Otto (2012) who analyze grain production in the Haihe in combination with temperature and precipitation data show that upstream counties maintain relatively stable grain production. This is the case even in dry years using water accumulated in reservoirs, while downstream counties are more dependent on the weather variability. At the local level, farmers who have few alternative income opportunities, tend to overuse water and fertilizers to maximize agricultural output. Water quality is also affected by heavy industry and mining located upstream.

Several authors provide descriptions of the poor performance of water governance system in China. The problems are associated with the vague delineation between the river basin commissions and administrative subunits of the central governments, and the local branches of these units. River commissions do not usually have the necessary authority to enforce regulation and laws when facing conflicting interests of other government agencies (Cheng and Hu 2012; Wang et al. 2013; Möhring and Otto 2012; Wei et al. 2012). In terms of the institutional interplay, each of the different departments involved in water management see the catchment only from their own perspective. They treat each of their interests, such as 'forests', 'water quantity', 'water quality', 'agricultural production', individually and not as an element of the overall catchment ecosystem. Participation of non-state stakeholders in water management is practically non-existent and there is a lack of political tradition, awareness and opportunities among stakeholders to take responsibility (Wei et al. 2012). Besides the organizational problems, water management in China still appears to be largely supply driven and engineering based. The most remarkable demonstration of this approach is the South-North Water diversion project (Ren et al. 2011) and the extensive use of groundwater resources in the basin (Werner et al. 2013).

According to Cheng and Hu (2012), water management that is more demand oriented could contribute to the improvement of water quality and minimize the negative impacts of water scarcity. Measures such as improved enforcement of policies and regulations, water rights and trading, and improved water pricing could be used. Such measures could stimulate water conservation, water reuse and recycling and improve overall water efficiency (Cheng and Hu 2012).

10.3 Research Approach

10.3.1 Research Methods

The data was collected in 19 in-depth expert interviews that were carried out from August 2010 to May 2011 during two research expeditions. In the interviews we followed a list of 14 questions. The questions were related to (i) the description of the work of the interviewee in respect to the Guanting basin, (ii) water related problems in the basin, (iii) a description of the most important actors, (iv) promising options that could help to improve the water situation in the basin and their perception, (v) cost and benefits of the options, (vi) responsibilities of different actors, and (vii) opportunities and barriers for the implementation of the options. At the end of each interview we also asked the interviewees to fill in a short ranking of 11 different characteristics of options in improving water management. The characteristics followed the framework provided by Otto-Banaszak et al. (2011) and its aim was to determine which characteristics of water management were important to each actor group and any potential conflicts in priorities of the different characteristics.

Table 10.1 List of the interviewees

No. of the interview	Function of the interviewee, organization	Sector
1	Researcher 1, Hebei Provincial Academy of Water Resources, Shijiazhuang	Research
2	Researcher 2, Hebei Provincial Academy of Water Resources, Shijiazhuang	Research
3	Higher Ranked Officer, Soil and Water Conservation Programs, Water Department of the Hebei Province, Shijiazhuang	Provincial administration
4	Engineer, Water Resources Center of the Hebei Province, Water Department of the Hebei Province, Shijiazhuang	Provincial administration
5	Engineer, Beijing Hydraulic Research Institute, Beijing	Research
6	Official, Water Saving Irrigation Unit, Zhangjiakou Water Resources Bureau, Zhangjiakou	County administration
7	Higher Ranked Officer, Sustainable Water Resource Management around Capital Project, Zhangjiakou Water Resource Bureau, Zhangjiakou	County administration
8	Higher Ranked Officer, Ground and Surface Water Monitoring, Zhangjiakou Water Resources Bureau, Zhangjiakou	County administration
9	Engineer, Water and Soil Conservation Unit, Zhangjiakou Water Resource Bureau, Zhangjiakou	County administration
10	Engineer, Water and Soil Conservation Unit, Zhangjiakou Water Resources Bureau, Zhangjiakou	County administration
11	Higher Ranked Engineer, Zhangjiakou Water Resources Bureau, Zhangjiakou	County administration
12	Higher Ranked Official, Huai'an Water Resources Bureau, Chaigoubu	County administration
13	Engineer, Hebei Provincial Academy of Environmental Science, Shijiazhuang	Research
14	Higher Ranked Official, Hebei Bureau of Hydrology and Water Resources Survey, Water Resource Department of the Hebei Province, Shijiazhuang	Provincial administration
15	Professor, School of Water Resources and Environment, China University of Geosciences, Beijing	Research
16	Engineer, Beijing Hydraulic Research Institute, Beijing	Research
17	Employee, Water Management Office, Zhangjiakou Water Bureau, Zhangjiakou	County administration
18	Analyst, Private Insurance Company, Europe	Business
19	Higher Ranked Official, Hydrological Bureau, Haihe River Conservancy Commission, Tianjin	River basin administration

The interviewees were selected using snowball sampling (Vogt 1999; Atkinson and Flint 2001). We started first to interview Chinese researchers from our project team and then we asked them to recommend people from the water administration that they thought were important sources of information on the governance of the river basin. One of the researchers also recommended we talk to an expert from the insurance sector. Each interview lasted about 1 h. Table 10.1 presents a detailed list of the interviewees.

10.3.2 Data Analysis

All the interviews were recorded, transcribed and analyzed with the Nvivo software that helps to assess the frequency of certain topics that appear in the interview and their context. We analyzed the interviewees according to three main topics: (i) perception of climate change and adaptation, which focused on the overall perception of climate change impacts and the understanding of adaptation; (ii) adaptation potential, which focused on the identification of promising adaptation options; and (iii) adaptation barriers and opportunities, which identified the most frequent barriers to implementation of the promising options as well as the opportunities that could facilitate adaptation. The data analysis was also supported by facts and numbers from statistics and reports that the interviewees shared with us during the interviews.

10.4 Perception of Climate Change and Adaptation by the Interviewees

10.4.1 Perception of Climate Change Impacts

Decreasing surface and ground water availability, irregular flows of surface water, and poor water quality were seen by all interviewees as the main problems in the research area. Regarding the reasons for the water shortages, the interviewees thought the main role is played by climate change and the overuse of water resources, together with land use changes and increasing populations, particularly in the Beijing area. As pointed out by a higher ranked official in the Sustainable Water Resource Management around Capital Project employed at the Zhangjiakou Water Bureau, some rivers, including the Yang river, have almost completely dried out (Fig. 10.3). Practically all interviewees also mentioned the decreasing ground water levels.

Interestingly, local officials from the Huai'an County and Zhangjiakou Prefecture explained the water shortages not only in terms of climate change but highlighted conflicts over water allocation between different provinces and sectors. In their opinion not much water is left for the local needs after engineering and transference of water to the reservoirs in the Beijing area. In addition, as they explained, farmers only obtain water after the needs of municipalities and industry

Fig. 10.3 Drying out rivers in the Zhangjiakou Prefecture

have been fulfilled. Since agriculture is given the lowest priority in water allocation, farmers are highly vulnerable to water deficits.

Water deficits in agriculture also linked to the problem of non-point pollution. As explained by the engineer from the Hebei Provincial Academy of Environmental Science, farmers wanting to intensify agricultural output under limited water availability, use excessive amounts of fertilizers and pesticides. These are partially subsidized and thus relatively inexpensive. The interviewee perceived that the excessive use of fertilizers and pesticides in agriculture has been seen as the main source of pollution in the rivers.

10.4.2 Awareness and Understanding of Adaptation

In general, the interviewees were not familiar with the term "adaptation to climate change" and admitted that future climate projections and possible climate change impacts were not taken into account in the projects carried out on the ground. There was a limited awareness of adaptation and the risk management approach, not only among the interviewees representing the local administration but also among the interviewees representing the provincial administration and the Haihe River Commission: "At the first stage of planning, even at the top level of the Ministry, they don't carefully consider the impact of climate change to the upstream waters of the Guanting reservoir." (Higher ranked official, Sustainable Water Resource Management around Capital Project, Zhangjiakou Water Resource Bureau).

As reported by several interviewees, in the research area there have been a few large soil and water conservation projects implemented, however, in most cases their main goals were not directly related to reducing climate change impacts. Except for erosion control and soil protection, mainly through land terracing the projects aimed at increasing productivity of the farmland in the poor areas and providing income for farmers. Another group of large projects that were reported, focused on water saving in agriculture. They were directly linked with increasing water use efficiency. The engineer in the Water and Soil Conservation Unit in the Zhangjiakou Water Bureau calculated that lining the water canals improved water use efficiency in the water saving project areas from about 30–40 % to about 80 %. In addition, he said that many rain collection facilities have been constructed in the research area. Only in the Zhangjiakou prefecture about 28,000 rain collection tanks have been installed. The costs of the projects were covered largely by the central government and local farmers contributed labor.

Other examples of actions potentially related to adaptation that we indentified in the interviews include subsidies to farmers for changing crop structure as well as legal and financial instruments targeted mainly at industry. For example, as reported by the engineer from the Water and Soil Conservation Unit in the Zhangjiakou Water Resource Bureau, farmers get a subsidy from the government if they don't plant rice that needs more frequent irrigation. They can get 500 yuan per μ[1] per year if they don't plant rice. The industry is encouraged to use new water saving technologies, and if they don't comply, the Water Bureau cuts some of the subsidy from their water tariffs. Similarly, domestic water users are encouraged to change to use water efficient household appliances.

At last, there are big water transfer projects under construction in the North-West and South-East parts of the basin. Despite awareness of its adverse ecological consequences and high economic costs, as reported by the engineer from the Beijing Hydraulic Bureau, there is no other choice: "The South-North water diversion project has been constructed. It will transfer several million m^3 water per year. It is hard to say whether it is good or bad. The reality is that there is no water in the North. The project is very costly: it is not good for the environment and ecology, but in Beijing groundwater decreases several meters every year. There is no choice, no water."

The local interviewees reported that a range of mostly spontaneous individual adaptation measures had been implemented. These included the use of plastic films and greenhouses in agriculture and simply switching to the use of ground water. As reported by the Water Saving Irrigation Specialist from Zhangjiakou Water Bureau, the total irrigation area has remained stable in recent years, showing that decreasing availability of surface water is compensated for by increasing groundwater use.

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[1]Chinese unit of land size, 1 hectare = 15 μ.

10.4.3 Promising Adaptation Options

Practically all the interviewees suggested some options for using water more sustainably. A few interviewees stated the need for an integrated water resource management approach. The interviewees believed that water saving engineering and application of new technologies should be complemented by the improvement of management and monitoring policies: "First we should have integrated and good policies in each water use field (…). We have to consider how to encourage water transfer from a water use field to a high water use field. This is a policy concept. Second, we should have effective measurement equipment to determine how much water is allocated between different fields. We have to measure how much water is used and calculate water use efficiency in different fields. Although we allocate water from the highest level to the bottom level, we still do not know how to monitor it." (Engineer, Water and Soil Conservation Unit, Zhangjiakou Water Resources Bureau).

Another interesting option that was highlighted in a few interviews is the development of a system of compensation to water users for using less water. According to the higher ranked engineer at the Water Resource Bureau in Zhangjiakou this should be developed in the whole basin. Downstream Beijing, where there is high economic development, should compensate Shanxi and Hebei provinces for delivering a sufficient amount of water: "In the upstream there is more and more industry that needs more and more water. This industry doesn't use water saving technologies (…). I think the downstream Beijing government could compensate the upstream governments and these monies could be spent on the implementation of water saving technology." (Engineer, Beijing Hydraulic Research Institute). According to this engineer, there were some pilot projects on the ground, but the amount of money offered for compensation was too low to motivate the upstream users to save water. Consequently the pilot projects failed. The development of a system of water compensation was seen as a precondition for introducing water rights and monitoring of water use. As reported by researcher 1 from the Hebei Water Research Institute, the Development and Planning Department at the Hebei province administration is interested in this idea at the moment and they plan a pilot research project in cooperation with the Hebei Provincial Academy of Water Resources.

Interestingly, options involving the establishment of water markets such as water trading were not mentioned.

Regarding promising adaptation options in agriculture, the interviewees listed green houses, changing the composition of species, land terracing, plastic films that reduce evaporation from the soil, and precise irrigation such as sprinkle and drip irrigation systems. As mentioned by the interviewees from the Huai'an Country, precise irrigation can currently only be used in areas irrigated with groundwater, since the surface water contains too much sediment that blocks the irrigation pipes. The higher ranked official from the Hebei Bureau of Hydrology and Water Resources at the Water Department of the Hebei province administration said that limiting agricultural production and buying food on world markets is also an option. A few interviewees also mentioned legal instruments such as water use regulations under different water scarcity levels and more frequent plant controls.

Finally, the analyst for the private insurance company, said that financial instruments such as drought insurance could be a promising tool to decrease farmers vulnerability. However, as he reported, at the time the research was carried out, insurance was only available for industry, there being no insurance programs for individual farmers: "Commercial insurance could replace financial relief provided by the state (…). The state currently takes only a very small share of weather related losses (…): I guess only about 1 % of total losses (…). The priority of the government's financial support is given to larger farmers or larger farmer organizations. Individual farmers have only a small proportion of their losses covered. The private sector could fill this gap between the governmental support and the real amount of losses." (Analyst, private insurance company).

As reported by the analyst from the private insurance company, the agricultural weather insurance market in China is potentially attractive for international insurance companies. However, the majority of farmers have small land plots with limited property rights and this increases the costs and risks associated with entering this market.

10.5 Barriers to, and Opportunities for, Adaptation in the Guanting Basin

10.5.1 The Role of Uncertainties and Knowledge Gaps

The first important barrier to adaptation that we indentified in the interviews was related to knowledge gaps at different levels of water management. Although the water in the area is extremely scarce, as reported by the interviewees, at the time of the research there was no reliable information system on how much water actually exists in the basin and how much water is used by different users. As pointed out by the engineer in the Water Resources Center at the Water Department of the Hebei province, a water monitoring system is urgently needed.

As stated by the higher ranked official in the Ground and Water Monitoring Unit at the Zhangjiakou Water Resource Bureau, "(…) currently the regional water capacity is not known. This should be a basis for making good use of the water resources (…). It is necessary to have a scientific water price assessment for different sectors and areas". A similar opinion was also expressed by Researcher 2 from the Hebei Provincial Academy of Water Resources: "We need predictions about the flow and rainfall in order to know how much water to allocate from the highest level to the lowest level. They [the administration] do not know how much water can be expected in the area in the future." A part of the problem is that some data is missing. However, we noticed that there is a weak information exchange between different units and departments responsible for water management in the basin. Our interviewees often reported that a certain problem was not within their competencies, to give an example: "In our office we just do some management work, we don't do the field test observations. This kind of work belongs to the Hydrology Water Resource Bureau." (Higher ranked official, Sustainable Water Resource Management around the Capital Project, Zhangjiakou Water Resource Bureau).

Farmers were reported by other interviewees to lack training and information: "The fertilizer is expensive, but the government gives some subsidy: about 100 yuan per mu per year (…). It is very easy and convenient to buy pesticide; it is just hard to know how much to use." (Researcher 1, Hebei Provincial Academy of Water Resources).

10.5.2 Weak Monitoring and Coordination

Another barrier to adaptation we identified was weak enforcement of rules of the water use. For example, as reported by officials from the Zhangjiakou Water Bureau, in the case of drilling wells without permission there are practically no sanctions on farmers who drill wells illegally: "According to the law, the farmer who drills an illegal well should pay a fine. But it is hard to punish them. Usually farmers are very poor; they don't have money to pay the fine. (…). Also, sometimes the local government wants to encourage more development and more production so they don't punish the drilling of illegal wells." (Higher ranked official, Ground and Surface Water Monitoring, Zhangjiakou Water Resource Bureau).

Weak monitoring and enforcement was also perceived to be a problem at the higher level of water governance: "Upstream and downstream users are together responsible for the problem of water scarcity (…). Upstream users, particularly industry, use too much water and then there is not enough left for others." (Engineer, Beijing Hydraulic Research Institute). This engineer suggested that only a strong river commission could improve the situation: "There should be one commission for the whole basin who should be responsible for management and for solutions of the problem of water scarcity (…). The current Haihe River Commission can solve some problems, but their capacity is limited (…). It doesn't have the power to solve the problem (…). For now the priority is development." (Engineer, Beijing Hydraulic Research Institute). As we were told by officials from the province administration, local governments are strongly focused on reaching development objectives since they are evaluated on their growth rate rather than their capability of saving water or contributing to environmental policies.

Due to different local rules, high entry barriers to international companies functioning in the insurance market were reported. It is very difficult for them to enter local markets. Negotiations have to be done separately with each local government: "The necessity to cooperate with a high number of various state and state related organizations increases transaction costs of new projects that could alternatively be implemented by the private sector" (Analyst, private insurance company).

10.5.3 Allocation of Responsibility for Adaptation to the Central Government

Interestingly, in contrast to adaptation practices in Western countries (e.g. Otto-Banaszak et al. 2011), practically all the interviewees believed in a strong and principal role of the government in the proposed changes. The interviewees allocated the responsibility for adaptation and its associated costs to the government, to give an example: "All government organizations should work together. For example the central government could provide the policy and investment. Then local government could teach farmers (…) which crops shouldn't be planted (…). The government should first find the crop which is suitable and then encourage farmers to switch their production to the crop (…). The farmers lack education, but if the government does more to open their eyes and enlarge the market for the proposed product, then farmers will follow." (Higher ranked official, Hebei Bureau of Hydrology and Water Resource, Water Resource Department of the Hebei province).

Financial instruments, such as insurance schemes, are frequently delivered by private companies through the market in other countries. Despite this, the analyst from the private insurance company believed that in China the government should be responsible for introducing such schemes.

As presented in Fig. 10.4, the most important characteristic of potential adaptation options to water extremes identified by our interviewees was whether the

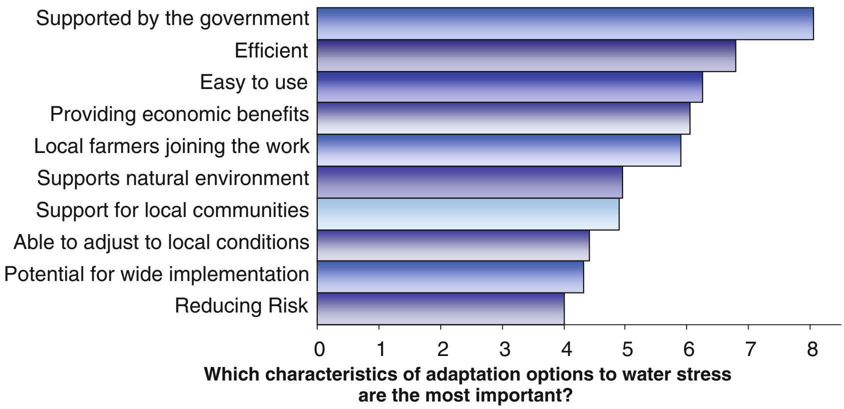

Fig. 10.4 Interviewee's ranking of characteristics of promising adaptation options to water extremes (10—most important, 1—least important)

option is supported by the government. Other important attributes of potential adaptation options included (i) efficiency of the option, (ii) whether the option is easy to use, (iii) whether it can provide economic benefits and (iv) whether farmers provide their labor during construction.

Nevertheless, despite the strong belief of the interviewees that either the central or local government should finance measures to deal with extreme weather events, there is a low willingness to participate in joint actions and governmental projects. The projects are financed by the government, and local farmers in theory should contribute labor. However, as reported by the higher ranked official in the Soil and Water Conservation Programs at the Water Department of the Hebei province, although the maintenance work in the big soil and water conservation projects was planned to be done by farmers, in fact the farmers do not want to work for free.

10.5.4 Central Planning

As reported by interviewees from the research sector, central planning results in many benefits to the Chinese economy, however, in water management projects it has certain adverse effects. The centrally planned projects were evaluated as lacking flexibility that would allow them to adjust to local conditions: "The government provides some funding to the local government to protect the environment, mainly to control sand and storms. But in fact the results are not so good (…). Some areas are very suitable to planting trees, but in some areas, for example in Inner Mongolia the area is suitable to plant grass. But if you plant grass you get less money from the central government. This is also a problem because the trees use groundwater, making the situation even worse." (Researcher 2, Hebei Water Research Institute).

A few interviewees reported that local governments need more autonomy and more flexibility: "At the moment policies are issued by the central government, the ministry of water department or the provincial water government. The lowest level, like the city level or the county level, does not have the right to issue or to carry out some policies. It takes a long time to issue a policy, and to move from the highest to the lowest level in the decision-making. Often it is too late as the situation is constantly changing." (Engineer, Beijing Hydraulic Research Institute). The same interviewee also believed that local governments should have more flexibility in setting water prices. Currently the prices are set at the provincial level and they do not take into account sub-regional differences in water availability.

10.5.5 Opportunities for Adaptation

The interviewees indicated that in China there is a strong tradition of highlighting good examples and demonstration projects and people are willing to follow such examples. Even farmers are willing to follow innovations if they can see that it

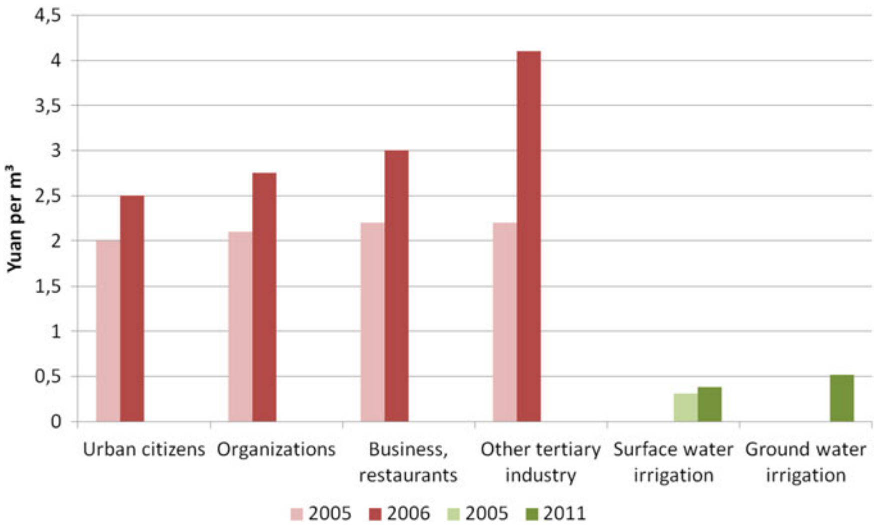

Fig. 10.5 Water prices in the Zhangjiakou county (*Source* data acquired in the Zhangjiakou Water Bureau Office; the price of ground water reflects average pumping costs)

works well in practice. As mentioned by the Researcher 1 from the Hebei Provincial Academy of Water Resources, lessons could be also learned from policies and tools used in other river basins in China. For example in the Qiantang river basin there was the first case of trading of water use rights in China between the Yiwu and Dongyang counties. As the researcher reported, the transaction occurred despite a regulatory environment where water rights and rules governing them were not clearly defined (the example is also discussed in the scientific literature, e.g. Speed 2009).

The same researcher mentioned that water trade between different areas and sectors, as well as introducing compensation to farmers for decreasing their water use, could play an important role in the Guanting basin. According to the information we obtained in the Zhangjiakou Water Bureau, the price that farmers pay for water is up to ten times lower than the price other water users pay and at the same time they consume the highest share of water resources (Fig. 10.5). The researcher from the Hebei Provincial Academy of Water Resources believed, that firms producing a higher value goods could compensate farmers for using less water and decreased agricultural production.

Although, as discussed earlier, the big centrally planned projects were reported to have certain disadvantages for water management, they were also perceived as resulting in a quick target achievement. It was not directly expressed by our interviewees, but adaptation could potentially advance quickly if targets could be set on specific adaptation options.

Furthermore, despite weak formal monitoring mechanisms, as was reported by the director of Huai'an Water Resources Bureau, there are strong informal ties within villages, and neighbors observe and control each other. There are informal sanctioning mechanisms in place if someone withdraws excess water, and also informal reward mechanisms if someone uses less than their share. Informal networks also play a role in contacts within the administration. Despite a lack of formal coordination mechanisms, some exchange and cooperation between government units and levels takes place as a result of informal connections between employees of various units and departments. Several times we have heard during the interviews that our interviewees have friends and former school or university mates in different departments and units and in case we would like to talk to someone else or acquire some data they could put us in touch with them.

It also seems that the Chinese stakeholders share rather similar mental models in respect to climate change impact and adaptation. Stakeholder conflicts related to different prescriptions how to adapt, that frequently block adaptation in the Western Countries (c.f. Otto-Banaszak et al. 2011), were not an issue in the interviews.

Finally, although it was again not directly mentioned by our interviewees, a big opportunity for the advancement of adaptation in the basin can be seen in its rapid economic development. The research area is located relatively close to the two megacities of Beijing and Tianjin which attract investment. This is accompanied by technology exchange and development, which is also applicable in the water sector. A few times during our Project duration, officials from the Hebei Province and the Haihe River Conservancy Commission visited project partner institutes in Europe during which they also met water industry representatives. During informal talks, the European business and industry representatives expressed worries about the weak legal protection of patent rights in China, hampering investments, especially of smaller foreign companies, in China. Adoption and development of water saving technologies could therefore be supported by institutional mechanisms such as the setting of technology standards and certifications.

10.6 Conclusions and Policy Implications

In the chapter we investigated how adaptation needs are recognized in China by regional and local stakeholders and the factors hindering adaptation at the regional and local level. We focused on the Guanting basin, which is one of the regions most exposed to water scarcity in North China. Interviews with local and provincial water administrators and experts show that climate change impacts have so far not been taken into account in planning water management in the basin. However the interviewees were deeply aware of water shortages and their impacts in the study area. The interviewees were also able to list a whole range of options that could potentially decrease the water stress. Many of the most promising options were in line with the Integrated Water Resource Management principles, and several interviewees, especially from the research sector, were aware of and mentioned the need to implement Integrated Water Resource Management in the Guanting Basin. However, the practice on the ground at the time of the research, seemed unrelated to the principles of Integrated Water Resource Management. The local stakeholders felt they had only a weak voice in the water allocation system, and we did not observe the inclusion of non-state stakeholders in water management. The measures implemented were mainly supply oriented, and several institutional inefficiencies were reported such as weak monitoring and enforcement.

Following Wilby and Dessai (2010) and Kundzewicz et al. (2008), we identified a high level of uncertainty about the actual climate change impacts at the regional and local level. All the interviewees were aware of water shortages, but many believed that after several dry years, wet years must eventually come. The institutions of water management, namely rules of water allocation and rules of information sharing on water availability levels within different provinces, prefectures, and government units in the basin, did not cater for the situation of permanent drought. For example, during interviews we observed that the administrators only had access to data on the prefecture or at best at provincial level. They did not have an overview of data on the whole river basin. Due to the character of central planning, the interviewees reported time lags from recognizing a problem at a lower level, to responding to it by issuing a policy by a higher level and finally to implementation.

Furthermore, water management in the basin is separated into different sectors and levels. The coordination across scales is also weak as there is weak rule enforcement (Wei et al. 2012). This problem is related to the actors' perception of the decision-making process and interactions with different levels of the government (Moser and Ekstrom 2010). Most of the interviewees believed that taking action was not within their competencies and they thought that the central government or a different administrative unit was responsible for adaptation. This contrasts with results of similar interviews carried out with stakeholders in Europe, where adaptation based on individual responses or participation of non-governmental organizations and private firms was more evident (Otto-Banaszak et al. 2011).

The most serious barriers to adaptation were related to the current institutional and policy settings. For example, local governments are forced to report higher economic growth indicators every year and in remote areas increasing irrigated production area or tolerating water intensive industry are important ways of improving the local economic growth indicators. Adapting to water extremes and saving water is not currently supported and not rewarded by the system which measures the performance of local governments.

Several interviewees pointed out the promising roles of the trading of water rights and compensation schemes for using less water. Water sold to agricultural water users is a few times cheaper than water sold to urban and industrial water users. Currently, the amount that farmers in Northern China can afford to pay for water is below its true economic value (Cai 2008). Potentially, farmers in the research area could make their living from rain-fed crop production alone, with compensation for abandoning irrigated agriculture. A precondition for implementation of this option is an institutional recognition of the water rights of different water users. Lack of fully recognized private property rights also blocks certain financial options such as drought insurance. Local governments and village leaders control land tenure rights, reallocations and farm land acquisitions still take place although they are formally not permitted (Mullan et al. 2011). Private insurers, who consider for example, selling weather insurance to private farmers, currently face high transaction costs in separate negotiations with each local government.

To conclude, there was a wide-spread awareness that adaptation to water extremes in China requires an institutional change not only in the Chinese water sector but also in Chinese policy objectives. Adaptation, unlike mitigation, happens locally, and requires flexibility and adjustment to local conditions, information exchange and learning (e.g. McEvoy et al. 2010). This is difficult to achieve in China, where on the one hand policies are issued in a top-down manner, but on the other hand their implementation depends greatly on local governments (c.f. O'Brien and Li 1999). An improved coordination of governmental departments and agencies within river basins and across sectors, as well as a stronger involvement of non-governmental actors could speed up the adaptation process.

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Chapter 11
Addressing Water Conflicts Through Context-Specific Institutional Analysis: A Handbook for Research Projects and Programmes

Jan Monsees, Ross Beveridge and Timothy Moss

Abstract An approach is presented to address adequately the prevailing political and institutional constraints and opportunities of IWRM projects across different domains. The proposed means to achieve this is presented in '*The IRS Handbook'* which provides an inductive, 'bottom-up' analytical framework and a methodological guide for utilisation plus an appendix of useful resources. The overall objective is to facilitate the embedding of these projects within specific socio-political contexts, rather than alongside or in conflict with existing institutional structures and practices. The IRS Handbook has four key elements. First, a *four-stage analytical approach* is presented ('Water Storylines', 'Domains of Problems/Solutions', 'Political and Institutional Feasibility' and 'Ways Forward'). Second, it is *two-speed* in design: a Fast-track version has been designed to fit with planning or pilot stages of projects. The In-depth version is intended to be used in the main phase of a R+D project. Third, it is *modular* in form: in each stage key approaches in the literature are detailed and linked into the overall framework in a modular fashion with suggestions as to how research could be extended or supplemented in important areas. Fourth, the framework encourages *iterative* research,

The chapter summarizes the online document "The IRS Handbook. Analysing institutional and political contexts of water resources management projects" authored by Beveridge et al. (2012a) which is an outcome of the research project "Strengthening Integrated Water Resource Management through institutional analysis: an analytical tool and operative methodology for research projects and programmes (WaRM-In)", funded by the German Federal Ministry of Education and Research (BMBF), 11/2010–07/2012. The cited online document is also available in German (Beveridge et al. 2012b).

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so that the researcher regularly tests and updates findings in what will normally be a changing institutional and political context. Overall, the IRS Handbook provides orientation for the best ways forward for most feasible solutions and an assessment of how less compatible solutions could be supported, including ways of adapting existing institutional arrangements.

Keywords Institutional analysis · IWRM · Water politics · Handbook

11.1 Introduction: The Institutional and Political Challenge of IWRM

Water management is inherently difficult and it is now widely accepted that water problems are not merely 'natural' or 'technical' but are, rather, a problem of governance (Molle et al. 2008, 4), often a result of the 'politics of water' (Mollinga 2008). Implementing solutions for water problems effectively is dependent on a wide range of interlinking factors: the socio-political context of planning, institutional arrangements, development and management practices, the form and effectiveness of legal frameworks, funding levels, socio-economic and environmental conditions, access to technology, governance modes and issues (e.g. transparency, corruption, etc.), educational and development levels, and the quality of research on water problems (Biswas 2004). "Sensitivity to the institutional and political dimensions of water management is fundamental to achieving any success in implementing IWRM (Integrated Water Resources Management)" (Beveridge and Monsees 2012).

Within this context the adoption of an 'integrated' approach like IWRM must be seen as both highly ambitious and very challenging to those involved in implementation (Mitchell 2005). This is particularly the case for project managers and researchers who are tasked with turning laudable objectives and principles into on-the-ground practices in often complex local contexts. Frustration has emerged with the lack of progress in implementing integrated approaches and many IWRM projects, especially those in Developing and Transition (D&T) countries (Beveridge and Monsees 2012), have been criticised recently for failing to address adequately the prevailing political and institutional circumstances at local, regional, national and transnational scales (e.g. Biswas 2004; Conca 2006; Molle 2008; Butterworth et al. 2010).

It is increasingly recognized that practical support on the ground is needed to help tune the interventions to fit the institutional contexts of implementation (Chéné 2009; Saravanan et al. 2009). International organizations may have devised toolboxes (e.g. GWP no date) and academics decision-making support systems (e.g. Giupponi 2007) to help implement IWRM, but they do not provide practitioners with the means to apply these off-the-peg guidelines in specific contexts of implementation. Such tools may alert managers to general institutional issues, but projects need to incorporate continuous analysis of the institutional opportunities and constraints as a core feature of their work programmes. There is, then, a need to strengthen social science research within IWRM projects. To support this process, guidance is required on appropriate analytical approaches and methods. To this end the Institute for Regional Development and Structural Planning (IRS) has devised '*The IRS Handbook*'.

In the following we will introduce in Sect. 11.2 the rationale, methodological approach and structure of the IRS Handbook as well as recommendations on how to use it. Section 11.3 then explains the general analytical framework in detail, covering in four subsections the four stages of research that structure the IRS Handbook: 'Water Storylines', 'Domains of Water Problems/Solutions', 'Political and Institutional Feasibility' and 'Ways Forward'. Section 11.4 summarizes and reflects on opportunities for applications of the IRS Handbook.

11.2 Addressing the Challenge of IWRM: The IRS Handbook

11.2.1 The IRS Handbook's Rationale

By employing a 'bottom-up' approach to research, the overall aim is to help project managers adapt the principles of institutional analysis to contexts of action. Our approach focuses on problems and solutions. The premise is not that these exist a priori and the task is simply to identify and tackle them. Rather problems are inseparable from people (and their perceptions), domains (in which they live and act) and possible courses of action (which they think could achieve a desired future situation) (Roth 1995). The key for research is to reveal the different ways in which problems are defined and constructed by actors so that the project can frame problems and solutions appropriately. It is about accepting the importance of power and the fundamentally political nature of these processes and water resources management in general.

The IRS Handbook provides an analytical framework to refine projects in both planning and implementation phases, a methodological guide for utilisation, an appendix of useful resources and general advice on the often difficult task of finding the information necessary to identify relevant political processes and institutional arrangements. By 'institution' we mean not only "those legal, political and administrative structures and processes through which decisions are made" (Ingram et al. 1984), but also the formal and informal rule systems (Mayntz and Scharpf 1995) and meaning contexts (Schmidt 2010) which shape actions. By 'political' we mean the "social relations of power" (Mollinga 2008). Water politics then is about the contestation of power and practices and prompts a concern for a "range of interaction patterns in water management, including negotiation and struggle, and also less explicit and longer term disputations and controversies" (ibid.). By encouraging and guiding a thorough assessment of institutional and political conditions, the handbook facilitates the embedding of policies and projects within specific socio-political contexts, rather than letting them run alongside or in conflict with existing institutional structures and practices.

Although the IRS Handbook primarily addresses the social scientist who is tasked with conducting institutional and political analysis in a water research project, it has also been written to accommodate and inform the project manager or, more generally, someone from a natural science or engineering background. Because the approach outlined here focuses the researchers gaze on contextual conditions, on the specificities found in a particular place at a particular time, it can be used in water research projects in different places all over the world, whether in Europe or beyond, notwithstanding the huge differences between EU and D&T country contexts (as well as between countries within each group). Accordingly, the premise of this handbook is that IWRM projects' objectives should be context-specific, attuned to the problems of water resources management in a particular place and sensitive to the existing institutional and political arrangements found there.

There is a need to put notions such as IWRM into context: to move from global, exogenous 'solutions' to local, endogenous plans of action (see Fig. 11.1). The realities of local contexts resist the ideal types and standard models which populate

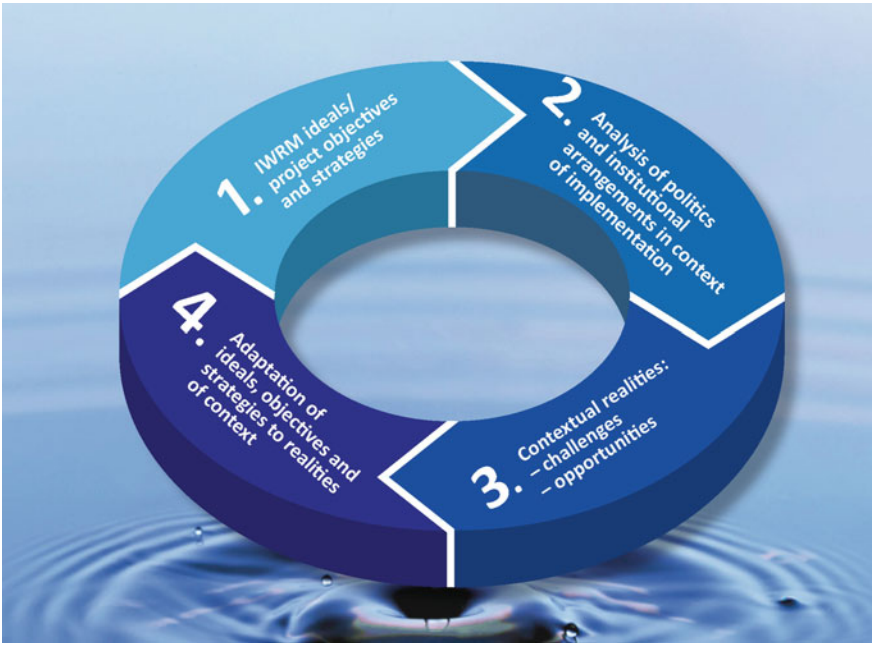

Fig. 11.1 Putting IWRM in context (Reproduced from Beveridge et al. 2012a)

much of the literature on water resources management. The key for projects is to address the institutional and political challenges typically encountered when implementing integrated approaches: e.g. problems of institutional interplay and spatial fit, lack of participation, equity and accountability, a general mismatch with needs and conditions in specific places (see Beveridge and Monsees 2012 for a detailed discussion). Conversely, detailed, continuous analysis should also reveal opportunities for achieving needs-based, context-sensitive reform. Hence, our analytical framework sets out an inductive, 'bottom-up' research process. Rather than starting with a theory and hypothesis of how things are, or should be, research begins with observation and learning, before moving to analysis and the proposal of ways forward. In this way we hope to encourage problem- and people-orientated reform and avoid the pitfalls of 'one-size-fits-all' approaches which often characterise mainstream research.

11.2.2 The IRS Handbook's Methodological Approach

First, it is important to note that the IRS Handbook does not draw on a single theoretical literature nor does it 'impose' a single analytical approach on researchers. Instead, it develops from a number of literatures an overarching approach to doing political and institutional analysis in water resources management projects. Therefore, the handbook was developed through detailed research of the literature and, crucially, in close conjunction with project managers and researchers themselves. The goal was to devise an approach which combines state-of-the-art research with an appreciation of the realities of working in water management projects. The first step was to review the institutional and political challenges of adopting integrated approaches to water resources management. From this we produced a database of approximately 500 titles, identifying key institutional and political challenges of IWRM in (a) D&T countries and (b) EU countries. We then validated these findings with expert interviews and two expert workshops addressing real experiences in the field. The criticisms of current practices which emerged informed the design and content of the analytical framework.

The second step was to consider the range of frameworks and tools of institutional analysis currently available. A database of frameworks was produced from a search of 30+ organizations, 35+ journals, 25+ databases and 15+ research projects globally. These provided the inspiration and building blocks for the analytical framework and supporting research resources. Following this we developed, tested and refined the analytical framework and operative methodology through active engagement with project managers and researchers. Draft versions were distributed for expert workshops; feasibility tests were conducted with researchers on projects. These provided crucial inputs throughout the writing process.

11.2.3 The IRS Handbook's Structure

The IRS Handbook consists of two interlinked main parts: (a) an Analytical Framework and (b) Research Resources. The Analytical Framework centres on a four-stage research process with clearly identified purposes, analytical questions and procedural research steps (see Fig. 11.2):

Stage 1 *Water Storylines* describes a means of researching problems and solutions in water resources management from stakeholders' perspectives. It is about identifying what is at stake in the project area and who the stakeholders are. More specifically, it examines their narratives about problems in the area, the ways they construct causal chains between issues, events, other actors and their general surroundings. It focuses on the ways in which problems and solutions are defined.

Stage 2 *Domains of Water Problems/Solutions* builds on the storyline research by mapping problems and solutions in terms of the political, cultural, spatial, hydrological and temporal domains within which they are embedded. More fundamentally, it details the nature of the problem, the issues to be addressed and changed, contests and power relations, as well as the courses of action deemed relevant to solving the problem. This is, then, about alerting projects to the factors most crucial to a consideration of problems and solutions.

Stage 3 *Political and Institutional Feasibility* shifts the focus firmly onto the assessment of solutions and their potential 'fit'/'misfit' with existing institutional arrangements and processes. These are assessed in terms of their key characteristics, such as their problem-solving approach and formal

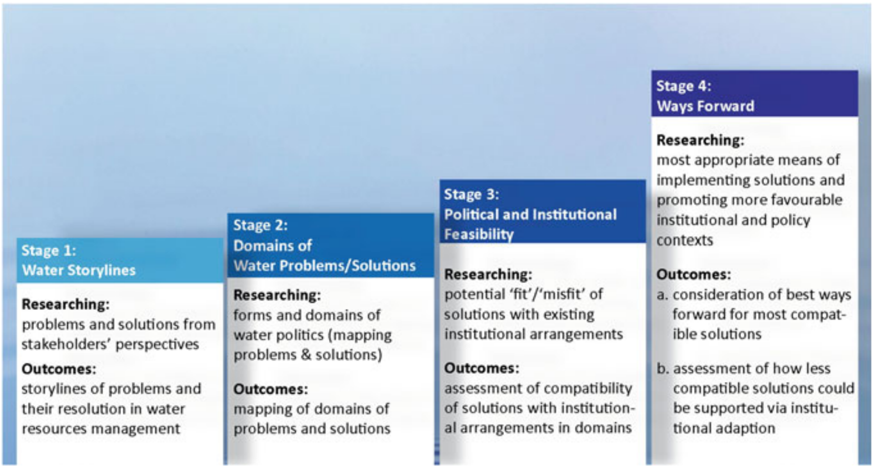

Fig. 11.2 The key steps and outcomes in the analytical framework of the IRS Handbook (Reproduced from Beveridge et al. 2012a)

and informal rules of interaction. The aim here is to expose the institutional arrangements and processes of the domains relevant to solutions and gauge the degree to which they might be amenable to such change.

Stage 4 *Ways Forward* is concerned with identifying the most appropriate means of implementing solutions and promoting favourable institutional and policy settings. The aim is twofold. First, an assessment is made of how solutions with a high degree of ‘fit’ with existing institutional relations might best be taken forward. Second, suggestions are made as to how those solutions with a low degree of ‘fit’ could be advanced by means of adaptation or reform to institutional arrangements at one or more of the relevant domains.

The *Research Resources* part provides brief information on other pertinent handbooks and a selection of existing approaches particularly relevant to conducting research in each of the four stages. Key texts, quotations, methodological guidance, useful links, further reading and diagrams etc. are displayed. These are often linked to specific research tasks outlined in the analytical framework. The approaches listed are by no means exhaustive and researchers are encouraged to draw on their own knowledge of literatures to carry out the analysis.

11.2.4 How to Use the IRS Handbook

We recommend proceeding according to the analytical framework following the four stages ‘Water Storylines’, ‘Domains of Water Problems/Solutions’, ‘Political and Institutional Feasibility’ and ‘Ways Forward’. Beyond these and the literatures deemed integral to their examination, the handbook has been designed to be adaptable both to ‘field’ conditions and the interests of the researcher. The handbook is based on a modular, two-speed approach. Within each stage a variety of approaches suitable to achieve research objectives are grouped into modules and links are provided to useful research resources. To help researchers use the two parts of the handbook interactively the relevant pages in the Research Resources section are cross-referenced in the Analytical Framework section. In the electronic PDF version researchers can click on the links provided to move between the two sections. Aware of time and resource constraints, we present ‘Fast-track’ and ‘In-depth’ procedures (see Fig. 11.3).

The *Fast-track procedure* has been designed to fit with preliminary, pilot stages of projects whereby the researcher aims, within a limited time period (6–12 months), to gain a general overview of the institutional and political context. The Fast-track version focuses on problems and proposed solutions endogenous to the context of implementation. This should enable R+D projects to align the objectives of their main phases to the problems facing stakeholders. Further, the four-stage analysis ultimately provides an assessment of the extent to which local solutions can be built into the R+D projects, i.e. a sense of the key issues, actors and organisations, as well

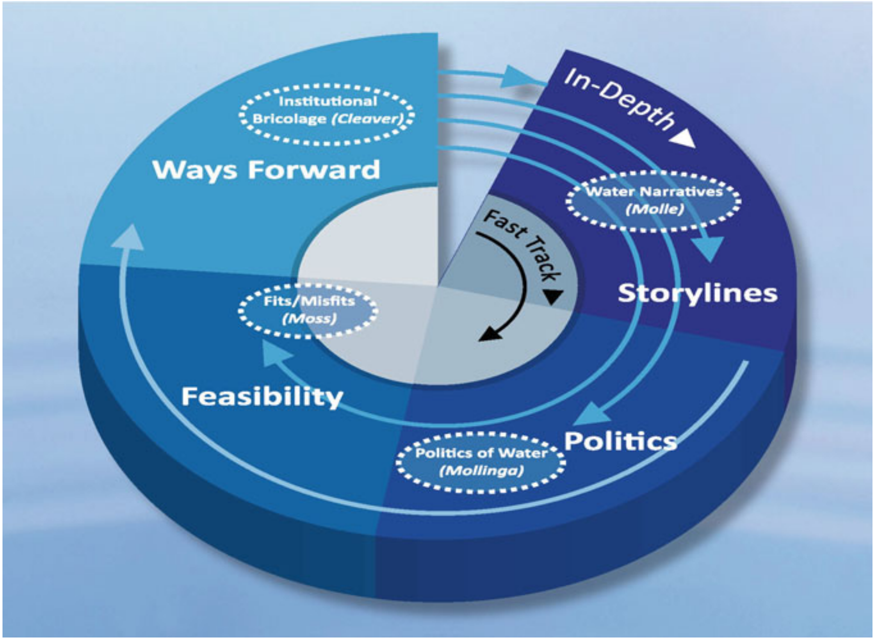

Fig. 11.3 The two-speed, four-stage modular and iterative approach to research in water projects (Reproduced from Beveridge et al. 2012a)

as areas of contestation and consensus. The outcomes of the Fast-track research should therefore provide a basis for designing the main project phase.

The *In-depth procedure* is appropriate to the main phase of an R+D project, in which the researcher aims to provide a much more detailed analytical account. Furthermore, the focus of research shifts to a consideration of the project's general objectives in relation to the institutional and political context of implementation. Thus if the Fast-track version is primarily concerned with unearthing endogenous solutions to water resources management problems (and assessing the extent to which they can be promoted within research projects), a specific concern of the In-depth research is to assess exogenous solutions. Research follows the same four-stage approach, but the project itself, its objectives and personnel, is now part of the analysis. The aim here is to assess the extent to which the project's own storyline regarding problems and their solutions can generate storylines that win support from actors and to assess the politics and institutional re-configurations they might entail. Alongside this it is important to note that the In-depth research continues to consider problems and solutions as perceived by local actors. Institutional and political contexts are rarely stationary; projects need to regularly update their research to take account of, e.g., changes in government or the emergence of a new water problem in a village community.

Iterative research processing is advisable, despite the apparently neat division of research into stages and modules, particularly in the 'In-depth' version. There are sound practical, ethical and methodological reasons for this. Revealing institutional and political conditions in relation to bio-geophysical and socio-economic dimensions is a complex task, one made even more challenging by the practicalities of conducting fieldwork. For instance, the need to build-up contacts with previously unknown local actors, information deficits, time and resource constraints necessitate a flexible approach to research. Thus it is appreciated that researchers may switch backwards and forwards between stages when dealing with particular issues (or 'storylines', problems/solutions) as and when necessary. Further, we have built in 'checks' to ensure that stakeholders are included throughout the research process and can assess the validity of research findings. This is crucial to the fair and accurate representation of all interests, as well as the accountability of the research project. Methodologically, this is also a good thing. It allows the researcher to regularly test and update findings in what will normally be a changing institutional and political context.

With this *flexible structure* and ethos in hand, it is hoped that researchers will use the IRS Handbook creatively. For example, different points of entry to the four-stage approach could be made according to the particular context of use. Thus if a researcher was tasked with doing institutional and political analysis for a project which already had set solutions to be implemented in a place (for example, an irrigation system in a particular sub-catchment), then s/he might begin with Stage 3 'Political and Institutional Feasibility'. Prior to moving onto 'Ways Forward', however, the researcher may feel that a broader knowledge of water problems in the area is required and thus conduct storyline research, drawing on the analytical and methodological material in Stage 1. Such an approach would be entirely justified as water projects have their own distinct shape and objectives. In short, while the approach here outlines a research process, it is accepted that it is 'idealised' and that the realities of a project may require significant adaptation.

11.3 The General Analytical Framework of the IRS Handbook

This section explains the general analytical framework in detail, covering in four subsections the four stages of research that structure the IRS Handbook. The purposes, guiding questions, procedural steps, research resources and products are outlined for each stage.

11.3.1 Stage 1: Water Storylines

Purposes The main focus here is on problems and solutions in water resources management as perceived by stakeholders themselves. If the goal of realising context-sensitive research projects is to be taken seriously, the first step must be an inductive one. Basic information about water resources management must come from the actors involved. Assumptions should not be made, preconceptions should be avoided. Instead, research must concentrate on what actors say and do. Researchers should be prepared that the realities may differ from what the formal organisational structures might suggest should happen. The main aims here are to identify what is actually at stake and who the stakeholders are in the context of implementation.

One effective way of conducting this type of research is to focus on 'storylines', on what people say about their surroundings and how they explain what they do. Stories are fundamentally important to the way we make sense of the world. They "use language to frame what has happened to a set of characters in a particular time and place" (Eckstein and Throgmorton 2003). The notion of "storylines" (cf. in particular Hajer 2006 and Fischer 2003) or "narratives" (see Molle 2008 on "water narratives") is a well-developed analytical concept in the social sciences. It is used to reveal the ways in which actors causally link events, people, their surroundings, etc., through some form of story. It should not be assumed that storylines always present a 'truth'. Rather, storylines should be seen as perceived truths, as making claims to what the truth of a matter actually is. Language is not neutral. Actors have strategic interests as well as limited information. Their stories will be reflections of both.

As such, storylines must be verified as far as possible through comparison. Overall, analysing storylines helps to identify the meaning context (Schmidt 2010) of water research projects. Identifying storylines also entails identifying the storytellers, the actors who promote a storyline and the way in which they represent other actors (see Hajer 1995). In carrying out research on this subject, it is crucial to include the project and the funding organisation in the analysis. Project managers and researchers should be considered in situ: within the contexts in which they work. They have their own perceptions, interests and objectives, and their actions have institutional and political effects. The same is true of the funding agencies, whose call for projects sets priorities and shapes the interests not only of project managers but also of the actors in the context of implementation. These can also be understood and analysed in terms of storylines, which may or may not be in conflict with the storylines of other actors.

Guiding Questions the Following Set of Questions Is Suggested to Guide the Research in Stage 1:

- What stories do actors tell about problems and their (possible) resolution in water management?
- How are problems defined? What are the perceived causes of problems and what kind of changes and (financial, technological, human) resources are mentioned as necessary to making improvements?
- Which actors are affected by problems, who is held responsible for them and who is seen as able to resolve them (i.e. who are the stakeholders)?
- Which problems/solutions are most frequently mentioned?

- What coalitions of actors are presented or, less directly, are discernable in storylines?
- Where are the points of consensus or conflict within and between different storylines?

Procedural Steps The analytical framework discerns eight steps for the research procedure in both, the *fast-track* and *in-depth* versions of stage 1, but with much greater effort and intensity in the latter. In detail, the procedural steps include: desk research, data collection, 'helicopter' interviews, identifying and interviewing key actors, identifying storylines from the material collected, characterizing and contextualizing storylines, linking actors to storylines and identifying the main stakes/stakeholders, comparing the storylines and reflecting on their similarities and differences, asking 'helicopters' to check the authenticity and relevance of storylines to the area, conducting more interviews in case of inconsistencies, revising the findings, comparing project with stakeholder storylines and discussing implications of the storyline analysis with the project manager (for the details see Beveridge et al. 2012a).

Research Resources Key theoretical and conceptual contributions on this topic have been made by Hajer (1995, 2003, 2006) and Fischer (2003) with respect to the importance of discourse to the conduct of politics and also by Schmidt (2010). She asserts the importance of discourse to thinking about institutions and views 'Discursive Institutionalism' as a fourth 'New Institutionalism' of political science. Hajer's 'argumentative' approach aims for an explanation of the prevalence of certain discursive constructions and for a study of the power structures in society (1995). Discourse is seen here as "an ensemble of ideas, concepts, and categories through which meaning is given to social and physical phenomena, and which is produced and reproduced through an identifiable set of practices" (2006).

Utilising this approach for water resources management, the focus is placed on actors' communication and contestation of ideas and norms surrounding water and land use; on revealing different 'storylines' and coalitions of actors (Hajer 2003). In-depth research might expand upon the storyline focus to study vocabularies and epistemic figures in water resources management (ibid.). In methodological terms, Hajer (2006) identifies at least ten practical steps necessary when doing discourse analysis and revealing storylines. Howarth (2005) provides more useful methodological insights on conducting discourse analysis and highlights problems in dealing with the wide range of rather different types of empirical data normally generated in case studies. Apart from the conceptual approach presented here the IRS Handbook does mention further complementary or alternative ones applicable in stage 1.

Stage Products The *fast-track* version of stage 1 produces a table outlining and comparing the storylines, the main stakeholders in problems/solutions and the actor coalitions seen to be supporting/opposing storylines. The *in-depth* version of stage 1 presents in a short report of the storylines research with particular emphasis on the comparison between the project's own storyline and those of the local actors and an assessment of points of consensus and conflict.

11.3.2 Stage 2: Domains of Water Problems/Solutions

Purposes Stage 2 builds on the analysis of water storylines by mapping out their political, temporal, spatial, scalar and hydrological dimensions. The aim is to locate problems and solutions, to think of them as existing in various 'domains'. All problems (as well as solutions) exist across a range of dimensions and different actors have different stakes in them. For example, problems related to water pollution through agricultural use might have, inter alia: political dimensions (which actors are negatively affected by this contamination?), institutional dimensions (is there a law covering substance input and runoffs?), and spatial dimensions (do the polluting activities occur in a different place to where the effects are felt?).

Thus the notion of domains of water problems/solutions denotes more than geographical locations in which problems/solutions are found. It is, more fundamentally, concerned with the actors and contestations revealed in Stage 1, including the strategies, tactics and power relations that shape them (Zeitoun and Warner 2006). Domains outline the 'politics of water' (Mollinga 2008). They could also be termed "issue domains" (Garb 2008) or 'action arenas' "where individuals interact, exchange goods and services, dominate one another or fight" (Ostrom 1999). Identifying domains is the first step in honing in on the relevant contexts of action for project managers. It is not just about identifying formal institutions and processes; analysis must go further than this. Rather, following Mollinga (2008), it is about determining the relevant "domains of interaction" in water resources management, which he views as inherently political. His topology of water politics discerns four domains of interaction according to different space and time scales, actor configurations, issue types, contestation modes and institutional settings:

1. the "*everyday politics of water resource management*",
2. the "*politics of water policy in the context of sovereign states*",
3. the "*inter-state hydropolitics*",
4. the "*global politics of water*", and
5. a fifth domain representing the *linkages* between the first four (ibid.).

According to Zeitoun and Allan (2008), power should be seen as crucial, even if researching it may prove challenging. All interactions between actors in water resources management are shaped by forms of power, however benign these may appear. Power and interests also inform actors' perception of problems and solutions—they must therefore be considered in water research projects. Analysis should attempt to ascertain what form these power relations take and how they are linked to actors and storylines. For instance they might be classified in terms of 'Hard Power' (coercion, the power over others); 'Soft Power' (the capacity to bargain, to influence without coercion); the power of ideas or the ability to control agendas, through a storyline for example (adapted from Zeitoun and Allan 2008).

Guiding Questions Research in stage 2 should be guided by the following set of questions:

- In which political/spatial/scalar/temporal domain(s) are problems/solutions located?
- What stakes do actors have in problems/solutions?
- Who has power according to these storylines?
- Who is portrayed as being responsible for problems? Who is seen as affected by them? And who appears to have the power to resolve them?

Procedural Steps In the *fast-track* version of stage 2 we suggest proceeding in five steps. It starts with a simple mapping of political/temporal/spatial/scalar/hydrological dimensions of the storylines gathered in stage 1, followed by a refined mapping which demarcates problems/solutions according to domains of the 'politics of water' in terms of 'what is at stake' in storylines ranging from 'everyday politics' to 'global water politics'. The findings should be presented to selected stakeholders by asking them to correct any mistakes and to address the guiding questions. After that diagrams should be developed on three dimensions of politics, space and time and the implications discussed with the project manager.

The *in-depth* version should first repeat the steps of the *fast-track* version if this has not recently been carried out, followed by another five steps. The IRS Handbook provides at this point several suggestions of how to use literatures relevant to conducting this type of research. This may include a more sophisticated mapping and categorisation of problems/solutions according to Mollinga (2008), an assessment of their temporal (and spatial) dimensions referring to Dore and Lebel (2010), a more substantial reflection on the scalar and spatial dimensions of storylines following Lebel et al. (2005) and an analysis of power relations with reference to Zeitoun and Warner (2006) or Zeitoun and Allan (2008). Finally, checking the findings with selected stakeholders (and perhaps a revision) and a discussion of implications with the project manager will conclude stage 2 (see in detail Beveridge et al. 2012a).

Research Resources There are a variety of approaches which could be utilised to plot out the different dimensions of problems/solutions. Besides Mollinga's (2008) forms of water politics and Zeitoun's and Allan's (2008) types of power there are other notable examples for theoretical and conceptual guidance in stage 2. For instance, Zeitoun and Warner (2006) pay special attention to trans-boundary water conflicts which are located in the 'inter-state hydropolitics' domain according to Mollinga's (2008) terminology. Their concern is that "conventional analysis tends to downplay the role that power asymmetry plays in creating and maintaining situations of water conflict that fall short of the violent form of war" (Zeitoun and Warner 2006). The conceptual framework of "hydro-hegemony" allows for the integration of power and varying intensities of conflict in the analysis of "the perennial and deeply political question: who gets how much water, how and why?" (ibid.)

In another key text Lebel et al. (2005) distinguish the “politics of scale, position and place”. They argue that appropriate scales in water resources management “cannot be unambiguously derived from physical characteristics … [but are] a joint product of social and biophysical processes”. In particular, spatial scales should not be taken as given, instead they might be created, constrained and shifted in the self-interest of certain actors who “can change power and authority by working at different spatial levels” (ibid.). Lebel et al. (2008) adopt a multi-level perspective to map and study governance challenges within a framework centered on three scales (groups, resources, spaces) which “correspond approximately to questions about who and why (groups), what (resources), and where (spaces)” (ibid.). Dore and Lebel (2010) demonstrate the application of mapping techniques with two spatial scales (hydrological and administrative-territorial) and overlapping time and planning scales.

Stage Products The *fast-track* version should produce a set of diagrams (with explanatory notes) mapping the domains of problems/solutions and a brief written assessment of the implications for the project. The *in-depth* version should aim for a more comprehensive report containing diagrams illustrating the domains of water problems/solutions and their various dimensions in much greater detail, but also written responses to the guiding questions and a thorough assessment of the implications for the project.

11.3.3 Stage 3: Political and Institutional Feasibility

Purposes Stage 3 analyses the political-institutional arrangements and processes relevant to potential solutions. Having mapped the relevant political/spatial/hydrological domain(s) of problems, this stage assesses the compatibility of proposed solutions. Clearly, this can only ever be a rough measure of how change might unfold. Most important here is that the analysis provides project teams with a clear idea of the relevant political-institutional arrangements in place and a general sense of the extent of change each solution might entail. The purpose is to ‘follow the solutions’: to trace the existing institutional arrangements relevant to the implementation of a proposed solution and reflect upon the feasibility of achieving change.

Again, analysis must go beyond formal institutions to include informal, even tacit, factors and beyond ‘static’ portrayals to include processes. There are, of course, a multitude of approaches which could be utilised to carry out this research. A useful way of thinking about compatibility in general terms is Moss (2003a) notion of ‘fit/misfit’ between proposed change and existing institutions. Research here focuses on comparing different components of institutional arrangements and processes with those likeley to be entailed in implementing a proposed solution. Building upon Göhler (1997), Moss (2003a) directs the analysis towards the following six key components of an institutional configuration which researchers, perhaps particularly those working in D&T countries, should add to, drawing on other literatures:

1. *Frameworks of action and problem-solving approach*: Informal institutions (e.g. conventions, norms, routines) which shape decision-making;
2. *Policy mechanisms*: E.g. legally-binding rules, property rights, planning laws, decision-making processes;
3. *Political-administrative structures*: Relevant organisations of the political system (e.g. water authorities);
4. *Market structures*: Means through which economic relations are governed (e.g. pricing mechanisms);
5. *Organised and non-organised actors*: Actors organised to represent their interests/those actors who are not;
6. *Rules of procedure and forms of interaction*: Formal legal rules governing procedures and informal means of coordination and discussion between actors (ibid.).

Guiding Questions Researching stage 3 raises, e.g., the following set of guiding questions:

- In terms of Moss' components, how is water resources management institutionally configured?
- Which political and institutional arrangements and processes are most relevant to implementing solutions?
- What kind of institutional configuration might the proposed solutions require?
- How compatible are the requirements of the proposed solution with the existing arrangements and processes?
- What level of fit/misfit exists between the proposed solutions and existing institutional arrangements?
- Overall, how feasible do solutions appear to be?

Procedural Steps The *fast-track* procedure in stage 3 comprises five steps: an assessment of the political and institutional configuration of water resources management in the country context according to Moss (2003a) which also includes a check with relevant stakeholders, a selection of those solutions which appear to enjoy the widest support referring to findings from research stages 1 and 2, a comparison of the findings of the first two procedural steps in terms of the compatibility of solutions in relation to the context of action, the preparation of a report which summarises the findings, and, finally, a discussion of the implications with the project team.

The *in-depth* version proceeds in seven steps: supplementary reading of other analytical approaches introduced in the Research Resources part of the IRS Handbook, a more detailed analysis of the institutional configuration through further review of literature and other sources followed by checks with relevant stakeholders, a careful consideration of the required institutional configuration to implement each of the solutions identified in research stage 1 including stakeholder consultations and focus group discussions, a comparison of the fit/misfit of solutions in relation to the domain of action, a deeper analysis using supplementary literature on fit, interplay and scale (e.g. Moss 2003b; Young 2002), a summarising report, and a discussion of the implications with the project team (for a detailed description of steps see Beveridge et al. 2012a).

Research Resources Among the more general and broader frameworks of institutional analysis the pioneering work of Elinor Ostrom and colleagues on the 'Institutional Analysis and Development' (IAD) framework, e.g. in Ostrom (1990, 2005, 2011) and Ostrom et al. (1994), is clearly the most prominent. Originally designed to understand rather limited common pool resource regimes the IAD framework has been extended recently to make it applicable to the analysis of much more complex systems, e.g. in McGinnis and Ostrom (2010). The IAD framework has also influenced and inspired a large number of scholars who have applied it in numerous case studies and also further developed, extended and enriched the original model, e.g. Ebenhöh (2007), Saravanan (2008), Clement (2010) and Pahl-Wostl et al. (2010). Clement's politicised version of the IAD framework could potentially be integrated with the discourse analytical storyline approach presented in stage 1 of the IRS Handbook. Other approaches draw more generally on a number of the IAD framework's components, e.g. the 'Institutional Decomposition and Analysis' (IDA) framework by Saleth and Dinar (2004).

It should, however, be noted that attempts by IAD proponents to identify universally applicable basic rules and institutional design principles have been contested by a number of scholars. Cleaver, for example, notes that "the school of 'institutional crafting' … is based on concepts which are inadequately socially informed and which ill-reflect the complexity, diversity and ad hoc nature of institutional formation" (2002). A similar view is expressed by Merrey and Cook (2012). Further notable examples of institutional analysis in water resources management comprise studies conducted by the International Water Management Institute (e.g. Bandaragoda 2000) and the pioneering work of Ingram et al. (1984) to develop guidelines for improved institutional analysis in water resources planning, the value of which for contemporary water research has been demonstrated recently by Poirier and Loë (2010).

Stage Products The main product of the *fast-track* research in stage 3 is a table which illustrates the relative compatibility or 'fit' of selected solutions with existing contextual conditions. It should be supplemented with some loose ranking of these solutions in terms of their feasibility, outlining potential pitfalls and windows of opportunity. Researching stage 3 *in-depth* should lead to a thorough written assessment of the degree of fit of all the proposed solutions with existing contextual conditions. Drawing on the wider literature, the report should include some ranking of the feasibility of solutions, with particular attention given to the project's solutions in comparison to competing or complementary stakeholder solutions.

11.3.4 Stage 4: Ways Forward

Purposes Stage 4 is concerned with identifying the most appropriate means of implementing solutions with a high degree of fit and promoting institutional and policy settings more conducive to those solutions which display a low degree of fit. The aim is to ascertain ways of encouraging problem-oriented reform to address the needs of stakeholders within the limitations of the project and finding equitable and realistic ways forward in water resources management. Policies and reforms are unlikely to succeed without the support of actors affected by them. It is important to note that the ways in which actors perceive benefits and disadvantages may be more important than a 'rational' assessment of costs and benefits. I.e. fostering support and credibility to ensure that a project is accountable may not be an entirely rational process. Changes are also unlikely to succeed if appropriate knowledge, resources, technologies, etc. are not available to implement reforms.

There are two parts to the research here. The first assesses how solutions with a high degree of fit with existing institutional relations might best be further promoted. This could refer to the targeted allocation of project resources, the development of alliances with relevant organisations, or the introduction of particular technologies, etc. Second, suggestions are developed as to how those solutions with a low degree of fit could be advanced by means of adaptation or reform of institutional arrangements at one or more of the relevant domains. This could, for example, entail the establishment of stakeholder groups to discuss particular problems or other means of encouraging learning processes and coalition building. It might even entail advising on re-shaping existing institutions. The overall objective here, then, is to explore opportunities for generating more favourable institutional contexts for a particularly desirable solution so that it is not sidelined as being unrealistic under current circumstances.

Guiding Questions In stage 4 the questions are differentiated according to the relative fit of solutions (adapted from Mollinga et al. 2007). In terms of solutions with a *high degree of fit*:

- What specific measures and resources are required to implement solutions?
- Who should be included/consulted in implementation?
- How long would it take?
- How should costs and benefits be equitably distributed?

In terms of solutions with a *low degree of fit* the guiding questions are:

- What will be the benefits of institutional and policy reform and how will these benefits be distributed? What will be the costs and who will bear them?
- Who will be the bearers of institutional transformation? Who will constitute the coalition of interest groups to push forward and implement the change?
- Around which storylines/issues can such efforts be organized most productively?
- How can these coalitions be supported?

- What can realistically be done to adapt the enabling and constraining conditions for this institutional transformation?
- How can knowledge producers/processors such as project researchers and managers, consultants and reflective practitioners play a more active role in this process?

Procedural Steps The *fast-track* version of research stage 4 is a four-step procedure which begins with the establishment of stakeholder meetings to assess the results of the previous three research stages from a perspective led by the guiding questions above. The next steps are the employment of other methods, e.g. cost-benefit analysis of implementing solutions, a meeting with the project team to openly reflect on the overall research results with a focus on planning for the main project phase, and, finally, the preparation of a brief report on potential pathways for both most and least feasible solutions.

Given that the main project phase may be underway and assessments and discussions have to be more targeted and detailed now, the *in-depth* version more clearly divides between pathways A (solutions with a high degree of fit) and B (low fit). It proceeds in seven steps: referring to the wider literature to better identify methods of facilitating practical and participatory research processes, establishing a series of stakeholder meetings to assess results of previous stages focused on pathways to be pursued during the project, investigating the wider literature to outline a series of pathways for the solutions, meeting with the project team as in the *fast-track* version but with decisions regarding which pathways A and B to be followed, presenting the results in a report, arranging further stakeholder meetings to reflect on the value of project work completed and prospects for change and, finally, discussing the findings with members of the project team to reflect on measures implemented and to devise a strategy for pursuing pathways after the project (for a detailed description of steps see Beveridge et al. 2012a).

Research Resources Theoretical and conceptual guidance on ways forward, especially for developing countries, is offered by Lankford (2007) and Lankford et al. (2007). This approach aims to move “from integrated to expedient water resources management” (Lankford et al. 2007) and usefully combines a concern for effectiveness with participation. Lankford emphasises that ‘solutions’ should be thought of in terms of ‘tasks’, i.e. “to break large issues into more manageable objectives” (Lankford 2007). This can be achieved through risk-based analysis to “identify component tasks and then identify which are effective in cost-benefit terms” (ibid.) and “specific conflict resolution exercises [that] address locally relevant and socially critical concerns” (ibid.).

Central questions that need to be addressed when taking solutions forward is the distribution of costs and benefits between different groups of stakeholders and the identification of potential carriers of, and opponents to, institutional transformation and their respective power and interest. Slootweg and Mollinga (2009) suggest a wide interpretation of the term ‘stakeholder’ and identify four main categories of stakeholders in relation to the impact of policies, projects etc.: beneficiaries, affected people, organised stakeholders, and future generations. They also make a further distinction between onsite (directly affected) and distant stakeholders (indirectly affected). In another example, IFAD (2008) has developed a helpful guiding matrix regarding possible strategies for engagement with different forms of stakeholder interest and power.

From an analysis of water sector reforms in six countries Saleth and Dinar (2005) find that processes of institutional change are “not entirely evolutionary or autonomous” (ibid.). They develop reform design principles such as institutional prioritisation, sequencing and packaging from sequential and structural linkages between different institutional components. These principles can be utilised as a means to alter the process of institutional change by minimising transaction costs, exploiting synergetic effects, countering political opposition to reforms and focusing efforts and investments on solutions with a high probability of success (ibid.). The authors also warn that “ad hoc approaches to reforms, as dictated by political and financial constraints, can be counterproductive owing to the dilution of their effects and consolidation of reform opposition” (ibid.).

However, in a critique of such universal institutional design principles, and in contrast to the school of ‘institutional crafting’, Cleaver (2002) advocates ‘institutional bricolage’. She rejects the common dichotomy of formal and informal institutions and instead distinguishes bureaucratic institutions from socially embedded ones (ibid., 13). She replaces the idea of “narrowly rational ‘institutional engineers’ in favour of ‘do-it yourself’ bricoleurs” (ibid., 17). The concept of institutional bricolage may also include the co-opting of existing, enduring, robust and socially embedded decision-making arrangements and relations of co-operation for new purposes rather than the deliberate crafting of new bureaucratic institutional arrangements for particular functions (ibid.).

Stage Products In the *fast-track* procedure of stage 4 a report should be prepared outlining potential pathways for a reform of water resources management in the main project phase. This should entail, first, a consideration of the best ways forward for most feasible solutions and, second, an assessment of how less compatible solutions could be supported, including possible means of adapting existing institutional arrangements in particular domains. When doing the *in-depth* procedure these same issues should be elaborated more thoroughly aiming for a much more detailed report which should be accompanied by a brief written outline of facilitated processes for pathways in both groups of solutions and strategies for pursuing them after the termination of the project.

11.4 Conclusion

Water resources management projects, however technical or research-focused, are fundamentally dependent upon political and institutional arrangements and processes. Indeed, a failure to address adequately the prevailing political and institutional circumstances has become a widespread criticism of projects as well as of the dominant paradigm of IWRM. Adopting a more ‘context-sensitive’ approach is, however, a complex task, particularly for project managers and researchers who are working within a resource-constrained setting with little practical support to help them tune their interventions to fit contexts of implementation.

Against this background the IRS Handbook aims to strengthen social science research within water management projects by providing guidance on conducting institutional and political analysis. While this obviously entails an engagement with theories and concepts, the objective was always to produce a practical guide and set of resources usable within R&D projects. Because the IRS Handbook was written first and foremost for social scientists some general knowledge of relevant theories and methods has been assumed. Nonetheless, the handbook has been composed in a way that makes it both accessible and informative to project managers or, more generally, someone from a natural science or engineering background.

The handbook provides an analytical framework to refine projects in both planning and implementation phases, an accompanying methodological guide for utilisation and an appendix of useful research resources. The approach is problem- and solution-focused. The rationale for this is that projects' objectives should be context-specific, oriented to the problems in a particular place and aware of the existing institutional and political arrangements found there. Thus the analytical framework presents an inductive, 'bottom-up' research process. Research starts with observation, before moving to analysis and ways forward. Another key characteristic of the approach is its openness and flexibility. The framework draws on a range of approaches, without imposing one on the researcher. Instead, a basic structure is provided and a number of suggestions are given as to how to adapt and extend the analysis to suit specific contexts of research and application.

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Part V
Public Information and Participation

Chapter 12
Participative Scenario Development as a Method to Integrate Science and IWRM—Lessons Learnt from a Case Study in the Jordan River Region

Janina Onigkeit, Karl-Heinz Simon, Joseph Alcamo and Katja Tielbörger

Abstract A scenario process was carried out in the Jordan River region aiming at the elaboration of strategic options for the management of its water resources up to the year 2050. The objective of the participative process was to provide scientific support for Israeli, Jordanian and Palestinian stakeholders involved in water management in the region. As a scenario method the "Story and Simulation" (SAS) approach was applied. This approach requires the participation of a variety of stakeholders in order to get a broad perspective on the water management issue and the involvement of scientists from a variety of disciplines to quantify relevant aspects of IWRM. We describe the process of scenario development for trans-boundary water management under different socio-economic futures and discuss it with respect to the interaction between science and practice of managing water resources. Four scenarios and water strategies were developed by combining exploratory and back-casting methods of scenario development. The resulting scenarios cover a wide range of socio-economic futures in the region which allow for and require a large variety of potential options to manage water resources. These options cover diverse aspects ranging from large scale high-tech solutions to societal changes affecting water consumption behaviour. At this point the strength of the SAS approach played out in that quantifiable and non-quantifiable elements of water strategies could be combined. This combination however, requires the opportunity and willingness of interaction between scientists and stakeholders so that both can profit from such a process and its outcome.

Keywords Scenario analysis · IWRM · Climate change · Stakeholder participation

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12.1 Introduction

The Jordan River region is one of the most water scarce regions in the world and it is expected that the management of water resources might become an even more challenging task due to increasing temperature and decreasing precipitation as a result of global climate change (IPCC 2013). Moreover, it is anticipated that socio-economic changes, including population growth and changing life styles, will put additional pressure on the water system. Given the long-term perspective of the climate change issue and the resulting high level of uncertainty, participatory scenario development and analysis was regarded as an adequate method to approach these problems in the region (Lynam et al. 2007). A scenario process was initiated as part of the GLOWA Jordan River (GLOWA JR) project (for a detailed description of the project and the study region see Tielbörger et al., Chap. 27). The primary aim of scenario development in GLOWA JR has been to address relevant aspects of integrated water resources management (IWRM) in a structured and comprehensive way and to provide new and state of the art scientific insights to support the management of water resources in the region. Moreover, joint scenario development was seen as a method to integrate and harmonize the results of the variety of scientific disciplines represented in the project in order to make them useful for the development of water management strategies in the region.

For the term "scenario" various definitions can be found in the literature (for an overview see e.g. Bishop et al. 2007; Amer et al. 2013 or Börjeson et al. 2006). In the Millennium Ecosystem Assessment scenarios are described as "plausible and often simplified descriptions of how alternative futures may develop based on coherent and internally consistent sets of assumptions about key driving forces and their relationships" (MA 2005). These future pathways can start from the current situation and develop into the future (explorative scenarios) and are consequently open with respect to the future state. In contrast, normative scenarios describe a (desirable) future state and how it evolves over time (back-casting scenarios) or what kind of strategies could be followed to achieve a defined goal (Leemhuis 1985). Scenarios can be developed in form of narratives containing qualitative information about the evolvement of the future, in form of quantified trends as it is the case in modelling tools or Bayesian networks (Lynam et al. 2007) or they can combine both elements as in the "Story and Simulation" approach (SAS, Alcamo 2008).[1]

An additional purpose of applying the scenario methodology in the GLOWA JR context was that it could stimulate strategic thinking and help to overcome thinking limitations by creating multiple futures (e.g. Amer et al. 2013). As such, scenarios are not forecasts or predictions but can prepare for the occurrence of unforeseeable

[1]We use the term "scenario story" for the narrative elements of scenarios and the term "scenario" for the integrated qualitative and quantitative aspects.

events. Scenarios should meet several criteria in order to be relevant: They should be creative and challenging (Alcamo and Henrichs 2008), plausible and surprising (Schwartz 1998) but also transparent (e.g. Durance and Godet 2010). In order to have an impact on the development and implementation of future water strategies it is important to organize the process of scenario development in a way that scenario developers can generate a feeling of "ownership" for the scenarios (see Schwartz 1998; van Vliet 2011; Kirschke et al., Chap. 13). The resulting scenarios can then be used to develop and test policy interventions and management strategies, their effectiveness and risks or other possible implications. To increase usefulness of scenarios for planning purposes robust elements of a strategy can finally be identified and tested against the scenarios to prove its plausibility and feasibility independent of a specific future development or scenario.

The aim of this article is to evaluate the process of developing explorative scenarios including water management strategies and the impacts of the process design on the integration of qualitative and quantitative elements. In Sect. 12.2 the methods are presented that were applied to develop scenario stories, the corresponding water management strategies and how the communication between stakeholders and scientists was organized in order to integrate quantified scientific aspects in the scenario process. The outcome of the process in form of narratives and quantified elements is summarized in Sect. 12.3. In Sect. 12.4 results are discussed and conclusions are drawn in Sect. 12.5.

12.2 Design and Methods

12.2.1 General Information and Overview

The GLOWA JR project was organized in three phases of 3 years each. The development of explorative scenarios started in phase two and addressed socio-economic development and the future of water and land resources in Israeli, Jordanian and Palestinian territories up to the year 2050. In phase three the focus shifted to an increase of practical relevance of the project's results including the scenario process which in this phase focused on the elaboration of water management strategies.

As a method for scenario development and evaluation the Story and Simulation (SAS) approach was applied. A similar approach was used in several scenario studies including the development of the so-called SRES greenhouse gas emission scenarios of the Intergovernmental Panel on Climate Change IPCC (Nakicenovic et al. 2000), the scenarios of the Millennium Ecosystem Assessment (MA 2005) or the water-related scenarios in EU-projects like SCENES (Kok et al. 2011). The approach is characterized by an iterative development and analysis of scenarios. It aims at an intensive dialogue between project scientists and stakeholders by alternately feeding back information into the process. Scenario development and analysis here ideally include the development of differing stories, an evaluation of the consequences of different development pathways, the development of response measures, and an evaluation of their effectiveness. All of these elements can consist of qualitative and/or quantitative information. A detailed description of the SAS approach can be found in Alcamo (2001, 2008).

In GLOWA JR a set of explorative scenarios was developed during the first set of three so-called Scenario Panel meetings (SPMs), each lasting 3 days. In the second set of three SPMs water and land management strategies were developed using the explorative scenarios as a context (see Leemhuis 1985).

Four different groups of actors were involved in the scenario process:

First, a *Scenario Panel:* Stakeholders from the region (together with a small number of scientists from the region) developed scenario stories in form of narratives and identified relevant issues to be addressed in the scenarios. The Scenario Panel consisted of experts covering a variety of perspectives on the water issue ranging from water planners to environmentalists. In this way credibility but also legitimacy of scenarios was expected to be enhanced since, these experts are beside scenario developers, the most likely users of the results of the scenario process. The group of stakeholders involved in the scenario process over the period of 5 years consisted of 70 persons. With 20 persons coming from Israel, 21 from Jordan and 26 from the Palestinian Authority the group was relatively balanced with respect to nationalities represented in the process. However, especially in the first part of the scenario process fluctuations of participants were large. Many stakeholders participated only once or twice. This changed in the second phase of scenario development presumably because stakeholder wishes were taken up and (1) meetings on country-level were held, (2) the focus of the process shifted to water management strategies and (3) involvement of regional members of the scenario team was intensified by serving as contact persons for regional stakeholders. The number of stakeholders participating at the SPMs varied between eight and twenty with the largest number of participants at the SPMs on country level. This could be due to several reasons such as high interest to discuss water planning first on country and then on regional level, the short duration of the meetings (1 day) and short travel times. Four out of five of the remaining meetings were held in Germany because it was easier for the majority of the stakeholders to travel to Germany than to meet in the region. The ministries and international organizations/NGOs that were represented in the scenario process are listed in Table 12.1. These organizations were represented throughout the whole process. However, participants from the different organizations changed during the process and they also changed positions within their organizations.

Second, *scientists* from a variety of disciplines contributed mostly quantified and model-based information on the future of water resources, climate change, ecosystem behavior, and other issues (for further details see Sect. 12.2.4.2).

Table 12.1 Organizations represented in the GLOWA JR scenario process

Israel	Jordan	Palestinian Authority	Others/NGOs
Israel Water Authority	Ministry of Water and Irrigation incl. Jordan Valley Authority	Palestinian Water Authority	FoEME—Friends of the Earth Middle East
Ministry of Agriculture	Ministry of Agriculture	Ministry of Agriculture	IPCRI—Israel/Palestine Center for Research and Information, Israel
Ministry of Environmental Protection	Ministry of Planning	Ministry of Planning	NCARTT—National Center for Agriculture Research and Technology Transfer, Jordan
Arava Institute for Environmental Studies	Water User Association	Ministry of Local Government	GIZ-Jordan (former GTZ), Germany
	Meteorological Department of Jordan	Environmental Quality Authority	
		Palestinian Hydrology Group	

Scientists provided data and results of simulation studies which were driven by quantified and qualitative scenario assumptions of the Scenario Panel. A limited number of senior scientists from Israel, Jordan and Palestine contributed to the development of scenario stories as members of the Scenario Panel.

Third, a *scenario team* coordinated the scenario process. Besides the organization of the SPMs and serving as facilitators during the meetings its main task was to harmonize and integrate the scientific input in a way useful for the scenario process. Additionally, the scenario team documented the SPMs in form of reports, formulated the scenarios based on the material provided at the SPMs and processed and communicated information generated by the Scenario Panel to project scientists so that it could be used as input for the simulation studies.

Fourth, a *moderation team*[2] facilitated the process of scenario development. Their task was, together with the scenario team, to design the process and to create an open and creative atmosphere which enabled the Scenario Panel to achieve results even in conflict-laden situations.

In the following, the methodological approach is presented for the explorative development of scenario stories during the first three Scenario Panel meetings (SPM 1–3) and for the identification of water options and strategies applying a back-casting approach during the second set of meetings (SPM 4–6). The chapter is concluded by illustrating the way how qualitative and quantitative scenario elements were integrated during the overall scenario process.

[2]The Scenario Panel meetings were professionally facilitated by Marc Gramberger and Katia Tieleman from PROSPEX (www.prospex.com).

12.2.2 Explorative Development of Scenario Stories

The development of scenarios consisted of the development of scenario stories and their quantification. This required a translation of qualitative scenario factors to quantitative driving forces which are suitable to serve as model input. Both, scenario factors and quantified model driving forces here can be defined as "the elements that move the plot of a scenario, that determine the story's outcome" (Schwartz 1998), i.e. variables that are strategically relevant (Schoemaker 1993). Scenario development was organized as an iterative procedure as depicted in Fig. 12.1.

Agreement on scope of scenarios, driving factors, and scenario logics

At the first Scenario Panel meeting (SPM1) stakeholders were given an introduction to scenario building in general including the SAS approach. Next, the Scenario Panel agreed on the objective of the scenario process: "The evaluation of the consequences of global and regional change on water resources in the region and the exploration of new ways of how society can adapt to anticipated changes in a sustainable way". The scenarios covered the territories of Israel, Jordan and the Palestinian Authority up to the year 2050 in order to adequately capture climate change impacts. Additionally, a mid-term period (2025–2030) was introduced to cover the time frames of decision making and water management more adequately.

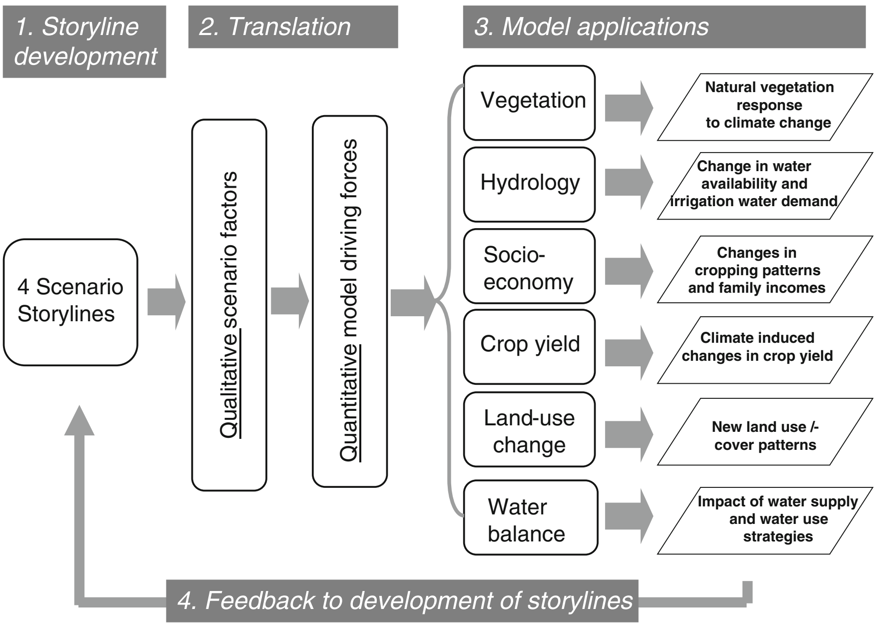

Fig. 12.1 The four steps of linking scenario stories and simulation results applying the SAS approach

After formulating hopes and fears with respect to the future regional handling and availability of water resources stakeholders identified factors which they regarded as decisive for the regional water situation. The resulting 14 factors were specified by identifying their most uncertain aspects when developing into the future (see Table 12.2, left column text in italics).

Applying the scenario-axes technique (Van't Klooster and Van Asselt 2006) or to be more specific the 2 × 2 matrix method (Ramirez and Wilkinson 2014) the next task was to identify those two factors which are the most uncertain, have the highest impact on the water situation and can develop independent from each other. The 2 × 2 matrix approach shows three main advantages: (1) The limited number and clear structure of scenarios facilitates their communication to people not involved in the scenario building process. (2) It avoids the development of a most probable or "business as usual" scenario which often leads to a neglect of other possible often extreme futures. (3) The polarized outcomes for the key factors encourage the consideration of more

Table 12.2 Scenario driving factors and corresponding quantified model driving forces

Scenario driving factor—*uncertain aspect*	Model driving force
1. Trade—*degree of emphasis on water-intensive export*	1. Change in area for water intensive agricultural exports
2. Energy—*costs*	*Not quantified*
3. Finance and pricing—*rate of economic growth*	2. GDP per capita
4. Water pollution and treatment—*extent of wastewater reuse*	3. Change in treated waste water production capacity
5. Competing water needs between sectors—*degree of water market liberalization*	*Not quantified*
6. Access to and allocation of water—*degree of multilateral sharing*	*Not quantified*
7. Water supply—*extent of technological break-through*	4. Changes in desalination capacity. Changes in water use efficiency: 5. in the agricultural sector, and 6. in the domestic sector
8. Values and attitudes—*focus on tourism/environmental water use vs. agricultural water use*	*Not quantified*
9. Education—*degree of change in attitude towards water conservation*	*Not quantified*
10. Nature conservation—*degree of protection of open space*	*Not quantified*
11. Demography—*population growth due to migration*	7. Population growth rate
12. Peace, war and regional stability—*degree of mutual recognition*	*Not quantified*
13. Global warming and cooling—*degree of increasing aridity*	8. Temperature, precipitation and other climate variables for the period to 2050
14. Agriculture—*degree of planning on regional scale*	*Not quantified*

extreme futures and challenge patterns of thinking (Randall 1997). Finally, four scenario stories resulting from the four combinations of factors were drafted.

Enrichment of stories including actors and actions, trends of key drivers

At the second Scenario Panel meeting (SPM2) the drafted stories were revised and enriched by identifying actors such as ministries or international donors and their future outstanding actions. In addition, stakeholders specified in a systematic way trends for the key driving forces derived from the key factors (see Table 12.2) for each scenario, each country and each period of time in linguistic form as a basis for the quantification of scenario drivers. Based on scenario presentations by stakeholders first versions of the scenario stories were formulated.

Harmonization of stories and consequences for water management

At the third Scenario Panel meeting (SPM3) stakeholders were asked to further refine and finalize the scenario stories. This included a balancing of information with respect to the three countries and levels of detail and a final check of consistency. Finally, insights from the four "Regional Development Scenarios" and their consequences for future water management were formulated. It became clear that the four scenarios differ substantially and consequently require a wide range of measures to adequately manage regional water resources in the future.

12.2.3 Development of Water Strategies

Following the suggestions of stakeholders to explicitly address problems of future water supply the second part of the scenario process (SPM4–6) focused on the elaboration of water management strategies. Three key issues were identified: (1) the potentials of new "unconventional" water sources, (2) the role of land-use planning and (3) how to deal with climate extremes.

Specification of water management options on the country level

The fourth Scenario Panel meeting (SPM4) was organized in form of three one-day meetings in Amman, Ramallah, and Tel Aviv and was primarily used to elaborate water management options on the country scale. A large number of new participants required an extensive introduction to the SAS scenario process. As part of this introduction a local member of the Scenario Panel, who was familiar with the process highlighted relevant aspects of the process for local water management. Then, the four "Regional Development Scenarios" were introduced. The subsequent elaboration of future water management strategies in scenario-specific working groups included the following:

- Identification of plausible water management options under a specific context scenario and its assumptions on economic development and cooperation in the region.
- Prioritization and specification of water management options for each of the scenarios. This included a qualitative estimation of the capacities of these

options, of the time frame for its realization, and the identification of barriers for implementation and how to address them.
- Identification of water management options which would benefit from cooperation and need discussion on the regional level.

Application of a back-casting approach to develop regional water strategies

At the fifth Scenario Panel meeting (SPM5) scenario-specific regional water strategies were developed using the back-casting approach which is an established approach (e.g. Kok et al. 2011; Kerkhof and Wieczorek 2005; Gomi et al. 2011) to deal with complex and long-term issues such as global change and its implications for sustainable development (Dreborg 1996). This approach allowed for shifting the focus from the question of how the future might develop (with an open end) to the question of how a desirable future vision might be attained (even under difficult conditions). Hence, back-casting as a normative approach requires the formulation of a final vision but it also stimulates creative thinking especially when challenging pathways including changes in existing trends are necessary to realize a vision (Carlsson-Kanyama 2013). These challenges emerged when visions were paired with scenario stories that required a lot of creativity and sometimes intriguing ideas to achieve consistency of the water management strategies and their scenario context. In detail, the following steps were carried out:

- A vision was formulated for each of the scenarios for 2050. The visions reflected characteristics of the scenarios and were formulated as challenges, providing different ideas of how the water sector and related areas should look like in 2050. Common to all visions was that they addressed the problem of an increasing water deficit in the future.
- Milestones were identified to be realized by the years 2040, 2030, and 2020 respectively and adequate actions as well as actors were specified to achieve these milestones. In order to test the developed strategies, different barriers and constraints were explicitly named and ways to address them to realize visions.

Identification of implications of strategies and robust options

At the sixth Scenario Panel meeting (SPM6) the participants further enriched the regional water strategies and discussed their implications. This included:

- a specification of measures to adapt to an increasing frequency and severity of droughts and other climate extremes;
- a compilation and discussion of the environmental impacts of water management options.

In a final step, robust water management options were identified, which means options applicable (with adaptations) under all scenarios. For this purpose all options were systematically discussed for each scenario. Finally, stakeholders elaborated a limited number of measures, the so-called “cross-cutting strategic options” which they considered as feasible to facilitate a region-wide cooperation for the management of water resources in the very near future.

12.2.4 Linking Qualitative and Quantitative Scenario Elements

In parallel to the development of scenario stories and the formulation of strategic elements of future water management as described above, relevant aspects of water resources management were quantified and had to be integrated in the scenarios and the scenario process. Three types of quantitative information were available, each requiring a different degree of stakeholder involvement. The most critical step consisted of the quantification of key driving forces of scenarios serving as input for model simulations and water strategies. This step required the strongest involvement of stakeholders and aimed at giving them a feeling of ownership for the scenarios (Schwartz 1998). Moreover, it increased consistency between scenario stories and quantitative elements of scenarios and allowed for the consideration of breaking trends or sudden events based on stakeholder anticipation. These kinds of events were normally not part of model simulations but are relevant because they often require fast and/or strong adaptation measures in water management (e.g. in case of in-migration of large numbers of refugees from neighboring states). The second type of quantitative information consists of the results of simulation studies in order to quantify impacts and implications of scenario assumptions. Third, the capacities and timing of differing scenario-specific water strategies on the country and regional scale had to be quantified.

These integration steps were organized at the SPMs, at the project's Status Conferences and at so-called scientific input or expert meetings. In all, 16 meetings were organized with the majority of them taking place in Germany and meetings dealing with water management options on country level in the region. The issues addressed at these meetings are summarized in Table 12.3 and more details are given in the following section.

12.2.4.1 Deriving Scenario Driving Forces

In GLOWA JR twelve simulation models could potentially contribute to the scenario process and ten of them required information in form of scenario-specific drivers. Two regional climate models provided drivers in form of transient climate change variables up to the 2050s driven by the IPCC scenario A1B (Nakicenovic et al. 2000). The remaining models either required input from other models and/or quantified socio-economic scenario drivers (the linkages between simulation models and the scenario process are depicted in Fig. 12.2).

Whereas at SPM1 scenario factors were identified, at SPM2 these factors were translated to quantified model drivers (see Fig. 12.1). Stakeholders were directly involved in the definition and quantification of a consistent set of scenario drivers. An approach was applied which is inspired by Fuzzy Set Theory (Zadeh 1975). This approach allows for dealing systematically and in a transparent way with the imprecision of linguistic terms normally used in narratives. At the same time it

Table 12.3 Sequence of meetings aiming at the quantification of scenarios

Meeting—date	Development of scenario stories	Quantified/scientific input
SPM1—06/2006	Drafting of scenario stories (factors, major uncertainties, scenario rationales)	Overview on research objectives, expected results, input requirements for simulation studies
SC—09/2006		Specification of research requirements, information flow between models
SPM2—02/2007	Enrichment of stories, introduction of actions and actors	Modeling results based on fast-track scenarios, derivation of quantified scenario drivers
SC—06/2007		Discussion of quantified scenario drivers with scientists
SPM3—11/2007	Finalization of scenario stories, integration of scientific results	Presentation of scenario specific simulation studies
SC—06/2008		Presentation of scenarios' qualitative and quantitative elements and scientific presentations with opportunities for discussion between scientists and stakeholders
SPM4—06/2009	Drafting of country water strategies based on Regional Development Scenarios	Presentation of scientific results and scenario drivers relevant for water strategies
SC—07/2009		Specification of scientific input required by scenario process, preparatory discussion of briefings of scientific results
SIM—11/2009 (Jordan)		WEAP and scenario presentation at Ministry of Water and Irrigation in Jordan
SIM—01/2010 (Israel, Jordan, PA)		Organization of information flow between models, elaboration of water management options
SIM—03/2010 (Germany)		Organization of information flow between models, identification of scientific indicators
SC—07/2010		Final discussion of key scenario drivers, prioritization of scientific indicators
SIM—09/2010 (Israel, Jordan, PA)		Specification and quantification of water management options and their implications
SPM5—10/2010	Finalization of country strategies, design of regional water strategies	Presentation of selected scientific results
SIM—03/2011 (Israel, Jordan, PA)		Specification of water strategies with focus on land-use impacts
SPM6—06/2011	Finalization of water strategies, identification of robust elements and options for short-term action	Very selected scientific impact with focus on management during drought periods

SPM Scenario Panel meeting, *SC* Status conference, *SIM* Scientific input/expert meeting

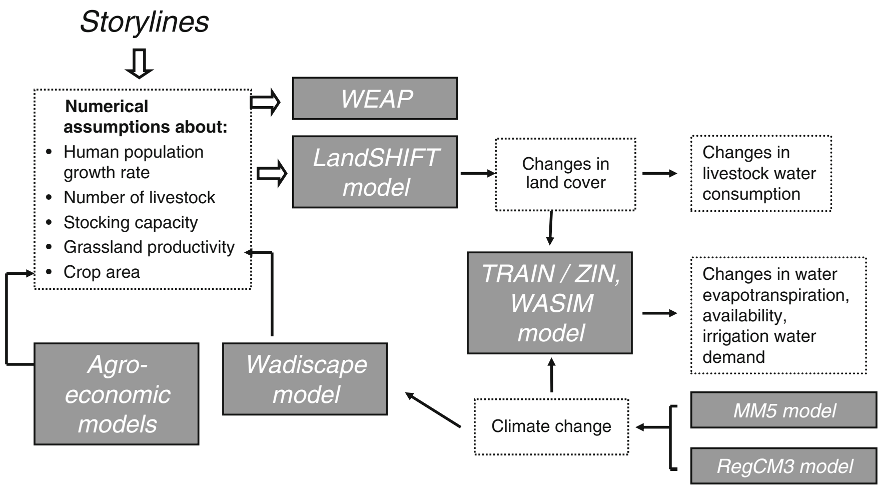

Fig. 12.2 Model coupling in the GLOWA JR project (simplified representation)

provides rules to translate the linguistic expressions into the numerical information required as model input. The following three steps were carried out during SPM2:

(1) Each of the four scenario working groups agreed on trends of driving forces in linguistic form for each of the scenarios, time steps and countries. For example, one scenario group stated that population growth was "medium" in Israel between 2000 and 2010.
(2) To construct fuzzy membership functions which serve as translation keys in this approach, each single stakeholder provided a range of values for the linguistic expressions characterizing the trends of driving forces. For this purpose, questionnaires were prepared which contained quantified background information for each of the driving forces in order to give stakeholders a feeling for plausible ranges. The result has been, for example, that one of the stakeholders perceived population growth as "medium" when the growth rate is in the range of 1.0–2.5 % per year. The estimates of the entire group for "medium" population growth ranged from 0.1 to 3.0 %.
(3) The estimates of the entire group of stakeholders were then used to construct fuzzy membership functions in form of a triangle. The minimum, median, and maximum value of the group's estimates defined the vertices of the triangle. To obtain single values for each of the linguistic variables the membership functions were "defuzzified" by identifying the center of gravity of the membership function. These values were then used to calculate trends of driving forces in a numerical form consistent with the agreed dynamics from step (1).

This translation procedure was assumed to represent the variety of perspectives of the whole Scenario Panel on dynamics of driving forces better than e.g. a simple mean or median of values. A more detailed description of the approach can be found in Alcamo (2008).

The procedure described above was carried out for the seven model drivers specified in Table 12.2. The resulting trends of drivers were then compared to existing estimates from the literature (if available) in order to test plausibility of the trends and their ranges and to build stakeholder's trust in the quantification procedure. Comparisons were possible with population scenarios of the United Nations (UN 2010) and with income development from the IPCC SRES scenarios (IIASA 2009).

In discussions with stakeholders limitations of the methodology became obvious. Although a thorough introduction was given on the variables, many stakeholders still had the feeling that more expertise is required to provide the numerical estimates that were used to construct the membership functions (step 2 of the quantification procedure). The importance of expertise is also stressed by Cornelissen et al. (2001) who state that in order to increase reliability of membership functions three aspects should be considered: (1) criteria that determine necessary qualifications of experts, (2) proper elicitation of expert knowledge to construct a membership function, and (3) methods to test reliability of a membership function.

Additionally, the drivers required by models are often aggregated variables which are different from variables water planners are usually working with. Consequently, it was often difficult for stakeholders to estimate future trends of these variables (step 1 of quantification procedure), although they were experts in the respective fields. See for example the percentage of change in water use efficiency in the domestic sector: In reality, it results from a combination of several factors ranging from reduction of physical losses in water pipes to behavioral changes in water use. Also, non-linearity in the dynamics of variables had an impact, for example, those for population growth or economic growth. Asking stakeholders for percentage rates of change often resulted in extremely high changes in absolute numbers when growth rates were applied over a long period of time.

Due to these limitations and when inconsistencies between scenario stories and drivers became obvious, stakeholders modified the trends of driving forces during the following SPMs. For Israel three population scenarios up to the year 2030 were officially made available by the Israeli Central Bureau of Statistics in the third phase of the project. Stakeholders decided to extrapolate these scenarios to 2050 and to assign the high, medium and low estimates to three GLOWA JR scenarios and to assume a continuation of the current population growth rate for the fourth scenario.

12.2.4.2 Integrating Scientific Results in the Scenario Process

The major aim of integrating science in the scenario process was to inform stakeholders on state-of-the-art scientific results, generated within the project, in a form useful for managing water resources in the region. A successful integration here meant that stakeholders got the opportunity to gain new knowledge and/or to prove and if necessary restructure existing knowledge (Baird et al. 2014) based on the scientific input to the scenario process. Scientists on the other hand required information from the stakeholders in form of plausible assumptions on quantified model driving forces, information on the way modeling results should be analyzed and which indicators are considered relevant for strategic water planning. A prerequisite for the bi-directional information flow was the facilitation of a dialogue between stakeholders and project scientists. For this purpose different formats of presenting and communicating science were applied in the course of the project (see also Table 12.3).

The focus of research in GLOWA JR was on the impacts of global climate change combined with socio-economic changes on water and land resources in the region and the revealing of ways to deal with them. Various models were available for this purpose covering a variety of scientific disciplines (see Fig. 12.2). In order to integrate and harmonize the simulation studies, quantified key drivers and other qualitative information was provided via the scenario process.

Scientific input at the Scenario Panel Meetings

The presentation of results of simulation studies to stakeholders during the SPMs was organized in three key issues (for a more comprehensive summary of the simulated variables and quantified results see Tielbörger et al., Chap. 27):

1. *Regional climate change and hydrological impacts:*
   - Analyses of changing climatic conditions including temperature change, precipitation change during the growing season and consecutive dry days index were based on the two regional climate models MM5 and RegCM3 (Smiatek et al. 2011; Krichak et al. 2007) which were driven by two global circulation models (ECHAM5, HadCM3) under the IPCC B2 scenario (preliminary results) and the A1B emissions scenario.
   - Impacts of climate change on the regional hydrological regime were simulated by the two hydrological models TRAIN/TRAIN-ZIN (Menzel et al. 2007) and WaSIM (for the upper Jordan River catchment) (Kunstmann et al. 2006). Results were presented on changes in evapotranspiration, water availability and irrigation water demand under the B2 scenario (preliminary) and the A1B scenario up to the 2050s. Regional averages were made available as well as changes on a higher spatial resolution. Additionally, monthly changes of water availability, the combined impacts of land-use change and climate change on water availability (Menzel et al. 2009) and changing potentials for urban and rural water harvesting were presented. In order to address climate extremes the changes in length and frequency of droughts were estimated.

2. *Land use change and agriculture:*
   - An ensemble of agro-economic models translated socio-economic scenarios including assumptions on sectoral water allocation into economically optimized spatial agricultural production patterns (Wolff et al. 2007; Kan et al. 2007).
   - Different regional sources of information on soil properties were combined to develop a region-wide map assigning the suitability for treated waste water irrigation (Schacht et al. 2011).

- Ecosystem productivity under changing climate conditions was simulated using the WADISCAPE model (Köchy et al. 2008) in order to assess e.g. the implications of scenario-specific management of rangeland for changes in open space. Analyses included changes in biodiversity and ecosystem services and risks of species extinction (Tielbörger et al. 2010).
- Changes in land use and land cover including the climate change driven expansion of irrigation area demand (Koch et al. 2012) and losses in open space due to the expansion of rangeland were simulated by the LandSHIFT.R model (Schaldach et al. 2006; Koch et al. 2011) by integrating all land-related information.

3. *Regional and sub-regional water balancing:*

- In order to analyze the implications of scenario assumptions on the regional water balance the results of the scientific sub-projects and regional data were integrated in the Water Evaluation and Planning tool WEAP (Hoff et al. 2011). WEAP was applied to estimate the trend of water deficits on different spatial and temporal levels so that conclusions could be drawn for a further specification of regional and sub-regional water management (e.g. Bonzi et al., Chap. 16, Al-Omari et al. 2014).

The **first Scenario Panel meeting** (SPM1) was used to familiarize stakeholders with the scientific analyses to be performed for the scenario process. Harmonized presentations were given showing the (scenario-related) objectives of model applications, the variables the simulation studies could deliver and the input they require. At the **second Scenario Panel meeting** (SPM2) first modeling results were presented by applying a so-called fast-track approach. Simulation studies were based on socio-economic drivers down-scaled from two scenarios of the Millenium Ecosystem Assessment (MA 2005) which show similarities with scenario stories drafted during SPM1. Although of preliminary character, the results gave an impression of the range of impact levels and of the kind of results stakeholders might expect from the simulation studies. For the project scientists this approach provided advices to adapt input and output routines of models in order to handle available model input from scenarios and adjust analyzes of model output to stakeholder requirements (e.g. to focus on the implications of climate extremes). As a concluding step of the science session stakeholders were asked to further specify research needs for the scenario process. At the **third Scenario Panel meeting** (SPM3) first harmonized and scenario-specific results originating from coupled modeling as shown in Fig. 12.2 and based on the scenario drivers derived from stakeholders' quantified assumptions at SPM2 were presented. Short and clearly structured presentations were given for each of the four scenario groups on the three key subjects described above. The quantified trends of the socio-economic drivers were adjusted if considered inconsistent with scenario stories. Then, stakeholders were asked to incorporate quantified elements or qualitative insights from the scientific presentations into the scenario stories or to evaluate consequences for the scenario stories and to adapt them accordingly.

In the second phase of the scenario exercise (SPM4—SPM6) the focus was on the development of water management strategies. At the **fourth Scenario Panel meeting(s)** (SPM4), quantified results of the first phase of the scenario process were presented in a country-specific form. Additionally, stakeholders were informed about region-wide challenges for the water sector caused by the impacts of climate change on precipitation, water availability, and irrigation water demand up to the 2050s. For the **fifth Scenario Panel meeting** (SPM5) a different format was chosen for the presentation of scientific results: Studies with selected results from the key subjects were presented in form of posters at the beginning of the meeting. These posters were then available during all 3 days of the meeting so that stakeholders could come back to them if necessary. At the **sixth and final Scenario Panel meeting** (SPM6) communication of scientific results was of minor importance since it was primarily used to identify robust water management options and a small set of options enabling a more cooperative regional water management.

Scientific input meetings

In order to improve communication of science into the scenario process in the final phase of GLOWA JR so-called **scientific input meetings** were organized in the region and in Germany (see Table 12.3). These meetings were necessary in order to intensify involvement of project scientists in the scenario process. Since the focus of the SPMs was on developing the scenario narratives, only a limited number of project scientists were involved at these meetings. The major aim of the scientific input meetings, however, was the organization of the information flow between the various models. A further objective of these meetings was to identify so-called policy-relevant scientific indicators relevant for planning and decision making in regional IWRM from the scientists' perspective. The scientists were asked to prepare one-page handouts which describe the indicators and the conclusions that could be drawn regarding the scenario-specific outcome of simulation studies.

Scientific input at the Status Conferences

In particular, at the **Status Conferences** of the third phase of the project emphasis was laid on stakeholder-oriented presentations of scientific results. Several opportunities for the presentation and discussion of scientific results with stakeholders were organized. A so-called "Poster Train" was arranged where key results were presented in a focused form to small groups of stakeholders and sufficient opportunity was given for questions and answers so that stakeholders could get more familiarized with simulation results. Additionally, the stakeholders were asked to specify which scientific indicators they consider especially useful. For this purpose the 26 so-called policy-relevant indicators identified at the scientific input meetings were presented in the DPSIR (driver-pressure-state-impact-response) format, a well-documented framework for the assessment of complex systems (see e.g. Smeets and Weterings 1999; Karageorgis et al. 2005; Razi Nezami et al. 2013). Each stakeholder was asked to comment on them and to identify the ten indicators most relevant for integrated water planning. The Status Conference was also used for a final discussion and revision of socio-economic scenario driving forces with a broader group of stakeholders.

12.2.4.3 Integration of Qualitative and Quantitative Aspects of Water Management Strategies

Facing future changes in both, the availability and the demand of water requires the development of strategies which consider quantitative and qualitative elements of a water regime. At the SPMs of the second phase of the scenario process mainly qualitative aspects of a future water strategy were elaborated. Information on quantified estimates of future capacities of water options were prepared at so-called regional expert meetings and were finally presented by stakeholders at the SPMs.

At **SPM4** held in each of the three countries, first quantified scenario-specific estimates of capacities from sea water desalination and reuse of treated waste water were presented as a basis for discussion.

The so-called **expert meetings** with stakeholders and additional experts in each of the three countries played a key role for the elaboration and quantification of water management options under the four scenarios. The results of these meetings included specific aspects of the major water options including the scenario-specific timing, potentials, relevant elements and costs of water measures. Here, existing plans in the respective countries were taken up if appropriate and were varied as required by the scenario stories.

At **SPM5** scenario-specific country estimates for water strategies were presented by stakeholders based on results of four expert meetings in the region which took place between SPM4 and SPM5 (see Table 12.3). Country-specific water strategies were conclusively discussed in sub-regional groups. Resulting recommendations for regional water options were further elaborated by the entire (regional) group of stakeholders for each of the scenarios by applying a back-casting approach in order to realize the previously defined visions for the regional water situation. Quantified estimates for the regional water strategies and water options were provided only for some elements. The major aim of **SPM6** was to finalize the water strategies and to draw some conclusions with respect to more cooperative water management measures in the near future. Quantification aspects played only a minor role at this stage of the process.

12.3 Results

The application of the scenario methods outlined above resulted in scenarios and respective water strategies which cover a wide range of future development pathways. These together allowed for the formulation of a set of conclusively justified robust options for water management in the region.

12.3.1 Narratives: Scenario Stories and Water Management Strategies

During the first set of three Scenario Panel meetings a set of four scenario stories was developed covering the time up to 2050 considering three time steps (short, medium, and long term). For this purpose, two highly uncertain and highly influential driving factors were combined to form the scenario space. The first factor is “finance and pricing” translated into the main uncertainties “recession” versus economic growth”. The second one is “access to and allocation of water” translated into the main uncertainties “multilateral sharing of water” and “unilateral dividing of water”. Combinations of the uncertainties form the rationales behind the four scenarios as is schematically shown in Fig. 12.3. The resulting “Regional Development Scenarios under Global Change” are:

1. “Willingness and Ability”, combining economic growth and multi-lateral water sharing,
2. “Poverty and Peace” combining economic stagnation and multi-lateral water sharing,
3. “Modest Hopes”, combining economic growth and unilateral dividing of water,
4. “Suffering of the Weak and the Environment”, combining economic stagnation and unilateral dividing of water.

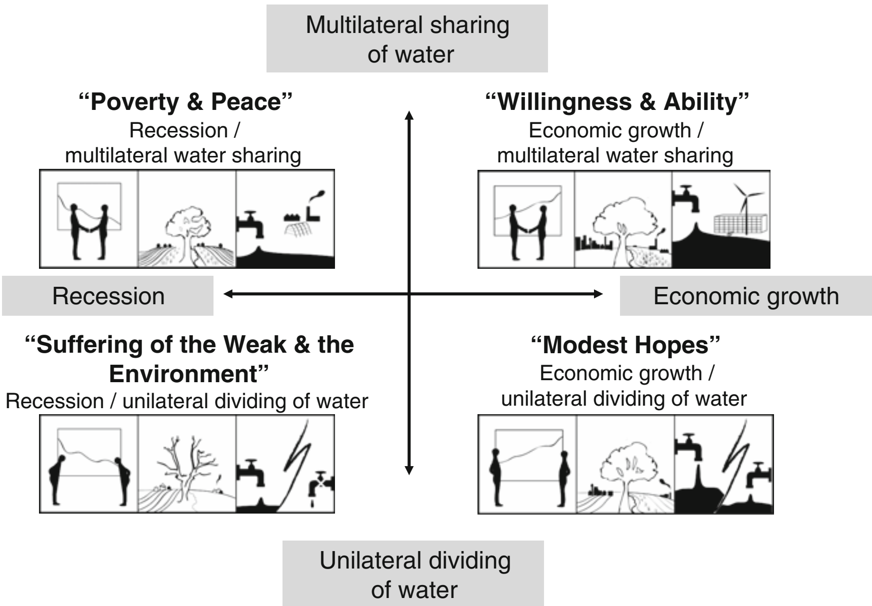

Fig. 12.3 Scenario logics of the four Regional Development Scenarios

Although an important output of the scenarios process, it is too space-consuming to present the full scenario stories and water strategies here. Key aspects of the scenario stories and the corresponding water strategies are summarized in Table 12.4. A more comprehensive description can be found in CESR(2009) and CESR & IPCRI (2011).

Table 12.4 Key aspects of scenario stories and corresponding water management strategies

Scenario	Storyline	Water management strategy
Willingness and Ability (WA)	This scenario reflects the most optimistic perspective of the future in which peace and economic prosperity reign. All parts of the society are profiting from the improved political and economic situation. However, high population growth together with a prospering tourist industry and the climate induced decrease of amounts and reliability of precipitation lead to a fast growing pressure on water and land resources	Economic development and cooperation on water issues allow for an early development of a regional water master plan. A fast realization of large scale water projects is possible due to the availability of financial resources from international donors. Campaigns to raise awareness for environmental issues lead to an increasing conservation of resources. Measures to cope with the adverse impacts of climate extremes are taken early and in a cooperative way so that substantial damages can be avoided
Poverty and Peace (PP)	This scenario represents a combination of peaceful development in the region without economic prosperity. Although the increasing cooperation leads to a more equitable sharing of water resources the overall water situation remains tense	"Make peace an economic value" is the premise of the water strategy under this scenario. It allows for modest economic development through development of region-wide ecotourism realized in part by allocating sufficient water to this sector and by taking care of natural ecosystems. Water resources can be augmented through cooperation on the basis of small scale projects. Tri-lateral water management can be realized very early through third party involvement in the beginning
Modest Hopes (MH)	Under this scenario it is assumed that the political climate in the region remains poor but that economic prosperity prevails. Money is available from international donor organizations mainly for water infrastructure projects on national level. The industrialization of agriculture leads to higher productivity but a decreasing number of jobs	The prosperity envisaged under this scenario leads to a politically stable situation in the region with limited informal cooperation (exchange of knowledge/technologies). The focus of water management is on increasing the supply of water by large scale desalination and waste water treatment and re-use, all on a high technical level

(continued)

Table 12.4 (continued)

Scenario	Storyline	Water management strategy
Suffering of the Weak and the Environment (SWE)	This scenario is a worst case scenario in which there is neither peace nor economic growth. International donors are unwilling to invest money in a politically unstable region so that it becomes challenging to even maintain existing water infrastructure. Rain-fed agriculture becomes increasingly difficult due to a decline in precipitation	This scenario represents the most vulnerable future with respect to climate change including climate extremes. Due to the anticipated increasing deterioration of the situation it was perceived as critical to take action very early. The implementation of emergency measures is regarded as essential to be prepared for future climate extremes. A combination of inexpensive water options, traditional measures and full use of governance options (regulations and laws to save water and protect resources from pollution) are adequate water strategies under this scenario

Insights from the scenario stories and corresponding water management strategies include:

- Population is expected to considerably grow under all four scenarios, either due to natural population growth or due to immigration. Especially immigration, caused e.g. by conflicts in neighbor countries, results in a sudden increase of water demand. Both aspects put pressure on the water- and land resources which considerably adds to the pressure which is expected as a result of changing climate conditions in all three countries. But also out-migration was formulated as a potential problem when skilled and well educated persons leave the region due to a lack of job opportunities and economic stagnation. This “brain-drain” could, according to stakeholders’ opinions, have implications for the tempo of the implementation and maintenance of high-tech water technologies including water saving technologies. However, how large this impact will be on the water balance is difficult to estimate.
- Climate extremes in form of extreme droughts and their impacts on water availability for agriculture are perceived as a threat which especially under the scenarios with limited financial capabilities can only be handled with help of international donor organizations.
- The strategies to cope with the challenges of increasing water demand on the one hand and scarce and increasingly unreliable water resources on the other hand differ widely: Under the more peaceful scenarios (“Willingness and Ability” and “Poverty and Peace”) the focus is on cooperation on water issues. Sustainable development is emphasized under both scenarios but for different reasons. Under “Willingness and Ability” large additional capacities to generate water resources are planned but in the medium term there is a shift to more

sustainable behavior i.e. water saving due to the fact that basic needs are fulfilled and people are increasingly concerned about the environmental impacts of increasing resource consumption. Under the "Poverty and Peace" scenario sustainable development is seen as a prerequisite for economic well-being especially through eco-tourism industry.

- Under the scenarios with a stagnating economy ("Suffering of the Weak…" and "Poverty and Peace") laws and regulations aiming at a more efficient use of water including behavioral changes are implemented and enforced to somehow compensate for the lack of development of new water resources. Here, beside some small scale water generating options such as rain water harvesting the management of water demand dominates the water strategies.

Cross-cutting strategic options

The concluding step of the scenario process was to identify those water options which are applicable across all scenarios, the list of so-called "cross-cutting strategic options". Out of this list three options have been discussed in more detail. These options were considered necessary and at the same time—considering the complicated political situation—feasible to realize first steps towards regional water management:

(1) *Implementation of a Regional Center for Water & Environmental Research*

- Research
- Education, training, public awareness campaigns
- Technology development and transfer, pilot studies

(2) *Towards harmonized planning*

- "Prepare for cooperation" e.g. identify regional management issues
- Share information, national plans, solutions
- Establish joint technical committee to discuss specific issues

(3) *Regional projects*

- Red Sea/Dead Sea Project
- Sea water desalination (Jordan Red Sea Project, Gaza, Mediterranean Coast)
- [Jordan River restoration]
- Waste water treatment

Especially the regional research center has been regarded as a promising option which would address several requirements. It would be a suitable frame to

(1) provide continuity for the dialogue between representatives of the three countries and other organizations working in the region which was started in the GLOWA JR project and intensified during the project's lifetime;
(2) integrate young scientists in a dialogue with stakeholders and decision makers in order to practice communication of scientific results at an early stage of their scientific career; and

(3) continue regional climate modeling, maintain, enable or intensify the application of the regional WEAP model e.g. by adding an economic module and including the continuous updating of databases as an indispensable prerequisite for a scientifically sound regional water management.

After the finalization of GLOWA JR an initiative was therefore started by stakeholders and key scientists from the region and from Germany to establish a regional center named "Sustainable Adaptation to Global Change in the Middle East–The SAGE Centre". For this purpose two workshops were held in 2012 and 2013 to work out a concept including a definition of the common goal, structure and organization as well as requirements to establish and sustain such a regional facility.

12.3.2 Quantified Results of the Scenario Process

12.3.2.1 Quantified Model Driving Forces

A major exercise for the quantification of scenarios was the translation of qualitative scenario factors into drivers suitable to serve as input to the GLOWA JR ensemble of models. Where future estimates were available from country's own future studies or water master plans these were used where appropriate and adapted accordingly. This was the case for Israel and for Jordan where population scenarios up to the year 2030 were available. Selected quantified estimates of key socio-economic drivers for the regional scale are shown in Table 12.5. These were used to simulate future municipal water demand (see Bonzi et al., Chap. 16) and the demand for agricultural commodities and thus land area (Koch et al. 2011).

12.3.2.2 Model Based Results—Policy Relevant Indicators

The simulation results of more than ten models were presented to stakeholders as integral part of the scenario process. For this purpose, model results have been summarized in form of policy relevant indicators. These cover a variety of disciplines ranging from climatology (e.g. the heat wave duration index (HWDI)

Table 12.5 Development of socio-economic key driving forces under the four scenarios

	Population (Million persons)					GDP (Billion 2000US$)			
	WA	PP	MH	SWE		WA	PP	MH	SWE
2000	14.2	14.2	14.2	14.2		133.6	133.6	133.6	133.6
2010	17.7	17.7	17.7	17.7		180.6	176.8	179.8	176.8
2030	28.4	24.5	23.5	24.5		439.5	278.2	311.4	271.1
2050	39.0	32.7	37.0	31.7		1064.3	396.4	863.8	306.9

describing changes in the maximum period of consecutive days with a maximum temperature higher than the respective maximum temperature in the reference period) to indices integrating climate related ecological and economic information such as the genuine saving index of sustainability as a measure for changes in ecosystem services (see Table 12.6). Indicators have been made available on regional or country scale and/or in form of maps if spatially explicit information is relevant. As such they cover the entire region as well as sub-regions and information about development trends in e.g. urban versus rural areas is available. Those indicators which are relevant for analyzing the implications of scenario assumptions on the regional and sub-regional water balance were consolidated in the WEAP model (see Bonzi et al., Chap. 16).

Table 12.6 Scientific issues, policy relevant indicators and their ranking based on stakeholder judgement

Rank	Overall issue	Indicator
1.	Water resource management and hydrology	Rainwater harvesting potential, urban
2.	Water resource management and hydrology	Rainwater harvesting potential, rural
3.	Water resource management and hydrology	Unmet water demand
4.	Climate change and other drivers of change	Additional municipal water demand
5.	Agriculture and land use	Land use change scenarios: land for natural ecosystems
6.	Water resource management and hydrology	Water availability, irrigation water demand
7.	Climate change and other drivers of change	Population development
8.	Agriculture and land use	Water productivity in agriculture: Irrigation, evapotranspration, percolation, yields
9.	Climate change and other drivers of change	Consecutive dry days index (CDD)
10.	Climate change and other drivers of change	Per capita income development
11.	Ecology	Plant biodiversity and extinction risk
12.	Water resource management and hydrology	Potential for rain-fed agriculture
13.	Water resource management and hydrology	Drought length and drought frequency

(continued)

Table 12.6 (continued)

Rank	Overall issue	Indicator
14.	Water resource management and hydrology	Frequency of 1998/99 drought under present and future climate
15.	Climate change and other drivers of change	Precipitation change during the growing season
16.	Climate change and other drivers of change	Heat wave duration index (HWDI)
17.	Agriculture and land use	Soil properties: land suitability for sustainable wastewater irrigation
18.	Agriculture and land use	Erosion risk
19.	Ecology	Sustainable stocking capacity
20.	Climate change and other drivers of change	Heat waves: change in the number of consecutive days with daily max. temperature >40 °C
21.	Climate change and other drivers of change	Green biomass and genuine saving index of sustainability
22.	Climate change and other drivers of change	Very heavy precipitation index
23.	Ecology	Biomass productivity of natural/semi-natural vegetation
24.	Climate change and other drivers of change	Extremely wet days
25.	Climate change and other drivers of change	Mean annual temperature change
26.	Agriculture and land use	Changes in water flow, water quality and land use

The quantified results can be found on the GLOWA JR website (http://www.glowa-jordan-river.de/OurProducts/Indicators)

12.3.2.3 Quantified Water Management Strategies

Developing unconventional water resources was regarded as the most important strategy to alleviate water scarcity in the region. Five major options to augment water resources were identified and elaborated for the four scenarios and quantified for the years 2030 and 2050 by stakeholders and other experts from the region.

As can be seen in Fig. 12.4, assumptions on the further development of sea water desalination capacities differ widely under the four scenarios. Considering well advanced plans for the future, further projects were assumed to be realized mainly depending on the availability of financial resources. To make water import e.g. from Turkey a considerable source of water both are required, financial resources and regional cooperation. The reuse of treated waste water (TWW) was regarded as a water source of increasing importance in the JR basin since it depends strongly on the future development of municipal water use. Moreover, the question of TWW is linked to the question of water quality and protection of the groundwater body as important reservoir for water storage. Water development options with a minor capacity such as rainwater harvesting and brackish water desalination could play an

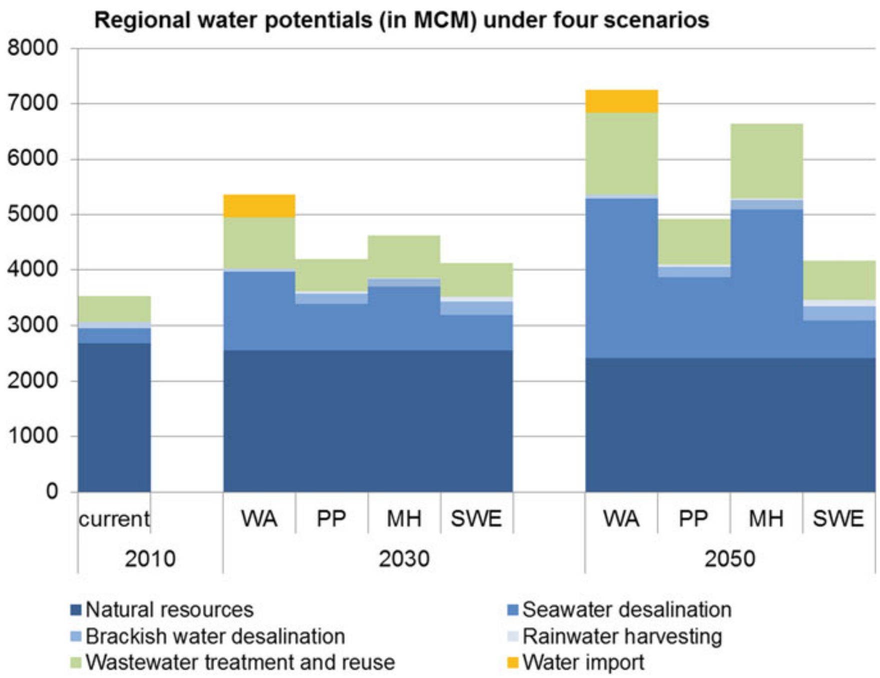

Fig. 12.4 Development of the regional water availability up to the year 2050 considering natural resources and five major "New Water" options. For natural resources a climate induced decrease of 10 % in 2050 relative to 2010 was assumed

important role on the local scale and were especially elaborated under the scenarios assuming economic stagnation since they can be realized without large financial efforts.

When integrated in WEAP the implications of the strategies to develop new water sources can be evaluated at a higher spatial or timely resolution, shortcomings of strategies can be identified and a further specification is possible as shown in Bonzi et al. (Chap. 16).

12.4 Discussion

12.4.1 The Process of Scenario Development

The scenario process was intended to stimulate the elaboration of a wide range of different water management options for the region. With respect to the process, three critical aspects should be mentioned:

First, there is the question of who participated. Which stakeholders and organizations and thus perspectives were represented? Which expertise was available and which was only weakly represented or not at all (such as the economic sector in general or the tourism industry) and what are the consequences for the credibility of the outcome of the process (Chaudhury et al. 2013)? Especially, missing aspects in the scenarios can have an impact on acceptance or recognition of the scenarios. Here, the strength of the 2 × 2 matrix approach played out. In order to adequately cover all combinations of key factors within the matrix, i.e. the degree of cooperation on water issues and the economic situation, a large diversity of issues had to be elaborated. Moreover, each of the scenarios had its own very special challenges or opportunities facilitating an integrated perspective on the management of water resources. It became obvious, also through quantification of the scenarios, that opportunities in their extreme form could easily show their disadvantageous face, turn into challenges and finally change trends within a scenario. This happened under "Willingness and Ability" where strong population growth paired with sufficient financial resources led to the assumption of strongly increasing capacities for sea water desalination. Under specific circumstances this could have adverse impacts on coastal ecosystems, thus possibly affecting tourism industry. Additionally, aspects of IWRM not considered by the stakeholders could be taken up by the scientists. This was the case, for example, for environmental issues such as the risk of species extinction driven by large land demand for agriculture or by explicitly asking stakeholders for information on quantifiable and unquantifiable "costs and benefits" of water measures. Also, a changing composition of the scenario panel throughout the scenario process can be perceived as disadvantageous. Time is required to familiarize new stakeholders with scenarios and the underlying assumptions. Reservations regarding verified narratives by new stakeholders and thus the legitimacy of scenarios could be problematic, time-consuming, and could hinder progress in the workflow. However, a positive aspect of a varying group of stakeholders is that comments on scenarios from a large number of different perspectives contributes to the richness of scenario stories thus considering the complexity of the IWRM issue more adequately.

Second, the project design of GLOWA JR had a considerable impact on the scenario process. Here, two aspects have to be mentioned: The organization of the project in form of clearly distinguished phases provided the opportunity to learn from previous phases and to adapt the project structure if necessary. A range of measures was taken to adjust the scenario process to stakeholder needs. These measures included a stronger involvement of stakeholders in the decision structure of the project, an adjustment of the thematic focus of the scenario process in its second phase and the organization of Scenario Panel meetings on a country level (SPM4). Especially the latter aspect helped to relate the development of future water strategies to the current reality of water management. Additionally, it helped to increase the number of stakeholders participating in the process. The drafted strategies and priorities with respect to regional water management resulting from these meetings increased the credibility of outcomes of regional meetings. However, since the discussion of country-level water management options was not finalized before SPM5 there was not enough time left for a further, more detailed specification of regional water management options which was the original intention of the process. The long duration of the project was cost intensive but it can be seen as an essential prerequisite for building trust between stakeholders from the three countries living in an ongoing politically tense situation. Additionally, it allowed for the organization of several so-called scientific input and expert meetings to improve and intensify the dialogue between stakeholders and scientists beyond the SPMs. These meetings were crucial for the elaboration and quantification of specific aspects of water management strategies but they also contributed to the communication of the GLOWA JR scenario process to a wider audience of (mostly) water-related experts.

Third, the applied scenario technique plays a crucial role and it has strengths and weaknesses. We combined an explorative approach, projecting the future development of key variables, with a back-casting approach to include normative viewpoints specifying a vision for the water situation. Explorative scenarios served as a context for the development of water management strategies. Such a combination of methods is helpful when strategies and requested solutions are critically compared with respect to their problem solution capability. However, it turned out that although scenario-specific water visions were formulated, the corresponding water strategies had the potential to change or add new aspects to the scenario stories. This, in some cases, caused inconsistencies or even contradictions between scenario stories and water strategies (see also Kok et al. 2011). A weakness with respect to the 2 × 2 matrix scenario method and the acceptance and thus usability of the scenarios was, in the opinion of some stakeholders, the difficulty of deriving explicit water strategies from the scenarios since no probabilities were assigned to them. Scenarios and respective water strategies were developed which were regarded to be plausible but which represent extremes with respect to the key drivers (economic development and multilateral sharing of water) in order to challenge thinking on water management strategies. This limitation was addressed by supplementing the scenario approach by identifying robust water management options as the final step of the scenario process.

12.4.2 Integration of Quantitative Scenario Elements

The major aim of this article is to describe how the strengths of qualitative and quantitative scenario elements were combined and where the integration was successful and where not. It was postulated that by feeding back model results into the discussion about scenario narratives the reliability and usability increases the usefulness of the resulting scenarios including the water strategies (Chaudhury et al. 2013).

Can the quantification of scenarios be regarded as successful? What was useful for the quantification? What was a hindrance or what was perceived as one? An approach inspired by Fuzzy Set theory was applied to derive quantified socio-economic drivers and other variables with direct involvement of stakeholders in order to generate model input. A large number of models, tools and approaches from several disciplines were applied ranging from agro-economic models to ecosystem models as it is required to cover a complex issue such as IWRM. Consequently, model simulations required a considerable number of input variables which could only partly be generated during the Scenario Panel meetings. Consequently, assumptions had to be made by modelers which resulted in a loss of transparency and possibly also credibility of model results. With respect to key driving forces, such as population dynamics, it turned out to be helpful or even necessary to consider available country estimates. For cases where official estimates were not available stakeholder estimates were regarded as useful and a comparison with published quantified scenarios helped to increase credibility and thus acceptance of scenario assumptions.

Modeling results were presented to stakeholders in order to illustrate and understand the implications of their scenario assumptions and to identify inconsistencies. The integration of simulation results in the scenario process had two important aspects: Firstly, they could be directly integrated into the scenario stories e.g. to underline the urgency of action as part of the message to be transported with the scenarios. Secondly, modeling results could be used to inform stakeholders, i.e. here scientific input aimed to generate new knowledge. However, the communication of results of in most cases very complex models turned out to be difficult when the typical communication format of scientists was used. Due to the complexity and the large number of available models and related simulation results it was difficult and time-consuming to agree on useful indicators for the purpose of water management. The situation changed when the exchange between scientists and stakeholders was intensified: Scientists made concrete suggestions on suitable indicators, stakeholders could accept them or make suggestions for modification if necessary and possible from the scientists' perspective.

Even if scientific results of simulation studies of GLOWA JR were directly integrated in the scenario stories to a limited extent only, scientific results were used by members of the Scenario Panel and related experts from the region in their local scenario studies after publication of the GLOWA JR scientific results (see e.g. Al-Omari et al. 2014).

12.4.3 The Resulting Scenarios and Strategies

The scenario stories are, as starting but also intermediate steps, important elements in the scenario process. Their use allows for an open and unrestricted reasoning about future framing conditions and their variability. Various stakeholders expressed their opinions and these were integrated in broadly accepted scenario stories in a structured way. At the same time, creativity and imagination were encouraged due to the qualitative type of information.

Quantified scenario drivers and scientific results e.g. regarding future climate change and its hydrological or agricultural implications were considered in the scenario stories mostly as qualitative elements and often indirectly to take aspects into consideration which have an impact from a sustainability perspective but not necessarily from a water management perspective (e.g. watering an increasing number of cattle will not need much water but might cause considerable soil erosion in case of pastoral farming in open land). In water management strategies quantified scientific results were used, although only in simplified form, as an average in order to facilitate communicability. So it became clear that climate change will have a considerable impact on the magnitude and reliability of future water resources. However, how large this impact will be is still a subject of discussion. The way out of this dilemma was to compile a large number of options of how the region could prepare for climate extremes under different future conditions represented by the four scenarios. In addition, it became clear that future socio-economic changes will add a challenge on the management of water resources at least in the same order of magnitude as that of climate change.

An important outcome of the process was the identification of options and the definition of strategies on how to organize water supply and demand in the future. Considering all four scenarios, the results of the strategy development process provided a good balance of both, supply side and demand side management options. The extreme difference in economic development and cooperation under the four scenarios required the consideration and elaboration of a large variety of water management options. However, it was beyond the scope of the project to quantify the water generating potential of small-scale decentralized water options in a comprehensive way. Also the costs and water saving potentials of measures aiming at behavioral changes regarding water consumption could not be estimated in a reliable way. In order to properly assess the potentials of these water options, further analyses, including from a social science perspective, are required.

Manifold aspects were represented by the different elements of the storylines, particularly optional actions and actors involved. However, the comprehensiveness of aspects favored a large number of measures and water options, sometimes at the expense of the profoundness of the suggested solutions.

12.5 Conclusions

To combine the development of scenario narratives with simulation studies is becoming state of the art in highly complex areas such as IWRM. However, the linking is far from being trivial. And it is even more complicated if results from a large variety of models are to be taken into account which aim to represent the complexity of the whole or parts of the system under consideration.

The coordination and harmonization of the simulation studies was one of the major challenges in the design of the GLOWA JR project. This is probably valid for many IWRM projects which combine participatory approaches with the application of models. Instead of applying a large number of models, partly building on each other, it would therefore be advantageous to have a limited number or even only one integrated model. This would increase the consistency of results and their usability, facilitate their communication and speed up analyses so that more rounds of iteration would be possible in a SAS scenario process. This modeling tool should, however, have a highly modular structure so that it remains flexible enough to be adapted to the requirements of the scenario process.

A central aspect of the applied “Story and Simulation” or SAS approach is the newly developed method to derive quantified socio-economic driving forces via an approach inspired by Fuzzy set theory. In the given complicated context of the GLOWA JR project the results seemed to be useful and accepted by stakeholders in cases where official country estimates had not been available. If methods existed to quantify driving forces in a more sophisticated way (e.g. by population models), or when country projections were available, stakeholders were interested in how the existing projections perform within the scenarios under development and these estimates were often regarded as more credible than own estimates. At this point the Fuzzy set based method of quantifying scenario drivers need some careful evaluation in order to increase trust in the method as well as the outcome of the method. This could be, for example, by better harmonizing the needs for quantified model input and variables stakeholders are used to deal with.

Despite the mentioned shortcomings, we conclude that the SAS approach under the given project design has been an effective and transparent way to integrate and balance qualitative and quantitative aspects in a scenario process. The extent of flexibility provided by this integration allows for a very structured and target-oriented participatory development of scenarios from the beginning on. Its iterative design led to mutual learning and a considerable improvement of the dialogue between scientists and stakeholders.

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Chapter 13
Benefits and Barriers of Participation: Experiences of Applied Research Projects in Integrated Water Resources Management

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Abstract The role and design of participation for the successful implementation of Integrated Water Resources Management (IWRM) has been intensely discussed. However, in the specific context of applied IWRM research, benefits of participation and specific conditions to realize these benefits are often neglected. Such disregard is problematic when scientific driven IWRM concepts are increasingly interwoven with actual IWRM implementation. In order to discover specific benefits and challenges of conducting participation in applied research, both quantitative and qualitative interviews were carried out amongst 15 German IWRM research projects in emerging and developing countries and contrasted with hypotheses in the literature. Results show that researchers tend to agree with hypotheses in the literature, e.g. in terms of the positive role of participatory processes, its different functions and specific design principles in term of skills of researchers and frame conditions. However, researchers of the IWRM funding initiative especially highlighted challenges with regards to several prerequisites like skills of researchers to conduct participatory processes or structural conditions. For

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instance, hard skills are often missing, e.g. the knowledge on how to design participation processes in view of the respective research goal. Moreover, unlike practitioners, researchers are rarely trained in soft skills like intercultural competences for adjusting participatory approaches to different cultural contexts. In terms of structural conditions, the German BMBF research context shows temporal and financial restrictions. Furthermore, conditions within the target country such as political and social aspects are important and not easy to overlook if the project is based in Germany like it is the case in most of the research projects investigated.

Keywords Participatory research · Participatory processes · Stakeholder involvement · Applied research · IWRM

13.1 Introduction

Participation is an intensely discussed topic within the field of Integrated Water Resources Management (IWRM). Both researchers (e.g. Mostert 2003; Pahl-Wostl et al. 2007; Özerol and Newig 2008) and practitioners (e.g. BMZ 1999; GWP 2000; The World Bank 2006) have underlined the importance of participation and specific design principles for participatory processes to achieve an effective IWRM. Against this background, research funding agencies require participation to be a fundamental element of IWRM applied research projects (e.g. BMBF 2013).[1] However, scholars have not systematically addressed the role and design of participatory research in the interdisciplinary IWRM research context. There are no systematic analyses of the role participation should play to achieve IWRM related research results that are aimed at implementation and which specific functions of participatory processes are relevant. More importantly, there is no systematic analysis of the specific requirements necessary for facilitating participation in IWRM related research. As a consequence, the specific roles and designs of participatory processes for applied research remain rather unclear within the IWRM research community.

The purpose of this paper is to contribute to this discussion. We first query if and in which way participation fosters IWRM related research results. Second, we ask for requirements to facilitate participation processes within the IWRM research context. For this purpose, we refer to participation as different forms of influence in the progress of generating and implementing research results by those that are not routinely involved in this process (adapted from Newig and Kvarda 2012). This definition differentiates from those that address actors for other purposes such as

[1]We refer applied research to the generation of knowledge in order to solve real world problems. In this article, we use the terms *applied research* and *research* synonymously.

general learning and thus distinguishes from the concept of capacity development (Ibisch et al., Chap. 14). Furthermore, we emphasize the generation and implementation of research results as in the case of applied research societal actors can take part in both processes.

To achieve our research objective, we followed a three-step approach. In a first step, we briefly introduced common hypotheses in terms of roles and prerequisites for participation (research). Here, we included common hypotheses in the field of participation in general and respective hypotheses in the field of participatory research. This was aimed at setting the frame for further analyzing the roles and prerequisites in the IWRM research context. In a second step, a standardized survey among researchers of 15 IWRM related research projects funded by the German Federal Ministry of Education and Research (BMBF) was conducted, among them projects of the funding initiatives "Integrated Water Resources Management", "International Water Research Alliance Saxony", "Research for Sustainable Development of Megacities of Tomorrow", and "Global Change and the Hydrological Cycle".[2] This survey was aimed at generating quantitative data on the understanding of participation, the role of participation in the research projects and the respective requirements for achieving benefits of participation. In a third step, qualitative in-depth interviews and discussions with researchers from the IWRM projects were conducted in order to get examples of the quantitative analysis and further detailed information on specific challenges of participation in the different projects since these challenges had just been tentatively indicated in a general way in the standardized survey.[3]

In this chapter, we present the results of this endeavor. Section 13.2 defines the potential benefits of participation within the IWRM research context. Here, we first discuss the expected role of participation for IWRM applied research results depending on scales and research topics. We then highlight the functions of participation explaining the attributed roles of participation in the IWRM applied research context. Section 13.3 further presents requirements to achieve these benefits. Here, we distinguish between hard and soft skills of researchers and structural

[2]The questionnaire can be found in the appendix.

[3]The quantitative survey was conducted by the main author. It was e-mail based and comprised mainly closed questions. It was send to the coordinators of IWRM projects and it was in their hand if they worked on it by themselves, handed it over to subprojects addressing participation, or discussed it with the whole project. The qualitative survey was guided and partly implemented by two of the subsequent authors. The survey consisted of telephone interviews and had the form of a guided interview. These interviews took place with IWRM researchers that were mentioned as the vital contact for participatory issues as a result of the quantitative survey. Furthermore, there have been six working group meetings with several participation researchers or facilitators of the IWRM projects. Next to exchanging lessons learnt, these meetings aimed at preparing and analyzing the interviews with the IWRM researchers. In general, researchers of the IWRM funding initiative that participated in the interviews and discussions have different disciplinary backgrounds like social science, natural science and engineering. Finally, all interviews and discussions took place in German. We thus did not cite the specific questions of the interviews in this text, but mentioned the results in those sections of the text that are directly linked to the questions.

aspects such as the frame conditions of German research projects and the conditions within the host countries. In a final section, we conclude by summarizing and discussing the results and giving ideas for further practice and research. In doing so, we hope to contribute to the theoretical discussion and the practical facilitation of participation in the IWRM applied research context and beyond.

13.2 Why Participatory Processes in the IWRM Research Context?

What motivates researchers to initiate participatory processes within IWRM applied research projects? To answer this question, we discuss both the attributed role of participation (13.2.1) and the respective functions of participation (13.2.2). More precisely, we refer to roles and functions that seem to be predominant in the literature (1) to test if these design principles are supported by the researchers for the IWRM research context and (2) to show in which way the design principles are implemented in the projects.

13.2.1 Role of Participation

As mentioned above, both researchers (e.g. Mostert 2003; Pahl-Wostl et al. 2007; Özerol and Newig 2008) and practitioners (e.g. BMZ 1999; GWP 2000; The World Bank 2006) often ascribe a rather positive role to participation in planning and decision-making processes. This refers to both political processes such as the implementation of the European Water Framework Directive (European Community 2000/60/EC; Newig et al. 2005) and research related activities such as in the field of environmental modelling (e.g. Voinov and Bousquet 2010). However, participatory approaches do not necessarily benefit the solution to problems in the field of environmental management (e.g. Newig and Fritsch 2009). Moreover, some researchers even emphasize negative effects of participation (e.g. Cooke and Kothari 2001).

The results of the standardized survey amongst the 15 German IWRM research projects in developing and emerging countries go in line with the rather positive picture of participation drawn in parts of the literature. In fact, the IWRM researchers assigned participation medium (5 projects) up to high relevance (8 projects) with regards to achieving IWRM related research results. Only two projects assigned participation a low relevance. No project considered participation as being irrelevant to achieve IWRM research results.

Following the IWRM scientists, such an important role of participation applies to different levels of society where IWRM research is conducted. According to 12 research projects, an important level for participatory processes is the macro level. The macro level refers to basin management planning across regional scales (e.g. local, national, regional and international) and different water using sectors (e.g. agriculture, industry and tourism). Examples are the development of common river basin management strategies or decision support tools. 11 projects also underlined a positive role of participation at micro level. The micro level refers to specific technological solutions such as desalination or wastewater treatment plants. The differentiation between micro and macro levels, however, does not exclude further levels of participation, the interaction of these levels in one project context or a restriction to specific actors at certain levels. It just describes the different scopes of problems IWRM related research projects preferentially deal with (for project descriptions see Ibisch et al. 2013).

13.2.2 Specific Functions of Participation

In the general debate on public participation, researchers basically argue that the need for participation results from deficiencies of authorized decision makers (Fung 2006). What this actually means becomes apparent by looking at the different functions, i.e. benefits of participation. In the general debate on public participation, researchers suggest a wide set of functions, like information exchange and mutual learning, the integration of interests, the acceptance and thus implementation of decisions, their ownership, as well as further qualification of stakeholders (below). The quantitative survey amongst IWRM researchers suggests that these functions hold true to different degrees for IWRM related applied research.

13.2.2.1 Information Exchange and Mutual Learning

Information exchange and mutual learning is an often mentioned function of participation (e.g. Beierle 2002; von Korff et al. 2010, 2012 in terms of information contributions; Pahl-Wostl 2007 and Luyet et al. 2012 in terms of mutual learning). In line with these statements, the quantitative survey showed that 13 out of 15 research projects underlined the function of information exchange and mutual learning of researchers and stakeholders in view of generating and implementing IWRM related research results. Qualitative interviews further revealed that these processes generally took place between various kinds of actors. First, different disciplines such as natural science, engineering and social science exchanged information and learned from their respective scientific knowledge. Such exchange could enhance solutions for common problems in a specific study area. Second, scientific actors on the one hand and practitioners of different sectors and levels on the other hand interchanged and learned from their respective scientific and practical knowledge. Such exchange could lead to an adjustment of research questions and approaches in order to make IWRM research more relevant for IWRM practitioners.

Furthermore, based on qualitative interviews and discussions within working groups, such information exchange and learning experiences are assumed to take place at different levels of IWRM research: At macro level, for example, participation processes could stimulate information exchange and learning between stakeholders in terms of a common strategy to manage water resources. Here, information on interests, competences and limits could be exchanged, thus building a common knowledge basis. An example for such a process is the scenario process initiated in the GLOWA Jordan River project. Here, the so-called story and simulation (SAS) approach was applied to integrate scientific knowledge and knowledge about regional conditions in order to develop long-term water strategies under climate change conditions for the Jordan River catchment (Onigkeit et al., Chap. 12).

At micro level, such information exchange and learning processes could refer to the usage of specific technologies. Within the CuveWaters project in Namibia (Liehr et al., Chap. 26), water users participated in the planning of water supply facilities (e.g. rain- and floodwater harvesting facilities and attached small scale farming, desalination plants), the construction process, operation and maintenance and the monitoring of the implementation. Especially during the planning phase as well as during implementation, the communities could influence the process significantly according to their demands (Zimmermann et al. 2012).

13.2.2.2 Integration of Interests

Integrating different interests is supposed to be one vital function of participation (e.g. Luyet et al. 2012). For instance, Beierle (2002) found out that participation increases the amount of joint gains. Gaddis et al. (2010) showed that participatory modelling efforts have contributed to finding new and applicable solutions to historically conflicting water pollution issues in Vermont. In line with such statements, the quantitative survey shows that 10 out of 15 projects of the IWRM funding initiative emphasize the integration and balance of interests as a vital function of participation. We base this on the fact that participation of stakeholders supports the exchange of information and opinions, thus building options for cooperation.

The qualitative interviews further suggest that this function is especially important at macro level, e.g. for the development of scientifically based common management strategies. For instance, in the Isfahan project, a workshop especially on water issues in the agricultural sector was conducted in order to support inter-sectoral, cooperative conflict resolution. Participants were representatives from the German and Iranian agricultural sector, the provincial government as well as independent consultants. Major topics were the actual situation of the agricultural sector in the basin, traditional water rights and their change, water use efficiency, new irrigation methods and techniques and options for financing. Another example is the GLOWA Jordan River project where the scenario methodology was applied in order to visualize and discuss the differing viewpoints on water issues in this conflict-laden region.

However, qualitative interviews also revealed that a balancing of interest may also be important at micro level. An example is the CuveWaters project, where several stakeholder workshops were conducted in the pilot village that had been selected for the technology of rainwater harvesting. The involvement of all residents of the pilot village in this process was a key to balance diverse interests within the village on the issues of the location of four pilot plants, the possible beneficiaries, but also the responsibilities for maintenance and management.

13.2.2.3 Increased Acceptance and Legitimation

In the general debate on participation, researchers suggest that participation enhances acceptance and thus implementation of decisions (e.g. Mostert 2003; Newig and Fritsch 2009; von Korff et al. 2010, 2012; Luyet et al. 2012). The quantitative analysis showed that 11 out of 15 projects of the IWRM funding initiative agreed that participatory processes foster acceptance of IWRM research and its results, thus providing the basis for further measures within the project context and beyond. Acceptance may be fostered through giving the opportunity to discuss approaches (e.g. in respect of their adaptability) and test conclusions of researchers as one interviewee stated.

Furthermore, the qualitative interviews suggest that at macro level, river basin management plans, strategies and decision support tools are assumed to be more accepted and thus implemented the more stakeholders are being involved in their development. In Iran, for instance, stakeholders have actively participated in the development of a Water Management Tool (WMT) in order to increase the acceptance of the tool and to build up ownership (Mohajeri et al., Chap. 23). An interactive workshop with representatives from the main sectors was conducted. It was supposed to address two main issues: the different perceptions regarding the main water management problems in the Isfahan region and the question of who should be responsible for the operation and maintenance of the WMT. Therefore, participants were invited to discuss which data should be fed into the tool in order to address the major water problems. Furthermore, they were given the opportunity to express their expectations towards the purposes the tool should serve.

Similarly, at micro level, specific technological innovations are more likely to be used if stakeholders participated in their conception. One example is the project IWRM Mongolia (Karthe et al. 2014). In this project, participatory methods were used in order to integrate the local population into the decision-making process about the sanitation system that was to be introduced (Siegel et al. 2014a, b). Within a participatory sanitation planning process, the needs and demands of the local population and other relevant stakeholders were queried. A stakeholder workshop was conducted in order to present the technical options, and eventually the residents chose their preferred sanitation system (for the description of the queries Sigel et al. 2012). Another example is the CuveWaters project where participatory processes such as the involvement of future beneficiaries in decision-making processes on the location and the organizational structure of the implemented rainwater harvesting and gardening technology as well as several capacity development measures enhanced the acceptance of small scale farming practices which had not been practiced before in the project region.

13.2.2.4 Generation of Ownership

Closely related to the question of acceptance, ownership is highlighted as an essential function of participation (e.g. Harrison et al. 2001). Ownership refers to the voluntary and self-binding adoption of responsibility. The quantitative survey suggests that 11 out of 15 IWRM projects think that participation enhances ownership for IWRM related research results. We assume that participatory processes lay the foundations for common decisions that are acknowledged by stakeholders as being their own. Conversely, if there are no participatory processes, people may perceive scientifically based management suggestions as imposed and thus possibly neglect them.

An example at macro level stems from the CuveWaters project. A digital atlas was developed in close cooperation with Namibian and German partners. This tool offers planners at different spatial levels information necessary for an integrated resource management. The GIS based tool includes maps, fact sheets on technological options as well as photographs and background information. In a next step it is planned to integrate it into a basin water information system which is currently under development by the Namibian Ministry of Water as it allows access and exchange of information and by this supports decision makers (Röhrig and Liehr 2011).

At micro level, participatory processes could enhance ownership for technological innovations generated and implemented within the project context. Positive examples are the pilot plants in Namibia (desalination and water harvesting plants). Within three years of operation almost no incident of vandalism or theft appeared and the users perceive the plants as their own property.

13.2.2.5 Qualification

In the general debate on participation, qualification in terms of competencies of participants (e.g. hard and soft skills) has been emphasized in two ways. Some researchers highlight competences as a precondition for successful participatory processes (Harrison et al. 2001; Özerol and Newig 2008; Korff et al. 2010). Some underline the development of "second order" effects (Renn 2006),[4] e.g. further civic competencies (e.g. von Korff et al. 2010) or competencies of local scientists to use participatory methods (Hirsch et al. 2010) as a result of participatory processes. In this latter case, we understand qualification as a possible function of participatory processes.

As the quantitative survey suggests, supporting the qualification of the public in terms of hard and soft skills was supported by just one third of the research projects as a function of participation. Such reservation may be explained by two aspects. First, there may be overlaps of this function with the topic of capacity development (Ibisch et al., Chap. 14). Second, scientists usually do not aim at inducing broader

[4]Renn (2006) refers to the effects of deliberation as one form of participation.

societal changes but want to answer a specific research question. In general, it is difficult to quantify effects of qualification processes resulting from the IWRM funding initiative since researchers usually do not take part in further processes after the end of their project and there is usually no post-evaluation phase after the end of projects.

In sum, participation seems to be conducive to develop and implement IWRM related applied research results based on various functions such as information exchange, balancing interests and creating acceptance and ownership. On the one hand, this is in line with the broader discussion on the relevance of participation for IWRM. Just as in the general debate, researchers of the IWRM funding initiative attribute participation an important role for an IWRM in general. They also support similar functions of participation. However, researchers of the funding initiative have another focus since they emphasize instrumental rather than intrinsic functions of participation. Participation is not conducted for the sake of basic democracy but rather in order to improve the output of decisions in terms of research results and their implementation (for the general discussion see Özerol and Newig 2008).

13.3 Prerequisites for Achieving the Potential Benefits of Participation

Even though researchers and practitioners underline the important role of participation for water management, participation is no panacea for IWRM. To achieve the potential benefits of participation, the respective design of participatory processes is essential (e.g. Mostert 2003 and von Korff et al. 2010 for water; Hage et al. 2010 for environmental issues as well as Rowe and Frewer 2000 and Bryson et al. 2013 in general). In the following, we start by discussing design principles with regard to skills of researchers (13.3.1) and continue with those referring to structural conditions (13.3.2). Here, we refer to design principles that seem to be predominant in the literature (1) to test if these design principles are supported by the researchers for the IWRM research context, (2) to show in which way the design principles are implemented in the projects and (3) to discuss if there have been specific problems when implementing such principles in the projects.

13.3.1 Skills of Researchers

To achieve successful participatory processes, those that implement such processes need both specific hard and soft skills. To clarify, we refer hard skills to the theoretical knowledge of how to design participatory processes in respect of specific goals and conditions. Soft skills refer to the personal skills of researchers to implement the approaches.

13.3.1.1 Hard Skills of Researchers

Theoretical knowledge about the design of participation processes includes several aspects like the questions of who should be integrated, to which degree, when and by which means.

Identification of Stakeholders
To achieve the benefits of participation, those that facilitate participatory processes first have to identify the respective stakeholder groups to be involved (Fung 2006; Hage et al. 2010), usually based on sophisticated stakeholder analysis (e.g. Bryson et al. 2013; von Korff et al. 2010). If the facilitators cannot build on recent stakeholder analyses, the definition of stakeholders requires skills to conduct such an analysis at the pre-phase of the project based on existing methods described in the literature (for an overview see Beveridge et al. 2012). However, research also suggests that there are also some general principles of who should or should not be involved in water management processes, e.g. decision-making authorities (Hirsch et al. 2010; von Korff et al. 2010). Furthermore, the type of actor to be involved may depend on the respective cultural context (Hirsch et al. 2010) and goals and thus also determines the degree (Biggs 1989) or method (Rowe and Frewer 2000) of participation. In terms of context, for instance, elites can both dominate and discipline the process (Hirsch et al. 2010). In terms of goals, aiming at generating new ideas might call for involving less powerful people (Hage et al. 2010).

In the quantitative survey, 8 out of 15 IWRM research projects underlined lacking skills as a basic obstacle to successfully facilitate participatory processes. Such a statement could suggest that sophisticated stakeholder analyses may not be the rule in IWRM research projects. However, the statement of lacking skills does not especially refer to stakeholder analysis but to the facilitation of participatory processes in general. In terms of specific actor groups, the survey goes in line with parts of the literature calling for the involvement of very heterogeneous actors in participatory processes. In fact, the most frequently mentioned groups are members of the political-administrative system and of the general public. Another relevant group are water companies, e.g. water supply and disposal companies. Furthermore, science, development agencies and the press were mentioned as well as the agricultural sector. Whereas this sector includes various types of actors, their nomination points to the necessity of increased exchange between water and agricultural sectors.

In the qualitative survey, researchers further emphasized that actors have to be involved according to the respective project goals and contexts. In terms of the project goals, the development of general river basin management plans may lead to the involvement of other types of actors than the goal of developing locally adapted technological solutions. For developing general river basin management plans and tools, actors from all water using sectors in a given basin should be integrated. In Iran, for instance, actors from the agricultural, water and wastewater, environmental, energy and mining sector were involved for generating relevant information for a decision support tool. In order to develop specific technological innovations, the directly concerned actor group should be integrated. Thus, rainwater harvesting technologies within the CuveWaters project have been developed with the residents of the Namibian pilot village, in particular.

Regarding the specific local setting, researchers suggested in our qualitative interviews to consider habits and routines of people which can result from specific political, cultural and natural conditions on site. Here, about half of the researchers underlined that political elites, seniors or experts have to be involved in the participatory process because of their technical know-how, knowledge of problem solving and of political decision making. One example is the development of technological strategies in Namibia. First it was suggested to implement groundwater recharge as a means of storing local floodwater in times of abundance as a source of drinking water for cattle during times of drought. In several workshops with Namibian and German experts, decision makers and researchers, it turned out that small scale flood water harvesting fits much better to the Namibian conditions. Thus, an adapted technology was developed which combines aspects of rainwater harvesting and the idea of storing water underground for purposes such as irrigation of crops rather than using the water as a source of drinking water for cattle. The result of this participatory process was a change both of the storage technology and the water usage.

In other cases, IWRM researchers suggested that the involvement of political elites, seniors or experts may be counterproductive. Strong hierarchies can hinder successful participatory processes, e.g. the presence of senior experts might undermine the participatory process by their authority. Thus, in order to deal with problems of authority, specific participatory methods are to be used. In the IWRM Iran project, for instance, researchers had to take into consideration that the existence of hierarchical structures may lead to problems when it comes to collaborative decision-making. In Iran there is no culture of "speaking one's mind" when seniors have already given their opinion. In this case, a proactive handling, i.e. addressing the problem and highlighting the importance of hearing all stakeholders' opinions, proved to be a useful approach.

Degree of Participation

In the general debate on participation, several different degrees of participation are differentiated, ranging e.g. from non-participation to different forms of citizen power (Arnstein 1969) or from information transfer to co-decision (Mostert 2003). Furthermore, scholars emphasize that there is no blueprint for an adequate degree of participation and that higher degrees are less common (e.g. Fung 2006). These assumptions are very similar to the debate on participatory research. Here, researchers differentiate between several degrees of participation which reflect varying degrees of participants' control over the research process, e.g. ranging from contractual over consultative and collaborative up to collegiate modes of participation (basically Biggs 1989, also Cornwell and Jewkes 1995; Barreteau et al. 2010). Researchers further argue that there is no blueprint for an adequate degree of participation and state that such a decision depends on the respective (research) objectives, contexts and stage of the process (Biggs 1989; Cornwell and Jewkes 1995; Rowe and Frewer 2000; Barreteau et al. 2010; Hage et al. 2010). In practice, some observe that higher degrees of participatory research are implemented to a lesser extent than lower degrees (Biggs 1989; Cornwell and Jewkes 1995; Hage et al. 2010).

The results of the surveys amongst IWRM researchers draw a similar picture as the above mentioned discussions and observations on degrees of participation. In the quantitative survey we differentiated between three degrees of participatory research, particularly according to Mostert (2003). At a lowest degree, researchers have to guarantee information transmissions to the respective stakeholders. A middle degree is defined by active involvement of stakeholders, e.g. by contributing to information lacks or by giving further recommendations. A high degree is defined by co-decisions of scientists and other groups. The results of the survey suggest that in general a low degree of participation, i.e. a steady information flow, is seen as the minimum prerequisite for the success of any IWRM research project. Moreover, information transmissions are to be completed by higher forms of participation, be it either information generation or co-decision making.

The qualitative interviews further suggest that if stakeholders either advise or co-decide in the research projects strongly depends on the respective research goals and contexts. In terms of research goals, the differentiation between rather basic and applied research is relevant. If the goal is to implement adapted technologies for local needs, stakeholders should be integrated to a higher degree as missing involvement may lead to less accepted decisions. An example is the implementation of three household rainwater harvesting tanks in the selected pilot village in Namibia. There was a budget for three tanks for three households. Within a community workshop the inhabitants of the village had to decide which household is to get a tank. This was a vital process to legitimate the tanks within the community (Zimmermann et al. 2012).

If researchers only generate basic knowledge or compile data for future decisions, actor involvement can in some distinct cases be rather low as actors may not contribute to the actual research task. In the case of the floodwater harvesting technology in Namibia, the selection of the pilot village was mainly based on hydrological as well as infrastructural considerations as it was most important to find a place where there is a reliable supply with floodwater as well as the possibility to use the place for demonstration purposes. Here, the involvement of the stakeholders within the village started after the selection of the actual location. However, in most cases participation may be required for data generation. An example is the monitoring of the operation of the Namibian facility. This was shared between the researchers and the users. They had the task to monitor rainfall, water levels in tanks and the amount of agricultural produce. This process generated data not only necessary for the project monitoring but also for the users to learn how to manage the water resource and facility. However, this shared monitoring was a long and strenuous learning process for the users.

In terms of the research context, the qualitative interviews suggest that the respective participatory culture is of relevance. That is, the degree of participation should be adjusted to the respective local cultural conditions. If stakeholders are used to co-decide, they should not be excluded from research processes. If they are not used to participate, a high degree of participation may be less useful as political decision-makers may not support the participatory processes. But again, there is no blue print, and researchers can also decide to act progressively. Experiences in Vietnam, Uzbekistan and Iran showed that a higher degree of participation was positively recognized. In Iran, project partners showed great reservations against participation at the beginning of the project. After the workshops, however, the feedback was very positive.

Timeframe

In the general debate about participatory processes and research, scholars often demand sufficient temporal resources for participation (e.g. Hirsch et al. 2010; Luyet et al. 2012). However, they seem hesitant to give general statements on timeframes for participatory research processes. If such timeframes are discussed, researchers emphasize the impact of the method and thus the research goal and context of participation (Rowe and Frewer 2000). Furthermore, researchers emphasize that the higher the degree of participation, the higher are the temporal demands for conducting participatory processes (Biggs 1989). Roux et al. (2006) emphasize that the transfer of tacit knowledge needs more time in contrast to explicit knowledge, in our view reflecting more intense participatory processes.

In the quantitative survey, researchers stated almost concordantly that planning for enough time to conduct participatory processes is important. We further asked if there are different time needs for specific actor groups, in our view reflecting different modes of participation. In general, researchers gave very heterogeneous answers dependent on actor groups. If the project has to deal with veto players, IWRM researchers suggested a time frame of approximately 3 years which fits the general duration of the projects. With regards to the involvement of other actors, the answers varied strongly, from very sporadic information to a continuous involvement of stakeholders.

The findings of the qualitative interviews suggest that the varying answers within the quantitative survey result again from specific research goals and contexts. On the one hand, the continuous involvement of veto players may be particularly important since all research projects aim at contributing to problem solving processes. On the other hand, varying answers as to other actor groups may result from different sub-goals and contexts of the projects. For instance, information transmissions to the public may be the more useful the less information and support there is in respect of the general water problems and its solutions.

Methods

In the general debate on public participation, different methods are suggested to achieve different goals (e.g. Rowe and Frewer 2005; Creighton 2005; Luyet et al. 2012). This also holds true for participatory research (Biggs 1989). Furthermore, scholars emphasize that the respective context impacts the effectiveness of methods (e.g. Rowe and Frewer 2000).

In the IWRM funding initiative, it became obvious how important it is to use different methods dependent on the respective purposes and contexts of research. In most projects, participation aims at generating information and developing solutions that take into account the different interests of stakeholders. Generating information is the basis for more adapted research results and is seen as a core goal of researchers. Integrating interests, however, is not a core issue of researchers but becomes part of their goals if they aim at contributing to results that can be implemented and that are sustainable. Both goals need different methods as can be exemplified using the case IWRM in Iran and the GLOWA Jordan River project. Within the IWRM Iran project, information could be generated within a goal oriented workshop using the technique of the World Café. In this case this meant having small heterogeneous discussion groups that were moderated ("hosted") by independent experts and followed by a plenum discussion. Within the GLOWA Jordan River project, even the discussion of joint river basin management strategies needed experienced moderation experts which were capable of dealing with the politically strained atmosphere in the Middle East.

In terms of different political and cultural contexts, diverse information techniques are useful dependent on facilitating participation in more or less open societies. In Namibia, for instance, the goal of information generation could be achieved by open discussions, given a rather strong participatory culture due to the developments achieved after the independence of the country in 1990. In the IWRM Iran project, in contrast, information from stakeholders for the decision support tools was gathered using the method of the World Café which had been adjusted to local conditions. In a land like Iran with a strong hierarchical social system it was not easy to conduct a workshop where every stakeholder regardless of his or her social standing was in a position to give an opinion. Usually, the seniors' word is law. Therefore, each discussion group was led by a moderator or "host" who was not a superior authority or senior official but an independent expert. Moreover, prior to the workshop, the seniors were asked to show restraint and to give every participant the opportunity to speak out on the issues. Despite major reservations even by the Iranian partners the workshop was a success in the end.

13.3.1.2 Soft Skills of Researchers

Apart from hard skills, researchers need specific soft skills to implement participatory processes. These skills comprise personal moderation skills, cultural knowledge and language skills in particular, dependent on the specific research goals and contexts. Furthermore, skills to handle the possible double role of investigating and practically implementing participatory processes are of relevance in some projects.

Moderation Skills

In the literature, high quality moderation or facilitation is often emphasized as a prerequisite for successful participatory processes (e.g. Anson et al. 1995 in general, Luyet et al. 2012 for environmental management). For instance, moderators can support to generate and integrate information (Rowe and Frewer 2005; Krueger et al. 2012) or to resolve conflicts (Reed 2008; Krueger et al. 2012). Moreover, highly sophisticated participation techniques and goals such as consensus building require facilitation (Bryson et al. 2013). However, Sigel et al. (2014) state that researchers do not necessarily have the skills to moderate processes since they are usually not trained in this regard.

Based on discussions among IWRM researchers, moderation skills are not only important for the IWRM research context but also highly challenging. These challenges result from the somewhat contradictory legitimation of researchers given their ascribed objectiveness as researchers on the one hand and the lack of political legitimation to moderate processes in foreign countries on the other hand. In order to maintain support by stakeholders in such situations, we state that scientists should not dominate or force the stakeholders but rather be hesitant to moderate the processes. This especially applies to projects in conflicting environments and where stakeholders have different communication and hierarchy traditions. However, it also applies to situations where the goal is to generate information in rather open atmospheres as in the Namibian context.

Cross-cultural Competence

Nations can vary across several cultural dimensions such as the degree of masculinity or uncertainty avoidance (Hofstede et al. 2010). These different cultural settings may influence participatory approaches (Hailey 2001). Among others, high degrees of masculinity and uncertainty avoidance may have a negative impact on the implementation of participatory water management approaches (Enserink et al. 2007). Take, for example, the lack of a discussion culture and bottom-up processes researchers experienced in the former Soviet republics (Hirsch et al. 2010).

The qualitative interviews suggest that cultural settings had an impact on participatory processes. For instance, some researchers highlighted cultural related passiveness as a vital problem when being responsible for such processes. However, they also emphasized that problems particularly arise when researchers do not have the same cultural roots as stakeholders in the host country as it is the case in the IWRM Isfahan project where parts of the project staff have an Iranian background. If researchers do not have the same cultural roots, they might work under more difficult conditions as their colleagues from the German development cooperation. First, researchers sometimes do not only have to deal with one cultural setting, but a larger amount of settings given the collaboration with several projects. Second, those that are facilitating participatory processes are not per se interested in and used to intercultural communication. Most importantly, researchers do not get any cultural training before working in a new cultural setting as it is common in the development context. For instance, the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) prepares their employees that are supposed to work in international settings in a special program lasting for several months. Even though such programs do not guarantee successful collaboration in an intercultural context, they are assumed to be a necessary prerequisite in this regard.

Language Skills

One further prerequisite for implementing successful participatory process refers to language skills of researchers. In the literature, such skills are discussed in two ways. On the one hand, researchers emphasize sufficient language skills as a prerequisite for facilitating successful participatory processes (Hirsch et al. 2010). On the other hand, researchers highlight that limited language skills can also foster process appropriation by locals (Daniell et al. 2010). If language barriers are assessed to have a rather negative or positive effect on participation may depend on the respective goal of the process, e.g. to which degree skills shall be transferred or research results shall be implemented (Daniell et al. 2010).

In the IWRM funding initiative, the researchers see language barriers as a hindrance to successful participation rather than a success factor. In fact, the quantitative survey showed that 11 out of 15 projects underlined that language barriers complicate the implementation of participatory processes. Qualitative interviews further suggested that if researchers do not speak the respective language, they should resort to professional translators or multilingual moderators rather than use third languages such as English. This is assumed to be important to avoid misunderstandings and to build trust between the researchers and the participating group.

Furthermore, as a result of the qualitative interviews, researchers support the idea that the role of language skills depends on research goals and further underline the respective context. If the goal of researchers is to generate knowledge within the research community of a given country, language skills may be less of a problem, as within the CuveWaters project when researchers work together with Namibian researchers or consultants. However, if the goal is to inform the broader public to enhance the chance of implementation of research results, the respective mother tongue should be used, e.g. when pilot technologies are implemented. Even though most Namibian villagers have basic English skills, it is difficult for them to express their opinions and emotions about certain parts of the technology or the operational concept in another language than their mother tongue Oshiwambo.

In terms of the context, the degree of mutual trust seems to be important. If the participating actors are rather skeptic towards the research process, language skills become more important to avoid misunderstandings and to build up trust. In the IWRM Iran project, for instance, the fact that some of the German project staff spoke Farsi was very helpful for smoothing misunderstandings between German and Iranian partners as well as stakeholders and to create a working atmosphere based on mutual trust.

Double Role of Researchers: Researchers and Facilitators of Participatory Processes

The double role of researchers as both researchers and facilitators of participatory processes has been described as a common trend in scientific processes (von Korff et al. 2012). This could be seen in a positive way, given the assumed impartiality of researchers. However, some scholars suggest that researchers should be rather reluctant in facilitating participatory processes. Instead, local leaders are suggested to facilitate such processes given their abilities to mobilize resources for implementation (Cornwall and Jewkes 1995). Hirsch et al. (2010) suggest that locals may be better to facilitate such processes since they can generate trust as a vital prerequisite for successful participation. Furthermore, some argue that the respective goal is important, suggesting researchers to facilitate social learning processes and practitioners to facilitate operational management related activities (Daniell et al. 2010).

Researchers within the IWRM funding initiative often execute a double role of researching and facilitating processes: On the one hand, they are researchers in a specific scientific disciplinary field, mostly within the natural and engineering science but also within the social science context. On the other hand, they are asked to facilitate participatory processes, i.e. where appropriate they are to initiate or to accompany participatory processes.

Despite such a double role, the quantitative survey showed that researchers are rather skeptical regarding the question if they should initiate participatory processes. Two thirds of the scientists mentioned other groups such as members of the political-administrative system and the civil society to initiate these processes. Just 6 out of 15 projects attributed scientists the role to initiate participatory processes. This could be justified by the fact that scientists may not be accepted or legitimated to initiate the processes, especially in less democratic countries, amongst others.

Qualitative interviews further suggest that double roles of researching and facilitating can negatively impact participatory processes. Next to lacking hard and soft skills or deficient interests of acquiring these skills, negative aspects encompass the neutrality and degrees of acceptance of researchers in particular. In terms of neutrality, researchers have to handle conflicts of interests both between different participating actors and between scientific and stakeholder interests. Conflicts of interests between different participating actors are problematic as scientists may give up their neutral position as a legitimation to conduct participatory processes. Conflicts of interests between scientific and stakeholder interests are problematic as they can lead to a lack of result open processes: either researchers could tend to direct the participating group in a specific direction. Or researchers may not accept the results of participatory processes if the project does not allow changes in the process design.

Such problems in the context of a double role of researchers can be avoided by integrating professional participation experts into the project. This was for instance the case in the project in Mongolia. Here, the researchers included a professional consulting enterprise, which is specialized in participatory environmental planning. The same applies to the CuveWaters project where participation workshops where usually facilitated by a nationally well-known and acknowledged institution. That gave the members of the project team the chance to avoid double roles when attending these workshops.

In sum, researchers tend to agree with the required skills mentioned in the general debate on participation. However, we observed several specific characteristics for the research context. Most importantly, researchers have to adopt skills in addition to their core scientific work. Furthermore, they are not supported by funding institutions as regards cultural training, for instance. Moreover, some skills are specific to the research context such as handling the double role of researchers as scientists and facilitators of participatory processes. Such problems may explain why two thirds of IWRM researchers underline lacking skills as a basic obstacle to successfully facilitate participatory processes.

13.3.2 Structural Conditions

Next to specific skills of researchers, the benefits resulting from participatory processes may depend on specific structural conditions. In the following, we discuss such conditions in terms of both the political conditions within the host country and the frame conditions of research projects.

13.3.2.1 Structural Conditions Within the Host Country

Structural conditions within the host country encompass both political and socio-cultural aspects, in particular.

Political Aspects

In terms of political aspects, the respective democratic culture may be of particular relevance. Such culture can differ along democratic traditions, being rather open or closed, and may influence both the political support for participatory processes and the degree of active participation when conducting participation processes.

Group discussions among IWRM researchers suggest that democratic cultures have an influence on participatory processes indeed. In fact, IWRM researchers had various experiences along different political settings. In rather democratic settings such as Namibia, where especially in the rural areas decisions are often made by local village committees, participation processes are fairly easy to implement. In countries such as China, though, communication between researchers and stakeholders is perceived as being affected by a steady control of higher authorities.

Socio-cultural Aspects

Next to general political conditions, the composition of social groups is of relevance. Social groups can differ along their social status, this one usually being defined by the degree of formal education, income and profession. However, in some contexts it can also be influenced by aspects such as gender, age or family relations. Scholars assume that the status impacts the degree of participation: the higher the social status, the more active are people to participate (Fung 2006). Also, researchers suggest that in certain contexts men are more active than women in participating, at once underlying that this depends on the very specific circumstances (Cleaver 2001). However, researchers also emphasize that the selection methods of stakeholders as well as the concrete circumstances influence such connections, occasionally causing inverse relationships (Fung 2006).

Based on group discussions, researchers of the IWRM funding initiative especially made experiences relating to the connection between participation and gender issues. Here, researchers had differing experiences: while most traditional authorities in Namibia are male, those who are more active in participation processes are usually women. This causes a systemic gender bias: the ones developing concrete solutions at micro level are others than the ones making decisions at macro level.

13.3.2.2 Frame Conditions of German Research Projects

Research projects are subject to specific frame conditions. In the IWRM funding initiative, the projects are especially subject to the conditions of the funding institution BMBF. In the following, we discuss relevant conditions in terms of both temporal and financial aspects.

Temporal Aspects
In the literature, researchers emphasize the need for long-term cooperation between researchers and practitioners (Roux et al. 2006; Sigel et al. 2014). First and foremost, this implies adequate project durations, e.g. programs of at least five years for successful knowledge transfers (Roux et al. 2006). Second, this may also imply stable job tenures within the project to build continuity and trust among the participants.

The reality in third party funding is different from these suggestions. As Sigel et al. (2014) state, "research projects often have planning cycles of only 3–5 years." In the BMBF funding initiative on IWRM, project durations are generally limited to pre-phases of 6 months to 1 year and main phases of about 3 years. In some cases, projects have several phases of 3 years. These limitations considerably impact the design, output and outcome of participatory processes: the shorter the project duration, the less time to build trust among the participating actors. Consequently, participation processes have to be adapted and expectations of outputs and outcomes have to be limited. For instance, in the CuveWaters project, an intensive participatory process of more than two years was necessary before the implementation could start. This was only possible with the project design of a two year preparation phase before a three year implementation phase started.

Next to limited project durations, researchers have to struggle with unclear and varying job tenures. This means that the duration of treaties does not always overlap with the project duration so that researchers that implement participation processes may change within the process. Such changes are particularly problematic since participation requires trust on the part of the participating stakeholder vis-à-vis the facilitator of participation processes.

Financial Resources
Next to temporal issues, financial resources are of relevance. These regard both the funding of the participatory processes and of the respective outputs. In terms of the processes, researchers especially emphasize enough funding, flexibility and incentives for participation. Above all, funders must provide appropriate financial means to ensure successful participatory processes (Rowe and Frewer 2000). Furthermore, researchers underline the necessity to create a flexible environment, e.g. to flexibly adjust participatory processes (e.g. Biggs 1989; Rowe and Frewer 2000; Korff et al. 2010; Webler et al. 2001). However, they also observe that such flexibility is not always given (Korff et al. 2010). This particularly applies to the funding flexibility. As Korff et al. (2010) state, for instance, researchers "often lack the funding flexibility to respond to communities' requests for research". Furthermore, researchers discuss funding as an incentive for participation. In this

regard, some researchers argue that stakeholders need incentives to participate in research (e.g. Cornwall and Jewkes 1995). Such incentives could be of financial nature. However, they can also consist of precise process descriptions, for instance (Barreteau et al. 2010). Finally in terms of outputs of participatory processes, researchers emphasize the need not to create "false hopes" (Cornwall and Jewkes 1995), in our terms to clarify which aspects can be funded and which not.

In group discussions among IWRM researchers, researchers emphasized that enough financial resources are to be secured for participation experts in the project, professional moderators, translators and locations, amongst others. Furthermore, flexible conditions are emphasized as a prerequisite to initiate and conduct adequate participation processes. However, researchers further criticize that participatory processes are often restricted by a rigid time frame. This is of particularly importance since researchers sometimes underestimate the required time and financial resources.

Furthermore, according to 10 out of 15 projects, there are indeed general needs to set incentives to participate. This is based on the fact that sometimes the benefit for participation may not be clear at the beginning of the process so that stakeholders may be less interested in participating. However, researchers tend to state that these incentives should rather not be of financial nature as it should be prevented that stakeholders participate for pure financial reasons. Thus, incentives such as further education, certificates or social events should be preferred to incentives such as financial aids or salaries.

During the implementation of the floodwater harvesting technology within the CuveWaters project, for instance, more than 40 people of the local community where involved in the construction process but only those who showed the most reliable commitment towards the project and participated in all accompanying capacity development measures where considered as future direct beneficiaries of the irrigation plots that are watered with the harvested floodwater. This incentive resulted in a very high commitment of the whole community towards the project and intense participation throughout the construction process as well as during subsequent project activities.

On the other hand, some researchers also underlined that insufficient financial means may negatively impact the participation process. If there are no funds available to honor the participation of stakeholders in terms of refunding travel costs and per diem allowances, people may not participate due to a lack of funding. This may be even more important when stakeholders from NGOs, public administrations or residents are part of the process.

In terms of the outputs of participation processes, 12 out of 15 research projects agreed that expectations regarding the funding are to be clarified. Within the IWRM research projects both scientific results and their implementation are pursued. However, whereas the scientific part is funded, the funding of implementation is restricted to subsequent implementation projects. Insufficient information on the respective funding may result in disappointments and losses of trust.

In sum, researchers have to handle both specific frame conditions of German research projects and the political conditions within the host country. Whereas practitioners face the same conditions in host countries, researchers might find it more challenging to adapt the relevant skills as described above. Furthermore, they have to act within the specific restrictions of the research context.

13.4 Conclusions and Recommendations

Based on quantitative and qualitative interviews, we have identified both possible benefits of participation for generating IWRM related research results and conditions to achieve these benefits. First, researchers emphasized the positive role of participatory processes on different levels, based on several participatory functions such as information exchange, learning, acceptance, legitimation, ownership and balancing of interests. Second, researchers underlined various prerequisites to achieve these benefits. These encompass skills of researchers and structural conditions. First, hard skills are important such as knowledge on who should be involved, to which degree, at which state of the research process, and the adequate method. Second, soft skills are of relevance like moderation techniques, cultural and language skills as well as handling the double role of scientists as researchers and implementers of participatory processes. Furthermore, the respective conditions within the target country such as political and social aspects are of relevance. Finally, specifics of the German research context such as temporal and financial restrictions have to be considered. Whereas many ideas of researchers are in line with the views expressed in the literature, some important differences exist with regards to the functions of participation, the skills and the frame conditions when comparing participation in general and participatory research in particular.

These results are based on quantitative and qualitative interviews within the specific research context of the IWRM funding initiative. The internal validity of results may be limited due to different understandings of the term participation, among others. Furthermore, the external validity is limited due to our reporting of IWRM results within the IWRM funding initiative only. We assume that different research contexts cause different problem contexts, e.g. in some cases a different cultural setting is more important than the double role of researchers as investigators and facilitators and vice versa. However, we argue that the results make a vital contribution to the debate on participatory IWRM research. Before, scholars discussed roles and prerequisites for successful participatory research in view of either IWRM in general or participatory research in general, related to other policy fields than IWRM, and usually based their discussions on “think experiments” or single case studies. We contributed to fill this gap by providing an analysis of roles and prerequisites for the IWRM research context, based on both a standardized survey and in in-depth qualitative interviews and discussions.

Based on these results, we made some recommendations for further scientific practice and research. In terms of scientific practice, we suggest to further implement participation and participation experts in scientifically motivated IWRM projects. The formal integration of participation is based on the clear and well-founded role that IWRM researchers attribute to participation to generate IWRM related applied research results. The integration of participation experts in IWRM related research projects is based on the various prerequisites that may hinder the successful implementation of participation processes. Experts having hard and soft skills, that are able to adapt to the specific structural conditions of research projects, may promote to overcome problems, thus enabling participation to contribute to project success. If there is no possibility to include participation experts in the project, comprehensive participation units should support IWRM researchers in the different projects to plan, implement and evaluate participatory processes. This suggestion goes in line with the general idea expressed in the literature that the involvement of social scientists in research projects positively correlates with the degree of participation and the adaption of methods to specific circumstances (Biggs 1989). Further, such experts must be enabled to conduct participatory research processes in a highly flexible manner.

In terms of future research demands, we suggest to further analyze the respective conditions for successful participation processes in view of different research settings. These analyses should focus on the relevance of specific actors (e.g. specific stakeholder groups versus the broader public) and specific methods (e.g. different moderation techniques) for different research steps (e.g. research agenda setting, research processes and implementation of research results) and research goals (e.g. implementing technological innovations, river basin management plans or effective versus efficient solutions etc.). Such analyses could generate more in-depths theories on the role of participatory research designs, and thus improve the knowledge basis for societally and scientifically relevant problem solving. Based on such research, the potential of participation for IWRM related applied research project success can be fully exploited.

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Appendix: Project-Specific Survey on Participation in IWRM

This survey aims at generating lessons learnt on participation in IWRM. Lessons learnt comprise four aspects, amongst (1) the definition of participation in IWRM, (2) the relevance of participation to achieve an IWRM, (3) the relevance of participatory research, and (4) the design of participatory processes.

The questionnaire was prepared by an inter-project working group. The results will be part of a key issue paper which is meant to provide guidance for research projects, project executing organizations and the Federal Ministry of Education and Research.

This survey will last approximately 20 min. Please mark with a cross the relevant response fields and add relevant information where applicable. After having analysed the results of the survey, we will send you a draft of the key issue paper and you will have the opportunity to comment the results.

The information that is gathered by the survey will be treated confidentially as long as you do not agree expressly the inverse case. Please mark with a cross the relevant response field:

☐ I would like that the information is treated confidentially, meaning that the project name is not matched with the answers in the further process.
☐ I agree that the project name is matched with the answers in the further process.

We thank you for participating in this survey. In case of any questions, please do not hesitate to contact:

Contact
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Your Contact details

Name of the project:
Name of the sub-project:
Contact person:

Name:
Institution:
Phone:
Email:

(A) What does participation mean in the context of IWRM?
Please mark with a cross and add relevant information where applicable.
1. What do you understand by IWRM?

☐ "a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". (GWP 2000: Integrated Water Resources Management. Stockholm: Global Water Partnership, p. 22)
☐ Other definition:

2. What do you understand by the notion of participation?

☐ Involvement of veto-players (persons that can circumvent or hinder decion-making or the implementation of decisions)
☐ Involvement of directly affected people
☐ Involvement of the wider public
☐ Other:

3. Which actors should be involved in participatory processes in your project?
4. Is there further relevant information on the definition of participation in IWRM that you would like to share?

☐ Yes, namely:
☐ No

(B) Which role has participation in your project to achieve an IWRM?
Please mark with a cross and add relevant information where applicable.
5. Which role has participation in your project to achieve an IWRM?

☐ High relevance
☐ Middle relevance
☐ Low relevance
☐ No relevance

6. Which concrete functions does participation fulfill in your project in view of achieving an IWRM?

☐ Further education of the wider public, e.g. in terms of how to handle technologies
☐ Further education/information exchange between stakeholders
☐ Integration and balancing of interests
☐ Acceptance of decisions
☐ Generating ownership
☐ Other:

7. At which levels does participation foster a sustainable water resource management in your project?

☐ Meta level: Comprehensive, inter-sectoral solution of problems, e.g. in the context of decision support systems
☐ Micro-level: Specific technological solution
☐ Other:

8. Which role has participation in view of implementing IWRM related project results?

☐ High relevance (active involvement of all relevant groups in the implementation process)
☐ Middle relevance (active involvement of several relevant groups in the implementation process)
☐ Low relevance (observation of the implementation process by “participants”)
☐ No relevance

9. Is there any further information on the role of participation in IWRM that you would like to share?

☐ Yes, namely:
☐ No

(C) How relevant is participatory research to achieve an IWRM?
Please mark with a cross and add relevant information where applicable.
10. Is participation an independent research topic in your project?

☐ Participation is from the beginning an independent research topic in the project.
☐ Participation is an independent research topic in the project. However, this was not initially planned.
☐ Participation is not an independent research topic in the project.

11. Which specific research questions does the project address related to the topic of participation in IWRM?

☐ Specific research questions are
☐ The project does not address specific research questions related to participation.

12. What are vital lacks of research related to participation in your project?

☐ Specific lacks of research are
☐ There are no specific lacks of research related to participation in the project.

13. Is there any further information on the role of participatory research in the project that you would like to share?

☐ Yes, namely:
☐ No

(D) How should participatory processes be designed to achieve an IWRM?
Please mark with a cross and add relevant information where applicable.

14. Which degree of participation is generally necessary to achieve an IWRM?

☐ Low degree (e.g. information sharing with those that are affected by a decision)
☐ Middle degree (e.g. involvement in discussions and recommendations for decision-makers)
☐ High degree (e.g. common decisions with decision-makers)

15. Which degree of participation is necessary in the research project to achieve an IWRM?

☐ Low degree (e.g. public-oriented events/information on project results)
☐ Middle degree (e.g. stakeholder as users of tools/methods)
☐ Hight degree (e.g. co-design of research proposals by stakeholders/ stakeholder as equal project partner)

16. What are criteria for a successfull participatory process in your project?

☐ All relevant actors/institutions are involved.
☐ There is a constant involvement of actors/institutions over the whole participatory process.
☐ The IWRM concept which was developed by participants is implemented in the long run.
☐ Comprehensive societal discussions are initiated at the relevant scale (local, national, regional or international).
☐ Other:

17. Is it necessary to set incentives for participants to enable participatory processes?

☐ No, because
☐ Yes, because

Incentives can be:

18. Which requirements have to be fulfilled for participation?

☐ High educational level of participants
☐ Transparency of informatiom
☐ Enough time
☐ Clarifying the funding of measures which regard the participatory process
☐ Long-term involvement of actors in the project
☐ Involvement of seniors/experts
☐ Other:

19. Please specify the timeframe for participation for specific groups!

☐ Veto-player:
☐ Directly affected people:
☐ Wider public:
☐ Other:

20. Which processual conditions foster output-oriented participatory workshops?

☐ Skilled facilitators
☐ Specific facilitation techniques such as
☐ Other:

21. Which actors initiate or accompany participatory processes?
22. Are there any problems if researchers initiate or accompany participatory processes?

☐ Yes, namely
☐ No

23. Which kind of practical impediments and problems come up when implementing participatory processes?

☐ Language barriers, namely
☐ Cultural problems, namely
☐ Too little knowledge of how to design participatory processes on the part of the researcher
☐ Other:

24. Do you have further lessons learnt with regard to the design of participatory processes which you would like to share?

Thank you very much!

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Part VI
Capacity Development

Chapter 14
Capacity Development for Integrated Water Resources Management: Lessons Learned from Applied Research Projects

Ralf B. Ibisch, Marco Leidel, Steffen Niemann, Anna-Katharina Hornidge and Ruth Goedert

Abstract This paper defines concepts of capacity and capacity development for Integrated Water Resources Management (IWRM), and particularly the recent contributions made by a German government funded research programme in this area. Based on the theoretical framework of nested domains of capacity development, the multi-level approach, the paper reviews previous work in this field and then summarises four case studies in Ukraine, Jordan/Palestine, Mongolia and Uzbekistan, which each highlight key aspects of these different domains. These activities took place under completely different settings, allowing some generic lessons for conceptual and practical advancements to be derived. The paper notes the need to align IWRM processes and capacity development processes as much as possible. The multi-level approach was found to be an essential framework for the activities. The paper also recognises the need for continuous and long-term approaches in capacity development, particularly in processes for organisational and institutional change where no single set of guidelines or practices will fit every situation. Specific directions for future work are suggested, including a closer link to work on water governance, as well as monitoring and the evaluation of capacity development.

Keywords Water governance · Institutions · Research · Training · Knowledge management

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14.1 Introduction—Needs and Opportunities

The paradigm of Integrated Water Resources Management (IWRM) has been widely accepted in recent decades as a core concept for improving water management worldwide (Hering and Ingold 2012; Biswas 2008; White 1998). IWRM has attracted special attention through international conferences, the most important being the first UNESCO International Conference on Water in Mar del Plata (1977), the Dublin Conference (1992), the Second World Water Forum & Ministerial Conference held in The Hague (2000), the International Conference on Freshwater in Bonn (2001), and the World Summit on Sustainable Development in Johannesburg (2002). The Johannesburg Plan of Implementation (JPoI) (United Nations 2002) stipulates that within 5 years all countries should have IWRM and water efficiency plans.

Although the global water community acknowledges the importance of an holistic management approach across sectors, there is substantial debate on the practical usefulness of generic concepts such as IWRM (Giordano and Shah 2014; García 2008; Jeffrey and Gearey 2006). On the one hand it has been criticized that IWRM lacks a clear and precise definition on which implementation could be based; that it remains elusive and fuzzy (van der Zaag 2005) and creates unnecessary misunderstandings, thus preventing the core idea of bringing together different perspectives (Jønch-Clausen and Fugl 2001). On the other hand, Biswas (2004) argues that one single concept is unlikely to be applicable in different contexts, i.e. in different cultures, economies and climatic regions. Authors such as Mollinga (2008b), Allan (2006), Mehta (2005), Mosse and Sivan (2003) argue that water management is inherently political. This criticism reflects the absence of power in the conceptual approach of IWRM. As Kim and Hornidge (Chap. 9) also discussed, IWRM can thus be seen as too simplistic and uninformed of the strategic practices and power struggles of different actors and agents involved in water management.

A United Nations status report on IWRM prepared for the Rio+20 Conference documents progress in the inclusion of IWRM in national policies and legislation but also states that only half of the countries with IWRM plans report an "advanced state of implementation" (UNEP 2012). Similarly, at the 2011 Dresden International Conference on IWRM, experts concluded that "the actual implementation of IWRM is lagging behind." They urged that "the implementation of IWRM and the realization of the respective programmes have to be accelerated" but also recognized that "successful IWRM includes targeted and coordinated capacity development" (Borchardt and Ibisch 2013).

Capacity development has been a guiding concept in international development cooperation since the late 1980s (Baser and Morgan 2008). The water sector was one of the first sectors in which the need for capacity development was identified and focused capacity development programs were introduced (Alaerts et al. 1991). Nowadays, it is increasingly recognized that major constraints for improved water resources management derive from inadequate governance structures and especially from the gap between existing and required capacities rather than technical shortcomings (Alaerts 2009).

Against this background the capacity for action by individuals, organisations and societies is a greatly significant prerequisite for the achievement of the sustainability approach in the IWRM process and thus for achieving the United Nations Sustainable Development Goals. Strengthening personal responsibility in the development of solution strategies (ownership) and adhering to a participatory approach e.g. introducing a balance of interests between various water-use requirements are central elements in the capacity for action. The implementation of specific water technologies in model regions must continue to be accompanied by specific training programmes in order to avoid user errors and increase long-term personal responsibility in the operation and maintenance of technical installations. For long-lasting impacts such programmes must be complemented by measures that facilitate implementation; e.g. the enforcement of water legislation by an improved enabling environment and organisational development. Not least, sensitising the public to the sustainable handling of the resource Water plays an important role in the acceptance of national IWRM strategies.

This paper bundles and conceptualises experiences with capacity development from a series of joint research projects and places them in the context of international efforts for sustainable development. From 2009–2013 practitioners in capacity development who were involved in IWRM research and development projects formed a working group in order to share their experiences and further shape their activities. This paper presents capacity development programs conducted in Mongolia, Jordan/Palestine, Ukraine and Uzbekistan and summarizes the experiences and gained insights. The aim of this paper is to document sustainable approaches and concepts within capacity development.

14.2 Defining Capacity Development

There is currently no internationally accepted definition of the term “capacity development”, but depending on their theoretical or political backgrounds different authors use different terminologies for “capacity” and “knowledge” management (Kaspersma 2013; Ubels et al. 2010a, b; Alaerts 2009; Blokland et al. 2009; Baser and Morgan 2008; Brinkerhoff 2005; Brown et al. 2001).[1] In the context of research-inspired capacity development, ‘transdisciplinarity’—the joint research and capacity development of researchers and potential end users of the research—is also used for conceptual and methodological reflection on the process of mutual knowledge exchange and further development, not ‘transfer’ (Pohl and Hirsch Hadorn 2007; Pohl et al. 2008; Mollinga 2010; Ul Hassan et al. 2011).

[1]For a summary on capacity development also refer to Leidel et al. (2012a, b).

The authors of this paper however follow the United Nations definition, whereby capacity development is defined as an integral process for the mediation, strengthening, preservation and further development of individual, organizational and societal capabilities, in order to (i) realize functions, (ii) solve problems and (iii) set and achieve sustainable goals (UNDP 2009).[2] According to Alaerts (2009) "capacity can be defined as the capability of a society or a community to identify and understand its development issues, to act to address these, and to learn from experience and accumulate knowledge for the future". Lopes and Theisohn (2003) argue that there are underlying capacities such as ownership, leadership, or knowledge networking that are essential for improving the overall effectiveness of capacity development.

In recent years the formerly popular term 'capacity building' has been replaced by 'capacity development', emphasising the role of locally available, endogenic stocks of knowledge as starting points for further development (Lopes and Theison 2003). Capacity in this context nevertheless continues to be understood as the abilities of individuals, organisations or systems to perform certain functions in an efficient, effective and sustainable manner (UNDP 1998). Three aspects become clear: (i) capacity is not a passive condition but a continual process, (ii) human resources and their use must continually adapt to change, and (iii) strategic capacity development should take the context in which organisations perform functions into consideration.

The concept of capacity development is oriented integratively towards the environment and the whole system in which individuals, organisations and societies act and interact. Even if the focus of measures is for example, on the development of an organisation or administration for the realisation of a certain task, it cannot take place without consideration of the legal, social and political environment. Capacity development does not mean that capacities are fully absent in a certain region but that existing capacities are to be developed and enhanced so that certain functions can be performed. Measures for the solution of water problems can only be sustainable when the generated knowledge of possible problem solutions is rooted in the regions themselves and adapted to the locally specific environmental, social, technical and institutional conditions. Capacity development can also be considered a political process dealing with power, politics and interests (Fowler and Ubels 2010).

However, Pahl-Wostl (2002) and Alaerts and Kaspersma (2009) point out that the process of capacity development is very complex and highly interconnected. This approach argues that the capacity of individuals and organizations in the water sector depends on a variety of inputs (such as types of knowledge, structure and procedures, leadership and individual managerial capabilities etc.) which tend to change over time and mutually interact. The complexity of the water sector results

[2] The aspect of achievement potential for good governance is emphasised in other publications however (Ernstorfer and Stockmayer 2009).

in non-linear cause-effect relationships and makes it difficult to predict and measure the outcome of capacity development interventions (Alaerts and Kaspersma 2009).

14.3 Levels of Capacity Development

"There is enough water for everyone" was stated in the United Nations World Water Development Report in 2006. Problems result not from insufficient amounts of water but from insufficient water management. Extensive knowledge and capabilities for the efficient handling of water are needed in order for this to improve. This affects all water users, the organisations directing the water sector and society as well as the framework conditions which ultimately determine the available room for development within the water sector. Capacity development is thus particularly significant in the realisation of strategies and the implementation of integrated water resources management.

The basic concept of capacity development is established on various levels and takes the specific requirements of a target region into account. The definition of target groups and target levels is directed by the specific needs of each, and can be structured in the relevant context as follows:

- Target levels: individuals, organisations and societies (often also used in the context of international development cooperation)
- Target groups: educational sector, science, economy, administration, local communities, general public, water users, users of technical installations, laypersons and decision makers

Van Hofwegen (2004) and Alaerts (2009) have put together the different elements of knowledge and capacity development in a schematic (Fig. 14.1), which encompasses three action levels: (1) the individual level, (2) the organizational level and (3) the enabling environment, which describes the legal and/or political framework conditions.

The multi-level approach displayed in Fig. 14.1 summarizes measures for knowledge and capacity development at each action level, what the outputs are and how key features could potentially change (outcome). The authors (van Hofwegen 2004; Alaerts 2009) follow a nested approach, as the individual acts whilst embedded in an organizational context, and the organization operates within the enabling environment. Visser (2010) states that one level cannot perform well without the other levels. It should be noted that all target groups mentioned above, i.e. school, general public, administration and science are represented on all three levels and are closely interlinked (Leidel et al. 2012a, b).

Typical knowledge transfer instruments on the individual level encompass education and training offered by various stakeholders. These should address all aspects of learning (knowledge, understanding, acquisition of skills and attitudes) so that sustainable success of the measures can be expected. The individual level is embedded in an organisational context in which ministries, regional/local

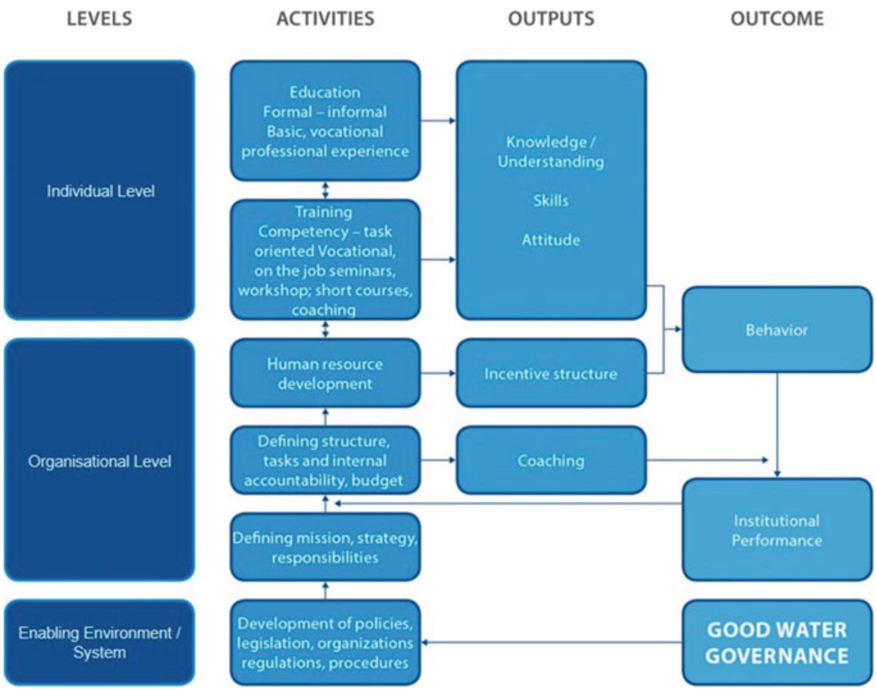

Fig. 14.1 Multilevel approach for capacity development (according to van Hofwegen 2004 and Alaerts 2009, adapted by the authors)

governments and water user associations act for example (OECD 2006). On this level fundamental measures for organisational development are the development of strategies, allocation of responsibilities and accountabilities, amongst others.

At the level of the enabling environment, knowledge transfer activities are usually indirectly covered by measures in the individual and organisational levels, or directly through political consultation. The "enabling environment" can be divided into the areas of institutional framework conditions (institutions, policies, legislation etc.) and civil society. Within civil society numerous formal and informal networks, associations and organizations interact and influence water sector performance. The knowledge and capabilities of individuals determine the productivity and efficiency of higher-level institutions. The power of these organisations depends on the one hand on the behaviour of individuals, and on the other hand on each organisation's own structural capacity (qualifications, incentive procedures and administrative processes).

Government representatives and other actors that shape the enabling environment also acquire capability and become more enabling by drawing lessons from international experiences. Political decision-makers learn mostly from international "best practice" projects in which successful processes have been implemented and demonstrated. In civil society, capacity already exists in the form of what is often called social capital or traditional knowledge. This can be further developed through comparisons with other communities. Networks, technical consulting and peer-learning activities also serve for the exchange of knowledge (Blokland et al. 2009).

14.4 Capacity Development as an Adaptive and Iterative Process

Capacity development is an adaptive and iterative process which reacts to change with a constant follow-up, and integrates the needs of the actors in developing countries (demand-oriented) and in the research projects (supply-oriented). Ideally the process chain for capacity development can be represented as a spiral (Fig. 14.2). It begins with contact to key stakeholders and the establishment of a broad network, also including non-governmental entities. A thorough capacity assessment (definition of competencies, strengths and weaknesses) is conducted in order to make sure that scarce financial resources are being used in the most efficient way, and must be allowed for in respective time plans. The adaptive capacity wheel (Gupta et al. 2010), the UNDP approach to measuring capacity (UNDP 2010), the World Bank capacity development and results framework (CDRF) (Otoo et al. 2009), the 5Cs framework for assessing organisational capacity (Baser and Morgan 2008), the framework for organisational assessment by the Inter-American Development Bank (Lusthaus et al. 2002) and outcome mapping (Earl et al. 2001) are some approaches for assessing capacity (not necessarily restricted to the water sector). Capacity assessment should also encompass or precede an analysis of actors if possible, and

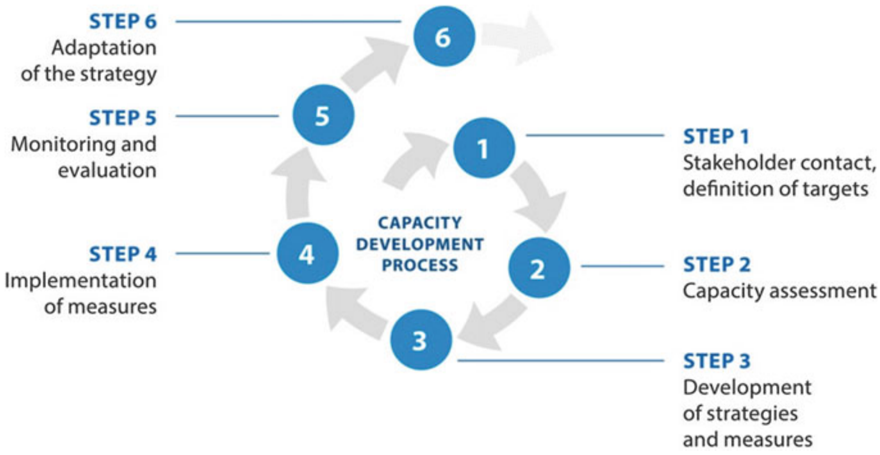

Fig. 14.2 Continuous implementation strategy for capacity development as an adaptive and iterative process (according to UNDP 2009, expanded)

an analysis of the institutional framework conditions in order to derive existent or absent competencies (capacity gaps) for an operational IWRM. However, the needs assessment must not necessarily be performed by research projects. Needs assessments are already available for many countries, e.g. compiled by donor organisations, international development co-operations or international educational institutions (see for example the country studies provided by iMove, www.imove-germany.de), and these can be referred to.

Based on the capacity assessment a comprehensive capacity development strategy is jointly formulated by stakeholders. This strategy will be a collection of capacity development actions that should address all the different levels (individual, organizational, system level). The implementation of a capacity development strategy is not a stand-alone or parallel process; it is an integral part of the implementation of the programme or project in which the strategy is embedded (UNDP 2009). Monitoring and evaluation of the capacity development strategy and measures are required to derive the lessons learned and adapt the concept to achievements and changes.

14.5 IWRM and Capacity Development

An essential framing factor for the sustainable implementation of IWRM is good (water) governance and capacity development (Salamé and van der Zaag 2010). Since capacity development reflects the ability of a society to strengthen its future, Lopes and Theisohn (2003) show that there is an inherent interrelation between governance and capacity development. Taking these points into account it becomes evident that capacity development should not only strengthen water management capabilities, but also governance-related capacities for implementing IWRM.

Capacity development is a component of contemporary IWRM handbooks, such as for instance the UNESCO-IWRM guidelines at river basin level (UNESCO 2009). In this publication the IWRM process is illustrated by a spiral, showing the continuous and adaptive progress of IWRM. According to this scheme however, capacity development is only a part of the first phase of the IWRM process. Yet as Leidel et al. (2012a, b) point out, capacity development should rather be seen as integral to all phases of an IWRM process, as knowledge and capabilities are often inadequate for implementing IWRM.

Active participation of stakeholders can only be assured if they have enough capacities to understand challenges and potential solutions. They should consequently be trained and educated during the entire IWRM process. Strengthening institutional structures and the enabling environment is essential in order to apply and implement acquired knowledge. Institutional capacity development must therefore be integrated into the IWRM process. Consequently, the IWRM process must be harmonized with the capacity development process, so that all phases of IWRM and capacity development will be in alignment (Leidel et al. 2012a, b). The authors conclude that IWRM and capacity development are mutually dependent.

This will be further demonstrated in the Ukrainian case study described below, in which capacity development and the development of IWRM concepts have been aligned from the beginning.

14.6 The German IWRM Research Programme 2006–2018

The German government (BMBF) has funded sixteen research and development projects on Integrated Water Resources Management in developing and emerging nations since 2006 and is expected to continue to 2018. The IWRM concepts developed under this initiative refer to a variety of highly different water problem situations, with consideration given to strongly different environmental, social, technical and institutional framework conditions. Capacity development interventions were a cross-cutting activity throughout the projects and closely linked to the specific research environment in each project. Capacity development measures were oriented to the local context in order to take desired sustainability principles into account. Measures were also specifically developed and adapted to the local situation, institutional structures and local requirements as far as possible. In the following sections approaches for capacity development in the projects carried out in Mongolia, Jordan/Palestine, Ukraine and Uzbekistan are presented in more detail, as these four case studies exemplify the implementation of the multi-level capacity development approach (van Hofwegen 2004; Alaerts 2009) in practice.

14.7 Case Study Ukraine—Supporting Environmental Administration in Improving River Basin Management

The International Water Research Alliance Saxony (IWAS) was dedicated to improving water management in five different world regions, one being Ukraine (Kalbus et al. 2011). The focus of the different country projects varied depending on locally pressing problems; for example urban water management in Brazil in heavily urbanising regions, the overexploitation of groundwater resources leading to saltwater intrusion in aquifers in the Sultanate of Oman, or the impacts of climate change on water resources management in Mongolia. Within IWAS, one important question was how to support the sustainable implementation of IWRM by adequate capacity development measures that fit to the existing water resources problem. All model regions therefore addressed capacity development as an essential component of IWRM on one or several levels in the multi-level approach (Fig. 14.1). Particularly within the Ukraine case study all three levels of the multi-level approach were consistently addressed for several target groups and related to the prevailing water resources problem, thus aligning model-based systems analysis with capacity development (Leidel et al. 2014).

The transition country Ukraine, and the Western Bug River Basin in particular, were chosen because of severe water pollution and ailing infrastructure (including the sewer system) leading to a major water resources problem in a challenging political environment (Ertel et al. 2012; Hagemann and Leidel 2014; Hagemann et al. 2014). A capacity development strategy was designed for the project to run in parallel with each implementation stage of the IWRM process (Leidel et al. 2012a, b). That means that the capacity development process was built on the results of a natural and technical systems analysis and a stakeholder and institutional analysis.

Capacity development in this project was based on an expanded approach from UNDP (2008, 2009; Fig. 14.2), which acknowledges that capacity development is an adaptive and iterative process. The "multi-level approach" was applied as visualised in Fig. 14.1 (Lopes and Theisohn 2003; van Hofwegen 2004; Alaerts 2009), i.e. that capacity development is conducted at the individual, the organisational and the systemic level. Within the IWAS project in Ukraine, capacity development was focussed on the three levels within the scientific community, public authorities, and the water services provider as target groups.

A capacity assessment was prepared for the public authorities (environmental administration and water authorities of the oblasts[3] in Lviv and Volyn, Western Bug Basin Department of Water Resources), and analysed, identifying which capabilities were available in the field of river basin management (RBM), and where further capabilities were needed. The participants were selected based on observations, document review and specific sampling techniques, especially expert sampling and snowball sampling (e.g. Henry 1998). The regional and national experts and the major relevant stakeholders with potentially different perceptions (authorities, NGOs, water service provider, universities) were identified. The major target groups for the study were selected based on this assessment, representing the relevant actors for the stated water quality problems in the Western Bug River Basin. Questionnaires were sent to participants in the first step of the capacity assessment. The 82 questions were structured into the following chapters: institutional and financial aspects, technical aspects (data and information management, planning, monitoring), and human resources development. The results (Leidel et al. 2012a) constituted the basis for a capacity assessment workshop (Fig. 14.3). In order to account for the holistic IWRM approach, the workshop participants were from all relevant authorities, national and international scientists and experts and from NGOs. Outgoing from the initial assessment, possible solutions for the existing capacity gaps were identified in relation to the existing water quality problems, i.e. different options were analysed according to financial, environmental and political feasibility. Finally, the participants identified and proposed prioritized capacity development measures and assigned responsibilities.

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[3]Ukraine's first level of administrative division is called oblast (state).

Fig. 14.3 Capacity assessment workshop in Kiev 2009

During the capacity assessment a system analysis was carried out and problems related to the capacity of organizations were identified. Decision making structures (within the Western Bug river basin) proved to be ineffective, not only because of unclear responsibilities, but also presumably due to informal rules that played an important role (Hagemann and Leidel 2014). Within the transformation process, additional competencies had been assigned to authorities, however they were frequently overruled by higher level authorities so that the rule of law was not fully implemented and thus led to ineffective decision making (Leidel et al. 2012a, b; Hagemann and Leidel 2014; Hagemann et al. 2014). Furthermore, actors at the local level were not used to independent decision making. Addressing those points in capacity development is a complex and long-term process due to the highly political nature. Notwithstanding, those problems were addressed within the working groups as described below. Despite the challenges within the institutional framework and political process of river basin management in Ukraine it was revealed that the areas of data management/collaboration, water monitoring, water modelling and human resources development were of high importance for the authorities (Leidel et al. 2012a, b).

14.7.1 Collaboration and Data Management

The exchange of data and information within and between administrative authorities and the public is an essential factor in the monitoring of water bodies. It is the legal situation in Ukraine that data and information must be exchanged on request. The Western Bug river basin authority had set up a geodatabase, but the data was not entirely open access. The legal order Nakaz No. 56 is an important document within the Ukrainian water legislation, and served as the basis for cooperation between actors, but without concrete guidelines, e.g. for data exchange. This is one reason why the exchange of data and information within and between authorities is still not working properly between the authorities in the Western Bug basin (Western Bug Basin Department of Water Resources, Environmental Administration and Water Authorities of the oblasts Volyn and Lviv) even if there is an agreement between them (Leidel et al. 2012a, b). Further reasons are amongst others, the reluctance to share data with other actors, no clear national legislation in terms of data exchange between authorities, personal sensitivities and a lack of common data exchange formats. Furthermore, data is frequently inconsistent and/or measured based on different methods and therefore difficult to compare.

This leads to a clear asymmetry in the distribution of data and information between different authorities, i.e. that not all authorities have the necessary or appropriate data for their tasks within the river basin management. Information asymmetries were observed between regional authorities, ministries at the national level and between state actors and the public (Leidel et al. 2014).

14.7.2 Water Monitoring

Harmonized monitoring of water bodies (rivers and lakes) is a prerequisite for obtaining reliable monitoring data necessary for the establishment and implementation of management plans. The monitoring program in the Western Bug river basin did not meet international standards in many cases, e.g. the EU-Water Framework Directive in terms of selected parameters (e.g. lacking biological parameters), defined quality targets, applied measurement and analysis methods, harmonisation of different measurement methods across the different measurement organisations, lacking regular and standardised internal quality management, etc. robust and reliable data and information as the fundamental basis for water monitoring was thus often missing or not available.

14.7.3 Water Modelling

Modelling of water quality and quantity is valuable for getting information on the current status of a river basin, as well as for delineating various possible future developments. A model-based systems analysis including coupling of various models was therefore conducted for the Western Bug River Basin (Ertel et al. 2012; Blumensaat et al. 2012; Schanze et al. 2012). Mass balance modelling for example showed that most of the nitrogen pollution (NH_4–N) can be traced back to the Lviv wastewater system (Helm et al. 2012). This shows that there is a clear demand for the application of modelling approaches; however in the Western Bug River Basin modelling was not used by authorities, or universities.

14.7.4 Human Resources

In the above mentioned areas, competent people are needed in the river basin management of the Western Bug River as well as within the Ministries on the national level. The knowledge and capacities of employees within the authorities reflected the current water management approach in Ukraine (Demydenko and Leidel 2010), i.e. that sectoral thinking is still prevalent. If river basin management will change in the future, human resources development, i.e. capacity development on the individual level, must also be adapted to the challenges of changing conditions.

14.7.5 Achievements Through Capacity Development

A strong commitment by national stakeholders was needed for improving river basin management in the region, particularly from the Ministry of Environment and the State Agency of Water Management, as the two main competent actors responsible for water quality problems and river basin management in Ukraine. One important capacity development measure on the level of the enabling environment was therefore the foundation of a working group with members from the Ministry of Environment, the State Agency of Water Management and the IWAS project. During several meetings of this working group, it was discussed that a streamlined coordination approach based on the existing administrative structures and capacities as well as the assignment of competencies will be a reasonable way forward for Ukrainian water management. Since river basin councils and administrations have been installed in Ukraine according to the Ukrainian water program 2002, the coordination of activities in the catchment will be within the scope of their responsibilities. IWAS recommended renewing formal agreements between the state actors within the Western Bug River Basin. This step is part of a future long-term strategy for improving river basin management in the region.

One of the objectives of the above mentioned working group was to re-establish meetings of the Western Bug River Basin Council. Periodic coordination meetings (River basin council meetings) are important for improving communication and cooperation between authorities, and providing mutual confidence, e.g. by achieving goals together. In 2012, a meeting was organized with an accompanying workshop on collaboration in river basins, because the coordination meetings had stalled and the last meeting had taken place 6 years previously (Fig. 14.4). Within the accompanying workshop as an individual measure, middle management from the participating authorities were trained on how to improve collaboration, and how collaboration between authorities is conducted in the EU. The IWAS project correspondingly suggested cooperation with foreign (e.g. German) authorities in the field of monitoring, data management and collaboration in order to exchange experiences between one another. This so-called public-public twinning is a proven tool for strengthening river basin management (Boag and McDonald 2010).

Fig. 14.4 Meeting of the Western Bug River Basin Council in Lutsk 2012

This goes hand in hand with measures on the organisational level, such as improving the scientific basis of monitoring for the introduction of river basin management planning for example. Research in this field (e.g. on biological monitoring) as performed in the IWAS project together with the responsible authorities is consequently an important means for the preparation of management plans. This is in accordance with the Ukrainian action plan for water management until 2020. The IWAS project therefore collaborated with the Western Bug Basin Department of Water Resources (WBBDWR) on hydro-morphological monitoring. The approach from the WBBDWR was compared to the German methodology and joint field campaigns and assessments were carried out to (i) strengthen mapping capacities, and (ii) to enhance the insight towards the importance of hydro-morphological monitoring for river basin management planning (Scheifhacken et al. 2012).

Furthermore, a strategy was necessary for data management and information exchange between authorities, for data provision to other actors (e.g. general public), and in order to meet reporting requirements. Setting up or improving an existing water information system was necessary for the sharing of data and information, and in order to reduce information asymmetry. A web service for data and information was developed by IWAS, but this web service is not yet officially accessible. The ultimate goal would be to integrate Ukrainian data, e.g. to combine it with the information system of the Western Bug River Basin Department.

Such measures also require educated employees that understand the importance of knowledge exchange. Strengthening of overall knowledge about river basin management on all levels within the administration was also recommended however. On the individual level (Fig. 14.1), courses on IWRM and an E-Learning module on IWRM[4] (Leidel et al. 2012b) have been developed for use in training and providing information to authorities as well as a support tool for universities.

[4] www.iwrm-education.de The E-learning module was developed by the IWAS project together with the German Secretariat of UNESCO-IHP/ WMO HWRP.

This process was initiated by the IWAS project in cooperation with local actors, so that eventually an IWRM learning module was jointly developed and executed together with the National University of Water Management and Nature Resources Use Rivne (NUWMNRU), which plays an important role in tertiary water management education, and the Lviv Polytechnic National University, an important university within the Western Bug River Basin. Within this seminar students and young scientists were trained, and the combination of theoretical issues with practical training was appreciated by all participants. This module has the long-term goal of ful integration into the curricula of existing study programmes. The importance of initiating this process can be seen by the fact that this IWRM learning module as well as the e-learning module on IWRM constitute the basis for an online course on "IWRM in Ukraine" developed by the Ukrainian NGO Mama-86 and the Global Water Partnership (GWP). However, further courses and curriculum improvements to existing educational programmes are urgently needed for authorities and universities. Further measures on the individual level were workshops and conferences for responsible stakeholders with the objective of exchanging knowledge on the improvement of water and wastewater infrastructures. Knowledge and capacity development is a continuous process. A facilitating mechanism is therefore necessary for continuous adaptation and learning, which integrates all relevant actors. We recommend a knowledge management platform, as knowledge exchange facilitates communication, cooperation and learning by actors. Eventually this contributes to narrowing the science-policy-interface by supporting informed and coordinated decisions.

14.8 Case Studies in Jordan and Palestine: Capacity Development Through Early Environmental Education

The fragile balance between competing needs for water resources in countries such as Jordan and Palestine might hinder development for an economically, ecologically and socially sustainable future. This implies a complex and long-term challenge for integrated water resource management and capacity development. In these regions increasing pressures on water resources are triggered by population growth, urbanization and development models that have changed lifestyles and cause a decrease in water availability and quality. The situation is further aggravated by the effects of climate change. The result is that sufficient clean water is or will become a scarce resource, which in turn will influence all human activities, social and economic welfare as well as ecosystem health. The outlined set of problems is complex and needs to be reflected in a thorough and long-term capacity development concept and programme considering the potentials, limits, and needs of the people in the aforementioned countries. The detailed understanding of the complex topic of sustainable water use is a key element in increasing awareness of both the importance of water resources and the influence of human behaviour on water availability.

In Jordan and Palestine sustainable water management includes creating new water resources by reusing treated wastewater for irrigation. The SMART project (Klinger et al., Chap. 28) has developed a transferable approach for the integrated management of existing water resources through decentralised wastewater systems solutions (DWWSS) in order to increase the available resources and water quality (MWI 2009; van Afferden et al. 2010; PWA 2014).[5] In addition to new technologies, specific regulatory framework conditions, adequate operation and maintenance procedures, effective wastewater treatment and reuse concepts also require awareness, acceptance, knowledge and skills in the population concerned.

Targeted and tailored capacity development activities were developed and implemented in the context of an IWRM research and development project in Jordan and Palestine (SMART project, running from 2006 and expected to continue to 2018). It was assumed that the three target levels (Fig. 14.1) are interdependent (Visser 2010) or closely interlinked (Leidel et al. 2012a, b). The SMART project nested multi-level approach addressed the individual level mainly through education and training in academia, as Ph.D. and master students were included in the project. On the vocational and professional level technicians and engineers were trained in decentralised wastewater treatment technologies and the operation and maintenance of these technologies. Primary school teachers also participated in training courses on basic early environmental education. The subsequently developed school program will be presented in greater detail below.

The organisational and the system level were directly addressed through the foundation of an interministerial "National Implementation Committee for Effective Decentralized Wastewater Management in Jordan" (NICE) (http://nice-jordan.org/EN/Default.aspx) by the Helmholtz Centre for Environmental Research (UFZ), Germany, in cooperation with the Jordanian Ministry of Water and Irrigation (MWI). Its purpose is developing key elements (technology and reuse standards, site development, operation and maintenance schemes, etc.) for suitable rural and suburban wastewater management that will enable the country to participate in instruments of international financial cooperation.

14.8.1 The School Programme "Water Fun"

The region- and problem-specific programme "Water Fun—hands, minds and hearts on Water for Life!" directly addresses the individual level through training

[5]Israel would have been, in view of the theme "decentralized wastewater management and capacity development" a very important partner. However, the country was not included in the project for security reasons: Israeli participation was politically undesirable from both sides: Israel and Germany.

workshops for primary school teachers, thereby contributing to the development of the institutional school level and facilitating the enabling environment which supports an informed and accepting society for sustainable water management. The programme has the aim of achieving early progress towards sustainable water use and water management and eradicating unsustainable practices. The programme is in compliance with the fundamental pedagogical and methodical principles of education for sustainable development (UNESCO 2006; de Haan 2010). It put teachers, disseminators and students alike in a position to be able to identify, name and understand the unfavourable local and regional water cycle and unsustainable water practices within this context. This programme also enables them to develop and implement potential solutions and empowers participants to shape their mindset and actions for a sustainable future.

The programme “Water Fun” was developed, implemented, monitored and evaluated by the Training and Demonstration Centre for Decentralised Sewage Treatment (BDZ), Leipzig, Germany, with scientific and technical support by the Helmholtz Centre for Environmental Research (UFZ)—Centre for Environmental Biotechnology (UBZ), Leipzig, Germany and infrastructural and linguistic support by Al-Balqa’ Applied University (BAU), Al Salt, Jordan.

Sustainable environmental thinking and action requires the ability to think ahead and in cycles. That is why it is reasonable to start the teaching unit with a deepening review of the natural water cycle. The capacity development programme starts with this basic concept and guides teachers and students through the journey of water in their daily lives. In this way they learn about water supply, how wastewater is generated in their everyday activities, the characteristics, restrictions and implications of wastewater for the environment. Through the production of artificial wastewater in the following unit with simple, safe ingredients teachers and students learn how to define the terms “clean water” and “quality guidelines”. Teachers and students understand the principles of water analysis and learn how to measure different substances in (waste-) water. Furthermore, “Water Fun” presents filtration as a simple treatment method, whereby students can experiment and realize that it is possible to remove pollutants from wastewater through filtration in eco-technologically constructed wetland models (Fig. 14.5).

To conclude, teachers and students learn that treated wastewater is a valuable resource and practise how it can be (controlled) reused for irrigation. The three-day workshop for teachers ends with a field trip to a demonstration site for decentralized wastewater treatment plants in Fuheis, close to Amman, Jordan (Fig. 14.6).

A region-specific teachers’ handbook for both Jordan and Palestine was developed that includes project and scientific background information, didactical and methodological references and recommendations, educational objectives, lists with needed materials and analysis forms for students. An additional students’ workbook presents detailed illustrations of each activity and experiment, thus supporting teamwork. A flyer for the field trip in English and Arabic completes the set of teaching and learning materials for both teachers and students and was developed by BDZ, Germany.

Fig. 14.5 Students filter artificial wastewater in constructed wetland models (North Jordan, Spring 2013)

Fig. 14.6 Teaching and learning outside the classroom at the "SMART—research, demonstration and training facility" in Fuheis, Jordan (Spring 2011)

Primary school teachers in Jordan were trained in three-day workshops in the adequate and sustainable use of the programme in classrooms; three teacher groups (from North, Centre and South Jordan) were given the opportunity to learn about the theory and practice of the programme. They received the complete set of media and materials required, and got the chance to discuss special adaptations for their respective school and students. The primary school teachers in Palestine (West Bank) were trained in "Water Fun" by a group of multipliers from the Palestinian Water Authority (PWA), Palestinian Hydrological Group (PHG), and the Ministry of Education and Higher Education (MOE), Ramallah, PNA. This multiplier group has been trained in Jordan by BDZ, Germany.

Between 2010 and 2013 around 54 primary school teachers in Jordan and 64 in Palestine participated in this capacity development programme. The programme reached approximately 4,500 primary school students in these two countries. As the previously trained teachers started performing in-house training for colleagues early

Fig. 14.7 Presentation of the programme "Water Fun" during the German Weeks in May 2014, Fuheis, Jordan organized by the German Embassy in Jordan

on in the programme, the number of "reached" teachers and "reached" students is presumably now much higher. As the teachers during the first workshop in April 2011 enjoyed themselves and learned that education for sustainability in this manner is not tedious, difficult or expensive they started to perform in-house training for colleagues. This dedication is still ongoing and was initially supervised and supported by BDZ, Germany, and a contact person in Jordan. The training programme has now also reached the interested public in Jordan through presentations by a trained teacher. This teacher is now a key multiplier of the training programme for the whole country (Fig. 14.7, woman on the left).

The capacity development programme has its own website in the meantime[6], which was created with the support of local teachers, amongst others. Participating teachers and multipliers have access in order to download media for further workshops. This website contributes to the further dissemination and development of the capacity development programme also outside of Jordan and Palestine and will in future provide additional services such as information and consulting, and the organization of workshops and field trips to decentralised wastewater treatment facilities in the region.

Sustainable development and sustainable water management cannot be goals in themselves; the development path itself is the goal. This path is long and may take generations in order to encourage lifelong learning and problem-solving processes. This is particularly important for Jordan and Palestine due to the extreme water shortage that both countries are already facing. Along this path the currently selected capacity development strategy must be repeatedly re-examined, chosen methods replaced if necessary, and target groups expanded. It is thus all the more important to

[6]http://www.waterfunforlife.de/home.html. The website is hosted and maintained by BDZ and UFZ, Germany and continuously up-dated when required.

begin education and learning for sustainability at an early stage, in primary schools or even better in preschools. This represents the most promising approach to achieving ecological integrity, economic efficiency, and social equity.

14.9 Case Study Mongolia: Development of a Science-Based IWRM

The Kharaa River catchment in North-East Mongolia was chosen as a Central Asian model region in order to develop, assess and implement an Integrated Water Resources Management (IWRM). In this region, water resources availability is limited and highly variable due the extreme continental climate (Karthe et al. 2015b). Challenges in quantitative and qualitative water scarcity prevail in the region and may in the near future be intensified by the effects of climate and land-use change, growing economic activities and demographic changes (Hofmann et al. 2011). Of particular importance is growing water demand due to increasing irrigation and mining activities, which are also an important source of water pollution. Since 2004 the Mongolian government has gradually adopted the IWRM concept as the guiding principle for national water policy with the overall goal of protecting the unique freshwater resources while promoting societal and economic development at the same time. The National Water Authority and National Water Committee identified 29 river basins of national importance for which river basin management plans (RBMPs) are to be developed.

Under the umbrella of a long-term bilateral political and economic cooperation between Mongolia and Germany a research and development project ("MoMo project") was initiated in 2006 and is expected to continue to 2018, which included research institutions, universities, private enterprises and public administration from Mongolia and Germany (Karthe et al. 2015a). An integrated water management strategy was developed in this project taking into account the specific challenges of the region, consisting of inter- and transdisciplinary research as well as the implementation of conceptual and technical solutions (Karthe et al. 2015a).

The existing capacities in the water sector were found to be too underdeveloped (Horlemann and Dombrowsky 2012) to cope with the multitude of challenges that the Mongolian water sector faces. Therefore, a multilevel capacity development approach (van Hofwegen 2004; Alaerts 2009) was developed and implemented within the framework of the MoMo research project, addressing the individual, organizational, and system level (enabling policy environment). The project addressed a wide array of different target groups within the multi-level capacity development: students at schools and universities, engineers and technicians in the water sector and national, regional and local administration staff.

14.9.1 The Individual Level

Under the umbrella of scientific co-operation agreements between Mongolian and German universities and research institutions around 25 Master and PhD students from natural, engineering and social sciences were closely involved in research activities, and completed work for their qualifications. German university teachers were regularly involved in teaching classes, seminars or practical courses at Mongolian Universities. The topics taught were closely linked to research topics in the project such as water resources assessment, ecological quality assessment, civil engineering, land-use changes, scenario development, or numerical modelling with the Kharaa river basin serving as a Mongolian reference area.

At a higher education level in Mongolia, topics related to water are part of a variety of disciplinary degree programmes at the three large national universities (National University of Mongolia, Mongolian University of Science and Technology, Mongolian State University of Agriculture) such as hydro-construction engineering, hydrogeology, geophysical engineering, hydrology, irrigated agriculture and environmental sciences. But interdisciplinary approaches were more or less absent until 2010. Based on recommendations by a Dutch donor project (MEGD 2013), the three universities developed a curriculum for a Bachelor and Master program on Integrated Water Resources Management in 2011 that combined existing disciplines, new and interdisciplinary topics and short-term inputs from foreign experts. Researchers from the MoMo project gave a regular input to the IWRM course but were restricted by the project duration. The future of the IWRM course is currently under discussion due to the reorganization of university structures.

The testing and implementation of technical solutions within the framework of IWRM in Mongolia was one of the core project goals. A modular concept for an integrated urban water management was therefore developed in order to secure water supply and sanitation for urban, suburban and rural populations (Karthe et al., Chap. 25). Ten pilot and demonstration plants were set up during the course of the project, such as a Sequencing-Batch-Reactor (SBR reactor) for a central waste water treatment plant in Darkhan city and a small decentralized system for waste water treatment in little villages (Karthe et al. 2015b). The technical capacity development on the individual level comprised of regular hands-on training and a continuous knowledge-exchange between German engineers and Mongolian technicians and engineers from the local water supply and sewerage company USAG. The technical capacity development was performed over the course of 6 years during the analysis of existing water infrastructures, the assessment of urban water resources, development of technical solutions and the construction and set-up of the pilot plants. The ultimate goal was (i) to ensure the long-term operation and maintenance of the pilot plants and (ii) to build ownership by the Mongolian operator.

Besides these scientific and technical capacity development measures, the project also focused on primary and secondary schools as an additional target group on the individual level. The MoMo project introduced the IWRM-related catchment perspective into Mongolian schools' environmental education programmes and initiated a school network. Five different towns and settlements were chosen along the Kharaa river (Batsumber, Tunkhel, Suunkharaa, Barunkharaa, Darkhan) and supplied with learning materials, simple water monitoring equipment and teaching modules both for the teachers and the pupils. The teaching modules were prepared by the Environmental Education Centre of the National University of Mongolia in cooperation with the MoMo project and school teachers were trained in their use. As these network schools were situated close to the river and in approximately equal distance from the next network school, each of them took the responsibility of monitoring a specific section along the river. By means of a toolkit (monitoring instruments, measuring devices etc.) provided by the project, the schools integrated physico-chemical water quality monitoring, biological water quality assessment and land use mapping into their curricula. Scientists from both Mongolia and Germany helped the teachers and pupils become acquainted with the monitoring, measuring and interpretation of results. Additional and continuous measuring of climatic parameters at the schools over the course of 3 years support the water-/river-related observations and allowed the pupils (mainly from grade 8 and 9) understand the complex structure and vulnerability of the ecosystem. First results from this innovative initiative were already shown at the network's first pupils' conference held in Ulaanbaatar in December 2012. Here, delegations from all the different network schools presented their results to each other, discussed respective findings both with the other schools' delegations and with attending scientists, and held a competition on the best presentation of elaborated results.

An additional effort partly related to this school network was the initiation of a partnership between two high-schools in Göttingen (Germany) and Darkhan (Mongolia). Since 2012 several groups of students from Mongolia have visited Germany and vice versa and the participants have been trained in cultural and water-related topics. The exchange is financed by participating families and schools and there are realistic perspectives for future continuation of the partnership, bridging environmental education and cultural exchange.

14.9.2 The Organisational Level

The organisational level in the MoMo project was addressed by close cooperation between the partner institutions. A core task during the first phase of the IWRM project was to analyse the actual status of water resources and related land resources in terms of quality and quantity, identifying significant pressures and impacts on water resources and develop scenarios for future possible developments. In order to perform such comprehensive monitoring, environmental data such as hydrological, biological, hydro-morphological, chemical, physico-chemical, climatological and land-use data but also information on water infrastructures were gathered during field surveys (Hofmann et al. 2011). Existing long-term data from the Mongolian water monitoring program was found to be scattered across a multitude of administrative bodies and institutions and often not shared among the authorities or reported in such a way that strategic river basin management could not be underpinned by hard data. The MoMo project organized a series of workshops for representatives of different administrative units such as the national water authority, local water providers and local health offices, in which monitoring results were discussed and exchanged. In this way the interlinkage between different institutions was strengthened.

One outcome of the reform processes in the Mongolian water sector was the establishment of the Kharaa-Eroo River Basin Administration in 2013 which will in the future be responsible for collecting relevant data on the catchment level and for preparing a river basin management plan. As sound data management is crucial for river basin planning the MoMo project developed and delivered an integrative database and data management system (geo-portal) that integrates data of the MoMo project and Mongolian authorities. The geo-portal also could be used for spatial planning (Paulsen et al. 2012). The officers in charge of river basin planning were trained in the use of the geo-portal and the geoinformatic background.

14.9.3 The Enabling Environment/System Level

The future implementation of IWRM components requires an enabling legal environment and institutional framework. During the MoMo project, the legal, political and institutional framework for IWRM implementation in Mongolia was systematically investigated (Houdret et al. 2014; Dombrowsky et al. 2014). As a response to the persisting difficulties in the implementation of IWRM and in the face of increasing problems such as water pollution and growing water demand, new institutions were gradually established in Mongolia under the 2004 and 2012 Water Law and the river basin concept was introduced. Water governance gained strong political influence at the national level, including the reorganization of the Ministry of Environment and Green Development (MEGD) and the establishment of the National Water Council, assembling representatives from six different ministries in order to enhance a cross-sectoral approach to water governance. 29 river basins of national importance were officially identified in 2004 and river basin management plans (RBMPs) are to be developed by newly established River Basin Administrations. Furthermore the new budget law provides for significant financial means for local governments, potentially benefitting local environmental governance and the implementation of RBMPs.

Despite these positive developments, large uncertainties remain with regard to the distribution of competences between different institutions (Houdret et al. 2014; Dombrowsky et al. 2014). Deficiencies in horizontal interplay, i.e. coordination and cooperation between institutions from different sectors (such as, e.g. construction, mining, environment, agriculture) and in vertical interplay, i.e. cooperation between institutions on different political levels (communities, provinces, national level) are still major obstacles to effective water governance. Based on a detailed assessment of the governance framework, the MoMo project supported the river basin management planning process by providing international experiences and advisory services on developing responsibilities, financing instruments and institutional structures. The capacity assessment was organized informally during a series of discussion rounds but will be intensified during the implementation phase of the project (2015–2018).

14.10 Case Study Uzbekistan: Follow the Innovation—A Transdisciplinary Research Experience

Research, education, and capacity development were the focal points of the interdisciplinary project 'Economic and Ecological Restructuring of Land and Water in the Khorezm Region of Uzbekistan' carried out by the Center for Development Research (ZEF), University of Bonn, in cooperation with UNESCO, the State University of Urgench and the German Aerospace Center (DLR) at the University of Würzburg from 2002 to 2012. Around 100 international researchers from the natural, social and economic sciences have conducted implementation-oriented research in close cooperation with local partners and stakeholders from local, regional and national level over the past decade, devising landscape restructuring concepts in order to ease environmental and socio-economic problems in the region.

The project's capacity development programme took on a multi-level approach, addressing the individual, organizational, and system level (enabling policy environment; van Hofwegen 2004; Alaerts 2009). It also comprised of a stepwise transition from disciplinary to multidisciplinary research in the first project phase (years 1–3) to interdisciplinary and finally transdisciplinary research in the second and third phase (years 3–10).[7] As such the capacity development activities focused on the individual and organisational level for the first two project phases, but the latter has received special attention since the onset of phase 3. In phase 3 additional efforts were directed towards the level of the enabling environment and the socio-political system.

From the perspective of knowledge production and innovation development through research, researchers from the first two phases of the project generated knowledge and assessed its scientific promise through a disciplinary and multi-disciplinary approach. Once developed into 'plausible promises', and as part of the research in phase 3, they screened and ranked innovations using an interdisciplinary approach together with local stakeholders with the intention of testing

[7]'Multidisciplinary' in this context signifies research conducted by several different disciplines adjacent to each other but as part of one project, and with few joint research activities taking place; 'interdisciplinary' is defined as research characterised by joint research problem identification and implementation by researchers from different disciplines; 'transdisciplinary' research is conducted by researchers from different disciplines together with practitioners and stakeholders.

and adapting the generated knowledge in form of innovations under real-life conditions. This was accompanied by a stepwise capacity development approach by researchers and local stakeholders through a series of training courses and the continuous facilitation of participatory processes in cooperation with local stakeholders (Hornidge et al. 2011a; Ul Hassan et al. 2011; Djanibekov et al. 2012).

14.10.1 The Individual Level

Activities on the individual level mainly comprised of disciplinary and academic capacity development in the form of Ph.D., M.Sc. and B.Sc. studies. More than 50 Ph.D. students conducted research within the framework of the project. By December 2011, 29 had successfully defended their dissertations, and 102 M.Sc. studies had been completed. The results fed into the project research and have been disseminated and published in refereed journals, books, conference and symposia contributions, discussion papers, and science briefs and will be multiplied when the graduates move into decision-making positions. Non-academic individual level capacity building was also achieved through training lab assistance, technical research assistance, drivers, secretaries, but also researchers in non-research related activities such as self-representation and public relations tasks. It nevertheless became obvious, that on the individual level the disciplinary focal points ‘interdisciplinarity’ and ‘transdisciplinarity’ as conceptual research approaches encompassing specific sets of research methodologies as boundary tools (Mollinga 2008a, 2010) were neglected in the early capacity development activities of the project. The resulting lack of understanding and valuation of inter- and transdisciplinarity as concepts and methodologies within the project team made moving from disciplinary basic research (laying the foundation for the more applied research of the later phases), to inter- and transdisciplinary research difficult and highly impeded the latter. The main lesson learned here was therefore that explicit capacity development activities for designing, conducting and analysing inter- and transdisciplinary research should have been part of the project internal learning strategy from phase 1 onwards and addressed on all levels of the project consortium (research assistants, junior researchers, senior researchers, project coordinators and project leaders).

14.10.2 The Organisational Level

The organisational level was addressed by cooperating closely with local, regional and national partner institutions. A “follow the innovation” approach was devised by the project in cooperation with local stakeholders and forms a participatory and transdisciplinary approach to innovation development (Hornidge and Ul Hassan 2010; Ul Hassan and Hornidge 2010; Hornidge et al. 2011a; Ul Hassan et al. 2011; Djanibekov et al. 2012). Three technological and one institutional innovation were tested and adapted to real-life settings in rural Khorezm. By conducting experiments with local stakeholders driving the process, in this case a water users' association, farmers and a local research institution in charge of salinity mapping, it was possible to build institutional capacities for using and diffusing adapted innovations in a systematic way. Another result was the establishment of a UNESCO chair for sustainable research at the University of Urgench with the aim of integrating research findings into the university curricula.

A crucial component for cooperation and knowledge-exchange on the organisational level was trust between the researchers and local stakeholders. This is not exclusive to the organisational level, but if absent here it has immediate consequences. As also shown in Ukraine, this trust-building requires time, well-qualified local staff and financial resources. Introducing this capacity development component only in the third phase of the project therefore resulted in insufficient time for trust development in order to ensure mutual cooperation as well as (as mentioned above) internal capacities (within the project research team) and external capacities (amongst stakeholders) for communication and cooperation in a way that leaves the required space for knowledge-exchange, adaptation and generation to take place. One way to overcome these challenges was to link the organisational level capacity development activities with those on the individual level. Partners who participated in the individual level capacity components had often been associated the project for years. Their additional organisational ties thus created the required bridges for the organisational level capacity development components.

The most immediate lesson learned is nevertheless to introduce a transdisciplinary approach to innovation development from phase 1 of the project by including local stakeholders as equal partners in scientific experiments as well as conducting these in real-life situations. For example, trees with the potential to reduce salt in saline soils were planted with the assistance of farmers in their own fields (not on enclosed research sites). Only the early inclusion of stakeholders in the process of applied knowledge generation and innovation development assures that the developed innovations actually address areas that lie within the 'window of opportunity' (Röling 2009) of local stakeholders. It also prevents the development of innovations which make scientific sense and which theoretically pose a 'plausible promise' for improving the system of livelihood generation in the region, but which for legal, financial, technical, political etc. reasons are not adoptable by local stakeholders.

14.10.3 The Enabling Environment/System

Future up-scaling and dissemination of the research output nevertheless requires an enabling legal environment and institutional framework. In order to develop these system level capacities, the project devised a series of interactions with the Parliament of Uzbekistan. These eventually resulted in the submission of four project innovation packages to the Ministry of Agriculture and Water Resources of

Uzbekistan that were developed under the organisational level capacity development. In December 2010, three of the four innovation packages were approved for further out-scaling by the Scientific Production Center for Agriculture within the Ministry of Agriculture and Water Resources.

Looking back at these activities on the system level, it can be said that in-depth research on the structures, actors and agencies of change (‘drivers of change’) on the national level should already have been conducted during the second phase of the project, creating an empirically-sound foundation for the later tackling of these ‘drivers of change’ by feeding project innovations into agricultural policy making system. Similarly, networking with high-level decision-makers and representatives of international financial institutions, which had been conducted on the national level, could have received a more specific focus by employing a responsible part-time local senior advisor to be a continual representative of the project and local network-builder in the capital at the beginning of the second phase, rather than the second half of the third phase. The third phase could then have been concentrated from the outset on submitting the selected innovations, which by that stage had already been jointly developed with stakeholders (i.e. water managers, farmers and soil salinity mapping organisations), provided the FTI component was introduced in phase 1 as mentioned above, to the national system of agricultural policy making. However, it must also be considered that the conducting of research on political actors, their networks and political practices in the capital Tashkent was neglected for some time, due to political sensitivity and potential negative consequences for the overall project. The Uzbek specific context therefore posed a special challenge to the inclusion of system level capacity development in and to the overall project.

14.11 Discussion: Lessons Learned for Sustainable Capacity Development

The outlined case studies suggest several generic lessons which can be derived. Irrespective of the specific focus in the wide array of IWRM issues, projects related to the IWRM initiatives described above proved the necessity of considering explicit capacity development activities from the beginning. This requires open (and financial) support from the initiative’s management and a strong link between capacity development and other activities in IWRM projects. Based on the experiences gained through the above case studies sixteen lessons were derived:

(1) Capacity development must be seen as a **central element in the implementation of IWRM** concepts. If actors involved in the water sector do not have the capacities to develop, implement and further develop a specific IWRM concept and the institutional and individual capacities to effectively operate, maintain and further develop existing systems, efforts by research projects in developing and emerging nations in providing knowledge, technical and conceptual solutions,

management tools or guidelines will not succeed in achieving their goals. In the case study in Ukraine, for example, the situation analysis showed that ailing infrastructure such as wastewater treatment plants are an important reason for water pollution. However, the vague legal situation, with scientifically unreasonable water quality thresholds and ineffective management with low enforcement capacities were also important in terms of pollution. Capacity development measures on the national political level were subsequently developed hand in hand with infrastructural improvements (Leidel et al. 2014). It can be concluded that the development of an implementation strategy for capacity development should run complementary to the development of an IWRM roadmap. As both processes for capacity development and IWRM are mutually dependent, early harmonisation of both processes should be prioritised up to the stage of operational IWRM implementation (Leidel et al. 2012a, b; Karki et al. 2011).

(2) Capacity development requires a **long-term approach** in order to yield sustainable effects that are locally operationalised and eventually embedded in local routine. In the Ukrainian case study, a 5 years project cycle was sufficient for a profound scientific situation analysis, setting-up of roadmaps for IWRM development and initiating first implementation measures. But, acknowledging the long term requirements, such projects will require follow-up projects, such as public-public twinning or projects in development cooperation. Project cycles that are normally adopted for 1–4 years are generally too short to optimize this complex and lengthy process (Ritzema et al. 2008). Often capacity development goes hand in hand with a long-term research programme aiming to build a robust, consolidated, and shared scientific knowledge base for improving understanding of coupled human and ecological processes and their interrelationships in order to promote Integrated Water Resources Management at the basin scale (Karki et al. 2011).

(3) Capacity development is an **adaptive and iterative process** that can be represented as a spiral (Fig. 14.2). During the case studies described here, a strong emphasis was placed on the assessment of existing capacities and legal, political and institutional framework. In the case study in Ukraine, capacity assessments were made based on a modified UNDP approach (UNDP 2008, 2010). In the case study in Mongolia well-structured and semi-structured interviews were used to assess the legal and institutional framework (Houdret et al. 2014; Dombrowsky et al. 2014). Based on intensive collaboration between stakeholders, a capacity development strategy was formulated and implemented. However, the institutional setting in Mongolia changed extremely rapidly from 2004–2013 due to political reforms and significant economic growth (Houdret et al. 2014) resulting in an ongoing need for continuous analysis of governance frameworks and reorganization of the capacity development strategy.

(4) Early **inclusion and participation of all key stakeholders** is of utmost importance during the first phase of the process chain, as much as it is in any subsequent stage of the capacity development process. However, local stakeholders and experts must not only be involved as equal partners in the political process of IWRM, but also in the development of joint research agenda and the designing of

joint scientific experiments in real-life situations, which is crucial for the success of the endeavour later on. This was particularly highlighted in the projects in Ukraine and Uzbekistan. Quite often however, even identifying stakeholders and engaging with them in a systematic way is a key challenge as the motivation to participate might be ambivalent and torn between different interests. Motivation for participating in an initially foreign-driven programme on a personal and/or institutional level might not necessarily, from a programme's initial steps onwards, coincide with the agenda. Identification and the continuous adaptation of a genuinely desired and thus sustainable activity is thus a time consuming, but utmost important task. The expectations of both sides should be clearly formulated in order to avoid friction, competencies should be clearly assigned, and a constant and transparent exchange of information guaranteed.

(5) **Trust building** was established as a crucial basis for stakeholder involvement, in the cooperation and exchange of different types of knowledge (implicit, tacit, explicit and communicable). Time is essential in trust-building as well as open-minded and empathic actors involved in the processes of capacity development. For example, the IWRM project in Mongolia established a partner network over the course of 10 years which was a crucial requisite for the adjustment of capacity development measures. Similarly it was only through the local presence of the Uzbekistan project over a 10 year period which made possible the implementation and further development of a transdisciplinary and thus participatory innovation development approach, which fundamentally differed in governance style from the locally pervasive authoritarian system and resulted in a state plan on agriculture. This stimulating environment of open-minded actors, the interest and acceptance of different perspectives, respect for other opinions, and confidence in negotiation partners was also recognized by the International Water Resources Association (Hamdy et al. 1998).

(6) The **development of strategies and measures** must be prioritised by project management as the duration and financial resources for research projects are limited and measures must be cost-effectively structured. Simultaneous planning for the long-term implementation of capacity development should take place, e.g. through networking with other educational providers. For example, in the Jordan/Palestine project, a school network (UNRWA[8] schools for Palestine refugees) expressed great interest in taking over the capacity development measure 'Water Fun' for primary schools in Jordan. In Germany and other countries there is a wide range of carriers and offers on capacity development which are fundamentally worth considering for networking: development co-operations, multilateral funding institutions (Regional Development Banks, World Bank etc.), water sector professional associations, universities, research institutes, consulting firms, research projects or the "German Water Partnership" network. The IWRM projects described in this chapter benefited substantially from contact established to local partners, providing

[8]http://www.unrwa.org/where-we-work/jordan.

socio-economic studies, teaching material, etc. by development cooperations with a permanent presence in the target country.

(7) Broadly defined, capacity **development measures follow a multilevel approach,** but often the weighting of capacity development measures on different levels shifts during the progression of an IWRM process. In the case studies presented here the emphasis at the outset of the IWRM process lay on the assessment of resources, governance analysis and the development of IWRM strategies, whereby capacity development components were particularly strong on the scientific level. With the progressive implementation of IWRM concepts and the realisation of technical solutions, the transfer of technical know-how and responsibility for the functioning of technical and other solutions gained increasing importance. However, it was also decisive that during the implementation of technical solutions a thorough governance analysis was followed by governance capacity development, e.g. the strengthening of responsible authorities.

(8) An implemented concept for capacity development requires the involved actors to **monitor and evaluate** individual measures and the overall strategy. In a best case scenario, lessons learned will be derived from the results of evaluation and subsequent further development of the concept will also be pursued. A good example of this is the project's school network along the Kharaa river in Mongolia. Two years after implementation the success of respective measures has been evaluated by students. Respective results were then even used to increase the sustainability of these activities and similar efforts.

For self-evaluation, comprehensive and objective standards should be established in advance. However, the development of knowledge and capacity is a long-term and not fully projectable process. Thus the challenge lies in devising coordinated approaches that build on decentralised strengths (Whyte 2004). Kaspersma (2013) states that there is a "paucity of research on the use of analytical tools and frameworks to measure progress over time" in capacity development (Pascual Sanz et al. 2013; Alaerts and Kaspersma 2009; Baser and Morgan 2008; Mizrahi 2004). But it seems more feasible to undertake monitoring and evaluation of capacity development programmes when capacities can be defined very specifically, and suitable indicators for impact monitoring are developed (performance can be assessed using quantitative measures, the capability to act and to adapt requires more qualitative tools) (Taylor 2010; Zinke 2006). It was the experience of the case studies presented here that in-depth impact monitoring and evaluation was often not financially feasible within the timeframe of the research projects.

(9) **Environmental and socio-economic changes** often and increasingly challenge existing forms of the stakeholders' knowledge on water resources management. The Uzbekistan project for example captured this under the concept of 'the moving target' that the research observes while it seems to be changing at an even faster rate than the research can capture. This results in the need (i) to update and continuously adapt activities to newly arising situations and (ii) to address different target levels simultaneously. For long-lasting impacts, capacity development must take place at all levels: for example, capacity development on the individual level

despite being commonly regarded as the most important one, in many cases only pays off when made use of (and multiplied) in institutions.

(10) Capacity development is **a transcultural process**, in which local realities form the starting point. **Intercultural projects** often face (frequently implicit) views about one type of knowledge being superior to another; getting from there to a more egalitarian value-guided action-base requires a high level of openness and a continual process of personal self-reflection, attitude building and learning. As research projects often bring people together from very different cultural and disciplinary backgrounds, the conception of an agreement's commitment can diverge substantially at the beginning on both sides. Especially in initiatives that are substantially driven by foreign projects, it needs to be kept in mind that local conditions (e.g. temporal aspects like seed, harvest, Ramadan, weddings, funerals) as well as prejudices and (religious) belief systems might significantly determine people's actions. Additionally, cultural sensitivity in the wording, planning, and acting of an initiative is of utmost importance. During the Jordan/Palestine project for example, workshop participants welcomed and appreciated the daily schedule which respected their praying times. In some cases the workshop location provided an extra room for praying time (separated by gender) or a mosque close by. The extra time and consideration made the participants more relaxed and open to the workshop topic.

(11) **Capacity development, participation and governance** questions are closely linked. Capacity development measures must lead to the strengthening of administrative and public structures and procedures so that IWRM concepts can be implemented. Supporting the establishment of river basin councils by developing responsibilities, providing international experiences, advisory services on financing instruments and institutional structures are typical actions in research projects and development co-operations. Yet caution is required: experience from Central Asia and the Caucasus for example shows that the (donor-driven) creation of water users associations as organisational units driven by water users does not at all mean that these will also be regarded as water users associations by the water users themselves (and made to actually work; Hornidge et al. 2011b). Similar results can be seen by the (donor-driven) creation of river basin management authorities in some river basins in Ukraine for example (Hagemann and Leidel 2014). Tropp (2007) highlights the need for new forms of governance that can work meaningfully with integrated management approaches like IWRM and proposes additional sociocratic knowledge and capacity development among water managers and decision-makers. The possibilities for influence within the scope of research projects, as described in this article, are however limited to advisory services in this regard. Research project structures are not suitable for developing good governance in the long term (in contrast to international development cooperation) as project duration is limited and the shaping of governance structures 'from outside' with external funds and by external actors cannot be a sustainable endeavour. However, they can offer substantiated analyses of natural and technical systems as well as of existing governance structures as the bases for further actions. E.g. within the Ukrainian case study detailed analyses have been developed, and these analyses were needed for

trust-building and as the basis for advisory services on the local, regional and national level. It was acknowledged by the project consortium and communicated to stakeholders that capacity development and the development of good governance should be an endogenous process, possibly supported by research projects in an advisory position.

(12) The overall goal of any IWRM effort should always be to encourage people's own reflection on water as a precious resource. In order to facilitate this and as outlined above by the Jordan-Palestine project, the provision of **locally adapted reference materials/learning manuals** is essential (adaptation to cultural realities, translation into local language, visualization via authentic photos and realistic drawings, respecting different learning styles and perceptions). It must be kept in mind however that as it is an intercultural process, developing these materials requires particular attention and time. This is especially true as training should generally be **conducted and repeated after a first round of individual experiences** ("learning-by-doing"-principle, "action-oriented learning"). Training, particular for *technical installations* often requires multiple repetitions (with the same people, in the same chronological order). In many places 'technical and vocational education and training' (**TVET**) does not exist at all and thus still needs to be set up from zero. Multiplication by a **"train-the-trainers"-approach** is useful here, perhaps more so than in any other field of capacity development, in order to efficiently use scarce project financial resources. The Jordan/Palestine project experienced that teachers were convinced by the offered programme and automatically "transformed" into multipliers without any incentive or other compensation.

(13) In **academic capacity development** (university level), inter-university cooperations turned out to be fruitful means for joint activities and their institutional embedding. The manner in which teaching takes place at universities etc. often needs further development in order to truly prepare the path for long-lasting sustainability. It could certainly gain additional value through further didactic training for lecturers, and the integration of didactical concepts such as collaborative learning or problem-based learning. Furthermore, e-learning tools can offer innovative possibilities where technical and communication equipment is available (e.g. www.iwrm-education.org). The joint development of curricula is an important aspect in achieving long-lasting impacts as it assures that academic capacity development does not end with finalization of the project. In the Ukrainian case study, the IWRM learning module jointly developed between the Technische Universität Dresden and the National University of Water Management and Nature Resources Use Rivne and the e-learning module on IWRM constituted the basis for an online course on "IWRM in Ukraine", developed by the Ukrainian NGO Mama-86 and the Global Water Partnership (GWP).

(14) As many IWRM projects have a strong 'pilot character', this infers a need for **flexibility** (with regard to strategy, measures, etc.) and is true for the implementation of management measures. Taking the limited financial resources of stakeholders into consideration with the possibilities of technical ingenuity, 'low-cost-solutions' are often revealed to be the most appropriate, e.g. rainwater

harvesting techniques and water storage options (Liehr et al., Chap. 26) being just two examples. On the other hand, new organizations emerging after a project has been planned (e.g. water point committees), may **need additional training** and flexible adaption of the capacity development strategy. The option of financial support for stakeholders' efforts should, although given consideration, always be evaluated carefully, as this might include the risk of provoking envy and resulting tensions. However, the need to consider capacity development as very much centre stage to any IWRM-related initiative not only applies to the plans within each initiative, but must also be directly embedded in local/regional/national administration and their strategic plans.

(15) A severe problem in many initiatives is what could be called the **'continuity issue'** in each counterparts' staff. All of the IWRM projects described above experienced varying counterparts at the administrative or political level over the project duration. At the political level key stakeholders and knowledge hubs were exchanged frequently and nearly all capacity development efforts were set to zero. Changes in stakeholders' and cooperation partners' staff do not only limit the value of previous training efforts (as the respective trainee does not gain the chance to translate new knowledge into improved action), but often entail a change in respective targets and policies at least when these changes take place at the management level.

(16) As a general conclusion it can be said that **"thinking outside of the (sectoral/didactical) tool box"** often leads to the development of 'innovative' approaches, especially in a context characterized by cultural heterogeneity. Although this was not an objective at the outset of the case study projects, the 'Water Fun'-approach in the Jordan-Palestine project and the 'Follow the Innovation'-approach in the Uzbekistan project can serve as methodological examples here. And finally with regards to the responsibility of the respective actors in each initiative: the excellent researchers involved in the case study projects did not always perform excellently as facilitators for participatory processes; support from professional facilitators should therefore always be considered.

14.12 Conclusions

Capacity development is a key factor in Integrated Water Resources Management. The examples presented in this paper show how research, training and advisory services can be linked to the multi-level approach as described by Van Hofwegen (2004) and Alaerts (2009). In the case study projects described here the three different levels, individual, organisational and the system level were systematically addressed and tailored capacity development programs were developed and implemented. It was possible to assemble a list of sixteen generic lessons learned from the specific experiences on-site, with the aim of reflecting on all the potential lessons learned during future capacity development programs in transdisciplinary research projects.

Since the 1980s there has been a growing emphasis on the importance of capacity development within the overall scope of development assistance (Franks 1999). Plenty of experience and information on theoretical and practical aspects is therefore available (Blokland et al. 2009). The experiences presented here were gained during the execution of IWRM research projects and could help to improve the success of such projects in the future and achieve the planned benefits.

The paradigm of IWRM is a world-wide accepted framework for achieving sustainability in water resources management. However, the actual implementation of IWRM is lagging behind the formal inclusion of the IWRM concept in national policies, strategies and laws. Key-factors for making IWRM operational are good water governance, a strong and informed civil society and individual and organisational capacities embedded in enabling environments in order to successfully locally adapt and implement IWRM. Harmonizing the concepts of IWRM (at the river basin level) and capacity development for supporting the implementation of improved water resources management is important (Leidel et al. 2012a, b). Capacity development should thus be seen as an integral and inherent part of IWRM.

It can be concluded that despite obstacles for the enhancement of IWRM, a combined approach of IWRM and capacity development has a high chance of success. The systematic and consistent hydrological, meteorological, biophysical, institutional and socioeconomic data base is essential for promoting Integrated Water Resources Management (Karthe et al. 2015b). According to the experiences presented here, implementing tailored, locally adapted and targeted measures has proven to ensure a high potential for successful outcomes. This strong emphasis on locally embedded capacity development assures long-lasting improvement by achieving good governance and thus enhancing prevailing sectoral water management.

In conclusion, IWRM and capacity development are interdependent processes: the successful implementation of IWRM depends, to a very large extent, on local capacity development; including the development of the capacity to define locally-embedded IWRM.

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Part VII
Water Knowledge, Information Management and Decision Support

Chapter 15
A Water Related Information System for the Sustainable Development of the Mekong Delta: Experiences of the German-Vietnamese WISDOM Project

Claudia Kuenzer, Florian Moder, Verena Jaspersen, Malte Ahrens, Manuel Fabritius, Tim Funkenberg, Juliane Huth, Vo Khac Tri, Trinh Thi Long, Lam Dao Nguyen and Stefan Dech

Abstract This chapter presents the evolvement of an environmental information system, built for the Mekong Delta, in the context of the German-Vietnamese research project WISDOM (Water related Information System for the Sustainable Development of the Mekong Delta). The WISDOM project (2007–2014) belonged to a group of Integrated Water Resources Management, IWRM, projects, funded by the German Ministry of Education and Science, BMBF, on the German side, and the Vietnamese Ministry of Science and Technology, MOST, on the Vietnamese side. Goal of the multi-disciplinary project has been to contribute to numerous knowledge gaps existing for the Mekong Delta. Applied research questions from the fields of hydrology, hydro-morphology, chemistry, geography, ecology, biology, socio-economy, as well as administration and law were addressed by a large group of PhD students and post-doctoral researchers active in the project. One goal

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and also one—but not the—central element of the project has been the design of a water related information system, which can serve as a planning aid for decision makers and stakeholders in the delta. At the same time the freely and online available, bilingual (English and Vietnamese) WISDOM Information System, serves as a central project hub, which ensures that the majority of project findings that come in the form of geodata, in situ measurement collections, maps, statistics, reports, or scientific publications is available to the public. In this paper, geographic background and challenges of the focus area, project set-up, Information System design, components realized, training measures undertaken, as well as general experiences when realizing large projects in emerging countries are elucidated and discussed.

15.1 Current Challenges in the Mekong Delta of Vietnam and the Theoretical Concept of Integrated Water Resources Management, IWRM

The Mekong Delta is the vast floodplain dissected by the nine arms of the Mekong River which all empty into the South China Sea. It comprises an area of 40.000 km^2, and offers natural resources for over 17 million inhabitants living in 13 of the 58 provinces of Vietnam (see Fig. 15.1). Frequent flood and drought events, increasing salt water intrusion and salinization of soils, limited drinking water availability, severe water pollution, the loss of species and habitats, such as the decrease of mangrove ecosystems, or the growing threat of typhoons all have negative effects on people's lives (Plate 2007; Gstaiger et al. 2012; Kuenzer et al. 2013b, c; Kuenzer and Renaud 2012; Manh et al. 2013; Vo et al. 2012a, b).

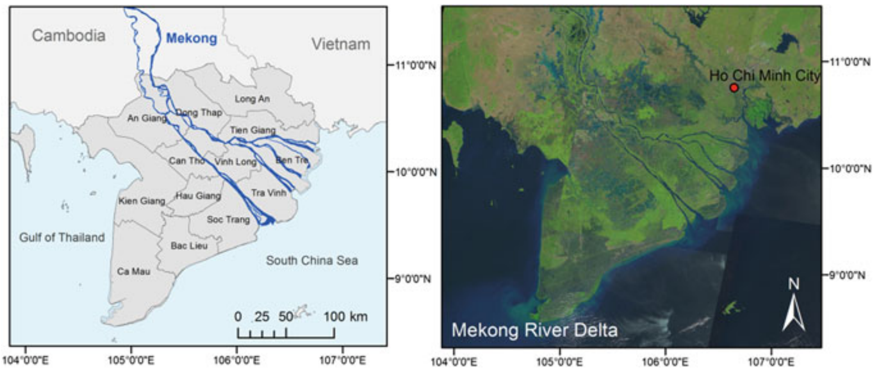

Fig. 15.1 The Mekong Delta and its 13 provinces in the South of Vietnam

Strong population pressure, increasing urbanisation and socio-economic transformation, and last but not least also upstream changes in the Mekong Basin impacting downstream riparian communities all lead to increasing challenges for the population of this region, and hence for local planning authorities (see Fig. 15.2). National and regional authorities face the problem to ensure a sustainable management of the Mekong Delta. Here, an important key aspect to support planning processes is the generation and open distribution of water–related information (Leinenkugel et al. 2011; Renaud and Kuenzer 2012a, b; Reis and Mollinga 2012; Kuenzer et al. 2013a; Moder et al. 2012; Delgado et al. 2010; Klinger et al. 2012).

Several authors have underlined the need of Integrated Water Resources Management, IWRM, for the Mekong Basin, as well as for the Mekong Delta (Moder et al. 2012; Kuenzer et al. 2013a; Jolk et al. 2011; Nuber 2009). According to the Global Water Partnership (2000: 22) the IWRM approach "emphasises coordinated management and development of water, land, and related resources in order to maximise the resultant economic and social welfare without compromising sustainability of vital ecosystems".

Fig. 15.2 Impressions from the Mekong Delta: Droughts (*upper left*), the over-application of harmful pesticides with little protection (*upper right*), decreasing fish catch (*lower left*), und increasing urbanisation and transformation (*lower right*) are just some of the challenges that the local inhabitants are facing

The IWRM idea, who's' roots reach back to 1977 and have been repeatedly formulated, criticised, and reformulated over the course of the last decades (Resureccion 2008; Varis et al. 2008) is characterized by an overarching, cross-sectoral approach of integration and cooperation. These most important characteristics of IWRM—especially the need for integration—contain the integration of the 'natural system' and the 'anthropogenic system' (see Table 15.1), as well as the integration of several water related functions and needs based thereupon. Simultaneously, the integration of different local groups, stakeholders and decision makers needs to be ensured.

IWRM in this context is understood as a bottom-up and top-down approach at the same time. This means that local participants, decision makers, and stakeholders from all hierarchy levels are integrated into the process. Local farmers and members of community-, district- and provincial government offices must be integrated just like national decision makers, international basin authorities, and related NGOs. Next to this integration between hierarchies and levels of governments the above mentioned integration between sectors must be ensured. This principle is shown in the following Fig. 15.3. Generally speaking, IWRM *is* a paradigm, a philosophy, a process. IWRM *is not* water engineering. It is about *how* to work and *with whom* to work in the context of river basin management. It is the process not the goal. IWRM requires an enabling environment through a general framework of national policies, legislation, and regulations, information for water resources management stakeholders, clearly defined institutional roles and functions of the various administrative levels, and last but not least management instruments, including operational instruments for effective regulation, monitoring, and enforcement that enable decision-makers to make informed choices between alternative scenarios.

It is in this context that the WISDOM project was funded: to contribute as a small puzzle piece to an ongoing IWRM process in the Mekong via the provision of water related information for the Mekong Delta, and to foster data and knowledge sharing via a Mekong Delta Information System. While hardly any information

Table 15.1 IWRM related integration of the natural and the human system

Natural system	Human system
• Integration of freshwater management and coastal zone management; • Integration of land and water management; • Integration of "green water" and "blue water"; • Integration of surface water and groundwater management; • Integration of quantity and quality in water resources management; • Integration of upstream and downstream water-related interests	• Mainstreaming of sustainable water resources management into socio-economic development objectives; • Cross-sectoral integration in national policy development; • Basic principles for integrated policy-making; • Integration of all stakeholders in the planning and decision process

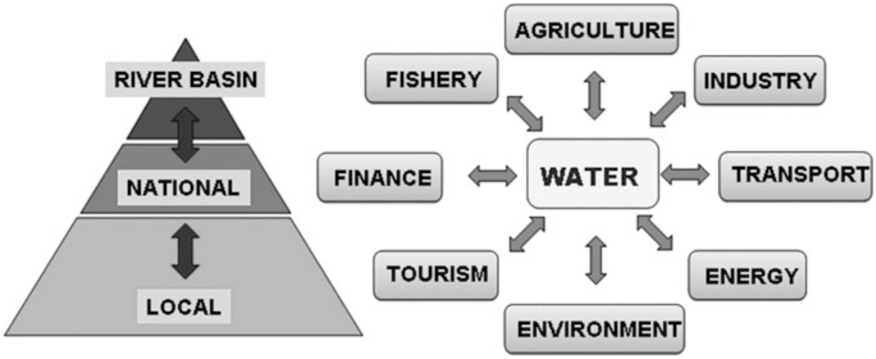

Fig. 15.3 IWRM: Exemplary integration between hierarchical levels and between sectors

system can be a tool to directly "answer all questions" of planners and decision makers at the "push of a button", it can be a tool, which provides knowledge and insight that can be used in discussion processes. In this way, an information system can be one component contributing to informed decisions.

15.2 Information Systems Supporting Decision Making and General Background of the WISDOM Project

Information systems (IS) are applied in many scientific and administrative fields. They are used for data management, processing, analysis, distribution, transmission, and visualization. Input data vary from alphanumeric, single or non-structured data to multi-dimensional, complex information incorporating spatial and temporal characteristics. IS can be grouped according to their functionality into simple data catalogues, static or dynamic IS, or decision support and modelling systems. However, transition between these groups is fluent.

For the field of geosciences and spatial planning several examples exist. Simple data catalogues type systems are for example provided by the Food and Agricultural Organization, FAO, hosting the Geonetwork catalogue application (www.fao.org/geonetwork) for the management of spatially referenced data resources. Users can search for data and access the retrieved information through a web client. A similar simple IS is the FAO AquaStat System (http://www.fao.org/nr/water/aquastat/catalogues/index2.stm), or the catalogue of water data sources in Kosovo (http://www.kosovo-water.eu). For the Mekong area, the Mekong River Comission, MRC, provides an information services portal, supplying image map data (no digital data) for the entire Mekong Basin (http://portal.mrcmekong.org/). Besides data search and access, further analyses or data processing is not possible with these kinds of applications. Additional GIS software and trained experts in the fields of geomatics are needed to put the data in use.

Also in the field of static and dynamic RS, a wide range of web enabled information systems in the water management context exist. Examples include the Australian Water Resources Information System (AWRIS) 2005 (http://www.bom.gov.au/water/about/wip/awris.shtml), the former Irtysh River Basin information system; IRBIS, (not online anymore), or the MRC water level monitoring system (http://ffw.mrcmekong.org/). User interaction with these IS is mainly limited to data visualization only. In some cases data is pre-processed and aggregated according to specific tasks to support users (Flood Forecast System of MRC). If users want to specify their area of interest or want to perform additional analysis with the available data, additional tools are still needed. However, also systems, which integrate most necessary functions within a web application, do exist. The Integrated Water Resources Information System (IWRIS) of the Department of Water Resources (DWR), California (http://www.water.ca.gov/iwris/) bundles base functionalities of data management, connects data sources from different providers, and enables end users to customize their requested information in manifold ways. Hence, it is a true web GIS with data processing capabilities and sophisticated mapping functionalities. DWR developed IWRIS to improve water data management in support of IWRM. Another example is WaterWare—a system that had been designed to support the implementation of the Water Framework Directive (2000/60/EC) or similar national legislation (http://www.ess.co.at/WATERWARE/). The application is implemented as an open-, object-oriented client-server architecture, runs fully web-enabled and Internet based, and supports the seamless integration of databases, GIS, simulation models, and analytical tools into a common, easy-to-use framework.

A comprehensive article evaluating the progress in decision support systems, DSS, for river basin management has be presented by Volk et al. (2010) presenting a comparative analyses of four different DSS. Also McIntosh et al. (2011) supply a well-rounded overview of environmental decision support systems (EDSS) development and present challenges and best practices. This valuable literature has not been available at the beginning of the WISDOM project, but we experienced many of the challenges depicted by the authors as well.

The WISDOM project (Kuenzer and Mehl 2009), coordinated by the German Aerospace Center, DLR, has been a bilateral, multi-disciplinary research project between Germany and Vietnam, which started in 2007 and ran until February 2014. The main goal of the project has been to contribute to numerous knowledge gaps existing for the Mekong Delta and to design a comprehensive Water related Information System for the Mekong Delta (WISDOM). Key findings of the project, transported via the information system, should support government agencies with their planning processes regarding the sustainable development of the region, as well as with adaptation to urbanisation, socio-economic transformation, and impacts of climate variability. Within the project a prototypical information system was developed. "Information System", IS, here is a technical term describing a knowledge cluster built up based on results from different research fields within the project, as well as a physically existing web-based information system.

Requirements for the IS design were analysed during three in-depth user requirement campaigns during the first 2 years of the project and were also partially defined by Vietnamese administration structures. At the highest hierarchical level, the Vietnamese Ministries of Science and Technology, MOST, Natural Resources and Environment, MONRE, and Agriculture and Rural Development, MARD, all had specific requests for system design. At the same time, the provincial representative offices of these ministries in the 13 Mekong Delta provinces (the DOSTs, DONREs, and DARDs) also all had localized requests (39 of these provincial offices exist). Additionally, Vietnamese WISDOM project partner institutes (see Table 15.2) under the auspices of further different ministries also had requests. At first, the requirement catalogue seemed overwhelming, but there was also a lot of common ground. Table 15.2 presents the information requests that different Vietnamese users at that time (2007, 2008) considered most relevant for integration into the Mekong Delta Information System.

For all users, internet access was available. However, it was also noted in 2007/2008 that in many of the institutions visited transmission rates were still very slow. However, this could be accepted, as a fast improvement in this field was expected (which proved to be correct over the time span of the project). Next to system requirements and data related requests also numerous requests for an improvement of IT hardware and software, strengthening of in-house IT capacity, and capacity building in the field of data collection, data storage, and maintenance, geodata management, GIS, remote sensing, and knowledge management were raised.

In the WISDOM IS data and information from multiple project disciplines such as hydrology, hydro-morphology, chemistry, geography, ecology, biology, socio-economy, as well as administration and law are all integrated and made available to the public. The data and findings within the system were all derived from in depth research, based on in situ measurements and ground surveys, the compilation of statistical data, as well as remote sensing data analyses. About 80 % of the user requirements presented in Table 15.3 could be satisfied. The users are not only able to visualize all project results and information, but also to navigate through the data, interpret them regarding special Mekong Delta related questions, create automatic map products, and download all available data. One key focus has been to develop the system in a way, which allows for future implementation in Vietnam. Thus, capacity building activities were carried out with project partners and stakeholders to realize sustainable and long-term usage of the system. German and Vietnamese WISDOM Project partners are depicted in Table 15.3.

It must be underlined here that the information system is the central, but not the sole development of the WISDOM project. In the course of two project phases (2007–2014) over 30 PhD students (half of them Vietnamese, the other half European) received their PhD degree at a German university. All PhD students (including the Germans) had to live 1 year within the Mekong Delta. Topics of PhD studies all included research related to user requirements, such as studies on water quality (pesticide contents and level of endocrine disruptors in Mekong Delta water, amongst others: Thi et al. 2012; Toan et al. 2013; Wilbers et al. 2013), water

Table 15.2 User requirements compiled during user requirement campaigns in Hanoi, Ho Chi Minh City, and the Mekong Delta (please note that the status is from 2009)

Associated	Institution	Needs/interests (information type, technology)
MONRE-related institutions in Hanoi	Department for Water Resources Management	All spatial geo-information *country wide*, especially flood situation, water levels, *water production, water consumption*, water quality, land cover, land use, infrastructure, land use change, climate change scenarios, *adaptation plans*, data bases with laws, regulations, and decrees, information system technology
	Centre for Water Resources Information	All spatial geo-information *country wide*, especially flood situation, water levels, *water production, water consumption*, water quality, land cover, land use, infrastructure, land use change, climate change scenarios, *adaptation plans*, data bases with laws, regulations, and decrees, information system technology
	Centre for Water Resources Investigation and Planning, Vietnam	All water related geo-information, especially flood situation, water level information, *water production and consumption*, water quality, ground *water information*, information system technology
	Hydrometeorological Centre	Water level from in situ sensors, flood situation (*country-wide* as well as locally high resolution), *precipitation information*
	National Remote Sensing Centre and Satellite Data Receiving Station	All remote sensing data, *country-wide*, and especially algorithms for data analyses and product generation
	Department of Surveying and Mapping	*Country-wide* geodata, especially validated land cover and land use, as well as land use change products

(continued)

Table 15.2 (continued)

Associated	Institution	Needs/interests (information type, technology)
MARD related institutions in Hanoi	National Institute of Agricultural Planning and Projection	High resolution land cover and land use data at province level and at even higher resolution local scale, algorithms for remote sensing data analyses
	Vietnam Institute for Water Resources Research	Hydrologic parameters (water level, sediment), water quality (salinity, chlorophyll, pesticides, *nutrients*, endocrine disruptors (hormones)), climate change scenarios, and *adaptation plans*
	Department of Science Technology and Environment	*Country-wide* geodata especially for the land area, coastal protection information, especially mangrove cover and *dykes*, information system technology
MOST related institutions in Hanoi	National Centre for Technological Progress	Information system technology, geodata for *natural hazard assessment*
Further institutions in Hanoi	Vietnam National Mekong Committee	*Country wide* geo-information, especially flood situation, water level information, *water production and consumption*, water quality, land cover, land use, infrastructure, land use change, climate change scenarios, adaptation *plans*
DONREs of the Mekong Delta provinces	especially DONRE Can Tho, DONRE Tam Nong, DONRE Ca Mau, DONRE Bac Lieu, DONRE Soc Trang, and 8 further delta provinces	Hydrologic parameters (water levels, sediment content), water quality (salinity, pesticides, *nutrition elements*, endocrine disruptors), local high resolution land use information, climate change scenarios, *adaptation plans*
DARDs of the Mekong Delta provinces	especially DARD Can Tho, DARD Tam Nong, DARD Ca Mau, DARD Bac Lieu, DARD Soc Trang, DARD An Giang. and 7 further delta provinces	High resolution land use information, updated geo vector data for the provinces, coastal protection information, climate change scenarios, *local adaptation plans*, vulnerability information for rural areas
CERWASS	Centre for Rural Water Supply and Sanitation of Can Tho Province	water quality (salinity, pesticides, *nutrients*, endocrine disruptors), information on water supply, climate change scenarios, local adaptation plans, vulnerability information for rural areas

(continued)

Table 15.2 (continued)

Associated	Institution	Needs/interests (information type, technology)
People's Committees	PPC Can Tho	Local up to date base data, easily understandable information products at the local scale, vulnerability information, climate change scenarios, *adaptation plans*, all at very local scale
Vietnamese Academy of Science and Technology	VAST-GIRS	Remote sensing data of different sensors, algorithms for data analyses
	VAST-SISD	Spatial socio-economic information, provincial statistics, vulnerability information, climate change scenarios, *adaptation plans*
MONRE related institute in HCMC	SRHMC	Water level information derived from in situ sensors, flood situation information for southern Vietnam, *high resolution precipitation information*
MARD related institutes in HCMC	Sub-Niapp SIWRR	For the southern part of the country up to date high resolution land cover and land use information, hydrologic parameters (water level, sediment content), water quality (salinity, pesticides, *nutrients*, endocrine disruptors), climate change scenarios and *adaptation plans*
MOE[a] related institutes in HCMC and the delta	VNU HCMC, GOC	Geodata for the Mekong Delta, information system technology, data bases and trainings in database design, information system technology, algorithms for satellite image analyses
	CTU Can Tho, Mekong Delta Institute, MDI	Mangrove maps and information fort the Mekong Delta, change detection analyses of Mekong Delta forest resources
	College of Agriculture/College of Environment	Scientific information on the Mekong Delta, incl. base data, especially land use, ecosystem maps, flood situation, water levels, water quality, database with legal information (laws, decrees, regulations), literature data base with information on the Mekong Delta, vulnerability analyses, climate change scenarios, adaptation plans

(continued)

Table 15.2 (continued)

Associated	Institution	Needs/interests (information type, technology)
Mekong River Commission MRC	Headquarters in Vientiane, Laos[b]	Geodata *for the whole Mekong Basin*, land cover, land use, flood situation, water levels, climate change scenarios, information system technology
Individual research groups and researchers	Different universities and organizations	Same requests as the above, in general with a "supply as much as possible" attitude (="the more information the better, we will sort out what we need or do not need")

The table represents a strongly condensed and shortened version of the user requirement survey
[a]*MoE* Ministry of Education
[b]In 2009 MRC headquarters were still in Vientiane, Laos
In italics: products or information that the WISDOM Information System could not provide at the end of the project; usually, because the data request was for regions larger than the Mekong Delta, or the data was not available or could not easily be generated (e.g. thematic topic not foreseen/funded in the context of WISDOM)

Table 15.3 German and Vietnamese partners of the WISDOM Project

German WISDOM Project partners	Vietnamese WISDOM Project partners
German Aerospace Center (DLR), the United Nations University (UNU), the Karlsruhe Institute of Technology (KIT), the University of Wuerzburg (UW), the University of Bonn (participating via the Institute for Development Research, ZEF, and the Institute of Crop Science and Resource Conservation (INRES), the German Research Centre for Geoscience (GFZ), as well as the small and medium enterprise (SME) companies DHI-WASY, EOMAP, 2wCom, HYDROMOD, Aquaplaner, and Iamaris	Southern Institute for Water Resources Research (SIWRR), Can Tho University (CTU), the Ho-Chi-Minh-City Institute for Resources Geography under the auspices of the Vietnamese Academy of Science and Technology (VAST-GIRS), the Geomatics Centre of the Vietnamese National University (VNU-ITP), the Southern Region Hydro-Meteorological Centre (SRHMC), the Southern Institute of Sustainable Development (SISD), the Sub-National Institute for Agricultural Planning and Projection (Sub-NIAPP), and the Institute for Tropical Biology (ITB)

quantity (Mekong flood pulse patterns, hydrologic modelling in delta provinces, amongst others: Dung et al. 2010; Hung et al. 2011; Manh et al. 2013), vulnerability (to extreme events such as droughts, floods, or sea level rise, amongst others: Garschagen 2013), administration (legal systems, informal networks, knowledge-sharing principles, amongst others: Evers et al. 2008; Evers and Benedikter 2009; Nguyen 2012), land cover change (mangrove losses, land use change, aquaculture, amongst other: Vo Quoc et al. 2012a, b), or information technology (database ontologies) to name only a few (see also Fig. 15.4). Furthermore, about 60 post-doc scientists actively contributed to the research.

Fig. 15.4 General concept of the Mekong Delta Information System as a central entity for the preservation and distribution of project results, in addition to functionalities supporting local planning and decision making processes

However, all this research led to valuable results, represented via geospatial data sets such as novel information and map products, novel time series and statistical data, summarizing reports, and document databases, extensive network and contact information databases, photographs, and last but not least PhD thesis' and publications. All these project outcomes have been and are still being integrated into the Information System. Largest challenge has been the integration of different types of data for different thematic, temporal, and spatial scales. Nowadays, the system is therefore a Mekong Delta knowledge portal, or information hub, ensuring that all results generated with tax payers funding are available openly and to everyone, and that none of the results is lost.

The interested reader, who desires more in-depth information about all these outcomes of applied research is referred to the project's website www.wisdom.eoc.dlr.de, as well as to the book "The Mekong Delta System—Interdisciplinary Analyses of a River Delta" (Renaud and Kuenzer 2012a, b). Pdf-files with the full text individual PhD theses can be requested from the individual researchers (see website). Furthermore, an account granting access to the WISDOM Information System can be requested via the system's entry portal site (accessible via the WISDOM website) at any time until (at least) 2016.

15.3 WISDOM Information System Architecture and Functionality

15.3.1 Overview of the WISDOM Information System Architecture

The overall concept of the project's bilingual information system is depicted in Fig. 15.4. Here it becomes clear that the Mekong Delta Information System is not only a software tool with various functionality, as elucidated later on in this chapter, but also the central organ for the centralized hosting of project results and their preservation after the project's end.

In the beginning it proved to be relatively difficult to explain the idea of a water related information system for the Mekong Delta to scientists, local planners, decision makers, and regional and national stakeholders; at least to those, who had not been involved in the set-up of the project from the very beginning. In 2007, when the project officially started, many local offices in the Mekong Delta—be it the Peoples Committees or the provincial ministerial offices—had only slow and often interrupted internet access. Capacities of planners and decision makers in information technology (IT), Geographic Information Systems (GIS), or geosciences in general were limited. The decision making process in planning was (and still is) influenced by a multitude of factors, such as power-relations, financial resources distribution and constraints, informal networks, impact of international donors and other large research- and development aid consortia, as well as personal preferences. Therefore, it was not always easy to convince local people of the usefulness of a centralized, openly accessible information system containing a lot of information and project results on the Mekong Delta.

To introduce the project's central idea in an easily digestible way, German and Vietnamese partners jointly came up with the idea of a "WISDOM restaurant" representing the future IS goals (see Fig. 15.5). Within the WISDOM restaurant a customer comes into the public area of the restaurant, takes a look at the menu, can see what is available, and can order his food. A waiter transfers the order from the public restaurant space to the kitchen, where the ingredients are cooked. To cook the meal, components have to be requested from the storage area and have to be delivered to the kitchen. Once the meal is cooked exactly as requested by the customer, the meal is then delivered. Of course the WISDOM Information System is not a restaurant, but consists of a Web Application with Graphical User Interface, GUI, as the front end, a processing environment, and databases for data storage. However, the easy-to-understand concept of the system in a food-focussed culture like Vietnam helped a lot to raise interest and even excitement with local authorities.

15.3.2 IT Architecture of the WISDOM Information System

The information system is a self-developed, license-free, lightweight Geographic Information System (GIS), which allows search and visualization of geographic as well as non-geographic information in the context of IWRM. The graphical user interface of the system can be operated using standard internet browsers, such as Firefox, Microsoft Internet Explorer, as well as Google Chrome, and thus is available online for everyone.

The main non-functional requirements that guided the architecture of the system are the following. Firstly, the system was requested to be easily accessible for a wide range of users; secondly, the system had to be designed in a modular way

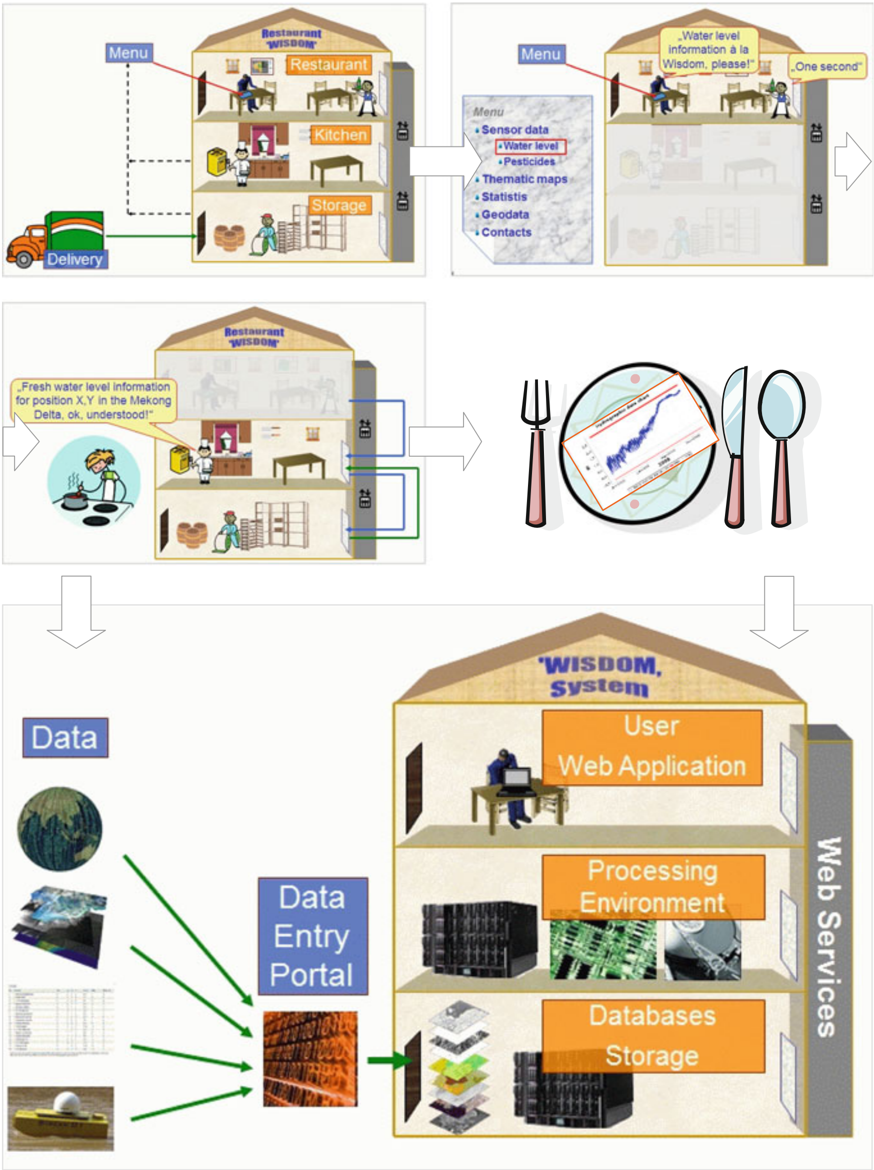

Fig. 15.5 Simplified representation of the three layers of the WISDOM Information System as a restaurant. Here the guest (user) can have a look at the menu (available results and information), can order his food (data), and in the kitchen the food (data) is processed exactly according to the guest's (user's) demand, and is then delivered (courtesy of S. Gebhardt)

making it open for other technologies; and thirdly, the system should be created as a system not requiring licence fees (free usage by the end users). The first requirement led to the decision to set up a web-based information system, to allow users the access from all over the world without the need to install software beforehand. The possibility of unrestricted access—no matter from where—does of course not grant the system's use, but is a first important step to enable use. The openness of the system required the implementation of state-of-the-art standards defined by the Open Geospatial Consortium (OGC, http://www.opengeospatial.org/). Furthermore, loose coupling between client and server is realized by the architectural style "Representational State Transfer" (REST). The REST approach introduced by Fielding (2000) is widely known in the IT community and is a widely used architectural style for distributed hypermedia systems. The third requirement results in the usage of open source software components.

The system consists of three layers. The user interface layer holds the graphical user interface (GUI) with which users have access to all functionalities and data in the system. The GUI directly communicates with the application server layer via HTTP 'talking' OGC and REST. This layer implements the business logic, so that it is able to handle all queries from the GUI, as well as to process data. The data resides in the data management layer, which is accessed by the application server layer on demand. Figure 15.6 sketches the three layers and their components.

The GUI is realized with the Google Web Toolkit (GWT, http://www.gwtproject.org/). This toolkit helps to minimize development costs in web development. The developer programs in Java and GWT's cross compiler translates the code into efficient JavaScript, readable by different standard browsers. Therefore, the GUI looks and behaves similar in, e.g. Firefox, Internet Explorer, or Chrome. The GUI follows the well-known Model-View-Controller pattern. A view is a functional entity, in which a user can follow a target, e.g. search for data. In Fig. 15.6a view is represented by a box in the first layer. Whenever a user interacts with the graphical elements in a view, requests are sent to the application layer, depicted by arrows in Fig. 15.6. The GWT bindings for Open Layers (http://openlayers.org/) allow the integration of a map within the GUI.

The application layer holds the implemented OGC standards Web Map Service (WMS), Catalogue Service for the Web (CSW), and Web Processing Service (WPS). WMS is used to visualize geographic information in a map. The interface is implemented by the open source software MapServer (http://mapserver.org). The MapServer connects to the data store, in which all map data is located, and renders images based on the client's requests. To speed up the request response cycle, the tool TileCache (http://tilecache.org/) is integrated in between MapServer and GUI to cache already rendered tiles. Figure 15.6 shows that the TileCache and MapServer are served by a REST interface, to hide the implementation details from the Graphical User Interface. The logic, when a tile is rendered directly from MapServer, or just loaded from TileCache is therefore hidden and can easily be adapted to changing needs in performance. Currently, whenever different users ask for the same tile, they get a cached version. This reduces processing time and the application server is much more responsive.

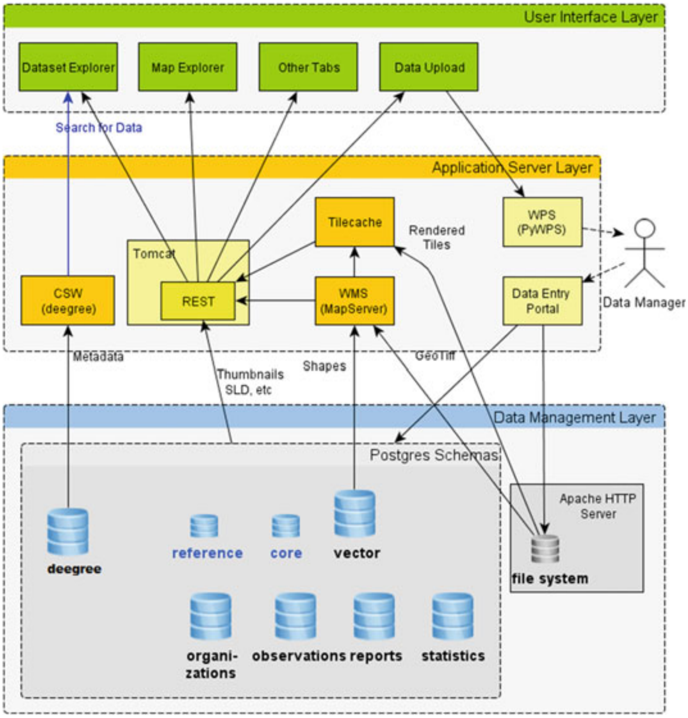

Fig. 15.6 Sketch of the three main components. The *arrows* indicate how data flows between the entities. Note that the REST component is an own development based on REST principles. Furthermore, components of the GUI and the Data Entry Portal are self-developed. Other components in the application server layer are third party implementations which we extensively configured to the project's/user's needs

The CSW handles all search requests for data, based on metadata descriptions. Every dataset in the database thus has to be described according to the ISO 19115/19139 standards (http://en.wikipedia.org/wiki/Geospatial_metadata gives a rough overview on the two standards). Here, the open source software deegree (http://www.deegree.org/) with its CSW implementation is used to handle metadata and search requests. As CSW is a widely used open standard, the system here is able to connect to other metadata catalogues. Furthermore, other systems could also query the WISDOM metadata catalogue to browse the metadata descriptions of existing data. In an environment of geographic data infrastructures (GDI), this is a must.

WPS is used to trigger the upload process of new data. When a user uploads new data, a WPS is used to pack the different pieces of data and to inform the data manager. The data manager then checks the quality of data and ingests the data via the Data Entry Portal. The dashed arrows in Fig. 15.6 denote that this is not an automatic process. It could be done automatically with the help of WPS. But during the development of the system, it has proven to enhance quality of data, if human interaction (for quality control of uploaded data) still is part of the process.

All other functions in the GUI, e.g. literature search, are realized by REST requests between the user layer and the application server layer. The shared language here is Java Script Object Notation (JSON). The application layer does not use Google's Remote Procedure Call (RPC) technique to be able to use different technologies for the GUI. Loose coupling is guaranteed by REST. The REST component is a Web Application Archive (WAR) that runs within an Apache Tomcat (http://tomcat.apache.org/). As the application server layer needs data to accomplish its tasks, it communicates with the database layer via the protocols jdbc, WebDAV, and HTTP.

The database management layer holds all the relevant data that are needed to run the application. PostgreSQL (http://www.postgresql.org/) with the extension PostGIS (http://postgis.net/) is used to handle all metadata, base data, and vector data. Raster data is still stored in a file system, so that the MapServer can access them easily. Documents, mainly pdf, are also stored in a file system. To ensure security, an Apache HTTP Server (http://httpd.apache.org/) is used to restrict access to all critical data in the file system. The database model within PostgreSQL is organized in different schemes, depicted in Fig. 15.6. The scheme named "deegree" (both times double "e") manages metadata and stems from the CSW implementation of the deegree framework. All other schemes are in-house developments to handle and manage geographic, non-geographic, user and application data.

The virtualization environment KVM (http://www.linux-kvm.org/) is used to provide different virtual machines for development, testing, and production mode. All virtual machines run with Debian Squeeze as the operating system of choice. Therefore, no license fees occur for the infrastructure.

15.3.3 Components and Functionalities

The WISDOM Information System consists of several components, offering a variety of functionalities to the user. These are shortly presented here. Beyond the entry portal of the WISDOM Information System (see Fig. 15.7), which offers the opportunity to create a new user account, the system is divided into several pages which aggregate functions.

These different pages within the system are the so called "Map Explorer", the "Dataset Explorer", the "Contact Search", the "Literature Search", and the "Data Upload" page. Furthermore, three individual tool-boxes were implemented, which are the "Sensor Toolbox", the "Question answering Toolbox", and the "Field Data Explorer".

The "Map Explorer" (Fig. 15.8) is the central place for viewing geographic data on top of a basemap. Data can be displayed on the backdrop of a satellite mosaic, an administrative boundary map, or open street map information. The "Map Explorer" offers GIS functionality, such as navigation and zooming tools, as well as tools to measure distances and areas of a polygon, which can be drawn within the map explorer (e.g. to measure the area of cities, or the size of flooded areas or

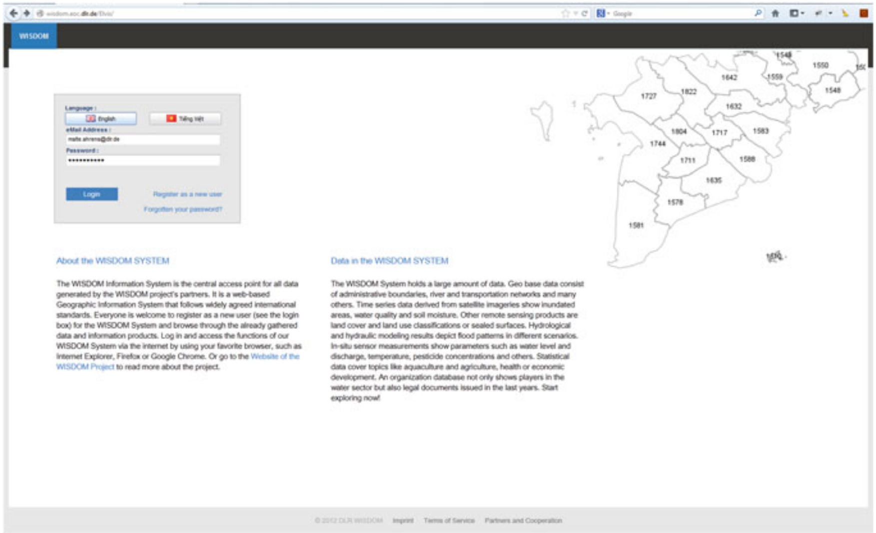

Fig. 15.7 The entry portal of the bilingual WISDOM Information System for the Mekong Delta. The system exists as an English and as a Vietnamese version. This simplifies usages especially for local users from Vietnam. New users can create a user account via this entry portal page

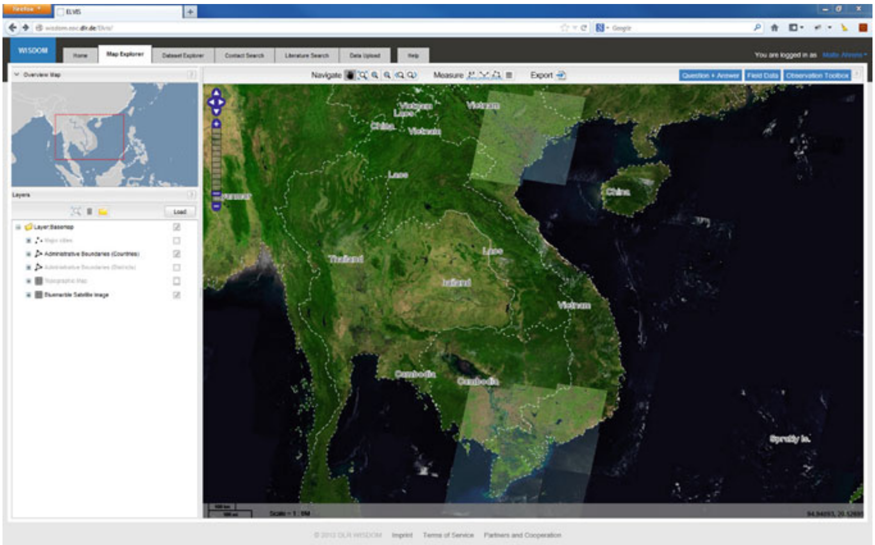

Fig. 15.8 The "Map Explorer" of the WISDOM Information System for the Mekong Delta. The Information System actually does not only serve the Mekong Delta, but also—to a limited extent—the Red River Delta in the North of Vietnam. Data for this delta was integrated to demonstrate the possibility of spatial transfer of the system

agricultural fields etc.). The order of the dataset layers added to the "Map Explorer" can be changed and single layers' visibility can be switched on and off. Furthermore, the "Map Explorer" grants access to the so called "Sensor Toolbox", where the user can visualize measurement values from in situ measurement stations. This tool delivers on the fly sensor measurement data from 17 stations that were (in the context of the WISDOM project) installed in the delta. These measurement stations deliver information on water level, salinity, sediment load, pH, as well as—in selected places—pesticide and endocrine disruptor concentrations.

Additionally, a so called "Field Data Explorer" enables—comparable to the similar functionality in Google Earth—to visualize photographs within the delta. Hundreds of photo quartets, representing the surrounding of a point towards the North, East, South, and West were captured in the delta in a standardized way, and were entered into the system. In the long run, this allows to acquire pictures of the same location at a later point in time, and thus to turn this feature into a tool, which can support the visualization of greater changes in the delta.

All spatial geodata or information that the user would like to display in the "Map Explorer" is selected on the so called "Dataset Explorer".

The "Dataset Explorer" (Fig. 15.9) is the central place to search for different kinds of datasets and project results, to show additional (metadata) information about these datasets, and add them to the Map Explorer. The user can search for spatial geodata results via three filter tools. Just like, for example in an online hotel booking portal, where the user can search his hotel room according to a time filter, a

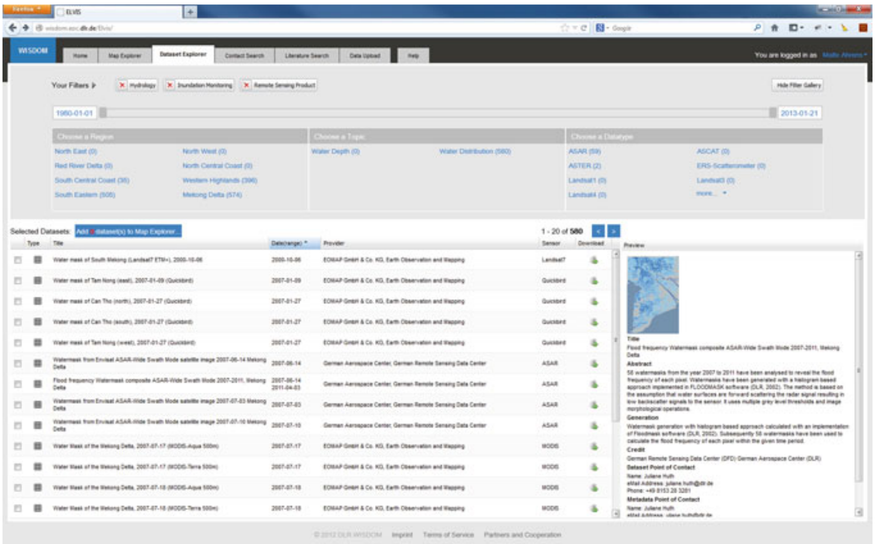

Fig. 15.9 The "Data Set Explorer", here showing search results on inundation monitoring related products derived from remote sensing data. 580 information products can be found within the system—these are so called "Water masks" derived from Envisat ASAR and TerraSAR-X radar data at near weekly intervals

location filter, and additional filters narrowing in the search according to price, hotel rank (stars), or special features, the “Dataset Explorer” allows the user to define the search via the application of four filters: a “location” filter narrowing in on the region (e.g. Mekong Delta province Bac Lieu), narrowing in on a topic (e.g. hydrology), and narrowing in the data type used to generate the information product (e.g. radar satellite data of a certain sensor), as well as a time range (only results between e.g. 2005 and 2009). Via these filters defining location, thematic topic, data type, and time range the user can exactly narrow in on his information product of his interest. For every returned result/map/dataset the user can view metadata describing this data, and if he finds the dataset suitable he can add the dataset to the “Map Explorer” or download it to his personal computer (Figs. 15.10, 15.11 and 15.12).

For not so advanced users, who prefer not to use the “Dataset Explorer”, the “Map Explorer” contains some extra features, such as the “Question answering Toolbox”. This toolbox offers the user to load predefined maps which answer specific, pre-defined (frequently asked) questions. Out of the 10 question scenarios provided by the “Question answering toolbox” one is for example: “Which areas in the Mekong Delta are inundated (flooded) at which frequency? Which areas are flooded often, which areas are flooded less often?” The “Question answering toolbox” can be extended for a number of scenarios, and is especially useful for users who do not have a lot of time to explore all system functionality.

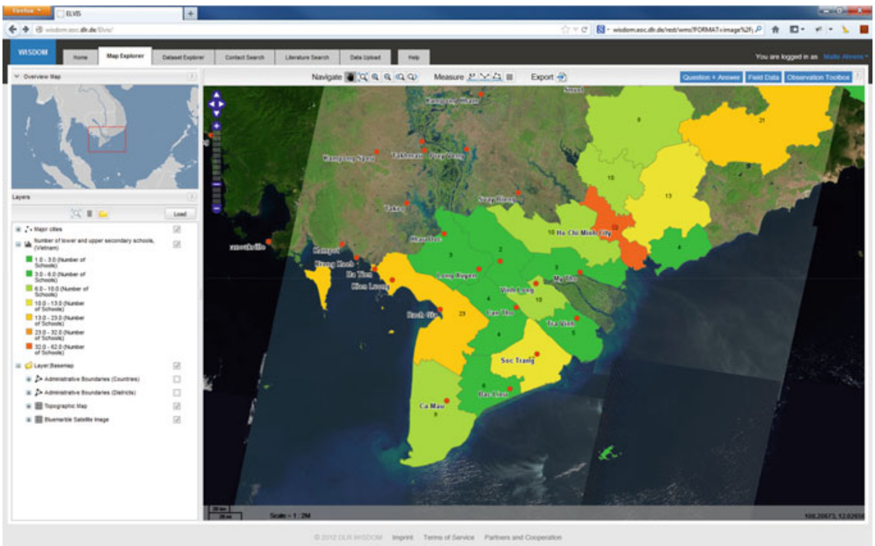

Fig. 15.10 Socio-economic statistical data can also be displayed in the system—in this case the number of secondary schools per province is depicted. The system is completely open-source, so no software licenses are needed for its use

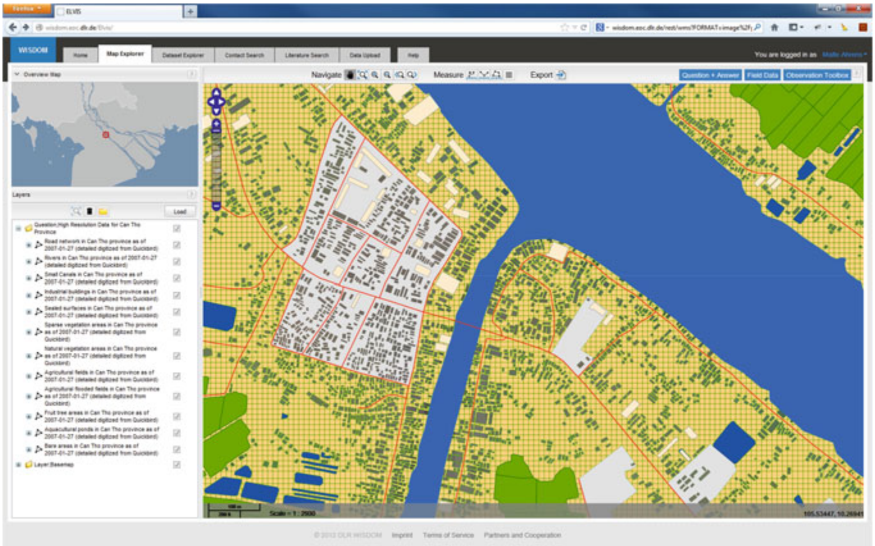

Fig. 15.11 An example of high resolution vector data available within the Information System—here for different settlement classes in Can Tho City, as digitized from high resolution Quickbird satellite data in 2012

Fig. 15.12 The Mekong Delta Information System exists as mirrored versions: one installation exists on a server located with a private data space providing company in Ho Chi Minh City (Saigon), Vietnam (above two photographs), which grants fast access for all users from Vietnam and Southeast-Asia. An identical installation exists at a server located in DLR, Germany, which grants speedy access to the system for European users

The “Contact Search” page allows the user to search for water related institutions that are active in the Mekong Delta. This includes government ministries, various administrative bodies, research centres, universities, and non-governmental organizations, amongst others. The search may be narrowed by specifying distinct search fields (location, key words in the organisations name, affiliation with the major ministries etc.). As a result the users receives information about the institution of interest such as address, contact details, organizational chart, a link to the homepage, as well as selected publications released by this organization.

Within an additional “Literature Search” the user can search for specific publications released by the WISDOM project, as well as other—freely available—related literature; including reports and documents on the Mekong Delta released by other entities. The user can search for a full title, title keywords, and authors. The results are categorized as “Articles”, “Books”, “Collections” and “Reports and Theses” and can be viewed (an—if permitted—downloaded) as a PDF file.

The “Data Upload page” is an assistant to help users to upload different kind of data into the system. The tool leads the user through a series of steps collecting the data (e.g. geodata files, styling information) and additional information (metadata) to upload data to the information system. The uploaded data—before visible to the public—will be checked for completeness, scientific soundness, and quality by the WISDOM data manager. After the data passes several tests (correct projection, copyright issues, proper styling, ethical issues etc.) the ingested datasets will then be accessible by all users.

All the functionalities are extensively documented via a bilingual “Help” page. This page serves as a user manual for the usage of the system. Furthermore, a 45 min video, guiding the user for the first time through the usage of the system, can be watched via the WISDOM project webpage (www.wisdom.eoc.dlr.de; upper right corner).

15.3.4 Data Upload and Metadata

Within the WISDOM Information System a large amount of datasets has to be handled. These datasets consist of geodata—for example—derived from satellite images. Land cover and land use products, maps on the current inundation (flood) situation, annual inundation frequency, or inundation depth, soil moisture products, coastal water turbidity products, or surface sealing products—to name only few examples—were generated and frequently processed from Earth Observation data. Furthermore, statistical data recorded during field surveys or adopted from statistical yearbooks, water related parameters measured by in situ sensor stations or derived from water samples collected during field campaigns, as well as reports, articles, and legal documents, all addressing IWRM related topics in the Mekong Delta were generated. For the maintenance of such large and diverse data volumes within a system the following aspects were of utmost importance.

Bearing in mind the great variety of datasets the information system has to deal with, the WISDOM project put an emphasis on the utilization of commonly and wide spread data formats to enable automatic procedures for the ingestion of new datasets, as well as for system internal data processing. For all WISDOM geodata this is implemented via a predefined data format, coordinate reference system, mandatory metadata editing, and mandatory map styling description. The ESRI Shape file format (.shp) and the GeoTIFF format (.tif) were defined as data standard for vector and raster data respectively. All data had to be projected in the Universal Transverse Mercator (UTM) Zone 48 North coordinate system, with WGS84 ellipsoid and geodetic datum as reference. Furthermore, all geodata had to be equipped with a metadata file based on ISO 19115/19139 standards and an OGC (Open Geospatial Consortium) compliant Styled Layer Descriptor (SLD) to specify the rendering of the dataset via a Web Map Service (WMS).

On the one hand metadata provide the end user with detailed information about the dataset, including—amongst others—the contact details of the person, who generated the data, a set of keywords on the main topic of the dataset, the regional affiliation of the dataset, the time span of data set availability, a short description of the dataset, as well as a description, how the dataset has been generated and further processed. This information is stored in the PostgreSQL database of the information system. Based on this metadata, the user is able to assess the quality of the dataset and its suitability for specific applications. All elements provided by the metadata are defined by the ISO 19115 standard, while the ISO 19135 standard defines how this information is stored in XML (Extensible Markup Language). On the other hand the whole search function for data in the information system (Dataset Explorer) is based on the metadata in a standard compliant way using the OGC Catalogue Service for the Web (CSW). In this way the system can respond to the query of an end user who defines specific filters (theme, region, time, data type) via the interface of the Dataset Explorer.

A further important point is that the extensive data pool has to be kept up to date. An information system loses some of its value, if the geodata and statistical data, as well as the document or contact database are outdated or erroneous. Therefore, the system needs to be frequently updated (we also address this point later on in the outlook). Novel sensor data, novel land use information, updated flooding information or coastal sediment load data, up to date soil moisture information, or recent reports, articles, and legal documents all have to be fed into the system in a semi-automated way. To allow the straight forward ingestion of geodata a Java tool, the so called Data Entry Portal (DEP), has been developed. With the help of the DEP new datasets can be ingested either offline or online. For offline ingestions the metadata file and the SLD file has to be stored in a zip file together with the dataset itself. Subsequently this zip file is handed over via command line to the DEP, which distributes the single components automatically to the right location in the file system and the PostgreSQL database of the information system. The generation of the metadata file in an offline environment is done with the help of a standalone graphical user interface based on the XML editor ALTOVA Authentic. The required SLD file on the other hand can be created with the uDig software for raster data or an SLD Converter for vector data. Online ingestion of geodata is done via the Data Upload interface of the information system. Here the end user is able to upload his own data to the information system. In a first step the end user choses the dataset he would like to ingest. Then, the metadata file and the SLD file can be specified with the help of predefined entry forms so that the use of auxiliary software is dispensable. Subsequently, the responsible data manager of the information system is automatically informed via e-mail that a new dataset is ready for upload. After a quality check by the data manager the dataset is ingested and available to every user.

Other datasets like sensor measurements, statistics, and literature are ingested via semi-automated SQL commands. These types of datasets have to be described by metadata as well and also must be available in a specific data format to simplify the ingestion process. In the case of sensor measurements and statistics the CSV (Comma-Separated Values) format is required, while literature has to be stored in the file system as PDF (Portable Document Format). In general, there is no restriction for data upload. Every person, who would like to add data to the WISDOM Information System can do so online. There are two ways to ensure, that no "nonsense" data is uploaded. Firstly, every person who wants to upload data (or in general just use the system) needs to create a user account for the WISDOM Information System. This process requests the user to enter a lot of personal details, including the working place, all contact details, and also the reason for wanting to use the system. In this way, a good overview of WISDOM users can be kept, and a quick check on people's backgrounds is possible. At the same time the developers receive a good feedback on why the system is considered to be of value. If then a user uploads his own data, the data is not directly appearing online. First a data manager (a person from the IT development team of the system) checks, if all metadata has been provided in correct format, and furthermore the data set is quality checked (does the person uploading the data has the right to upload the data? Are coordinates correct? Is the data of good quality and useful? Are any ethical standards violated?). In this way one can ensure that only good quality geodata, maps, in situ measurements, or reports are being entered into the system.

15.4 Capacity Building for Information System End Users and Trainings of Trainers

Within the WISDOM Project over 100 Capacity Building courses were held by project partners from all the different disciplines. Be it DLR's or the University of Würzburg's strong involvement in GIS and remote sensing trainings, ZEF's trainings on knowledge management, or UNU's trainings in water quality laboratory analyses—to name only a few: the training efforts in the WISDOM project were extensive, and were not only provided from German partners to Vietnamese partners, but also vice versa (e.g. intercultural trainings). However, in the following only the information system related trainings will be elucidated.

The best information system does not fulfil its purpose, if the information products are not passed to relevant users or cannot be understood by the same. In the case of WISDOM, users had to be enabled to use and understand the added value, provided by the Mekong Delta Information System. For this purpose regular capacity building measures took place for Vietnamese authorities on local, regional, as well national level. To ensure a sustainable training process, prior to the capacity building measures, a capacity building group responsible to educate so called “Trainers” was established. This trainer group, which consisted of Vietnamese scientists and IT specialists only, was—next to the German IT experts—taught how to operate, maintain, and teach the usage of the system. Especially in 2009 and 2010 intensive “Training of Trainers” workshops were conducted in Vietnam. Subject of these “Training of Trainers” seminars, conducted by the WISDOM Team in cooperation with the MOST Southern Representative Office, MOST-SRO, and Vietnam National University, VNU, was to facilitate the trainers to maintain, apply, and develop the WISDOM Information System further. The trainings included relevant IT topics, such as virtualization technologies, server installation, and maintenance tasks, as well as data management, and data maintenance strategies. The overall goal to understand the components of the system architecture, interaction of different technical components, and data requirements to fill the system with content, was achieved and put on the test by extensive capacity building tours, conducted in the Mekong Delta (see Fig. 15.13). These were especially realized during the second WISDOM project phase after the information system had reached a certain intermediate maturity. Quarterly capacity building tours were undertaken to provide trainings to local authorities in the Delta (such as the district offices of the Ministries of Natural Resources and Environment (DONREs), and of the Ministry of Agriculture and Rural Development (DARDs) as well as at national level for IT related departments within the Ministry of Natural Resources and Environment (MONRE).

A great asset here was a local CIM (Centre for International Migration) expert, fully financed by the BMBF, who was full time located in Vietnam and supported project coordination and trainings. Figure 15.13 below depicts some routes of training tours undertaken in the Mekong Delta in 2011 and 2012.

Fig. 15.13 Exemplary routes of capacity building tours in the Mekong Delta

All capacity building and training workshops in the Mekong Delta and in Hanoi were held bilingual, in English and in Vietnamese—either with simultaneous, or with consecutive translation. Also all hand-outs and other trainings materials (PowerPoint slides, handbooks etc.) were provided in both languages. This was crucial especially for the trainings in the local Mekong Delta provinces, were the proficiency of oral English was usually not yet well developed. It should also be mentioned here that the translation of the materials posed a great challenge and took a lot of effort, as many technical terms did not (yet) exist in the Vietnamese language, or were hard to translate (e.g. the term “Sustainability” does not exist in Vietnamese language). In this context it has also to be mentioned that the common denominator for all applied software during the capacity building tours, whether it was for server administration or for sophisticated desktop geodata analyses, has been the use open source software. Avoiding costs for commercial software is considered as a pre-condition to ensure the longevity of the WISDOM system in the present landscape in Vietnam.

The capacity building group (see Fig. 15.14) always adjusted their tutorials based on the current situation in the local province. While in some areas flood extent and flood related scenario analyses were in the foreground, in other

Fig. 15.14 Capacity building in provinces of the Mekong Delta: local stakeholder participants working on the WISDOM Information System

provinces land cover and land use change or demographic migration patterns were in the focus of the trainings. For example, provinces at the coastline have to deal with issues such as sea level rise, salt-water intrusion into surface water, aquifers, and soils, while provinces in the inner part of the Mekong Delta are more likely to be interested in Mekong flood pulse related hazards, or trans-boundary issues. Through these tailor made adaptations in course curricula it was possible to draw the attention to the large potential of the Mekong Delta Information System.

Next to the improvement of IT skills and system usage the trainings also included an emphasis and demonstration on how data can be shared. Data ownership is considered to be a competitive advantage in the administrative landscape of Vietnam. Water relevant data are rarely shared. All sorts of information exists scattered on individual hard discs, partly redundant, and in undefined format. In terms of data quality there is no national standard in place yet. Furthermore, data is commonly sold or "traded" in other ways ("I give you this data, you do me this favour"), which means that data is seen as a monetary or power resource. This makes it very hard to get and to use data. The capacity working group addressed all these issues, and examples of good practice were shown, referring to international data format- and quality standards, as well as long term benefits of data sharing and interprovincial cooperation.

15.5 Local Feedback on WISDOM Trainings: Advantages and Shortcomings

A participatory approach and anonymous evaluation of the capacity building exercises was crucial to improve the quality of the provided trainings, to monitor the performance of the trainers, and to receive feedback on system functionalities as well the overall potential and quality of the information system. For this purpose standardized online questionnaires were developed. After a training unit (2–3 days) had taken place, the participants were asked to fill out these questionnaires voluntarily and anonymously. The questionnaires contained a mix of different question types, such as open format questions, where the participants could freely share their opinion/suggestions, as well as closed format questions—here in particular dichotomous questions and rating scale questions. This feedback had a strong impact on the "evolutionary" development of the training materials, but also on the content and functionality of the system itself.

The following statistical overview is categorized into three main training periods. Training period one took place in September 2011, training period two in March 2012 and training period three in June 2012. Data were adjusted to avoid duplicate answers from the same person. The questions were answered by about 90 people, which correspond to 50 % of the overall number of trained persons. This has to be attributed to the fact that mostly two persons were working jointly on one computer. All questions were provided in Vietnamese/English and answered in

Vietnamese. In the following, selected results are shown and discussed. The questionnaire covered basically three main groups of questions:

(a) General questions about the WISDOM Project and the WISDOM Information System
(b) Technical questions about functionalities and performance
(c) Rating of the training material and the performance of the trainers

The first group of questions (a) is related to the popularity of the WISDOM Project itself. For example, we asked, if the participants have ever heard about the WISDOM Project. The participants could choose between "Yes" and "No". In the first workshop period only 36 % had ever heard of the project activities of the WISDOM Project, in the second training period it was already 40 % and in the last training period already 54 % (compare Fig. 15.15).

It is important to mention that the participants were government employees of provincial authorities in the Mekong Delta, who mostly had no link with the scientific part of the WISDOM project before. So when answering "Yes (we have heard about the project)" this rather refers to the practical aspect of the WISDOM Information System, which they have heard about. In this context the question was raised "Would you be interested in a long term cooperation with the WISDOM Project?" The participants interested comprised 72 % in the first workshop, 80 % for the second workshop period, and an overwhelming 97 % for the third workshop. These answers indirectly reflect the fact that user suggestions for improvement of the system were realized by IT development and in this way the information system underwent a major transition from a rather scientific tool to a tool which provides solutions for daily tasks of local authorities. However, this trend cannot be considered isolated from the next group of questions, which dealt with technical aspects.

The technical question complex (b) was related to the performance, content, and user-friendliness of the provided information system. The first question aimed at quantifying, if the WISDOM Information System is easy to understand. During the first and second training tour 80 % answered "Yes". In the third capacity building tour 90 % of the participants confirmed this, since the system underwent a major make-over. A similar trend in terms of improvement is reflected by the following

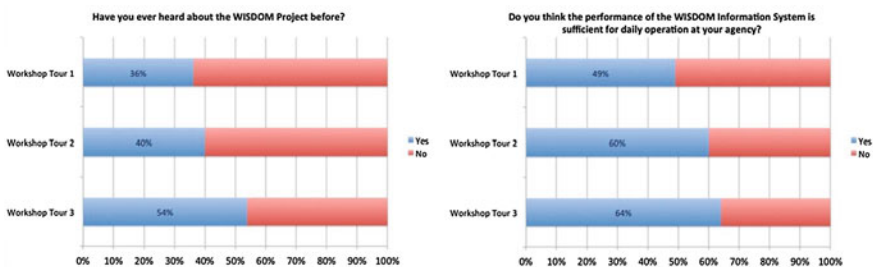

Fig. 15.15 Answers to "Have you ever heard about the WISDOM Project before?" (*left*) and: "Do you think the performance of the WISDOM Information System is sufficient for daily operation at your agency?" (*right*)

answers on the question, if the participants think that the performance of the WISDOM Information System is sufficient for daily operation at his/her agency. This was answered positively during the first training tour by 49 %, during the second tour by 60 %, and during the third tour by 64 %. Thus, a clear positive trend could be identified (compare Fig. 15.15, right side). The overall impression of the information system was on average graded with 2.3 during the first tour, with 2.0 during the second tour, and the third tour yielded an average rating of 1.8—rated on a scale 1 (excellent) to 6 (insufficient).

The third question group (c) was related to the overall performance of the trainers and the tutorial material. Here questions included: "Did the workshop help you to understand the WISDOM concept?" or "Was the tutorial helpful for you to understand the basic structure and functionality of the WISDOM Information System?" etc. This was mostly answered with "Yes". This trend is also reflected in the rating of the overall impression of the workshop. During the first workshop tour an average mark of 2.3 (scale from 1 for excellent to 6 for insufficient) was given, during the second training tour a mark of 1.8 could be reached, and the third training tour yielded mark of 1.8. Especially for this set of questions the results here were overwhelming positive and constant. As it has to be noted that in Asian culture people tend not to criticize other persons openly, overall, the monitoring via anonymous questionnaires proved to be a very valuable tool.

Over the course of further and repeated trainings, the rating of the technical components of the WISDOM System improved drastically. Figure 15.16 shows the

Fig. 15.16 Answers to questions on the suitability of the WISDOM project, the Information System and selected technical functionality towards the end of 2012

Fig. 15.17 Impressions of the Mekong Environmental Symposium 2013, hosted by DLR and held in Ho Chi Minh City, Vietnam, from 5 to 7th of March 2013

answers to three more technically oriented questions—here from a training held end of 2012 in Can Tho Province with around 50 participants.

The monitoring of the trainings to assess the project-, system-, and trainer performance proved to be a very valuable source of information for improvements, especially in terms of technical and content related issues. Feedback and adapted user requirements and expectations were forwarded to the IT developer group at the German Aerospace Center, DLR. Here, suggestions of the training participants were prioritized, and then—step by step—implemented. Better marks for the technical components in the following training evaluations showed that this strategy worked well, and that the improvements were acknowledged (Fig. 15.17).

15.6 Information System Implementation and Long-Term Accessibility

The overall purpose of the WISDOM Information System is to ensure that all project results achieved and collected by the large project consortium—be it map products, geostatistical analyses, in situ sensor time series, publications, or contact data bases—are accessible to the public also after the project has ended. The WISDOM Information System is a central platform for Mekong Delta related information exchange.

Already during the project time span itself numerous activities targeted on a long-term implementation of the system. Not only trainings for the usage of the system as well as custom adaptation to the specific user requirements of local authorities pointed already in this direction. Close information exchange with donors and development aid organizations such as the Asian Development Bank (ADB), World Bank (WB), the bank "Kreditanstalt für Wiederaufbau" (KfW), or the German Federal Ministry for Economic Cooperation and Development (BMZ), and the German Development Cooperation (GIZ) was fostered; last but not least supported by the BMBF funded initiative for the "Aid for Implementation" (AIM). In the context of this initiative about 4 years after project start visits and project presentations at the ADB Headquarters in Manila (2010), and visits to KfW in Frankfurt (2010) were realized. Here, we learned that—for a side-lining of research projects as well as for the chance to (financially) support implementation by such agencies, it is important to involve them from the very beginning of a project—namely even from the project design phase, when first ideas for a project are born. Furthermore, donor agencies such as WB, ADB, or KfW (status 2012) prefer to invest in "hard, solid, technology", where the results later are visible (e.g. in the form of a hydropower dam, a water treatment plant, or infrastructure for example). Here we learned that such organizations should have been included in the project's design from the very beginning.

However, even now after project's end DLR still hosts the WISDOM Project's Website, as well as the WISDOM Information System (accessible via the Website after requesting a login) for two more years after the project's end at own costs. The WISDOM Website (www.wisdom.eoc.dlr.de) at current state (August 2014) has several hundred visitors per month, and we have over 250 registered users of the Information System, of which over 75 % are Vietnamese. In the past year, the WISDOM scientists and IT developers have been addressed by numerous other consortia, which are currently forming in the context of Mekong related project opportunities released by different donors. System statistics reveal that access and data downloads especially increase in time of open project calls.

Also the mirrored server and system in Vietnam is still up and running. The WISDOM Information System has been handed over the two Vice Ministers by the German BMBF during the Mekong Environmental Symposium 2013 in Ho Chi Minh City, Vietnam, organized by DLR. During this symposium, where over 400 scientists, local decision makers, national stakeholders, as well as companies and consultants gathered, the WISDOM Information System was presented to a large audience life and online. A lot of feedback received after the live online demonstration of the system, as well as feedback on many project results presented, enabled us to run the WISDOM project in its last year with full concentration, always having user requests in mind. Furthermore, future research and development gaps could be identified.

The WISDOM Information System is currently one of the backbones of a new national Vietnamese project (called Mekong GIS, or MGIS) supporting the IWRM of the Mekong Delta. So the technology of a German-Vietnamese research project has now been taken over by national Vietnamese institution, which will ensure stepwise system adaptation to updated user requirements, and which will ensure the ingestion of updated data during the next years. Furthermore, MARD is planning a national Water Resource Information System for the complete country, and considers partial use of WISDOM components. On the German side a project extending the activities from the Mekong Delta towards the whole Mekong Basin (CATCH-MEKONG Project) is currently set-up. This project, which will be led by the DLR as well, plans to use the WISDOM Information System and to extend it to basin wide functionality, supplying it to transboundary stakeholders, such as the MRC.

15.7 Conclusions and Further Thoughts

In this chapter we presented the development of an environmental information system, built for the Mekong Delta, in the context of the German-Vietnamese research project WISDOM (Water related Information System for the Sustainable Development of the Mekong Delta). Goal of the multi-disciplinary project has been to contribute to numerous knowledge gaps existing for the Mekong Delta. At the same time the freely and online available, bilingual WISDOM Information System was established, which serves as a central project hub, and which ensures that the majority of project findings, which come in the form of geodata, in situ measurement collections, maps, statistics, reports, or scientific publications are available to the public. Despite the successful hand over of the WISDOM Information System in 2013 and despite the fact that even after project's end the system is still up and running, the system design, development and implementation has been very challenging.

Typical setbacks that we also encountered have already been elucidated in other comprehensive papers (McIntosh et al. 2011; Volk et al. 2010) and can be grouped into setbacks caused by internal and external disturbances, which again can be classified into people-, administration- and technology related disturbances. Project internal, people-related and administration-related disturbances and challenges were amongst others administrative and staff changes on both project partner sides, "brain drain" (Vietnamese trainers, which left the project to look for chances outside of Vietnam, after they had reached a certain level of IT expertise as well as a certain level of oral English). Furthermore, relatively uneven funding of the projects in the two countries automatically led to a different level of involvement. Internal technology related disturbances were limited or interrupted internet access, virus problems, relatively limited IT skills in the Mekong Delta at the start of the project (2007/2008), a very flexible development process always readjusting to re-formulated user requirements, as well as the extremely fast evolvement of IT technology and new software solutions over the course of a 7 year project. External challenges were amongst others changes in the administrative and legal landscape of Vietnam, up to changes of province boundaries (with severe effects on the geo database), the handling of data and information, which underlies strict data policies and cannot be shared (usually high resolution data from within Vietnam), as well as a very diverse and crowded project landscape in the Mekong Delta of Vietnam. In this region international research and aid projects often work on redundant topics, and simultaneously might compete for international donor funds. Thus, even at international level data sharing has not always been easy.

However, overall the WISDOM Information System has developed beyond our initial expectations. For future projects and a successful development and implementation we consider the following points of high relevance. Technology related, in the current time, an open source technology based approach will grant largest acceptance in emerging and developing countries. In times, where satellite data providers open up their archives, journals prefer to be open access, and more and more software is open source, an information system that follows this concept and can be utilized free of charge and without the need for license fees has the largest potential for acceptance. Furthermore, it is crucial that in emerging or developing countries the systems or knowledge hubs are provided in the local language. It was a key asset of the WISDOM System that the system's interface, all metadata, all help files, as well as all trainings materials etc. were available in Vietnamese language. A purely English system would not have been accepted. At the same time, implementation concepts—including financing concepts for implementation—should be developed at (or even before) the start of the project. Here, the most sustainable way is national funding via the country that has an interest in the system. That we could reach this in the context of WISDOM, and that the system is now taken over by two to three other projects is rather a product of chance. At the same time (at project start) a thorough user requirement campaign is of utmost importance to ensure that the data and information provided meets the working reality of the end users. To have a rather small and clearly defined group of users will ease the development process, including the amount of information and results that has to be generated, but at the same time might decrease the chances of implementation as well.

Reflecting our experiences in the context of IWRM, it must be underlined that for a sound Integrated Water Resources Management, IWRM, certain pre-requirements need to be fulfilled. Usually, environmental protection or the maintenance of ecological diversity are not the top priority, if large parts of the population of a country still face much more pressing challenges, such as poverty and hunger, diseases, limited electricity, limited infrastructure access, illiteracy, or repeated exposure to natural hazards.

In Europe it took several decades of preparation until the Water Framework Directive (or more formally the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy) was finalized and activated. In this European Union directive EU member states actively commit to achieve a healthy qualitative and quantitative standard of inland and near-shore marine water bodies until the year 2015. The directive defines the standard/status of a water body depending on ecological and chemical characteristics (conditions similar to the absence of anthropogenic influence) and prescribes distinct steps to reach the common goal of such defined water body standards for all of Europe. In the context of the directive so called River Basin Management Plans need to be published in frequent intervals. The last RBM plan was published in 2009—new versions must be finalized in 2015 and 2021. Compared to the Mekong Basin, the horizontal and vertical linkages and also responsibilities of involved stakeholders and decision making agencies is more clear, and in most countries law enforcement can be relied upon. However, this was not reached overnight, but came naturally along with the economic and societal development of the countries involved.

The level of IWRM achieved in a country—according to our understanding—is a function of economic development parameters: the reduction of poverty, the increase of general education, the improvement of environmental consciousness, as well as investment in water technology, and later, resource efficient green technology—all flanked by proper political measures and law enforcement. According to Benedikter (2014), who published a comprehensive work on "The Vietnamese Hydrocracy and the Mekong Delta" there is still a long way ahead. "Apart from horizontal struggle between ministries, IWRM, [for the Mekong Delta] is also paralyzed due to competition between central and local state agencies. Or, to paraphrase, competition between networks based on regional provenance over the allocation of power and financial resources. Administrative, pluralism and fragmentation is the result and hampers IWRM, which would require ideas of increased collaboration and coordination not only between, central and local administrative levels, but also among local governments. Under the current type of (water) bureaucracy, putting IWRM into practice remains an ambiguous objective difficult to achieve" (Benedikter 2014).

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Chapter 16
Analysing Stakeholder Driven Scenarios with a Transboundary Water Planning Tool for IWRM in the Jordan River Basin

Christopher Bonzi, Janina Onigkeit, Holger Hoff, Brian Joyce and Katja Tielbörger

Abstract Although IWRM has become the mainstream concept for water management, its implementation in transboundary, politically tense settings, such as the Jordan River basin, is still limited. In this study we present the application of a transboundary spatially explicit water resources simulation and planning tool in support of decision making in this contentious setting. We integrated socio-economic scenarios and water management strategies resulting from a stakeholder process, thereby including socio-economic uncertainty, using the WEAP modelling software. Tool development was supported by an active transboundary dialogue between scientists and stakeholders. The tool was used to identify water scarcity effects and spatial-temporal response patterns under four regional scenarios up to the year 2050. These scenarios suggested that the positive effects of large scale water management options such as sea water desalination and the increased use of treated wastewater can be strongly limited by insufficient water transport infrastructure and/or a lack of cooperation. Respective responses to water scarcity should be pursued with the same intensity as currently the implementation of large scale supply-side options.

Keywords IWRM · WEAP · Water resource planning · Scenario analysis · Jordan River basin

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16.1 Introduction

16.1.1 Background

Despite the broad acceptance of Integrated Water Resource Management (IWRM), there have been challenges in implementing the concept (Biswas 2004, 2008). This especially applies to assessing and resolving water policy and management in an overall societal and development context (Biswas 2004). The 'Human System'—mainstreaming water in the economy, cross-sectoral integration in policy development and involvement of stakeholders—needs to be integrated in management approaches (Jonch-Clausen and Fugl 2001). The implementation thereof is particularly difficult when it comes to cross-boundary catchments, low data availability and sharing, or highly contentious political contexts. The understanding of integrated and adaptive water management approaches in this kind of setting is still limited.

In the Middle East transboundary resource management needs to address the contentious political setting. It is one of the most water-stressed regions in the world (cp. Tielbörger et al., Chap. 27) and political and economic problems hamper sustainable solutions to the water crisis. A complication for IWRM is the fact that the direction of the economic and political development is inherently unpredictable, making planning very difficult. Therefore, IWRM must aim to address uncertainty and be effective under a range of changing economic and political conditions (Pahl-Wostl 2007).

Hydrology and water management models have been established for parts of the Jordan River (Sivan et al. 2007; Alfarra et al. 2012). However, there are very few models or datasets addressing the whole Jordan River basin (EXACT 1998; Hoff et al. 2011; Comair et al. 2014). Integration of climatic variability into hydrological and management models is not uncommon and has been done on sub-catchment scale in the Jordan River catchment (Abu Sadah 2009; Al-Omari et al. 2009; Samuels et al. 2010). However, only few implementations are known that integrate socio-economic boundary conditions (Jayyousi and Almasri 2010). This is regrettable because these conditions may have a much larger impact on the water balance than climatic variations. For example, it seems obvious that a potential doubling of the population in the focal regions in 20 years, such as predicted by the FAO (United Nations 2013), will likely be as important for determining the water budget in the region as the predicted climate change impacts (cp. Tielbörger et al., Chap. 27). Further, the implementation of water management responses will strongly influence the regional and local water budget. To date no research has attempted to evaluate the relative importance of these man-made processes on a regional level considering spatio-temporal response patterns and the current water management system in place. This study aims to fill this gap.

In order to accomplish this task, we combined a set of stakeholder-driven scenario assumptions with a regional water planning model. The model is based on the water balance accounting program Water Evaluation and Planning (WEAP) tool. The stakeholder-driven scenario settings were developed using an interactive and participatory methodology named the "Story and Simulation" approach (SAS). They describe four different future water resource situations in the Jordan River basin up to 2050 (see Onigkeit et al., Chap. 12). The water planning model—which we call the Jordan River basin WEAP model—represents a first in spatially explicit, cross-boundary, full basin water planning in the Jordan River basin.

The power of this approach lies in the ability to integrate current and future water demands, water supply and possible water management decisions coming from the stakeholder driven scenarios. The WEAP platform is one of the central decision support tools used in the GLOWA JR project (see Tielbörger et al., Chap. 27). The project aimed at providing scientific support for evidence-based sustainable water and land management in the Jordan River region.

16.1.2 Scope of the Study

Using a spatially and temporally explicit water management tool we compared the local, regional and transboundary distribution of water resources, deficits and the systemic effect of different management options in the different scenarios. We analyzed the model approach and outputs asking the following questions:

1. How do regional socio-economic development scenarios unfold with respect to water deficits and possible solutions for effective water management?
2. During the scenario process two main response strategies with considerable impact on the regional water balance were identified: (1) large increase of seawater desalination capacities and (2) a more efficient re-use of treated wastewater throughout the region. To what extent do these water management strategies influence the water management in place and the spatial and temporal capability to meet the future water demand in the region?
3. This work is a first attempt to couple qualitative-quantitative, stakeholder driven regional development scenarios and a quantitative, geographically defined water management tool for the whole Jordan River basin. To what extent did this approach successfully handle socio-economic uncertainty in a contentious cross-boundary setting and promote an IWRM approach in the region?

In order to focus on the key drivers and response strategies of the scenarios we did not consider the effects of climate change in the planning model. It should be noted that although climate change can be expected to impact natural water resources and demand patterns in the Jordan River basin, especially by changes in frequency and severity of drought events (Törnros and Menzel 2013), effects of socio-economic changes (namely population growth and economic development) and changes in water management are at least of equal importance (Hoff et al. 2011).

16.2 Methodology

For this study, we combined the following two approaches:

- The "Story and Simulation" (SAS) scenario process, which developed four regional development scenarios including consistent water management strategies until 2050; and
- a regional, cross-boundary water resource planning model based on the WEAP platform

Using WEAP, assumptions on global and regional change drawn from the SAS scenarios can be integrated into a consistent framework for assessing supply and demand in support of IWRM planning. Outputs from the WEAP planning model were presented during the SAS scenario workshops to stakeholders. This allowed quantification and visualization of storyline implications and the challenges concerning water demands, resources and management. The ongoing exchange with stakeholders concerning the SAS scenarios stories and the data structure in the planning model resulted in the improvement and acceptance of scenarios and model.

16.2.1 SAS Scenario Process

Using the SAS scenario approach, four quantified socio-economic and political scenarios covering the area of all three participating countries up to 2050 were developed jointly by scientists and stakeholders from the region. A characteristic of this approach is that it integrates qualitative regional knowledge on handling water resources (storylines) and quantitative, model based elements like river run-off in a balanced way (Alcamo 2008). Within the process, water demand projections and corresponding water management strategies have been developed iteratively between stakeholders and various modelling groups. The process is described in more detail in Chap. 12 (Onigkeit et al.—Chapter 12). The scenarios are located in a space defined by two main axes of uncertainty which had been identified by the stakeholders: (1) cooperation regarding water issues reflecting the political situation in the region and (2) economic development. Based on the two extremes of these two aspects, storylines for four "GLOWA Jordan River Scenarios of Regional Development under Global Change" were developed and quantified. In brief, the storylines can be summarized as follows.

Willingness and Ability (WA)
The "Willingness and Ability" scenario reflects the most optimistic scenario in which peace and economic prosperity reign. Due to a combination of high population growth, a prospering tourism industry, and a climate-change induced decrease in annual precipitation, the pressure on water and land resources increases. Even so growing regional cooperation on water issues leads to a successful handling of the situation. The overall water availability can be increased sufficiently through an early

region-wide spread of high-tech solutions, such as desalination plants, waste water treatment and reuse, and the construction of the Red Sea—Dead Sea canal. The availability of financial resources and an increasing level of public awareness for environmental issues guarantee a sustainable development in the region.

Poverty and Peace (PP)
The "Poverty and Peace" scenario represents a combination of peaceful development in the region without economic prosperity. Due to regional cooperation, water resources can be augmented through cooperation. First steps in trilateral water management are realized quickly through third party involvement from the beginning. Political stability leads to a slow but steady spread of technology throughout the region. However, cooperative projects remain small-scale and remain dependent on financial support from outside the region. The continued shortage of water resources, combined with a lack of financial means, requires a high level of public awareness about environmental and political problems over the entire scenario period.

Modest Hopes (MH)
The "Modest Hopes" scenario assumes that no peace agreement can be reached, but that economic prosperity nevertheless prevails. This results in fairly stable conditions in the region with limited informal cooperation in the shape of an exchange of knowledge and technologies between the countries. In the context of water management the focus is on increasing the supply of water by large scale desalination and reuse of treated waste water. Efficiency of water use for irrigation is increasing fast through development and application of new water-saving technologies in agriculture. Increasing desalination capacity and rainwater harvesting help to make up for the decreasing reliability of natural water availability.

Suffering of the Weak and the Environment (SWE)
The "Suffering of the Weak and the Environment" scenario is a worst case scenario in which there is neither peace nor economic growth. Both the development of new and maintenance of existing infrastructure becomes increasingly difficult due to the lack of funding by international donors, who are unwilling to invest money in a politically instable region. A combination of inexpensive, small-scale water options, traditional management measures, and full use of governance options (regulations and laws to save water and minimize pollution) are seen as the most adequate strategies to cope with future water scarcity. Water is allocated in favour of the domestic sector so that agriculture is particularly negatively affected by the situation.

As each storyline is characterized by different political and economic developments, the options for sustainable water management vary among the scenarios. In summary, more peaceful scenarios enable cooperation and exchange of water saving technologies, while the economic prosperity scenarios allow realization, or faster completion, of costly technologies for increasing water supply and new water infrastructure for treatment and transport.

Furthermore, the economic and political situation in the region affects population growth (incl. migration), which in turn will greatly affect water demand. These

Table 16.1 Development of key scenario driving forces, municipal water withdrawal and new water supplies under the four scenarios

	Population (millions)				GDP per capita (2010 US$)[a]			
	Scenario				Scenario			
	WA	PP	MH	SWE	WA	PP	MH	SWE
Israel								
2010	7.5	7.5	7.5	7.5	28,522	28,522	28,522	28,522
2030	10.9	9.6	9.6	9.6	44,946	34,802	34,802	34,802
2050	15.6	10.9	15.6	10.9	70,828	42,465	54,843	34,802
Jordan								
2010	6.2	6.2	6.2	6.2	4371	4371	4371	4371
2030	9.0	9.0	9.0	9.0	10,953	5333	10,953	4371
2050	11.0	13.2	14.2	12.2	27,444	6508	27,444	3798
PA[b]								
2010	4.1	4.1	4.1	4.1	1209	1209	1209	1209
2030	8.5	5.9	4.9	5.9	1905	1209	1905	671
2050	12.4	8.7	7.2	8.7	4774	1475	3002	373
Region								
2010	17.7	17.7	17.7	17.7				
2030	28.4	24.5	23.5	24.5				
2050	39.0	32.7	37.0	31.7				
	Per capita municipal water withdrawal (m^3/cap/yr)				New water supply (mcm/yr) Sea water desalination/TWW reuse			
	WA	PP	MH	SWE	WA	PP	MH	SWE
Israel								
2010	110	110	110	110	290/381	275/381	290/381	290/381
2030	95	87	99	102	600/499	600/390	600/453	600/439
2050	84	87	90	96	1100/642	600/442	1050/686	600/448
Jordan								
2010	55	55	55	55	0/82	0/82	0/82	0/82
2030	77	50	60	50	230/255	250/148	250/209	0/126
2050	77	50	60	50	550/386	850/247	850/414	0/194
PA								
2010	50	50	50	50	0/4	0/4	0/4	0/4
2030	67	50	71	50	115/159	0/40	100/98	0/40
2050	77	50	76	50	310/442	0/123	280/255	0/69
Region								
2010	77	77	77	77	275/467	275/467	275/467	275/467
2030	81	64	78	70	945/913	850/578	950/760	600/605
2050	80	62	76	66	1960/1470	1450/812	2130/1355	600/711

[a]For PA = 2005 US$, [b]PA = West Bank and Gaza Strip; Onigkeit et al., Chap. 12

scenario-dependent developments and resulting water quantities were calculated for each scenario (Table 16.1) and served as input into the water planning model. The aim when generating the storylines was to come up with a water strategy that assume all demands can be satisfied on a regional level by 2050. As such there is a fairly even regional water balance concerning yearly regional demands and resources between the scenarios.

16.2.2 Regional Water Planning Model for the Jordan River Basin

Water resources, demands and allocation were simulated using the Water Evaluation and Planning tool (SEI ongoing). WEAP is a platform for simulation-modelling based on water accounting principles. In its simplest form, it is similar in structure to other water allocation support tools like RiverWare (Zagona et al. 2001) or Oasis (Randall et al. 1997). It also provides features to link dynamically to other models such as Qual2K for water quality modelling or MODFLOW for dynamic groundwater modelling. It uses demand and resource nodes and a linking system to model the supply, demand and management of water resources. For every system component, parameters can be directly entered or calculated, allowing for the projection of changes in water supplies and demands over a long-term planning horizon. The system also allows for the exploration of physical changes to the system, such as new reservoirs, transfers or desalination, as well as socioeconomic changes, such as policies affecting water allocations or population development. WEAP calculates water balances at each time step (e.g. daily, weekly, monthly, or yearly) for every node and link in the system. The input and output parameters (e.g. water volume, flow, demands or unmet demand) can be displayed or exported for every system component using the built-in results viewer or scenario explorer. For more detailed information on the WEAP platform, the reader should refer to Yates et al. (2005).

WEAP was selected because it facilitates a scenario-based approach allowing the integration of driving forces such as changing human water demands and infrastructure development, while modelling demands and corresponding operational water management decisions in a quantitative and spatially explicit way. WEAP allows the modeller to use data of different spatial resolution, detail and complexity as required. This paper recognizes initial conceptual models and representations of national and local water systems in WEAP (Abu Sadah 2009; Al-Omari et al. 2009; Sivan et al. 2007) and based on that developed an overarching regional water planning model, integrating aggregated data and model outputs from the different sub-models.

Jordan River basin (JRB) WEAP model

The JRB WEAP model provides a basin-wide framework to consolidate the available water data from the riparian countries Israel, Jordan and the West Bank. Rather than calculating hydrological processes based on drivers such as precipitation or evaporation, datasets on hydrology and water use were read in for the base year and for the model period (scenarios). The base year was set to 2010. Input data was aggregated to monthly time steps or, in a few cases (e.g. for less well monitored wadis), disaggregated by overlaying measured annual data with monthly variations from the nearest available basin. Data was obtained from—or at least cross-checked by—official sources. All data were checked for inconsistencies and harmonized across countries. For more detailed information and a model verification the reader should refer to Hoff et al. (2011).

The system representation in the JRB WEAP model was kept as simple as possible without losing the key structures and functions. A level of resolution was chosen that would allow assessment of regional and national level water management decisions while still permitting effects on the local level to be incorporated—which also effect national and regional water budgets. An overview on data input, operational assumptions and model set-up of the JRB WEAP model is provided below.

Network Topology

The geographical focus of the model is the river basin and the main water management features within the watershed. These comprise agricultural and municipal demands, the major tributaries, the major groundwater aquifers, main water bodies, major irrigation channels (King Abdullah Channel), and major trans-basin diversions (mainly the Israeli National Water Carrier, which transfers water from the basin to the coastal plains). Regions which are not directly or indirectly connected to the Jordan River were not part of the model (such as the Arava Valley) the Jordanian highlands and Gaza. Due to missing data, Syrian demands, resources and management could only be modelled as a single demand node, while the Lebanese part of the Hasbani catchment was modelled using runoff data from a gauging station in Israel. Figure 16.1 displays the main features of the water system.

Water supplies and demands

Data input for rivers, wadi flows and groundwater bodies was based on average records for the period 1970–2000 received by the respective national authorities. For the base year average monthly discharges and water levels were used. For the transient scenarios the past variation was mirrored into the future, assuming the same hydrological characteristics in future. For non-conventional water resources (desalination, treated wastewater) the actual production quantities for the reference year were used.

Treated wastewater inflow and use was based on the following factors: (1) consumption of water in the demand nodes; (2) node-specific percentage of return flow connected to a wastewater treatment plant (WWTP); (3) individual WWTP capacity; (4) maximum amount of treated wastewater (TWW) that can be used given physical constraints; and (5) maximum percentage of TWW used in agricultural node.

Agricultural water demands from national statistics were aggregated to the main agricultural districts in the Jordan Valley and the West Bank. They are represented by a respective agricultural area and multiplied by an average irrigation requirement. Israeli demands were implemented by total quantity of water used. Agriculture

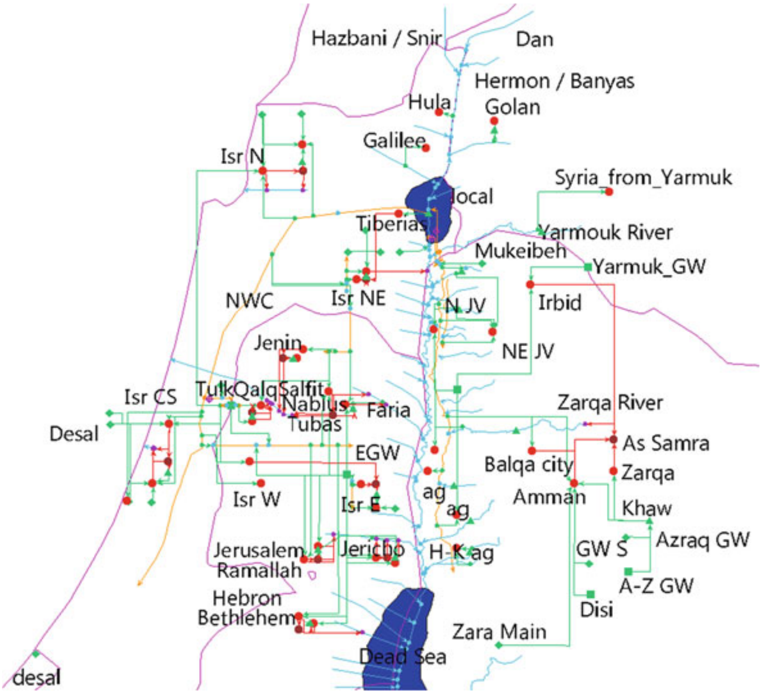


Fig. 16.1 Conceptual representation of the JRB WEAP model showing supply nodes and transmission lines in *green*, water diversions in *yellow*, and demand nodes and return flows in *red*

demands from outside the basin (Israel) were only included up to the extent they are affecting water withdrawals from the Jordan River catchment.

All municipal demands were considered up to the extent they affected water withdrawals from the Jordan River catchment. Given the severe resource and political restrictions in access to water on Jordan and the West Bank, we agreed with local project partners to apply a minimal per capita demand of 50 m^3/s. Israeli demands on the other hand were implemented by using real per capita consumptions. Water demand and delivery data (Table 16.2) was based on 2000–2005 records.

16.2.3 Integrating SAS Scenario Drivers in the Regional Planning Model

The JRB WEAP model calculates demand and supply based on geographically defined units. These were chosen according to current water demands, water resources, water management infrastructure and sub-regional political boundaries. The SAS approach resulted in trends of key driving forces and assumptions on political and socio-economic developments that were integrated in the regional

Table 16.2 Approximate water budget for the base year in million m^3 (MCM)

Surface water supply	Annual streamflow (MCM)
Upper Jordan River (Hazbani, Dan, Hermon)	680
Yarmouk River	500
Zarqa and Lower Jordan River wadis	170
Total supply	1,350
Groundwater and other supplies	**Annual net production (MCM)**
Mountain aquifer–groundwater/springs	693
Jordan–groundwater/springs	139
Israel—groundwater/springs and flood capture	700
Israel–desalination[a]	250
Total	1,782
Water demand	**Annual demand (MCM)**
Jordan municipal	290
Jordan agricultural	350
West bank municipal	140
West bank agricultural	185
Israel agricultural—in and out of basin	1100
Israel municipal—in and out of basin	900
Upper Yarmouk diversion to Syria	400
Total demands	3365

[a]Note that Israel's desalination capacity is reaching a potential of up to 600 MCM by 2015

planning model. Population growth, economic development on a country level, technological trends and land use change associated with each of these scenarios served as inputs for the JRB WEAP model. Based on the socio-economic and political settings in the region, the scenarios also imply a set of proposed management strategies that consider cost intensive large-scale and small-scale inexpensive options depending on the underlying socio-economic scenario assumptions.

Not all figures and quantities generated by SAS could be directly implemented in the JRB WEAP model because ways of modelling elements, resolution or system boundaries were not completely congruent between the two approaches. Regional assumptions on demand and supply were adjusted to the resolution of the regional planning model and operational management decisions were adjusted according to the story lines (Table 16.3).

We analysed the results of the scenario process asking (a) how do the response strategies influence the regional (whole basin and diversions) and sub-regional (national and local) water balances, and (b) how do spatial and temporal distribution of unmet demands (i.e. shortage) occur in order to identify critical regions and time steps which pose an extra challenge to water management not observable when analysing scenarios on a country level or for one point in the future. We focus on the effect of large scale desalination capacities and the effectiveness of recycled

Table 16.3 Integration of SAS key driving forces and assumptions in the JRB WEAP model

	SAS driving force and assumption	Integration in JRB WEAP model
Water demands		
Municipal	Explicit annual water use rates per capita and country	Adjusted by inter-nodal variation of the model baseline year (actual demands vary according to demand nodes)
Agricultural	Annual demand per country considering fresh water and TWW reuse	Agricultural demands based on area and water use per area. Land area change according to the land-shift model, which uses SAS Key driving forces (Schaldach et al. 2011)
Losses	Fractions of annual water use rates	Annual water use rates in demand nodes were adapted accordingly
Resources		
Natural	Same data origin for SAS and JRB WEAP model; regions not directly or indirectly connected to the Jordan River were not part of the JRB WEAP model (Arava Valley, the Jordanian highlands and Gaza)	
New water	Additional conventional and non-conventional water supplies such as sea water desalination, rainwater harvesting and water import implemented according to SAS story lines	
Treated wastewater (TWW)	TWW use computed by: connected to network, % return flow, treatment efficiency and % used in agriculture	JRB WEAP model uses same factors. Inter-nodal variation gained from base year adjusted by assumption on access based on SAS story lines
Operation		
Mountain aquifer (MAB)	Groundwater access and distribution is a result of story line setting	WA: Full aquifer sharing reached by 2030
		PP: Full aquifer sharing reached by 2050
		MH: no sharing, currently untapped water is developed by West Bank by 2050
		SWE: no sharing, no developments
Jor-Isr treaty	Adjustments to peace treaty not part of storyline. Current operation according to peace treaty (Israel-Jordan 1994) stays in place in all scenarios	
TWW distribution	No explicit information on distribution of TWW	WA: Installation of TWW conveyer by 2020
		PP: No installation of TWW conveyer
		MH: Installation of TWW conveyer by 2035
		SWE: No installation of TWW conveyer

water (treated wastewater) use. The SAS scenario process identified both response strategies to have a considerable impact on the regional water balance. For each of the two analytical questions we undertook the following:

(a) Analysis on overall and spatio-temporal variation in unmet demands

Simulated unmet demands were analyzed for the different scenarios and compared to the regional water balance computed by the SAS approach. This revealed how the scenarios unfolded with respect to water deficits under existing water infrastructure and management approaches.

(b) Analysis of large-scale technical solutions: desalination

We assumed that the effect of local large-scale measures would strongly affect the water balance far beyond the immediate surroundings. For example, new desalination capacities in the coastal plain metropolitan area would decrease unmet demands also in the north of Israel by reducing pumping requirements in the national water carrier. Similarly, desalinated water may reduce competing municipal demands for Jordan River and aquifer water and at the same time yield additional wastewater for reuse in agriculture. This in turn would make water available for satisfying the demands of currently underserved water users elsewhere in the basin.

We analyzed large-scale desalination options, such as the Red Sea or Red Sea—Dead Sea desalination projects in Jordan or the installation of desalination plants along the Mediterranean Coast, and their impact on unmet water demands in space and time. Desalination capacities were biggest in the economic growth strategies, which is why we focused on the "Willingness and Ability" and the "Modest Hopes" scenarios. We compared the effect of large amounts of new water (including large desalination plants) to the same scenarios minus the installation of large desalination capacities. For this comparison we excluded desalination capacities for which tenders have not yet been approved, i.e. Israeli desalination of 600 MCM are active in both versions of the scenarios.

(c) Analysis of treated waste water use

The SAS process provided information on the development of treated wastewater capacity and on average distribution capacities on national levels, but not on local level or on required storage capacities. We therefore examined how the temporal and spatial availability of treated wastewater (TWW) corresponded to agricultural demands. First, we analyzed which amounts of TWW would remain unused, because production, storage and distribution in all the scenarios were not ideal.

We then compared the distribution of areas with high amounts of unused TWW and agricultural demand. We also compared the economicly favorable scenarios, which assume a better infrastructure for the distribution of TWW (Table 16.3) to the economicly less favorable scenarios. The JRB WEAP model assumed that TWW conveyers would transport water generated in higher altitude to demands centers in the Jordan Valley floor.

16.3 Results

(a) Overview on water demand and unmet demands

Regional demands within the economically favourable scenarios “Willingness and Ability” and “Modest Hopes” grew markedly faster than in the scenarios with economic stagnation (Fig. 16.2a). This can be attributed to the higher population growth in these scenarios and the resulting increased domestic demand (Table 16.1). However, at the same time, enhanced water supply resulting from new water resources increased as a result of the possible investment into water generating technologies. The resulting regional water balance is close to balance, i.e. there is a slight surplus in water in most of the scenarios when we compare total supply (conventional and unconventional sources) to total demands (Fig. 16.2b). This indication of high volume reliability is due to the fact that the inherent structure of the scenarios and the respective strategies were actually designed with the aim to meet demand.

Although the regional annual water balance only displays a deficit in the “Suffering of the Weak and the Environment” scenario, the JRB WEAP model did identify considerable unmet demand throughout all four scenarios because it observed spatial distribution patterns and runs transient scenarios. Local deficits occurred because the temporal and spatial availability of water resources, infrastructure and management on the ground are not perfect. Therefore, sub-regional and local water scarcity can be significant, albeit highly variable among scenarios and in space and time (Fig. 16.2c).

(b) Effectiveness of large scale desalination capacities

In both economic favourable scenarios large amounts of new water were generated in desalination projects in the Red Sea area (incl. Red Sea—Dead Sea canal) and the Mediterranean Sea area (additional 1200–1500 MCM in 2050, see Table 16.1). If we compare the results for the “Modest Hopes” and “Willingness and Ability” scenarios under normal scenario assumptions to the same scenarios minus the large quantities of new water, no significant difference in unmet demands

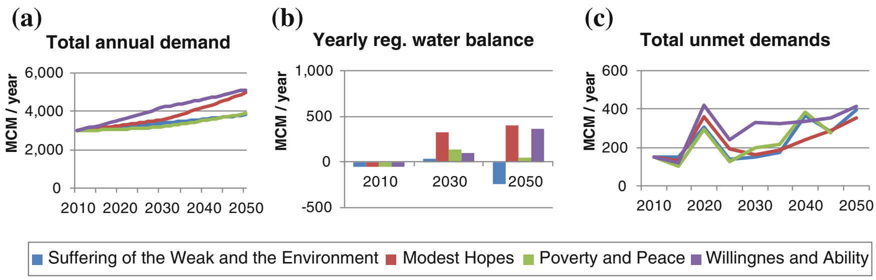


Fig. 16.2 **a** JRB WEAP model results showing transient demand development; **b** regional water balance comparing all water resources and demands for 1 year (supply minus demand for the baseline year (2010) and every 20 years thereafter); **c** JRB WEAP model results showing aggregated yearly demands for the whole region

during the year 2015–2022 were visible (Fig. 16.3a). Growing unmet demands during this time period relate to the Jordanian demand nodes (Fig. 16.3b). Jordan is currently facing immediate water shortage and the country will continuously be challenged thereby. In Jordan, large desalination capacities are planned, starting with 200 MCM in 2022 and reaching up to 850 MCM per year in 2050 under the economicly favourable scenarios. Thus in Jordan, even under economic growth, unmet demands will significantly increase until the expected effects of the red sea desalination projects kick in.

The results show that not all the desalinated water lead to a reduction in unmet demands. This is less so in the "Willingness and Ability" scenario, which assumes an increase in regional cooperation (Fig. 16.4). Due to limited cooperation the exchange of water between the West Bank, the Jordanian and the Israeli water systems is currently restricted. WEAP simulates the exchange of water according to the current condition and the regional context of the scenarios. In the JRB WEAP model, unused new water either did not reach the system (there is no demand in the vicinity of the supply nodes) or groundwater bodies, surface water bodies or reservoirs filled up indirectly and discharged water unused downstream, eventually evaporating or entering the Dead Sea.

Thus large quantities of desalinated water did lead to significant less reduction in unmet demands in the case of non-cooperation, where new water (e.g. along the Mediterranean coast) didn't affect the situation in another demand region, most importantly the West Bank. This is in contrast to the cooperation scenario "Willingness and Ability", where an indirect effect was caused by a change in groundwater access: While Israel continuously relies on new water, the West Bank gains better access to the mountain aquifer.

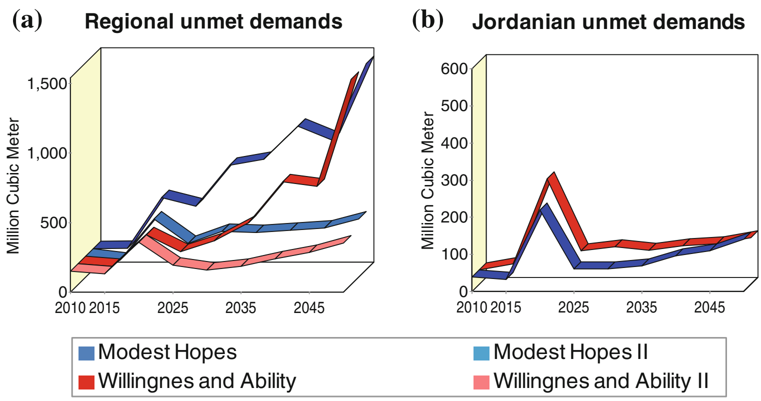


Fig. 16.3 **a** Regional unmet demand in the 'Modest Hope' (*blue*) and the 'Willingness and Ability' (*red*) scenarios. The *dark coloured lines* (marked II) represent the scenario-versions without large desalination capacities. **b** Unmet demands for all Jordanian demand nodes in the two economic growth scenarios

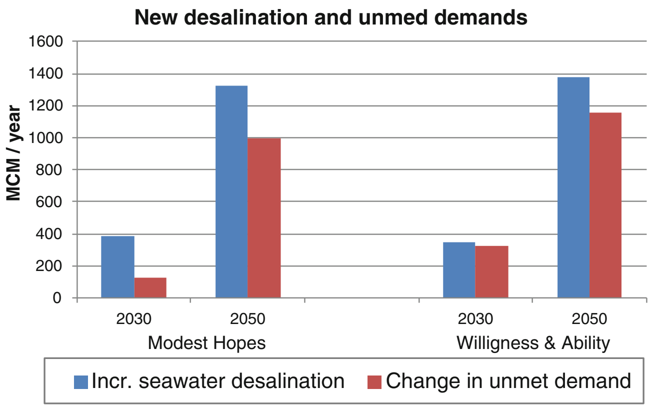


Fig. 16.4 The comparison of the amount of desalinated water entering the system and the reduction in unmet demands in the corresponding scenarios

(c) spatial-temporal distribution and use of treated wastewater

Model results revealed that under all four scenarios large quantities of TWW were not used, because production, storage and distribution were inefficient. For example, of all the wastewater that could be tracked through the model (approx. 80 %), up to 30 % or 300 MCM per year were not used due to missing demands at the respective places and time (Fig. 16.5).

In Israel, current infrastructure was sufficient to produce, store and distribute the large quantities of TWW. In the West Bank, we see an uneven spatial distribution of production and demands (Fig. 16.6). For this comparison we focused on the "Suffering of the Weak and Environment" scenario, because in this scenario the percentage of unused TWW is average and no mitigation effects through the installation of TWW conveyers were visible. Large quantities were unused in

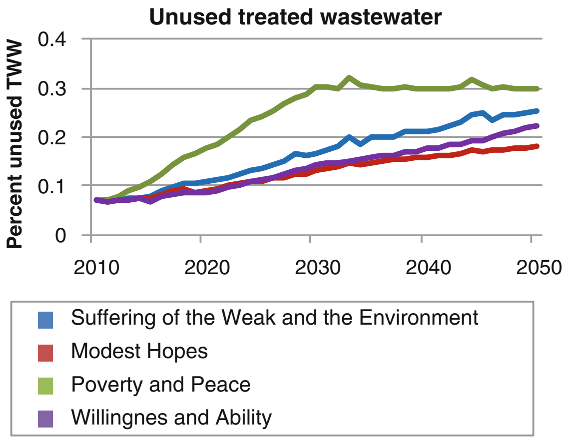


Fig. 16.5 Fraction of unused TWW due to mismatch between local demands at the time and place of production and missing storage or distribution infrastructure

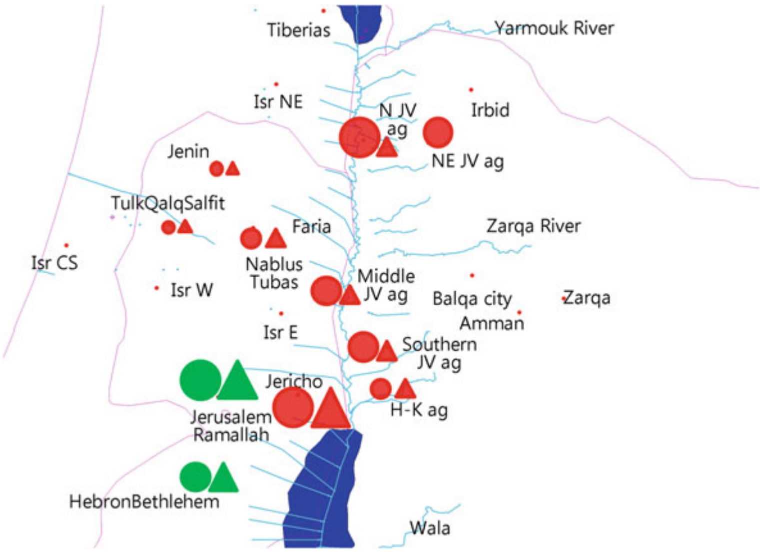
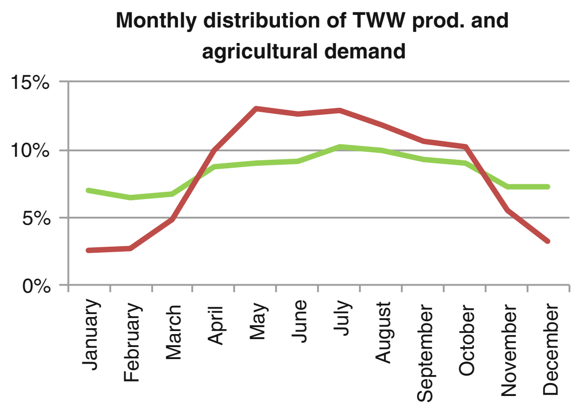


Fig. 16.6 Spatial distribution of unused treated wastewater, size of nodes indicates the amount of unused treated wastewater (*green*) and agricultural unmet demands (*red*) for the years 2030 (*triangle*) and 2050 (*circle*) under the 'Suffering of the Weak and Environment' scenario

the Jerusalem/Ramallah and Hebron/Bethlehem areas. On the other hand, there were large unmet demands in Jericho and the Jordan Valley floor.

It should be noted that areas with large unmet agricultural demands are generally at lower altitudes than the areas with large surplus of treated wastwaster. When comparing the scenarios with economic growth (and a better distribution of TWW) we did find significant reduction in unmet agricultural demands. This lead to lower percentages of unused TWW under "Willingness and Ability" compared to the "Poverty and Peace" and in "Modest Hopes" compared to "Suffering of the Weak

Fig. 16.7 Average monthly variation of wastewater production (*green*) and agricultural demands (*red*)



and Environment" (Fig. 16.5). Nevertheless high amounts of unused TWW still remained. This was due to the fact that monthly variation of TWW production does not correspond to the monthly demand variation of irrigated agricuture (Fig. 16.7). Whereas large storage capacities do exist in Israel and Jordan, allowing for seasonal storage of TWW, this doesn't apply for the West Bank. Thus all scenarios showed an increase of TWW that will need an expansion of storage infrastructure.

16.4 Discussion

In this study we combined two approaches—SAS and WEAP. The SAS scenario process provides coherent and consistent assumptions on regional changes comprising of technological and socio-economic developments. The SAS approach emphasizes the regional and national perspective, but does not answer questions concerning how these developments affect and are affected by local water supplies, management and demands (drivers and domestic demand on national scale see Table 16.1). To address this deficiency we used a spatially explicit water balance and management modelling approach using the WEAP platform for a scenario analysis going more into detail. This allowed for the testing and visualization of different water management strategies and their spatio-temporal implications for the regional (transboundary) and sub-regional (local) water budgets using a consistent approach for all levels in space and time.

Model results confirmed that infrastructure and management on the ground require considerable improvements in order to match the temporal and spatial availability and demand of water. Otherwise, water deficits on the local and even the national level will continue—even if there is enough water from a regional perspective. The large quantities of water desalination along the Mediterranean coast or in Jordan, and storage or distribution facilities for TWW, would lead to a significant reduction in unmet demands. However, many demand areas suffering from water scarcity were not reached in time or at all:

- Large quantities of new water in Jordan and Israel did not effectively radiate into areas with existing water deficits in the West Bank. This applies particularly for the first twenty year of the scenario-timeline in the "Modest Hopes" scenario.
- In the "Willingness and Ability" scenarios the new water radiated through the system better, because the scenario allowed for an indirect re-distribution of water by a change in groundwater access.
- In none of the scenarios did new water produced in the western parts of the model radiate into the Jordanian parts of the model, leaving the current water shortage in Jordan unchanged until Jordanian desalination quantities steped in.
- In all scenarios, large quantities of treated wastewater were not available for irrigation use because production, storage and distribution capacities are inadequate. Water infrastructure for treated wastewater should be adjusted in order to (a) distribute treated wastewater to the agricultural demands centres in the Jordan Valley and (b) assure that sufficient TWW storage capacities are installed.

The SAS approach does not consider how storylines impact future water resource situations on local, national and sub-regional scales nor does it consider the corresponding effects over time in a transient manner. However, these effects are of high importance for water managers and decision makers. IRWM planning must be able to address uncertainty and be effective under a range of economic and political conditions *and* predict their implication on the ground (Sigel et al. 2010). The WEAP platform enabled this linkage of global and regional change scenarios, such as the SAS scenarios, within a consistent framework of supply and demand for IWRM planning. It allows for the integration of demand and supply-based information together with hydrological simulation capabilities to facilitate the analysis of uncertainties, including those related to changing human water demands and infrastructure development. The flexibility to adapt to different levels of data availability and its user-friendly graphical interface make it a suitable tool to use in a basin such as the Jordan River, where data can be scarce and stakeholder interest is high. A further key advantage of WEAP is its low license fees. The usefulness of the tool has been confirmed by a growing number of applications by scientist and authorities throughout the Jordan River basin (Bonzi et al. 2010).

A water planning model that relies on a large number of input data and management assumptions will always face some level of uncertainty. We applied WEAP in its basic form, without using any of the options to simulate individual processes such as runoff generation or crop water use. Therefore the JRB WEAP model relies on the quality of the input data in combination with the topology of the water system and the accuracy of the management assumptions. Calibration and validation of the model in a strict sense, e.g. comparing simulated against measured river discharge, was not possible. However, key system elements, i.e. the main groundwater aquifer, the main reservoir (Lake Tiberias) and main water transfers have been validated against independent measurements ensuring that the overall balance and general behaviour of the model is correct (Hoff et al. 2011). In view of the necessity of informing stakeholders and policy-makers on the constraints of a model (Isendahl et al. 2009) it can be said that the general behaviour of the model components are represented correctly and the results we present in this study are therefore accurate. However, quantitative model outputs in absolute numbers on local scales are subject to a certain amount of uncertainty and should be communicated accordingly.

16.5 Conclusion

With this approach of integrating the SAS scenario approach in a Jordan River basin WEAP tool we managed to implement a range of socio-economic regional condition and trends provided by stakeholder throughout the basin in a quantitative modelling approach. Considering the contentious setting in the region, we believe this to be an important achievement. We were able to model effects and spatial response patterns of water management strategies under four different plausible future development pathways in a consistent way on the local, national, and regional scales.

Model results show that both water management options (sea water desalination and TWW reuse) are currently limited by missing water transport infrastructure and cooperation. While the impact of large desalination capacities is limited due to the fact that (a) large parts of the water system are secluded from these effects, and (b) the installation of the planned desalination capacities will take many years, countries will continue to be confronted with water shortages. Hence, although the region will supposedly be highly dependent on generating new water resources through large scale desalination plants and the installation of wastewater treatment facilities, the limitations of the current water transport infrastructure and treaties on water cooperation should not be forgotten. This may be of equal importance if water scarcity problems art to be tackled throughout the whole basin.

IWRM planning should address uncertainty and be effective under a range of economic and political conditions. The contentious setting of the Jordan River region complicates constructive and productive discussions on future sustainable basin-wide water management. Assumptions on regional development and future water management are highly unreliable under this setting. The integration of stakeholders is a challenging task, especially regarding the communication and illustration of complex and debated modelling outputs and when it comes to regional socio-economic scenarios.

Our approach facilitates an open, creative, and at the same time well structured discussion between stakeholders and scientists on water management options, responses and the consequences thereof. We see this as a prerequisite for the discussion of a sustainable basin-wide management. We invite further collaboration so that these tools continue to be applied by institutions with a regional perspective, demonstrating the advantages of a transboundary integrated management of water resources. Moreover this approach also provides a good basis for participatory and problem-oriented analyses on reasonable and equitable water use such as described in Brooks and Trottier (2010).

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Chapter 17
Decision Support in the Context of IWRM: Lessons Learnt from Research Projects in Developing and Emerging Countries

Christian Stärz, Stefan Kaden, Bernd Klauer and Larissa Leben

Abstract Decisions in integrated water resources management (IWRM) tend to be complex. Decision makers often face diverging and conflicting rights of use and interests in the utilisation and valuation of resources. The application of IWRM ranges from drinking water supply and groundwater management to wastewater treatment, irrigation, flood protection and navigation as well as the use of waters for tourism, without compromising the functionality of vital ecosystems. For the decision-making process, economic principles such as cost-effectiveness, cost-recovery and the costs-by-cause principle must be taken into account. Scientists or political advisers are often consulted in order to bring their expertise to the table. Good decision-making in IWRM requires the examination and comparison of alternative actions. Specific systems and methods are applied in order to support relevant decision makers and guarantee transparency for all participants in the decision process at all times. Decision Support in IWRM was conceived and implemented very differently across the funding priority launched by the German Federal Ministry of Education and Research (BMBF). Depending on the individual water management objectives, (geographical) information systems, knowledge platforms, decision tools or mathematical models were developed and implemented

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as Decision Support System. This paper classifies and discusses the contents, methods and functions of Decision Support Systems in the 13 research projects.

Keywords DSS · Water management · Knowledge management · GIS · Mathematical models

17.1 Decisions in IWRM

Integrated water resources management (IWRM) is oriented towards the sustainable use of the vital resource water. Important characteristics of an IWRM are the organisation of management in the relevant catchment areas (river basin management) and the integral, holistic consideration of management effects across different sectors, administrative boundaries and hierarchies. All management involves decision making. However, with extension of the management object and demands for an integrative approach to the problems, IWRM typically deals with highly complex decision situations with many actors involved in the decision making process, and many people affected by resulting decisions (Ganoulis 2005). Decision making in IWRM also takes place under high uncertainty and partial ignorance of e.g. potential management measures, the consequences of these measures, and the preference of those affected (Sigel et al. 2010).

Decision Support Systems (DSS) become relevant due to the complexity of decision situations and difficulties arising in making good decisions. These systems are computer-based tools that process decision-relevant information in order to provide interactive support to the decision-making process.

This paper presents results from the working group "Decision Support in IWRM" which was set up in the context of the IWRM funding priority of the BMBF. The objective was to identify obstacles occurring between the development and implementation of DSS and thus derive lessons learnt by summarizing and generalizing the experiences across the 13 projects on the development and application of different DSS. In these research projects diverse DSS were developed and implemented, depending on the objective of the projects in infrastructure and technology, water supply, water quality and sanitation, waste water treatment, groundwater management, irrigation or flood control.

17.1.1 Decision Processes

Generally, decisions on the sustainable development of water resources are not taken ad hoc but are the result of a long and careful planning and decision-making process. Consequently there is time to collect and order decision-relevant information, to develop and think through decision alternatives, to seek the advice of others, involve affected parties and to weigh positions, facts and evaluations in order to reach a balanced assessment and ultimately make an appropriate decision.

The basic model of decision making from Keeney and Raiffa (1976) is often used for structuring decision-making processes. It differentiates between the environment, which can be controlled by the decision-maker and the non-influenceable environment, in which external factors can affect the decision problem. Long-term effects due to climate change and regional socio-economic developments are examples of external factors on which decision-makers have little to no influence. However, these factors can have significant impacts on water resources in the water catchment area and consequently cause further side-constraints and uncertainties in the decision-making process. The following factors need to be taken into consideration. Uncertainties can, for example, be reflected in different development scenarios. In the controllable environment, which can be influenced by the decision-maker to a certain extent, the decision-making process comprises both planning and decision. Initially, decision alternatives such as a combination of water management measures would have to be elaborated and the possible consequences determined. In IWRM this task is generally very labour-intensive and includes both water management planning and efficient management of the water management system or river basin. The decision encompasses a comparative assessment of the alternatives as well as the actual selection of one alternative to be ultimately implemented. The decision-maker(s)'s preferences are crucial in the evaluation of subsequent consequences.

An advanced model of a decision process in IWRM was described by Dietrich and Funke (2009). They integrated progress supporting activities like monitoring and managing of process, information and learning into the five main responsibilities according to Mintzberg et al. (1976): problem identification, design, choice, authorisation and implementation (Fig. 17.1).

In practice, the simple idea of one person being solely responsible for decision-making needs to be modified. Typically, the decision-making process in IWRM involves at least one democratically legitimized competent authority acting within a hierarchy of administrative levels and consulting neighbouring administrative divisions (e.g. authorities responsible for agriculture or transport), and also involving stakeholders in the decision-making process. It is not always clear what the preferences of a public authority are and/or should be, unlike the more transparent consumer preferences. DSS can be used as an instrument to find out and make transparent preferences within an authority. The system can support communication within a group of decision makers as well as stakeholder participation. All kinds of DSS can be autonomously applied by a competent decision maker or can be run by professional consultants or scientists.

17.1.2 Decision Support Systems

The term Decision Support System dates back to the early 1980s, and resulted from new developments in systems analysis, operations research and computer technologies. User-friendly computer terminals made an online man-machine dialogue

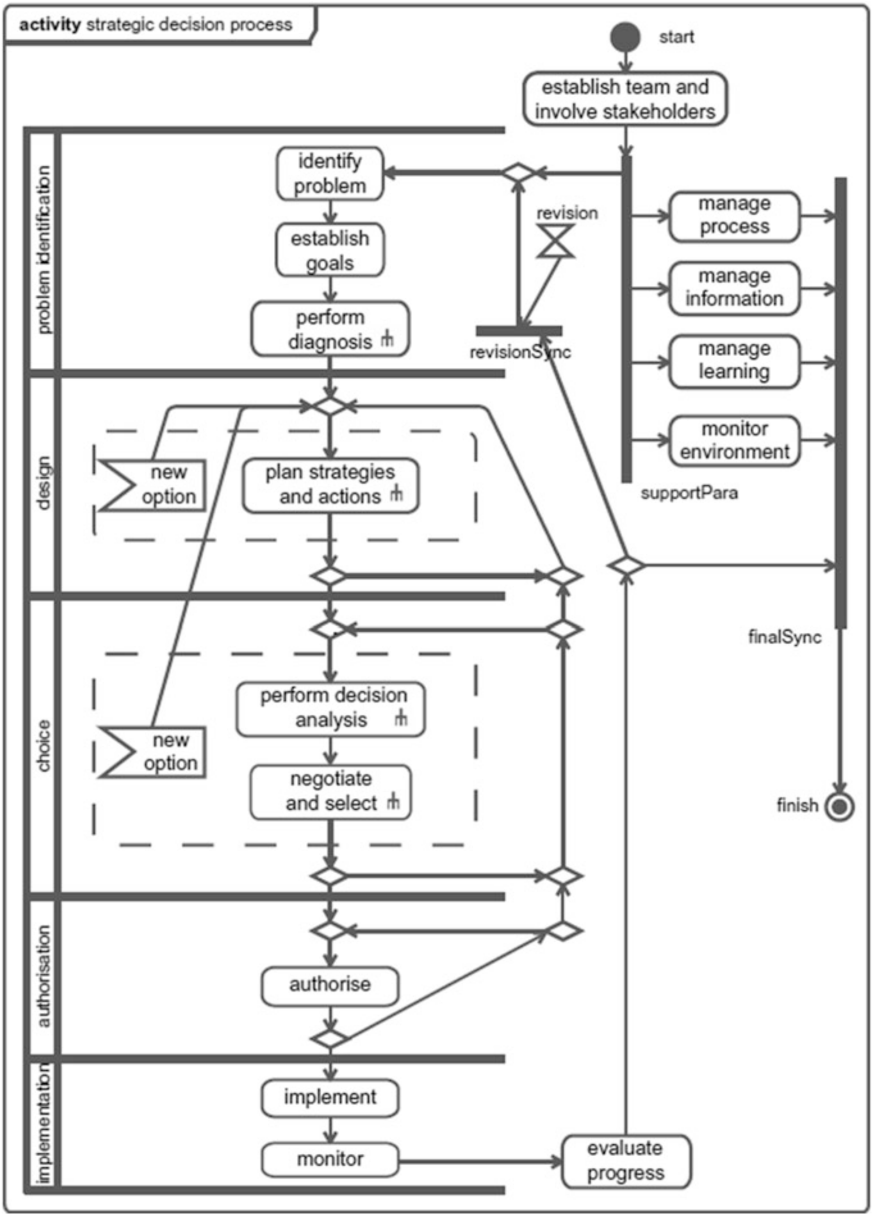

Fig. 17.1 Model of a decision process in IWRM (Dietrich and Funke 2009)

possible. One strong field of development has been water management due to its often highly complex nature. A number of water-related DSS were developed at the IIASA International Institute for Systems Analysis, Laxenburg, for example (e.g. Orlovski et al. 1986). Since that time the DSS market has emerged, not just in water management of course. With the triumphal procession of workstations and PCs beginning in the 1990s this process accelerated further; but not many of those DSS developments have been successfully implemented in practice. There are three major reasons: the DSS cannot cover the full complexity of problems, DSS are rarely tools for political decision makers, and the consideration of human factors and socio-economic criteria is practically limited.

There is a wide range of definitions and interpretations of the meaning of "Decision Support Systems". A rather general definition is given by Simonovic (1996): a DSS is a computer-based tool which enables decision makers to combine personal evaluation and computer-based results in a man-machine dialogue in order to gain substantial information for decision making. According to Haimes (1998) DSS are interactive, computer-based systems, which support decision makers in using data, mathematical methods, simulation and optimization models in an effective way in order to generate decision alternatives and to solve both structured and unstructured problems.

Our analysis has shown that in water management a wide range of methods appear under the term "DSS", from (geographical) information systems, mathematical models, decision tools to complex DSS. The systematization of the different DSS forms in IWRM is complicated due to the uniqueness and complexity of each application, the high variety of possible system solutions, the specifics of decision-making processes depending on the study region etc. A number of systematization and classification attempts can be found in the literature. A few examples are given below.

According to Dietrich (2006), various specializations of DSS have been developed and have resulted in a multitude of acronyms due to different designs and applications of DSS, as shown in Table 17.1. Further information on the stated system types can also be found in Sauter (1997), Marakas (1999) and Malczewski (1999).

Combinations of the types are obviously also possible. The parentheses indicate that further DSS-subtypes are possible. According to Evers (2008) DSS can be classified into four different levels: a technical level, a management level, a decision-making level and an architectural level. Examples and further notes on each level are given below, in Table 17.2.

Table 17.1 Types of DSS (Dietrich 2006), extended by the authors

Acronym	Description	Notes
DSS	Decision Support System	Generic term for any DSS
GDSS	Group Decision Support System	Decisions in IWRM are not taken by a single person but by groups of decision makers with frequently controversial positions
SDSS	Spatial Decision Support System	IWRM per se are regional, spatially-related tasks; that is why GIS often play a strong role in DSS for IWRM
ADSS	Adaptive Decision Support System	DSS are frequently not only used once, but adapted to changing boundary conditions, socio-economic and environmental development
MDSS	Multi-criteria Decision Support System	DSS with multi-criteria optimization

Table 17.2 Characterization of DSS in different levels (after Evers 2008)

DSS level (Evers 2008)	Examples	Notes
Technical level	Data-driven, model-driven, optimization-driven DSS	The most advanced technical level combines all three
Management level	Planning/policy support systems and management oriented DSS (Geertman and Stillwell 2009)	Planning/policy support systems are long-term/strategic, have broad societal content and focus on simulation and exploration. Management-oriented DSS are short-term/immediate, have a specialized sectoral context and are optimization oriented
Decision-making level	Passive, active and cooperative DSS (Hättenschwiler 1999)	Active DSS result in the formulation of concrete proposed decisions. A cooperative DSS enables a step-by-step improvement of decision alternatives through both the decision-maker or decision-consultant and also through the system within an interactive process. Passive DSS aid the decision-making process but cannot give concrete solutions
Architectural level	(a) Hahn and Engelen (2000): User interface, data base, tool base, model base; (b) Power (2002): Communication-driven, knowledge-driven, data-driven, document-driven and model-driven DSS	The architectural level comprises fundamental components of a DSS; (a) this is a simplified but common structure of many DSS from the software technical point of view; (b) here the focus is different, the dominant system component or the application and desired functionalities are taken as the criterion

In this publication an approach for the systematization of DSS in IWRM is derived in consideration of fundamental system components and their application (according to Power 2002, see below; section “Classification of Decision Support Systems”).

In the past DSS was implemented on main-frame computers, later on workstations and PCs. These days DSS are increasingly accessible via the internet. This opens up the possibility of broader access to DSS for everyone from experts, to the public. The latter results in higher demands for user-friendliness, easiness of use and transparency in DSS-handling. In addition to classical DSS, as characterized above, formal Decision Support methods are also important. Included here for example, are structuring of the decision-making process that is adapted to both the problem and regional conditions, as well as monitoring of the decision-making process through specialist counselling and a wide range of participative measures during the decision-making process (Gregory and Keeney 2002; Klauer et al. 2012). Depending on the degree of computerization those methods and tools might also be called DSS.

The use of computer-based DSS has various advantages for decision-makers, such as improved efficiency, effectiveness, transparency, robustness, more reliable decisions or speed in decision support. DSS may lead to better (compromise) solutions where solution-finding happens with less effort. The chosen decision can be presented to third parties in a more extensive, illustrative and thus more convincing way. Decision Support therefore leads to more rational, robust and reproducible decisions. This means that, assuming the preferences and decision environment were the same, similar decision alternatives would be recommended every time.

Formal or computer-supported DSS address decision-making problems that the decision-maker finds too difficult, work-intensive or complicated. Decision-making in the context of IWRM always has something to do with evaluation, selection and preference behaviour. Human skills often exceed the abilities of the implemented DSS in this regard. Human beings are not dependent on computers whereas, computers do rely on human beings. Today many decisions depend on computers to a large extent (not necessarily on DSS). DSS can make the decision process faster, more efficient and more transparent, as mentioned above, but DSS should not attempt to automate decision making. Human ("decision makers") interaction with the DSS is crucial in order to consider preferences, expert knowledge etc. According to Mysiak et al. (2005) a successful DSS depends on the early involvement of future DSS users and a user-friendly intuitive interface.

17.2 Decision Support in the Funding Priority IWRM

A survey on Decision Support was carried out across the 13 IWRM research projects, and the results were analysed in order to illustrate the cross-cutting issue "Decision Support". Table 17.3 shows the surveyed projects and the partner countries involved. The questionnaire comprised the following range of topics:

- Characterisation of the problem and task
- General aspects of Decision Support
- Decision Support Systems
- Participation in Decision Support and
- Challenges to Decision Support in the implementation of project results

Decision Support was characterized based on this analysis. For the systematization it was determined which core functions are supported in practice within the decision process (Fig. 17.3), which in turn allowed the assignment of the particular method to the decision-making process.

The majority of the IWRM projects (n = 10) carries out the IWRM investigations in river basins, whereby pilot studies are carried out in representative subareas. Only the AKIZ project is limited on the local level due to planning issues.

Table 17.3 Projects from within the BMBF funding priority on IWRM

Project	Partner countries
Water-related information system for the sustainable development of the Mekong Delta (WISDOM)	Vietnam
Sustainable water resources management in the coastal area of Shandong Province (SHANDONG)	China
Sustainable water and agricultural land use in the Guanting watershed under limited water resources (GUANTING)	China
Economic and ecological land and water use in Khorezm in Uzbekistan. A pilot project in development research	Usbekistan
Integrated water resources management in Gunung Kidul, Java (GUNUNG)	Indonesia
Integrated water resources management in central northern Namibia—Cuvelai-Etosha Basin (CUVEWATERS)	Namibia
Integrated water resources management in Central Asia—model region Mongolia (MOMO)	Mongolia
Integrated water resources management in Vietnam (IWRM VIETNAM)	Vietnam
Integrated waste water concept for industrial zones exemplified by the Tra Noc industrial zone (AKIZ)	Vietnam
IWRM pilot project "Middle Olifants" in south Africa with technology transfer through a franchise concept	South Africa
IWRM in the Lower Jordan Valley—sustainable management of the available water resources with innovative technologies (SMART)	Palestine, Israel, Jordan
Development and implementation of a scientific based management system for non-point source pollution control in the Miyun basin near Beijing	China
Integrated water resources management in Isfahan	Iran

The joint projects support decisions for different areas of IWRM depending on the particular water resources management problems addressed. Figure 17.2 shows the different focuses of the projects. The majority of Decision Support is related to the expansion of water infrastructure and the implementation of new technological solutions for increasing water supply. A number of these projects link the planning tasks with questions of management, or the operation of water management systems; for example, the intermediate storage or allocation of water. The expansion of wastewater treatment is often a fundamental aspect in the improvement of water quality and sanitation. Water supply during water scarcity and dealing with conflicts of interest on water use are preferential tasks (e.g. SMART). Decision Support also concentrates on land-use, for example with measures for groundwater management (e.g. implementation of artificial recharge facilities, SHANDONG), irrigation and flood control. An essential aspect of water supply management is the minimization of leaks in water pipe systems (e.g. GUNUNG and MOMO). Approximately half of the projects also integrate climate change scenarios in the DSS in order to take possible future changes in precipitation, water availability and the effects of extreme weather events into account.

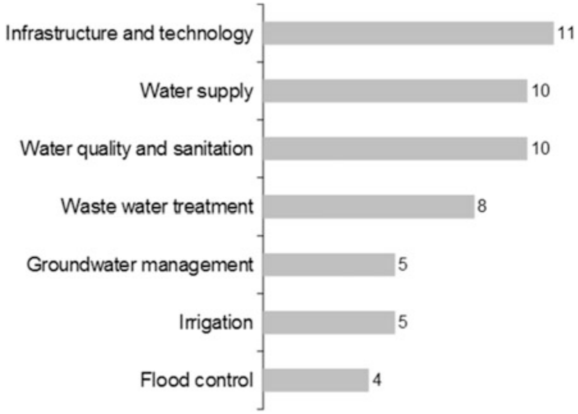

Fig. 17.2 The numbers of research projects addressing IWRM topics. *Source* Decision Support survey within the IWRM funding priority (n = 13)

17.2.1 Core Functions and Requirements of Decision Support Systems

Hättenschwiler and Gachet (2000) defined core functions of Decision Support as shown in Fig. 17.3. In this publication a (computer-based) decision tool, knowledge platform, mathematical model or (geographical) information system is defined as DSS as soon as it supports at least one of the listed core functions directly or indirectly. The IWRM projects have been analysed with regards to how far they correspond to these functions.

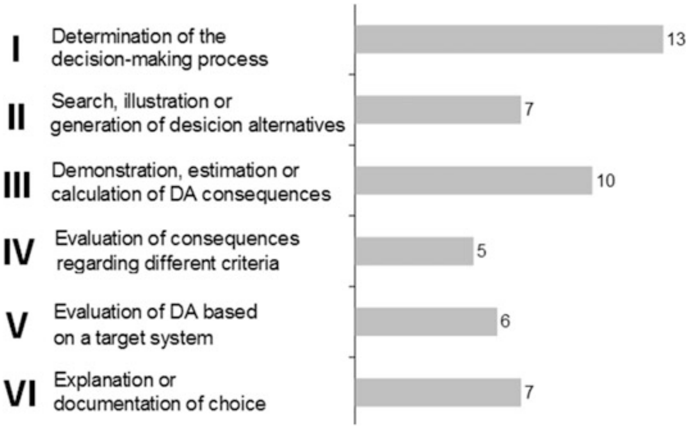

Fig. 17.3 Core functions of Decision Support and the number of IWRM projects (n = 13) realizing these functions (modified after Hättenschwiler and Gachet 2000)

The experiences from the IWRM projects on the functions of DSS can be summarized as follows:

I. Determination of the decision-making process

The decision situation can be determined by an information system for example, which collects decision-relevant data, assumptions, restrictions, tasks, targets or guidelines (from decision-makers). Decision-relevant data can be illustrated with information systems, analysed and presented in a structured form. All of the IWRM projects therefore rely on information systems, mostly some kind of geographical information system (GIS). The WISDOM and IWRM VIETNAM projects are two examples for broad decision support based on GIS.

II. Search, illustration or generation of decision alternatives

Decision alternatives (DA) frequently evolve from combinations of specific measures. The evaluation of consequences from the possible implementation of single decision alternatives includes the selection of special socio-economic and ecological decision criteria that best express essential IWRM development targets. Approximately half of the projects offer computer-based decision support for the selection, search or generation of specific (water management) measures (core function II). These include, for example, the planning of facilities for controlled groundwater recharge (SMART-project), waste water treatment (GUNUNG-project) or rainwater harvesting (CUVEWATERS-project). This also applies to the planning of measures for land-use and irrigation agriculture (Uzbekistan). A wide variety of measures from water saving to land-use planning is analysed e.g. in the GUANTING-project (Wechsung et al. 2014). From a methodological point of view the multi-level approach used for scenario selection (Fig. 17.4), which is implemented e.g. in the SHANDONG-project (Kaden and Geiger 2013), is interesting: The advantage of this stepwise system is that in the beginning of the planning process, when only coarse data are available for the multitude of aspects, potential

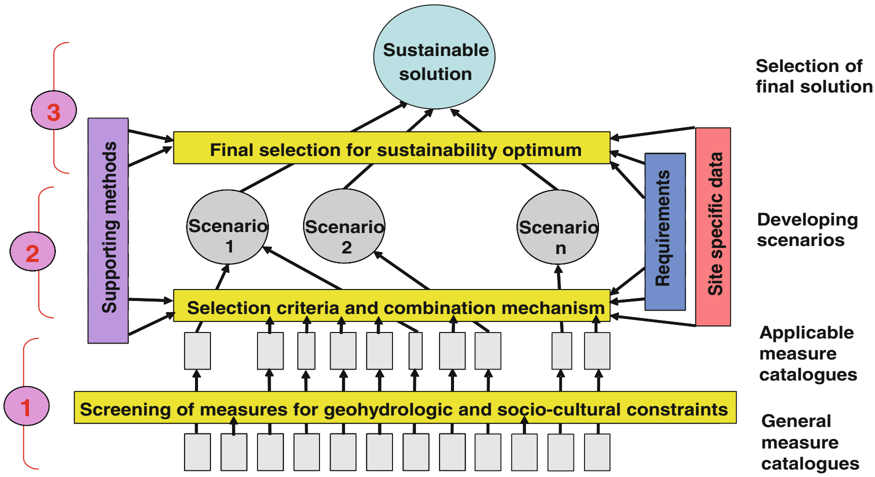

Fig. 17.4 IWRM—system for achieving sustainable water management (Geiger 2011, simplified)

actions can be screened roughly for their success and linked to potential solutions. DSS Stage 1 is designed to be gradually improved whenever more detailed information becomes available. It forms the basis for DSS Stage 2. There, preselected alternatives need to be studied in more detail. In the last stage the final solution is developed and analysed.

III. Demonstration, estimation or calculation of DA consequences

A majority of 10 projects demonstrated, estimated or calculated consequences of decision alternatives but only three of those did so by using computer-based systems which can be used to support the development of IWRM strategies as combined (water management) measures. Highlighted here are the DSS used in the previously-mentioned SHANDONG-project, the GUANTING-project and the MOMO-project toolbox.

IV. Evaluation of the consequences regarding different criteria

Five of the 13 projects used computer-based Decision Support in order to evaluate the consequences of different criteria.

V. Evaluation of DA based on a target system

Roughly half of the IWRM projects have implemented mathematical models in order to investigate the consequences of the possible implementation of decision alternatives, and for the evaluation of alternatives based on a target system (see below, section "Classification of Decision Support Systems")

VI. Explanation or documentation of choice

Explanation or documentation of the decision process or suggested decisions has been a core function of Decision Support in about half of the IWRM projects.

17.2.2 Classification of Decision Support Systems

To facilitate decision-making, Decision Support has been implemented by all research projects of the IWRM funding priority. Depending on the specific management activities, decision processes and decision-makers in IWRM, different types of Decision Support were implemented. In order to systematize these different types, a distinction is made between complex, integrative DSS on the one hand, and systems named after their main component on the other; either as a knowledge platform, (geographical) information system, decision tool or mathematical model. These components were either applied separately and independently (as stand-alone tools) in the IWRM projects, or combined with other components.

17.2.2.1 Knowledge Platform

In the IWRM projects knowledge platforms are mostly web-based and strengthen participation in the decision process, communication between stakeholders and public relations. The implementation of such systems therefore increases the probability of successful implementation of the developed IWRM strategies

(Pinheiro and Böhl 2007). The aim is to determine and structure decision-making relevant information, similar to the (geographical) information systems. These systems can also be integrated with (web-based) decision tools and contribute to the explanation of the selected decision. Therefore, decision support can be extended to all core functions apart from core function III (estimation or calculation of the consequences of decision alternatives). This is due to the fact that coupling with mathematical models has proven difficult.

17.2.2.2 Geographical Information Systems

In IWRM data-based information systems usually command a geographical platform for the illustration and analysis of spatial information and can be integrated in DSS. Georeferencing the data used is of decisive importance for GIS and this is what differentiates GIS from Knowledge Platforms. Commercial software, for example ArcGIS (ESRI Inc.), Oracle or open source software (e.g. GRASS GIS, SAGA GIS, Quantum GIS) can be used for development. These systems can also be seen as DSS, as long as they can be specifically applied to Decision Support or they fulfil at least one core function. Frequently, these systems concentrate on the determination and structuring of decision-making relevant information and thus support core function I (see Fig. 17.3) (Renaud and Künzer 2012). GIS are commonly coupled with specific decision tools or mathematical models. Decision Support can thus be extended to core function II, III and V; an example being the determination and comparison of alternative locations for the implementation of controlled groundwater recharge using GIS-based spatial analysis (Rahman et al. 2012). Different system components can be incorporated into a DSS. For example, the web-based information system used in the WISDOM project comprises system components such as data, logic and presentation tier in order to deal with environmental monitoring, water management, demographics, economy, information technology, and infrastructural systems (Gebhardt et al. 2010).

17.2.2.3 Stand-Alone Tools

Stand-alone tools are decision tools which can be applied for Decision Support independent of a main system. Further, those tools can be integrated in a “Tool Base” of integrated DSS as shown in Fig. 17.4. They are often based on Operations Research methods, particularly multi-criteria analysis, and can be used for the determination, evaluation and selection of decision alternatives and for explanation of the decision choice (core functions II, IV, V and VI). Multi-criteria analysis methods enable the comparative assessment of decision alternatives in different socio-economic and ecological situations, and with opposing preferences, as well determining compromise solutions. These processes are therefore of utmost importance for integrated water management. These include the analytical-hierarchy-process (AHP) according to Saaty (2008), the Fuzzy-process (Liu 2008), ELECTRE, PROMETHEE (cf. Klauer et al. 2006), Goal Programming, Compromise Programming and others. Hajkowicz and Collins (2007) and Zarghami and Szidarovszky (2011) address the possible applications of the different processes and discuss the selection, quantification and weighting of decision-making criteria in this context.

17.2.2.4 Mathematical Models

Mathematical models are mainly used in DSS for determining the consequences of decision alternatives. These include simulation models, which can be used to illustrate components of the water cycle but also water management models such as WBalMo (Kaden and Kaltofen 2004). The simulation model MONERIS, for example, makes the simulation of discharges, retention and loads in river systems possible (Venohr et al. 2008). Statistical processes and climate models also belong to this group. They can be used to determine the influence of development scenarios, particularly socio-economics and climate change, on relevant factors for water management or to foresight actions (Werner and Gerstengarbe 1997). Various water allocation and user-behaviour scenarios can be simulated and analysed in the Middle Olifant project using the "Water Evaluation and Planning" system (WEAP) (Lévite et al. 2003).

Finally, all mathematical models that enable the assessment of socio-economic or ecological criteria for decision alternatives (core function IV) belong to this group. Other examples are tools used for cost-benefit analysis or for the determination of economic indicators (Hellegers et al. 2010).

17.2.2.5 Complex DSS

The DSS is often seen as a complex system composed of several components and supported by a number of core functions. Figure 17.5 shows the basic components of a complex, integrative decision support system. A complex DDS integrates a database system with mathematical models and specific decision tools. A graphic user interface supports interaction with the system user. Professionals or decision-making consultants can thus communicate directly with decision makers on this basis. MULINO-DSS (Giupponi et al. 2004) and Elbe DSS (Kok et al. 2009) are examples of complex, integrative DSS in the context of IWRM.

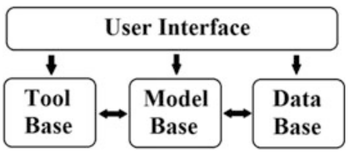

Fig. 17.5 Basic components of a complex, integrative DSS in IWRM (Hahn and Engelen 2000)

17.2.2.6 Variety of Decision Support in IWRM Projects

The distribution of different types of DSS in IWRM projects is shown in Fig. 17.6. A complex, integrative DSS has only been developed for the IWRM project China (SHANDONG). The system enabled the generation, assessment and selection of alternative IWRM strategies as a combination of measures. Other projects focus on the application and development of computer-based systems, classified according to their main component as geographical information systems, knowledge platforms and decision tools or as models. In addition to decision tools used for the assessment of decision alternatives, GIS-based tools are also used, e.g. for water allocation. Apart from GIS, mathematical models and model systems have been often implemented. Models using a GIS interface are also used, for example to illustrate hydro (geo)logical processes and not spatial systems, e.g. to generate and analyse development scenarios. For example the Khorezm project combines hydro(geo)logical field-level modelling and GIS approaches in order to improve groundwater recharge estimation (Awan et al. 2013). The majority of decision tools which are components of an integrated DSS are stand-alone tools and can also be used independently. Some of these tools analyse the current situation and support the decision process until a defined target has been reached e.g. thresholds for water quality standards (Stärz 2012) in the IWRM VIETNAM-project. DSS are often web-based in order to improve access to the system, increase participation and the distribution of tools. Several projects (n = 5) apply formal Decision Support in order to structure the decision-making process. Only three projects (SMART, Khorezm Uzbekistan and GUANTING) applied standards for the implementation of decision processes. For instance, the GUANTING project implemented the so-called Integrative Methodological Approach. It is characterized by the following steps: (a) scenarios: compilation of a catalogue of so-called developmental scenarios, which combine frames of development, including a set of global change scenarios on climate, demographic, economic, and societal developments, and possible policy actions at the regional scale (land use, policy etc.), (b) indicators and criteria: identification of context-relevant indicators and corresponding criteria for the evaluation of different developmental scenarios, (c) impact analysis: analysis of the scenario impacts with respect to the selected indicators and criteria, using all available data, models as well

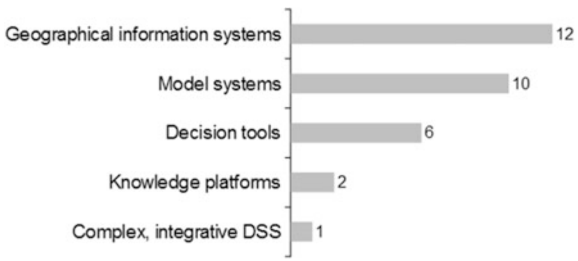

Fig. 17.6 Number of projects using different types of DSS in IWRM (n = 13)

as expert and literature knowledge, and (d) evaluation: multi criteria analysis and equity analysis to assess the results, and especially the policy strategies, in face of current policy objectives and actor preferences (see Wechsung et al. 2014).

Most of the developed DSS are designed by the IWRM projects in that way to be transferable to problems in different regions.

17.2.3 Obstacles of Implementation of DSS

During the implementation of DSS within the projects, a number of drawbacks occurred (Fig. 17.7). Across all projects long-term, bilateral cooperation is considered to be essential for project success. Furthermore, intensive training is regarded crucial by most projects for the sustainable implementation of Decision Support. This is necessary in order to prepare specialists and advisers for decisions on site and the efficient use of the developed systems, and in order to implement the decision process transparently. Staff turnover amongst the project partners, acceptance as well as language barriers also constitute further obstacles in the use of DSS.

17.3 Discussion

Decision Support has been implemented very differently within the IWRM projects. According to the results of the survey, Decision Support must be individually planned for each river basin depending on the legal background, water management objectives, spatial and temporal framework conditions, and social, ecological and economic aspects. Successful Decision Support is achieved through concerted and interdisciplinary cooperation between relevant stakeholders on all levels. Intensive exchange on the expert and decision-making level is particularly important in order to formulate highly acceptable corporate compromise solutions for challenges

Fig. 17.7 Problems arising during IWRM projects with regards to the implementation of Decision Support (n = 13)

arising from mostly opposing interests (Fig. 17.7). This implies participation and communication between all stakeholders in all phases of the decision-making process (see also Kok et al. 2009). In this context, Volk et al. (2010) propose an improved methodological stakeholder involvement through an iterative development process that enables social learning of the different groups that are involved in the decision-making process.

Kok et al. (2009) postulated: "Most DSS developments in environmental issues […] are science-driven rather than user-driven, which means that the design is based on models and data addressing specific scientific problems, instead of real-world issues from a potential users' perspective." It may hold true in many cases that the DSS in IWRM described in this paper neglected the user perspective to a certain extent, but we disagree with the statement that those DSS are solely driven by scientific problems. Obviously there are many "scientific DSS" described in the literature that have not found their way from case study application to practical implementation (e.g. Gallego-Ayala 2013). But there is indeed a second commercial DSS world, which is in turn not extensively documented in scientific publications, but can be traced in the internet (e.g. www.bgr.bund.de or www.dhigroup.com).

However, it is beyond doubt that Decision Support Systems are helpful tools in IWRM. In this context, crucial questions are: do the DSS meet the requirements of real-world decision problems, are those available in-time for decision making and are the DSS successfully implemented? The success of DSS in practice depends above all from: the client, the developer, the software, the maintenance and the operation of the DSS. In this section the influence of these factors will be discussed in more detail. The major intention of this paper was to describe and evaluate the development of DSS for IWRM within the research projects of the named BMBF funding priority. Here, this topic will be moved beyond that scope and real-world water-related DSS will be discussed in general.

The client/the user

Both, client and user (if different from client) can be single institutions or groups of institutions. For complex DSS in large study areas the identification of clients and users is difficult. Mostly the different members of the groups have different functions, responsibilities and objectives. This makes the development and implementation of complex DSS rather difficult. In case of third party funded Research and Development projects there is not a real client (who pays). There is (or should be) a user (-group). For any type of DSS in IWRM it is important that there are continues problems to be solved and according to that long-lasting interest of the client/the user applying the DSS. The problems encountered during the design of a DSS as well as its (institutional) implementation by the users have led to scepticism regarding the usefulness of these tools (de Kok et al. 2009). Although some time has gone by since then, this scepticism still exists.

The problems addressed in the DSS

DSS are implemented for certain study areas. The range is from small catchments up to international river basins. According to Global Water Partnership (2012) "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." If possible a DSS should indeed address the three "pillars" of sustainability, economy, society and environment. However, more decisive than such abstract claims should be that the DSS meets the objectives of the client/user and that it reflects the conditions and the structure of the decision making problem. In order to guarantee a proper representation of the decision problem by the DSS the participation of the client/the user from the region under study is crucial. Otherwise the DSS may be of scientific but low practical value.

The developer
The developers are typically teams from Research and Development institutes or commercial IT companies. Only in rare cases the clients/users themselves work as developers. In case of DSS developed in funded Research and Development projects, the developer is in most cases a group from different institutions with a leading institution. The more development partners are involved the more difficult the development process is. Also the integration of clients/users in the development process gets more difficult. Additionally, the partners frequently come from different scientific disciplines with different languages which might be fruitful and even necessary in order to tackle the problems at hand but creates additionally communication problems.

The software
In Sect. 17.2.2 different types of decision support have been described, from knowledge based systems to complex DSS. Consequently different software is used, from single software (models) and toolboxes up to complex software systems. In many cases the components rely on certain basic software (as DBMS, GIS and different programming languages). This may result in design problems of interfaces between modules. The advantage of toolboxes is that components of the DSS can be used separately for specific tasks and users.

The data
The data of the DSS should be as far as possible complete and up-to-date to the problems to be solved. As already discussed in previous sections the data scarcity is the main challenge for the development of a successful DSS. For a continuous DSS application, the data need to be up-dated in the DSS on a regular basis (see below maintenance).

The maintenance
The maintenance of a DSS has two aspects: maintenance of the software and of data. It needs to be clarified who is responsible for that and who bears the costs. Maintenance of basic software relates to the maintenance of the software tools, in case the tools depend on basic software (as e.g. GIS software). With new releases of basic software usually the tools that are based on it have to be (re-)adopted. Maintenance is especially complicated if the development was financed by research funds because of the high fluctuation of the developers at research institutes and the discontinuity of the funds.

The operation
In general the user or a third party assigned by the user should operate the DSS. Again the question arises: who pays? With the complexity of the DSS and consequently the diversity of users in a user group this becomes even more difficult. A basic presumption for successful operation is the training of operators by the developers of DSS.

17.4 Conclusions

The success of DSS depends on many factors. Hättenschwiler and Gachet (2000) summarize the basic requirements for computer-based DSS, by emphasizing user-friendliness, performance, integration and data interfaces which enable future system expansions. In IWRM, only those systems which have a clear client/user, real-word and continuous problem contents, durable software concepts and stable data basis, guaranteed long-term operation and maintenance will be successfully implemented and sustainably used. In this respect, the development of complex, completely integrative DSS is not always strictly necessary, and often not even possible due to complexity, the unavailability of resources and time constraints. There is a tendency that more complex decision problems favour more complex DSS. With increasing complexity of the DSS software in turn design problems, problems of data availability and above all long-term system maintenance increase. In most cases developer and operator of the DSS will be different—it is not the task of the research community to operate DSS for practice beyond the research projects. Next to central DSS, the application of stand-alone tools can indeed make sense in decision-making and is common practice. Advantages of this are the targeted implementation of individual systems for specific IWRM problems, reduced training expense, easier transferability and applicability to similar problems in different regions, reduced development expenses and accelerated deployment.

Independent of the kind of DSS, participation was deemed crucial in all phases of the decision processes supported in the IWRM projects. To assist this, web-based systems improve the acceptance of stakeholders directly involved in the decision-making process. Easy access to decision-relevant information and systems improves participation and increases understanding of the methodical approach. This is particularly true for geographical information systems, knowledge platforms and decision tools. Similar to this, Volk et al. (2010) mentioned that data availability needs to be improved to allow more efficient development and use of DSS. Moreover the authors suggest an improvement of scaling issues, model integration, calibration, validation and uncertainty analysis.

For all BMBF joint projects, long term cooperation is deemed essential. A decrease in staff turnover, improved training measures and the prevention of language barriers could be the key to a higher acceptance, and thus lead to successful long term cooperation. As problems with acceptance often occur in the initial phases, long-term projects should make sure to establish confidence between network partners. Regarding the avoidance of language barriers, the extensive documentation of DSS published as a handbook in local languages and the usage of those by individuals on the ground could be taken into consideration. An advantage that comes along with this is the decrease of time between effective workflows due to staff turnover. To achieve long lasting collaboration, Kok et al. (2009) suggest that project budgets should allow for maintenance of the DSS and keep users involved in its further development.

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Part VIII
Integrated Land and Water Resources Management

Chapter 18
The Use of Treated Wastewater for Irrigation as a Component of Integrated Water Resources Management: Reducing Environmental Implications on Soil and Groundwater by Evaluating Site-Specific Soil Sensitivities

Karsten Schacht, Yona Chen, Jorge Tarchitzky and Bernd Marschner

Abstract The use of non-conventional water resources like treated wastewater (TWW) is a contribution to alleviate the pressure on available natural water resources in water scarce regions, as it allows higher quality water to be available for other purposes. Population growth, improved living standards and expected climate change impacts will raise the importance of water reuse progressively. TWW can be utilized for various purposes, such as for irrigation, conservation, groundwater recharge or domestic and industrial use. In the eastern Mediterranean region, irrigation with water of marginal quality has a long history, with Israel being the promoting pioneer in advanced treated wastewater use policy and technology. However, apart from health and crop quality concerns, there are potential adverse effects of TWW application on soil and groundwater quality to be considered. In aiming to avoid unsustainable exposures, the regional risks related with TWW irrigation have to be specified and differentiated according to regional soil properties. Within the multinational joint research project network GLOWA (Global Change and the Hydrological Cycle) Jordan River, a regional based land evaluation

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was conducted for the area of Israel, Jordan and the Palestinian Authority by combining supraregional spatial soil data using a geographic information system (GIS). These data were used to identify land more or less sensitive towards TWW irrigation and for the implementation in regional decision support systems (DSS) related to water allocation and the extension of irrigation infrastructure.

Keywords IWRM · Decision support system · Treated wastewater use · Irrigation · Soil sensitivity evaluation · Israel

18.1 Introduction

Populated arid and semi-arid regions of the world are facing considerable water stress. Climate change is expected to have associated shifts of precipitation and temperature patterns that will increase the pressure on natural water resources. Moreover, population growth and enhanced living standards are raising the domestic water demand, accompanied by an increase in wastewater volumes. This development may lead to overexploitation and decline of natural water resources in water scarce regions. Thus, the use of formerly non-conventional water resources like TWW is becoming an essential method to equilibrate the water balance. In the process of Integrated Water Resources Management (IWRM), where all available water resources have to be covered, TWW is a significant and reliable water resource to be used for various purposes, especially in arid regions (Friedler 2001; Bouwer 2003). Hence, practicing treated wastewater use allows a more sustainable management of the water resources, particularly regarding the demand for irrigation water in agriculture. This would allow reserving higher quality water for domestic purposes.

In the course of its primary use, freshwater (FW) normally becomes contaminated to some degree, depending on the type of use. Municipal and industrial effluents are usually enriched with organic matter and other compounds. These can be inorganic substances like salts, macronutrients or trace elements as well as pathogenic microorganisms and organic micro pollutants (Feigin et al. 1991). While conventional secondary and tertiary treatment processes can decrease or even eliminate organic and nutrient components, the quality of TWW is still poorer than that of FW, because of higher concentration of dissolved salts that is unaffected by conventional wastewater treatment processes. Land application of TWW, including agricultural irrigation, thus implies certain potential risks for the environment.

From 2001 to 2011, the research subgroup "Green water management" within the multinational joint research project network GLOWA Jordan River has worked on the analysis of soil units and soil properties in large parts of the Jordan River catchment and adjacent areas, with the aim to develop a data base for conducting a regional based land evaluation for TWW use. The goals of our study were (1) to identify and define significant agricultural and environmental risks in collaboration with regional experts; (2) to provide sensitivity maps (low, moderate, and high sensitivity) for each of the identified risk categories; and (3) to aggregate these maps into a total sensitivity map displaying the total sensitivity of soil and groundwater towards agricultural TWW use. The results were published in an open access journal, including GIS-readable supplements (Schacht et al. 2011). Furthermore, the resulting maps are displayed online and publically available in the GLOWA Jordan River atlas (Claus et al. 2013).

This article describes, focusing on Israel, the potential environmental impacts of TWW irrigation on soil and groundwater and explains the development and methodology of a spatial database identifying suitable sensitive areas towards the agricultural reuse of TWW as a potential component of decision support systems (DSS) in water management. Its simple functional principle could be transferred to any other region of interest, when taking the specific regional risks and soil conditions into account.

18.2 TWW Reclamation and Use for Irrigation in Israel and Ecological Implications

Many Mediterranean countries have a long tradition and great breadth of experience with TWW use. A comprehensive overview about the current status and policies of water reuse for the Middle East and North African region is given by Qadir et al. (2010) and Guardiola-Claramonte et al. (2012). Fostered by a process of integrated water resources management already established in Israel's state policy more than 50 years ago, Israel became a pioneer in the development of TWW use practices (Angelakis et al. 1999; Fischhendler and Heikkila 2010; Guardiola-Claramonte et al. 2012). While other countries often were not consistent in the implementation of water reclamation, Israel promoted the issue of wastewater reclamation and use progressively, which resulted in almost complete collection, treatment and use rates (Shelef 1991; Kfouri et al. 2009). As a result, the Israeli water management system is often cited as a model for other countries (Fischhendler 2008; Fischhendler and Heikkila 2010; Futran 2013) (Fig. 18.1).

With total reuse rates >75 % (Scheierling et al. 2010; Brenner 2012); Israel is a world leader in TWW use for agricultural irrigation (Hamilton et al. 2007). According to the Israeli Water Authority (2014), 35.4 % of Israel's total FW consumption of 1212.7 hm^3 in 2012 was used for agricultural purposes and 57.2 % for domestic purposes. Within the total agricultural water consumption for Israel in 2012 (1085.6 hm^3), TWW makes up 39.6 % and thus equals the FW proportion. Additional water resources for irrigation were brackish water (15.7 %) and flood water (5.2 %). Israeli national policy aims for even higher TWW use rates and calls for further gradual replacement of FW in irrigated agriculture. Beginning in the 1970s, improved standards and regulations for TWW reuse in irrigation were discussed and have been enforced (Lawhon and Schwartz 2006; Inbar 2007; Juanicó 2008; Provizor 2009). Thus, the wastewater treatment facilities were continuously improved to meet the upgraded standards (Aharoni and Cikurel 2006). It is

Fig. 18.1 Wastewater irrigated orchard in Israel

expected that almost all municipal wastewater will be treated and reused, mainly for agricultural irrigation and groundwater recharge, by 2020 (Brenner 2012). Consequently, wastewater reclamation and use will continue to be a mainstay in Israel's water management strategy involving non-conventional resources, beside further initiatives regarding water desalination and water harvesting (Tal 2006).

The quality of the TWW depends on its original water source, the "pick-up" during usage, the treatment technology and its after treatment dilution. Therefore, TWW contains higher concentrations of nutrients and soluble salts (e.g. Ca, Mg, N, Na, K and P), organic substances and inorganic and organic pollutants compared to FW (Feigin et al. 1991; Chen et al. 2011; Iannelli and Giraldi 2011). While the nutritional value might be beneficial for crop growth, TWW irrigation was consequently found to have various side effects on the environment, like enhanced levels of soil salinity, sodicity and nitrate leaching to the groundwater (Bond 1998; Jalali et al. 2008). Moreover, it has been shown to be associated with other potential detrimental effects on the chemical quality of the soil, e.g. related to contaminations with boron, chloride, heavy metals, trace organics, changing soil organic carbon regimes, or on soil physical properties, such as reduced hydraulic conductivity or changed wetting behavior and patterns (Levy et al. 2011). Anthropogenic contaminants are a matter of growing concern (Fatta-Kassinos et al. 2011), particularly those which are not or only partially degraded in the treatment process. These substances comprise residues of pharmaceuticals, hormones, pesticides and surfactants, which find their way into water bodies due to TWW irrigation or regular discharge (Cordy et al. 2004; Toze 2006). If such compounds are not eliminated by drinking water processing or are adsorbed to irrigated crops, they can be ingested by organisms and potentially lead to adverse effects on human and animal health, including disruptions of endocrine regulation (Bouwer 2000; Falconer et al. 2006; Toze 2006; Graber and Gerstl 2011; Shenker et al. 2011). In order to ensure an unrestricted use of reclaimed water, future water management concepts should address this issue, by either reducing the contaminants at their source or by upgrading wastewater treatment processes to remove the contaminants from the wastewater before its use (Zoller 2006; Futran 2013).

Comprehensive overviews about wastewater reclamation, use and the benefits, risks and implications of TWW irrigation are given in the publications by Feigin et al. (1991), Lazarova and Bahri (2005) and Levy et al. (2011).

18.3 Soil Sensitivity Assessment for TWW Irrigation

As there are possibilities for spatially adapted planning of the development of water treatment and irrigation infrastructure, it is of interest to determine if there are areas of spatial preference regarding the possible adverse effects of TWW irrigation. Soils are heterogeneous; their physical and chemical properties are not homogeneously structured and they are spatially very variable. Thus, their effective sensitivities regarding different potential risks related to TWW irrigation are differentiated regionally. With this in mind, the idea and aim of the research subgroup "Green water management" within the multinational joint research project network GLOWA Jordan River was to create a regional database for the project area to be able to evaluate site-specific soil suitabilities for TWW irrigation. This information is valuable for a DSS regarding the allocation of TWW resources for agricultural purposes. Several issues had to be solved: (1) to define the major agricultural risks associated with TWW in the region, (2) to acquire regional information about soils and soil properties, (3) to find criteria in terms of the risks based on soil properties and to develop methods to review the criteria for the respective soil sensitivity definition, (4) to weigh the particular sensitivities in order to calculate the total sensitivity and finally (5) to display and distribute the results. This process and its results were documented in detail by Schacht et al. (2011).

18.3.1 Risk Definition

The most current and relevant soil-related risks associated with TWW irrigation were discussed in collaboration with regional experts. The six risks defined were:

(A) Mobilization of inorganic adsorbable pollutants, e.g. of heavy metals
(B) Slaking of the upper soil layer, causing reduced infiltration capacities and higher runoff rates

(C) Soil salinization in the vadose zone as a consequence of the contamination with soluble salts, affecting e.g. soil hydraulic properties and soil fertility
(D) Mobilization of boron, potentially leading to decreased crop health
(E) Groundwater pollution by inorganic non-adsorbable pollutants, e.g. nitrate and chloride
(F) Development of hydrophobicity, impairing water use efficiency.

18.3.2 Spatial Data and Soil Properties

The spatial information about the distribution of soils was gathered from three different sources: the Soil Association Map of Israel (Dan et al. 1972; covering Israel and the Palestinian Authority), the Jordan River Soil Map (Karablieh E and Al-Bakri J, personal communication; covering the Jordanian Jordan River valley area) and the Harmonized World Soil Database (FAO et al. 2009) for the remainder of the project area (Fig. 18.2). The particular soil properties information, classified for two depths (0–30 cm and >30 cm), was extracted from these sources, matched with recent field survey data or gathered by a thorough literature study and comprehensive expert interviews. The maps were processed and aligned using GIS (ESRI ArcGIS 9.3). Recorded soil properties were, e.g., soil texture, organic matter

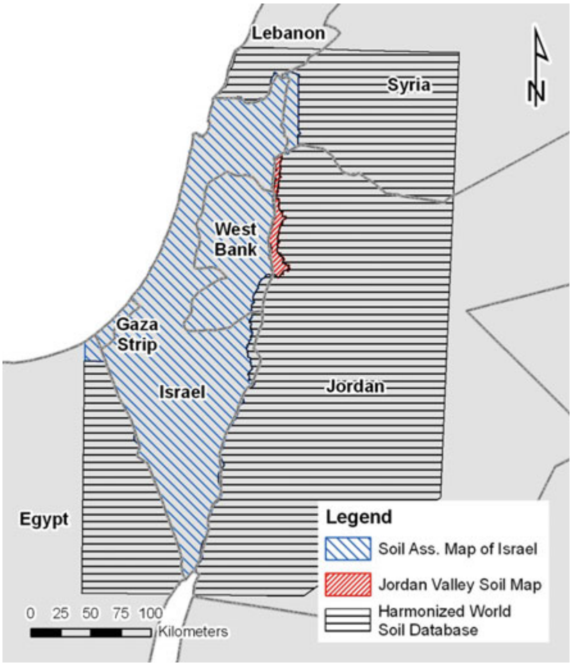

Fig. 18.2 Coverage and particular sources of the soil information for the soil sensitivity evaluation

content, bulk density and pH. From these, additional parameters were derived, e.g. field capacity, effective rooting depth and hydraulic conductivity. Supported by the GLOWA Jordan River working group "Climate and Hydrology", leaching rate data based on a 1 km × 1 km grid was integrated. Finally, data displaying the hydrogeological sensitivity for wastewater irrigation in Israel was provided by the Israeli Hydrological Service, Jerusalem, for the extent of Israel and the Palestinian Authority and added to the database.

18.3.3 Criteria and Methods for Evaluation

The criteria to be evaluated for the soil sensitivity assessment had to fit to the available soil properties dataset. The main processes related with each single agricultural risk were defined and broken down matching these properties and associated parameters. Methods for determining the criteria related to the soil property information were found or newly developed. By this, for instance, it was possible to define buffering capacities for inorganic pollutants (cadmium, boron) and to assign the results from the assessment to different sensitivity classes. For means of comprehension, a three-step scale was chosen to visualize the results according to a traffic light labeling system (red—high sensitivity/yellow—moderate sensitivity/green—low sensitivity).

18.3.4 Results of the Assessment of Particular Sensitivities

Depending on soil properties and criteria for evaluation the particular sensitivity levels are spatially very differently distributed:

Risk A: Mobilization of heavy metals was identified to be only an issue for soils with relatively low pH-values. This applies to the aeolianitic Kurkar soils (lithificated sand dunes) and Hamra soils (Chromic Luvisols) in the coastal region of Israel, while only low sensitivities were observed for further inland soils.

Risk B: Silty soils with low organic matter contents are susceptible to surface slaking. Soils matching these criteria were found partly in Israel's coastal area (Hamra soils—Chromic Luvisols), but are mainly associated to the loessial arid brown soils (Fluvisols) and loessial Serozems (Yermic Gypsisols) of the Negev and the eastern Judean Hills.

Risk C: Soils having low leaching rates are prone to salinization. Based on the assessment, these were defined as soils with low hydraulic conductivities and high field capacities in the root zone. These heavy soils, usually high in clay content, are located all over the assessed area and comprise, for example, Vertic Cambisols, Rendzic Leptosols, Calcic Luvisols and Vertisols.

Risk D: Soils were defined to be susceptible to the mobilization of boron, when they are low in clay and organic matter content, in dependency to their pH-value.

These soils, e.g. Chromic Luvisols, Regosols, Orthic Solonchaks, Calcic Xerosols, are found all over the project region, in particular in the coastal regions of Israel, the Negev, eastern Judean Hills, the Jordanian Jordan Valley Escarpment and parts of the Jordan Highlands plateau.

Risk E: The risk of groundwater pollution was considered to be high when the exchange rate of the soil's water is high. This was calculated based on information regarding leaching rates and the soil's particular field capacity in the root zone. In addition with coupling of the hydrogeological sensitivity, high sensitive areas are located especially in the northern Galilee, the karstic Samarian and Judean Hills and partly in the coastal area of Israel.

Risk F: The soil's sensitivity towards hydrophobicity was defined in dependency on the texture, with sandy soils being especially susceptible. These very sandy Arenosols were found mainly in the coastal plain and the northern Negev in Israel.

18.3.5 Particular Risk Weighing for Aggregation

For the compilation of the aggregated soil sensitivity, the results for the particular soil sensitivities had to be weighed. This was done again in collaboration with all regional partners according to expert opinions. It was generally agreed that the particular risk of soil salinization (C) and groundwater pollution (E) are of most importance, each were given relative weights of 25 %. The slaking risk (B) was weighed as second in importance (20 %), all others (A, D and F) were weighed with 10 %. The particular risk values were multiplied with their relative weight and summed. The class benchmarks for the total risk were set in order to have an equal distribution of the single classes.

The resulting map of the overall soil sensitivity towards the cumulative and weighed risks of TWW irrigation shows three regions, which are especially susceptible: The northern Galilee and the Golan Heights, parts of the coastal area and parts of the Samarian and Judean Hills (Fig. 18.3).

18.3.6 Presentation and Distribution of Results

The result of the assessment is a digital, spatial dataset indicating the particular soil sensitivity. From this, maps can be generated for the chosen region. As the dataset was processed in GIS (Esri ArcGIS 9.3), the outcome was released also as digital vector data files. From these, soil sensitivity maps were generated for publication and ArcGIS layer files were exported. As intended, the results were made publically available; the documenting article was published (Schacht et al. 2011), including ArcGIS layer package files and shapefiles as digital supplement. Additionally, the GLOWA Jordan River-Atlas, a GIS-tool provided by the project, utilizes these data (Claus et al. 2013).

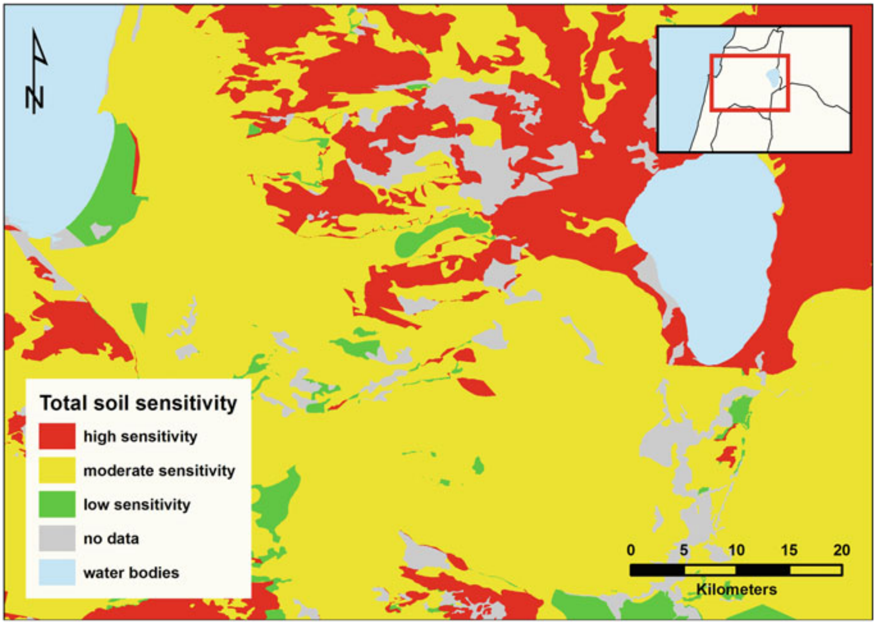

Fig. 18.3 Cut-out of the assessment map visualizing the aggregated total soil sensitivity towards TWW irrigation

18.4 Conclusions

In an environment with growing population and industrialization, sustainable water supply is a constant challenge, especially in arid and semi-arid environments. In order to alleviate the pressure on the natural water resources, the water shortage leads to adapted water management strategies. Since potable water resources are increasingly allocated to domestic use, the use of TWW is becoming a key component in covering the agricultural water demand. Since population growth and demand for diversified food sources are constantly increasing, agriculture is expected to increase or at least will be preserved in its current extent. Water reclamation, water conservation, and an increase in water use efficiency are essential. To prevent unsustainable ecological burdens to soil and groundwater, standards have to be further determined and spatially quantified to decrease pollution at its source and to impose improvement of water treatment technologies. For example, as desalination by reverse osmosis has been shown not to be an absolute barrier for organic micropollutants, other advanced treatment processes, like activated carbon or advanced oxidation processes, should be considered in addition (Sahar et al. 2011). The special composition of desalinated water may in turn lead to a subsequent additional enrichment with certain elements, e.g. magnesium (Lahav et al. 2010). Until these advanced treatment processes will be implemented, in practice of agricultural irrigation with TWW the particular soil suitability should be considered to exclude sensitive areas if necessary. For this, knowledge of the site-specific properties is essential. Implemented in spatial data bases, this information could be a valuable component of IWRM in supporting a more sustainable allocation of available water resources.

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Chapter 19
Agriculture in Mongolia Under Pressure of Agronomic Nutrient Imbalances and Food Security Demands: A Case Study of Stakeholder Participation for Future Nutrient and Water Resource Management

Jürgen Hofmann, Dooshin Tuul and Bazarradnaa Enkhtuya

Abstract To gain independence from food imports, Mongolia's agricultural system is facing significant changes with respect to land-use intensification and an expansion of arable land. The resulting depletion of nutrient resources was analyzed on the regional scale in a 3-year field study (2010–2012) in the Kharaa River basin in north central Mongolia. With a share of 20 % of the national crop yield of wheat, the Kharaa River basin is an important part of the national "breadbasket". The results of soil surface nutrient balance for the agriculturally sown areas in eleven municipalities (sums) showed a significant negative balance for nitrogen and phosphorus (period 2008–2010). The average deficit for nitrogen is approximately −20 kg ha year^{-1}, and for phosphorus, this value is approximately −4 kg ha year^{-1}. The reason for these deficits is that the nutrients, which are primarily lost due to crop harvest, are neither replaced by natural input sources nor by the application of chemical fertilizer. Thus, a nutrient imbalance between rural and urban areas can be confirmed: area-specific nutrient emissions indicate that urban areas are "hot spots", characterized by the accumulation of nutrients, whereas agricultural areas show negative N-balances with a continuously decreasing trend. With respect to future fertilizer demands, the identification of a sustainable land and fertilizer management practices is of high priority in order to achieve the demanded crop yields. To facilitate integration and inclusion of farmer perspectives, we conducted a participatory approach that also included the national and regional government levels. Several options for integrated

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nutrient-cycling strategies of cities and agricultural production will be presented and discussed.

Keywords Stakeholder participation · Agro-ecosystem functioning · Nutrient imbalance · Kharaa river basin

19.1 Introduction

19.1.1 Agriculture in Mongolia

With most of Mongolia's area being in an arid to semiarid environment, its agricultural production is strongly limited by a short growing season, (generally being from 80 to 100 days, but varying from 70 to 130 days depending on altitude and location), low precipitation and high evaporation. Approximately 80 % of the total land area (156.4×10^6 ha) can be used for pastoral activities, but only 1 % is suitable for cultivation. The total size of arable land is estimated to be 1.2×10^6 ha, of which 664,300 hectares is used as cropland, while 561,000 ha is abandoned. The share of the agricultural production in the gross domestic product (GDP) is an average of 27 %. Thus, agriculture is one of the major economic sectors of Mongolia.

Due to its significant spatial and temporal variability of water resources, nomadic pastoralism, coupled with small-scale agriculture during times of sufficient rainfall, has been a common and traditional land-use strategy in Mongolia since the end of the 1950s (Pederson et al. 2012). The first attempts to develop the cropping sector on a profound scientific base took place in 1959 with support from Russian agronomists. At that time, Mongolia's agricultural sector was characterized by food import dependency as well as weak domestic production of wheat, potatoes and vegetables. The main goal was to satisfy growing national food demand.

As a result of effective governmental intervention and sizeable investment, Mongolia became full self-sufficient in flour productions. In the mean time, Mongolia began to export domestically produced agricultural products to neighboring socialist countries.

Crop production fell sharply after the political collapse in 1990 and as result of the following privatization of the large state-controlled farms into private farms. The situation was exacerbated by a lack of management skills, funds and technologies. In 2007, the self-sufficiency rate of flour had dropped to 25 %, for potatoes to 86 % and for vegetables to 47 %.

However, Mongolia has recently entered a new agricultural era with strong attempts to gain food self-sufficiency and resource independence (Pederson et al. 2012). To stimulate the development of agricultural resources, the National Government launched the third National Crop Rehabilitation Drive (Campaign of Reclaiming Virgin Lands, Virgin Land III progam) in 2008 to revive the cropping sub-sector and to ensure domestic self-sufficiency in wheat, potato, and other major vegetables (Bayar 2008; Regdel et al. 2012). Since this time, various innovations have been made in legal, economical and technological spheres, achieving domestic self-sufficiency in the production of wheat in 2012 (Khuldorj et al. 2012; Kiresiewa et al. 2012). Wheat flour is a strategic product by the Food Law of Mongolia given that it covers 48 % of the daily food requirement of the urban population and over 70 % of the daily food requirement of the rural population. Thus, cereals account for more than 90 % of the total sown area in Mongolia. Fodder crops, potatoes and vegetables make up less than 10 % of the agricultural cultivated area.

As shown in Fig. 19.1, the national crop yield of wheat rose from 9.4 dt ha in 2007 to 15.5 dt ha in 2012 (dt = deciton or 0.1 t). An effective reduction of the sown area would be possible if the wheat yields could reach 35 dt ha.

The yearly national demand requires 328,000 tons of wheat to produce 240,000 tons of flour nationwide. Concerning wheat, 465,000 tons was harvested from 306,000 ha in 2012, fully satisfying domestic demand for this crop. The abundant wheat harvest allowed the country to export 100,000 tons of wheat. The harvest in 2012 provided 100 % of the domestic demand in wheat and potato and 52.6 % for vegetables (Fig. 19.2).

The implementation of the Virgin Land III program has contributed to the adoption of no-tillage technology in order to both conserve soil fertility and to promote highly productive planting as well as harvesting equipment and machinery (Baatartsol et al. 2013).

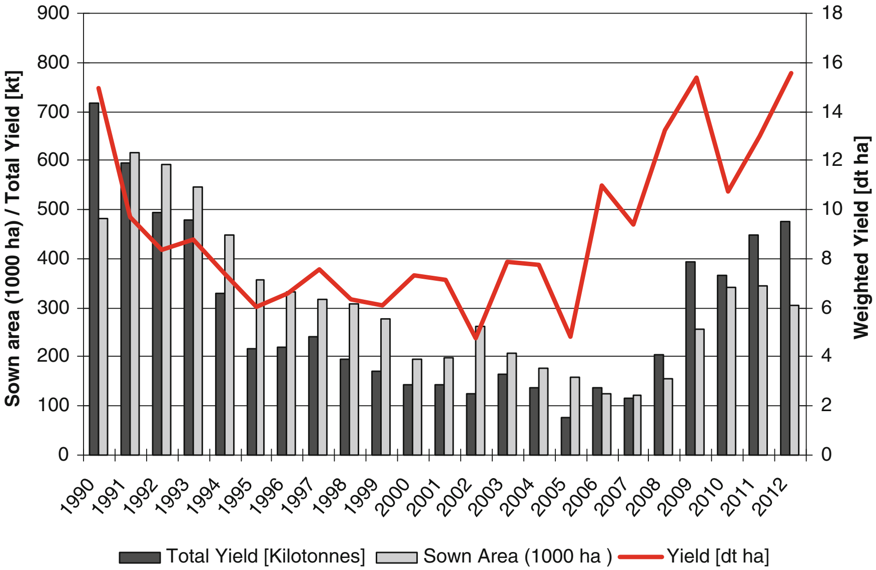

Fig. 19.1 The sown area, total grain yields and area-weighted yields (dt ha) of national wheat production in Mongolia from 1990 to 2012 (Data source: Mongolian Statistical Yearbooks)

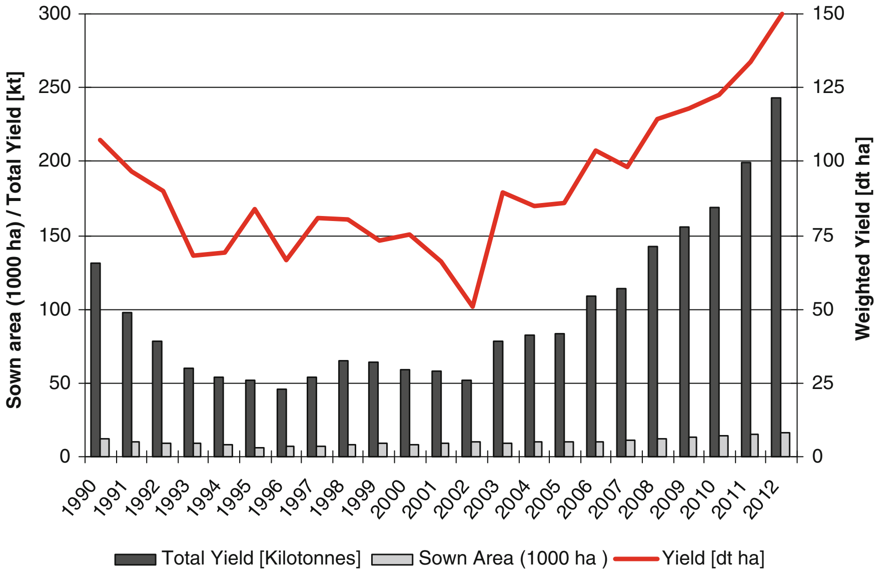

Fig. 19.2 The sown area, total grain yields and area weighted yields (dt ha) of potato production in Mongolia from 1990 to 2012 (Data source: Mongolian Statistical Yearbooks)

The first no-tillage experiments in Mongolia began in 2000 at the Plant Science and Agricultural Research Institute (PSARI) in Darkhan. The results have been positive for no-tillage compared to minimum and conventional tillage systems in terms of time and energy consumption. Yields for no-tillage have been comparable (more than 0.1–0.2 t ha) to other tillage and seeding practices. In 2012, there were 148,000 ha of no-tillage systems in the country.

The Mongolian government has intensified efforts to expand crops, and as a result, the area under wheat cultivation has increased from 350,000 to 623,000 ha over the last 5 years. During the same period, the irrigated area has increased from 5.5 to 7.5 % of the total area. In 2013, the agricultural area comprised 665,000 ha of arable land, of which 45,000 ha were irrigated.

Mongolia's agroecosystems are extremely vulnerable; global climate change, which is expected to result in higher temperatures with increased evapotranspiration (Angerer et al. 2008; Batima et al. 2005) therefore creates a serious challenge. In the past 70 years, the average annual air temperature in Mongolia has increased by 2 °C. The regional climate in Inner Mongolia (China) has been even more affected by climate warming, with a heating rate over 0.8 °C/decade, leading to an increase of approximately 4 °C in the past 50 years (Yang et al. 2011). Climate change causes an increased frequency and scope of natural disasters. In particular, unseasonable frosts and severe droughts can cause harvest losses of 10–30 % of crops.

19.1.2 Agricultural Policy Context

The relationships between the development of the food and agriculture sectors, food supply and food safety in Mongolia are regulated by the following several laws "Food", "Land", "Water", "Protection of Animal Health and Gene Fund", "Embargo on transboundary transportation of animal and plant derived productions", "Crop farming", and "Hygiene".

To improve the legal environment of the food and agricultural sector, the "Law on water" was passed in 1995, the "Law on Plant Protection" was approved in 1996 and the "Law on Seeds and Varieties of Plants" was endorsed in 1999. Amendments were made to the "Law on Land", the "Law on Cooperatives" and the "Law on Insurance of Crop Farming" in 2002. The "Law on Land Ownership" and the "Law on Prohibition and Inspection of Animals, Plants, Animal and Plant Origin Products during Export and Import" were recently passed.

The "National green revolution" and "Revival of land farming" projects and the "Seed" and "Fallow" sub-projects have been implemented successfully to support crop farming. The most pressing issue in Mongolia is to create a legal environment for a "Crop insurance" to mitigate risks in the cropping sub-sector of agricultural production. Currently, the development of the "Law on crop insurance" in Mongolia is being reinitiated.

Despite the existing "Law on Land" and "Law on Plant Protection", the actual promotion and implementation in the countryside is weak. The government of Mongolia has been implementing specific programs and projects on food supply and nutrition for the population in all phases of the country's development.

The priority of the government policy is to intensify crop production and irrigated farming and to improve land-use efficiency. The Government of Mongolia plans following complex measures to strengthen achievements in cropping sub-sector, to introduce innovative technologies, to improve land productivity and crop quality, and to intensify crop production:

- Draft the Law "Crop insurance" to mitigate risk in the cropping sub-sector, to establish a legal environment for the cropping sector and to have this Law adopted by the parliament;
- Reflect the issues of cropland possession by producers in respective laws and legal acts to improve land use;
- Legalize allocation of a certain percentage of mining income to the agricultural cropping sector development as an investment;
- Promote the rotation of cash crops, preserve soil fertility, plant shelterbelts and build fences, and improve both seed quality and supply;
- Construct new irrigation schemes and restore old schemes.

19.1.3 Motivation and Objective

The nutrient emission model MONERIS (MOdelling of Nutrient Emissions in RIver Systems, www.moneris.igb-berlin.de) was applied in the framework of the research project "Integrated water resources management in Central Asia: Model region Mongolia" (MoMo project, website: http://www.iwrm-momo.de). This model revealed through area-specific nutrient emission measures that urban areas are "hot spots", whereas agricultural areas show a remarkably low contribution due to diffuse nutrient water pollution. Moreover, a continuously increasing trend of observed total nitrogen loads at the river basin outlet is an indication for the increasing nutrient release to Kharaa River by diffuse sources, mainly urban areas without connection to treatment plants (Hofmann et al. 2013). These facts motivated us to investigate the nutrient balances of agricultural areas in detail.

Concerning future sewage trends and fertilizer demands, the identification and closing of the nutrient cycles between agricultural production and urban consumption is of high priority. We used an approach consisting of in-depth interviews with key-actors to obtain stakeholder participation in the integrated nutrient-cycling strategies of cities and agricultural production.

The specific objectives were as follows:

- collect and evaluate recent data of soil fertility and crop yields;
- analyze the recent agricultural nutrient balance;
- compare the recent situation (2012) with the strategic plans of governmental authorities for the time horizon 2021;
- obtain perspectives and knowledge of different stakeholder groups, and
- propose different options for future soil fertility management practices.

This study presents the first nutrient balance data of the cropping systems in Mongolia that identifies deficits and possible options to close the nutrient loop. Previous studies of nutrient emissions have indicated such imbalances (Hofmann et al. 2011). Based on these results, we analyzed the agricultural crop production system to elucidate the causes and consequences. The process of stakeholder participation has been established as a two-stage procedure. First, we organized stakeholder meetings of agricultural experts to discuss the outcomes of the nutrient balances and the regional differences in these measures. Our feedback to stakeholders took place in a series of NUBA workshops (NUBA = NUtrient BAlance). These workshops were held to present the interim results of our calculations and to prove that there are already nutrient deficits in agricultural areas. This issue was perceived as important, especially by farmers and the Mongolian Ministry of Agriculture (MOFA). Second, face-to-face interviews were conducted to actively involve stakeholders on different levels (farmers, experts, province and ministry level) and to gain knowledge of soil fertility and crop yields, irrigation and water consumption, food security and decision-making criteria, especially for the introduction of future nutrient management strategies.

Moreover, the stakeholders' opinions and perceptions were considered when interpreting the findings. This participatory approach will be illustrated here using the study case of the Kharaa River basin (KRB, north central Mongolia), one of the nutrient imbalance hot spots in the Mongolian breadbasket. This study area is experiencing decreasing soil fertility, impacting economic activities and food security. Therefore, the need to evaluate measures for improving economic and ecological conditions is addressed.

19.2 Materials and Methods

19.2.1 Site Description

The exemplary investigation of nutrient balances was conducted in the Kharaa River basin (KRB), located in north central Mongolia between latitudes 47°53′ and 49°38′N and longitudes 105°19′ and 107°22′E. Our decision to use KRB as a study area was based on three reasons: (i) KRB is a characteristic Mongolian agriculture region, being located in a relatively small area and close to the capital Ulan Bator; (ii) KRB provides a significant percentage of Mongolia's food resources, providing more than 20 % of the national wheat production; it is therefore an important and representative area of the Mongolian breadbasket (Pederson et al. 2012); and (iii) due to ongoing research of the above-mentioned MoMo project, there are sufficient data and a high willingness of all stakeholder groups to cooperate. KRB represents the transition from the open steppe landscape to the southern boreal forest as it grades into the taiga of southern Siberia (Fig. 19.3).

The lowest elevation, located near the outlet of the catchment, is approximately 654 m a.s.l. The highest point (2,668 m a.s.l.) is located in the vicinity of Asralt Hairhan, the highest peak of the Khentii Mountains (2,799 m a.s.l.), being the headwaters of important Mongolian rivers (e.g., Eroo, Tuul).

Based on its physiogeographical features, the river basin has been subdivided into 10 hydrological sub-basins (Hofmann et al. 2010, 2011) and can be distinguished as follows:

- The upper reaches of the Kharaa are characterized by mid- to high mountain ranges of the Khentii Mountains, with steep valley slopes and rises.
- In the middle reaches, the relief is dominated by broad valleys, with significant terrace levels, hilly uplands and gentle slopes, as well as remnants of denudated rocks.
- The lower reaches are typical of open steppe and lowland landscapes, with features of peneplain formation processes and emerged isolated outcrops of the basement complex. In the lowlands, the Kharaa Gol flows as a natural meandering river system, with ancient cut-off meanders in certain areas.

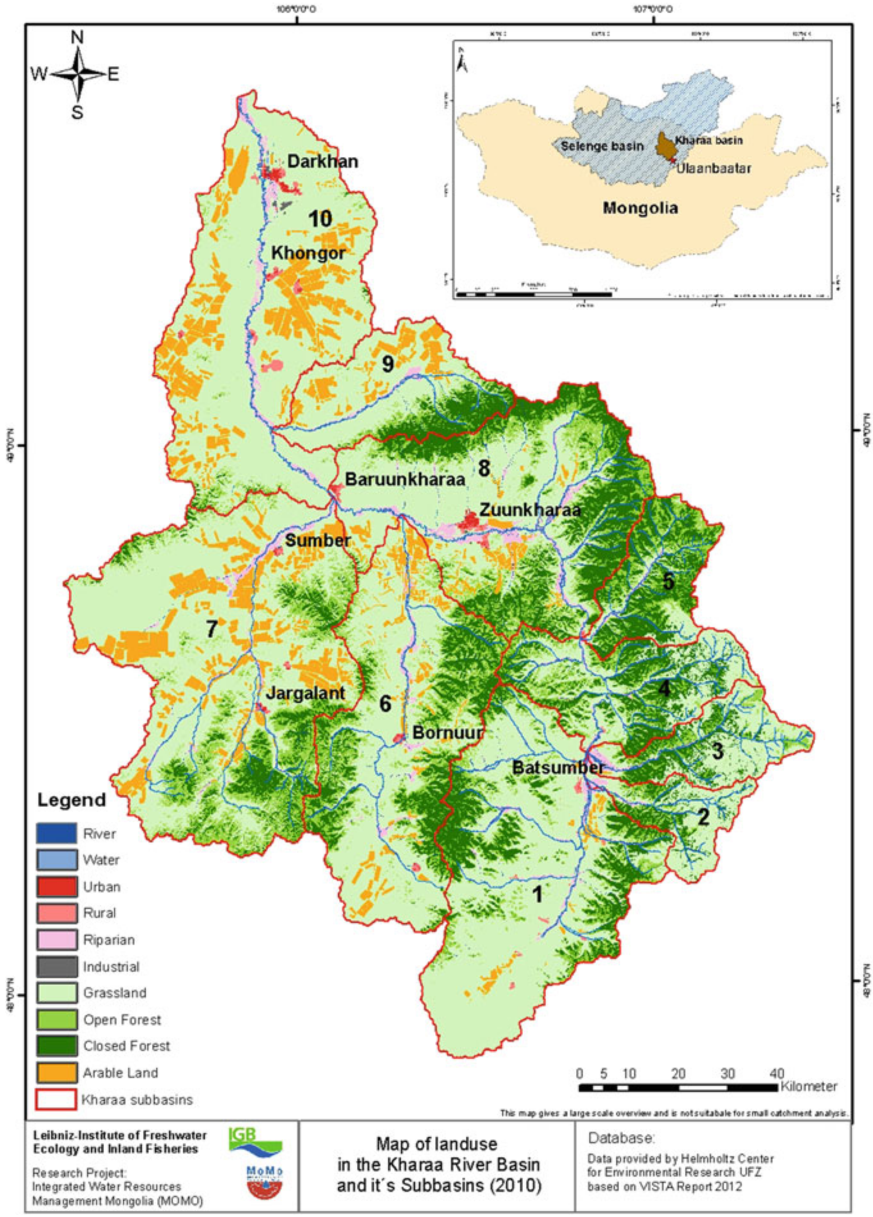

Fig. 19.3 Land use in the Kharaa River basin in 2010. The *black numbers* indicate the individual sub-basins that have been chosen for nutrient emission modeling purposes (Hofmann et al. 2011). Note that the class of arable land also contains portions of fallow land. As shown in the overview map (*upper right corner*), the Kharaa River basin (*dark area*) is part of the Selenga catchment (*hatched area*), which drains into Lake Baikal

The climate in the Kharaa basin is within the transition zone between the boreal climate with cold and very dry winters and arid steppe climate. The mean annual air temperatures are oscillating approximately 0 °C. The winters are typically very cold, long and dry, and the mean monthly temperatures in January range between −20 and −25 °C (with minimum temperatures dropping to −40 °C). In contrast, the short summers are warm to hot, with the average July temperature exceeding 15 °C, and the majority of the scarce precipitation falls between June and August.

The mean annual precipitation in the Kharaa basin ranges between 250 and 350 mm; however, there is a large spatial and temporal variability (Menzel et al. 2011). As the potential evapotranspiration is high during summer, most (between 85 and 95 %) of precipitation is lost by evapotranspiration (Menzel et al. 2011). The runoff regimes of Kharaa river with a mean annual discharge (MQ) of approximately 12 $m^3 s^{-1}$ (Hofmann et al. 2013) primarily follow the rainfall distribution, i.e., the months with highest discharge occur during summer, and a secondary peak occurs around May when meltwaters from the Khentii temporarily raise the water levels.

Most of the river basin is covered by grassland (59 %) and forest (26 %), while only 11 % of the land is arable land (Priess et al. 2011). The population and land-use distribution in the individual sub-basins show that agricultural land use is primarily concentrated in sub-basins 7, 9 and 10 with the production of wheat. The grassland is primarily used as pasture with a high livestock density. The entire population of the KRB is approximately 147,000 (census data as of 2005, mean population density of approximately 10 inhabitants km^{-2}). Most of the inhabitants live in the city of Darkhan (approximately registered 74,000 inhabitants) near the river basin outlet and in Zuunkharaa (20,000 inhabitants) in the middle reaches.

The principal soil type is dry-steppe chestnut soil, which covers some 40 % of Mongolia. The other major soil types are brown desert-steppe and grey brown desert soils. Nearly 90 % of arable land consists of chestnut soils, which are typically light, fine-silt, approximately 20–30 cm deep. These soils have an organic matter content of less than 4 % and a pH of 6–7.6.

19.2.2 Actual Agricultural Situation

The central-northern part of Mongolia comprises the Selenge, Tuv, Bulgan and Darkhan-Uul aimags (aimag = Mongolian term for province). This region is the major crop production area and accounts for approximately 67 % of all cultivated land, with nearly 90 % of the total crop production in Mongolia. Wheat production in KRB covers at least 20 % of the national demand.

The cropping system in KRB is located at the boundary of rainfed agriculture. Hence, it is a set of related technology systems that consists of crop composition, allocation, and ripening cycles. The system is also characterized by several planting patterns, including monoculture, mixed intercropping, rotation, and continuous cropping in a region or a production unit.

On the catchment scale, a similar trend in the expansion of sown area is visible as is observed on a national level. Especially from 2008 to 2009, vast areas have been taken under cultivation, primarily with wheat. In total, the cropland in KRB covers an area of 134,200 ha, with portions in Selenge, Tov and Darkhan-Uul aimag. Cereals, occupying nearly 116,900 ha, covered 87 % of the total cropped area in 2012.

The main agricultural products are wheat and potatoes. The growing season is between May and October; furthermore, different vegetables grow within the investigation area. Most farmers use crop-rotating systems. The single cropping system can be described as a rotation pattern with different characteristics: (i) the summer wheat-fallow-summer wheat rotation pattern (Fig. 19.4), and (ii) the wheat-potato-fallow and wheat-fallow-potato rotation.

After the growing of wheat/potatoes, the land usually lies fallow for a year. On irrigated fields, crop rotations with a fallow period are not used. Usually, in these cases, either wheat follows potatoes or wheat is cultivated again. Major problems for the agricultural sector are the short growing season (less than 120 days), frequent water scarcity, wind erosion and inadequate production technologies (Sarantuya et al. 2007). The crop rotating system used in Mongolia for most of the agricultural areas leads to difficulties in identifying cultivated fields on a yearly basis from satellite images (Fig. 19.5). Therefore, ground truthing has been applied in our study.

Due to the cold winters and long periods of frozen ground, no winter cereals are cultivated in Mongolia. The typical sowing period begins in May (depending on the degree of soil defrosting), and the harvesting period is between September and October. However, there is considerable year-to-year variability due to climatic conditions.

Concerning the agro-economic situation, approximately 519 crop-producing entities and farmers with 103,000 ha of cropland lie within the KRB. There are different types of farms with very different sizes of cultivated fields. Small private

Fig. 19.4 Crop rotation system in Saikhan Sum (ca. 35 km southwest of Darkhan, see Fig. 19.5), with 90-m wide strips of fallow land (*brown color*) and summer wheat production (*yellow color*) after harvest on 6 September 2007. In the following year, the fallow land is used for wheat production, while the harvested areas become fallow land (photograph by J. Hofmann)

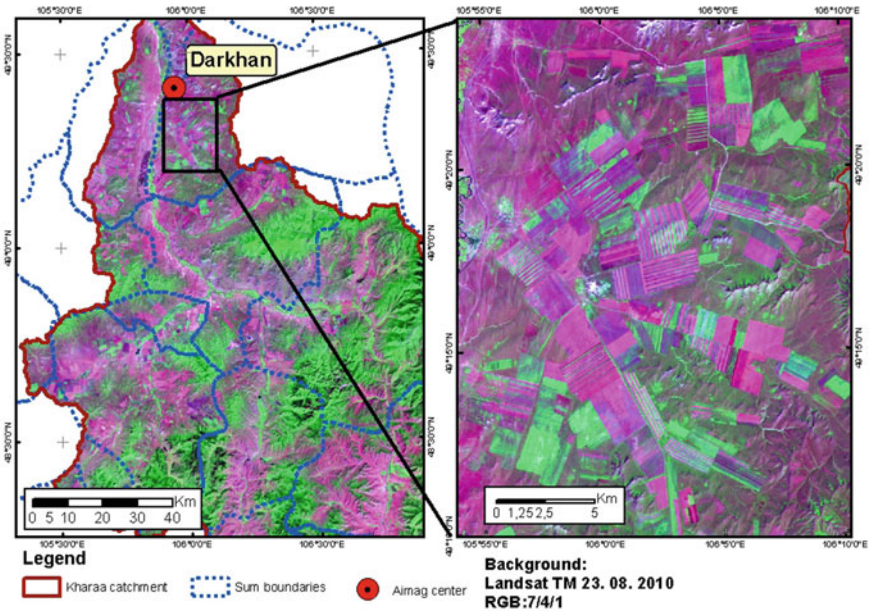

Fig. 19.5 LANDSAT image in false colors as of 23 August 2010. The *left image* gives an overview with the city of Darkhan for orientation. The *right image* illustrates the different types of fields with the strip pattern of crop rotation in Khongor Sum (see Nr. 9 in Fig. 19.8). *Green* indicates active, dense vegetation. Thus, a large proportion of the agricultural fields was fallow in 2010 (Bach and Altenburger 2011)

farms have 10 cultivated hectares or less, and very large farms that are run either by companies or private individuals can have one or two thousand cultivated hectares.

Each aimag (province) has formulated an agriculture development plan of its own, with a time horizon of 2021 to achieve self-sufficiency in food supplies. Thus, there is a plan not only to widen irrigation fields but also to seed high-yielding and safe crops.

19.2.3 Calculation of Nutrient Balances

19.2.3.1 Methodology

The identification of diffuse nutrient inputs from agriculture to ground- and surface waters requires a methodology for the calculation of regionally differentiated nitrogen (N) and phosphorus (P) balances. A powerful and well-established approach is the OECD methodology (OECD 2001, OECD/EUROSTAT 2007). Using this consistent and well-established methodology, all of the OECD member states are required to calculate and provide gross soil surface nutrient balances for N and P. Due to its professional acceptance and for reasons of comparison, we applied this method in our study. The methodological background of this balancing scheme is described in detail in the OECD/EUROSTAT (2007) handbook and discussed by both Bach and Frede (2004) and Panten et al. (2009).

However, there are two basic assumptions of the adapted nutrient balance scheme: the net mineralization/assimilation of nitrogen in the soil is negligible and nutrient losses via soil erosion are not considered (Bach and Altenburger 2011). The input and output parameters are based on values in the literature and statistical data from the Ministry of Food, Agriculture and Light Industry (MOFA), as well as from the Mongolian Statistical yearbooks (2005/2012). The applied methodology for the nutrient balances based on the OECD approach is shown for nitrogen (Fig. 19.6) and phosphorus (Fig. 19.7).

The use of chemical fertilizer and the output factors (harvest and animal withdrawal) are spatial and temporal variables.

For the calculation of soil fertility, we used the available phosphorus and potassium soil tests. These levels are reported in units of mg per 100 g soil, and nitrogen is reported in mg per 1 kg soil. Soil testing is a necessary prerequisite to determine the proper application rates of fertilizers and the current availability of nutrients in the root zone, within the uppermost 20 cm of the soil surface. The sufficiency level of nutrients has been analyzed to meet yield expectations on the basis of the soil testing procedure. The soil test recommendations are given in kg ha of nutrients (Tuul et al. 2012).

19.2.3.2 Data Collection and Data Uncertainties

As nutrient balances are simplifications of complex and variable processes, several uncertainties are involved. These uncertainties are primarily associated with either

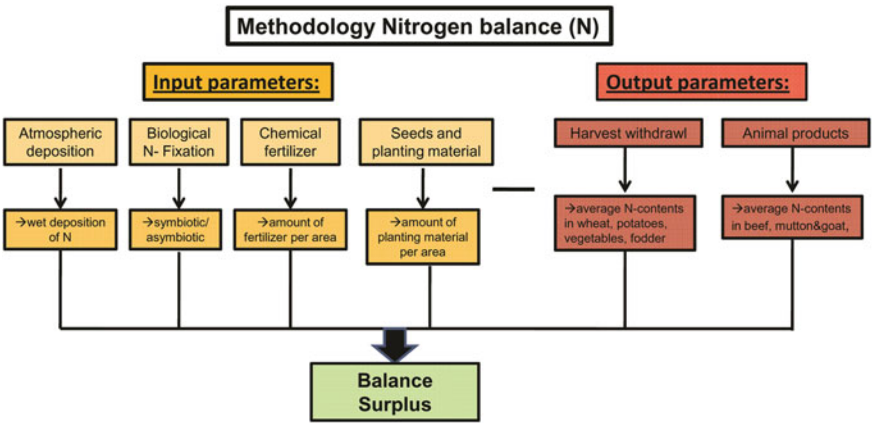

Fig. 19.6 Methodology of determining the nitrogen balance (Bach and Altenburger 2011)

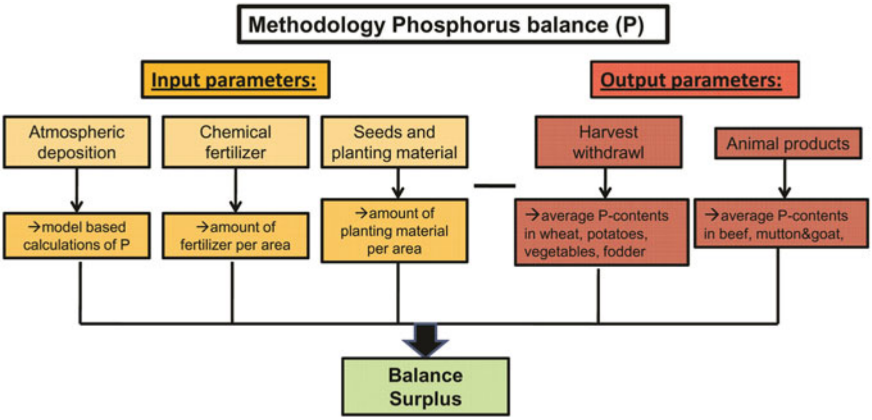

Fig. 19.7 Methodology of determining the phosphorus balance (Bach and Altenburger 2011)

the statistical database or the coefficient library used to convert the statistical data into nutrient quantities. Therefore, the absolute balance values do not reflect the actual situation for a given area. Nevertheless, if a consistent method of balance calculation is used for all of the considered years, it is possible to derive meaningful trends in nutrient surpluses or deficits (Panten et al. 2009). The data required for the calculation of the gross N soil surface balance are the use of mineral and organic fertilizer, livestock manure, biological N fixation, seeds and planting material and the total harvested crops and fodder. Each of these variables is further segmented. Additionally, land use data are required for the calculations. Mineral fertilizer and livestock manure are the major contributing input variables in the balance. The levels of mineral fertilizer are based on sales figures, and its actual level of application on arable land is unknown. The input from livestock manure is calculated from the number of animals. The animals are counted annually, but for taxation reasons, there is an incentive for herdsmen to report lower animal numbers than is actually the case. This factor may lead to an underestimation of the manure input. As farm gate balances are not available in Mongolia, we used the data on the administrative level of the "sums" (Mongolian term for counties), which are comparable to the administrative levels of counties in the nomenclature of territorial units for statistics in the EU. These units are abbreviated "NUTS" from the French, Nomenclature of des Unités Territoriales Statistiques. In this nomenclature, counties are referred to as EU NUTS-3 level. Hence, we began a cooperation with the Mongolian Ministry of Agriculture and Light Industry (MOFA) to use the official data (arable land, sown area, crop yields, fertilizer application) of the sum level, which was considered the most relevant input data. To ensure the possibility of cross-checking, we also cooperated with agricultural experts from Darkhan (Plant Science and research Institute, PSARI) and selected farmers with different farm sizes as representatives of the farming level. With respect to administrative boundaries, the KRB contains 19 sums among 3 aimags (Fig. 19.8).

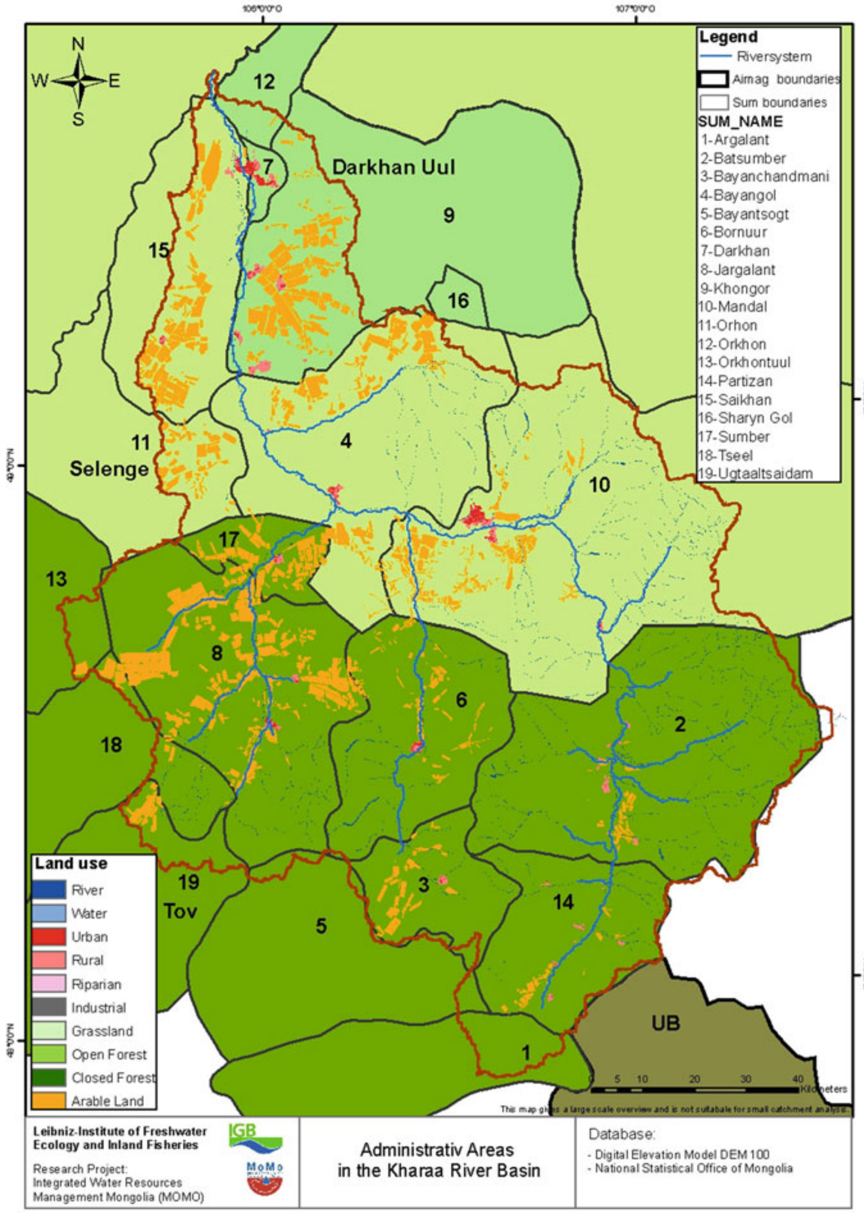

Fig. 19.8 The administrative boundaries in the study area (Kharaa River basin, *red line*). The *colors* indicate the shares of Aimags (the Mongolian word for province): Selenge Aimag (*light green*), Tov Aimag (*dark green*) and Darkhan Uul Aimag (*green*). The *black lines* delineate the individual sums (Mongolian term for counties). The *black numbers* indicate the name of the sum (see legend). The largest farms of the participating farmers (L4) are located in Sumber sum (Nr. 17, two companies with 5000 and 2879 ha) and Jaragalant Sum (Nr. 8, 6500 ha)

Approximately eleven of the 19 sums were selected for the analysis given that they are not only located completely in the river basin but also comprise the major share of arable land. The remaining 8 sums cover only minor portions of the study site and are not relevant for agricultural production in the KRB.

Further uncertainties in the nutrient balance measurements are caused by the inconsistencies that result if the reported N and P coefficients are not congruent with the variable classification used in the OECD methodology. Due to the different nutritional needs of animals in Mongolia compared to OECD member states, we used coefficients from the East Asian countries of Korea and Japan (Liu et al. 2009; Tsukuda et al. 2006).

The Fixed Input values for the nitrogen balance include the following:

- atmospheric deposition (1.7 kg N ha)
- symbiotic nitrogen fixation for fodder crops (30 kg N ha)
- asymbiotic nitrogen fixation (2.2 kg N ha) (Liu et al. 2009)
- seeds and planting material (4.2 kg N ha)

The Fixed Input values for the phosphorus balance include the following:

- atmospheric deposition (0.02 kg P ha) (Tsukuda et al. 2006)
- seeds and planting material (0.65 kg P ha).

19.2.4 Participatory Approach: Interviews and Respondents

The participatory process in our study is a method for structuring group processes so that non-scientists can also play an active role in contributing their knowledge (Van Asselt and Rijekens-Klomp 2002). As shown by many previous studies (e.g., Bravo et al. 2010), the participation of stakeholders is important for the assessment and acceptance of governmental policies. The chosen interdisciplinary approach of integrating stakeholder groups enables the analysis of the acceptance of political measures. Among other criteria, the economic viability, in terms of the benefits outweighing the implementation costs, is also of special importance in Mongolia. The form of participation used is determined according to the goal of the application. In this context, the procedure can be seen as a decision support process. With a strong focus on the environmental issue of nutrient balances ("NUBA"), we established a cooperation with stakeholders on the following levels (L):

- L1: Mongolian National Government (Mongolian Ministry of Food, Agriculture and Light Industry MOFA, http://www.mofa.gov.mn, Ulaanbaatar, Dept. of crop production and strategic policy, 8 participants);
- L2: Aimag (province) administration level (Food, Agriculture and Light Industry Departments of Tov, Selenge and Darkhan Uul Aimag, FALID, 11 participants);

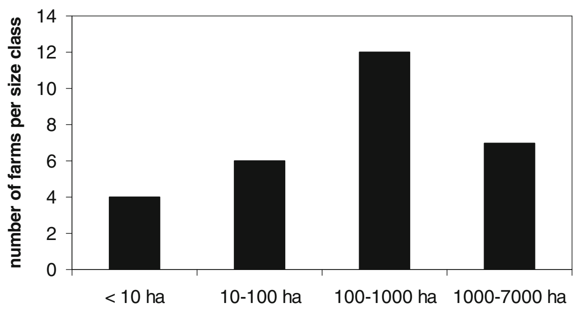

Fig. 19.9 Distribution of farm sizes for the interviewed group L4 (farmers)

- L3: Agricultural expert level (Plant Science and Research Institute Darkhan PSARI, Agricultural University Darkhan AUD, 10 participants);
- L4: Farmers and agricultural companies, including livestock herders (31 participants; in total, representing approximately 35 % of total registered cropland in KRB). An overview of the farm sizes of the interviewees is given in Fig. 19.9.

As a first step, we conducted a series of four NUBA workshops in the spring and autumn of 2011 and 2012 in Ulaanbaatar (L1) and Darkhan (L2, L3). In these workshops, we presented and discussed the methods and outcomes of the calculation of nutrient balances. Additional field excursions were made to gain insight into real farming conditions (L4). In the second step, the participatory approach was implemented by conducting interviews with all four groups (L1 to L4). The aim of these interviews was to address the concerns and to propose possible solutions. Thus, the collected information originated from respondents who represented the interests of organizations/companies they belonged to. The possible impacts, spatial distribution of costs and benefits, and potential conflicts were then discussed in the final workshops in Ulaanbaatar (L1) and Darkhan (L2 to L4) in April 2012 (Hofmann et al. 2012).

19.2.4.1 The Interviews

A series of in-depth, semi-structured interviews was used as a tool to obtain insight into the perceptions and suggestions of stakeholders. In this context, face-to-face interviews were chosen as a suitable and inexpensive option.

The text of the answers was checked with the respondents to correct possible misunderstandings. Anonymity of the interviewees was assured. The choice of the interview protocol and the interview questions depended on the relevant work activity and on the characteristics of several of the participating institutions. The open-end questions that were presented to the interviewees addressed the following main points (see Appendix):

1. General views and perception of environmental problems in the study area;
2. Soil fertility and crop yields;

3. Irrigation and water consumption;
4. Food security (proposals for developing management measures)
5. Decision making: criteria for choosing among measures.

With these interviews, we sought to integrate stakeholder participation, expert knowledge and feedback regarding their willingness to adopt nutrient-cycling methods. Therefore, the main objectives of this study were to analyze nutrient measures and to estimate costs and value efficiency of the implementation of nutrient-cycling strategies in KRB.

19.2.5 The Cause Response Framework

The DPSIR framework of the European Environment Agency (EEA 1999) was adopted to address the complex human-ecosystem interactions that characterize our study case. The role of the interviews in achieving an approach that makes use of multiple perspectives is shown in Fig. 19.10.

In this study, three points will be considered in detail: perceived environmental and agro-economical problems (impact), conflicting interests in the catchment (socioeconomic drivers) and suggested decision-making criteria for policy measures (response) in terms of nutrient-recycling strategies.

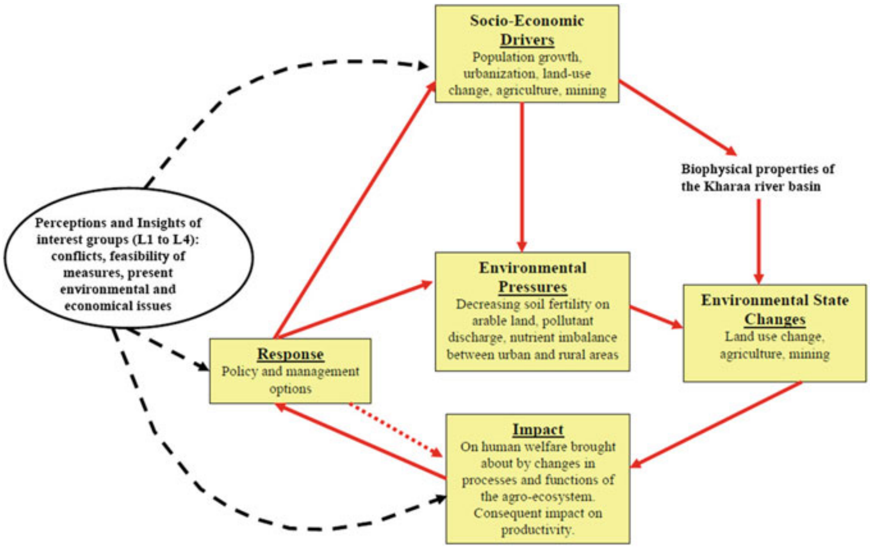

Fig. 19.10 The DPSIR approach, linking social and environmental processes adapted to the Kharaa River basin. The participatory approach functions are summarized in the oval, the *slashed arrows* represent the outcome of the interviews for the operationalization of the scheme

The DPSIR framework is based on the assumption that the river basin acts as a dynamic system linking social systems (human activities and the resulting pressures) to ecological systems. Both systems are connected by feedback loops, which, depending ultimately on political choices (responses), can enhance or mitigate impacts on the environment and the consequent effects on humans. Drivers are generally seen as socio-economic factors that cause environmental pressures and consequently lead to changes in the state of the environment. These changes can impact social, economic and ecological processes and, as a result, alter ecosystem functions (e.g., reduction of soil fertility). To mitigate these undesired effects, management responses or policy options (e.g., the introduction of nutrient recycling) can be implemented to influence the system at different levels (e.g., changing drivers, state or impact).

19.3 Results and Discussion

19.3.1 Nutrient Imbalances

The calculation of the nutrient balance shows negative values for both nitrogen and phosphorus for all 3 years (Bach and Altenburger 2011). The total nitrogen deficits for the agricultural areas of the 11 Sums were 738 tons (2008), 1351 tons (2009) and 1603 tons (2010). The average deficit in kg nitrogen per ha for the period 2008–2010 is given in Table 19.1.

The average deficit is approximately −20 kg N ha year^{-1}, with a range of −43.88 to +5.35 kg N ha year^{-1}. This deficit is in sharp contrast to the nitrogen surplus in countries in Europe (EU-28) or East Asia (China). For example, the German N gross soil surface balance from 1992 to 2006 shows a surplus of between 89 and 121 kg ha year^{-1} N (Panten et al. 2009). Note that no area-weighting was performed in this calculation. Only one calculated sum in 3 years shows a surplus in nitrogen (Batsumber sum, Nr. 2 in Fig. 19.6). This is due to a very low reported potato yield in combination with an absence of wheat cultivation and a high percentage of fodder cultivation.

For phosphorus, the total deficits were −144 tons (2008), −255 tons (2009) and −297 tons (2010). The average deficit of phosphorus in kg ha year^{-1} for 2008–2010 is given in Table 19.2.

The average phosphorus deficit is approximately −4 kg P ha year^{-1}, with a range of −6.39 to −2.56 kg P ha year^{-1}. The decreasing values in the total deficits for both nitrogen and phosphorus are caused by the expansion of the sown areas from 2008 to 2009 and a higher overall yield from 2009 to 2010, especially for wheat.

Figure 19.11 shows the spatial patterns of agronomic P and N imbalances in the 11 calculated Sums for 2010. Tables 19.1 and 19.2 show the implemented input and output values. All of the given numbers represent the nutrient balance in kg ha of agricultural area, which is the sown area on Sum level. Fallow land is not taken into account in this calculation.

Table 19.1 Nitrogen balance on sum level (equivalent to EU NUTS-3 level for counties) in the Kharaa River basin for the year 2010 (Bach and Altenburger 2011)

2010 Nitrogen		Input					Output		Nitrogen
Sum Name	Aimag	Atm. Dep	Asym N fix	Sym. N fix	Seeds	Fertili	Harvest with.	Animal with.	Balance
(1) Khongor	Darkhan	1.7	2.2	0.7	4.2	0.3	29.2	0.04	−20.1
(2) Darkhan	Darkhan	1.7	2.2	0.0	4.2	0.0	31.9	0.29	−24.0
(3) Orhon	Selenge	1.7	2.2	0.1	4.2	0.0	32.2	0.07	−24.1
(4) Bayangol	Selenge	1.7	2.2	1.5	4.2	0.4	30.8	0.07	−20.9
(5) Mandal	Selenge	1.7	2.2	1.2	4.2	0.0	37.1	0.02	−27.7
(6) Saikhan	Selenge	1.7	2.2	0.0	4.2	0.0	37.5	0.04	−29.4
(7) Jargalant	Tuv	1.7	2.2	0.3	4.2	0.0	36.5	0.12	−28.2
(8) Bornuur	Tuv	1.7	2.2	4.5	4.2	0.0	37.5	0.05	−24.9
(9) Batsumber	Tuv	1.7	2.2	14.7	4.2	0.0	17.3	0.13	5.4
(10) Bayanchandmani	Tuv	1.7	2.2	10.1	4.2	0.0	26.7	0.13	−8.6
(11) Sumber	Tuv	1.7	2.2	1.9	4.2	0.0	29.8	0.03	−19.8

All of the values are given in (kg ha $year^{-1}$) (Input: *Atm. Dep* atmospheric deposition, *Asym N fix* asymbiotic nitrogen fixation, *Sym N Fix* symbiotic nitrogen fixation, *Fertili* fertilizer application; Output: Harvest withdrawal, animal withdrawal)

Table 19.2 Phosphorus balance at the sum level (equivalent to EU NUTS-3 level for counties) in the Kharaa River basin for the year 2010 (Bach and Altenburger 2011)

2010-Phosphorus		Input			Output		Phosphorus
Sum name	Aimag	Atm. Dep	Seeds	Fertili	Harvest withdrawal	Animal withdrawal	Balance
(1) Khongor	Darkhan	0.02	0.65	0.16	4.51	0.009	−3.7
(2) Darkhan	Darkhan	0.02	0.65	0.0	4.91	0.066	−4.3
(3) Orhon	Selenge	0.02	0.65	0.0	4.96	0.016	−4.3
(4) Bayangol	Selenge	0.02	0.65	0.18	4.78	0.017	−4.0
(5) Mandal	Selenge	0.02	0.65	0.0	5.75	0.005	−5.1
(6) Saikhan	Selenge	0.02	0.65	0.0	5.78	0.010	−5.1
(7) Jargalant	Tuv	0.02	0.65	0.0	5.66	0.028	−5.0
(8) Bornuur	Tuv	0.02	0.65	0.0	5.97	0.010	−5.3
(9) Batsumber	Tuv	0.02	0.65	0.0	3.22	0.030	−2.6
(10) Bayanchandmani	Tuv	0.02	0.65	0.0	4.56	0.029	−3.9
(11) Sumber	Tuv	0.02	0.65	0.01	4.64	0.007	−4.0

All of the values are given in (kg ha year^{-1})

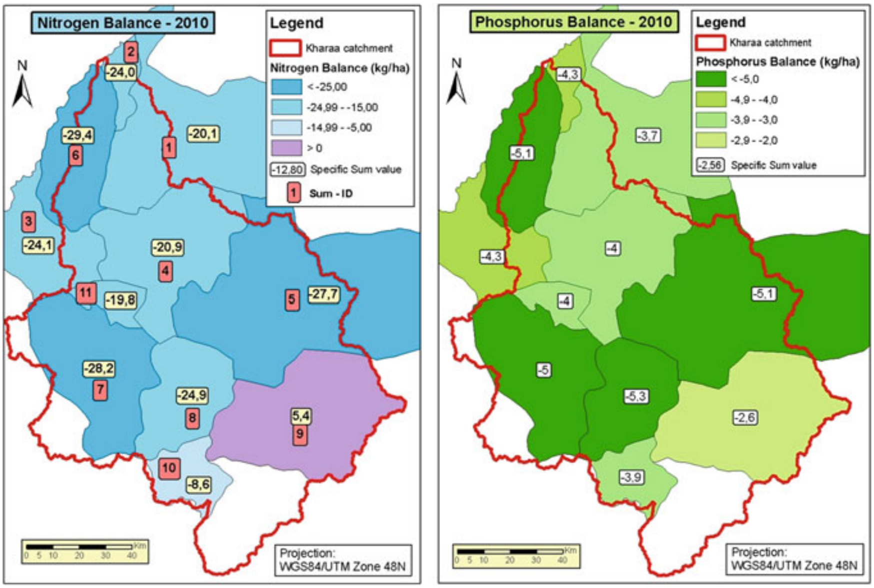

Fig. 19.11 Nutrient balances for nitrogen (*left*) and phosphorus (*right*) in 2010 on the sum level (equivalent to EU NUTS-3 level for counties) in the Kharaa River basin (Bach and Altenburger 2011)

The calculation of the nitrogen and phosphorus surface balances at the Sum level is characterized by three different critical items. First, the data on fertilizer application on the Sum level is likely to be both incorrect and to underestimate the actual use of fertilizer. Companies are required to report the amounts of fertilizer used to the local authorities. However, there is no incentive to do so, and not all companies reported their data appropriately to the authorities until 2010. Furthermore, it is very likely that FAO data overestimates fertilizer application. Specifically, downscaled values from a national level do not properly represent the agricultural reality in the KRB. For this reason, the data on the Sum level received from the Ministry of Food, Agriculture and Light Industry has been applied for the calculation scheme. The extent of error in the data collection for fertilizer use is difficult to predict. Based on fieldwork experience in May 2011, an average fertilizer application in the investigated area is very likely less than 2 kg N ha $year^{-1}$ for nitrogen, equivalent to approximately 400 tons of fertilizer. This is approximately ten times the value that is reported by the Ministry of Food, Agriculture and Light Industry. In this case, balances would still be negative for all Sums (except for Batsumber 2010, number 2 in Fig. 19.8).

Secondly, despite several decades of scientific investigations, the complexity of the nitrogen cycle and its interaction with human activities cause considerable uncertainties. The complex constraints with respect to biological nitrogen fixation lead to very large spatiotemporal variations, even within a single ecosystem. These uncertainties make quantifying fixed nitrogen for certain areas very difficult.

As described above, an asymbiotic nitrogen fixation value for grassland ecosystems was used for the calculation. Most of the cropland in the study area is cultivated in a 2-year crop cycle, again resulting in uncertainties. However, the magnitude of the estimated uncertainties cannot be predicted due to the lack of local investigations in Mongolia.

A third point that is critical for the calculation of the nutrient balance is the withdrawal of animal products. On the one hand, only meat products were examined in the calculation; wool, milk, hide and skin products were not considered due to a lack of data. One the other hand, agricultural fields do not represent the main pasture areas even if they are grazed by animals, as occurs, for example, after the harvest season. Therefore, it is assumed that the average output via animal products from the agricultural fields is substantially lower than from typical pasture/grassland areas. However, the output of nutrients via animal products does not play a dominant role in the nutrient balances of agricultural fields.

Methodologically, it is assumed that the levels of nutrients that are taken up by livestock and the levels that go back to the grazing area as manure are almost the same, with the difference being explained by the withdrawal of animal products. As there is no external input of animal fodder, the components of nutrient uptake and nutrient loss by animals are not considered.

This decision assumes that all of the animal manure remains in the soil surface system and is furthermore available to the plants. When considering agricultural areas, which are primarily used as pasture areas, the effect of nutrient loss via surface runoff can play a crucial role in nutrient balances. During winter, manure accumulates on the grassland and is partly washed into the river network in the subsequent spring season, causing nutrient flushes in running waters (Hofmann et al. 2011).

To test the range of the calculated negative balances for nitrogen and phosphorus, we also applied coefficients of OECD countries. Even then, the deficit is not replaced by natural processes, such as atmospheric deposition, or by the use of chemical or organic fertilizers. This result indicates a trend of a significant decline in nutrient and humus contents in the topsoil of arable land (see Sect. 19.3.3).

In summary, it should be noted that most of the sown agricultural areas use a crop rotation system; the negative balance for nitrogen and phosphorus (for a single field) should therefore not be considered to occur every year, but every second year.

19.3.2 Perception of the Present Situation (Questionnaire Block 1)

Depending on the activity of the organization they represented, every interviewee perceived certain problems to have different levels of importance. However, there were several points that were addressed by participants on all levels.

Perception of current implementation of legislative framework
Although different legislative initiatives have been taken to increase and protect soil fertility, in reality, the implementation of these laws is rather weak (e.g., Law on Land, Law on Plant protection). All of the groups noted that the lack of agricultural specialists in Parliament is a major obstacle for subsequent revisions and improvements of the existing laws. In addition, the formation of a national farmers association could strengthen the position of farmers. The crucial question of land possession is still a point of ongoing contention among all groups. While the ministry level (L1) prefers the existing leasehold system, but most of the farmers (L4) would prefer to own the land. In general, the top-down approach of agriculture policies requires a counter balance with bottom-up approaches from the farmers to reflect and implement real farming conditions.

Environmental issues of the highest concern
The most serious impacts on agricultural production and soil fertility are, in order of priority, as follows:

- Increase in livestock number and population growth;
- Increase in soil erosion (mostly deflation) and sand movement caused by overgrazing and the loss of pasture capacity,
- Environmental pollution as a result of mining (i.e., gold) and sand quarry activities;
- Deforestation of the meadow plain and the mountains, with negative impacts on water resources;
- Environmental pollution by urban waste due to a lack of reprocessing and transporting waste management.

Divergent views from the agricultural experts (L3) mentioned the very limited variety of high quality seeds for cereals as an important bottleneck. The seed varieties that are available for wheat production have only a middle maturity and resistance to drought and heat. However, there are no high-yield varieties with early or mid-late maturity. In addition, there is a lack of seed varieties of secondary cereals, such as barley, oat and triticale. Concerning climatic variability and political objectives, the necessity to develop high-yield varieties with resistance to drought, heat, pests and diseases is an important issue.

Agroeconomical and legal issues of highest concern
From the agro-economical perspective, the most serious impacts are listed by priority:

- Petrol and finance deficiency during spring tillage and harvest;
- Land use is only possible as a leasehold, not as a property;
- Lack of crop insurance;
- Lack of soft loans for small entities;
- Insufficient legal conditions to protect the domestic agricultural market;
- Lack of a direct marketing system from farmer to customer;
- Increasing number of non-professional farmers.

All farmers (L4) have leaseholds on land and can use the land for a maximum duration of only 60 years. The land is always state-owned and must be returned at the end of the leasehold period. The farmers are using the land only for their immediate benefits. Thus, farms seldom or never use fertilizer to avoid the depletion of soil fertility. In recent years, most of the cultivated lands in rural areas have been owned by both foreign and domestic companies and individuals. Hence access to cultivated lands is considerably hampered for local citizens. The farmers also addressed the necessity to organize farmer field schools to promote knowledge of good management practice in agriculture and horticulture before planting and harvest time.

19.3.3 Soil Fertility Status and Crop Yield (Questionnaire Block 2)

Soil fertility
The majority of respondents and all farmers (L4) reported a yearly decrease in soil fertility in the KRB. One reason causing decreased soil fertility is the lack of mineral fertilizer application.

As a result of intensive cultivation practices during the last 50 years, the soil humus content has declined by 15–44 %. Approximately 71 % of cropland soil has less than 2.5 % humus content, indicating low soil productivity.

Approximately 579,000 ha of cropland and 347,000 ha of abandoned cropland soils were evaluated within the National program “Third Campaign of Reclaiming Virgin Lands”. The agrochemical analysis of soil samples revealed that 70 % of the total cropland of Mongolia does not meet the required satisfactory level of nitrogen and phosphorus concentrations in the topsoil. Depleted natural soil fertility combined with low levels of fertilizer application represent the principal constraints for the intensification of agricultural production.

In the specific conditions of Mongolia, balanced fertilizer application can serve as an effective tool to improve soil fertility. The application of organic fertilizer (manure 20 kg ha) will increase the humus content of chestnut soils by 1.8–10.4 %. Some high-yield wheat varieties that performed well under irrigation and intensive use of fertilizers (N120 P80 K80) have the ability to increase crop yields by 3.4 t ha (Tuul 2004, 2011a).

Therefore, the intensification of crop production, especially under irrigated conditions with fertilization, has acquired increased attention in Mongolian agriculture. According to research results, more than 48 % of the total cropland has low nitrogen provision levels, and this measure is 35 % for phosphorus. The results of fertilizer application revealed that the grain yield of wheat improved the average yield by 2.84–3.66 t ha under irrigated conditions and by 0.8–1.5 t ha under non-irrigated conditions (Myagmarsuren and Tuul 2012).

Humus content

The desertification and soil degradation of cropland is a serious and complex problem with social, economic and environmental impacts in Mongolia. More than 80 % of the country's cropland is characterized by a light brown Kastanozem soil. This type of soil always contains poor organic matter contents and, accordingly, has a light structure. Continuous cropping in combination with the inadequate replacement of nutrients that are removed in harvested materials or lost through erosion have depleted fertility and decreased crop productivity.

The increased adoption of improved crop varieties as well as land and water management practices are required to halt and eventually reverse land degradation. Reversing the soil productivity crisis in Mongolia requires increased and balanced use of fertilizers. Widespread use of all type of organic fertilizers is especially needed.

Humus in soils is widely accepted to improve soil fertility and to increase plant growth. Table 19.3 shows the amounts of soil organic matter that are characteristic of cultivated soils after different periods of use compared to virgin land.

Cultivation generally results in a 14.6–43.6 % loss of organic matter, depending on time of the cultivation period. The analysis of long-term field experiments has

Table 19.3 Humus content (organic matter given in % of total solids) of brown (chestnut) soil in the KRB at different depths on cultivated land after periods of 15, 20 and 30 years of utilization

Brown soil's (depth in cm)	Humus content (%) Virgin land	Humus content (%) after different cultivation periods		
		15 years	20 years	>30 years
0–20	2.80	2.39	2.08	1.58
20–40	1.99	1.94	1.85	1.32

As a reference. the natural condition is given by data for virgin lands in the left column (Tuul 2004) shown different impacts of various rotation systems on humus content in chestnut soils (Tuul 2004). A considerably higher accumulation of humus (2.09 % or 50.2 t ha) was observed under perennial grasses. However, under fallow land, the humus content was significantly lower (1.27 % or 30.5 t ha). The experimental field sites from PSARI revealed that humic acid content increased to 20–35 % of total C under perennial grasses and green fallow. As a consequence, the humus type acquired more fulvic/humic characteristics.

Our study showed that the plant uptake coefficients of the major nutrients from soil and fertilizers were approximately 50–60 % for N, 15–20 % for P_2O_5, and 40–70 % for K_2O (Tuul et al. 2011a, b).

Erosion

All of the respondents reported impacts of wind erosion on their arable land, which exceeds erosion by surface water runoff. However, the respondents did not invest money into erosion countermeasures due to a lack of knowledge and insufficient loans. In the study area approximately 61.4 % of total arable land was highly affected by erosion, 34.9 % was moderately affected and 3.7 % was slightly affected. In a nationwide survey performed during the Virgin Land III program, it was found that 61 % out of 579,000 ha cropland used across the country was strongly affected by erosion as a result of intensive cultivation practices during the last 50 years. It was estimated that over the past 30 years, the average soil loss of cultivated land due to erosion was in the range of 35–50 t ha year^{-1}. In the KRB, the actual rate of brown soil loss exceeds the critical threshold rate of 2.5–5.0 t ha by a factor 7–10 (Gungaanyam 1998).

Fertilizer application

Low soil fertility has been recognized as one of the major constraints of agricultural production in Mongolia. In the specific environment of Mongolia, fertilizers could effectively improve both soil fertility and crop yield. Annual fertilizer consumption declined from 88,000–90,000 t year^{-1} between 1972–1992 to only ≈3,200 t year^{-1} in 2001 due to the unavailability of mineral fertilizer; this decrease occurred primarily due to economic reasons (Fig. 19.12).

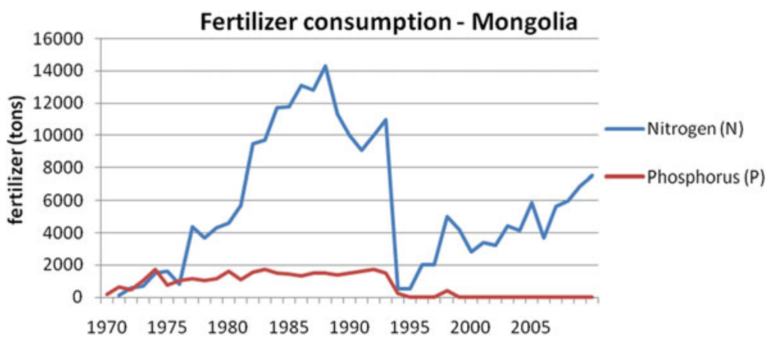

Fig. 19.12 Fertilizer consumption (t year^{-1}) in Mongolia from 1970 to 2009 (National Level) (Mongolian Statistical Yearbooks)

The application of fertilizers (N60 P40 K40 and manure at 10 t ha or biological fertilizer at 2 t ha) increased the grain yield of wheat by 0.54 t ha (68.4 %). To determine the actual use of fertilizers, long-term experiments on nutrient cycles have been carried out over the last 40 years (Tsermaa 2000). The results suggest that fertilizer should be applied to crops in basal and top applications. In general, nitrogen fertilizer should be applied during seeding time at 10–20 kg N ha $year^{-1}$. However, in our study, only one farmer reported applying potassium fertilizer on 0.5 ha of potato and vegetable crops in 2011 (Orkhon sum). All of the other respondents reported that they performed no chemical fertilizing given that fertilizer is expensive and has limited availability.

The farmers that were surveyed during our research used manure application. However, due to the lack of barns, the collection and application of manure is possible only in the vicinity of the corrals.

Crop rotation with legume plants (e.g., fallow-potatoes-green fertilizer) is not performed given that there are only a small number of legume plant types available. In addition, legume seeds are expensive and are unavailable on the market. The interviewed farmers recognized the advantages of crop rotation. However, they do not plant legumes due to low profits, unavailable seeds, and a lack of planting technology.

Crop yield

Between 410,000 and 430,000 tons of wheat are required annually to satisfy the nation's growing demand. In 2011, 448,000 tons of wheat were harvested from 301,000 ha, fully satisfying the domestic demand for wheat. To maintain this high level of production, it is of high priority that Mongolia become independent of imports. However, analyses of the soil samples indicated that 73 % of the total cropland in KRB has low nitrogen provision levels, with this figure being 35.3 % for phosphorus. As wheat is the dominant cultivated crop, it is the biggest nutrient output factor from the agricultural system (Fig. 19.13).

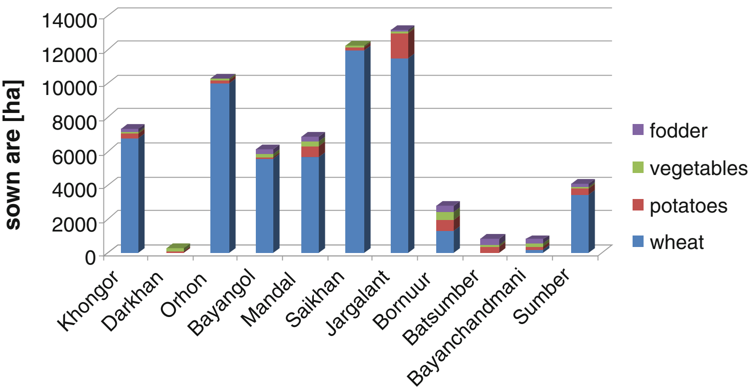

Fig. 19.13 Sown areas at the sum (NUTS 3) level for wheat, potatoes, vegetables and fodder in the study area (2010), given in hectare (Data source: MOFA 2011)

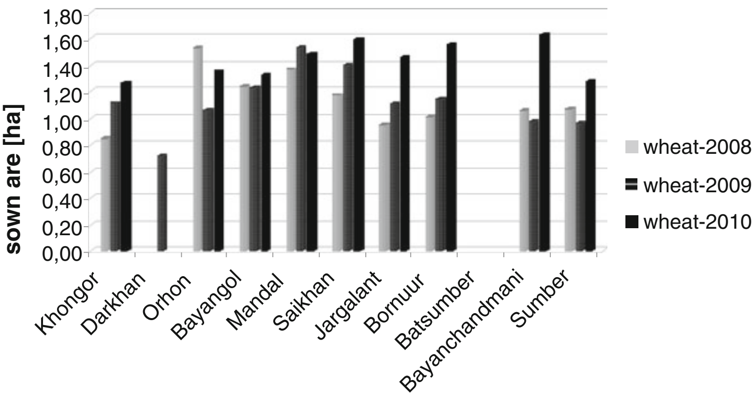

Fig. 19.14 Crop yields at the sum (NUTS 3) level for wheat in the study area from 2008 to 2010, given in tons ha year^{-1} (Data source: MOFA 2011)

Wheat yields generally rose from 2009 to 2010 in almost all of the considered Sums. The average wheat yield for nine sums (excluding Darkhan and Batsumber) was 1.44 t ha year^{-1} for 2010. Figure 19.14 shows the wheat yields for three years (2008–2010). The increase of crop yields is the effect of extensification of arable land and the introduction of irrigation systems.

19.3.4 Irrigation and Water Consumption (Questionnaire Block 3)

National level

In 2010, the total water demand in Mongolia was 327 × 10^6 m^3, of which approximately 54 % was for agriculture, 21 % was for municipalities, 15 % was for industries (including mining), 10 % was for energy and 1 % was for other uses, such as tourism and transport (Mongolian Ministry of Environment and Green Development 2013; Mongolian Water National Programme 2010). Although the agricultural sector is currently (2010) the largest user of water, the projected water demand of the mining sector is projected to exceed the water usage of agriculture in 2021. Approximately 82 % of all water was extracted from groundwater resources. As a result of the Virgin Land III program, the area of wheat cultivation has increased from 350,000 to 618,000 ha between 2005 and 2013. During the same period, the irrigated land area has increased from 5.5 to 7.6 % of the total cropland. Crop yields have been showing a similar pattern of improvement: from 0.7 t ha in 2006 to 1.5 t ha in 2012. This increase has been due to increased irrigation facilities, expansion of the cultivated area, and socio-economic support provided to farmers. In 2012, the total irrigated area reached 48,000 ha. Irrigated land, just 7.6 % of total cropland, supplies 11.1 % of the grain produced; therefore, irrigation has become increasingly important in Mongolian agriculture.

The "Government Strategy of Food and Agriculture", which was approved in 2003, proposed a plan to achieve a total irrigated area of 50,000 ha by the end of 2012. Additionally, the new Government strategy will foster the development of irrigated agriculture and support investment. During the 2010s, cereal crops in Mongolia accounted for approximately 20–40 % of the area irrigated by sprinkler systems; for potatoes and vegetables, this figure was 5–10 %, and for fruit, less than 2 %.

Regional level (*Kharaa River basin*)
Within the KRB, approximately 15,800 ha with the potential for irrigation were identified in the early 1970s. Of this area, 10,912 ha were registered with the potential for irrigation in the 2010s. In 2012, the total area with potential for irrigation was estimated as 4822 ha (Fig. 19.15).

In most cases, an open channel system is used to divert water from the Kharaa River. On the national and province (aimag) levels, the construction of dams and reservoirs on the Kharaa River for the retention and usage of surface water is being planned. Some agricultural companies in Khongor and Zuunkharaa already have installed central pivot irrigation systems to use groundwater.

However, the management of water abstraction remains poor. The water pricing policy is decentralized, and local authorities are entitled to set and revise the water tariffs. Water use for agriculture is free, although every user must establish a contract for the use of water, and household users pay small water fees. In 2012, apartment households had to pay a water fee of 320 MNT per 1 m^3 water (MNT = Mongolian Tugrik, equivalent to 0.13 € or 0.17 USD), while the water fee for the mining companies is only 150 MNT per 1 m^3 water.

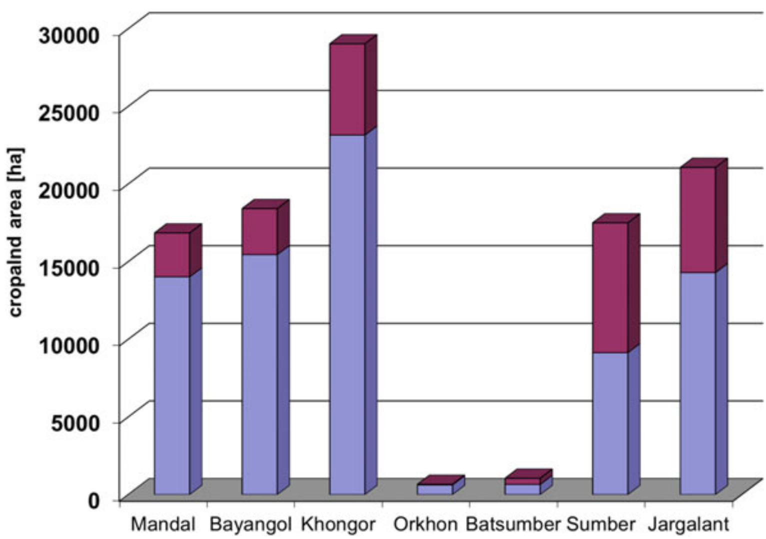

Fig. 19.15 Share of irrigated cropland (dark part of the column) in the Kharaa River basin (Data source: Agrostatistical data of PSARI 2012)

In rural areas, water fees are calculated on the number of wells. In cases of water scarcity, there are no regulations. Water conflicts can arise in KRB between local communities and mining industries, as has already occurred in Boroo Gol. Most of the respondents noted that groundwater extraction has become more important with increasing pollution of the surface waters. Although groundwater resources are sufficient (Hofmann et al. 2014), the technical and economic feasibility of groundwater abstraction are increasingly limiting factors.

19.3.5 Food Security and Future Nutrient Demand (Questionnaire Block 4)

Most agricultural soils have deficits in nutrient provision levels, especially nitrogen and phosphorus. Fertilizer application can significantly increase crop yields, as occurred in the late 1980s. However, Mongolian farmers are coping with widespread low soil organic matter levels, reduced soil nutrient contents, droughts and wind erosion (see Sect. 19.3.3). Despite the potential for increased yields and income by the application of fertilizers, the small and medium-sized farms in this study did not have the resources for this measure.

Nutrients are commonly not replaced to the degree that they are removed by crop harvesting and other losses, resulting in high negative nutrient balances, with a significant deficit of 20 kg ha $year^{-1}$ for nitrogen.

Closing the nitrogen and phosphorus cycles, for example, by the appropriate application of livestock and human waste, could increase cereal and vegetable production. The total per capita annual excretion is approximately 4.4 kg of nitrogen and 0.5 kg for phosphorus. The excretion of total population in the KRB is equivalent to 575 t fertilizer (N, P, K) and is therefore a valuable nutrient resource. The safe use of wastewater, excreta and greywater is an option for future nutrient re-use in agriculture of peri-urban areas (WHO 2006; FAO 2012, UNEP 2011).

Urine is a good natural nitrogen-containing substance (AdeOluwa and Cofie 2012). Using urine as a fertilizer for plants and trees has a centuries-old history. It is a renewable organic resource with the perfect combination of plant-growing nutrients. It also saves water and chemicals when kept out of the sewage stream. Urine provides ideal amounts of nitrogen, phosphorus, and potassium. These three nutrients are essential for the growth of plants.

In Mongolia, the usage of urine as fertilizer has not been accepted. Researchers and farmers agree to use the urine as fertilizer if the required knowledge and technology are provided. However, the usage of feces requires a detailed scientific testing phase to avoid contamination (e.g., fecal pathogens, heavy metals). The application of feces as fertilizer should only be used for non-food production (gardening and trees). Based on calculations for the total nutrient demand (N, P, K) in the KRB, a total of 11,700 t of fertilizer (N, P, K) is required in 2013 to reach a satisfactory level in topsoil of arable land. This amount should be allocated with

8440 t for fallow land and 3260 t for seeds, as calculated by the PSARI in Darkhan (Personal communication by Dr. Tuul in her presentation during the final MoMo conference in April 2013).

19.3.6 Decision Making Criteria (Questionnaire Block 5)

The planning and implementation of measures for future nutrient-cycling strategies requires a decision-making process. The respondents were asked to evaluate several criteria for determining which measures should be taken. Using a matrix of 16 criteria, we wanted to ascertain the relevance of the decision-making criteria. The question was:

If you must make a decision regarding the adoption of a nutrient-cycling strategy by recycling household nutrients (urine and feces), which criteria are relevant?

These criteria can be used in a future participatory multicriteria analysis (MCA) for evaluating measures to choose the preferred nutrient-cycling strategy. As shown by Messner (2006), participatory MCA approaches can include criteria regarding the acceptability of measures and their compatibility with current water policy practices. Moreover, these approaches can be combined with cost effectiveness (CEA) and cost benefit (CBA) techniques (Perni et al. 2013). As a first approach, we identified the weights for the criteria by simply asking the stakeholders about their preferences. This approach underlines the need to improve the process of decision-making by obtaining participation of affected parties with no or reduced decision power. The chosen decision-making criteria are given in block 5 in Appendix. A criteria list was obtained from all four levels (L1 to L4) with 58 respondents, distributed as follows:

- L1: Mongolian National Government (Mongolian Ministry of Food, Agriculture and Light Industry MOFA, 7 respondents);
- L2: Aimag (province) administration level (Food, Agriculture and Light Industry Departments FALID, 11 respondents);
- L3: Agricultural expert level (PSARI, AUD, 10 respondents);
- L4: Farmers and agricultural companies, including livestock herders (31 respondents).

Most of the criteria were addressed by all participants; only criterion 1 (technical feasibility), 2 (low costs) and 4 (low uncertainty regarding specificity) were been ignored by more than 50 % of participants due to a lack of knowledge.

As shown in Fig. 19.16, the most relevant criteria are the assessment of health risks (7), followed by market feasibility (11) and ecological side effects (6). The criteria with the lowest relevance are political acceptance (10) and the financial burden-sharing of stakeholders (13).

The highest degree of consensus concerning the relevance of criteria in all four groups is found for the assessment of health risks (7), organization for the division of labor/duties (14) and ecological side effects (6). However, the highest dissent

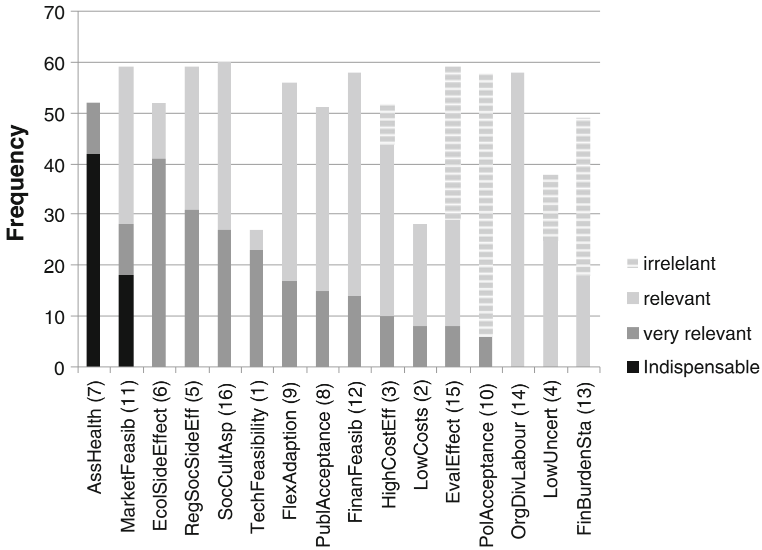

Fig. 19.16 Ranked criteria for decision-making concerning the reuse of nutrients from households (i.e., urine and feces). The Y-axis indicates the frequency of respondents of all of the groups (L1 to L4), and the X-axis refers to the criteria for selecting measures to be evaluated in terms of importance in the decision-making procedure (e.g., AssHealth (7) = Assessment of health risk side effects, criterion No. 7 of block 5 in Appendix)

appears for political acceptance (10): only the Government level (L1) proved this as very relevant, while all other levels (L2 to L4) stated it as irrelevant. Also for market feasibility (11) the group L4 (farmers) marked it as relevant only, while L1 and L2 stated it as indispensable.

The ranking of importance gives a clear message: the implementation of nutrient-recycling from households requires safety guidelines to avoid health risks, measures to convince the consumers for food safety and sustainable management procedures for handling the recycling process.

19.4 Implications for Integrated Nutrient Management (INM) and Its Connection with Integrated Water Resources Management (IWRM)

The applied DPSIR approach highlighted the following situation: an ineffective institutional framework, conflicting interests and lack of coordination hamper the sustainable development of the agro-economic environment. Particularly, the development of a 'forum' for participatory decision-making is needed. This procedure would allow the setting of (achievable) goals and, in the ideal case, would involve all interested parties. One of the most ambitious goals consists of the establishment of sustainable, reasonable and balanced economic integrated nutrient (INM) and water resource management (IWRM).

North America, Europe (EU-28) and China overuse fertilizers, which has already led to a nutrient surplus (MacDonald et al. 2011; Vitousek et al. 2009; Mahowald et al. 2008) as well as pollution, causing eutrophication of freshwater ecosystems and nitrate enrichment in groundwater. In contrast, the agricultural system in Mongolia is characterized by negative balances of the macronutrients N and P. The ambitious aim of self-sufficiency can only be reached by a very large extension of arable land and the price of decreased soil fertility.

In terms of an integrated nutrient management (INM, World Bank 2010), the future nutrient management must calculate and address the regional agronomic P and N imbalances. These imbalances depend on the aggregate effects of many complex factors, such as nutrient management decisions by individual farmers, socioeconomic conditions, government policies and the environmental setting. The key question formulated by Jones et al. (2013) is therefore "How does society socially and environmentally re-engineer these systems at a local and national scale?"

Integrated nutrient management (INM) can be defined as a strategy for the efficient use of all nutrient sources. The primary challenges in sustaining soil fertility areas follows:

- reduce nutrient losses;
- maintain or increase nutrient storage capacity;
- promote recycling of nutrients in plants and human waste;
- apply additional nutrients in appropriate amounts;
- apply shallow/no-tillage and straw mulching instead of traditional plowing techniques;

However, the success and effectiveness of these measures depends on the available water resources and the implementation of the IWRM approach. With respect to water quantity, agriculture is still the most important water consumer in Mongolia due to the high demands of irrigation and livestock. The water demand, especially of the mining sector, is growing rapidly. Discharge trends of rivers show a significant variability, and the use of groundwater becomes increasingly important. In the short term, it may be possible to produce more crops at the cost of depleting (ground-) water resources and/or reducing water availability for downstream users. Thus, in addition to groundwater extraction, water harvesting and recycling, as well as water use efficiency (e.g., drip irrigation), is of increasing importance for agriculture.

Water quality will be an important and limiting factor given that the present situation is characterized by increasing nutrient accumulation in urban areas (solid and fluid waste without reuse). Specifically, there is a high organic and nutrient load in urban waters and a depletion of soil nutrients on croplands. Thus, the increasing nutrient levels of Kharaa river downstream of Darkhan give evidence of a significant eutrophication potential. Due to the release of contaminants (e.g. arsenic) especially from mining activities, the groundwater quality is endangered in some areas close to water abstraction wells in the KRB and other mining areas in Mongolia (Pfeiffer et al. 2014). It will be an important task of the newly created river basin administrations (RBA) and river basin councils (RBC) to apply the IWRM approach under consideration of the INM. This focus on water quality could benefit the nutrient balance in that reuse of nutrients from municipal waste management systems could be used as fertilizer in agriculture (Karthe et al., Chap. 25).

The following factors emphasize the connection between INM and IWRM that also have triggered increased concern on food security in Mongolia:

- increasing human population;
- migration of the rural population into the cities, and growth of peri-urban informal settlements (so-called Ger-areas) with uncontrolled herd populations;
- increasing water demand of different sectors, especially for the mining sector (gold and rare earth);
- increasing livestock numbers in combination with alterations in nomadic migration patterns, which have already led to intensive usage and subsequent degradation of pastures and increasing water demand;
- vulnerability to climate change.

In total, our participatory approach addressed the following measures as priority issues:

1. One of the best ways to maintain fertility and grow healthy crops is to return manure and plant residue (e.g., straw) to crop fields. These materials recycle a large portion of plant nutrients and the carbon removed in harvested crops.
2. Promotion of mixed crop and livestock is essential. Farms with both crops and livestock have the potential to recycle a large portion of the nutrients used by crops back to the soil. This nutrient return is possible because approximately 75 % or more of the NPK consumed in animal feed is excreted as manure or urine. Efficient recycling depends upon storage, handling, and application methods that minimize losses. An effective nutrient management plan should consider the application of manure to fields in amounts that match crop needs with the nutrient content of the manure. Within a farm, manure applications can be a method of transferring nutrients between fields.
3. Growing legumes as a rotating crop to fix atmospheric N reduces the need for purchased fertilizer and increases the supply of N stored in organic matter for future crops. Rotating crops also increases soil biodiversity and nutrient-cycling capacity.
4. Growing cover crops and green manure crops can be performed as a type of crop rotation. Many of the benefits of this approach are the same as those achieved with crop rotation.
5. Efficient fallow management is an essential part of reducing erosion in a crop rotation system. No-tillage is the fundamental management practice that promotes crop stubble retention under longer unplanned fallows during which crops cannot be planted. Such management practice that succeed in retaining

suitable soil cover in fallow Mongolian agricultural areas will ultimately reduce soil loss.

6. A balanced use of synthetic fertilizers (N, P, K) can reduce the current rate of soil nutrient stripping to a certain extent. However, the application requires a holistic protocol consisting of integrated nutrient management (INM) and consulting of agricultural experts in order to avoid negative effects (e.g., a possible nutrient surplus, with negative effects such as nitrate enrichment in groundwater and surface water).
7. Improvement of seed production and quality control is necessary to create reliable and drought-resistant seeds and super seeds. Moreover, the cropping diversity is important given that monocropping of wheat has negative ecological impacts.
8. Opportunities for recycling and recovery of nutrients along food/feed/non-food chain should include the collection and/or recycling of food waste and wastewater sludges (biosolids, urine, feces). Also necessary are inter-farm transfers of livestock manures, industrial-scale recovery of nutrients from large livestock holdings (e.g., pigs and poultry) and sewage treatment works. For the city of Darkhan, a concept and its planned utilization in agriculture has already been elaborated for integrated wastewater management, the reuse of nutrients from households (Karthe et al., Chap. 25)
9. Cost-effective and innovative technologies are required to convert the nutrients contained in bulky organic wastes and wastewater into transportable fertilizers. In addition, the recovery and logistics of transporting must be solved in a cost-effective manner (Jones et al. 2013).
10. Water harvesting, recycling and conservation in the root zone is necessary to reduce the need for supplementary irrigation.

The consequences of the current agricultural extension mechanisms and soil nutrient stock deficits require a holistic approach (Jones et al. 2013). Without the input of organic matter, degraded soils have low water and nutrient capacities. Therefore, these soils often do not respond to the addition of inorganic fertilizer. Numerous studies indicate that there can be strong synergism in the use of both organic and inorganic fertilizers (World Bank 2010). The challenge of supplying sufficient P and N to meet agricultural demands without degrading soil and freshwater resources will be a key issue for Mongolia's agriculture and water resource management in the 21st century.

19.5 Conclusions

Achieving self-sufficiency in the food supply and improvement of the highly endangered soil fertility will require remarkable scientific and technical efforts of those involved in the management of agricultural production in Mongolia. Although Mongolia could increase crop yields by conversion of grassland to arable land, new problems have emerged. These include conflicts with the pasture management of herdsmen and the decrease of nutrient and carbon concentrations in the topsoil, which is favored by the mono-cropping of wheat. Another user conflict is emerging in the water sector; the water demand of the mining sector has acquired increasing importance in Mongolia and is likely to exceed the demand of agricultural irrigation. In addition to this intersectoral competition on available water quantity, the efficient use of water and nutrients will be an upcoming task for the implementation of sustainable measures. Thus, the concept of integrated water resources management (IWRM) needs to consider integrated nutrient management (INM). As has been shown for a modular concept of nutrient reuse in Darkhan city (Karthe et al., Chap. 25), such reuse could improve both sanitary conditions and reduce the nutrient surplus in urban areas. Thus, the multiple use of water and the reuse of nutrients in peri-urban agriculture could reduce the observed agricultural nutrient deficits. The options for sustainable land management include (i) the adoption of no-till farming in conjunction with cover cropping and complex rotations (conservation agriculture); (ii) integrated nutrient management (INM) involving biofertilizers and inorganic fertilizers to create a positive nutrient budget; and (iii) water conservation (water harvesting and recycling), including supplemental irrigation using drip sub-irrigation.

For the first time, a nutrient balance for the cropping systems in Mongolia has been established, with the KRB as an example. As a result of the stakeholder participation, we can conclude that in addition to a lack of land possession rights, economic constraints are an important bottleneck. The main issues are as follows: a lack of effective crop insurance in the agribusiness sector, insufficient soft loans, petrol and finance deficiencies during spring tillage and harvest, a lack of direct marketing from the farmer to the customer and low storage capacities. The situation is exacerbated due to increasing numbers of non-professional farmers within the growing agricultural business.

There is agreement among all levels (L1 to L4) regarding the necessity of substituting conventional farming systems with improved technologies (including irrigation), sustainable tillage, fertilizing techniques and improved marketing conditions. However, the public participation of stakeholders for the selection of cost-effective measures is just beginning in Mongolia. Thus, to sustain small farm productivity, there is an urgent need to increase farmer participation and to include farmer perspectives in both national and province agricultural development planning as well as in policy formulation processes.

The scientific concepts that underlie soil fertility and the knowledge of local farmers can be combined in a participatory process that allows a better understanding of the current situation, which is necessary for the selection of cost-effective measures. This process is now increasingly supported by researchers and policy-makers. As demonstrated in the context of water management issues, local knowledge and the participatory process are able to select cost-effective measures properly (Perni and Martínez-Paz 2013). Regarding our study case, the stakeholders agreed that the establishment of sustainable nutrient-cycling strategies is a priority for avoiding the current state of “soil mining”. The re-use of nutrients from households can only cover approximately 5–10 % of the total nutrient demand for agriculture in our study area. However, it would be a first step for peri-urban agriculture and would provide a double benefit given that the collection and re-use of urine and feces would improve the existing sanitary problems in villages and urban areas. Scientific and effective concepts of productive sanitation and soil fertility improvement should be able to achieve the desired degree of participation given that this topic has a strong connection to both water/nutrient resources management and food security.

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Appendix: The Questionnaire

Foreword

The IWRM project "MoMo" (Integrated Water Resources Management in Central Asia: Model Region Mongolia) is funded by the German Federal Ministry of Education and Research (BMBF) in the framework of the "Research for Sustainable Development" (FONA) program (www.fona.de). During the project period 2006 to 2013 the development and implementation of strategies leading towards an integrated water resources management (IWRM) has been developed and locally adapted. More information about the project can be found at the official MoMo homepage (www.iwrm-momo.de)

The objective of the interviews was the integration of stakeholder participation, expert knowledge and the feedback of their willingness to adopt for future nutrient cycling methods. Therefore the main objective was the analysis of measures, their costs and efficiency for their implementation into future nutrient cycling strategies in Kharaa River Basin (KRB).

On the one hand we considered the development of strategic plannings for agriculture on aimag (Mongolian term for "province") level (Darkhan Uul, Selenge and Tov aimags). On the other hand the participatory approach also included the perspective of the following levels:

L1 = National Government (Mongolian Ministry of Food, Agriculture and Light Industry MOFA, http://www.mofa.gov.mn)
L2 = Aimag level (Departments of Food, Agriculture and Light Industry (FALID) of Darkhan Uul, Selenge and Tov Aimag) and Soum (Mongolian term for countries) level (=Khongor (Darkhan), Sumber (Tov), Jargalant (Tov), Mandal (Selenge)
L3 = Agricultural expert level (Plant Science and Agricultural Research Institute PSARI, Agricultural University Darkhan AUD)
L4 = Level of farmers and agricultural companies including livestock herders

Block 1: General questions

1.1 Please give a short description of the main tasks and objectives of your Department (L1), your municipal authority (L2)/your working unit (L3)/your private company (L4)/your field of interest (L5).
1.2 Only for levels L1 to L3: What are the most important changes after the last elections for the National Parliament (June 2012) for the sector of Food Security and strategic development planning for agriculture?
1.3 Only for levels L1 to L3: What is the importance of the National Development and Innovation Committee (Is it belonging to the Ministry of Finance and directly mandated to the Prime minister?)
1.4 Only for levels L1 to L3: What is the current status on the legislative initiative for a "Crop insurance" to mitigate the risks in cropping sub-sector and to establish legal environment of the cropping sector?
1.5 Only for levels L1 to L3: What is the current status on the legislative initiative of cropland possession by crop producers in respective laws and legal acts to improve landuse?
1.6 Only for levels L1 to L3: What is the current status on the legislative initiative to legalize allocation of certain percentage of mining income to agricultural cropping sector development as investment?
1.7 Only for level L4: How much agricultural area is cultivated by your private farm or company? And how much of it belongs to fallow land?
1.8 Only for level L4: The agricultural area can only be used as a leasehold. What is the maximum time period of leasing the agricultural land? Would you prefer to be the owner of our land?
1.9 In total 519 crop producing entities and farmers with 102,000 ha cropland are situated within the Kharaa river basin. Could you give a short overview about the agro-economical situation in the Kharaa river basin? How many of the 519 crop producing entities can be allocated to small scale (<500 ha), medium scale (500–2000 ha) and large scale level (>2000 ha)?
1.10 Are any foreign companies active in agriculture and horticulture? If yes, please give details.
1.11 Are there any agriculture cooperatives in the Kharaa river basin? If yes, please give details.
1.12 Are there any Farmer Field Schools to promote knowledge of good management practice in agriculture and horticulture? If yes, please give details.
1.13 What are in your opinion the most relevant economical problems for agriculture and horticulture in the Kharaa river basin?
1.14 What are in your opinion the most relevant environmental problems for agriculture and horticulture in the Kharaa river basin? (e.g. erosion, insufficient plant nutrition etc.)
1.15 How important are these topics (Questions 1.10 to 1.14) for your activity or to what extent do they affect your interests?

Block 2: Soil fertility and crop yields

2.1 Only for level L3: Which system is used to have an index number for soil fertility?
2.2 Only for level L3: How does soil fertility vary in the Kharaa river basin?
2.3 What was the crop yield per ha for wheat and potatoes in the year 2011?
2.4 Which kinds of crop rotation systems are used in your area of interest? What are the benefits of those systems?
2.5 Where do you get your seeds from?
2.6 What is your experience with regard to reliability and drought-resistancy of seeds?
2.7 Only for level L3: How could seed quality and supply be improved?
2.8 Do you use fertilizer? If yes, which type of fertilizer? And where do you get your fertilizer from?
2.9 What is the price for fertilizer? (Tugrik per kg or tons)
2.10 Only for level L4: Do you use manure (e.g. from barnstables or sheep corrals) as natural fertilizer for horticulture? If yes, what is your experience?
2.11 Which kind of subsidies are provided by the government to buy fertilizer?
2.12 Which kind of loans are provided by the government or agricultural banks for investments in machines for seeding, ploughing, harvesting?
2.13 Are there any problems with soil salinization within the arable land? If yes, please give details to specify the location, explain the occurence and possible countermeasures.
2.14 Only for level L4: Do you own any livestock? If yes, how much sheeps, goats, horses, cows?
2.15 Is there any import of extra fodder (hay) for livestock into the Kharaa river basin? If yes, please give details.
2.16 Are there any conflicts between farmers and livestock herders? If yes, please give examples of conflicts and their possible solutions.
2.17 Only for level L3 and L4: Are there any cash crop rotation systems in combination with legumes? If yes, what is your experience?
2.18 Only for level L3 and L4: What is your general working scheme for ploughing, seeding and harvesting?
2.19 Only for level L3 and L4: Are any erosion control measures by preserving cultivation feasible? If yes, what are the additional costs for investment (a) and running costs (maintenance costs) (b) (Tugrik per ha) for the farmers?
2.20 Only for level L3 and L4: Are any erosion control measures by cultivation/ploughing parallel to the contours/slope feasible? If yes, what are the additional costs for investment (a) and running costs (maintenance costs) (b) (Tugrik per ha) for the farmers?
2.21 Only for level L3 and L4: Are any measures against wind erosion applied by planting shelterbelts? If yes, what are the additional costs for investment (a) and running costs (maintenance costs) (b) (Tugrik per ha) for the farmers?
2.22 Only for level L3 and L4: Which other measures should be implemented for erosion control?

Block 3: Irrigation and water consumption

In the Kharaa river basin different economic sectors (agriculture, households, energy, industry, horticulture, mining) use large amount of surface water and groundwater.

In the agricultural sector (and other sectors) several information gaps exist, which we need to reduce to establish a meaningful IWRM framework.

Several technologies are applied using surface and groundwater sources. We identified open canal surface irrigation using water from reservoirs; groundwater or surface water pumping for surface irrigation with tubes by individual farmers or companies, large sprinklers usually using groundwater; drip irrigation in greenhouses for vegetables using groundwater (and surface water?) by farmers and companies.

3.1 How many hectares are irrigated in the Kharaa River Basin using which technology (sprinkler system, open channel, irrigation well with aluminium pipes)? Please use Figs. 19.1 and 19.2.
3.2 Please allocate the irrigation users to the size distribution of irrigation schemes (four classes: 0–10, 10–50, 50–200, 200–500 ha). If possible, mark them on the map in Fig. 19.2.
3.3 Are there any programmes on national or Aimag level to support the rehabilitation of old irrigation schemes, to expand irrigated farming area, to introduce innovative irrigation technologies and to construct rain water collection systems? If yes, please give details.
3.4 What is the price for construction of irrigation systems as open channel (Tugrik per km length), sprinkler irrigation (Tugrik per ha of irrigation area) or other systems?
3.5 Are there any plans to build dams or reservoirs at Kharaa river for the retention and usage of surface water? If yes, where and to which extent?
3.6 How are water abstractions by agriculture managed? Are there any regulations? Or can they abstract as much water as they want?
3.7 Which restrictions or laws are relevant for the water management/water abstraction of the agricultural sector?
3.8 Is there any prioritisation of the water users in case of water scarcity (laws or regulations or recommendations)?
3.9 Which type of water fees apply for the different users and how much do they pay per m^3?
3.10 What other users' interests conflict with yours in the area of water consumption? Who is particularly affected by these interests?
3.11 What initiatives and measures do the affected people, NGOs or political organisations undertake in order to solve this situation?

Block 4: Food security

410,000 to 430,000 tons of wheat is required per year to satisfy the growing demand of the nation. 448,000 tons of wheat was harvested from 301,000 ha in 2011, fully satisfying domestic demand for wheat. For the future the preservation of this level has a high priority to become independent from imports. But: Analysis of soil samples indicated that 73 % of the total cropland of Kharaa river basin has low provision level of nitrogen and 35.3 % by phosphorus.

4.1 The priority of the government policy is to intensify crop production and irrigated farming, and to improve land efficiency. How would you evaluate the current institutional structure in this frame? What are its strengths and weaknesses?
4.2 During the last 50 years as a result of intensive cultivation practices the soil humus content has been reduced by 14.6–43.6 %. Which measures are necessary and feasible to increase the humus content of soil?
4.3 The total per capita annual excretion is about 4.4 kg of nitrogen and 0.5 kg for phosphorus. This is a valuable nutrient resource. Safe use of wastewater, excreta and greywater is an option for future nutrient re-use in agriculture of periurban areas. What is your opinion about products made from urine and faeces as fertilizer?
4.4 What policy could improve the water consumption sector (e.g. taxes, stricter controls, stricter laws and regulations, stricter targets, voluntary agreements)?
4.5 What policy could establish a nutrient recycling sector (e.g. taxes, stricter controls, stricter laws and regulations, stricter targets, voluntary agreements)?
4.6 What policy could improve transport and marketing of agricultural products (e.g. taxes, stricter controls, stricter laws and regulations, incentives)?
4.7 How would you evaluate the current institutional structure in this frame (Questions 4.4 to 4.6)? What are its strengths and weaknesses?

Block 5: Decision making criteria

Planning and implementation of measures for future nutrient cycling strategies requires a decision making process. With the following matrix we want to know the relevance of your decision making criteria. The question is:

Which criteria are relevant, if you have to make a decision for a new measure for nutrient cycling strategy (reuse of urine and feces from households). Please evaluate each of the criteria by marking it with a cross (X).

No.	Criteria for selecting measures to be evaluated in terms of importance in the decision-making procedure	Evaluation: This criterion is			
		Indispensable	Very relevant	Relevant	Irrelevant
1	Technical feasibility				
2	Low costs				
3	High cost effectiveness				
4	Low uncertainty in specificity				
5	Regional socio-economic side effects				
6	Ecological side effects				

(continued)

(continued)

No.	Criteria for selecting measures to be evaluated in terms of importance in the decision-making procedure	Evaluation: This criterion is			
		Indispensable	Very relevant	Relevant	Irrelevant
7	Assessment of health risk side effects				
8	Public acceptance				
9	Flexibility for necessary adaptions				
10	Political acceptance				
11	Market feasibility				
12	Financial feasibility				
13	Financial burden sharing of stakeholders				
14	Organisation for the division of labour/duties				
15	Evaluation of the effectiveness				
16	Socio-cultural aspects				

Additional question: Do you have questions or suggestions in relation to the questionnaire?

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Chapter 20
WebGIS-Based Approach to Simulate Water and Solute Fluxes in the Miyun Basin in China

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Abstract The Miyun reservoir, located approximately 100 km North-East of the Beijing municipality, is one of the main surface water supply sources for the 20 million people living in this metropolitan area. For a variety of anthropogenic and natural reasons the Miyun reservoir suffers from increasing water quantity and quality problems. Over the past 20 years the reservoir water level has declined by 10 m and the water quality status is classified as "mesotrophic" with a tendency to "eutrophic". This means the water does not fulfil the requirements for use as drinking water. This book chapter describes the bottom-up research strategy for monitoring and modelling water and solute fluxes in the catchment as a basic precondition to establish sustainable management strategies. It focuses on the connection of hydrological investigations from plot to field via sub-catchment scale and meso-scale modelling in the Miyun catchment area with the STOFFBILANZ model. It is demonstrated how this model was adapted to the natural conditions of Northern China. Based on practical examples of land use change strategies and

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improvement of wastewater treatment the use of the model to calculate different scenarios to reduce non-point and point source pollution in the Miyun catchment area will be shown.

Keywords Water protection · Diffuse pollution · Hydrological measuring system · Lysimeter · Modelling

20.1 Introduction

The Miyun reservoir is the main source of drinking water for the Beijing agglomeration. It suffers from increasing water quantity and quality problems caused by a relatively high population density that increases economic pressure on soil and water resources. Inadequate land use, monocultures, over-fertilization, excessive livestock breeding in scattered areas, uncontrolled disposal of waste and insufficient wastewater treatment in the rural areas are the main causes for an increasing trend of water pollution in the reservoir. Additional stressors which influence water quantity as well as water quality are long term droughts, water abstractions by farmers, sediment delivery, fishpond aquaculture and growing tourism. Over the past 20 years the reservoir water level has declined by 10 m. Intensive agriculture is now practiced on the former lake bed. The mentioned reasons led to a continuing deterioration of the raw water quantity and quality from the Miyun reservoir, which is endangering the sustainable access to drinking water for the capital city. Improving the management of the Miyun watershed environment is therefore vital to secure a sustainable drinking water supply of the Beijing agglomeration.

Different studies have been published which deal with the problems of water quantity and quality in the Miyun catchment area (Ou and Wang 2008; Xu et al. 2009; Ma et al. 2010; Chen et al. 2011). Nevertheless, there is a lack of specific regional knowledge of the processes of runoff generation, as well as of sediment and nutrient dynamics. Quantification of water, sediment and nutrient fluxes and identification of relevant processes is difficult and has not yet been accomplished. Ongley et al. (2010) compared methods for non-point source estimation developed in the United States with regard to their application to the Chinese natural and economic conditions. They postulate: ‘Empirical research is limited and does not provide an adequate basis for calibrating models…’ and: ‘The Chinese agricultural situation is so different from that of the United States that empirical data produced in America as a basis for applying estimation techniques to rural non-point sources in China often do not apply.’ The monitoring results of our project emphasize the necessity to explore and learn from the processes first and then to parameterize the modelling tools to consider the very regional specific situation of climate, relief and management (Meissner and Hagenau 2013). A bottom-up research strategy (Fig. 20.1) was used in order to develop and implement a scientifically based management system for point and non-point source pollution control in the Miyun basin.

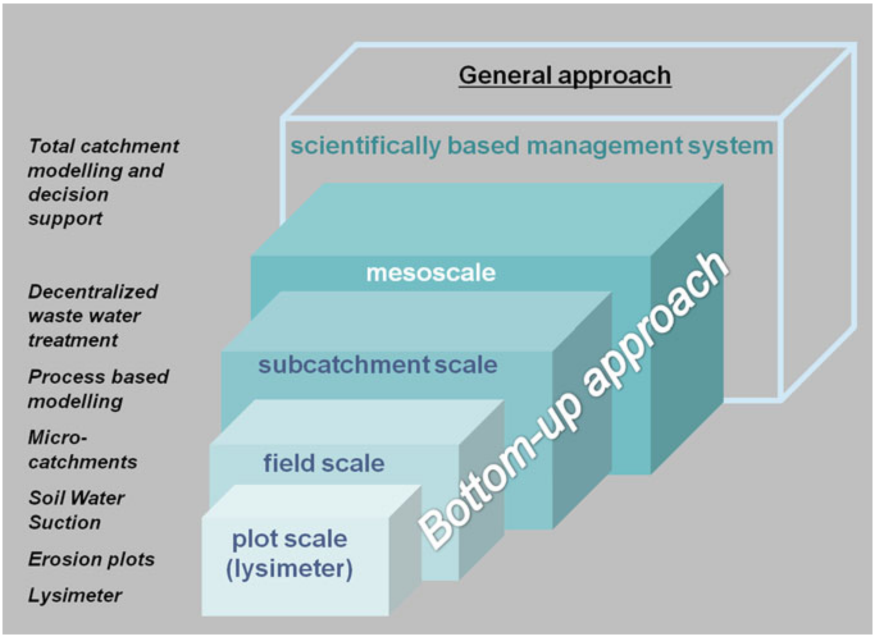

Fig. 20.1 Conceptual design of the bottom-up approach

This approach was based on the following topics:

- Establishment, respectively refining of a pedo-hydrological monitoring network on a plot, field, and sub-catchment scale in representative areas to identify main water and nutrient pathways.
- Evaluation of wastewater treatment systems for settlements in the rural areas, adapted to the needs of the region as well as development and demonstration of technical solutions and management systems for the reduction of nutrient inputs into the reservoir.
- Adaptation of the WebGIS-based water and solute balance model STOFFBILANZ based on monitoring results as well as wastewater treatment findings and additional data review on climatology, geography, hydrology, land use, population etc.—for the entire Miyun catchment as the fundamental tool to support the scientifically based management of the basin.

The main focus of the book chapter is (i) the presentation of the research concept regarding pedo-hydrological measuring activities on different scales, (ii) to display the connection of the aforementioned activities to improve the model STOFFBILANZ for a future use in the region, and (iii) to show mitigation options to reduce diffuse and point source inputs into the Miyun reservoir.

20.2 Materials and Methods

20.2.1 Study Area

The area of the Miyun catchment with a total extent of 15,654 km^2 is part of the provinces Beijing and Hebei, bordering the Mongolian Plateau in the Northern parts of China (Fig. 20.2). During the investigation period approximately 381,000 people were living in the entire Miyun catchment area; approximately 273,000 people in rural areas and 108,000 people in urban areas (Statistical Yearbook of China 2009/2010, data from the Beijing Water Authority-BWA).

The major part of the Miyun catchment area with altitudes ranging from 60 to 2,200 m above sea level is mountainous with steep inclinations. Annual average precipitation in the semi-arid continental monsoon climate is lower than 500 mm/a and occurs mainly in summer, whereas winter and spring are extremely dry (Chen et al. 2010). Precipitation increases from East to West; annual average temperature increases from South-East to North-West, ranging from 6.3 to 10.9 °C. Land cover is dominated by rocky mountain forest (54.8 %) with a smooth transition to shrubbery, heath and dry grassland (31.5 %). Cropland (10.7 %) can be found mainly in the valleys and in intra-mountainous basins (cf. Fig. 20.2), carrying fertile soils in quaternary sediments (e.g. loess), but also on the dry lakebed of the Miyun reservoir

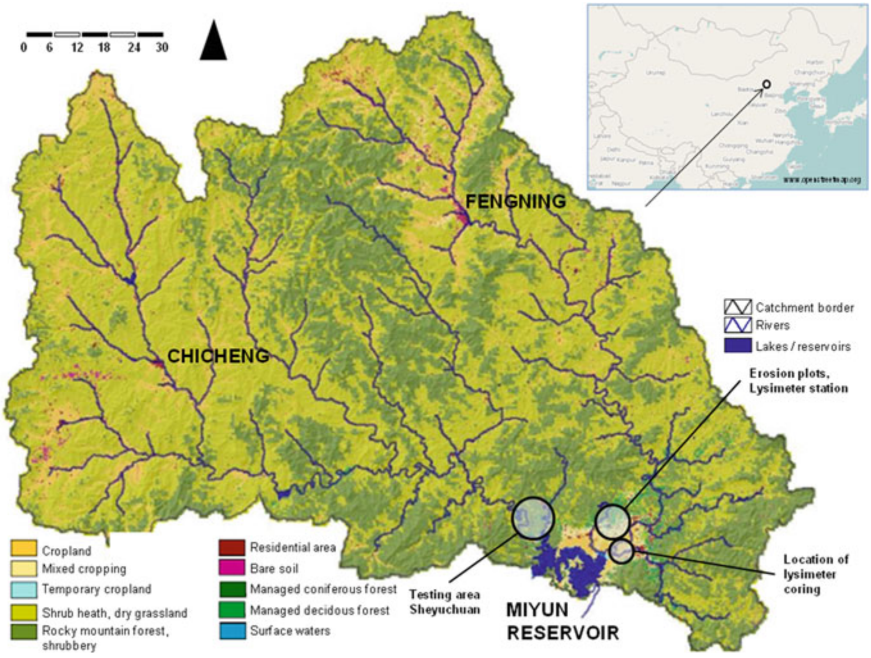

Fig. 20.2 Land use and monitoring network in the Miyun catchment North-East of Beijing

with its continually decreasing water surface caused by droughts in the last 20 years. Residential and commercial areas as well as deciduous and coniferous forests have a share of 1 %. Surface waters cover 0.5 % of the catchment. Parameters of agricultural management, livestock density and population density were taken from the China Statistical Yearbooks. Census data were provided by the Chinese authorities, aggregated to the township level for both provinces Beijing and Hebei. Recently, major planted crops are maize (59 %) and vegetables (16 %).

According to the typology of the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009) there is a mixture of Fluvisols, Luvisols, Cambisols and Kastanozems/Greysems in flat or hilly areas, whereas the mountainous area is mainly covered by Leptosols. The soil information is based on the Food and Agricultural Organization (FAO) soil map, combined with a terrain analyses to exclude natural vegetation areas, which are not significantly represented in this map.

20.2.2 Monitoring Network

20.2.2.1 Pedo-hydrological Network

A basic precondition for the development of a realistic management system for the Miyun reservoir is the availability of representative hydrological data sets. A first survey showed that basic measuring stations in the investigation area are available but not in use or damaged. According to the bottom up research strategy a scale dependent pedo-hydrological network was established. It was the aim of this network to measure essential water and solute balance parameters. In cooperation with the Chinese partners different pedo-hydrological measuring systems at plot, field and sub-catchment scale have been installed during the years 2010 and 2011. It should be mentioned that the measuring network is still in operation under supervising of the Beijing Water Authority (BWA).

For an improved management of the Miyun reservoir the elucidation of different pollution pathways is important. The surface pathway via erosion or point pollution via wastewater was already known or expected. But no information existed regarding the subsurface pathway, especially the amount of groundwater recharge and seepage water quality. Furthermore, basic soil hydrological parameters as actual evapotranspiration (ETa), water content, matrix potential were not available or completely unknown. For this reason a sophisticated weighable container lysimeter station was established (Fig. 20.3). It was constructed and prefabricated in cooperation between the Helmholtz Centre for Environmental Research-UFZ and the UGT-Environmental Devices Company Muencheberg Ltd. in Germany and transported to China. The lysimeter container was installed into the Shixia-experimental station where the Chinese project partner BWA carried out long term erosion experiments with Wischmeyer-plots (Wischmeyer and Smith 1978) (cf. Fig. 20.2). Two representative and undisturbed soil columns (surface area 1.00 m^2, depth

Fig. 20.3 Construction of the lysimeter facility at the Shixia research station: **a** prefabricated lysimeter station after the seaway transport; **b** pit for the lysimeter station; **c** preparation of the steel lysimeter vessels; **d** insertion of the prefabricated lysimeter container station; **e** monolithical extraction of the lysimeter soil column; **f** insertion of the lysimeter vessel into the container lysimeter station; **g** view to the almost finished lysimeter station with two lysimeter vessels and a manhole for inspection and maintenance; **h** maize plants at the finished lysimeter station in July 2011; **i** principal sketch of the weighable container lysimeter station

2.00 m) were extracted from a now dry part of the former reservoir bottom. This site is especially vulnerable because the lake disappeared and is the area is presently used for the intensive production of maize with a high amount of fertilizer application. A detailed description regarding the construction, operation and practical application of this weighable gravitation lysimeter type, the extraction technology and the twofold containerized lysimeter station can be found in Meissner et al. (2007). Furthermore, the site was equipped with two conventional rain gauges (Hellmann-type) at a height of 1.0 m. Since April 2011 the lysimeters were used and managed by the Chinese partners. As mentioned before, both lysimeters (used as replicates for statistical reasons) were planted with maize-monoculture and agriculturally managed and fertilized according to the typical regional farmers' practice.

Besides the lysimeter station, soil-hydrological measuring stations have been installed in the catchment at six representative positions (Table 20.1). These hydrological units cover the spectrum of the pedo-hydrological characteristics of the Miyun basin. The stations are usually equipped with tensiometers to measure the matrix potential in the soil at two depths (mostly between 10–30 and 40–60 cm, depending on the soil conditions). Additionally, temperature probes and suction plates to extract soil solution (for chemical analysis of soil water quality) at the same depths have been installed. The measuring system works continuously and all data are stored in a data logger. These hydrological field measuring stations ensure a reliable picture of the soil water balance at the different sites of the Miyun catchment area.

To close the gap between the plot, respectively field measuring to a hydrological unit, gauges at the sub-catchment scale were installed or former available gauges were renovated (cf. Table 20.1). The variety of these gauges include intensively used (e.g. Sheyuchuan and Huairou sub-catchment) as well as widely pristine areas (e.g. Renji Golf Ressort). By this strategy it was possible to compare the runoff

Table 20.1 Pedo-hydrological measuring network in the Miyun catchment

Name of the pedo-hydrological unit	Location and vegetation	Type of measurement	Geographical position
Shixia	Former lake bed, approximately 4 km from the Miyun-reservoir, planted with maize; extraction site for the two lysimeter soil monoliths	Soil-hydrological measuring station	40° 32′ 30.99″ N 117° 2′ 46.36″ E
Sheyuchuan Terrace West	System of terraces, north of Shenmiao, chestnut vegetation with beans and maize	Soil-hydrological measuring station and two gauges to measure discharge	40° 39′ 1.46″ N 116° 48′ 32.97″ E
Sheyuchuan Terrace East	System of terraces (stone wall), chestnut vegetation with beans and maize	Soil-hydrological measuring station and gauge to measure discharge	40° 39′ 0.01″ N 116° 48′ 38.54″ E
Huairou sub-catchment	Terrace with apricot trees	Soil-hydrological measuring station and gauge to measure discharge	40° 21′ 49.15″ N 116° 32′ 5025″ E
Huairou Gully	Gully erosion, strong slopes, poor soil, chestnut trees	Soil-hydrological measuring station	40° 23′ 25.15″ N 116° 33′ 30.31″ E
Renji Golf Ressort	Ephemeral stream, natural vegetation (largely pristine area)	Soil-hydrological measuring station and gauge to measure discharge	40° 21′ 14.01″ N 116° 32′ 37.82″ E

formation at different pedo-hydrological conditions. The gauges measure the discharge and store the data in a logger continuously. Furthermore, the Chinese partners tried to take event based water samples at the gauge at irregular intervals and analysed essential water quality parameters such as nitrogen (N), phosphorus (P), electrical conductivity, and pH-value. In addition, it should be mentioned that the Sheyuchuan sub-catchment (experimental catchment with an area of approximately 28 km^2) was used to establish a nested approach for the detailed investigation of runoff formation (cf. Fig. 20.2). Therefore gauges have been installed at different hydrologically relevant positions (0.8 km from the upper stretch, than after 5 km at the middle stretch, and 5 km before the tributary leaves the sub-catchment) to measure the detailed development of runoff formation in the area and to compare it to the results from pedo-hydrological measuring stations which are also located in the sub-catchment.

20.2.2.2 Wastewater Treatment Facilities

Beside N and P, which enter the Miyun reservoir via the diffuse pathways from the surrounding agricultural and forest areas, a further major pollution pathway is the input of untreated sewage. In the Miyun area wastewater is mostly discharged without any treatment. Therefore, point sources from settlements were investigated to get the necessary information about the wastewater pathway and its impact on nutrient emissions (Kröger et al. 2012). Additionally, to demonstrate sanitation technologies in rural areas two different types of wastewater treatment facilities were designed, constructed and installed. First, a rotational biological contactor (RBC) was built in 2011 as a pilot plant and further intended as a training facility to demonstrate the effectiveness of small biological treatment plants. As a second sanitary concept a composting toilet with urine separation was built in 2012 according to the EcoSan (ecological sanitation) principles (Haq and Cambridge 2012). This simple sanitation technology should demonstrate the sustainable use of natural resources in the rural area.

20.2.2.3 Model STOFFBILANZ

The WebGIS based software STOFFBILANZ (Gebel et al. 2012a, b, 2014a, b) was used to calculate runoff, soil loss, sediment and nutrient input into the Sheyuchuan experimental sub-catchment as well as in the entire Miyun catchment area. The approach requires a minimum of parameters to run the model and is suitable for modelling at the meso-scale. These data were integrated into a grid with variable cell size (125 × 125 m up to 500 × 500 m; app. 366,000 grid cells) (Fig. 20.4). Cropland as well as residential areas got the highest resolution in order to optimize the indication of critical source areas. Due to limitations of governmental data, freely available spatial data (30 × 30 m ASTER DEM, 30 × 30 m Landsat TM, Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009,

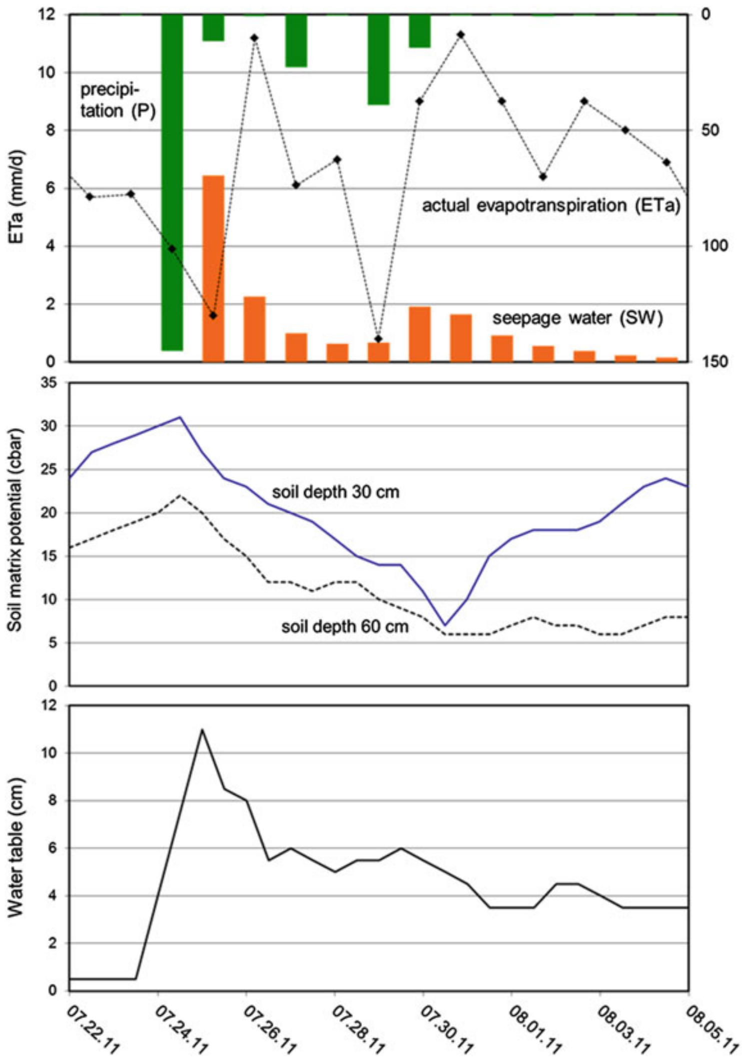

Fig. 20.4 Short term effects of rain events in July and August 2011 on essential water balance parameters in the Miyun catchment; time course of **a** precipitation, seepage water amount and actual evapotranspiration from a gravitation lysimeter planted with maize, **b** matrix potential in two different depths at a soil-hydrological measuring station at Shixia, and **c** changes of the water level at the Sheyuchuan lower gauge

combined with a digital soil mapping procedure) were mainly used to get information about the basic landscape pattern.

Grid-based climate data were only given as monthly long-term average values from the WorlClim dataset (1960–1990, 1,000 × 1,000 m, http://www.worldclim.org, accessed 11 Sept 2013, Hijmans et al. 2005). In order to generate a daily distribution of temperature and precipitation values, the monthly WorldClim dataset was combined with a daily distribution from a given meteorological station in the central part of Miyun catchment area for the reference year 2009. Thus it was possible to consider the runoff events with a daily resolution, whenever the monthly sum of precipitation corresponds to the long-term WorldClim dataset. Daily meteorological data are the result of this disaggregation and do not correspond directly to observed values in detail. If real values were available in the future, they should be used instead of the modeled ones. Nevertheless, it was possible to simulate water fluxes based on these data, which give a typical impression of the recent situation of runoff formation with a daily resolution for this study area which is typically influenced by monsoon climate. In the Sheyuchuan sub-catchment climate data from Chinese BWA experimental Shixia station were used for the year 2011.

To guarantee a sufficient temporal resolution in the simulation, the following procedures were carried out on a daily basis:

- calculation of the FAO dual crop evapotranspiration under soil water stress conditions (Allen et al. 1998),
- direct runoff calculation according to the Curve Number Approach (Hawkins et al. 2009; Gebel et al. 2012a),
- estimation of erosion yield according to the USLE-M approach (Yu and Rosewell 1996; Kinnell 2001) and sediment input into surface water according to Voges (1999), Veith (2002) and Halbfass (2005).

Calibration of the model was done with the help of the process based monitoring results as well as the point source information from representative residential areas. Particulate P inputs into surface waters were calculated considering sediment input, nutrient enrichment and total P (TP) content in topsoil, which was derived from land use type and soil texture (Zhang et al. 2005). In addition, we simulated diffuse dissolved P losses with the help of estimated P export coefficients for seepage water and direct runoff. The simulation of N surplus in the root zone, N input via direct runoff and N input via deep percolation is based on mass balances calculated for each grid cell (Gebel et al. 2012b). Calibration and testing of the meso-scale modelling approach was done on the basis of the continual monitoring activities directly in the Miyun catchment area at the lysimeter station (plot scale), the soil-hydrological measuring stations (field scale) and in the small experimental sub-catchment Sheyuchuan (sub-catchment scale).

20.3 Results and Discussion

20.3.1 Hydrology

After the monitoring system was fully installed, evaluation of data series covering more than 1 year in some cases, depending on location and purpose, could be commenced. The lysimeters have been generating continuous high-quality data since the end of April 2011. All other measurement systems which have been installed during the investigation period now work reliably as well.

The lysimeter data revealed that seepage water is present, leading to a degree of groundwater recharge that has not been anticipated in the study area (data not shown). This finding was surprising, especially for the Chinese partners, because the climatic water balance (difference between precipitation and evapotranspiration) is highly negative. However, this result corresponds to own investigations in floodplain areas where groundwater recharge also occurred in some periods during the year, even though the yearly climatic water balance is negative (Bethge-Steffens et al. 2004). Furthermore, a tendency was found that the seepage water carries a heavy load of N (about 100 kg N ha) and also P (about 0.1 kg TP ha), so there is an acute risk of nutrient transport into the Miyun reservoir via a subterranean (groundwater) pathway (data not shown because of very limited availability). Especially vulnerable are the dry areas of the former Miyun reservoir lake bed. These sites are intensively used for agriculture (maize production) and have been identified as critical source areas for diffuse nutrient input. This management practice should be stopped as the water level in the reservoir may increase again.

The results from the pedo-hydrological network showed that individual rainfall events in the study area give rise to quite marked hydrological responses. For example, a heavy rainfall of 140 mm within 4 h on 24 July 2011 led to a significant increase in the amount of seepage water from the lysimeters (Fig. 20.4a). At the same time the matrix potential in both soil depths decreased at the Shixia pedo-hydrological measuring station (Fig. 20.4b; location not far away from the position of the lysimeter facility at Shixia experimental station). In addition the surface runoff and the discharge at the corresponding Sheyuchuan gauge increased markedly, visible at the rising water level (Fig. 20.4c) and caused a soil erosion event and a transfer of sediments into the surface water (data not shown). During the investigation period it could be observed that just a few rainfall events were responsible for most of the pollutant transport into the reservoir.

20.3.2 Modelling and Examples of the Implementation

20.3.2.1 Lysimeter Observation and Modelling Soil Water Balance

Calibration and testing of the meso-scale modelling approach STOFFBILANZ was done on the basis of the continual monitoring (Meissner and Hagenau 2013) at the lysimeter station (plot-scale) and in the small sub-catchment Sheyuchuan (micro-scale).

The lysimeter data revealed a substantial amount of seepage water in July 2011, caused by a heavy rainfall of more than 100 mm d^{-1} (cf. Fig. 20.5). The monitoring results underline that the episodic character of the rainfall pattern and the processes which this sets into motion have to be modelled with high resolution at the meso-scale in order to properly depict critical source areas, transport pathways and

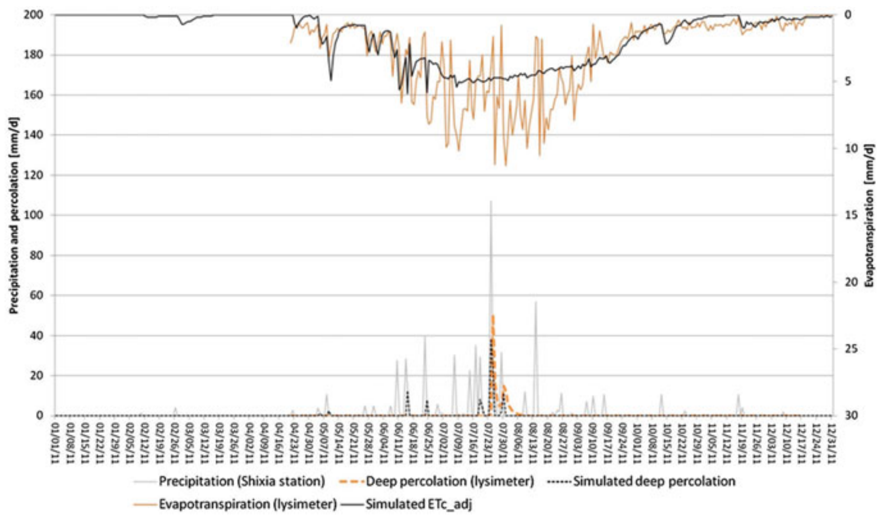

Fig. 20.5 Comparison of measured lysimeter data and model results with STOFFBILANZ for actual evapotranspiration and deep percolation for 2011

solute loads. The lysimeter as well as field and sub-catchment observations were used to learn from the processes of runoff generation and to calibrate the crop evapotranspiration under soil water stress conditions (ET_{cadj}) and deep percolation simulation (cf. Table 20.1).

The difference between the observed rainfall at the lysimeter and the corrected rainfall at a meteorological station nearby (Hellmann rain gauge) underlines, that there is a significant influence of dewfall, especially at the plant-covered lysimeter plot in summer (Meissner and Hagenau 2013). To consider this additional water supply of approximately 60 mm during summertime the observed “Hellmann”-rainfall was corrected by 1.15 on rainy days for June, July and August as the result of an iterative approach based on the analyses of available lysimeter data (UFZ). The increase of rainfall amount is about 61 mm. A further correction was made for the reference crop evapotranspiration term (ET_0), which meant a reduction factor for the same period of time of 0.90. This is due to the fact that evapotranspiration was overestimated during the summer period with rainfall and dewfall and very high air humidity at the crop site (Meissner and Hagenau 2013; Gebel et al. 2014a).

Figure 20.5 depicts the result of this calibration. The simulation of evapotranspiration corresponds well with the observation. In summertime the amplitude of simulated evapotranspiration is much lower than the one observed by the lysimeter. This is due to the fact that the simulated soil moisture as well as the evapotranspiration term remains at a constantly high (maximum) level during that period. Plant interception and the evaporation from the plant surface are not included in the modelling in an adequate way, because it is focusing on soil-water-plant-interactions. In contrast to that the lysimeters give continual (every 10 min) information about the changes of mass, caused by the fluctuating evapotranspiration term. A positive peak appears after the rainfall event and shows, how much water is evaporated from the wetted soil, but also from the wetted plant surface. The observed evapotranspiration by the lysimeter is therefore a little bit higher compared to the simulated one. The simulated values were compared to the observed ones for average values of periods of 7 days. The calculated Nash–Sutcliffe model efficiency coefficient is 0.78 (Nash and Sutcliffe 1970). According to the soil-water-fluxes, which are more important from our point of view, the results of the simulated deep percolation correspond well with the observed one with a calculated Nash–Sutcliffe model efficiency coefficient of 0.75 for the 7 day periods. A daily comparison was neglected, because flow distance and retention time is neither included in the soil-water-budget of the ET_{cadj} approach nor in the curve number approach.

20.3.2.2 Comparison of Runoff Monitoring and Runoff Simulation in the Sheyuchuan Experimental Sub-Catchment

Simulations in sub-catchment Sheyuchuan were done for 2011 too, using available information about the runoff situation at the automatic gauging station for this year. The hydrograph is based on the observation of the water level (h) at a 5 min interval, combined with a h/q (runoff)—relationship. Observed total runoff is about 80,000 mm/a and 7 mm/a, respectively (Fig. 20.6).

A first significant runoff peak appears on July 24, precipitation events before this time are not relevant for the runoff at the weir. The sum of observed runoff in this sub-catchment is rather small, in comparison to regional literature data. According to Ma et al. (2010), there is an average total runoff of 41.8 mm/a in the Miyun catchment area from 1984 to 2005, with an estimated water abstraction of 20 % for irrigation purposes. For the period from 1998 up to 2005, total runoff is lower than 30 mm/a. Nearly half of this amount is abstracted for irrigation leading to a respective decrease of the inflow into the reservoir. This evaluation corresponds to the BWA data for the period 2000–2005 with average runoff values of 17.3 mm/a (Bai River) and 15.4 mm/a (Chao River in the more dry Western part) respectively, but also to UNEP (2008) with an annual total runoff in the Miyun catchment area of 13 mm/a.

A closer look at the Sheyuchuan sub-catchment shows that there might be a large water abstraction too, which could exceed 100,000 m^3 per year. For the biggest reservoir upstream of the weir a storage capacity of approximately 40,000 m^3 was estimated. It was completely filled with water in winter, which was probably stored for water supply on cropland in spring time. It is assumed that there is a large water abstraction in the following months, too, to ensure irrigation on cropland during the vegetation period. This has to be included in the discussion of monitoring and modelling results with the Chinese partners in the region.

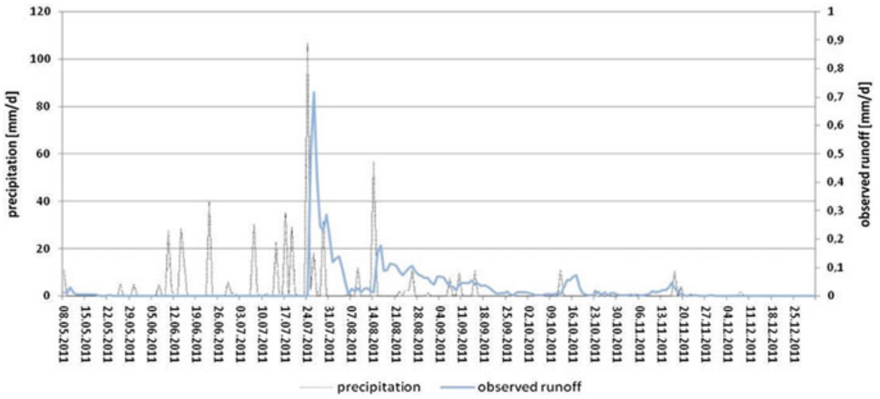

Fig. 20.6 Observed runoff at the downstream weir of the north-western part of Sheyuchuan in 2011

Simulated direct runoff for 2011 is about 27 mm/a. Higher values were calculated on cropland, residential areas and bare soil, lower ones on areas with a natural or semi-natural vegetation (mountain forest, shrubs).

The results of the deep percolation modelling according to the ET_{cadj}-approach showed higher percolation rates on cropland, residential areas and areas with bare soils. A significantly lower percolation was simulated on sites with a natural or semi-natural vegetation, because of the higher soil coverage by plants and the higher evapotranspiration rates. A comparison of measured and simulated runoff parameters for Sheyuchuan is shown in Fig. 20.7. Simulated water fluxes are dominated by direct runoff (26.9 mm/a), deep percolation is about 1.7 mm/a only. Simulated total runoff is about 28.6 mm/a; the observed one is much lower with only 7 mm/a. The calculated Nash–Sutcliffe model efficiency coefficient for average values of 7 day periods is 0.01, which is an expected low value (Nash and Sutcliffe 1970). Comparing the simulation to observed values one has to be aware that the model is not able to record the time delay of groundwater flow in general. Flow distances and retention time are not included in the soil-water-budget of the ET_{cadj} approach.

According to the modelling three big rainfall events in July are causing runoff events as well. Only two of three showed a significant runoff peak at the weir. For the last rainfall event before the big rain on 24 July 2011 starts the simulated runoff peak is not confirmed by the weir observation. One reason for this phenomenon might be that the runoff is stored in different reservoirs upstream of the weir. The runoff generation at the weir will then start after the storage capacity is exceeded. The first simulated runoff event is about 4 mm and corresponds to the estimated storage capacity of the biggest of these reservoirs (estimated to be 40,000 m^3). Additionally, one has to be aware that the observed difference can be caused by uncertainty of the simulation as well. Secondly, it has to be considered that there is no meteorological station located in the sub-catchment to give detailed site-specific

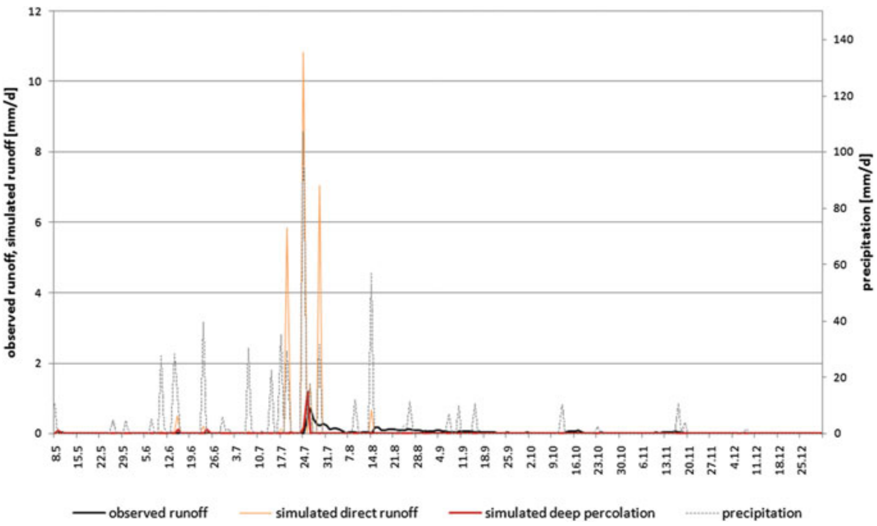

Fig. 20.7 Comparison of observed and simulated runoff parameters for Sheyuchuan sub-catchment in 2011

information about the events. Therefore data from Shixia experimental station were used, which is about 20 km away from Sheyuchuan.

Finally, we can state that the main events in the simulation are described well from a chronological point of view. The differences in simulated and observed runoff amounts can be explained at least to a certain extent by the practiced water abstraction. However, reliable information about the amount of this water abstraction is missing at the moment. The results were also compared with the deterministic WaSiM-ETH-simulation (Meissner and Hagenau 2013). The simulation of the total runoff for reference year 2011 of Sheyuchuan (45.8 mm/a) underlines the thesis that there is a large water abstraction upstream of the weir. The simulation by the STOFFBILANZ software also corresponds well to average values given in the literature (see discussion above). In summary, it should be possible to give sufficient information about runoff generation and water fluxes at the meso-scale too.

20.3.2.3 Runoff Simulation in the Miyun Catchment Area

After successful calibration with lysimeter results and testing in the Sheyuchuan sub-catchment, the knowledge of local process generation was transferred to the total catchment area of Miyun. According to the meteorological data set all calculations are based on the climate data pool of 1960–1990, combined with the event-based daily meteorological data for the year 2009 from the central Shixia meteorological station in the Miyun catchment area. Thus, it was not possible to validate the results for a particular year, but only for long-term observations of total runoff.

The results of the FAO-grass reference evapotranspiration modelling range from 970 mm/a in the South-Eastern part to 1.293 mm/a in the North-Western part. The simulation of direct runoff is presented in Fig. 20.8.

The average value for the total catchment area is about 11.7 mm/a. Percolation from the evaporating layer into the root zone was calculated by the ET_{cadj}-approach with an average value of 132.5 mm/a for the total catchment. Percolation from the root zone into groundwater is about 3.1 mm/a (Fig. 20.9).

According to UNEP (2008) the annual water inflow into the Miyun reservoir is about 200,000,000 m^3, corresponding to a total runoff of 13 mm/a. BWA confirmed these data for the period 2000–2005 with average runoff values of 17.3 mm/a (Bai river) and 15.4 mm/a (Chao river), respectively, and a range from 7.4 to 31 mm/a (Bai river). Water abstractions, which can be estimated to be at least 20 % of the total runoff (Ma et al. 2010), have to be added to compare the observed values with the simulated total runoff in the Miyun basin of 15 mm/a. According to these estimations the simulation results are in good agreement with the range of the literature and monitoring data. Nevertheless, the simulation tends to be a little bit too low because of underestimation of the cropland share (Xu et al. 2009) by the remote sensing survey. Cropland and residential areas are the most important land use types for runoff generation.

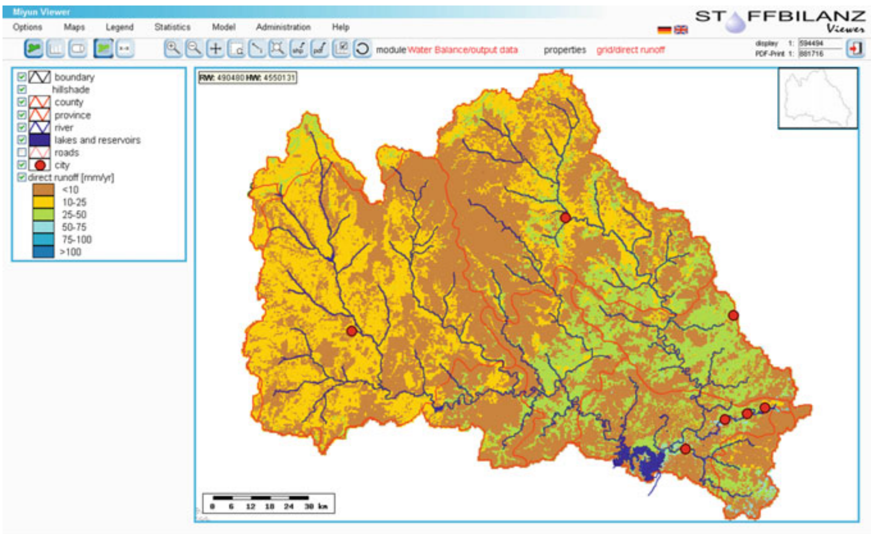

Fig. 20.8 Simulation of direct runoff in the Miyun catchment area (reference year 2009)

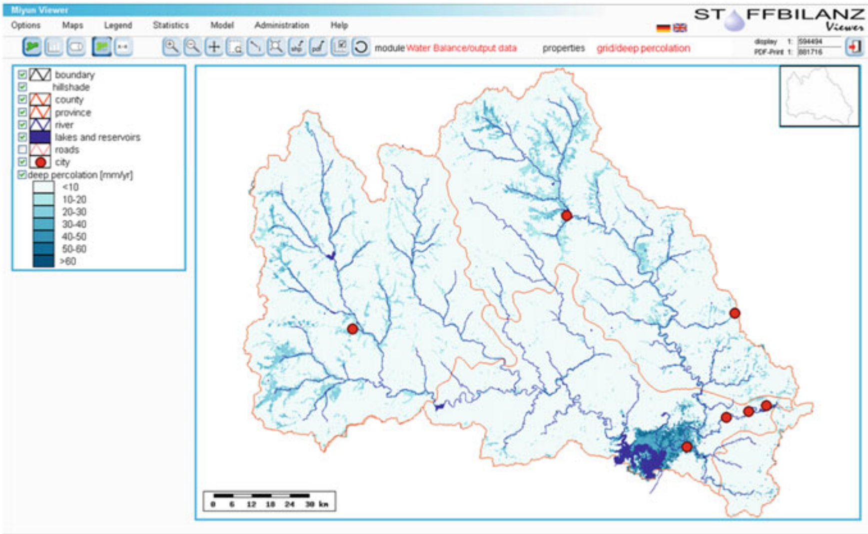

Fig. 20.9 Simulation of deep percolation (groundwater recharge) in the Miyun catchment area (reference year 2009)

20.3.2.4 Meso-Scale Estimation of Nutrient Inputs

Non-point source input

The estimation of N surplus was realized by a very soft balancing approach due to the lack of more precise data of agricultural management and waste water treatment in the region. N surplus in the root zone from cropland is about 154.4 kg N ha. Non-cropland contributes an average surplus of 6.1 kg N ha.

Total diffuse N losses from each grid towards the catchment (N input) are given by the sum of the load from grid based direct runoff and deep percolation. Average values of N input into surface waters via direct runoff and deep percolation are about 2.7 kg N ha and 2.2 kg N ha, respectively (cf. Fig. 20.10). Nitrate concentrations in leachate (deep percolation) were calculated as 409 mg/l on temporary cropland of the dry bottom of the Miyun reservoir. These values are well in the range of the first observed seepage concentrations from the lysimeter (on average 398 mg/l NO_3^-) and the soil water samples from areas near the reservoir (on average 409 mg/l nitrate in subsoil horizons deeper than 60 cm). Nitrate concentrations from forest sites are much lower (on average 23.6 mg/l in Miyun county) and also correspond to the monitoring results in the Sheyuchuan sub-catchment (on average 39.4 mg/l nitrate in 2008, data from BWA).

Diffuse N input into surface waters from all land use types is 7,833 t year^{-1} in total (4,217 t year^{-1} by direct runoff; 3,616 t year^{-1} by deep percolation towards the surface water bodies).

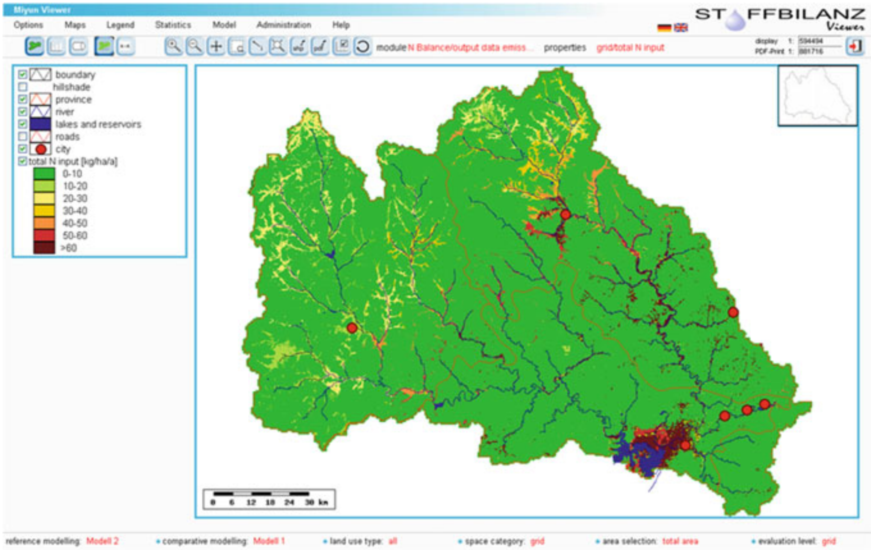

Fig. 20.10 Simulation with the model STOFFBILANZ of the total diffuse N input in the Miyun catchment area (reference year 2009)

The simulation of soil erosion (1,457,908 t year^{-1}) and sediment input from all grid cells into the catchment (172,713 t year^{-1}) is well within the range of observed values from soil erosion plots at Shixia station and sediment and runoff observations for the Chao and Bai river (further details see Gebel et al. 2012a, 2014a, b).

Based on TP content of the topsoil and simulated sediment input, the particulate P load into surface waters from all grid cells was calculated in sum as 178,402 kg year^{-1} (average of 0.114 kg ha). Diffuse dissolved P leaching (sum of 5,008 kg year^{-1}, average of 0.003 kg ha) is based on estimated P concentrations in the soil matrix for the different land use types. The resulting average total diffuse P concentration in total runoff is about 0.78 mg/l in Miyun county. This value is well in the range of the observed drain concentrations of the lysimeter and the soil water samples from areas near the reservoir (n = 19, different subsoil horizons, average: 0.89 mg/l, standard deviation: 1.42, range: <0.01 to 4.41 mg/l, data from BWA and UFZ).

Point sources input

To assess the effectiveness of the different treatment technologies to mitigate the nutrient emissions into the Miyun reservoir the loads and pathways of wastewater in the basin and inside the different technologies have to be defined (Table 20.2). Daily human nutrient loads due to excretion from the population were taken from Jönsson and Vinnerås (2004).

Table 20.2 Pathways of wastewater from different treatment systems and the assumed efficiency for the model STOFFBILANZ

Parameter	Unit		N	P
Daily excretion	G cap^{-1} d^{-1}		10.9	1.6
Pathway 3-chamber-septic tank	%	Degradation Fluid phase Sludge	0 99.3 0.7	0 88.0 11.2
Pathway MBR	%	Degradation Fluid phase Sludge	65.1 16.5 18.4	0 0.8 99.2
Pathway RBC (pilot plant, see scenario 3)	%	Degradation Fluid phase Sludge	0 86.8 13.2	0 77.5 22.5
Pathways Compost toilet (see scenario 4)	%	Degradation Urine Faeces	0 80 20	0 55 45

In settlements near the reservoir most of the wastewater is discharged into soakaway pits or 3-chamber-septic-tanks (Kröger et al. 2012). For the modelling it was assumed that approximately 70 % of the wastewater is treated in this treatment systems and the rest is discharged directly without treatment. Septic tanks have a relatively low cleaning efficiency. For the modelling a reduction of 7 % for N and 11 % for P was assumed in the cell structure of the heterotrophic biomass. These anaerobic treatment systems are mostly built of bricks, which is why solutes from untreated wastewater seep directly into the ground. Therefore, it was assumed in the modelling that 50 % of the dissolved nutrients seep into the reservoir.

In tourist villages with a highly developed rural infrastructure sophisticated biological treatment plants (membrane bioreactor plants—MBR) are available. However, they are poorly maintained, overloaded and the cleaning efficiency is extremely low. In the modelling, the potential effect of this technology should be assessed. Because measured effluent concentrations were not available, potential achievable nutrient removal under normal operation was considered, assuming that the plant complies with the Beijing local standard (BWA, unpublished). In the model it was assumed that the sewage sludge of the treatment systems would be applied to the fields and that the nutrient amounts lead to an equal reduction of mineral fertilizer. Information about industrial sewage were not available and therefore not taken into account in the calculation of the resulting N and P inputs from rural and urban municipalities into surface waters. The modelled emission pathways for the current status are summarized in Table 20.3.

Total input

In the total area point sources are of minor importance for the entry of N (9 %) but certainly more relevant for P (29 %). Point sources are poorly treated wastewater from households and from numerous poultry farms.

Table 20.3 Nitrogen and phosphorus inputs into surface waters from diffuse and point sources (without industrial emissions), modelled with STOFFBILANZ

	N emission into surface water (t $year^{-1}$)	P emission into surface water (t $year^{-1}$)
Diffuse sources—cropland	6857	176
Diffuse sources—non-cropland	976	7
Point sources—rural area—direct discharger	326	48
Point sources—rural area—septic tanks	403	68
Point sources—urban area	71	1
Diffuse and point sources—total area	8633	300

20.4 Scenario Analysis for Mitigation Options

Mitigation options were integrated into the model STOFFBILANZ to show their effects on N and P reduction in order to optimize future management in the catchment area as part of a decision support process. For the demonstration of different mitigation strategies the following four scenarios were created:

- Scenario 1: N is mainly determined by the high N surplus on farmland. In order to achieve an effective reduction in these areas the fertilizer amounts were reduced to 50 %.
- Scenario 2: It was assumed that an implementation of conservation tillage (no-till cultivation) is carried out on the share of farmland in Miyun County that was assessed as non-terraced (≤3° inclinations).
- Scenario 3: In this scenario it was assumed that in rural areas direct dischargers use the RBC (rotational biological contactor) plant technology for wastewater treatment. For the simulation the locally determined cleaning effectiveness of 5.3 % for N, and 4.5 % for P was taken into account according to the results of our monitoring in the pilot plant which was established during the project (detailed data not shown).
- Scenario 4: Finally, it was assumed that all direct dischargers in rural areas will use composting toilets. 100 % of the collected urine and faeces are used as fertilizer, the applied quantity of N-P-fertilizer will be reduced by this nutrient equivalent (Kirchmann and Pettersson 1995; Stintzing et al. 2001; Jönsson and Vinnerås 2004; Malisie et al. 2007).

In scenario 1 the N load over all grid cells and land uses was reduced on average from 5.0 kg to 3.9 kg ha. The concentration of N in seepage water from cropland will be reduced by 25 % (corresponds to a decrease of 99 mg/l). In the total catchment area over all land uses the effectiveness was significantly lower with a reduction of 23.4 mg/l (corresponds to a decrease from 108.9 to 85.5 mg/l). By this mitigation option the N load into the reservoir will be reduced by 1,775 t $year^{-1}$ in total (Fig. 20.11). The investigations at the lysimeter confirmed that there is no reason to expect yield losses due to the supposed fertilizer reduction.

Soils with a (temporarily) missing vegetation cover are the main sources for soil erosion and particulate P input from each grid into the catchment. For this reason it was assumed in scenario 2 that the conventional plough-tillage on the mono-culturally used cropland (app. 100 % maize, no crop sequences) will be totally replaced by conservation tillage (C-factor according to the Universal Soil Loss equation = 0.06; Gebel et al. 2014b) on all cropland sites in Miyun county (South-Eastern part of the catchment area) which are not terraced. This limitation was necessary, because a no tillage practice needs machinery which cannot be used on terraces due to technical restrictions. Compared to the present state with conventional tillage, soil erosion on cropland in Miyun county could be reduced from 9,272 to 2,620 t ha. Particulate P input could be reduced from 35,968 to 9,597 t $year^{-1}$ (Fig. 20.12).

For the mitigation of nutrient input from point sources the installed wastewater facilities were included in the simulations of scenario 3 and 4 (Fig. 20.11). In comparison to the RBC plant (scenario 3), N would be reduced by 17 t $year^{-1}$ (0.2 %), and P by 2.2 t $year^{-1}$ (0.7 %), respectively. Scenario 4 assumed that the excrements from composting toilets would be used as organic fertilizer and lead to an equal reduction of mineral N-P-fertilizer. The reduction for N input was calculated as 326 t $year^{-1}$ (3.8 %) compared to the present state scenario. P would be reduced by 48 t $year^{-1}$ (16.0 %). The mitigation effect of sanitary systems on eutrophication may be quite low compared to measures in agriculture, especially in Miyun county. But with regard to the oral-faecal route of diseases (e.g. cholera, hepatitis, typhus) an efficient wastewater treatment is highly important. In turn, this means that the listed evaluation criteria in future studies must be completed.

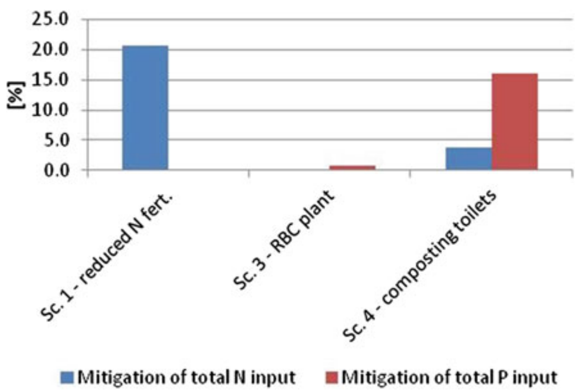

Fig. 20.11 Mitigation of N input in the entire Miyun catchment area by the scenario (Sc.) 1, 3 and 4, modelled with STOFFBILANZ (scenario 2 see Fig. 20.12)

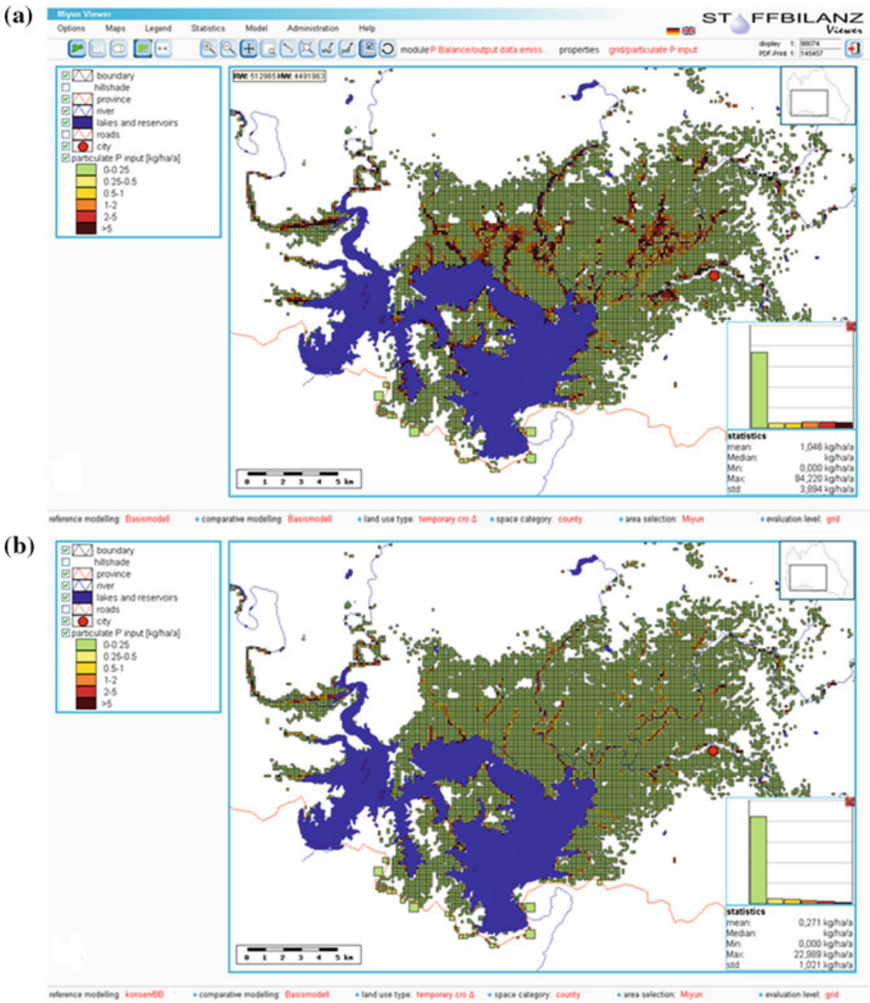

Fig. 20.12 Particulate P input in Miyun county on cropland for **a** present state and **b** scenario 2—conservation tillage, modeled with STOFFBILANZ (reference year 2009)

20.5 Conclusions

The Miyun reservoir, the main surface water supply source of Beijing suffers from a decreasing water quantity and quality. To secure a sustainable water supply of the Beijing agglomeration an integrated management system is necessary for this catchment. A fundamental step in this direction was the establishment of a pedo-hydrological monitoring network and the application of a balance model to estimate water and solute fluxes. After the determination of nutrient input and transfer dynamics at different scales, the data were used to simulate runoff, soil losses, sediment and nutrient inputs in the total catchment area with the WebGIS-based model STOFFBILANZ. According to our simulation cropland is the most relevant critical source area for N input, followed by the point source pollution in the rural area. P input is dominated by particulate P inputs via soil erosion and sediment input, followed by point sources.

A first decision support was given by different simulations considering a selection of mitigation options in order to improve future management in the catchment area. By a combination of scenario 2 (conservation tillage on cropland) and 4 (compost toilets/use of faeces to substitute mineral fertilizer) an approximately 85 % P reduction could be possible in Miyun county. A reduction of N input by about 21 % was estimated by scenario 1 (reduced mineral fertilizer) in the entire catchment area. Compared to that the effects of scenario 3 (sewage treatment by RBC plant) and scenario 4 (composting toilets) are much lower. Nevertheless the simulations of present state and future scenarios are preliminary and only a first step to establish an integrated water resources management because the availability of spatial and monitoring data (runoff, nutrient loads and concentrations) was very limited. The high uncertainty of data should be reduced in future water resources management by the responsible water authorities in order to heighten the reliability of the simulation results. The basis to reach this goal is the future use of the monitoring network. Furthermore, training courses with the model STOFFBILANZ for the Chinese scientists and stakeholders have been carried out during the last years. The model is also freely available for the Miyun region in a basic version. Stakeholders and scientific staff of project partners are invited to use this framework to add own results and to improve the process of decision making. Modelling results are now available on the Web interface and can be used for decision support and regional management implementation by the local water authorities.

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Chapter 21
Dynamic Land Use Change as Challenge for IWRM: A Case Study in Central Brazil

Carsten Lorz, Pablo Borges de Amorim, Claudia Franz, Rene Höfer, Lars Koschke, Jorge Enoch Furquim Werneck Lima, Franz Makeschin, Michael Strauch and Holger Weiß

Abstract The management of water and land resources in the Distrito Federal (DF), Western Central Brazil is characterized by very dynamic changes of land use/land cover driven by economic development, population growth and climate change. This problem is addressed by the project IWAS-ÁGUA DF which aims at creating a scientific base for the sustainable management of water and land resources in scope of an IWRM approach for the Distrito Federal. Land use change and climate change are affecting water resources in the Distrito Federal already substantially. Major effects identified during the project phase are (1) decreasing base flow during the dry season, partially caused by the expansion of agriculture and urbanization and (2) sediment generation and siltation of reservoirs mostly caused by urbanization. The general objective of the project is to contribute to an IWRM approach for the Distrito Federal, identifying causes of problems and possible solutions to maintain sustainable water supply for the region. The objective of the selected five case studies was to develop approaches with focus on all river basins of DF (1) to assess effects of land use on water resources in the past and with focus on the Pipiripau river basin (2) to predict the efficiency of measures (environmental services) and

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(3) to develop approaches for land use planning as part of an IWRM. For the Lago Paranoá basin two further case studies (4) for the identification of sediment sources and (5) to classify urban areas in terms of effects on water resources were carried out.

Keywords Base flow · Land use planning tool · River basin management · Sediment sources · SWAT · Water scarcity

21.1 Introduction

Water and land resources in Brazil have recently come under considerable pressure due to dynamic change of land use and land cover (LULCC) driven by economic development, population growth, and climate change. Urbanization, high shares of urban population and expansion of agriculture are seen as major causes for environmental problems in Brazil, e.g. overexploitation and pollution of water resources (Braga et al. 2008; Hespanhol 2008; Tucci 2001, 2008). This applies in particular to regions prone to water scarcity and/or water pollution. In addition to the specific natural conditions, i.e. strong seasonal contrasts and climatic variability, the rapid changes of land use/land cover—caused by the drastic expansion of agricultural land and urbanization processes—have severe effects on water resources. However, global climate models predict substantial changes in future climate and, in consequence, severe additional effects on water resources are to be expected. In addition, rising demand for water supply and production of waste water can be expected—both in terms of amount and spatial expansion—due to higher population densities caused by natural population growth and migration as well as higher per capita consumption (PGIRH 2012). Understanding the complex interactions between water, climate, land use and society is a crucial step to achieve sustainable water supply with high standards in regard of quality and reliability. The Distrito Federal (DF) in Western Central Brazil belongs to the type of region described above. As climate change and very dynamic processes of urbanization and expansion of

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agriculture are going on in this area, substantial impacts on water resources can be expected. In conclusion it can be stated, that the demand for IWRM concepts is increasing, also due to rising awareness for a sustainable and reliable water supply.

In scope of an IWRM approach, the Brazilian-German project IWAS-ÁGUA DF (www.ufz.de/iwas-sachsen/index.php?de=18049) aims at creating a scientific base for the sustainable management of water resources for the Distrito Federal. The project follows the DPSIR approach (EEA 1999), which identifies driving forces and pressures on the water resources system and analyses the state, the impacts and the response of these compartments. Reasons for choosing the region are the unique opportunity to have an outstanding data base on water relevant information, the existing high standards in terms of technology and capacity development in the water sector, and very dynamic changes in land use, especially urbanization.

The general objective of the project was to contribute to an IWRM approach for the DF, identifying causes of major water related problems and showing possible solutions to maintain sustainable water supply for the region. The objective of the selected five case studies was to develop approaches with focus on all river basins of DF (1) to assess effects of land use on water resources in the past and with focus on the Pipiripau river basin (2) to predict the efficiency of measures (environmental services) and (3) to develop approaches for land use planning as part of an IWRM. For the Lago Paranoá basin two case studies (4) for the identification of sediment sources and (5) to classify urban areas in terms of effects on water resources were carried out.

21.2 The Study Region

The Distrito Federal covers an area of 5790 km^2 (Fig. 21.1) and is located in the high plains (*planalto*) of Western Central Brazil with altitudes between 1000 and 1450 m a.s.l. The geological underground consists of series of metasediments, i.e. argillic to sandy rocks of the Paleozoic period. Soils are mostly Oxisols, Cambisols—developed in deeply weathered saprolite or outcrops of the rocks mentioned above—and Gleisols developed in alluvial sediments. The study region belongs to the outer tropics (Aw climate after Köppen) having mean annual precipitation of 1300–1700 mm and mean annual temperatures of 20–21 °C (WMO 2010). The climatic conditions are characterized by strong seasonality. The dry season comprises 5–6 months, during south-winter, from late March to late September. The amount of precipitation during rainy season is in average four times higher than during dry season.

Effects of climate change are already observable for the last three decades in Central Brazil (Borges et al. 2014). Since the end of the 1970s a trend to longer dry season with less rain days at the beginning and the end of the dry seasons as well as a general trend for lower mean annual precipitation has been observed for five monitoring sites in the Distrito Federal (Table 21.1). However, this trend is not significant for all stations but it explains a part of the dramatic decrease of base flow discharge during the dry period (Lorz et al. 2012). For the future longer dry seasons are predicted for DF (Borges et al. 2014).

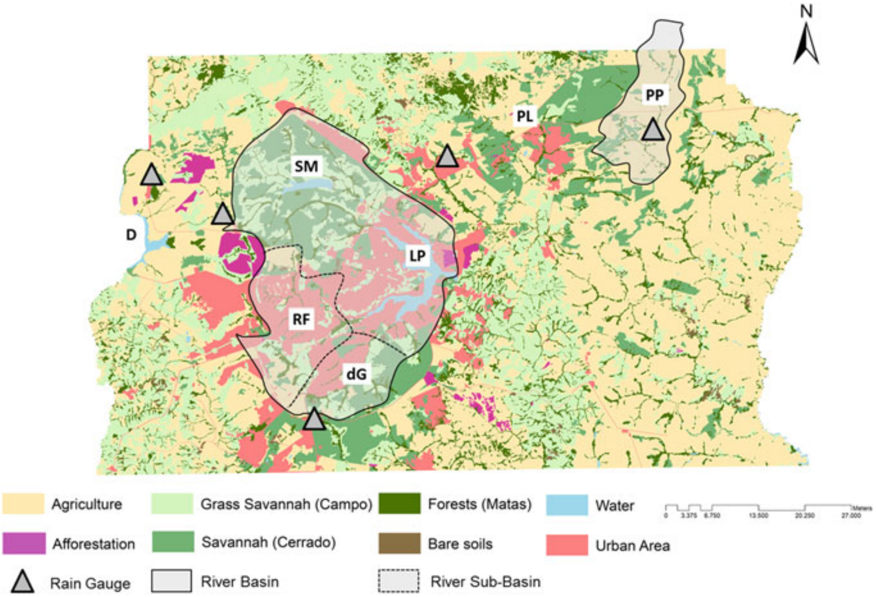

Fig. 21.1 Land cover of the Distrito Federal in 2006 (Fortes et al. 2007), *LP* Lago Paranoá basin, *SM* reservoir St. Maria, *D* reservoir Descoberto, *PP* Pipiripau river basin, *RF* Riacho Fundo river sub-basin, *dG* Gama river sub-basin, *PL* Planaltina

Table 21.1 Mean annual precipitation (MAP) for five rain gauges (see Fig. 21.1 for location) in the Distrito Federal and trends (Kendall's tau) for rain days at the begin/end of rain seasons and annual precipitation (Mann-Kendall test) (Lorz et al. 2012)

Monitoring station	Period	MAP (mm)	Rain days April/May	Rain days October	Annual precipitation
A 1547013	1978–2009	1332	*−0.25*$^+$ *(May)*	**−0.26***	*−0.24*$^+$
B 1547014	1979–2006	1480	**−0.36** (April)**	*−0.18*$^+$	*0.08*$^+$
C 1547015	1978–2004	1419	*−0.17*$^+$ *(May)*	**−0.26***	*−0.04*$^+$
D 1548007	1978–2008	1560	*−0.25*$^+$ *(May)*	**−0.26***	*−0.12*$^+$
E 1548008	1979–2006	1444	**−0.31* (May)**	**−0.35****	**−0.33***

$^+$Two-sided $p > 0.05$ (not significant), *two-sided $p < 0.05$ (significant), **two-sided $p < 0.01$ (very significant), rain days are days with any recorded rainfall

The study region is part of the Cerrado biome, which covers nearly a quarter of the total surface area of Brazil. The dominating natural vegetation form is savannah (Figs. 21.1 and 21.2 [right]). Grass dominated savannah (*Campo*) is interchanging with typical tree savannah (*Cerrado*) depending on topography and water availability (Oliveira and Marquis 2002; Silva et al. 2006). Forested areas are divided in dry forests (*Cerradão*), riperian forests (*Mata de Galeria, Mata Ciliar*) and pine or eucalyptus plantations. Protected areas include the national park of Brasília—around the reservoir Santa Maria (Fig. 21.1)—and several smaller state reserves.

However, most of the region is covered by pastures and arable fields. Large mechanized agriculture cultivating soy bean, corn and beans account for more than 90 % of the total arable land (IGBE 2010). Large scale crop cultivation with no-tillage practice is prevailing in the eastern part of the Distrito Federal, whereas in the western part small scale farming and horticulture are dominant. Large areas are urbanized with all levels of development, i.e. irregular settlements with less developed infrastructure, residential areas with high development standards and commercial areas (Fig. 21.2 [left], Höfer 2013). Significant industrial activities do not exist in the region.

The region has experienced a substantial change in land use since the foundation of the national Capital Brasília in 1960 (Fig. 21.3), as it has been also observed for other regions in Brazil (Simon et al. 2010). Land use/land cover change compromises a substantial increase of agricultural land and urban sprawl. The loss of areas

Fig. 21.2 *Left*, Northern Hotel Sector, in the background the reservoir Lago Paranoá; *right*, Cerrado vegetation in the National Park of Brasília

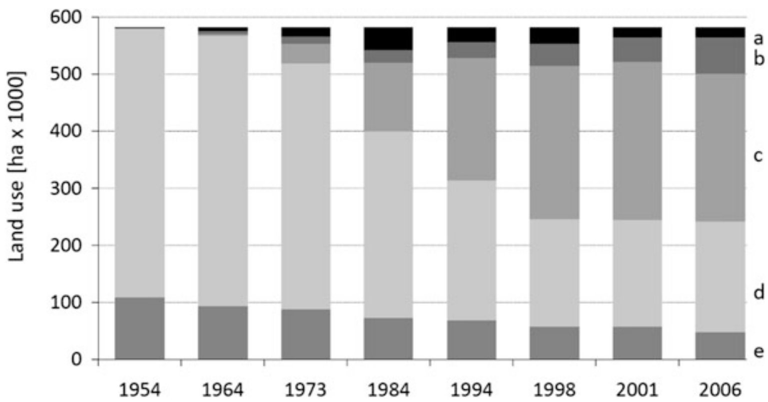

Fig. 21.3 Land use change from 1954 to 2006 (Fortes et al. 2007 and UNESCO 2002); *a* other land-uses, *b* settlements, *c* agriculture, *d* savanna, *e* forest

with natural vegetation has been quantified with 58 % for the period 1954–1998 in Distrito Federal (UNESCO 2002) which is in the same order as reported for the Cerrado biome in general (Klink and Machedo 2005). The share of (semi)natural vegetation was around 40 % in 2006 for the Distrito Federal. From 2002 to 2007 the area of arable land (without orchards) increased by 47 %, from 84,240 ha in 2002 to 123,692 ha in 2007 (IBGE 2009).

Urbanization is the second major process of LULCC for the Distrito Federal and is associated with urban sprawl and the spatial expansion of sealed areas. The share of urban areas increased for the period 1954 to 2001 from 0.02 to 10.62 % (CODEPLAN 2007; Fortes et al. 2007).

The region of Brasília is one of the urban aggregations of Brazil where the capacities of the existing systems for water supply are already near their limits and where the demand will increase dramatically in the near future (ANA 2009; CAESB 2010). For the Distrito Federal, the situation is even more pressing since 94 % of the population lives in urban areas. The predicted growth of population from 2.5 million in 2006 to more than 3.2 million in 2025 will take place almost only in urban areas (PGIRH 2006).

Currently, water supply for the region is provided by two major reservoirs, Lago Santa Maria and Lago Descoberto (Fig. 21.1). These reservoirs cover about 78 % of the total water supply of the Distrito Federal. The remaining water comes from the extraction of stream water and groundwater. For the future, the regional water supplier *Companhia de Saneamento Ambiental do Distrito Federal* (CAESB, regional state owned water supply company) is planning to extract around 2.8 $m^3 s^{-1}$ from the Lago Paranoá, an artificial urban lake in the center of Brasília (Fig. 21.1). An alternative plan in realization is the use of Corumbá IV, a reservoir for hydropower generation around 80 km to the south.

21.3 Land Use Change and Effects on Water Resources

Land use change is affecting water resources in the Distrito Federal substantially. A major indicating phenomenon is the decreasing base flow during the dry season. Time series of base flow, i.e. 5th percentile of discharge, were considered as suitable indicator to assess the effect water extraction from stream water during the dry period and the use of groundwater throughout the year. Measured discharge data was taken from the public database *hidroweb* (http://hidroweb.ana.gov.br/).

The river basins Descoberto and Pipiripau (Fig. 21.1) experienced a statistically significant decrease of base flow discharge (5th percentile of discharge, Fig. 21.4) since 1979. This trend seems to proof true for other river basins in the Distrito Federal, which show decreases of 40–70 % of base flow discharge during the dry season of the last three decades (Lorz et al. 2011). We assume amount and patterns of rainfall as well as LULCC—including irrigation—to be major controlling factors in the decrease of base flow discharge in both river basins.

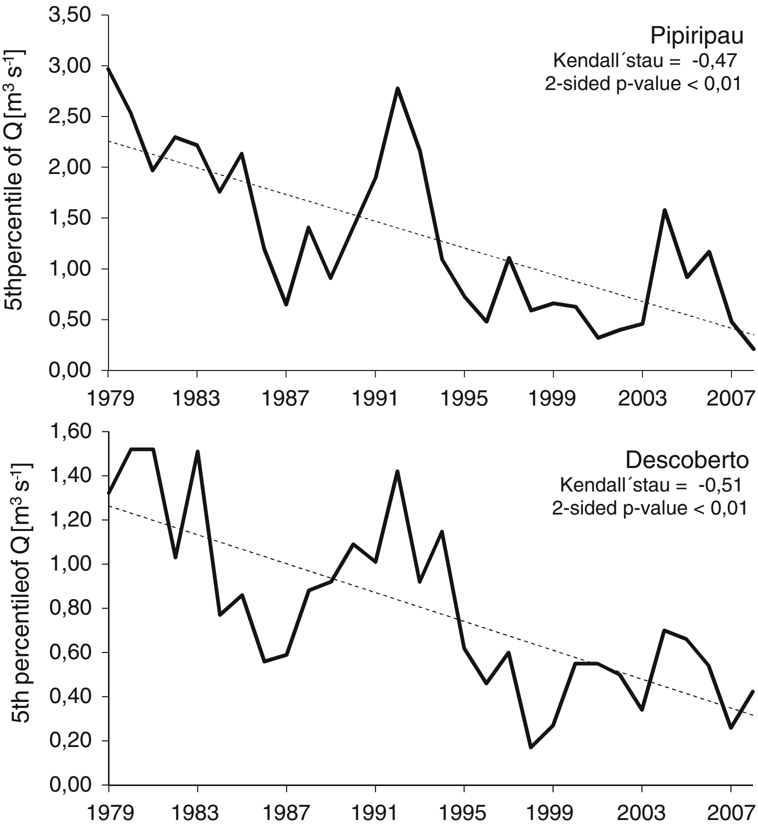

Fig. 21.4 Time series (1979–2008) of average annual base flow discharge (5th percentile) for the river basins Pipiripau and Descoberto (data source: www.hidroweb.ana.gov.br), trend lines and results of the Kendall-Test (Lorz et al. 2011)

The significant correlation with the decreasing shares of (semi)natural vegetation, i.e. savannah and forest, in both river basins (Fig. 21.5) might be either explained as coincidental with the decrease in annual rainfall and changes in rainfall patterns (Table 21.1) and/or caused by increasing water extraction mostly from surface water for irrigation purposes along with the expansion of cropland (Lima et al. 2004; Oliveira and Talamini 2010). Irrigated areas accounted for 11,227 ha in 1998 and 16,039 ha in 2004, i.e. increase by 43 %, for the Brasília region (PGIRH 2006). However, an earlier assumption about the increase of evapotranspiration by farmland has been proven wrong, with the exception of degraded pastures having reduced infiltration capacities.

Data from river basins with substantial share of urban areas is rather scarce. For the Gama river basin (Fig. 21.1) the share of urban area changed from 0 % in 1973 to 25 % in 2006. The shares of agricultural land are rather low (<12 %) while the

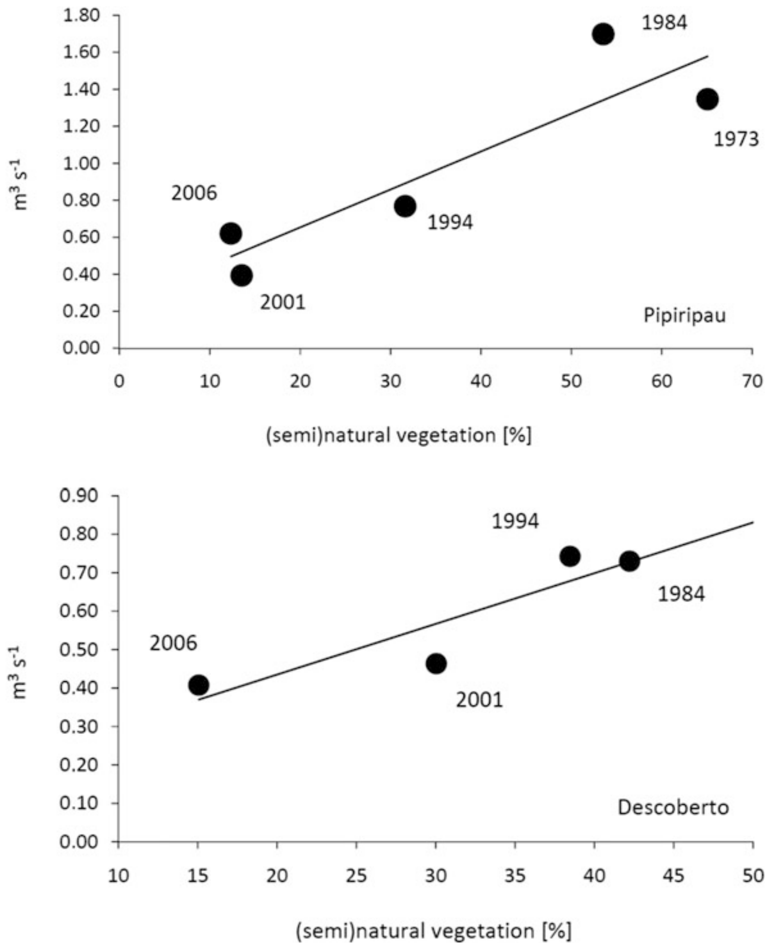

Fig. 21.5 Average annual discharge of base flow discharge (5th percentile) for the period 1979–2008 for the river basins Pipiripau and Descoberto and shares of (semi)natural vegetation during the time steps 1973 (only Pipiripau), 1984, 1994, 2001 and 2006 (Lorz et al. 2011)

shares of natural land are rather high (>66 %). In consequence, only a slow decrease of base flow discharge—compared to Pipiripau and Descoberto basins—has been observed for this river basin since 1984 (Fig. 21.6 [left]). Although, groundwater use (Cadamuro and Campos 2005) and surface sealing will favor faster water flows and lower groundwater recharge rates and might contribute to the decrease of base flow. Other factors, e.g. imports through the water supply system, might compensate these effects.

In addition to the effects on discharge, a distinct relation of land cover on suspended solids (sediments), nitrogen and turbidity has been observed. In particular, urban areas have been found to cause the decrease of water quality (Lorz et al. 2011).

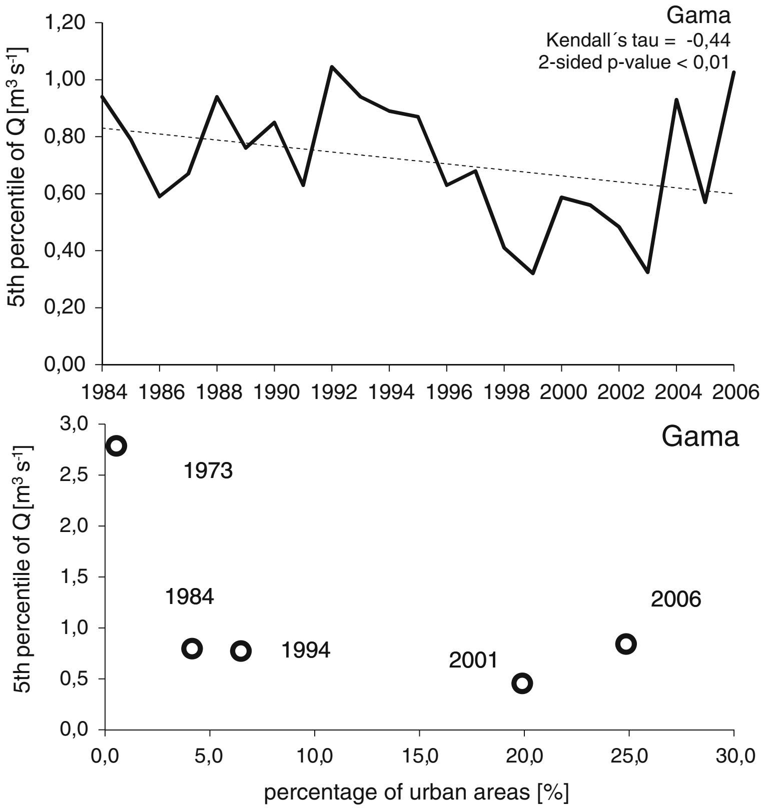

Fig. 21.6 *Left*, time series (1984–2006) of average annual base flow discharge (5th percentile) for the river basin do Gama (data source: www.hidroweb.ana.gov.br), trend lines and results of the Kendall-Test and, *right*, shares of urban area during the time steps 1973, 1984, 1994, 2001 and 2006 (Lorz et al. 2011)

21.4 Simulation of Land Use Management in River Basins

One of the areas in DF prone to conflicts among water users is the 215 km^2 Pipiripau river basin (Fig. 21.1). Mean discharge for the period 1971–2009 is around 3 $m^3\ s^{-1}$. Land use is predominantly agriculture with a share of 60 %. Water is extracted from rivers and creeks for drinking water supply of a nearby town (Planaltina) and for irrigation. The Pipiripau river basin is part of the program *produtor de água* (www.ana.gov.br), which aims at improving water quality and quantity by restoring or preserving (semi-)natural vegetation along streams and by implementing Best Management Practices (BMPs) in agriculture. This project aims to introduce Payment-for-Environmental-Services schemes and supports the dialogue between stakeholders.

Quantification of the effects of agricultural BMPs and crop rotation on the water resources can be only made by using numeric simulation models. Combined with estimates of implementation costs cost-abatement curves can be derived and thus the efficiency can be assessed. The Soil and Water Assessment Tool (SWAT; Arnold et al. 1998) was used to study the impact of BMPs and crop rotation on stream flow and sediment load in the Pipiripau basin, while at the same time precipitation derived uncertainty was considered (Strauch et al. 2012, 2013). Due to the predominant agricultural use, the importance for regional water supply and the participation in the program *produtor de agua*, this basin offers a unique opportunity to establish integrated management solutions in line with the principles of IWRM.

In a first step the effects of precipitation uncertainty on SWAT outputs and parameterization were evaluated by using an ensemble of different yet reasonable rain input datasets varying in terms of data source (ground or satellite based), spatial distribution (lumped or distributed), and temporal distribution (raw time series or moving average) (Strauch et al. 2012). The rain input model ensemble was calibrated and validated against measured stream flow and turbidity-derived sediment loads and later on used for scenario simulations considering relevant BMPs for the region (Strauch et al. 2013). BMPs being evaluated were (1) parallel terraces to different proportions on agricultural areas, (2) small sediment retention basins (*barraginhas,* Fig. 21.11) to different quantities, and (3) a multi-diverse crop rotation including crops during dry season as an alternative to the prevailing monocultures of soybean and corn, likewise to different proportions on cropland. The aim of the simulations was to quantify the reduction in sediment generation and the changes in water yield.

The study using SWAT for the Pipiripau basin had four major outcomes.

(1) Using a precipitation data ensemble leads to more robust model results, e.g. by providing ranges for model parameters and model predictions (see the ranges in the results given in Fig. 21.7).
(2) Multi-diverse crop rotations including irrigated dry season crops were found to be disadvantageous in terms of water availability by significantly reducing stream flow during low flow periods.
(3) Structural BMPs such as parallel terraces and small sediment basins (*barraginhas*) can lead to sediment load reductions of up to 40 %. The implementation of these measures did not adversely affect the water yield.
(4) The relation between effect of BMPs and costs of implementation is shown exemplary in the curve of Fig. 21.7 and can be used to assess the cost-efficiency of BMPs.

Despite the existing uncertainties, the model results are useful for water resource managers to develop water and soil protection strategies for the Pipiripau river basin and for watersheds with similar characteristics.

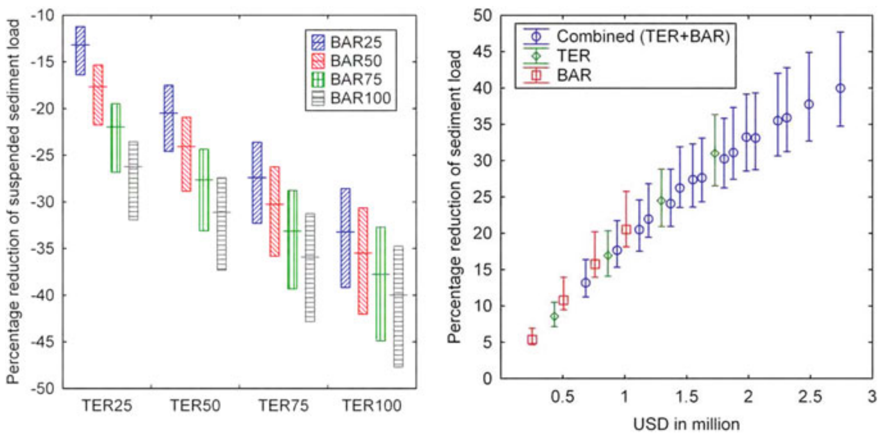

Fig. 21.7 *Left*, Average percentage change of suspended sediment loads for combined scenario simulations, where the ensemble mean is displayed as crossing line within the range of the different rain input models; *right* Average percentage reduction of sediment load (ensemble mean as dots and ensemble range as whisker) due to different BMP strategies related to the costs of implementation (Strauch et al. 2013)

21.5 Development of the Planning Support Tool "*Letsmap Do Brasil*"

In context of river basin management a planning support tool as major element of sediment management was developed for the meso-scale river basin (Pipiripau) in the north-eastern Distrito Federal (Fig. 21.1). The tool aims at emphasizing the effects of land use on sediment input into river network and other landscape functions. For this purpose we modified an existing planning support tool to simulate the effects of land use change on (1) sediment input into river networks, (2) runoff control, (3) agronomic value, and (4) nitrogen retention.

The planning support tool has been developed to facilitate the evaluation of different land use scenarios and their effects on landscape processes and functions (LPF) (for details see Fürst et al. 2010 or www.giscame.com). The basic idea of the tool is a cellular structure that considers land use and its effect on LPF. Major advantages of the tool are accessibility, fast calculation of results, and user friendliness due to easy handling and a less complex structure.

The user interface of *Letsmap do Brasil* provides an easy access to the system. The most visible part is the land use map (Fig. 21.8a) that depicts a grid map where one grid cell represents an area of ~10 ha. For each grid cell or group of cells, the user may choose a new land use class from a drop down menu. *Letsmap do Brasil* will then calculate the changes for the LPF on basis of the new land use map. The land use specific values of LPF (Table 21.2) are used to calculate the area weighted

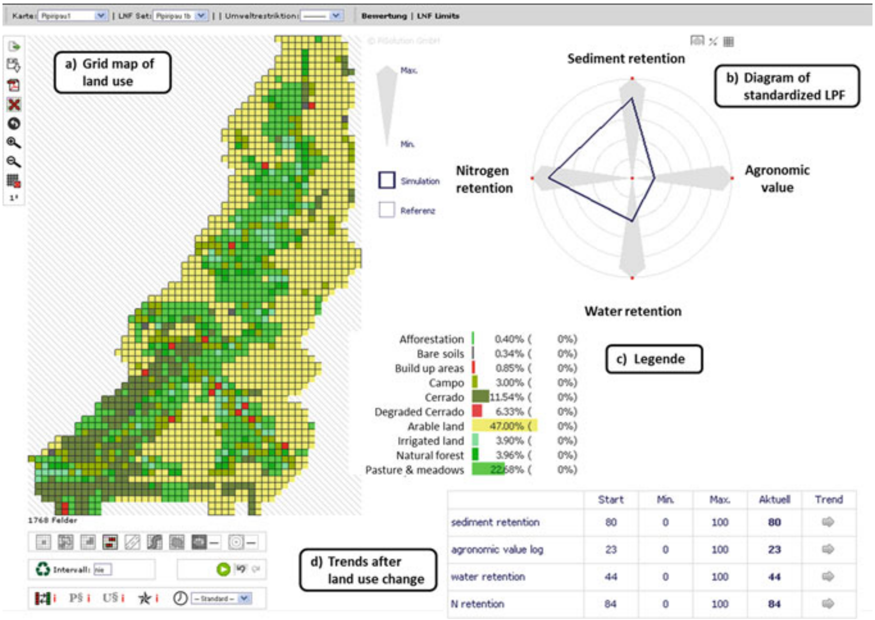

Fig. 21.8 User interface of *Letsmap do Brasil* for the river basin Pipiripau (Lorz et al. 2013)

mean for the whole river basin. The results may be shown in three formats, as star diagram in comparison with reference and simulation (Fig. 21.8b), as legend with percentage of land use classes (Fig. 21.8c), or as table of trends and total values for LPF (Fig. 21.8d).

In a first step, land use was classified by focusing on land management and crop cultivation using an existing land use map of 2006 (Fortes et al. 2007). Land use types were further distinguished into land use classes compromising also information on soil management. The land use classes “arable land, soy” and “arable land, corn” cover large parts of the region and are most important drivers of soil erosion. Therefore, these land use classes were subdivided into no-tillage and tillage practice. From the list of land use classes users of *Letsmap do Brasil* may choose their desired land use and test the effect of a changed land use pattern on LPF.

The core of *Letsmap do Brasil* is the assignment of values for all LPFs in each land use class (Table 21.2). The simulation results for land use change effects depend to a large extent on this relation. We used information from published research or from public data, i.e. official statistics. Only for the land use class pastures and meadows the agronomic value was estimated.

All values were standardized on a scale from 0 to 100, where a value of 100 means the maximum regional contribution to a LPF. For estimating the effect of land use on soil erosion, we used the Cover-Management factor or C factor of the

Table 21.2 Land use classes and values for landscape processes and functions (modified after Goldbach 2010)

<table>
<tr><th>Landscape processes and function (LPF)</th><th colspan="2">Parameter</th><th colspan="2">References</th></tr>
<tr><td>Sediment retention</td><td colspan="2">C factor (USLE)</td><td colspan="2">Morgan (1995), Silva (2007), Roose (1977), Halbfass and Grunewald (2008), Lima and Lopes (2009)</td></tr>
<tr><td>Agronomic value</td><td colspan="2">yield (€ ha^{-1} a^{-1})</td><td colspan="2">IBGE (2009)</td></tr>
<tr><td>Water retention (runoff control)</td><td colspan="2">CN value</td><td colspan="2">US SCS (1972), USDA (2004), Gonçalves (2007), Franke (1994/1995)</td></tr>
<tr><td>Nitrogen retention</td><td colspan="2">applied fertilizer (kg N ha^{-1} a^{-1})</td><td colspan="2">FAO (2010)</td></tr>
<tr><td colspan="5">Examples, numbers in () are standardized LPF values (0–100)</td></tr>
<tr><td></td><td colspan="2">Arable land, soy (tillage)</td><td colspan="2">Coffee</td></tr>
<tr><td>C factor</td><td>0.35</td><td>(65)</td><td>0.22</td><td>(78)</td></tr>
<tr><td>Agronomic value</td><td>504 € ha^{-1} a^{-1}</td><td>(45)</td><td>1226 € ha^{-1} a^{-1}</td><td>(64)</td></tr>
<tr><td>CN value</td><td>72</td><td>(11)</td><td>66</td><td>(23)</td></tr>
<tr><td>N fertilizer</td><td>7 kg N ha^{-1} a^{-1}</td><td>(94)</td><td>155 kg N ha^{-1} a^{-1}</td><td>(0)</td></tr>
</table>

Universal Soil Loss Equation (Wischmeier and Smith 1978). The C factor describes the complex effect of plant cover and tillage practice on soil erosion. C factors were mostly taken from studies dealing with conditions similar to the study region. Agronomic values were taken from the official statistics of the Instituto Brasileiro de Geografia e Estatística (IBGE 2009). The values per ha were calculated from cultivated area and total value of agricultural products in DF. All agronomic values were log standardized. The effect of land use on runoff control was assessed using the curve number method by the US Soil Conservation Service (US SCS 1972). The CN value gives the runoff/precipitation ratio for each land use class for storm events and is frequently used because of its simplicity (Garen and Moore 2005). We standardized the CN value for the hydrologic condition "fair" and the "hydrologic soil group A", both are most common in the study area. For estimating the impact of land use classes on water quality we used the recommended amount of applied nitrogen fertilizer from a study on Brazilian fertilizing practice by the Food and Agriculture Organization (FAO 2010).

Beside the land use map with the related LPFs, a second layer contains information on landscape properties and potentials (LPP) obtained from spatial data available for Pipiripau river basin. By overlaying LPP and land use, a spatially explicit assessment of effects of land use on LPF is possible. In future, the results of combining LPP's with LPF's will be visualized in separate maps, which can be shown optionally. The parameterization of LPP's was realized by using methods

Table 21.3 Landscape properties and potentials (LPP's)

Landscape processes and functions (LPF)	Landscape property and potentials (LPP) and method
Sediment retention	Likeliness of sediment input with "area connectivity" (Halbfass and Grunewald 2008)
Agronomic value	Suitability for agricultural use (Spera et al. 2004)[a]
Water retention	Runoff control after Zepp (in Marks et al. 1992)[a]
Nitrogen retention	N leaching potential (Müller 2004)[a]

[a]Not yet implemented

widely used in meso to large scale assessments of landscapes (Table 21.3). So far, we included a map of likeliness of sediment input into the river network. This describes the probability of sediment input from arable land to rivers as a function of the probabilities of the following parameters: (1) erodibility as combination of slope length, slope (LS factor) and texture (K factor), (2) flow accumulation, and (3) distance to water body.

For first simulations we used a scenario that is based on current land use (Fig. 21.8) and three test scenarios (Fig. 21.9). All scenarios aim to demonstrate the function of the tool and have limited connection with the real world.

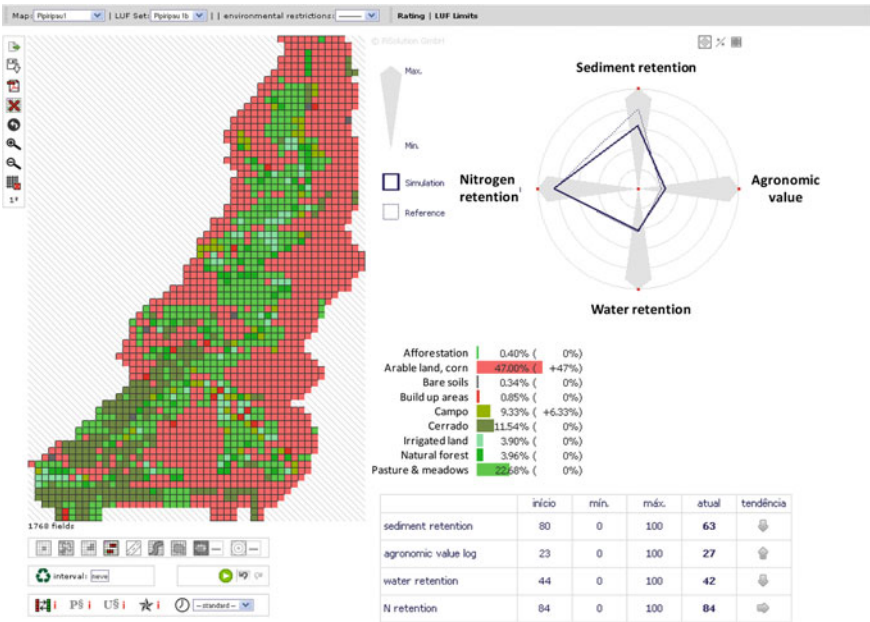

Fig. 21.9 Test simulation with Letsmap do Brasil for (**a**) scenario "arable land, unspecified into arable land, corn", **b** scenario "pasture and arable land into arable land, corn", **c** scenario "afforestation, pasture and arable land into Cerrado"

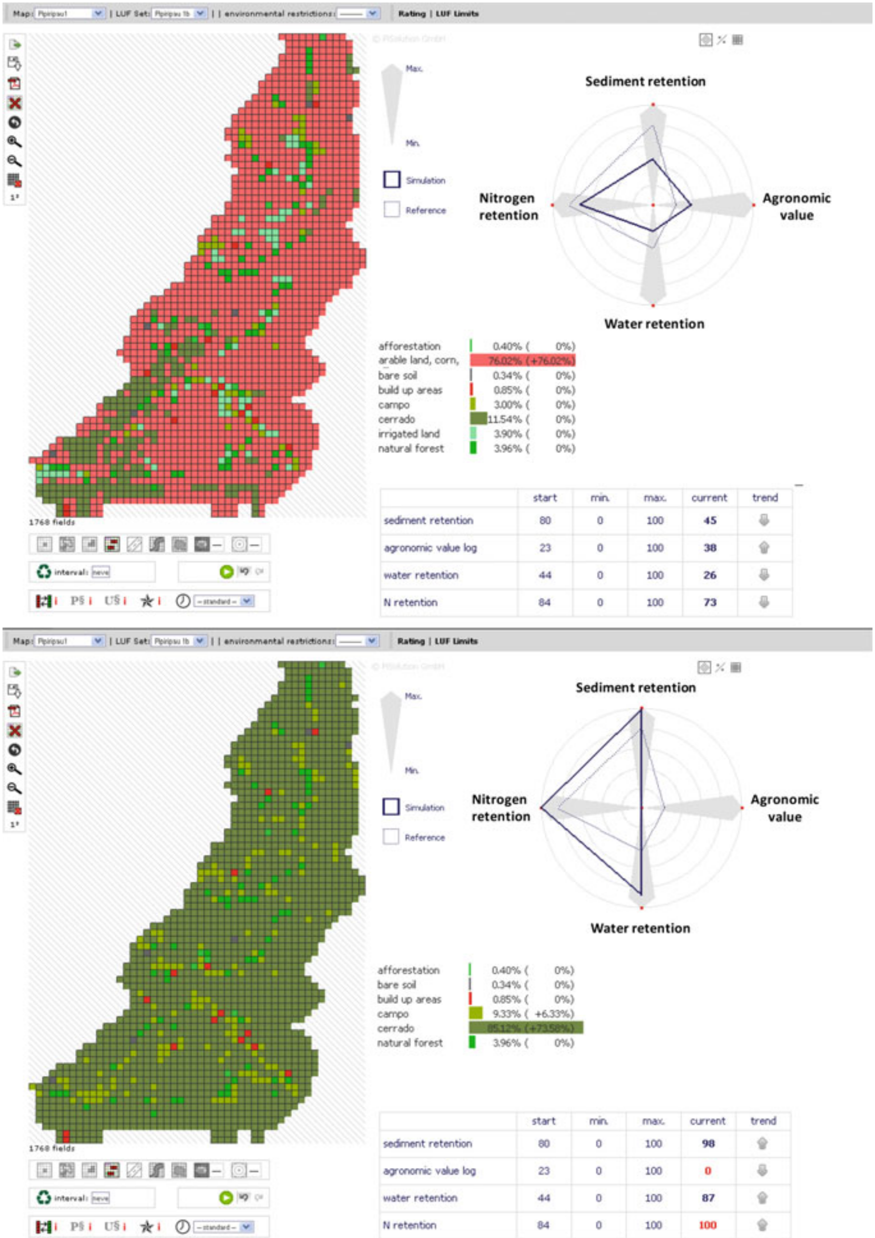

Fig. 21.9 (continued)

The current land use pattern (Fig. 21.8) produced rather high values for sediment retention and nitrogen retention due to the prevalence of no tillage practices and the low amounts of fertilizer used. Agronomic value and runoff control are rather low.

Scenario a (Fig. 21.9a) compromises the change of all arable land (mostly soy bean no-tillage) into arable land, corn (no-tillage) (cover ∼47 %). The resulting changes are rather small, but the negative effect of conventional tillage practice on sediment retention is noticeable. The changes in agronomic value and runoff control, i.e. a change in the surface runoff/infiltration ratio, are rather small. Scenario b (Fig. 21.9b) is a modification of scenario a. It adds the change of all grassland into arable land corn (no tillage) (cover ∼76 %) to the previous scenario. The substantial increase in agronomic value is due to cultivation of areas with previously rather low agronomic value, e.g. pasture. The decrease of nitrogen retention results from higher applied amounts of fertilizer typically related to the cultivation of corn. However, sediment retention will decrease because of conventional soil management. Scenario (c) (Fig. 21.9c) is the change of all non-natural land use, except build-up areas, into Cerrado, the most common natural savanna vegetation. The loss of agronomic value is total, but the increase for the other LPF′s is substantial. The mapped LPP's which may influence the impact of land use on LPF's reflect site properties such as texture, slope, distance to river networks etc. (Table 21.3).

21.6 Sediments

Siltation of reservoirs is a major risk in the study region. The consequences of siltation might be the total loss of the storage capacity for smaller reservoirs and for bigger reservoirs a loss of storage capacity within 3–4 decades (Menezes 2010). In addition, sediment bodies accumulate potential pollutants and nutrients, which might be released under changing hydrochemical regimes.

For a better understanding of sediment generation we used the idea of the sediment cascade (Fig. 21.10). In the catchment of the Lago Paranoá four major sources were found, where sediments are mobilized and transported towards the final sinks, i.e. lake/reservoir. The slopes of agricultural land, urban areas/construction sites and gullies (Fig. 21.11) are major sources of sediments outside alluvial plains. The alluvial system itself might be a major source of sediments and temporal sink at the same time. Final sinks are the alluvial systems in the inflow of reservoirs and the reservoirs. In addition, a great number of small basins for sediment retention have been built (Fig. 21.11). In the long-run these sinks are rather temporary with varying life time depending on the level of maintenance.

A crucial aspect in understanding the sediment system is the identification and quantification of sediment sources. The sedimentation rate for alluvial flood plains during the period after 1960 have been found to be 10–100 times higher compared to earlier periods (Franz et al. 2012). The identification and quantification of

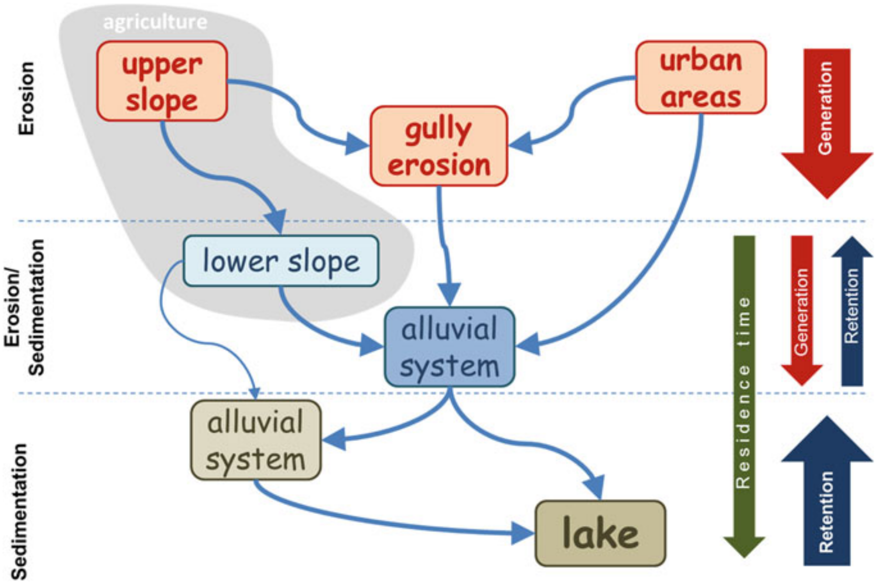

Fig. 21.10 Sediment cascade for the Distrito Federal (Franz et al. 2013)

sediment sources have been achieved by using a combined approach of geochemical fingerprinting and statistical analysis (Franz et al. 2013a, b) for the catchment of the Lago Paranoá and the Riacho Fundo sub-basin (Fig. 21.1). By using this approach, urban areas were identified as major sources of alluvial sediments in both catchments, showing a mismatch between spatial share and contribution to alluvial sediments (Table 21.4). For the Riacho Fundo sub-catchment a further distinction of urban areas showed that sediment generation in more developed urban areas with paved roads is limited. In contrast, the sediment delivery from still expanding urban areas with extensive construction activities, semi-detached housings, and unpaved roads is rather high. Bare soils and exposed grounds are the "hot spots" of sediment generation. Three quarter of the alluvial sediments come from construction sites and less developed residential areas in the Riacho Fundo sub-basin.

The small share of agricultural areas in the Lago Paranoá basin is reflected by the low contribution to the alluvial sediments (Table 21.4). In the Riacho Fundo sub-basin the larger share of agricultural area is underrepresented in the alluvial sediments (Table 21.4). Areas with (semi)natural vegetation, i.e. Cerrado, Campo and forests, do not substantially contribute to alluvial sediments in the Lago Paranoá basin despite of their high spatial share. The relative higher share of sediments from natural areas in the Riacho Fundo sub-basin might be explained by higher shares of bare soils which favor the formation of gullies which may expand uphill and thus also affect natural areas.

Fig. 21.11 Sediments in the study region, construction sites near the Riacho Fundo (*upper left*), gully erosion (*upper right*), sand banks at the Riacho Fundo (*lower left*) and sediment micro basins (*barraginhas*) (*lower right*)

Table 21.4 Results of the sediment source contribution for the whole Lago Paranoá catchment and Riacho Fundo sub-basin (Franz et al. 2013)

Source category	Weighted mean relative sediment contribution[a] (%)	Share of land use (%)
Catchment Lago Paranoá		
Urban	85 ± 4	34
Agricultural	5 ± 4	8
(Semi)Natural vegetation	10 ± 2	58
Riacho Fundo sub-basin		
Urban	53 ± 4	38
Agricultural	31 ± 2	47
(Semi)Natural vegetation	16 ± 3	12

[a]Relative mean errors for Lago Paranoá 13.9 % and Riacho Fundo 12.3 %

21.7 Urban Structure Types

Water resources are expected to be increasingly affected by population growth through planned and unplanned urban development, uncontrolled use of ground water, water contamination, urban drainage, conflicts between urban water consumption and agriculture depending on irrigation, erosion caused by construction activities and agriculture, or the contamination of soil and water bodies (Leite da Silva 2007). To analyze these impacts, the concept of Urban Structure Types (UST) was applied. The UST concept offers the possibility to describe the urban system in terms of heterogeneous areas of open and green spaces, infrastructure, type of building complexes, and the proportion of impervious surface (for studies using the concept of UST in different disciplines see Wickop et al. 1998; Ellis and Revitt 2008; Strauch et al. 2008; Wurm et al. 2010; Krellenberg et al. 2011; Taubenböck et al. 2011; Schanze et al. 2012). The UST concept was used within the IWRM to monitor and characterize the urban area and to link the obtained data with water-relevant information. This approach allowed illustrating the effects of quantitative and qualitative changes of urban areas on the water resources. The advantages of UST are (1) UST can be measured directly, (2) their derivation is cost- and time-efficient, and (3) the approach is transferable to other situations (Höfer et al. 2012; Firmbach et al. 2012).

The study site is part of the wider region of Planaltina (Fig. 21.1). The area is characterized by demographic changes (population growth rate of 4.79 in 2005; GDF 2008). In 2010, the population in the study area was around 170,000 inhabitants with a population density >2,500 inhab/km^2 (IBGE 2010). According to the recent census (2010), 91 % of the households in Planaltina are connected to the water supply network, but >30 % are not connected to waste water collection network.

Very high resolution remote sensing (RS) data—Quickbird image with a spatial resolution of 0.61 m (panchromatic) and 2.44 m (multi-spectral) from August 2008—was pan-sharpened to use the high geometric resolution of the panchromatic band together with the high spectral resolution of the multi-spectral band. The processed images were combined with GIS data (e.g. administrative limits) and used to characterize the urban area. The different data sources were analyzed by using the semi-automatic OBIA approach (Blaschke 2010).

In a first step of the analysis, the existing UST for the DF were identified and a classification key for the study area was developed. The applied classification compromises the most relevant characteristics, i.e. such as building structure, amount of green spaces, impervious surface, population density, land use (Fig. 21.12; Höfer 2013). Residential areas (single family houses, apartment blocks, high rise buildings, gated communities), public buildings, open areas (green spaces, parks, recreation areas), industrial and commercial sites, and transportation areas were taken into account for the analysis of the representation of water relevant information. Information corresponding to water-related processes such as infiltration/runoff, erosion potential, water consumption, and pollution was derived

UST	Parameters	Characterisation
RH 5 – medium density	location	Sector Traditional - Planaltina, Paranoá, Vila Planalto, Guara
	building structure	concrete (roof - ceramic, some asbestos or clay), 150m^2 to 250m^2, 1 and 2 storeys high, residential use
	lotsize	from 250 to 500 m^2
	impervious surface	from 50 to 75%
	green area	low
	runoff	very high
	urban water infrastructure	WS, WC, DS, S
	water consumption	from 200 to 300 l/inhab*day
	income	low to average
	legal status	legal
	description	heterogeneous buildings, few swimming pools and small yards

Visual example

UST Detail

Fig. 21.12 Urban Structure Type classification key (*RH*—residential houses, *WS*—water supply, *WC*—waste collection, *DS*—drainage system, *S*—sewage disposal)

from RS, census and GIS data. The coefficient of variation (CV) was calculated for each UST to analyze to which degree the IWRM-relevant parameters are represented by UST. CV describes the dispersion of a variable independently of scale and dimension (independently of variable units). The higher the CV, the greater is the dispersion (Bruin 2011). Because census units may contain more than one UST, a final iterative analysis was performed.

The classification key was implemented in eCognition. The basic land-use/land-cover (LULCC) classes, e.g. different roof types, barren land, vegetation, streets, swimming pools, were identified on the basis of the Quickbird satellite image using different segmentation levels. The basic LULCC classes were classified and validated (>60 ground truth points were selected for each LULCC class). The basic LULCC classes show an overall accuracy of 72 % and a kappa coefficient of 0.68.

The specific composition of the basic LULCC classes led to the derivation of UST. The UST were classified on the basis of the administrative limits of *quadras*. The results of the classification were validated using a ground truth layer. The accuracy assessment showed an overall accuracy of 38.9 % and a kappa value of 0.29. The rather low accuracies may be explained by (1) heterogeneity of UST, e.g. PB, (2) areas in transformation, e.g. RH3, (3) inconsistent definition of *quadras,* e.g. inclusion of adjacent streets, and (4) restriction of identifying functions of buildings in mixed areas, e.g. M2.

However, the limitations are not among the restrictions of the UST concept in general; it is a methodological problem when deriving UST (Höfer 2013). Nevertheless, it was possible to achieve a highly accurate aggregated UST level, which has to be further differentiated using additional information. To avoid errors in the statistical representation of the census variables (caused by classification errors), the analysis was performed on the basis of the validation layer with the correctly derived UST (Fig. 21.13). For the UST RH6, I, C2, and T (Fig. 21.13) it was not possible to calculate any census information due to a small sample size or a very high variation within the UST. The representation of census attributes and RS data varies between UST. The degree of variation depends on the spatial distribution within the census unit, the number of samples, and the degree of the development of the UST.

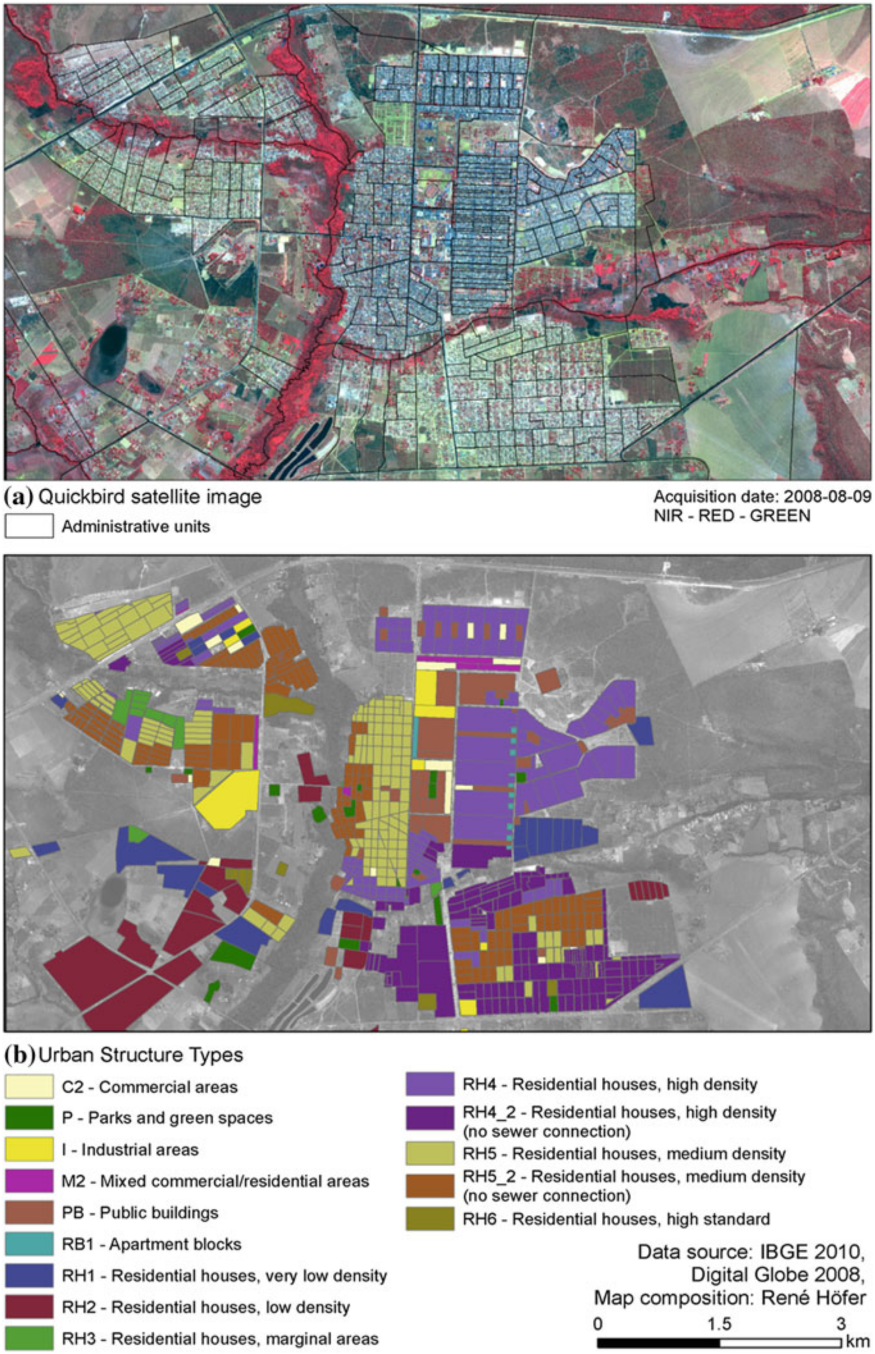

Fig. 21.13 **a** Overview about the administrative census units of the urban area of Planaltina, and **b** the classified Urban Structure Types (validation layer)

Census variables represented in the UST are population density, household density, people per household, connection to the general system for water supply, and waste collection. Moreover, rudimentary cesspits used for sewage disposal are well represented by UST. Not represented by any of the UST are households without any sewage disposal system or with sewage disposal in septic tanks, and those with water supply by wells or springs (Höfer 2013).

The representation of water-relevant information from RS shows a high representation of the average amount of vegetation (except for M2), the average amount of impervious surface, and roof area. Worst represented by the UST RH1, RH4, RB1, PB, and M2 is the variable bare soil (low accuracy in the basic LULCC classification of less than 60 %).

In conclusion, the results show that the UST concept offers the opportunity to characterize and monitor urban areas. In particular, the application of RS data in the classification of UST helps to obtain up-to-date information in highly dynamic areas in a fast and cost-efficient way. UST can represent water-relevant information such as information about the average water consumption, the amount of waste water, and the connection to the sewer system. Moreover, parameters for the infiltration capacity, the surface runoff, and sediment and pollution loads can be derived from UST and RS data.

21.8 Conclusions

Within the IWRM approach for the Distrito Federal we were able to show exemplarily the integration of data from regular monitoring, field and lab data from specific focus-projects, and of simulated data using numeric models and planning support tools. The major conclusions for an IWRM to be developed for the region are:

(1) The increasing extraction of water during the dry season and in general the LULCC can be considered as causes for the dramatic decline of base flow discharge for the river basin Pipiripau. However, changing climate has affected water resources during the last three decades substantially and more severe effects have to be expected for the future.

(2) For the Pipiripau river basin, part of the national program *produtor de água* (environmental services and water resources), the efficiency of BMPs in terms of sediment generation, water yield and costs for implementation were simulated using the numeric model SWAT. It was exemplary shown how to adapt the model and to use it for applied questions.

(3) Land use management in river basins can be only achieved if land use change and its effects can be visualized in order to enable stakeholders with different backgrounds to participate in planning and management processes. The tool *Letsmap do Brasil* was developed and successfully tested as transparent and user-friendly system for the Pipiripau river basin. The approach might contribute substantially to manage land resources in river basins in the region.

(4) For the Lago Paranoá basin the identification of sediment sources by using a geochemical-fingerprint approach showed that sediments are generated to a large extent in urban areas. For these areas especially bare soils, i.e. construction sites or areas without vegetation, are "hot spots" of sediment generation and might be considered as priority areas for measures to reduce sediment generation.
(5) Urbanization is a major driver for changing frame conditions of water resources in some basins of the study region. The predictions of water demand and effects on water resources is a major challenge for the future, which will be only solved by approaches integrating social, technical and scientific knowledge. The developed Urban Structure Types approach for the town Planaltina shows the options and restrictions for using it in frame of an IWRM.

Overall, the study showed the major objective of an IWRM approach, a long-term cost efficient management and protection of water resources, can only be achieved if the complex interaction of land-water system is an integrated part of the IWRM itself and a data base of high quality is available. This is a challenge of interdisciplinary cooperation using modern methods as well as a challenge for close cooperation between applied science and practice.

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Part IX
Regional Case Studies and Pathways to Sustainable Water Management

Chapter 22
Reconceptualising Water Management in Khorezm, Uzbekistan

Recommendations Towards IWRM

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Abstract Khorezm region is located in the northwest of Uzbekistan, approximately 350 km from the current shore of the Aral Sea. It comprises a large-scale irrigation system which conveys water from the river Amudarya to agricultural land cropped mainly with cotton, wheat, and rice. Khorezm's water resources are vulnerable because they depend on upstream developments and are indispensable for rural livelihoods and state budgets. Since water scarcity is expected to increase in

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the future, sustainable water management is a necessity. Hence the objectives of the paper are to (1) conceptualise the distinctive features of water management in Khorezm, (2) provide an integrated analysis of water management by establishing linkages between society, technical infrastructure, and the bio-physical environment, and (3) make policy and technology recommendations for improved water management. To conceptualise water management in Khorezm, the paper distinguishes three types of practices: formal practices, strategic practices, and discursive practices. Based on these, it presents an analysis of water management on the state water management level, the water user association level, and the farmer and field level. For each level, recommendations are given. The paper concludes that elements of IWRM such as transparency, accountability, participation, and technical efficiency are relevant to improve water management in Khorezm as elsewhere. In addition, it suggests for Khorezm, in particular, to create legal space for agency and innovation. Technical tools such as models acquire additional importance in this context for facilitating transparency and enabling agents across the management hierarchy to access and make use of information.

Keywords Irrigation water management · IWRM · Interdisciplinary research · Agency · Social construction · Uzbekistan · Central asia

22.1 Introduction

The Aral Sea crisis in Central Asia is a well-known example for unsustainable use of water resources. The diversion of large quantities of water from the tributaries of the Aral Sea into the irrigation of cotton, wheat and rice has led to the desiccation of major parts of the Sea. This continues to threaten ecosystems and livelihoods, particularly in the circum-Aral region.

The province Khorezm, located in the northwest of Uzbekistan, comprises a large-scale irrigation system that allows for intensive agricultural production (Fig. 22.1). Considering the degree to which the livelihoods of its approximately 1.5 million inhabitants depend on water for irrigation, inefficient water management and decreasing water availability pose a direct threat to the region. Efficient and sustainable water management in Khorezm is therefore a necessity. Hence the objectives of this paper are to:

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Fig. 22.1 Location of Khorezm province

1. conceptualise the distinctive features of water management in Khorezm, i.e. the practices of the actors involved and the roles and rules that shape them,
2. provide an integrated analysis of water management by establishing linkages between society, technical infrastructure, and the bio-physical environment, and
3. make policy and technology recommendations for improved water management in Khorezm.

This paper is directed at water researchers from different disciplines and particularly researchers who engage in interdisciplinary water research. We are further addressing organisations and researchers who are dealing with water management in similar regions in Central Asia and who are looking for ways to improve it.

In the subsequent section we will describe key regional characteristics and conclude with a problem definition of water management in Khorezm (Sect. 22.2). Section 22.3 will discuss the desired state of water management according to IWRM principles and present three types of practices of actors involved in water management in Khorezm. We will conclude this section by summarising our conceptual understanding of water management in Khorezm. Sections 22.4–22.6 will then discuss water management on different scales, namely the state water management level, the water user association level and the farmer and field level. Each of these sections contains recommendations for water management improvements.

22.2 Key Characteristics of Khorezm and Problem Definition

The Amudarya is one of the two (now intermittent) tributaries of the Aral Sea. Khorezm is situated in the river's lowlands in a distance of approximately 350 km from the current shore (Fig. 22.1). It encompasses an area of 5,060 km^2 and was inhabited by 1,517,500 people as of 2008 (UzStat 2009). The majority of the Khorezmian population lives in villages working in agriculture either as private farmers (*fermers*), peasants (*dehqons*), workers on private farms, or a combination of the latter two. Unemployment rates are high and about 28 % of the population live below the poverty line (1 US$/day) (Mueller 2006). Boxes 1 and 2 summarise the key regional characteristics of the bio-physical and socio-political system.

Box 1: The bio-physical system

- Precipitation approx. 90 mm, annual average potential evapotranspiration approx. 1,500 mm, shallow groundwater levels approx. 1.2 m below ground during peak irrigation period (July) leading to secondary soil salinisation but also contributing to crop development
- Average annual temperature increase in Central Asia between 1950–2000 above the global average (Giese and Mossig 2004), glacier-melt runoff predicted to bring gains in water availability in short or mid-term perspective, but long-term water availability expected to become lower, average annual temperature increase of 1–2 °C predicted for 2010–2039 (Cruz et al. 2007), long-term evapotranspiration increases
- Medium and heavy loam soil textures prevailing, clayey light loam and sandy loam soils less widespread (Forkutsa 2006), approx. 50 % of soils moderately or strongly saline (GME 2007 quoted in Ibrakhimov 2004b)
- Main crops: cotton, winter wheat and rice with frequent double cropping of plots to wheat (winter, spring) and rice (summer)
- Between 3.5 and 4.0 km^3 of water during vegetation period and 1.0–1.5 km^3 during winter period diverted from the Amudarya (Conrad 2006); irrigated area in Khorezm is around 275,000 ha
- Canal system length of 16,233 km (Conrad 2006) reaching from the Amudarya to the borders of Turkmenistan and Karakalpakistan, only 11 % of the canals lined (Ibrakhimov 2004a), on local level no discharge measurement structures
- Irrigation water pumped or diverted by gravity from canals, applied as furrow irrigation for cotton and some vegetables, basin irrigation for wheat, rice, maize and sorghum

- Drainage system of 9,255 km length (open ditches and collectors) (Ibrakhimov 2004a), main collector Ozerny conveys drainage water into the desert of Turkmenistan (Sarykamish depression); drains frequently blocked by farmers to secure water availability for crops

Water reaching Khorezm from the Amudarya's catchment area in Afghanistan and Tajikistan is ample in the majority of years (Veldwisch 2008). If efficiently used, the available amount exceeds Khorezm's crop requirements. Within Khorezm the finiteness of water resources becomes apparent mainly in the large differences between the head and the tail end areas of the irrigation system as well as during drought years such as 2000, 2001 and 2008. That very little water is allocated to the environment within or downstream of Khorezm is another characteristic of the region—the most prominent consequence being the desiccation of the Aral Sea. In the long run, water resources are predicted to become scarcer in Khorezm (Sehring and Giese 2009; Froebrich et al. 2009; Sehring et al. 2007). Figure 22.2 shows five trends which are likely to influence this process either by increasing demand or by decreasing supply. The upstream irrigation and energy developments mentioned in the figure highlight the significance of the Amudarya watershed being a trans-boundary management unit. Water allocations within the watershed as well as the operation of the Amudarya's many hydraulic structures are negotiated in fragile political processes between and within the riparian nations.

Box 2: The socio-political system

- State-centric, top-down governance approach with little public participation; accountability and transparency upwards
- Strong hierarchical organisation of society with distinction between katta (big) and kichkina (small) Uzbeks and a complex system of coercive reciprocity (Turaeva-Hoehne 2007), limiting the individual's flexibility and risk-proclivity
- Since independence in 1991 partial transition from planned economy into market economy; market regulations with regard to agricultural production of cotton and wheat still in place (Mueller 2006)
- After independence in 1991, state farms (sovkhozes) turned into collective farms (kolkhozes), then into joint-stock companies (shkirkats, literally 'associations'), in the early 2000s completely dismantled and divided into *ferms* (private farms) (Veldwisch 2008).

- *Ferm* land (usually >80 ha) is state property and leased to *fermers* in lease contracts of for up to 50 years; tomorqa plots for household production (approx. 0.25 ha) are owned by *dehqons* (peasant farmers) and inherited
- Despite ongoing lease contracts, *ferm* land consolidation in 2008 with land redistribution into bigger plots and approx. ¾ of *fermers* losing their land
- Three forms of production: state-ordered production of cotton and wheat, state-order freed commercial production of the cash crop rice (and less vegetables, sunflower and fodder) and *dehqon* (peasant) production for home consumption and petty trade (Veldwisch 2008); almost every rural household is engaged in *dehqon* production
- Area- and production-based yield quota for state-ordered crops; compulsory sale to the state at fixed prices; subsidised inputs; agricultural *norms* to regulate cropping patterns and agricultural practices, norm compliance monitored and enforced

In summary, this paper deals with a region in which water resources are currently abundant in the majority of years, but are vulnerable because they depend on upstream developments and are indispensable for state budgets and livelihoods. Water scarcity currently only occurs with regard to temporal and spatial distribution and ecosystem demands, but will increase in the future. Water management in the region will have to cope with the changed situation. Options to ensure this and improve water management in Khorezm have to fit into the local context, which can be summed up as (1) an arid climate with global warming above average, (2) a downstream location within a trans-boundary watershed, (3) a state-centric governance system with agriculture under state-order, (4) a changing land tenure system, (5) a cropping pattern of cotton, rice and wheat, and (6) shallow groundwater levels and saline soils.

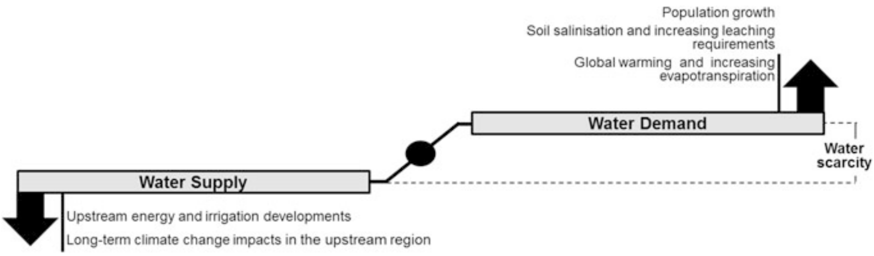

Fig. 22.2 Trends of water supply and demand in Khorezm

22.3 Methods

22.3.1 Basic Features of the Approach

The findings presented in the paper are based on field work in different locations within the districts Qo'shkopir, Gurlen, Xiva, and Xonka. Case studies for water management practices and institutions were three water user associations, namely Amudarya (Gurlen) at the head of the irrigation system, Shomoxulum (Xiva) in the middle, and Ashirmat (Qo'shkopir) at the tail of the irrigation system (Fig. 22.3), as well as the state water management organisation Shavat-Kulabat UIS (sub-basin organisation). Research on bio-physical and technical aspects was conducted on different field trial sites in Xiva and Xonka district and in the water user association Shomoxulum (Xiva).

Interdisciplinarity The current problems and future challenges of water management in Khorezm are caused by a mix of bio-physical, technical and socio-economical factors. Hence an adequate solution consists of an interdisciplinary approach combining technical procedures, economical methods and sociological analyses. We use therefore the bio-physical system in the case study region

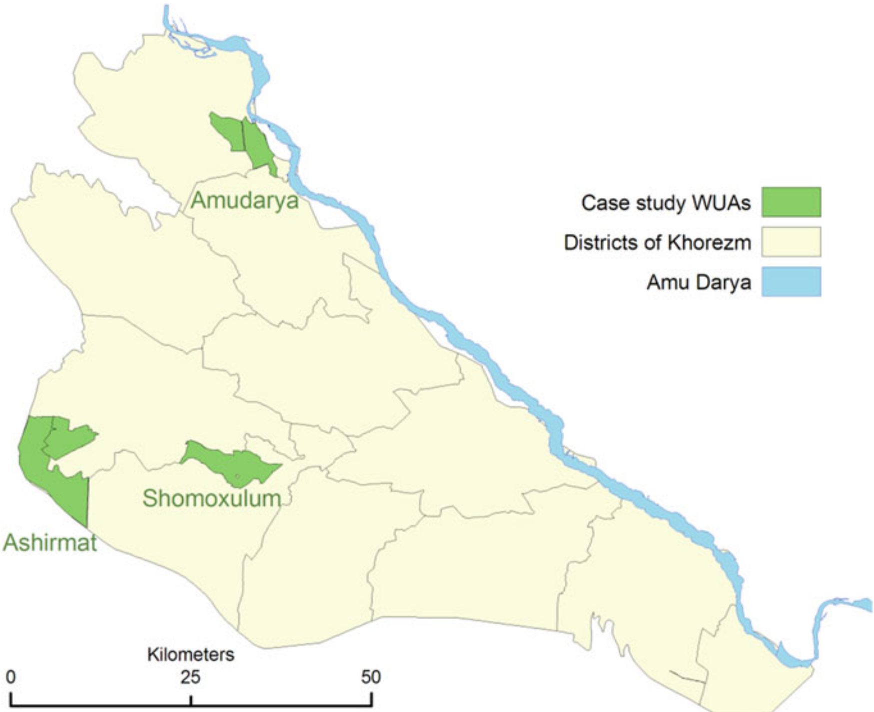

Fig. 22.3 Location of the case study WUAs

Khorezm as a starting-point to work out modeling approaches and to derive interventions as opportunities towards improving the current water management. These opportunities will then be embedded into the institutional and economic context by considering options to lessen constraints regarding technical, institutional and economic factors.

Focusing on field/farm level The focus on the field level was guided by two major reasons: (i) Providing the farmer with options to cope with variable water supply, since this is urgently needed and becoming increasingly relevant; (ii) Considering the field level reflects a bottom-up approach from field to system level and which has become more appropriate after the restructuring of the production units by the national administration.

22.3.2 Social Science Approaches

Farm survey In 2008 and 2009 a farm survey was conducted with all farmers under the state plan in the study WUAs was conducted on the topics irrigation satisfaction, water availability perception and farmer practices.

Semi-structured interviews and participant observation The survey data were additionally framed by a series of semi-structured interviews, and extensive field observations in the period 2008–2011. Yet, for reasons of privacy, we will not mention names or use direct quotes. In 2008, we interviewed 50 leaders of cotton and wheat farms from Ashirmat WUA, only 11 of whom persisted as farmers under state plan after the land consolidation late in that same year. In 2009, all 21 remaining cotton and wheat farmers of Ashirmat and of two other WUAs were surveyed. Further interviews were conducted in 2010 to provide additional insight: 20 took place with farmers, water managers and local officials in Ashirmat; 30 were carried out with officials and experts in Urgench; and 20 were undertaken with farmers, officials and local experts in other WUAs on the present practices of water and land governance.

22.3.3 Modeling Approaches

Modeling soil water fluxes As an alternative to the static norms presently dominating the estimation of the irrigation water distribution in Uzbekistan, a modeling approach considering explicitly the components of water and salt balances was used. Based on the HYDRUS model (Simunek et al. 2005) and FAO's dual crop coefficient concept (Allen et al. 1998), the approach allows modeling the water fluxes and salt dynamics including the relevant capillary rise. Forkutsa (2006) applied the approach to establish water balances and to derive net irrigation amounts and irrigation timing. The dual crop coefficient enables a differentiation between evaporation and transpiration and consequently measures can be derived to reduce non-productive evaporation (by practices of conservation agriculture) and base irrigation scheduling explicitly on the transpiration. As the modeling describes the hydrological processes in detail, the approach has the potential to be used with a high spatial resolution considering even within-field variability. This is in particular advantageous in a situation of increased number of water users with diversified requirements (compared to the past setting in Khorezm with large and uniform production units) as emerged in the study region.

Linked irrigation scheduling-groundwater model The implementation of flexible irrigation strategies at schemes level needs to be supported by tools taking the groundwater dynamics into account. Awan (2010) developed a tool linking the irrigation scheduling model CROPWAT (Clarke and El-Askari 1998) and the groundwater model FEFLOW (Diersch 2002). To overcome the missing consideration of the capillary rise in CROPWAT, the HYDRUS model (Simunek et al. 2005) was used. This configuration allows establishing the field water balance, deriving optimal irrigation schedules and quantifying the spatio-temporal behavior of groundwater. In contrast to the currently, rigid irrigation scheduling since based on static norms only, this tool allows to respond adequately to temporal changes in water availability, meteorological situation and groundwater (Awan 2010). The expected increase in variability of these factors underlines the relevance of the approach. Furthermore, the tool enables to derive site-specific solutions and to consider conjunctive use of surface and groundwater resources.

AquaCrop for deficit irrigation To adapt to limited and non-reliable supply at farm level, a tool minimizing the impact of non-avoidable under-supply on the crop yield by controlled deficit irrigation is urgently needed to assist farmers. As the AquaCrop model (Steduto et al. 2009) has clear advantages in estimating the crop yield depending on water stress compared to CROPWAT, Akhtar (2011) combined the AquaCrop and HYDRUS models and developed a tool to work out deficit irrigation strategies and to compare these with full irrigation.

Salt management at field level HYDRUS allows modeling of salt dynamics (salt accumulation and leaching). As a consequence, site-specific and flexible leaching dates and amounts can be derived aiming at highest possible leaching effectiveness and ensuring non-exceedance of crop-specific salt tolerances (Forkutsa et al. 2009).

Application process According to field analyses by Forkutsa (2006) and Awan (2010), the application efficiency in Khorezm ranges between 40 and 50 % only. Measures for improvement consist thus of (i) adapting the application discharge to field size, soil conditions, slope and irrigation amount based on modeling the advance, recession and infiltration of applied irrigation water, (ii) introducing advanced handling of furrow irrigation (e.g. surge flow, alternate furrow (Pereira et al. 2009; Bekchanov et al. 2012) and (iii) laser-guided land leveling. Due to very flat topography in Khorezm, directing the water from both ends of the furrow (double-side irrigation) provides also a feasible option (Poluasheva 2005) to increase uniformity and in turn efficiency of water application (at respective locations in Khorezm).

22.4 Conceptualising Water Management in Khorezm

The concept of IWRM has gained wide-spread acceptance in the last decades for improving water management. The Global Water Partnership defines IWRM as "a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2000). IWRM has attracted special attention through international conferences in the 1990s, the most important being the International Conference on Water and the Environment (ICWE) in Dublin (1992) which led to the formulation of the Dublin Principles (box 3). Basic ideas of IWRM are empowerment and participation of water users, transparency of governance and accountability of actors involved in water management, the integration of ecosystem needs and human needs, and the idea of management units based on hydrographic boundaries. The three "E"s, efficiency, equity and ecosystem vitality, are what IWRM strives for.

Box 3: IWRM—The Dublin principles

1. Water is a finite, vulnerable and essential resource which should be managed in an integrated manner
2. Water resources development and management should be based on a participatory approach, involving all relevant stakeholders
3. Women play a central role in the provision, management and safeguarding of water
4. Water has an economic value and should be recognized as an economic good, taking into account affordability and equity criteria (GWP 2000).

Improved water management as we aim for in Khorezm is well represented by the principles and objectives of IWRM. They reflect our understanding that it is necessary to bridge the gap between sectoral management approaches as well as livelihood and conservation needs by integrating management tools with an enabling institutional setting. While we thus see IWRM as the *desired process* for Khorezm and the objective of the recommendations presented in the subsequent section, we do not consider IWRM sufficient as *a concept to analyse* water management processes and to base our recommendations on.

Our concerns are well represented by three groups of critics of IWRM. The first group has argued that IWRM lacks a clear and precise definition on which its implementation could be based, that it remains elusive and fuzzy (van der Zaag 2005) and creates unnecessary misunderstandings. Thus preventing a core idea of IWRM: to bring different perspectives together (Jønch-Clausen and Fugl 2001). A second type of argument against IWRM has been brought forth by Biswas (2004) who states that one single concept is unlikely to be applicable in different contexts, i.e. in different cultures, economies and climatic regions. The third type of criticism refers to the absence of power in the conceptual approach of IWRM. Authors such as Mollinga (2008), Allan (2006), Mehta (2005), Mosse and Sivan (2003) argue that water management is inherently political. IWRM can thus be seen as too simplistic and uninformed of the strategic practices and power struggles of different actors and agents involved in water management. In addition, our research supports Mehta (2005) in stressing that there are social construction processes taking place around water resources and their management. The IWRM concept fails to reflect this.

In light of both the normative and integrative strength of IWRM as well as the mentioned criticism, we apply two concepts in this paper. Firstly, we use IWRM as a benchmark of what we aim for in Khorezm, and secondly, develop our own conceptual understanding of water management as it takes place on the ground. We do this based on Khorezm-specific water management practices. This section therefore identifies three types of practices common in Khorezm, assesses their guiding institutions and underlying rationales and discusses their relevance as drivers or barriers of change; change here being an unquestioned part of improving water management along the lines of IWRM.

22.4.1 Formal Practices

Once water is diverted from the Amudarya into Khorezm's irrigation system, a number of state organisations on different administrational levels (Fig. 22.4) are formally responsible for the allocation and delivery of water from the off-takes along the river to the entrance of the water user associations (WUAs). Allocation hereby refers to the assignment of so called water *limits* to different units within the

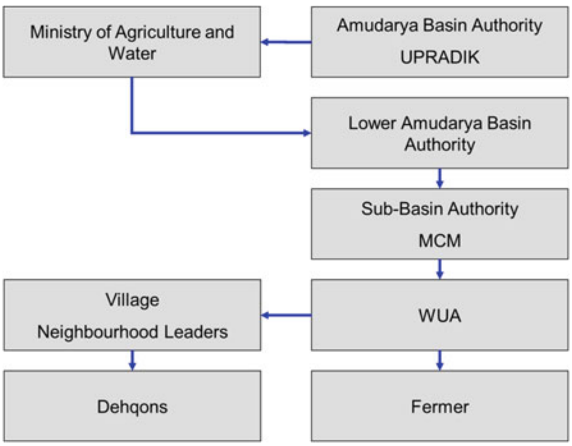

Fig. 22.4 Water allocation through limits

irrigation network. These *limits* are determined through water requests based on irrigated area, planted crops and the respective irrigation state *norms*, which are passed on and aggregated on various organisational levels from the *dehqon* (peasant) and *fermer* (private farmer) via the WUA, UIS (sub-basin irrigation system authority) and BUIS (lower Amudarya basin irrigation system authority) to the Ministry of Agriculture and Water Resources on province level. The allocation of *limits* is done vice versa from the Ministry of Agriculture downwards and water quantities are allocated among different water management units on each level (Veldwisch 2008).

On the level of the former *kolkhozes*, water allocation is formally in the hands of WUAs, which were introduced between 2000 and 2005 in Khorezm. The (donor-driven) WUA design is based on Western ideas of participation and democracy, WUAs are supposed to consist of water users (*fermers* and *dehqons*) and their elected representatives. They do not receive a state budget, but are meant to recover their costs via fee collection from water users.

22.4.2 Strategic Practices

The physical delivery of water, i.e. the operation of technical structures, is done only by some of the water management organisations, mainly the Main Canal Management (MCM) units of UIS, the WUAs, and the water users themselves (Veldwisch 2008). Formally, water delivery should match the water allocations. In reality, however, delivered water quantities depend on many factors, only one of them being the official *limits*. Veldwisch (2008) has shown for Khorezm that water management in averagely water abundant years reacts rather effectively to water users' demands and shows considerable flexibility. He explains this on the basis of different strategies which water users apply to get access to water outside the formal functioning of the water management organisations. Such strategic practices are a deviation from the formal rules of water management in Khorezm, reveal a strong agency of the actors involved and follow their own set of informal institutions.

One example is the use of small, mobile pumps to lift water into field canals, which is formally considered illegal theft of water, but is informally a wide-spread practice (Oberkircher and Ismailova 2015). At pumps which are shared between *fermers* and sometimes *dehqons*, pump management is a negotiation process in which social relations play a large role for determining the rules of water use. Using social relations strategically becomes even more important when actors aim to influence decisions on water delivery. Oberkircher and Ismailova argue that the pursuit of individual (water) interests as a social activity derives its legitimisation from the role of an individual within a network of patron-client relationships. It is accepted by the clients and sanctioning can be expected only from superior or competing patrons. By catering to individuals' water demands, this delivery according to strategic practice (both with the help of technical means as well as social relations) is a deviation from the formal water management institutions but at the same time effectively compensates inadequacies of the formal water management organisations—at least for influential agents.

22.4.3 Discursive Practices

Water management in Khorezm is thus shaped by two parallel systems of practices: (1) the official system with its practices that reflect clearly formulated formal institutions and (2) the strategic practices that individual agents apply to pursue their interests and that follow informal institutions. As the strategic practices are no exceptions, but were found to be wide-spread in the case study locations on different levels of the water management system, it is surprising that they are not more clearly sedimented in the formal body of water management. It should be expected that such practices would in the long-run result in a contestation of the formal water management structure leading to (formal) institutional change. Despite change taking place based on deviation, it is not as prominent as one could expect. On the contrary, change seems to be taking place slowly and sporadically, and in the midst of frequent malfunctioning of water management and widespread deviation, the formal structure appears to be surprisingly resilient.

We would like to explain this high level of resilience of the formal water management system towards change by pointing to continuous processes of strengthening and reproducing the system through discursive practices of the actors involved. While deviation is commonly taking place, the actors involved spend considerable effort and resources on the discursive compensation of these deviations. When *fermers* diverge from the rule that cotton as a state crop should be irrigated before the cash crop rice, observations in the case study WUAs have shown that they are very likely to state in any official conversation that cotton needs to be irrigated first. At the same time as individuals take water management actively into their own hands and pursue their own interest, their statements suggest that 'water management is up to the state'.

Certainly, this behaviour to some extent reflects the political risk that any openly admitted deviation carries in an authoritative state with severe repressions threatening contesters. It is also understandable that many actors have multiple roles of being individual agents with a distinct role in the patron-client network on the one hand and state representatives on the other, the latter creating a stake for them to preserve the status-quo of the formal water management institutions. But the very prominence of these discursive practices on all levels of the hierarchy down to the peasant farmers suggests that there is a meaning of such practices that goes beyond these motivations. It is argued here that the discursive compensation essentially reflects the extent to which the formal rules and roles of water management have been institutionalised in the sense of Berger and Luckmann (1966). According to Berger and Luckmann, reality is a social construct, produced by humans through their social practices and reproduced in and through discourses. Institutions which we encounter in Khorezmian water management have been constructed in their historical context as rules of conduct and specifically defined roles for actors involved. These institutions and their roles are ‘reified’ (Berger and Luckmann 1966), unquestioned, accepted and passed on in society as social facts.

Box 4: Three types of practices

- *Formal practices*: Reflect the formal rules of water management
- *Strategic practices*: Are applied due to the agency of individuals to pursue their (water) interests; follow informal institutions
- *Discursive practices*: Are applied to compensate deviations from formal rules and by doing so discursively reproduce the formal rather than the informal institutions of water management

Verbal reference to the formal institutions can be understood as a way to actively reproduce the formal water management discourse instead of formalising informal practices. Acts of deviation, such as the strategic practices discussed above, are thus compensated by means of discursive practices. They acquire the character of exceptions, special acts in a particular situation—no matter how frequently they occur. They are accepted and applied but do not challenge the formal water management discourse. But what makes the reified institutions so inviolable and resilient—although deviation is even habitualised, sedimented in informal institutions and little sanctioned? We argue here, that a collective aspiration of stability motivates this resilience. It was observed that change in Khorezm since the independence of Uzbekistan was perceived as having occurred largely towards the worse, particularly within agriculture. The population in the case study WUAs portrays Soviet times as golden times of order and abundance, followed by a process of decay and chaos since independence. The path of Uzbekistan after independence has been described as a process of ‘thirdworldisation’ by Trevisani (2008), which reflects this understanding that change may be considered as highly undesirable.

Box 4 summarises the three types of practices and Fig. 22.5 illustrates their interrelation. Formal institutions, while influential, are nevertheless frequently side-stepped and replaced by informal institutions. Even though this deviation from the formal rules may be necessary to reach individual goals or cope with malfunctionings of the formal institutions, the resulting display of agency and the strategic practices are of a rather applied and situational nature. They are used as coping strategies in struggles over power and water, but are not followed easily by change and innovation in the discourse. Formal water management thus shows a very strong continuity which is the result of an equilibrium of deviation and agency on the one hand and discursive practices, strengthening the formal institutions, on the other hand.

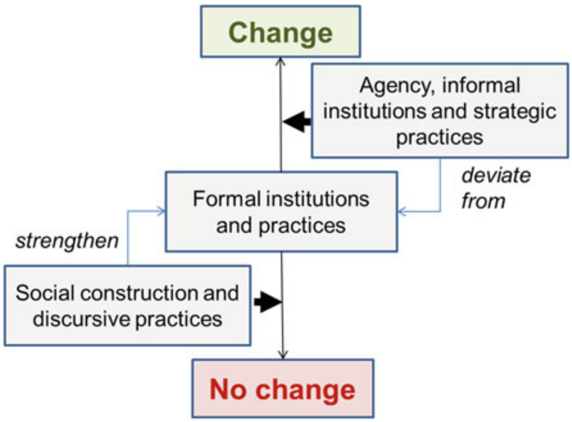

Fig. 22.5 Types of practices and their relation to change

In summary, there are three dimensions of water management in Khorezm underlying our conceptual analysis and recommendations (Hornidge et al. 2013). The first dimension is the type of practices that actors in water management apply—formal, discursive or strategic. The second dimension to be taken into account is embedding in the bio-physical and/or socio-political systems characterising the region. Finally, we differentiate between levels of water management in Khorezm, namely state water management, the WUA, and management at the level of the farmer and field. Questions that arise based on this understanding are: How do formal, strategic and discursive practices of actors shape the bio-physical and socio-political system on the different levels of water management and vice versa, how do the bio-physical and socio-political systems interact on these levels and how can these systems be improved to change practices towards IWRM in Khorezm? We will address these questions in the context of different water management levels in the following sections.

22.5 State Water Management Level

Deficits in human and financial resources of the state water management organisations (WMOs) have resulted in poor functioning of the irrigation and drainage network and are leading to problems with the provision of measurement and communication equipment and the maintenance of the irrigation and drainage infrastructure (Wegerich 2010). Many bureaucratic routines discursively strengthen the formal institutions, but are often bare of an actual function for water management. These practices block human resources which could be used differently. Together with the lack of financial resources, this has led to a situation where the WMOs cannot effectively control the water delivery process.

In most years, Khorezm is (still) receiving ample water supplies. Under this abundance, the WMOs are able to distribute more water than theoretically required by the crops to compensate for institutional malfunctioning. This is facilitated by the technical path-dependency of a system which was originally designed for the conveyance of large quantities of water to collective farms, as common during Soviet times. The water needed for such excessive water use delivery is used at the cost of the environment both within Khorezm as well as in downstream regions. Considering a likely decrease of water resources in the future, this practice can certainly not be considered sustainable.

Particularly (but not only) in times and places of water scarcity, the institutional deficiencies of the WMOs furthermore create a necessity and the space for water users to show agency and take matters into their own hands. Formal institutions are then almost entirely replaced by informal institutions and strategic practices of actors who struggle over resources using their patron-client networks to support their claims. This is facilitated by the fact that like land, as described by Trevisani (2008), water is used as an asset by the water management staff who thus builds up and maintains patron-client relationships and creates extra incomes on the side (e.g. in the form of bribes)—one of the reasons why water allocation and delivered quantities mostly do not match. Individual agents, such as district governors (*hokims*), state water managers, WUA chairmen or influential *fermers*, pursue their own interest in water, either for commercial agriculture, for satisfying the demands of clients or for fulfilling the state production targets and thereby accumulating social capital and stabilising their position within the state hierarchy. It was thus observed that water was frequently distributed based on social relations and social capital instead of based on official *limits*.

In addition, there are structural reasons for the mismatch of water allocation and actual water delivery. The official water requests and *limits* are calculated based on the state orders of wheat, cotton and other cultivated crops and on the official data on tomorqa plots cropped by *dehqons*. Rice on *fermer* land which is mostly cropped on areas freed from state order or as second crop after wheat is not included in the official water allocations (Veldwisch 2008). Consequently, almost all WUAs regularly exceed their *limits* and pay fines generally recovered from rice growing *fermers*. This gap in the official water planning facilitates individual agents to pursue their interests, with rice cropping being both the most profitable as well as the most secretively handled business of *fermers*.

In conclusion, the pluralism of formal and informal institutions results frequently in a mismatch between official water allocations and the actual delivery of water. It is thus the main reason for the lack of clearly defined, transparent and enforced rules of water management according to which people are held accountable. Particularly in times of water scarcity, as expected for the future, such rules will become increasingly relevant. Figure 22.6 summarises the problems at the state water management level and highlights the links between the socio-political and the bio-physical system.

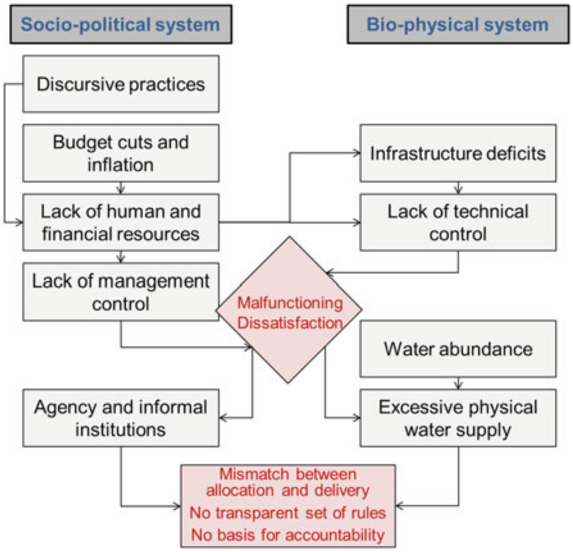

Fig. 22.6 Links between the socio-political and the bio-physical system on the state water management level

22.5.1 Transparency and Accountability

Information for and about water management decisions need to be transparently accessible for all involved in order to allow for the active participation of different actors aiming at collective rather than individual benefits. Furthermore, decision-makers need to be held accountable for their practices.

Options to create and improve transparency and accountability are the following:

- Introducing a WUA chairmen board: Abdullaev et al. (2009) have observed representatives of different WUAs to assemble in so called Unions of Water Users (UWU) in Ferghana valley in Uzbekistan. They suggest to implement such UWUs also in other regions and to introduce 'joint governance boards' between the UWUs and state water managers. By bundling the influence of the individual chairmen, the UWUs will form an important counterbalance to the state in water management and be able to hold the state water managers accountable for their practices.
- Integrating rice irrigation into water planning: To be able to keep track of water in the irrigation system and make decision-making on rice irrigation water more transparent, we suggest that rice on *fermer* land which is freed from the state order should be included in the formal water allocations and in the water fees of the WUAs as separate position.

Monitoring	Assessment & modelling	Capacity building
• reliable and consistent datasets • regional processing and calculation of biophysical parameters, agriculture and climate variables • long-term time series and up to date data	• assessing the status of a WUA based on a combination of monitoring with secondary data • toolbox for modelling land and water parameters and water distribution at WUA scale • indicator package at WUA and Oblast level	• visualization of land and water recommendations in terms of maps and tables • knowledge transfer within project and with stakeholders • transparent information for policy makers

Equity indicator	Productivity indicator	Sustainability indicator	Efficiency indicator
Water consumption	Yield & Biomass	Crop types	Crop water deficit

TOOLBOX

Scale	Input data		Outcome / Benefit
Oblast level	Moderate resolution satellite data on 259m to 1km per image pixel (e.g. MODIS, freely available and validated)	GIS database	Land use mapping Actual and potential evapotranspiration Yield and biomass modelling
WUA level	High resolution satellite data on 15m to 60m per image pixel (ASTER and Landsat)	Secondary data	Land use mapping Actual and potential evapotranspiration Water distribution modelling
Field level	Very high resolution satellite data on m to 6.5m per image pixel and temporal resolution of 14 days (SPOT and RapidEye)	Ground truth	Modelling biophysical parameters (fraction of photosynthetically active radiation) Updating cadastre maps Field based land use maps Identifying crop rotations

Fig. 22.7 Remote sensing toolbox for the state water management level

22.5.2 Technical Tools

As improvement for the technical performance of water management we suggest the use of a remote sensing toolbox (Fig. 22.7) which has been developed for the region.

22.6 Water User Association Level

In 2000, non-governmental, participatory WUAs have taken over the responsibility for water management from the dismantled *sovkhozes*, *kolkhozes* and *shirkats*. But research in the three case study WUAs Ashirmat, Shomoxulum and Amudarya has shown that the WUAs have immense problems recovering their costs. *Fermers* are unwilling to pay their water service fees, the only revenue of WUAs, thereby pushing the WUAs to the verge of insolvency. The vicious circle of *fermers* not paying fees and WUAs consequently not being able to provide good and timely services, has been described by Veldwisch (2008) and Abdullayev et al. (2008).

The malfunctioning of WUAs is reflected also in the technical deficiencies at this level. Maintenance deficits reduce the hydraulic capacity of canals, especially those of low hierarchy, and drainage is impacted by severe outlet problems of drains and main collectors. Insufficient coordination of irrigation activities between the field and the network level and between different network hierarchies causes high operational losses (Veldwisch 2008). Infrastructural deficits such as missing or non-appropriate diversion and measurement structures prevail and make spatially and temporally precise water distribution difficult. Furthermore, today´s rather small *ferm* units with diversified demand have significantly different requirements on the canal system than the larger uniform production units of the Soviet times. Canals are therefore mostly over-sized, which increases water losses. Altogether, the technical performance of water management on WUA level is unsatisfying. Results of our study in an irrigation sub-unit (850 ha) revealed that the gross water input, including pre-season leaching, amounted to 2640 and 2810 mm in 2004 and 2005, respectively. However, an overall technical efficiency of approx. 30 % and a field application efficiency in the range of 45 % reflect that a high share of these quantities do not reach the crops. Instead, a reduction of actual evapotranspiration to 80–90 % of potential evapotranspiration even in water rich years shows that the water demand of crops is not satisfied. For tail-end locations, Conrad (2006) shows an even less satisfactory situation with actual evapotranspiration reduced to 75 % of the potential level in 2005, although gross water withdrawals were high averaging to 2240 mm for the whole Khorezm region in the vegetation period 2005.

Research in the three case study WUAs shows that the feeling of ownership regarding the WUA amongst *fermers* is very limited. This holds true even more for *dehqon* farmers, who often are not aware of the WUA's existence (Ul Hassan et al. 2010). Veldwisch (2008) states that *dehqon* water use is prioritised in comparison with water for state cropping and commercial cropping, but research from the water scarce year 2008 shows that this does not always hold true. In the case of water scarcity and conflicts over water, *dehqons* are highly disadvantaged. They are excluded from governance processes, from water management and information on water availability. Since many of the *dehqons* are women, who are generally granted less authority than men, they are further excluded (a problem acknowledged also in the IWRM Dublin principles (box 3)).

Research on social mobilisation in WUA Ashirmat has shown that even if water users are granted the possibility and space to get involved, they are very hesitant to do so. The common governance structures people are used to are based on a top-down approach with centralised command and control mechanisms. WUAs rely on good relations with state representatives to represent water users upwards and lobby for water. In return, interference into WUA-activities from the WMO-level, district and regional governors can be observed regularly. How to govern water in a participatory way does not come natural to *fermers*, *dehqons* or the local elites. Experience and knowledge on how to conduct elections and meetings or how to ensure transparency are often not available. Instead of using the WUA as platform to show agency, farmers rely on their patron-and-client networks as described above. This leads to a side-stepping of the WUA and further weakens its possibilities to function adequately.

Figure 22.8 summarises the problems at WUA level. They have led to a situation in which neither the water users, nor the WUA staff, nor the state water management staff are satisfied with the resulting water management. During the water scarce year of 2008, dissatisfaction of all involved led to incessant complaints with the WMOs. Their overstraining was certainly one of the drivers for consolidating farm land in 2008 reducing the number of water users substantially and thereby easing water management on this level.

In case of a second round of consolidating farm land, the future role of WUAs is unclear. The abolishment of WUAs and replacement with differently shaped state or non-state organisations seems possible.

WUAs or their future replacements will be faced with similar challenges. The different rationales of decision-making, finance, communication as well as operation between the WMOs and the water users meet at this level and have to converge to allow for efficient coordination, a matching of supply and demand. The technical infrastructure is outdated, responsibilities for rehabilitation and maintenance need to be clarified and funds mobilised. To accomplish this, participation of all water users and their representatives in decision-making processes, operation and maintenance is necessary. This can take place within WUAs or within any other organisation which might be created on this level during the reform process. While we are discussing improvement strategies for WUAs in the following paragraphs, we thus suggest these likewise for any successor organisation which may follow in the course of further reform processes.

Such additional functions can benefit the farmers to increase agricultural production. It will decrease the marginal cost of the production and will motivate them to pay for water. Once fees are regularly paid, the WUA can provide additional

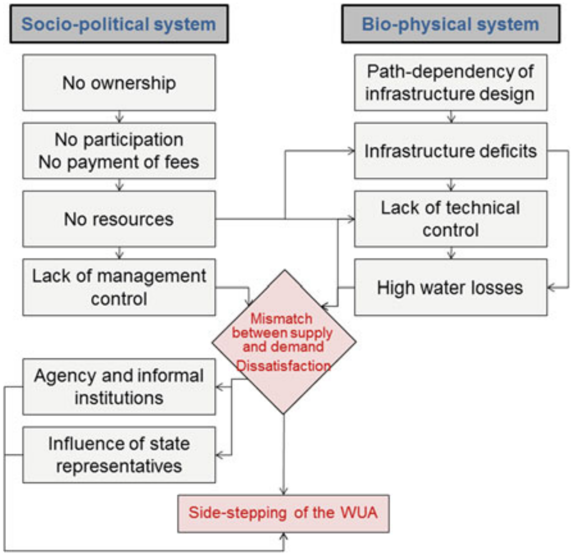

Fig. 22.8 Links between the socio-political and the bio-physical system on the WUA level

functions for societal benefits using the resources raised. If the users perceive benefits generated from such function, they will be further motivated to pay the fees. The WUA and its water users should follow reciprocal accountability, i.e. if a water user does not pay for services he does not receive water, and, in turn, the WUA is not paid if it fails to provide required services.

22.6.1 Increasing Participation: Empowerment and Social Mobilisation

A joint experiment of researchers, *fermers* and WUA staff in WUA Ashirmat has shown that social mobilisation implemented by well-known and accepted people can increase awareness of water users about the WUA's existence and work (Hornidge et al. 2009). However, this is only the first step towards higher participation in the WUA's activities. To create room for water users to communicate their needs and represent their interests, it is necessary for the WUA to conduct regular meetings, so that water users' needs are acknowledged and ownership of the WUA is developed. Stratification among the water users which is related to geographical location should be reduced by introducing canal managers for different parts of canals so e.g. tail-enders have representation mechanisms to secure their water access.

WUAs need to improve their functions as arena of participation particularly for *dehqons* who are currently excluded from information and decision-making processes. This can be done by making the neighbourhood leaders (*elatqoms*) active members of WUA meetings and by introducing an election system in which *dehqons* can participate in WUA decision-making processes through their representatives. To empower *dehqons* further, practical measures can help formalise the *dehqons*' influence in water management. In WUA Amudarya, it was observed in 2009 that pumps were explicitly allocated to *dehqons* instead of the common allocation to *fermers* who then share the pumps with *dehqons*. The *dehqons* managed the operation of the pumps through the neighbourhood leaders and were granted explicit water *limits* for the pumps. Contrary to the situation around pumps, which are shared between *dehqons* and *fermers*, it was thus not possible to exclude the *dehqons* from water access. This practice should be introduced also in other WUAs.

22.6.2 Improving the Technical Performance: Infrastructure Rehabilitation and Modelling Tools

The technical performance at the WUA level is currently largely impaired by a missing or not functioning hydraulic infrastructure. Figure 22.9 gives an overview over the infrastructure which needs to be rehabilitated as a basis for technical improvements.

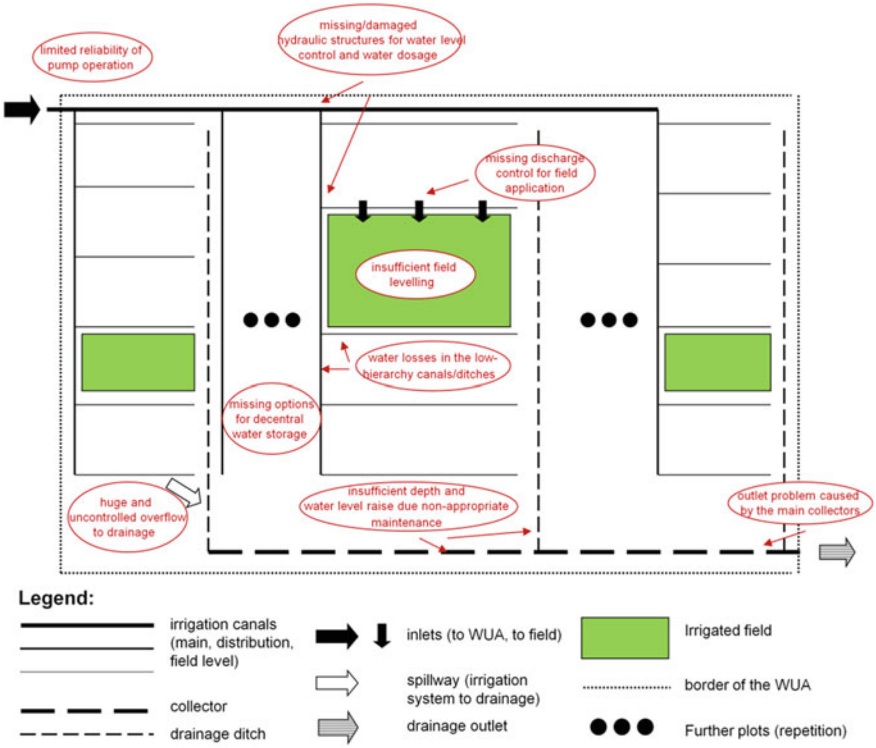

Fig. 22.9 Infrastructure deficiencies

Once the necessary infrastructure is in place, the results of modelling tools can be utilised to implement optimal water distribution within sub-systems. Tools that we have developed for improved irrigation management are shown in the boxes 5 and 6. The water distribution model deals with a larger sub-system (developed for an area of 11 WUAs), the integrated flexible irrigation scheduling and groundwater model with the area of one WUA.

Box 5: Water distribution model

Location and Aim

- Modeling the water distribution process within a sub-system covering 11 WUAs and approximately 3000 fields
- Modeling water demand, water distribution and management including locally used practices and infrastructure

Innovation

- Within season model update concerning water demand based on remote sensing products on different scales
- Involving project innovations on water saving approaches for modeling the improvements on regional scale

Outcome

- Comparison and collaboration with locally used water distribution management and policy makers
- Water management optimization during times of water shortage

In addition to difference in scale, the two presented models differ with regard to the principles according to which they determine the distribution. In general, water can be allocated to water users according to the size of the water user's unit, the crops, the soil and groundwater characteristics, a combination of them or according to modelled crop demands—all reflecting different understandings of equity. Current water distribution in Khorezm following the *norms* considers crop, area, soil and groundwater conditions in a generalized way. This is reflected in the water distribution model as described in box 5. To cope with changing situations (diversified cropping plans; increasing variability of water supply), however, the relevance for water distribution according to flexible modelling taking site-specific conditions into account increases. The flexible irrigation scheduling and groundwater model (box 6) realises this approach and allows for determining temporal and spatial demand. Furthermore, the model enables the integration of groundwater use into irrigation strategies.

Box 6: Integrated flexible irrigation scheduling model

Location and Aim

- Developing irrigation schedules based on linking flexible models for water balancing and integrating the interface to the groundwater system
- Modeling irrigation scheduling process taking the groundwater system into account with respect to a WUA covering around 1900 ha irrigated area

Innovation

- Linking irrigation scheduling and groundwater models for integrated use of surface and groundwater resources
- Use of detailed models (CROPWAT, SEBAL, HYDRUS, FEFLOW) enabling to react to changing environments

Outcome

- Optimized irrigation schedules taking surface and groundwater resources into account
- Strategies for controlled deficit irrigation to minimize the impact of water stress on yield
- Assessing the impact of irrigation strategies on groundwater resources

While the water distribution model is thus closer to the currently practiced way of distributing water and more likely to be adopted for use by local water managers, the flexible irrigation scheduling and groundwater model allows for a further optimisation of the distribution. To implement it, infrastructure rehabilitation and the availability of site-specific information are prerequisites.

22.7 Farmer and Field Level

The technical situation at the farmer and field level can be characterised by a non-appropriateness of water supply indicated by reduced actual evapotranspiration. According to monitoring at the level of an irrigated field carried out in the vegetation period 2003 (Forkutsa 2006), the actual evapotranspiration was reduced to 70 % of the potential level mainly caused by inadequate irrigation timing, which did not match the time-depending crop water requirements especially in the beginning/middle of the vegetation period. Water is usually delivered to *ferms* in water rotations, roughly coordinated according to the demands indicated by *fermers*. However, the management problems discussed for the WUA level make on-time water delivery highly uncertain. This unreliability of supply is reflected in practices of tail-end *fermers* who tend to over-irrigate once water is available and block drains and collectors to raise the groundwater level so groundwater can contribute by increased capillary rise to crop water requirements. While this beneficial effect makes sense in the *fermers*' situation of uncertainty and in the short-term perspective, it also has negative impacts, such as secondary soil salinisation. Using hydrological measurements at two field sites, an analysis revealed, that salt input in the rootzone by capillary rise exceeded the input by irrigation water by around 40 % (Ibrakhimov et al. 2007).

Groundwater, canal water and salinity are in general strongly linked on the farmer and field level through the process of irrigation and leaching. Besides seepage from the irrigation canals, high application losses are the major source of groundwater recharge in Khorezm. At the end of the winter period without irrigation, the groundwater level drops to 2.3 m below ground, reaches after leaching 1.4 m in April and approaches the highest level of 1.2 m in August, consistent with the most intensive irrigation period in July and August (Ibrakhimov 2004a). This groundwater dynamics reflects a low application efficiency which is a result mainly of irregular micro-topography due to poor land levelling, insufficient information on the site-specific as well as the temporally appropriate irrigation depths, lacking optimization of application discharge according to field characteristics and missing infrastructure for proper handling of the application discharge.

The technical deficiencies on farmer and field level are thus caused by an outdated or missing technical infrastructure, technology and information and are further exacerbated by the institutional setting in which the irrigators act. Irrigation scheduling in Khorezm is based on *norms* which were developed in the 1960s. Since then, water user units have decreased in size, cropping patterns have diversified (particularly on *ferm*-land freed from state plans), awareness for limiting water withdrawals have increased and modelling tools to calculate evapotranspiration, determine capillary rise and estimate irrigation efficiencies have improved. Consequently, these *norms*, while remaining helpful tools for estimating large-scale water requirements for irrigation seasons, fail to provide insight into water management requirements under changing situations.

The high degree of state regulation of agriculture is furthermore reflected in area- and production-based state quota on cotton and wheat on the one side and a high level of uncertainty regarding land use rights on the other. Land is state property leased to *fermers* in up to 50 years contracts (Trevisani 2008). Despite these contracts, leases remain subject to state will as illustrated by the event of land consolidation in 2008 (box 7).

Box 7: Land consolidation 2008

At the end of 2008, farm land was recollected and redistributed in bigger plots to roughly one fourth of the former *fermers*. In WUA Ashirmat (2,116 ha of irrigated land) for example, *ferm*-land had been leased to 93 *fermers* from 2000 onwards. In October/November 2008, these 93 *fermers*—after being asked to do so by the government—returned their land lease contracts to the state and the land was redistributed to currently 21 remaining *fermers*, many of which consider a second round of land consolidation as likely to take place.

The combination of a reliable state plan and unreliable land lease contracts absolutely increases the dependence of *fermers* on the fulfilment of the state plan, proportionately weakens their potential to independently plan, invest or innovate and lowers their interest to take the path of longer term planning and risk-taking. For water management on the farmer and field level, this means that water-saving techniques which come with investments on field level are not practiced (Oberkircher and Ismailova 2015).

Furthermore, little economic incentives exist to encourage water saving. Water is priced only by electricity costs for pumping and highly subsidised (often not paid)

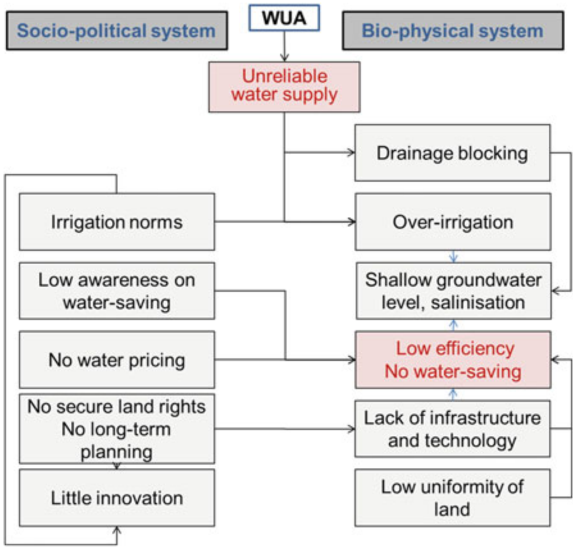

Fig. 22.10 Links between the socio-political and the bio-physical system on the farmer and field level

WUA fees, resulting in observable water wastage. Despite considering it a bad practice to let water run from the canal to the drain, it happens frequently. The state organisation Uzsuvnazorat (Department of Water Inspection), responsible for preventing water wastage and promoting water-saving, has one inspector per district checking on water wasting as well as illegal rice cropping. Considering the large areas of appointment, Uzsuvnazorat is understaffed, not able to prevent water wastage or to sanction it accordingly.

In conclusion, technical efficiency at farm and field level is low and cannot be balanced by the institutional setting (Fig. 22.10).

Awareness on water-saving is low and water wastage is little sanctioned. There is no planning security and water supply is unreliable while at the same time highly subsidised, which steers farmers' behaviour towards risk minimisation rather than towards efficiency and water saving. To improve the efficiency at farm and field level, technical options should go alongside changes in the institutional setting that create awareness on water-saving, lower the risk and disincentives of farmers to apply water-saving practices and create space for innovation. The following paragraphs discuss our suggestions for accomplishing this.

22.7.1 Technical Aspects

- Adequate irrigation amount and timing: Modelling soil water and salt dynamics proved to be an appropriate tool to provide the irrigator with reliable information regarding amount and timing of irrigation and leaching events answering spatially and temporal changes of requirements. Matching the timing of irrigation

events to actual crop water demand, instead of norm-based irrigation scheduling, allows to avoid water stress (with current level of field water input) or to enable a water saving potential of 20 % (without changing the current level of water stress). Forkutsa et al. (2009) showed in a simulation with the HYDRUS model that 25 % of the leaching water can be saved without reducing the leaching effect. Combining simulation models (HYDRUS) with refined monitoring techniques considering spatial distribution of soil salinity (electromagnetic induction device EM-38) is a promising tool to raise leaching efficiency. Akramkhanov et al. (2008) showed that EM38 can provide timely and site-specific information on the current level of soil salinity as a reliable input for salt dynamics modelling.
- Optimizing the water application process: Due to the flat topography double-sided irrigation is a promising approach in Khorezm. Field tests resulted in a more uniform water distribution along the furrows, resulting in a 15 % saving of the seasonal gross irrigation water input to the field (Paluasheva 2005). Furthermore, the increase in salt accumulation at the end of the furrows due to low irrigation water application and high capillary rise could be halved (compared to 300 m furrows) and as a consequence cotton yield increased by 0.5 t/ha (Paluasheva 2005). Improvement in operation and design of the furrow technique (optimizing application discharge; introducing surge flow; laser land levelling) allows to raise the application efficiency from currently 45 to 65 %.

22.7.2 Institutional Aspects

- Strengthening water inspection: In 2009, WUA Ashirmat introduced local water inspectors (Ul Hassan et al. 2010)—a promising innovation which is here suggested also for other WUAs. Local water inspectors should cooperate with the district inspectors of Uzsuvnazorat and make use of its formal sanctioning mechanisms. It can be expected that the local inspectors will feel more bound to their fellow villagers than to the state organisation Uzsuvnazorat and would try to avoid a control function with sanctioning mechanism. However, the mere existence of water inspection on local level and social sanctioning mechanisms would have a strong impact on water-saving awareness on the local level, as suggested by Veldwisch (2008).
- Build capacity and promote water-saving: In addition to these control mechanisms, Uzsuvnazorat together with local water inspectors should widen their functions and adopt a more prominent role in the education of water users on water wastage and water-saving. Concrete water-saving measures are currently only promoted through the annual *Pakaz* meetings of *fermers* in which state representatives communicate agricultural *norms* and regulations, which occasionally also relate to water-saving (i.e. shorter furrows). Awareness-raising campaigns as well as capacity building during and in addition to the state

trainings should be conducted more systematically and frequently. By continuously being adverted to water-saving and by acquiring the skills to practice it, water users would be able to develop an ownership for water-saving instead of referring to a discourse in which water management and water-saving are 'up to the state' only.

- Loosen *norms* for irrigation: As mentioned above, irrigation practices in Khorezm are subject to *norms* which prescribe to *fermers* the amount of irrigation and the application technique. These *norms* are monitored throughout the season and if *fermers* do not apply them they may get into difficulties with state representatives with the possibility of land loss (Oberkircher and Ismailova 2015). To be able to improve the adequacy and efficiency of irrigation and to react on changing environments (especially on increasing variability of water supply in the future), changes are necessary which may contradict the *norms* (e.g. with regard to ploughing when practicing conservation agriculture). To allow *fermers* to practice water-saving, the *norms* therefore need to be loosened and presented as benchmarks and justified non-compliance with them be possible without sanctioning.

The technical and institutional options suggested above have to go hand in hand as they rely on each other to improve water management on farmer and field level. Table 22.1 gives an overview of the linkages between the measures and the overall improvement that can be expected from a joint implementation.

Table 22.1 Linkages between technical and institutional recommendations on farmer and field level

	Technical measures	Institutional measures	Expected improvement
Adequacy of irrigation and leaching amounts and timing	• Determine spatial and temporal crop water and leaching requirements through • Soil water and salt modelling • Salinity measurements with EM-38 • Apply the necessary water amounts	• Loosen irrigation *norms* regarding irrigation amount • Raise awareness on water-saving and sanction water wastage through a strengthened Uzsuvnazorat	20 % water-saving during vegetation season and 25 % water-saving during leaching which can be used to reduce early season water stress Increase of application efficiency from 50 to 65 %
Application efficiency	Practice • Laser land levelling • Optimising discharge • Double-sided furrow irrigation • Surge flow irrigation	• Loosen irrigation *norms* regarding application process Provide information and training on water-saving techniques	

22.7.3 Agency and Innovation

Anticipated changes in water availability make it necessary that Khorezm does not only rely on state planning and responsibility but uses all its human capacity and resources to improve its resilience and adaptability. Farmers as fundamental agricultural actors should get the chance to increase and use their knowledge and show agency in being active innovators (Röling 2009). To facilitate this, we suggest the following measures.

- Assure land rights: *Ferm* land is state property and land use rights are not secured. Events such as consolidating *ferm*-land in 2008 negatively affect risk proclivity and innovateness. Many *fermers* perceive another round of land consolidation as likely, which even in the current form of a rumour, further hampers individual investments into the land. Assuring land rights and leases therewith is crucial for increasing the ability and willingness of *fermers* to implement long-term land- and water-use planning.
- Improving the quota system: Abolishing area-based production quota, while maintaining production-based quota, is assumed to foster *fermers*' innovativeness to identify ways to increase yields; therewith fulfilling production quota with less land and input used. This could later be developed into a system of tradable cotton quota, allowing the specialization of some for cotton farming and others for alternative crops.
- Introduce innovation plots: Assigning specific plots of land for *fermer* innovation would give *fermers* the physical and legal space to experiment and improve their farming practices. Additionally it could strengthen the individual's feeling of responsibility to be active not merely as implementer of state *norms* but furthermore as conceptual driver, knowledgeable person and local innovator. It would thus open up room for agency to move from the domain of deviation to areas within the legal system where it can spur flexibility and innovation.

22.8 Conclusions

The previous sections of this paper have analysed water management in the province Khorezm of Uzbekistan and presented recommendations on how water management can be improved towards IWRM. The analysis takes into account the local context of water management as described in Sect. 22.2 and derives its results from a joint analysis of socio-political and bio-physical aspects. While IWRM was presented as the framework which our recommendations are meant to create, we base our conceptual understanding of water management in Khorezm on additional insights. In Sect. 22.3 we have described three different types of practices, which actors involved in water management apply: formal practices, strategic practices, and discursive practices. We have concluded that all three types of practices shape water management in Khorezm and furthermore keep the institutional setting in a state of equilibrium with strategic practices pushing for a change and discursive practices strengthening the formal practices and preventing change. Sections 22.4–22.6 have analysed water management on the different levels from the state water management level to the farmer and field level. Table 22.2 summarises the problems and recommendations for the different levels as well as the benefits that can be expected from the implementation of the recommendations.

Table 22.2 Summary of recommendations for different water management levels in Khorezm

	State water management level	WUA level	Farmer and field level
Main problems	Mismatch between water allocation and delivery	Mismatch between supply and demand (spatial and temporal)	No water-saving practiced
	No transparent set of rules	No ownership and participation	Little farmer innovation
	No basis for accountability	Side-stepping of the WUA	
Recommendations	Creation of transparency and accountability through • Revision of water law • Introduction of a WUA chairman board • Use of remote sensing toolbox for transparent communication • Integration of rice irrigation into formal water allocation	Development of WUAs as business units with ancillary functions	Strengthening of Uzsuvnazorat
Institutional setting			Promotion of water-saving Abolition of norm-based
			irrigation directives
			Land tenure reform
			Abolition of area-based quota
		Empowerment and social mobilisation of water users through • Activity of social mobilisers • Regular WUA meetings • Introduction of canal managers for different geographical parts of the WUA • Integration of neighbourhood leaders (*elatqoms*) in WUA activities and decision-making • Introduction of *dehqon* pumps	Introduction of innovation plots

(continued)

Table 22.2 (continued)

	State water management level	WUA level	Farmer and field level
Recommendations	Remote sensing toolbox	Infrastructure rehabilitation	Soil water and salt dynamics model
Infrastructure and technical management tools		Introduction of monitoring infrastructure (e.g. discharge measurement devices)	Soil salinity measurement tool
		Water distribution model	Improved furrow application techniques through • Laser land levelling • Double-sided furrow irrigation • Surge-flow irrigation • Optimising discharge
		Irrigation scheduling and groundwater model	
Expected benefit	Clearly defined rules, rights and responsibilities which are transparently communicated and according to which actors are held accountable	Increased representation and participation of water users in water management	Higher application efficiencies and practice of water-saving
		Better financing and technical functioning of WUA water management	Agency as driver of innovation and adaptability to future water scarcity
	More balanced influence of state and water users respectively	More adequate water distribution according to demand	
	Higher technical efficiency		

Some of the results presented in the table reflect the general discussion of IWRM in other countries and agricultural systems. An example is that transparency, accountability and participation matter and need to be improved to create an enabling environment for IWRM. Furthermore considerations on infrastructure, the bio-physical system and technical efficiency are relevant to develop and use technical management tools to improve water management. These technical aspects need to be understood in the wider institutional setting—an IWRM principle which clearly applies to Khorezm as well as elsewhere. There are, however, also elements which reflect a special situation of Khorezm and Uzbekistan and which call for specific improvement measures.

What we have shown above is that the way human agency is currently displayed in Khorezm and compensated again through discursive practices, is a barrier to change and *limits* the human capacity to innovate. This occurs in addition to formal restrictions, through which state control pushes agency towards the domain of illegality. The two processes together prevent human capacity from unfolding in favour of improvements. They constrain the participation of knowledgeable actors for a collective benefit and make the region less flexible to adapt to future water scarcity. Specific for Khorezm are thus all those recommendations which aim at creating legal space for agency and innovation. Furthermore, tools such as models acquire additional importance in this context besides their technical function. They facilitate transparency and enable agents across the management hierarchy to access and make use of information. Once agency can enfold openly and strategic practices of actors are better integrated into water management, they do not consist of a deviation from the formal rules anymore and compensation through discursive practices will occur less frequently. We believe that such a positive feedback loop for change is what is needed to improve water management in Khorezm and prepare the region for future water scarcity.

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Chapter 23
Integrated Water Resource Management in Isfahan: The Zayandeh Rud Catchment

Shahrooz Mohajeri, Lena Horlemann, Sebastian Sklorz, Michael Kaltofen, Sharare Ghanavizchian and Tamara Nuñez von Voigt

Abstract The river Zayandeh Rud is the most important surface water in central Iran. The catchment area has been affected by two drought periods within the last 15 years. Decreasing surface and groundwater availability has been accompanied by an increase in water withdrawal for irrigation, domestic uses, industry, and water transfers to neighbouring provinces. This has led to severe ecological and social consequences. While the Iranian government is officially committed to the IWRM idea, water management decisions have still been based on supply-driven strategies, and supply and demand have mainly been balanced by water transfer projects. Existing simulation models have not been used for management decisions because their development lacked participatory elements and therefore they are considered as being biased. The aim of the project IWRM Isfahan was to develop a locally adapted IWRM process for the catchment area which integrates organisational, participative and technical measures. To this end, three different simulation models have been developed and merged into a Water Management Tool (WMT). WMT serves as the main instrument for a better understanding of water management processes within the catchment area and it provides the authorities in charge with a decision support tool. In order to achieve ownership and acceptance of the results and recommendations, accompanying measures like reforms in water governance or the establishment of WMT commissions need to be realized. The first steps in this direction have already been taken applying participatory methods. Initial estimations show that the implemented measures as a whole carry the potential for successful conflict resolution.

Keywords IWRM process · Water management tool · Zayandeh Rud dam · Gavkhuni · Stakeholder involvement

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23.1 Introduction: Current State of IWRM in Iran and in the Zayandeh Rud Catchment Area

Iran's water resources and their ecology have been under pressure because of climatic conditions as well as their heavy overuse in many regions of the country. To date parts of the population suffer from water shortages particularly during the dry summer months. The drinking water supply and also water supply to the agricultural sector and the environment are in danger in the long-term (Foltz 2002).[1] There exist usage conflicts between single sectors as well as conflicts among water policy objectives, for example between resource use and resource protection.

The Iranian government has long since recognised the need for action and officially there is a willingness to reform the water sector (Bertelsmann Stiftung 2012). At the world summit for sustainable development in Johannesburg in 2002 the Iranian government had already committed to the IWRM idea and had produced a strategy paper in 2003 which takes up IWRM as the leading approach (UN DESA 2008). There are some international projects which work on regional IWRM strategies on behalf of the government and in summer 2013 the Iranian commission to UNESCO applied for an "international centre for integrated management of water and natural resources".[2]

Even 12 years after the Johannesburg summit fundamental institutional problems remain unresolved. There is still a lack of experience, operational organisations and effective instruments for implementing IWRM. Water agencies, provincial administrations and environmental agencies still lack the human and financial resources they would need to manage integrated cross-sectoral tasks. Moreover they focus too much on their respective interests and until now the Ministry of Energy has taken the main political decisions concerning water management. This results in short and long-term goals being very much focused around technical solutions like the regulation of water resources through dams or expensive water transfer projects[3] (Mohajeri et al. 2009a).

Reactions to droughts have been short-sighted, like the prohibition of surface water withdrawal for agricultural purposes (Safaei et al. 2013). This again led to an increase in groundwater extraction and a lowering of groundwater levels. Moreover, social unrest and the destruction of pipes for water transfers to other provinces by protesting farmers were consequential events (Al Monitor 2013, France24 2014).

[1]The German broadcaster Deutsche Welle Farsi alone released nine articles in July 2013 with headlines like "Water shortage in Iran reaches critical levels", "Water shortage and pollution from North to South" or "Save the Ourmiyeh Lake".

[2]The centre is supposed to be one of 81 international and regional centers under the auspices of UNESCO. The costs are to be assumed by the Iranian government.

[3]For example a transfer from the Persian Gulf to the province Fars. See Tehran Times July 8th 2013.

The Zayandeh Rud is the most important and at the same time most endangered river of central Iran (see Sects. 23.2.1–23.2.3). Institutional and organisational weaknesses (Sect. 23.2.4) and the lack of water simulation models that can be accepted by all stakeholders were the starting point of the IWRM Isfahan project which seeks to initiate an IWRM process in the Zayandeh Rud catchment. Economic losses, increased uncertainty among investors in the industrial sector, social unrest and protests by environmentalists are direct consequences of incorrect policy and water management decisions. Therefore, in the course of the project instruments and procedures were developed, which allow for the promotion and support of an IWRM process and measures for conflict resolution at the same time. The first phase of the project has been finished, and initiated processes still have to be pursued in the future.

In order to initialise this IWRM process a Water Management Tool (WMT) has been developed together with the relevant local actors. With this WMT the consequences of political decisions regarding water resources can be visualised. For the development of the WMT quantitative data about the water resources in the catchment area have been used (see Sect. 23.3.1).

The lack of availability of surface water in the catchment area has been compensated particularly through overuse of groundwater during the last 15 years. Therefore, in Sect. 23.3.2 the results of the calculations of the FEFLOW groundwater model as part of the WMT will be described. FEFLOW is the main tool to describe the complex interaction of surface and groundwater and therefore provides vital data for water management decisions in the catchment.

Following the subsidiary principle of IWRM, the aim of the WMT is that visioning and strategic planning follow an iterative process (see Fig. 23.1): National, regional and local stakeholders should deliver inputs for the definition and

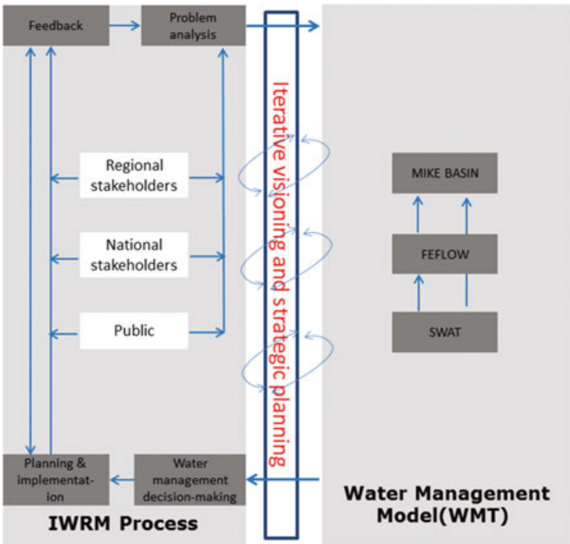

Fig. 23.1 Visioning and strategic planning as iterative process using the WMT. *Source* inter 3

description of water problems and the resulting consequences. Using the WMT the responsible actors should take joint decisions, plan and implement the respective measures and obtain feedback from all stakeholders on how far measures have led to solutions to water related problems.

A kick-off for the establishment of respective responsible organisations for carrying out these iterative processes as well as the technical responsibility for the WMT took place in the form of an interactive workshop (see Sect. 23.4.1). In the next project phase, questions concerning the institutional and organisational implementation shall be clarified and the WMT shall be handed over to the Iranian stakeholders. Section 23.4.2 describes the necessary steps towards sustainable and effective use of the WMT as well as towards a comprehensive implementation of IWRM in Iran. This involves the institutional, legal and organisational framework conditions, but also the capacity development of WMT users and actors who promote the IWRM process in general.

23.2 Zayandeh Rud—The Research Area

The research area is located in central Iran (see Fig. 23.2), in the province of Isfahan, with Isfahan City nearly in the centre. The river Zayandeh Rud, which gives its name to the region (the catchment area) is the most important surface water in central Iran. The catchment area stretches across two provinces, covering a total area of 26,000 km^2. The river originates in the province Chaharmahal-va-Bakhtiary

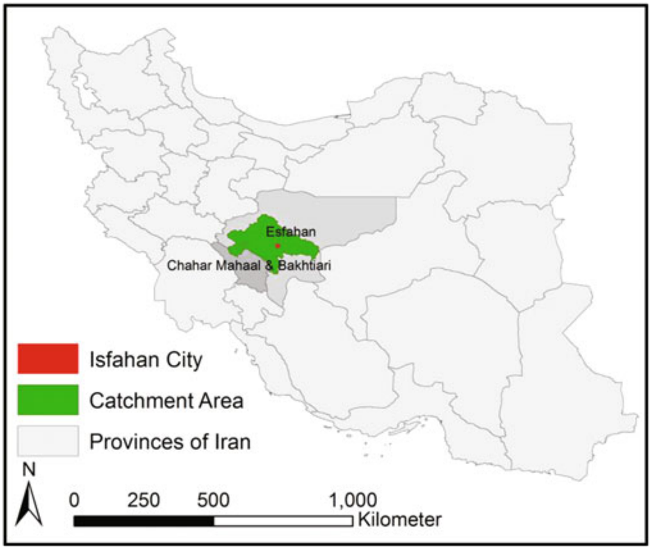

Fig. 23.2 The Zayandeh Rud catchment area. *Source* DHI-WASY

in the area of the Zāgros Mountains in the north-west of the catchment area. However, most of the river lies in the province of Isfahan. It ends in a seasonal salt lake and marsh in the south-east of the catchment area. On its way the Zayandeh Rud passes through fertile regions, large industrial settlements as well as the important city of Isfahan whose historical buildings were declared UNESCO world cultural heritage sites. The salt lake Gavkhuni became one of the first internationally recognised marshlands at the UN Ramsar convention (Nadjari 2004).

After the Islamic revolution in 1979 and at the beginning of the Iran-Iraq war in 1980, the Isfahan province attracted thousands of people from other provinces. The heavy population increase was accompanied by the rise of Isfahan as an important industrial and agricultural centre. As a result the city of Isfahan today is the 3rd most populated city in Iran and the province is the second largest industrial area in the country.

23.2.1 Characteristics of the Catchment Area

On its 405 km course the Zayandeh Rud runs through extremely different climatic and natural conditions (Shafaghi 2003; Hossaini Abari 2000). The area of its headwaters in the Zāgros Mountains, at an altitude of 4,000 m, is dominated by a cold and humid climate. At the river's estuary, the salt lake Gavkhuni at an altitude of approximately 1,500 m, the climate is arid. Thus, the average precipitation decreases from 1,500 mm at the source to only 80 mm at the mouth. Moreover, the average monthly air temperatures that differ between 1 to 24 °C and a potential evaporation of up to 3,100 mm/a suggest the particular challenges of managing these water resources.

In order to achieve controlled management of the water resources, a dam with an average inflow of 40 m^3/s was built by a French-Iranian consortium in 1972. For the purpose of covering the increasing water demand, three tunnels were built in 1954 and later in 1985, through which water is being rerouted from the neighbouring province toward the Zayandeh Rud dam. The demand driven water management led to the building of two more diversions that are supposed to redirect additional water towards the catchment within the next 7 years.

On its way from the dam to the salt lake the Zayandeh Rud can be divided into three main parts (see Fig. 23.3). In the first part the water flows in what can be described as quite good quality around 100 km from the Zayandeh Rud dam to the Chamaseman dam, the extraction point of Iran's biggest water works (Mohajeri and Dierich 2008). During the last few years, the region around the Chamaseman dam lake has become a famous destination for families and anglers from the city of Isfahan. Here, the drinking water for the 4.5 million citizens of the Isfahan province and other cities outside of the catchment area—like Yazd, Kashan or Nain—is being extracted. Additionally water is used for agricultural purposes.

In the second part of the river further downstream up to Isfahan, a number of agricultural businesses as well as big industrial sites (oil refineries, steel industry)

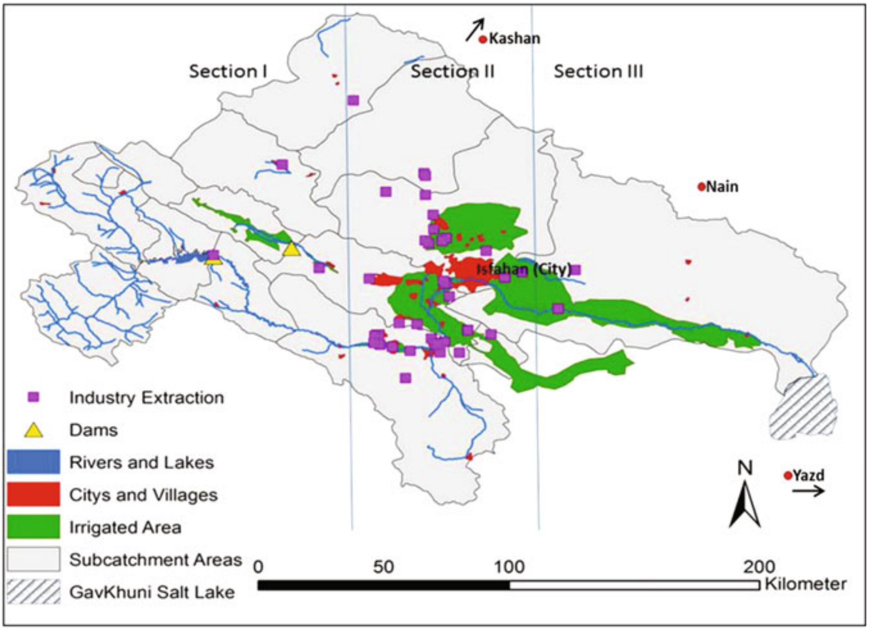

Fig. 23.3 The Zayandeh Rud catchment. *Source* DHI-WASY and inter 3

are located. Here the river water is heavily polluted through waste water and agricultural drainage water. In the last part of the river, water is used mainly for irrigation. In the last 15 years the water arriving at the Gavkhuni Lake has been almost only agricultural drainage water, heavily polluted by pesticides (Soltani 2009).

23.2.2 *Water Availability*

The long term yearly discharge from the dam lake is 1314,7 million m^3 based on values from 1996 to 2012 (Source: Isfahan Regional Water Board). Also between 2000 and 2008, an average of 1,300 million m^3 water per year from the dam lake was available to cover the water demand within the catchment area. At this time, the water availability decreased to 533 million m^3 during the dry period at the beginning of the millennium, and had its peak of about 1,800 million m^3 in 2007 (Table 23.1).

As a result of the arid climate there is no significant groundwater recharge downstream of the dam. The results of the SWAT model—as a part of the Water Management Tool (WMT) (see Sect. 23.3)—show an average groundwater recharge of about 142 million m^3 for the entire area downstream of the dam. This is

Table 23.1 Yearly release from Zayandeh Rud dam (2000–2008)

Year	Release from dam (m^3/s)	Release from dam (million m^3/year)
2000	28.9	911.4
2001	16.9	533.5
2002	39.9	1258.3
2003	48.4	1525.2
2004	47.8	1506.2
2005	51.0	1608.3
2006	50.0	1576.8
2007	57.8	1821.7
2008	31.0	977.6
AVG	41.3	1302.1

Source Isfahan Regional Water Board

the main reason for the heavy overuse of groundwater resources especially during the dry years. The results have been considerably decreasing groundwater levels during the last 15 years by 20 m, in some parts by even 50 m (see also Sect. 23.3.2). This represents an overuse of groundwater resources of around 5 billion m^3 over a period of 15 years or an average of 315 million m^3/year.

23.2.3 Water Withdrawal

The biggest share of surface and ground water resources in the catchment area is being used for irrigation. For the distribution of surface water, irrigation systems with multiple distribution structures and channel systems were built in the 1970s and late 90s. Additionally a lot of ground water has been extracted from 35,000 wells for irrigation purposes.

Most of the irrigated area in the catchment is irrigated by flood irrigation like furrow irrigation. In 2006/2007, for example, all irrigated crops were supplied by flood irrigation while orchards were supplied by pressure irrigation (Felmeden et al. 2014).

From 2000 to 2008, the agricultural sector took an average of 787 million m^3 of water directly from the river. There were also about 391 million m^3 of groundwater as well as the illegal use of treated effluent from the sewage treatment plants with an estimated total of about 269 million m^3. The water that seeped away from the mostly traditionally irrigated farmland is available as return flow for the irrigation of further agricultural areas. This process of reuse is repeated throughout the entire basin up to 3.5 times. Through this return flow, the average available amount of water for agricultural use increases from around 1,450 million m^3 to around 5,000 million m^3. With this amount of water 230,000 ha of agricultural land is irrigated; this is equivalent to almost 5 % of the total irrigated land in Iran. In the course of the extreme dry periods over the last 3 years, irrigation of agricultural areas in the catchment area has been completely or partially banned.

While agriculture has suffered from serious supply problems recently, the number of industrial businesses, including the water demand for industry, has risen steadily. Today the amount of water used by industry in the catchment area is around 150 million m^3/year. About 25 % of this water is being shared among more than 3000 small scale industries within Isfahan municipal boundaries, 13,000 small and medium sized industrial units and 29 large industrial settlements and zones. In addition there are over 30 large individual industrial units like Mobareke Steel Co. which share approximately 75 % of the total industrial water consumption in the catchment area.

The average daily consumption of drinking water in rural areas measured by individual water meters stands at 150 and 230 l/capita in urban areas. These figures are significantly higher than the average use of 90 l/capita for rural areas and 160 l/capita for urban areas as envisaged by the Iranian Ministry of Energy. And they have to be complemented with water losses caused by network leakages of up to 50 % in rural areas and 25 % in cities. This means a total water consumption of 225 l for rural residents and 285 l per urban user. Today, about 350 million m^3 of water resources is required to supply drinking water. Additionally around 100 million m^3/year is taken from the Zayandeh Rud to supply the inhabitants and agriculture outside of the catchment area, like the city of Yazd.

Experts estimate the water requirements of the salt lake Gavkhuni as being between 70–150 million m^3/year, an amount which hasn't been reached in years. Quite the contrary, the high water consumption coupled with the growing length of recent dry periods have left the riverbed in the centre of Isfahan virtually empty (see Fig. 23.4).

Fig. 23.4 Empty Zayandeh Rud river bed in 2013. © IWRM Isfahan

23.2.4 Challenges in Water Governance and Management

The implementation of IWRM requires the creation of an enabling environment, supporting institutional and governance structures, adequate water management instruments, an infrastructure development that is adjusted to the defined IWRM objectives and, last but not least, profound financial backing (UNEP 2012). IWRM promotes the river basin as the proper scale for water governance (Global Water Partnership 2000) and requires stakeholder participation (see e.g. Mitchell 1990; Mostert 2006).

Although the Iranian government accepted the general idea of IWRM, water governance and management still face severe problems: Overall, a general master plan (and regional action plans accordingly) for the management of the national water resources is still missing. Moreover, despite a formally decentralized water governance structure, there is no actual decentralization of responsibilities with their respective rights and duties (NWWEC and inter 3 2009). This leads to non-transparent decision making processes and vague responsibilities.

In general, three dimensions of institutional and governance challenges appear in the management of natural resources (Young 1999) and thus in the implementation of IWRM processes (Moss 2004). First, it is assumed that environmental institutions work best if they match the boundaries of the ecological systems they refer to. In the case of the Zayandeh Rud, however, two province governments are responsible for decisions over one river. Second, the coordination and cooperation between institutions within the catchment area, i.e. between sectors at the same level, are of major importance in order to integrate different interests regarding the water resources. In Iran, and particularly in the case of the Zayandeh Rud, sector agencies pursue their own goals with regards to and compete for water resources. Third, the coordination between institutions at different levels, for example between national and regional levels, is crucial. Ideally, command-and-control approaches should give way to participatory, bottom-up decision-making and management procedures. Addressing these coordination problems would require a realignment of governance structures and respective institutions, as has been described for many other countries (Bandaragoda 2000; Saleth and Dinar 2000; Rogers and Hall 2003; Dombrowsky 2005; Horlemann and Dombrowsky 2012; Huitema et al. 2009). The realignment of institutions and organizations along the scales of river basins in a water sector reform, however, is highly political because it would inevitably shift decision-making powers currently in place (see e.g. Schlager and Blomquist 2008; Saravanan et al. 2008).

It is obvious that a perfect fit and interplay of institutions can never be reached at the same time, and sometimes it is not even desirable, e.g. when newly established organizations at river basin level replace regional organizations that worked well (Moss 2003). For Iran, a breakdown of the water sector into a clear-cut regulative pillar, an executive or operational pillar and a control pillar to enhance coordination could also be an option (Mohajeri et al. 2009b).

The integration of interests concerning the water resources but also with regards to political and individual influence has been a main working point of the IWRM Isfahan project. So far, the Ministry of Energy and its subordinated entities at national and provincial level are responsible for water management. The ministry presides over (inter-provincial) water transfer measures which are a delicate political and social issue in the face of conflicting water usage. While the provincial government possesses the formal power of decision over water management issues, the ministry oversees the distribution of financial resources. This means that formal decentralization is not yet backed by financial autonomy of the provinces. The different entities and administrations would rather act as competitors and negotiators than pursuing the goal of sustainable water resources management.

The lack of cooperation and coordination is also reflected in the absence of water management simulation models that are accepted by all stakeholders and that are used by the responsible authorities. Several models have been developed during the last years, many of them by universities. These models, however, have not been applied in practice since they are considered as being biased. The reason is that they were developed without involving the relevant actors with their respective stakes in the water resources. It is important, though, that the data used in a model are agreed upon by all stakeholders to make the model a neutral knowledge base on which generally accepted decisions can be taken. Usually, the data available from different sources in Iran are not consistent, calculated at different scales (e.g. provincial level, catchment scale) or collected in non-transparent ways. The creation of a widely recognized data base and jointly developed water management tool was therefore the main objective of the IWRM Isfahan project.

23.2.5 Interim Conclusions

- An analysis of the extracted water volumes and their consumption in different sectors for the years 2000–2008 is shown (see Table 23.2).
- Each year an average volume of 2,026 million m^3 of water was consumed by various sectors in the catchment, including 269 million m^3 of treated municipal waste water (see Table 23.2).
- More than 70 % of the used (sewage) water resources were used for irrigation.
- The internationally recognised wetland Gavkhuni did not receive any water from the Zayandeh Rud during this time.
- At the same time groundwater resources were overused by 315 million m^3/year.
- Despite the overuse of groundwater resources and the extreme deprivation of the Gavkhuni, there were repeated protests by farmers and a virtually empty river bed in the centre of Isfahan city on eight occasions.
- Despite the official commitment of the Iranian government to IWRM there is still no water management master plan.
- Due to non-transparent, top-down decision making specific regional challenges in water management are allowed for insufficiently.

Table 23.2 Withdrawn water resources and water use in different sectors (2000–2008)

(Sewage) water resources in million m^3 as average value for the years 2000–2008	
Dam discharge[a]	1300
Overused groundwater[b]	315
Groundwater recharge in the catchment area after the dam[c]	142
Treated municipal wastewater[d]	269
Total	2026
Water withdrawal of different sectors in million m^3 as average value for the years 2000–2008	
Transfer to Yazd[e]	49
Transfer to Chaharmahal	50
Urban and rural Water and Waste Water Co.[f]	350
Industry[g]	130
Gavkhuni Lake	0
Agriculture[h]	1447
Total	2026

[a]Observed data
[b]Analytical result of the FEFLOW model
[c]Analytical result of the SWAT model
[d]Information from Isfahan Water and Waste Water Co
[e]Information on water transfers are from the Isfahan Water Board Co
[f]Information from Isfahan Water and Waste Water Co
[g]Own research. See Mohajeri et al. (2013)
[h]Calculated and observed data have been compared and revised

- A realignment of water institutions, an adjustment of institutional fit and interplay and the introduction of participative procedures are necessary steps towards IWRM.
- Existing simulation models lack acceptance by stakeholders from different sectors because they are based on data considered as being biased.

23.3 Water Management Tool as a Tool to Build an IWRM Process

The aim of the IWRM Isfahan project is to develop a locally adapted IWRM process for sustainable water management in the Zayandeh Rud catchment area, together with the Iranian stakeholders. To this end, three different simulation models have been developed and merged into a Water Management Tool (WMT).

The WMT is the main instrument for a better understanding of the hydrological process in the catchment area on the one hand and on the other as a decision-support tool. In this way the tool can be used as a decision support system in the IWRM process. It can be used to justify and legitimise water management decisions in advance, to show possible alternatives and to assess the consequences. Thus, decision makers are able to develop concrete goals and action plans including the necessary measures for sustainable resource management in the catchment area Zayandeh Rud.

23.3.1 Description of the Water Management Tool (WMT)

The WMT combines the simulation results of all three models (MIKE Basin, FEFLOW and SWAT) and calculates the amount of available water and the supply for each individual user.

23.3.1.1 Water Management Tool—MIKE Basin

The Water Management Tool is a GIS-based decision support tool built on MIKE Basin. In MIKE Basin the use of available water resources can be mapped taking into account technical, ecological, economic and social conditions (DHI-WASY 2013). The aim of the WMT is to picture all anthropological impacts on water resources in the catchment area in space and time. This includes the inflow into the dam, the discharge of surface water in the southern part of the Zayandeh Rud and all natural and artificial inflows (caused by irrigation), effluents and groundwater extraction along the river.

The strength of the model is to determine the water needs of all defined users and to contrast them with the actual water resources available. The MIKE Basin model represents the intersection of all three software-based models and accumulates the results (see Fig. 23.5).

MIKE Basin imports the natural runoff and climatic data on a monthly basis from the SWAT. The exchange between surface water and groundwater along the Zayandeh Rud is calculated as a function of groundwater extraction from the FEFLOW model and also imported by MIKE Basin. The model covers the entire catchment area, a region of about 26,000 km^2. The Isfahan province is divided into 21 sub catchments (4201–4221), of which only the sub catchments 4201–4216 are part of the Zayandeh Rud catchment. The FEFLOW model is limited to the province of Isfahan aquifer below the dam and considers the sub catchments 4201, 4202, 4203, 4205, 4206, 4207, 4208, 4209 and 4217 and extends over an area of approximately 10,500 km^2. The spatial extent of the three models is shown in Fig. 23.6.

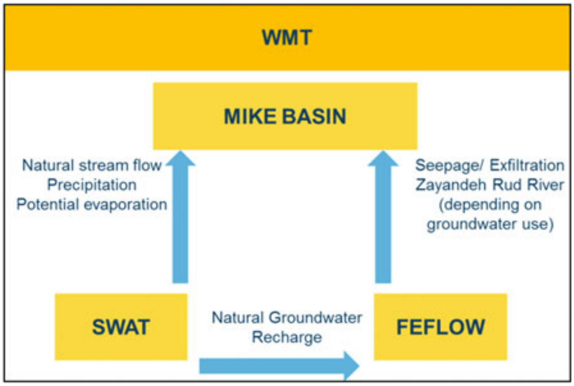

Fig. 23.5 Conceptual information exchange between the three software-based models. *Source* DHI-WASY (2013)

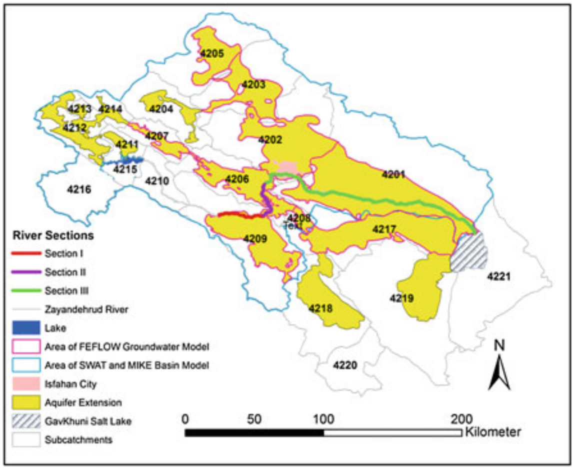

Fig. 23.6 Overview of the extension of the three models, the extent of the aquifer, and the division of flow sections for the exchange between MIKE Basin and FEFLOW. *Source* DHI-WASY (2013)

23.3.1.2 Groundwater Model—FEFLOW

The groundwater model was built up with the groundwater simulator FEFLOW—a software package that calculates water flow, mass and heat transport in porous media (Diersch 2012, 2014).

The aim of the FEFLOW model was to calculate the water exchange between the surface water in the Zayandeh River and groundwater in space and time for the simulation period 1995–2009 and to transfer the exchange rates to the MIKE Basin model. FEFLOW was chosen because it is professional software for small to large scale groundwater modelling. The option of local mesh refinement, powerful pre- and post-processing methods and several links to other software systems makes it a good choice for realizing the project aims.

23.3.1.3 Hydrological Model—SWAT

The hydrological model (SWAT—Soil and Water Assessment Tool) calculates the natural runoff based on simulation of hydrologically relevant processes that take place in the soil zone (Arnold et al. 2012). It covers the entire catchment area of the Zayandeh Rud aboveground (see Fig. 23.6). The calculation takes place on the basis of about 360 sub-basins. Within the project area-wide soil mapping was carried out for the entire SWAT model area in which the first 2 m of the surface in up to five different layers were separated. Each layer has been assigned with specific physical parameters that influence the impact of the soil zone on hydrological processes.

23.3.2 Results of the FEFLOW Model

In the article the groundwater model FEFLOW will be used as an example to describe technological procedures for several reasons. First, the FEFLOW model is at the utmost stage of development. Second, groundwater is the most important water source for the different uses in the catchment. Third, groundwater modelling can be regarded as the core function of the WMT because the interaction of groundwater and surface water is an important process in the catchment area.

However the surface water represents only 26 % (1237 million m^3) of the water used within the catchment area, the largest part of 74 % (3460 million m^3) comes from groundwater (data by Water and Sustainable Development). The steadily declining groundwater levels over the last 15 years have recently developed a legal, economic and environmental focus for the regional authorities. Some regions have been declared protected zones into which no new permits for groundwater withdrawal may be issued. In the future, significant socio-economic changes in these regions are expected with regards to agriculture and industry. For this reason, the partial results of the FEFLOW model are described herein. In order to sufficiently determine the water resources with regards to the groundwater in the catchment area, hydrological and hydrogeological issues have been considered and will be explained below.

23.3.2.1 Method

The model was built transiently for the period 1995–2009 and calibrated, mainly for a zone of 5 km around the Zayandeh Rud river. As the aquifer was already partially dry during the simulation period, an unsaturated model approach was chosen. The model consists of five layers, which divide the otherwise unconfined aquifer in the western part by a layer of clay into stressed and unstressed conditions.

The natural groundwater recharge as calculated by the SWAT model was divided into two streams. The lateral inflow was implemented using well boundary conditions while the vertical flow was implemented as ‘in/out flow’ on ‘top/bottom’.

In order to accurately depict the almost 40,000 wells, qanats[4] and natural springs with the different extraction rates in the model, the groundwater discharges were applied to grid squares of 1 km in length each. The proportion of the groundwater discharge to the total discharge per sub-catchment was determined and divided into deep and shallow discharges. The implementation in the model was carried out through 'in/outflow on top/bottom' on slice 5 and 'source/sink' in layer 3. The applied groundwater discharge in the model corresponds to the average discharge of the period 1999–2009.

The river was integrated with a third kind boundary (Cauchy) vertically and with half of the average breadth of the river between the first two slices. For the river, which is considered as being well connected, 'in/out transfer rates of 5,000' were estimated which correspond to a colmation layer of 0.5 m with a k-value of 0.03 m/s.

For the calibration, 311 observation wells were available of which 55 are located within a distance of 5 km from the river and therefore were considered as relevant for the model's goal. For the relevant observation wells which show a lowering of up to 50 m within 15 years, an average deviation of 5 m between the measured and calculated groundwater levels was identified.

23.3.2.2 Lowering of Groundwater Levels

The groundwater levels in the catchment area have diminished by approximately 20 m and in some parts even 50 m over the last 15 years. The lowering of groundwater levels varies a lot. The closer in proximity to the river, the less it decreases. This fact can be mapped by the current FEFLOW model. Figure 23.7 shows the vertical cross-section through the sub-basin Najafabad.

The blue line marks the measured groundwater level at the beginning of the model run (January 1995). Even at this time the groundwater level in the left north-western part of the cross-section does not show any natural conditions (no more discharge to the receiving stream). The green line shows the measured groundwater level at the end of the simulation period (December 2009). The groundwater level calculated by FEFLOW is indicated by the red line.

For this part the FEFLOW model provides a good depiction of the declining groundwater level. It becomes obvious that within a period of only 15 years the thickness of the aquifer has been reduced significantly. Only the river on the right side supports the groundwater levels through infiltration in its immediate vicinity. Under natural conditions rivers carry a combination of rainwater inflow and groundwater outflow. This means that under natural conditions groundwater flows in the direction of the receiving stream. As Fig. 23.9 shows, the overuse of groundwater affected the natural groundwater flow more than 15 years ago.

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[4] An ancient technology used to extract ground water.

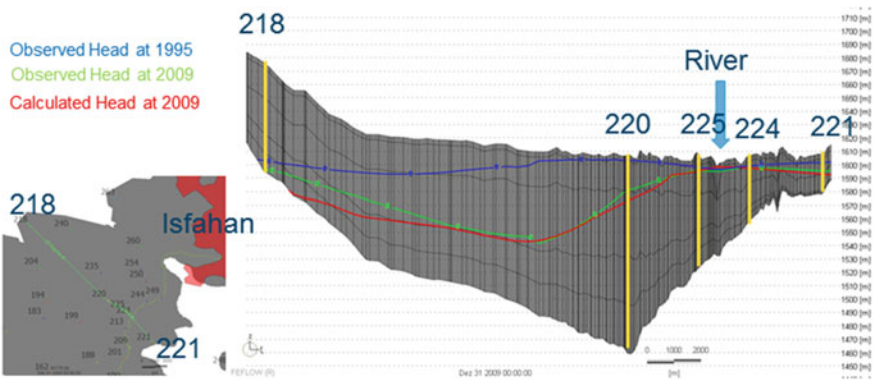

Fig. 23.7 Cross section views through sub-catchment 4206 (Najafabad) with observed heads at 1995 and 2009 and calculated heads at 2009; 50 times vertical exaggeration. *Source* DHI-WASY (2013)

23.3.2.3 Groundwater Budget

The basic water balance is crucial for sustainable water management. The natural groundwater recharge rate (calculated by the SWAT model) of 0 to locally 77 mm/a is comparable with the data from other authors like Nikouei et al. (2012) who presented average recharge rates of 12 mm/a and Gräbe (2012) who presented average recharge in arid environments of 8–71 mm/a). Additional inflows into the groundwater occur as surface/groundwater exchanges along the river as well as the anthropogenic-driven return flow.

The return flow was assumed using a local variable coefficient adopted for local groundwater use. The resulting ratios and volumes were in the range of previous investigations like those by Water and Sustainable Development, who presented a Return Flow of 1867 million m^3 for the 9 sub catchments covered by the Model area and Global Water Partnership (2012) quantified the additional groundwater recharge caused by irrigation in arid environments with around 300 mm which leads by an irrigated area of 3140 km^2 to 942 million m^3.

The resulting groundwater balance for the FEFLOW model is shown in Fig. 23.8. The natural groundwater recharge of 76 million m^3/year represents only 2 % of the total groundwater inflows. By far the major share (76 %) of the groundwater inflow is provided by the return flow of 1682 million m^3/year. The inflow of the Zayandeh Rud of 484 million m^3/year as calculated by the FEFLOW groundwater model represents 22 % of the total and thus must be considered an important amount of the groundwater budget. The average groundwater deficit is quantified as 379 million m^3.

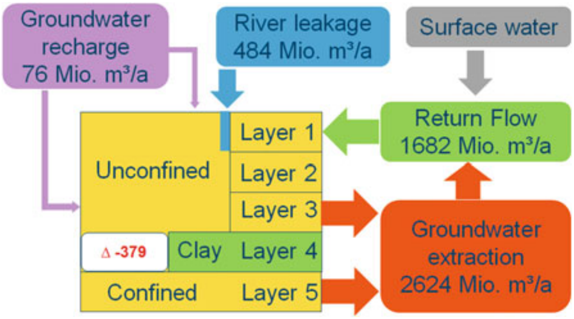

Fig. 23.8 Structure of the five-layer groundwater model which budgeted groundwater recharge, groundwater withdrawals, the return flow and seepage from the river into the groundwater. *Source* DHI-WASY (2013)

23.3.2.4 Exchange Between Groundwater and Surface Water

Analysis of the observed groundwater data showed that the water table has a hydraulically lower level than the surface water in the Zayandeh Rud River and hence the flow exfiltrates into groundwater.

The river was divided into three sections along which the temporal process of exchange was assessed. These sections were caused by level and flow monitoring stations and are shown in Fig. 23.6. The exchange rates for these three sections as calculated by the FEFLOW model are shown in Fig. 23.9.

Within the first 2 years the exchange rates in all sections increase severely. This is probably due to an overestimation of feed rates during the first years for which no data was available and therefore could not be included in the calculation of the long-term average. The exchange rate in Sect. 23.1 remains constant after 1996,

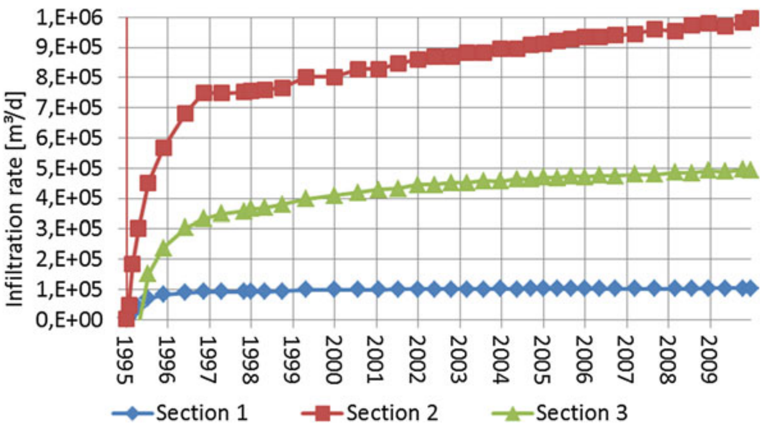

Fig. 23.9 Exchange rate between surface water and groundwater. *Source* DHI-WASY (2013)

while the exchange rates in Sects. 23.2 and 23.3 continuously increase after 1997. This effect can be explained by the partially severe lowering of groundwater levels in the surrounding aquifer. The drop in groundwater levels, again, is due to extensive groundwater withdrawal. Thus, there is a direct link between groundwater extraction and the exfiltration of the river into the aquifer.

23.4 Stakeholder Involvement for WMT Implementation

In theory, a decision support system (DSS) can provide the basis for successful participatory planning. However, in real life only few of the DSS developed for different countries and catchments have found implementation and experiences with water management models have shown that even a careful and practice-oriented development of a model does not guarantee that decision makers will actually use and further develop the model (see for example Jao 2011). This is not least because they are often designed by technocrats and lack adequate stakeholder input (Serrat-Capdevila et al. 2011). Successful implementation involves the participation of stakeholders from the earliest possible stage on. This way, the DSS can be adjusted to the needs of the end users. Moreover, not only the policy decisions based on the DSS models have to be taken in a coordinated way. The data fed into the data base also have to be agreed upon by all relevant stakeholders to guarantee maximal acceptance of the outputs. Only this can lead to a joint decision that can be fully acknowledged by all parties. Serrat-Capdevila et al. (2011) state that

> […] any decisions based on information provided by the models will not be considered sufficiently trustworthy if the models are perceived by the stakeholders as (a) not being transparent, and/or (b) if they are not convinced the model addresses their views and concerns, and/or (c) their input has not been requested or integrated into the development of the model.

23.4.1 Assessment of Needs and Demands

A major challenge of the project was to identify and harmonize the different interests and expectations of the decision makers towards the WMT. For this purpose, a participative, culturally adapted workshop was conceptualised and conducted, involving all relevant stakeholders.

The development of the methodology had to deal with two major challenges: In general, the implementation of a decision support system that puts previous forms of decision making into question. In Iran where hierarchical thinking prevails, the participative development of a tool means to negotiate classical working methods and principles of decision making (Ghanavizchian and Mohajeri 2013). Moreover, there are severe inter-sectoral conflicts of interest, particularly in the Zayandeh Rud catchment area, which have to be overcome. On occasion, these conflicts can be quite emotional.

These challenges could be resolved by addressing the problems in an open way. First, the problem of hierarchical thinking was discussed with the respective authorities and senior participants. Second, three small discussion groups were formed and participants were systematically chosen from different sectors, hierarchical levels and academia. The discussion groups were then chaired by an independent, unbiased person. The aim of the workshop was to clarify four main issues regarding the WMT:

- Current problems and future challenges of the WMT
- Advantages and expectations of WMT
- The issue of data collection, coordination and validation
- The question of WMT updating and availability

Regarding the current problems and future challenges of water resources management, the stakeholders mentioned both the decreasing availability of water and declining water quality. As a main cause and future challenge they highlighted the lack of integrated water management due, basically, to two factors. One is the lack of cooperation between sectors and other stakeholders (e.g. the public and decision makers) because of mistrust and opposing interests. The second factor is the lack of data management. On the one hand, data have never continuously been integrated into a data base; on the other hand decisions are rarely taken upon scientific data, leading to often ineffective or even wrong outcomes.

With regards to the assumed advantages of the WMT and the stakeholders' expectations of the tool, two main points were mentioned. First, stakeholders expect that the prediction and identification of their decisions' consequences will be improved. Second, this will help them to optimize their decisions. Since the tool is fed with scientific as well as socio-economic data, it is capable of analysing the impact of certain water allocation measures on water rights. While the tool is able to visualize how and where decisions may lead to changes in the catchment, it is also helpful in raising awareness for the different facets of water management among the stakeholders. Furthermore, it can assist in taking decisions about new technologies or the location of new industries. Eventually, the WMT may lead to a decrease of social conflicts about water resources in the region.

Regarding the question of who should be responsible for data collection and coordination some critical points have to be addressed. First, up to now data are collected within the single sectors, and there is no culture of sharing data. Second, in this atmosphere of mutual mistrust the stakeholders have to accept the actual data that are lastly fed into the WMT. Two proposals were discussed in this regard. The first proposal suggested that an independent committee consisting of experts of the respective regional organizations or sectors should be in charge of collecting the data. Being independent, the committee should at the same time be autonomous enough to be capable of collecting the required data, and it should have the actual mandate to claim due data from defaulting stakeholders. The second proposal suggested that a professional entity, i.e. the Isfahan Regional Water Board, should be responsible for data collection and coordination. The final decision on this question is still to be made.

However the collection and management of data does not only require a capable and acceptable organization. For providing valid data, standards for the measurement and for the data themselves have to be set. This may also require the introduction of new technologies and data collection techniques. Moreover, it was stated that questions of capacity building, adjusted legislation, feedback mechanisms and financing have to be further elaborated on. These points were also not decided on during the workshop.

The last question that was discussed in the working groups was about the responsible entity for WMT updating and its further development. New (social, environmental, political) trends and developments in the catchment have to be detected and translated into valuable data. The WMT has to be further developed accordingly. Here, three possible organizational solutions were discussed as well: transferring the tasks to a commission, an independent company or consultant, or to the Isfahan Regional Water Board. The final decision will also depend on the question, which organization is most likely to be trusted uniformly, and which is regarded as being most capable of balancing all interests.

The results of this interactive workshop were then presented in various rounds by different stakeholders. This led to a fruitful discussion within the region about the establishment of new necessary organisational units which are supposed to manage the IWRM process in the future (see also Sect. 23.4.2).

23.4.2 Establishment of WMT Commissions

The approach of the German-Iranian cooperation has been to accompany bargaining processes among stakeholders within the river basin which could eventually lead to the improvement of their coordination and cooperation. The joint development of new instruments like the WMT was a start, and vice versa the WMT is supposed to serve as an instrument to improve cooperation. The set-up of an adequate institutional and organizational framework that serves integrated water management needs to follow in due course (see also Sect. 23.4).

This will include the decision over, and appointment of, the responsible commission for data collection, adjustment and harmonization (Georgakakos 2007). Until now, not only between different agencies but even within agencies data has not been harmonized, so they cannot yet be used in the WMT. A second commission is needed that identifies and names water problems, applies the WMT, assesses the WMT output and translates it into a water management decision. In this commission, stakeholders of the different government levels, of the different sectors as well as of the civil society should be represented in order to achieve overall acceptance of the decisions taken. The involvement of representatives of the Ministry of Energy in such a commission is essential in the face of the current structure of the Iranian water sector. The participation of its representatives is particularly necessary in order to legitimize water management decisions within the ministry which require high investments. Moreover, the ministry representatives have the task of introducing necessary information from the neighbouring province into water management decisions. This is the only way that sustainable decisions can be taken for the entire catchment area. In the long run representatives of the neighbouring province will also become permanent members of the commission. Furthermore, representatives of the main actors responsible for water management in the region, like the regional Water Board, water and waste water companies, agriculture, environmental department, industry and municipality, have to become commission members. NGOs and environmentalists are supposed to speak for the needs of marginal groups and the environment.

The commission can, among other tasks, develop ideas for sustainable groundwater use in the catchment area. This could for example mean a change in the water use rights or modified land use (re-cultivation). The possible consequences of such decisions can be retraced by means of the WMT; the result can be discussed and finally be approved by the commission.

In periods of water shortages, e.g. because of droughts, the commission can also use the WMT to identify reasonable water use bans which can be assessed by means of their socio-economic consequences. To date, water use bans are only imposed on agriculture. This led to serious protests by farmers particularly in 2013 as they complained about inequality in the distribution of water.

23.4.3 Capacity Development

In general, the introduction of IWRM requires the development of respective capacities at the operational level as well as at decision making level. In the course of the project, both levels have been or will be addressed.

The WMT works with highly specialized models and can therefore only be used by experts. The Iranian Water Authority is the main user of the WMT. Therefore, experts will be trained on the usage of the WMT within the project. At the level of decision making, this could be addressed by a "German Iranian Competence Centre for Water and Wastewater Management (GICC)" where German and international experiences could be shared and where training in the field of IWRM could be merchandized and applied.

Project experiences have shown that the establishment of theoretical as well as practical knowledge transfer and exchange on the topic of IWRM between German and Iranian authorities, companies and scientists is of great importance (Mohajeri and Nuñez von Voigt 2011). At the GICC German experiences and knowledge about the implementation of sustainable water resources management can be exchanged and passed on. The GICC can also take up those standards which are lacking in the Iranian water sector. Next to its function as a training and technology transfer centre it can undertake the task of establishing German norms and standards as well as applying, adjusting and implementing German waste water regulations in Iran. In this way a permanent link between the German and Iranian water management sectors may be founded.

23.5 Conclusions and Outlook

The salt lake Gavkhuni, an internationally accepted marshland according to the Ramsar convention, and its valuable ecological habitat for migratory birds, has suffered the most as a result of the recent socio-ecological developments in the Zayandeh Rud catchment area. The intense use of groundwater in the Zayandeh Rud catchment area has led to a severe reduction of groundwater levels over the last 15 years. This change in natural conditions has led to a reversal of the hydraulic situation along the Zayandeh Rud River. Thus, according to the classification system of the Global Water Partnership it can be incorporated into the fourth level of water resources development which is called 'mining of aquifer reserves'. The two drought periods since 2000, which lasted 3 and 5 years, have reduced the availability of water in an unprecedented way. During the recent dry period (2008–2012) alone the amount of precipitation was 25 % below average. As a result, climate change has become an issue for water management decision makers but has not as yet led to actual operational developments.

Water management decisions are still based on supply oriented strategies. The balancing of the climactically induced decrease in water supply and increasing demand will mainly be addressed by transferring water resources from neighbouring regions. With the completion of two tunnels currently under construction, around 500 million m^3 of water per year will be redirected from the province Chaharmahal-va-Bakhtiary towards the Zayandeh Rud. This will result in unpredictable environmental and socio-economic consequences.

The fact that a master plan for the development of the individual regions as well as a political and legal framework are missing reduces hopes for sustainable urban planning and industrial development. There is evidence that the growing number of citizens who are connected to the drinking water supply system will lead to a rise in water demand by approximately 25 % to 450 million m^3 in 2025. Even though the impact of domestic water use on future water management is less important, saving potential has to be applied. Bringing down the current level of water use of 230 l/day and a reduction of network leakages of more than 25 % have to be promoted. Even more important are the extension of wastewater systems and an improvement of wastewater treatment in order to allow for a hygienic and ecological reuse of these water resources.

The stagnation of industrial development seems to be neither realistic nor economically judicious. The high number of well-educated experts, the strategic location of the province Isfahan in the centre of Iran and the available resources—except for water—make the region attractive for new industrial settlements. Estimates suggest that industrial water use in the catchment will increase by between 70 % (260 million m^3) and 140 % (370 million m^3) by 2025. Industrial development will depend heavily upon the political framework and the international standing of Iran. A successful change of the industrial development in the region is necessary: turning away from water intense industries like steel industry, to industries which do not depend so heavily on water, like the IT sector. Moreover, the implementation of eco-industry parks instead of unsustainable industrial settlements has to be promoted. Here, as well, the main focus will have to be on the lack of wastewater treatment and reuse.

Agriculture, as the main water user, will play the major role with regards to the restructuring of water resources distribution. Apart from Gavkhuni Lake and the groundwater resources, mainly the agricultural sector—in the eastern part of the catchment in particular—suffers from water shortages. It is assumed that on average up to 300 million m^3 or 20 % less water resources will be available for agricultural purposes. This is inevitably accompanied by a discarding of agricultural land. This decision, however, will create potential for socio-economic conflict. Next to the loss of income and an increase in unemployment, this could lead to the breakdown of regional ecology. An expansion of the desert towards the city of Isfahan will presumably become unavoidable. For this reason it will be important to plan and implement a slow and socio-ecologically compatible reform of the agricultural sector, while at the same time aiming at the greatest benefit for water resources. In this process the WMT will play an important role as a decision support tool.

The FEFLOW model shows a clear linear connection between exfiltration of the surface water and groundwater discharge at the river banks. It calculates that 20 % of the withdrawn water in the downstream catchment area are bank filtrates. This fact increases the importance of an optimized surface water management considerably. Due to the occurrence of longer dry periods where no water seeps into the ground, the inflow rate to the groundwater and thus the supporting property of the river on groundwater levels, will be further reduced. It is therefore to be expected that with the frequent occurrence of an empty riverbed the groundwater levels near the river will fall more in the future than they have been doing in the past.

In order to create a lasting IWRM process, the WMT is supposed to support decisions built on jointly developed and therefore a generally accepted data base. It is important that the WMT will be used in a routinized way and support the day-to-day work of responsible authorities developing political measures for IWRM.

Future steps will have to involve institutional and organizational changes at national and provincial level. Reforms concerning the enhanced intergovernmental interactions at national and provincial level will have to include changes within the water sector institutions, in order to create increased independency in decision-making at local levels, and law enforcement and monitoring. A next step would be the development of IWRM strategies for the national river basins and the establishment of respective organizations that are responsible for IWRM implementation in the long run. The first steps in this direction have already been taken and hopes have been raised for a permanently flowing Zayandeh Rud.

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Chapter 24
Overall-Effective Measures for Sustainable Water Resources Management in the Coastal Area of Shandong Province, PR China

Stefan O. Kaden and Wolfgang F. Geiger

Abstract The Huangshui River basin, located in the Northeast of Shandong Province, PR China, is an outstanding example for water conflicts arising from piecemeal action as well as rapid growth of population, industry and agriculture that can only be solved by an integrated water resources management approach. Over-exploitation causes eminent problems for water resources management and agriculture resulting from saltwater intrusion into the groundwater system. The development not only of industry but also of agriculture as the population's main source of income is seriously impeded by water shortage, and water pollution causes negative consequences for ecology and the people's quality of life. In order to contribute to a sustainable water management in this region, a joint Chinese-German research project within the IWRM funding priority of BMBF was initiated. The paper introduces the methodological concept developed and major project results for the study area. These include socio-economic analysis, a multi-level decision support system, monitoring concepts and instruments, and concepts for water saving and reuse including pilot projects.

Keywords Sustainable water management · Water saving · Salt-water intrusion · Decision support system · Integrated modelling of water systems · Groundwater monitoring

24.1 Background

Water scarcity and water pollution are severe problems in Northern China, seriously affecting socio-economic development and standards of living and environment. The Shandong province in specific is plagued by water scarcity. Although water

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demand already exceeds available water resources, the demand with economic growth is still increasing. On top, water pollution caused by intensive utilization and insufficient discharge management in urban and industrialized areas further reduces the available resources.

In the coastal catchments of Shandong Province, water scarcity further is aggravated by saltwater intrusion into seaside groundwater bodies, rendering them unusable. Industrial and agricultural development is extremely hampered by water scarcity and pollution. Water pollution in addition poses serious risks for ecology and health.

Agriculture with a share of about 65 % is the most important economic sector in the region. Although water saving irrigation techniques were introduced, agricultural water demand still increases. According to the present water supply ability, the water shortage is about 3.4 billion m^3/year. It is estimated that the annual water shortage could be up to 6.3 billion m^3 by 2020 and 7.7 billion m^3 by 2030, unless appropriate measures are taken for water management (Xinhua News 2010).

The pressing water problems in the coastal areas of Shandong Province and the resulting socio-economic and ecological problems have forced Chinese authorities to implement a variety of measures to relieve water scarcity and abate saltwater intrusion. Many research efforts and previous international funding have produced a comprehensive information base on hydrologic and hydrogeologic conditions, which is useful and needed for the application of newer Integrated Water Resources Management (IWRM) methods and tools. Despite considerable research, not much has been achieved so far because measures are not coordinated in their effects and the impact on cost-benefit relations has not been sufficiently considered.

In order to contribute to a sustainable water management in this region, a joint Chinese-German research project within the IWRM funding priority of BMBF was initiated. The base for the BMBF IWRM Shandong project was laid in the years 2004/2005 within the framework of a preliminary project under the auspices of the

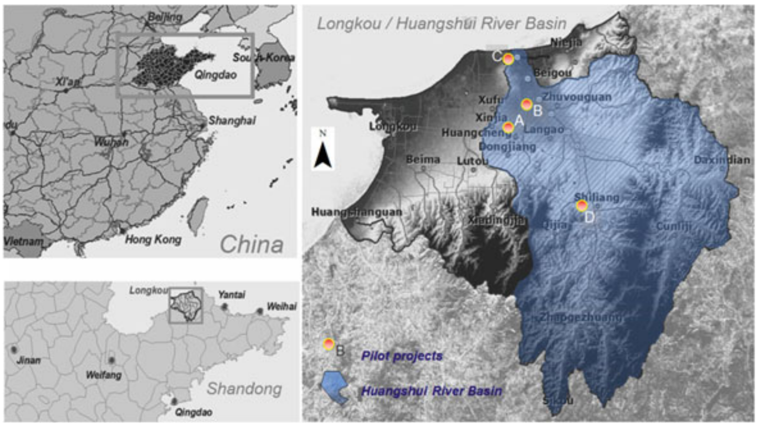


Fig. 24.1 Study area Huangshui River basin/Longkou and pilot project locations

Fig. 24.2 Upriver view at the dammed Huangshui River

University of Essen (Prof. Geiger) with the support of Shandong Water Resources Institute (SDWRRI; Prof. Liu/Prof. Zhang). The project was funded by the Ministries BMBF on the German side and MOST on the Chinese side. It was started in 2008 with the general goal of creating technical and management methods for the development of an IWRM concept suitable for the Huangshui River basin located mainly in Longkou County (893.32 km^2), Shandong Province (Figs. 24.1, 24.2).

This paper gives an overview on the methodological approach and major project results of the Chinese-German IWRM project. A comprehensive report is given in Kaden and Geiger (2013).

24.2 Methodological Approach

In up-to-date water management, it is vital to equally consider technical, social and political issues from the very beginning. More and more Decision Support Systems (DSS) are implemented to assist. A major problem is that most existing DSS require detailed data before they can yield substantial results. Such data are seldom readily available in initial planning stages, especially in countries as China. Consequently, a stepwise decision support approach was developed for this project. The advantage of the stepwise system is that at the beginning of the planning process, when only coarse data are available, potential actions can be screened roughly for their success and linked to potential solutions, taking into the account geohydrologic and socio-cultural constraints. Then in the second stage, preselected alternatives are studied in more detail, which requires additional data. In the final stage the final solution is developed and analysed. The framework of the stepwise DSS is outlined in Fig. 24.3.

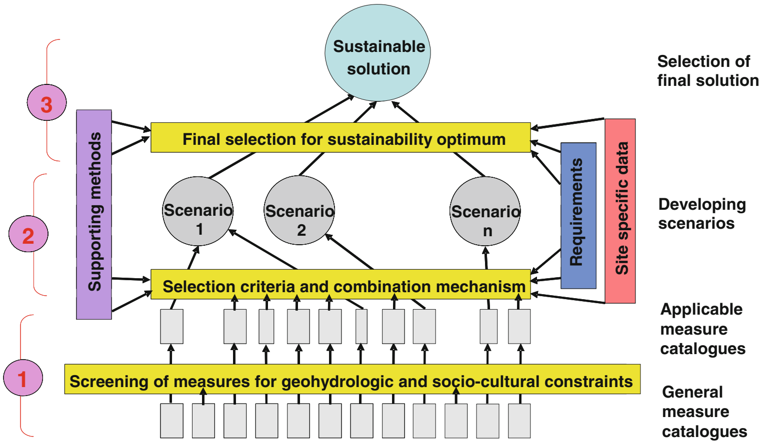


Fig. 24.3 IWRM-system to achieve sustainable water management (Geiger 2011, simplified)

Actions often focus on local and acute problems without considering demographic alterations, economic development, altering living standards, or climate change effects. Moreover, water management obliges to be not only cross-sectorial, but also open for temporal and spatial adaptions. All of these concerns are considered from the very beginning according to their data availability.

DSS stage 1 was designed that it can be gradually improved whenever more detailed information becomes available. It forms the basis for DSS stage 2.

The application of most water management technologies cannot be realized without the support of economic and social policies. The classification of measure catalogues according to the mentioned sectors of society separates the individual technologies from the support potentially available to their implementation—such as policies.

This may result in complaints from people at the basic implementation level that the social conditions do not yet favour the application of the technologies on the one hand, while on the other hand practitioners complain that the policies are too theoretical (Geiger 2011). For a DSS stage 2, precise and reliable data are essential.

In the course of the project, both the tasks within sub-projects as well as the interaction between them were adapted to the project basics in collaboration with Chinese partners. The following Fig. 24.4 gives a rough overview.

The major Chinese project partners have been the Shandong Water Resources Research Institute (SDWRRI), Longkou Water Authority (LWA), Shandong University (SDU), Shandong Agricultural University (SDAU), Shandong Normal University (SDNU) and Shandong Jianzhu University.

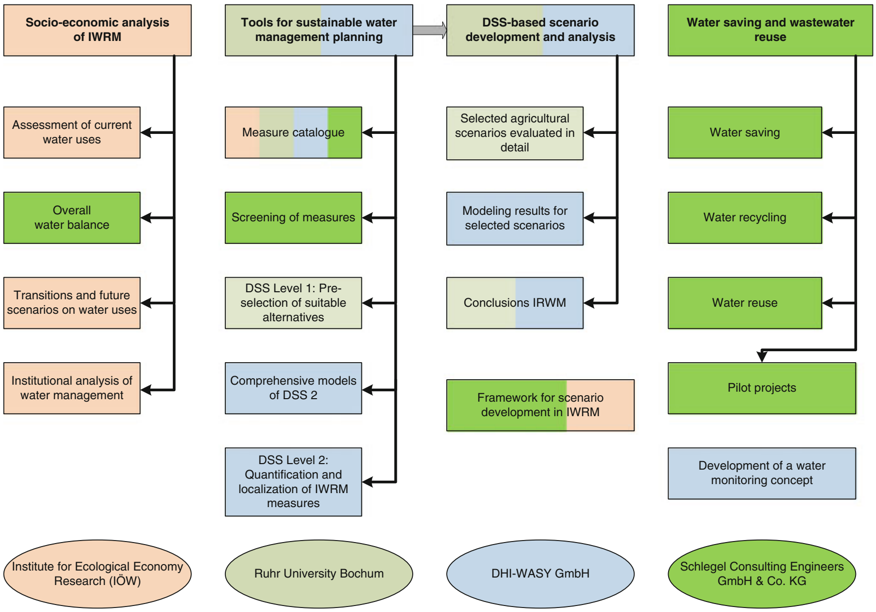


Fig. 24.4 Project structure IWRM Shandong, the colours indicating the responsibilities of different German project partners

24.2.1 Major Project Results

At the beginning of the project, the current water management situation in the Huangshui River basin and in Longkou City was systematically investigated and existing water availability problems were identified by means of a river basin water balance and a water use trend analysis. The Chinese partner institutes had a substantial database on water quantities, but little on water quality. As even lesser data existed on socio-economic conditions related to water, approximately 30 interviews and some workshops were conducted with regional and local experts and stakeholders.

The overall water balance shows, based on data from 2009:

- precipitation of 885 Mm^3/year, as the only input (no inflow from surrounding areas)
- evapotranspiration of 821 Mm^3/year
- runoff to the sea of 76 Mm^3/year.

This means, under long-term average conditions, the system loses about 13 Mm^3 of water annually, which is due to the overexploitation of deep groundwater.

A detailed water balance was made for agricultural irrigation, which indicated that the total real water loss during conveyance and field application easily could be lowered from 113 Mm^3/year (55 % of input) to 80 Mm^3/year (66 % of input) through technical measures alone. Here, the mitigation of real water loss refers only to the prevention of evapotranspiration by technical means. Percolation to groundwater is not regarded as a loss, and percolation to deep groundwater is assumed to be so small that it can be neglected. However, cost estimates on the implementation of measures showed that the technical measures would not pay back at water costs. It was immediately clear that the low cost of water results in an overall unwillingness to invest in water saving measures (Hirschfeld et al. 2013).

24.2.1.1 Decision Support (DSS)

In a **first stage** a general comprehensive measure catalogue containing potential measures for all disciplines involved, i.e. technical, non-technical, structural, non-structural, legislative, administrative, educational, social, socioeconomic, economic, curative, preventive and even political measures was established ensuring that planners are made aware of all possible options available.

The catalogue contains 60 measures, each with a description, assumptions and remarks, as well as the water availability potential for the study area (Mm^3/year), the unit cost (Yuan/m^3), the degree of implementation, the amount of water saved (Mm^3/year) and the total cost for the study area (Million Yuan), implementing the measure.

In this context an effective and user-friendly, implementation oriented and hierarchal decision support tool for pre-planning under scarce data conditions has been developed. With it, strategies, policies, socioeconomic and technical measures, and questions for data collection can be organized according to the required level of detail, objectives and administrative responsibilities, and with respect to application sector, cost-efficiencies, impacts on WRM goals, and acceptance. Figure 24.5 shows an excerpt from the Measure-Answer-Matrix where criteria for screening of measures are defined. The tool may improve communication between stakeholders at different levels within the relevant organizations. A number of socio-economic concerns were formulated and integrated into this hierarchy. Subsequently, measures not applicable to local meteorological, geologic and socio-cultural conditions were screened out.

For a first rough examination of all potentially suitable measures, a multi-criteria analytic hierarchy process was developed that is used to judge the overall effectiveness of quantified measures. This ranking is a convenient way of comparing the overall effectiveness of a large number of measures in early stages of planning. The developed tool can offer support during the first stage in the process of collecting information about the status of the environment, desired environment protection goals, action priorities and acceptance, and it can help decide which measures are worth being examined in more detail in the following stages of a study. Finally, in the first stage possible scenarios were developed by considering their environmental impact effectiveness. Based on this first stage, a number of possible water saving

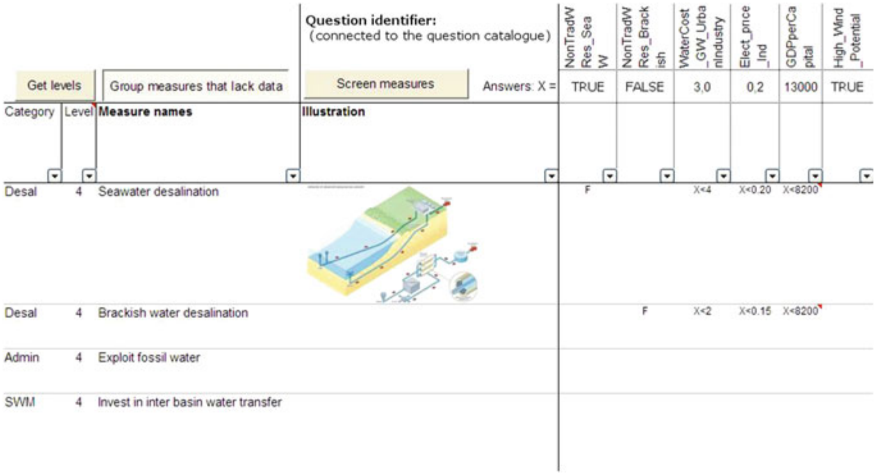


Fig. 24.5 An excerpt from the measure-answer-matrix where criteria for screening of measures are defined

measures could already be discarded for the specific study area due to their inapplicability or ineffectiveness.

The tool ranks the most optimal (according to the cost/benefit analysis) measures to be implemented according to different filters. It is clear that, although some measures might seem economically sound (negative costs, in other words: revenues), they contribute negligible amounts to the reduction of groundwater deficits, as for instance the retrofitting of shower heads. Even more importantly, the groundwater balance method is based on quantities far beyond the effects of small measures of this type and thus, these measures probably fall beneath the error or detection margin of the methodology; at least for this rural study area dominated by agriculture. The result with the tool developed shows that crop changes, the implementation of water pricing on top of crop changes, as well as irrigation changes and the implementation of water pricing on top of infiltration rank as the top four measures. Other very promising important measures for the local hydro system were swale infiltration and dam creation.

In the **second stage** of the DSS these most promising measures were compared with each other with respect to their costs and effects. Different measures, however, have a different impact on the water resources system, which inhibits objective cross-comparison. In the river basin water balance it was shown that the groundwater deficit severely threatens sustainability in the area. Thus, for an objective comparison of all measures in the measure catalogue, their net effects on groundwater quantity had to be calculated. To do this, the water balance over the complete region was further refined and included in an Excel based application. In this application, the input parameters of the water balance can be changed via a convenient user interface. It also instantly illustrates changes in the water balance in an easily understood flow sheet when a single measure or combinations of measures are selected for implementation. A routine was written that, using the water balance algorithms, evaluates all measures and their ranges in one hydrological year individually and in combination and writes out their costs and benefits, in this case groundwater quantities. A dynamic water balance was computed for stationary conditions for a time period of 1 year in a single time step. The balance was derived to specify the relevance of the different water uses and the impact of declining yearly amounts of precipitation. It is dynamic as the user has the option to make "if-then" analyses changing the water demand of users as well as the yearly amount of precipitation. Based on this objective evaluation of all measures, crop changes and irrigation changes were listed as the most cost-effective measures for this specific study area.

After crop and irrigation changes were selected by the water balance routine, the impact as estimated in the measure catalogue had to be reaffirmed and specified by detailed modelling. A detailed agricultural model was set up to calculate the effects (in terms of water saving and yield) of crop and irrigation changes. Figure 24.6 illustrates model results for probabilistically generated crop changes.

To incorporate unknown parameters such as the willingness or ability to change crops, historical or cultural restraints, legal or marketing restrictions, a conservative force was introduced into the model.

This caused the stochastic model not only to look for the optimal crop change (no economic yield loss and minimizing water use), but for the optimal crop and irrigation change whilst minimizing all changes to the existing agricultural structure; hence optimizing for social acceptance. The yield means here the economic income of farmers derived from a transfer of crop yields into incomes.

Over the entire study area, with a very good acceptance and even an increase in yield, a slight shift towards corn and grapes, away from wheat and pears, allows saving about 4–9 Mm^3 of water. With increased irrigation technology, this can be increased to 14 Mm^3 of water, thus equalizing the deficits in the water balance.

In the **third stage**, in DSS2, the most cost-effective measures are quantified and spatially located. For that purpose a GIS based and model-supported system was developed. Figure 24.7 illustrates its overall structure. This system integrates GIS

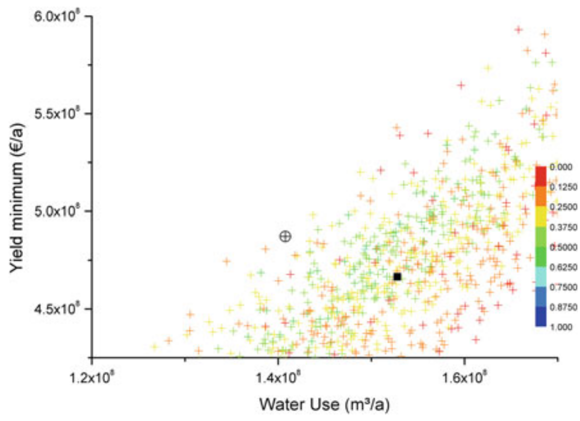


Fig. 24.6 Combined acceptance level for probabilistically generated crop changes. *Black square* is the current, and encircled plus sign is the "best" crop distribution

based information with a set of comprehensive hydrological models (groundwater recharge model, groundwater flow and mass transport model, and water allocation model). A coarse model is used to verify the deficits for each single user in the area on a monthly base for a period of 58 years, and a detailed model estimates the development of groundwater heads as well as salinity values. All models are DHI models and include MIKE SHE, SIWA, WBalMo, MIKE11 and FEFLOW (http://www.dhigroup.com). Interfaces were developed to link all models to the necessary coupling level and the entire model system is integrated into an ESRI ArcGIS based information system. The information system automatically prepares the models with adaptions related to the measures and transfers and summarizes the model results in a format which can be evaluated together with the socio-economic effects. To find an optimal solution for the Longkou region, additional routines are implemented to compare all combinations of measures analysed with the system.

The models were implemented for the study area and calibrated.

For the study area a two-tiered approach was applied. In **Step 1**, a detailed and coupled model was used to spatially differentiate and quantify the required reduction amounts in groundwater use in order to halt the saltwater intrusion. As an example Fig. 24.8 shows results of FEFLOW based modelling of saltwater intrusion (based on present situation).

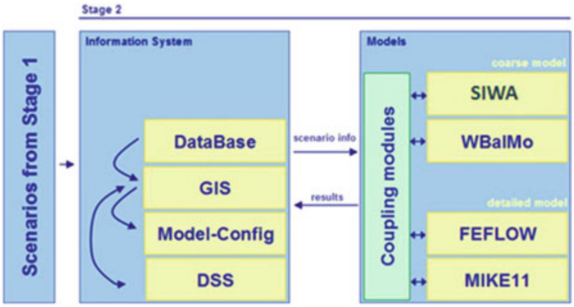


Fig. 24.7 DSS2—GIS and models

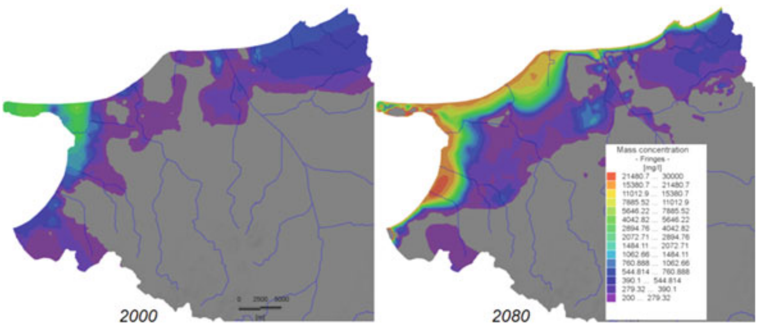


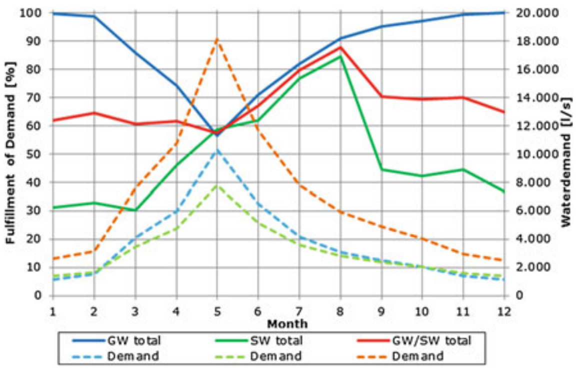
Fig. 24.8 Saltwater intrusion at the start of the simulation and after 80 years

The water allocation model was developed using the WBalMo program. The water resources management model forming the basis of WBalMo operates according to the Monte-Carlo technique. The water utilization processes of river basins can be re-produced covering any time frame, in time steps of 1 month. The registration of relevant system states allows a statistical analysis of registered events after completing the simulation. As a result, approximate probability distributions are made available for the result values, being reservoir storage levels, water supply deficiencies for individual water users, or discharges at selected river profiles. Using this, the quality of a selected management strategy can be assessed for the investigated river basin. An improved strategy can be obtained by gradually changing the variables. The following Fig. 24.9 shows the average fulfilment of water demand per month in the study area for the present state. The figure illustrates that the highest demand coincides with the lowest water availability.

Different spatial scenarios were calculated: on and between the main saltwater intrusion points, across the entire lowlands, in the main groundwater deficient areas, etc. Reducing groundwater extraction between the main saltwater intrusion points (Scenario 2) proved to require the lowest total amount of water use reductions (±22.7 Mm^3 in the selected catchments) in order to halt saltwater intrusion. However, this amounts to a 100 % reduction of groundwater extraction for the catchments in Scenario 2. For reductions in and between the saltwater intrusion points (Scenario 5), 30 Mm^3/year of groundwater demand had to be reduced. This means a reduction of 85 % of the recent groundwater extraction within the respective catchments. This analysis allowed the specific optimal location of the measures.

In **Step 2**, the crop and irrigation changes are determined which are able to generate the required reduction in extraction, for each of the saltwater intrusion scenarios. The same agro-economic model was used as in DSS1, but tailored to each of the sub-basins. This way, detailed crop and irrigation changes were determined individually for each sub-basin in order to achieve the required reduction in water use, determined in Step 1. Unfortunately, stochastically no measures were found that could achieve the requirements of Scenario 5 without yield losses.

Fig. 24.9 WBalMo results for surface water and groundwater totals



Nevertheless, with a reasonable acceptance, 10.2 Mm^3/year could still be saved using crop changes and irrigation techniques without yield loss in the sub-basins of Scenario 2. Applying the same model on two sub-basins upstream, another 12.7 Mm^3 could be saved there. If the saved water amount upstream from the sub-basins of Scenario 2 could be transported and used for irrigation downstream, the targeted spatial reduction of 22.7 Mm^3 in total could be achieved locally without significantly impeding the agricultural economy.

In **Step 3**, both previous steps are combined in an IWRM Shandong GIS Client. The IWRM Shandong GIS Client offers tools which automatically implement selected measures within the geographical setup of each hydraulic model and tools which visualize (as maps and time series) the results of these evaluations and enable the user to compare them with previously analysed measure scenarios. Finally, the GIS Client includes documentation routines which summarize the analysed measures and give a clear overview of their effectiveness. Figure 24.10 gives an impression of the user interface.

In the IWRM Shandong GIS Client, the crop and irrigation changes determined in Step 2 were tested and validated. The simulations show that if the proposed measures are applied, the groundwater levels will significantly increase and the saltwater front will be halted by this local groundwater increase, even to be slowly

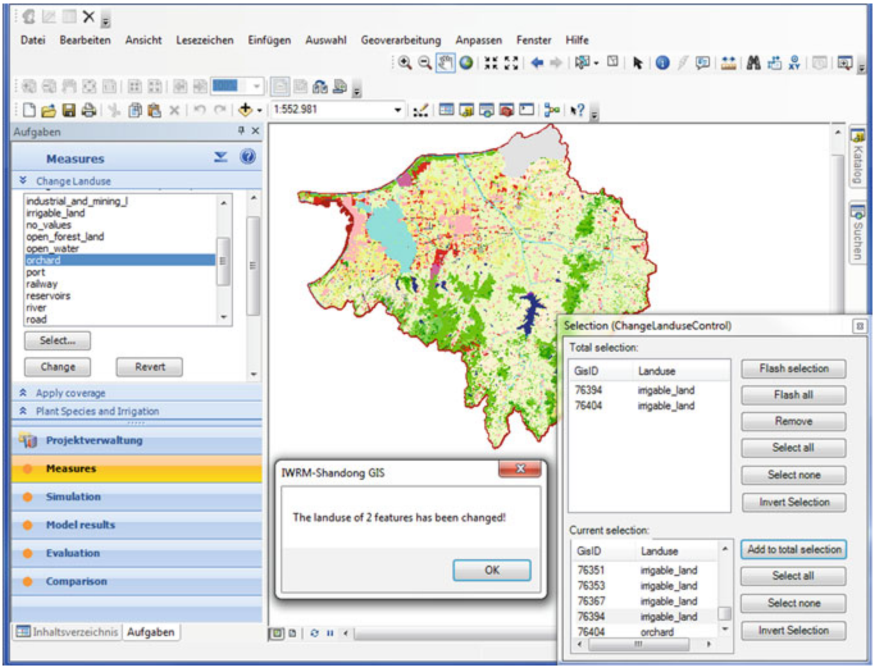


Fig. 24.10 Scenario 2 using the change land-use measures sub-task of the IWRM Shandong GIS client to change irrigable land to orchards

eliminated in time, thus resolving both the imbalance in the water budget and the saltwater intrusion with a minimum of changes and costs and a maximum of acceptance.

The suggested three-stage decision support system is now able to integrate technical, social and political issues for water management decisions. This type of approach is actually already envisaged by Chinese laws and regulations. The suggested decision support system, however, can only succeed if administrative changes are made. For details see Monninkhoff et al. (2013a, b).

24.2.1.2 Monitoring System

Further, a monitoring concept and technical components for the measurement of groundwater levels and groundwater quality were developed, implemented and transferred to the Chinese partner.

The depth-dependent groundwater monitoring system was developed and implemented by subcontractor UGT (Environmental Equipment Technology). The objective of the research contract was to develop a "multi-level" quality measurement system that is especially suited to monitor seawater intrusion. The multi-level quality measurement system was developed and combined an innovative mobile sampling system called the Sampling Shuttle System (SASS) with a stationary system measuring physical parameters.

As a prerequisite to capture water quality parameters in distinct groundwater aquifers, one absolutely vertical borehole needed to be drilled for each new measurement point, with the boreholes penetrating the uppermost confining layers and passing at least three aquifers. By positioning the filter screens at various depths according to the confining layers in that measurement point, groundwater from the distinct layers would enter the various screened sections of the well pipe separately. Importantly, to avoid any mixing, the distinct groundwater types had to be kept separate from each other by packers and plugs inside the well pipe, as well as sealing material outside the well casing.

The stationary part of the monitoring system consists of probes mounted in different depths inside packered (confined) sections opening to different aquifers.

The measuring points are fitted with two solar-powered multi-parameter radio probes each. The probe sensors MPS-D8 by SEBA-Hydrometrie measure the five standard parameters conductivity, temperature, pressure/water level, redox state, and pH value. The probes were customized so that two probes could be connected to one well cap. The well cap transmits the data via GPRS to an internet database daily, making it available anywhere from a connected website (development by UGT). The probes can optionally be supplemented with sensors for nitrate and chloride. However, Chinese partners did not opt for these additional sensors due to the high expenses for maintenance and calibration.

To enable discrete monitoring from different aquifers penetrated by a single borehole as required, the individual aquifer zones must be physically sealed off against each other. This is done by applying impermeable material (clay, bentonite) at the transition levels of the sediments outside the well casing. On the inside, the borehole is plugged by a specially constructed packer, which can be penetrated by the SASS device for sampling. Additionally, the respective lengths of the filter screens in the well pipes are limited to segments of ca. 1 m, set in the vertical middle range of the targeted aquifer.

In each measurement point, the sensors are connected to a FlashCom radio well cap by cables, which, in the case of the lower probe, run through the packer separating the upper and lower groundwater horizons. Energy is supplied by storage battery and solar panels and thus independent of external net connection. Logging intervals, operating times of the modem, as well as frequency and time of data transmission, can all be configured via text message. Data are recorded by an integrated logger once hourly, and are transmitted by GSM to a server once daily. They are accessible on a website by Chinese and German project partners. Next to the data being accessible at any time, this also has the advantage of enabling to check whether technology is functioning properly. Probes are connected to the well cap by separate cables, and thus can be mounted, removed, exchanged or serviced independently.

With standard groundwater sampling systems, only mixed samples can be drawn from the penetrated aquifers. Depth specific sampling in the multilevel wells demands a special sampling system.

The two-piece SASS is suited to draw water samples pressure-neutrally, aquifer specific, and in unadulterated quality from groundwater monitoring wells penetrating several aquifers. This prototype for the study area is an adaption of a device originally designed by Groundwater Research Centre Dresden (DGFZ e.V.), and was specifically adjusted by UGT to project requirements.

In case the physical water quality parameters, which are automatically recorded by the measurement point sensors, indicate significant changes of water quality, this mobile sampling system is used to draw water samples. These are subsequently analysed for chemical parameters in the laboratory. In the present case where salinity is most important, the parameters chloride, sulphate, and nitrate could be analysed in water samples to find the cause for elevated conductivity or salinity values.

The sampling station of this novel two-piece device is installed inside the well using two packers to separate one aquifer from the residual groundwater. The sampling shuttle is then used to draw a sample from this differentiated groundwater reservoir. It is lowered into the well until it docks to the sampling station by piercing its septum with a cannula. If required, the sample can be drawn and transported avoiding any pressure gradient (isobaric) or exchange with outside air or water.

Such a monitoring system is crucial for determining the overall groundwater deficit as well as local deficits and groundwater quality. It also provides a better understanding of the exact locations suited best to apply certain measures, to direct available funds more effectively. It is proposed to establish a monitoring authority that collects data according to catchments instead of according to administrative areas, because precipitation in the mountainous areas is likely to be significantly higher than it is in the lowland townships. Once more differentiated data is available, individual water balances could be made for each of the four catchment areas, which would allow better recognising where water saving measures are most urgent and cost effective to be implemented. For more details, see Bossel et al. (2013).

24.2.1.3 Pilot Projects Focussing on Water Saving and Reuse

In respect to water saving and reuse four pilot projects were carried out by Chinese and German partners and additional five pilot projects were done by Longkou City.

(1) **Green housing concept of Songfeng Garden in Huangcheng area of Longkou city:** A complex rainwater harvesting system has been suggested for this new domestic development (Fig. 24.11). However, only parts, especially selected storages for roof runoff and for infiltration of storm water were implemented by the private investor.
Unfortunately, only a limited part of the ca. 27.000 m^3/year technically available roof and street run-off was used. Previously it was planned to use only pumped groundwater for irrigation. Now the installed subsurface tank allows storing excessive rain during the summer for irrigation during the much dryer autumn and spring months.

(2) **Water saving in paper industry:** Until 2007 the integrated paper and pulp factory Yulong Paper Industry Co. Ltd. partly produced pulp by themselves. Due to the high water consumption, extensive pollution, and the low market price of pulp, the pulp production was shut down. Since then commercial pulp was imported from abroad. The paper mill uses about 0.8 Mm^3/year groundwater today. A considerable reduction of the water consumption has already been reached through the stepwise increase of white water reuse ratio by gradual installation of four dissolved air flotation units. The current unit water consumption for the paper production is about 13.4 m^3/t (2010). The study showed that by optimization the existing biological treatment and adding a tertiary treatment step with sand filtration and subsequent nano-membrane filtration, the current unit COD-discharge could be reduced from 1.1 kg COD/t to below 0.7 kg COD/t. The concentrate could be dewatered through lime precipitation (Möhring et al. 2003). The permeate from the nano-membrane filtration can be used as high quality water in the paper production, thereby reducing the unit water consumption to 9 m^3/t, which corresponds to an annual reduction of about 0.3 Mm^3. An investment and

Fig. 24.11 Construction site of rainwater harvesting in Songfeng residential area

operation calculation showed that the present water resources fee of 1.6 ¥/m^3 is not high enough to serve as an economic incentive for advanced tertiary treatment alone and the factory management has pushed the investment to their medium-term investment schedule. Since this water saving investment would currently only reduce the profit margin from 17.4 to 16.9 %, a small increase in the water price, stricter effluent limits or lower water availability would quickly shorten the time frame of the investment.

(3) **Wastewater reuse in Dongcheng wastewater treatment plant:** Estimations showed that there exists a large water availability potential for reclamation of municipal wastewater in the region, which is socially acceptable and will improve surface water quality. Reclaimed water can be used in dual water supplies for toilet flushing, urban environmental use and cooling in power plants. The level of treatment received by reclaimed water makes it acceptable for irrigating lawns and most landscapes; washing cars, boats, or heavy equipment; washing roofs and buildings as well as for fountains and decorative pools. Even though a series of national Chinese standards have been promulgated by government, which provide the legal basis and guidelines for reclaimed water reuse, the project for reclamation of municipal wastewater for infiltration and irrigation has not yet been implemented due to the current financial situation. Instead of the proposed more costly sand filtration and

UV-disinfection, a simpler solution with an aerated lagoon was investigated and proposed by Chinese partners. However, such a solution cannot completely eliminate the risk of diseases from waste water being spread to agricultural products.

(4) **Water saving irrigation in the grape nursery garden of Weilong Wine Company:** The pilot project for modernization of irrigation techniques for grape production, which was implemented on a much larger area than planned during the first phase of the research cooperation, showed that after modernization of irrigation techniques for saving water only about 20 % of the labor was required. The cost for changing from furrow irrigation to micro spray in 340 ha vineyards around Wangwu Reservoir was estimated to about 0.5–0.7 ¥/m^3. Comparing this estimate with the current water extraction cost for farmers of 0.02 ¥/m^3 indicates that with the current water, electricity and labour prices, farmers are not saving money when upgrading their irrigation techniques. Actually, traditional and modern techniques do not show a significant difference in total cost under the present prizing system, but the modern techniques do require more investment capital, and reduce the labour force demand. On the other hand, a detailed socio-economic study on irrigation techniques indicated that the irrigation cost only takes up 1–5 % of the gross profit margin without irrigation costs.

The pilot projects clearly show that the implementation of water saving measures is difficult to justify at the present local water prices, especially considering the groundwater extraction, which is free of charge, and the insufficient enforcement of water and environment laws. For details see Nilsson and Würzberg (2013).

The Chinese pilot projects were:

(1) **Longkou Xinxing Tools Co. Ltd. water conservation saving project:** This Company produces hardware tools. Surface treatment of the tools caused three types of wastewater. Each of them contains chromium, nickel and acid or alkali. The pilot study project aimed at a separated collection of the different wastewaters. Separated systems for chromium, nickel and acid and alkali wastewater treatment system were installed to reach the wastewater discharge standard. By using flocculation automatic dosing technology (PAC), flocculation automatic mixing technology (PAM) and PH automatic controller to direct the treatment process and ion exchange resin protection system to further exchange heavy metal ions in wastewater have been realized. After finishing the new wastewater treatment systems, the quality of water reached the first-class standard of comprehensive discharge standard of sewage (GB8978-1996). Such it is available for wastewater reuse, helping water conversation, energy saving and environmental protection. 36,000 tons of wastewater now is treated per year under full load conditions and two tons of chromium-nickel compositions are produced which values 77,000 ¥.

(2) **Longkou Zhenglong Bio-chemical Engineering Co. Ltd. water conservation project:** This project included ‘alcohol production device resources saving conservation and integrated utilization’ and ‘biogas power generation and integrated utilization’. The alcohol production and integrated utilization adopted differential pressure thermal coupling distillation, stewing in moderate temperate, high-concentration mash fermentation, reuse of reclaimed water and clean fluid provision techniques. Imported advanced heat exchange technology was installed. Closed water cycles increased the water reuse rate. The biogas power generation and integrated water utilization using waste gas and energy from biogas generator to cool high temperature cooling water, with an refrigerating capacity of 5000 kW, produces 570 m^3/h of 12 °C water for alternative use. The pilot project achieved a water consumption of 10.2 m^3 per ton of alcohol and a water reuse rate of 90.5 %, which reach the secondary standard (domestic advanced level of cleaner production) of Alcohol industry clean production standard (HJ581-2010). A water amount of 200,000 m^3/year can be saved.

(3) **Crop irrigation pilot project of Lutou town:** A pressure line takes water from Beixingjia Reservoir. The length of the main canal is 8.5 km with the length of branch canals being 14.3 km. The whole length of irrigation pipelines amounts to 64.5 km, with an average of 6.5 m/mu (1 mu = 666.7 m^2). The water use efficiency in the canal system improved by 23 % and the irrigation water use coefficient improved by 25 % after finishing the pilot project. It can save 161 m^3/mu/year compared to the original soil canal irrigation system.

(4) **Water-saving irrigation for fruit trees:** 11 thousand mu of irrigation were established in Majia and Wangliang, Dazong villages. The fruit trees irrigation pilot project includes a micro-spray irrigation area with 1375 mu, a sprinkler belt irrigation area of 3791 mu, a small tube outflow irrigation area with 1412 mu and a pipe irrigation area with 1883 mu located in Zhuyouguan township. The guaranteed rate of irrigation was 75 %. 1261 fruiters applied straw mulching, plastic film mulching, storing water tillage and formula fertilization. 260 mu of persimmon garden were equipped with a soil moisture content forecasting and an irrigation automation system. After the implementation of the project the production of the fruit increased up to 17.9 % and water use efficiency of irrigation increased at least by 20 %. After the implementation of the project 2.02 Mm^3 of water were saved and production value increased to 4.94 M¥/year.

(5) **Reuse of reclaimed water and seawater utilization:** The Shandong Bainian Electric Power Corporation implemented an advanced wastewater treatment system that can treat 2,000 tons of domestic sewage per day at a rate of 100 % reaching the industrial wastewater treatment standard. It can be reused as industrial cooling water and an average of 400 thousand tons of water can be saved per year. This corporation also utilized seawater for cooling. The seawater consumption was about 0.876 billion tons which can save 6.6 Mm^3 of fresh water per year.

24.2.1.4 *Some general recommendations for sustainable water management*

At current water prices, only installing a few water efficient household devices is cost-effective. Not until water prices increase further, households will be motivated to invest more in water saving techniques. It is estimated that if the domestic water price is increased from 3.0 to 4.5 Yuan/m^3, the life cost-benefit of most water saving devices would at least break even. However, this would not suffice, because the payback time would still be between 10 and 25 years.

Similar to the banning of inefficient light bulbs in Europe, China with certain especially inefficient water devices such as simpler types of water faucets and shower heads could follow suit by banning the sale of water inefficient devices. Such a policy could have an impact even if water meters were not installed in all households. If the efficiency of water devices in households should be enhanced without regulating sales, the water supplier should be made responsible for installing a water meter.

Further exploitation of surface water resources by renewing existing dams for Wangwu Reservoir is a relatively cost-effective alternative, even just considering the potential for increasing surface water availability by increased retention time. If the impact on flood mitigation were considered, cost-effectiveness would further increase.

Without considering the potential mitigation of flood risk, the cost-effectiveness of strengthening decentralized storm water management was shown to be very low, thus a detailed study would also serve to better understand the cost-effectiveness of this type of measures. This is due to the fact that under the current price system, infiltrating water does not give any monetary benefit, thus it is proposed to implement a fee for land owners. This fee should be calculated based on estimated coefficients of run-off from each property, which would be reduced when implementing decentralized storm water measures.

The existing water infiltration through the Huangshui River bed, in conjunction with an underground dam around the river mouth, recharges large amounts of surface water from the lower reaches of the river into groundwater bodies. Consequently, it is very important to keep the river in good quality and to improve municipal wastewater treatment with high priority. Infiltrating polluted water has a detrimental long-term impact on the groundwater aquifer.

In addition to the investigated technical measures, it was felt, that appropriate approaches for the implementation of economic instruments are:

- Raising water prices for industry, households and agriculture
- Raising wages and prices for agricultural products in order to increase the social acceptability of higher water prices
- Introducing subsidies for new irrigation technologies to enable also small scale farmers to switch from less efficient irrigation practices to highly efficient options

- Introducing tradable water use permits serving as a basis to negotiate water uses within and between river basins and sub-basins
- Launching information campaigns, advisory services and educational programs

It is obvious that those measures cannot be implemented on the local scale in Longkou County only, but do require political decisions on higher levels.

24.3 Conclusions

Decision support systems (DSS) inherently have difficulties to develop sustainable solutions for complicated water systems, equally reflecting social, ecological and technical aspects. A stepwise DSS and a dynamic water balance can help to consider many different types of measures and can serve as a communication basis for diverse stakeholders already in early planning and project phases. This is achieved by a catalogue of technical water management measures which are roughly categorized with respect to application sector, cost-efficiencies, impact on WRM goals and peoples acceptance.

Socio-economic issues are expressed as strategies or policies. The relationships between strategies, policies and technical measures then are systematically organized in a hierarchy.

While all options are considered at the beginning the system allows to gradually eliminate unfavourable options. Thus, in the time consuming and data intensive final phase of modelling and ranking of alternatives, efforts can focus on precision and correctness of a few final options. Still, one has to keep in mind, that the DSS itself does not solve problems but helps to identify the most socio-economically viable compromise to achieve sustainable water management. Besides implementing the measures, it is essential to enforce related laws. The methodology suggested seems to bear the potential to achieve sustainability in IWRM. However, in order to fully integrate socio-economic concerns in the IWRM decision finding process, further research is needed. The methods and tools developed successfully have been applied to a part of the coastal region of Shandong province, China and may be applied to other regions of China and beyond.

Due to the limited time and resources of an IWRM research project it is not possible to evaluate the sustainable implementation of IWRM in the study region. What we learned is that already for our small study area it was difficult to get and to keep all stakeholders on board. The more complex the processes are and the more stakeholders are involved, the more difficult is the development and implementation of IWRM methods. And with regard to socio-economic measures (e.g. changes in water prices, subsidies) one has to take into account that those, especially in China, have to be embedded into the overall governmental system. Within the IWRM project effects can be illustrated but not implemented.

Nevertheless we believe that IWRM principles in China are accepted and will be considered increasingly in future due to the huge environmental and related socio-economic problems.

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Chapter 25
Modular Concept for Municipal Water Management in the Kharaa River Basin, Mongolia

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Abstract Mongolia is a country with limited water resources but a rising water consumption due to an increasing population, urbanization and economic growth, which is largely driven by a booming mining sector. These processes do not only lead to greater water abstractions, but also contribute to water quality and aquatic ecosystem deterioration. Urban areas play a key role in this context, since water abstractions and waste water generation are concentrated here. However, there are considerable disparities between urban centers with centralized water supply and sewage infrastructures and peri-urban regions. Where existant, infrastructures for drinking water supply and wastewater collection and treatment are often in a poor state of maintenance, leading to the contamination of groundwater and surface water bodies with pathogens, nutrients, and other chemical substances. This paper presents components of a modular concept for urban water management at the

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example of Darkhan Uul Aimag, which were developed and pilot-tested in the context of a project aiming at the development and implementation of an integrated water resources management (IWRM) for the North Mongolian Kharaa River Basin. It is discussed how solutions were adapted to local situations, considering both sustainable resource utilization and local acceptance.

25.1 Introduction

Located between two powerful neighbors, Russia and China, Mongolia's recent past has been marked by political and economic dependence. In 1924, Mongolia became the world's second socialist peoples' republic after the Soviet Union (Janzen 2012). During this period, the previously largely nomadic population was forced into sedentariness and a functional city system was developed. A new "socialistic identity" was meant to replace the traditional Mongolian lifestyle. The establishment of industrial cities in the 1960s, equipped with new amenities like electricity or piped water supply was at that time seen as an important step towards a modern socialistic state. In the more recent past, poor maintenance and socioeconomic and demographic changes have not only led to the deterioration of existing infrastructures but also to the formation of new settlement areas without centralized water infrastructures.

25.1.1 Urban Development in the Transition Period

During socialist times, the center settlements of both provinces ("aimags") and municipalities ("sums") were equipped with infrastructural facilities according to their function and population size (Gardemann and Stadelbauer 2012). This order was suddenly questioned by many when in 1990 the Soviet Union lost its control over Mongolia, initiating a period of political and socioeconomic transition. People were suddenly free to choose their place of residence. On the one side, the provision of public services, but also destructive natural disasters and the lack of alternative employment possibilities took a leading role in promoting internal migration from the countryside into cities. However, many small towns lost a considerable part of their inhabitants, with (semi-) deserted settlements not only losing their supra-regional importance but also experiencing a decay of their infrastructures. Mongolia's capital Ulaanbaatar stands at the forefront of the urbanization process and has to deal with drastic amounts of immigrants and thus concentrates the socio-economic and environmental problems triggered by the rapid population growth. Similar developments can be observed in the country's second and third largest cities, Erdenet and Darkhan. Most of the arriving immigrants initially (and often permanently) move to the peripheral "ger" areas where people live in traditional felt tents or simple wooden houses. These quarters are often excluded from urban services and facilities and lead to a massive spatial expansion of the cities. With rising distance from city centers, poverty and exclusion are rising and the provision of basic infrastructure like drinking water supply and wastewater disposal is vanishing (Genté 2013; Taraschewski 2012). The city centers of Ulaanbaatar, and increasingly of Darkhan and Erdenet, see a westernization process with modern buildings, boutiques and post-Soviet hotels forming a part of their new face (Genté 2013). A key driver of this emerging development and wealth is the booming mining sector which has opened new export opportunities for Mongolia. China, Mongolia's other powerful neighbor, is the main importer of most mining products, including coal, copper and other metals—and therefore plays an important role for Mongolia's future development (Sandmann 2012).

25.1.2 Key Issues of Water Resources Management in Mongolia

In the light of Mongolia's rapid economic and demographic change, efficient and sustainable water resources management is a key challenge. In a situation that is typical for large parts of Central Asia, Mongolia has arid to semi-arid climate conditions. Therefore, water availability is often already a limiting factor for the development of social, ecological, agricultural and industrial resources. Mongolia's landlocked position, a temperature rise well above the global average (UNEP 2009) and an intensification of socio-economic and demographic pressures (Malsy et al. 2011) mean that improved wastewater treatment and water reuse are needed—ideally in the context of an integrated water resources management (IWRM) concept. In the German-Mongolian research and development project "Integrated Water Resources Management in Central Asia: Model Region Mongolia (IWRM MoMo)", a modular and at the same time holistic municipal water management approach forms an important component of an IWRM for the Kharaa River Basin, which had been selected as a representative model region for Central Asia (see Fig. 25.1; Karthe et al. 2012a).

Besides urban settlements, agriculture and mining are the two major water users in the region. Given the climatic conditions, water is already the most important limiting factor for agricultural production. In recent years, irrigation and agricultural water demand have been increasing (Menzel et al. 2011; Karthe et al. 2013). A series of relatively dry years following the mid-1990s has already led to drastic water deficits, causing not only the desiccation of rivers but also leading to the cultivation of increasingly large areas to balance the emerging yield losses (Priess et al. 2010; Schweitzer 2012).

The mining industry has gained substantial importance as a source of employment and foreign exchange for both Mongolia and the Kharaa River Basin in particular. In 2009, the mining sector provided 19.8 % of Mongolia's GDP. The Kharaa River Basin accommodates the Boroo Goldmine, which is one of the largest

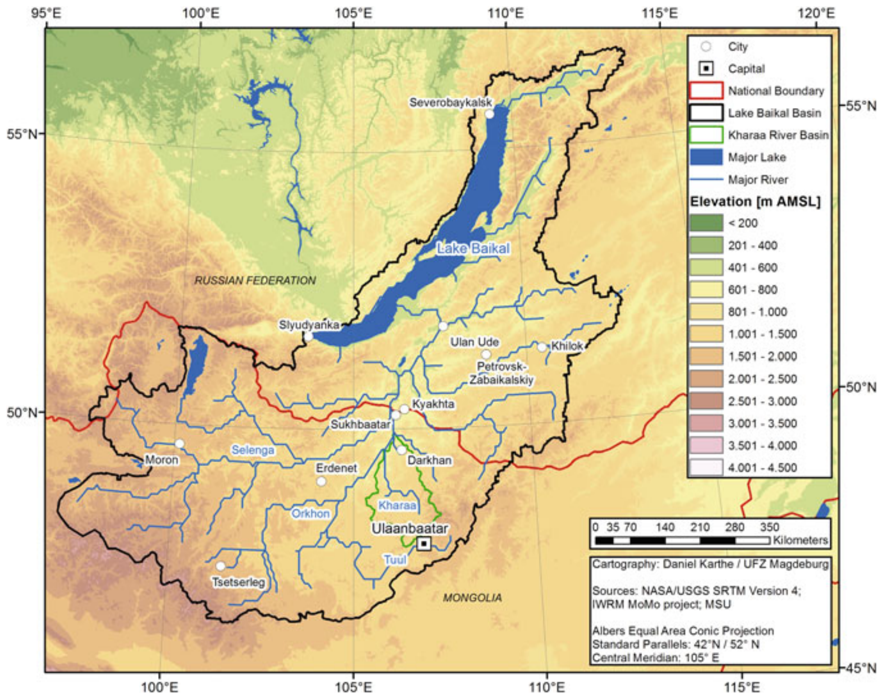

Fig. 25.1 Location of the Kharaa River Basin within the Selenga-Baikal Basin

Mongolian mining sites (Sandmann 2012), as well as several smaller gold mines. Gold processing does not only require large quantities of water, but also causes serious wastewater contamination, particularly with cyanide and mercury. The release of these substances into rivers causes irreversible damages to aquatic ecosystems (Avlyush 2011) and is a serious threat to human health. This is best illustrated by an incident which took place in Khongor Sum (Darkhan-Uul Aimag) in May 2007, where the official drinking water supply from wells had to be suspended temporarily due to accidental contamination by an illegal gold extraction facility. Elevated cyanide and mercury concentrations were subsequently detected in several wells in Khongor Sum. Nevertheless, the local population soon after the accident continued to use their private wells, potentially exposing themselves and their livestock to contaminated water (UNEP 2007; Hofmann 2008; Watson and Scharaw 2012).

A good quantitative status can currently be stated for groundwater. The long-term annual average rate of abstraction in the most heavily used groundwater body around the city of Darkhan does at present levels not exceed the levels of groundwater regeneration. However, future water abstractions with intensified water demand of mining, agriculture and households in combination with reduced groundwater recharge due to climate and land cover changes may lead to an increasing risk of water shortages (Hofmann et al. 2015).

As a consequence, the three main water consuming sectors, urban areas, agriculture and mining, are in growing competition over the limited water resources. Poor management in one sector may be prohibitive for water reuse in another sector, e.g. when the (accidental or chronical) mining-related release of toxic substances leads to a contamination of ground and surface water sources. On the other hand, options for intelligent cross-sectoral management and water reuse exist in general, e.g. when treated domestic wastewater which is enriched in nutrients is used for agricultural irrigation.

25.1.3 Municipal Water Management in Mongolia—the Examples of Darkhan and Orkhon Sum

In the context of the IWRM MoMo project, Darkhan and Orkhon Sum were chosen as model sites to analyse municipal water management structures and develop and test pilot solutions which are embedded as components into a holistic management system. With a registered population of 74,738 Darkhan is the third largest city of Mongolia (National Statistic Office of Mongolia 2010). One feature that is typical for urban centers in Mongolia, including Darkhan, is the clear differentiation between central urban areas characterized by concrete apartment buildings and peri-urban ger areas, which both have distinct water supply and sewerage systems. On the other hand, Orkhon Sum, with a population of 3000, is representative for hundreds of similar sum centers in the country.

Darkhan has a municipal water supply company ("USAG") that is responsible for both the drinking water supply and wastewater management in the city. The planned parts of the city, mostly consisting of Soviet-era apartment houses, are connected to centralized water supply and wastewater treatment. A major problem on the supply side is water loss due to leakages in the water distribution system. Since water fees are comparatively low (currently around 0.32 €/m^3 in apartment buildings) and metering is often not yet implemented, there is little incentive to save water. Therefore, the per capita water consumption in Darkhan was about 400 L/d in 2009 for those areas connected to the central water distribution system (MoMo Consortium 2009). Darkhan's central wastewater treatment plant was commissioned in 1968 and was designed mainly to reduce COD. It is equipped for mechanical, biological and chemical sewage treatment. About 40,000 inhabitants are connected to this wastewater treatment plant, which currently uses only one third of its capacity, mainly because equipment has become dysfunctional over time. The mechanical treatment consists of sewage screens as well as primary and secondary sedimentation tanks (Scharaw and Dietze 2010). However, contrary to previous assumptions that extremely low winter temperatures could inhibit biological treatment processes for several months/year (MoMo Consortium 2009; Hofmann et al. 2011), relatively high waste water temperatures (typically above 7 to 8 °C even during the coldest months) mean that biological treatment processes are possible almost at all times. The chlorination unit to treat the effluent is out of order without plans for reactivation (Scharaw and Dietze 2010).

Nearly half of Darkhan's population lives in ger areas which are neither connected to the central water supply nor to the wastewater disposal system. Consequently, there are substantial deficits in hygienic sanitation and sufficient water availability (Gawel et al. 2013). Especially ger areas located in the floodplain close to the Kharaa river are exposed to floods and high health risks as families often use private wells for the abstraction of shallow groundwater (Tarschewski 2012). The quality of this water is not routinely monitored, but the likelihood of contamination from unsealed pit latrines and animal excreta is considerable (Sigel 2012; Karthe et al. 2012b). Lacking infrastructure and the very time and energy consuming water supply by either shallow wells or water kiosks, where ger area inhabitants have to pay nearly five times more compared to inhabitants of apartments that are connected to the drinking water supply, results in a very low water consumption of 8–12 l per person per day. In this way, the minimum norm for drinking, preparation of food and adequate sanitation and personal hygiene considered by UNICEF & WHO of 15–25 l could not be matched (MoMo Consortium 2009). In general, this lack of available water results in deficient possibilities for personal hygiene, while a questionable water quality makes ger dwellers prone to high infection rates with water-borne diseases. It is suspected that the elevated prevalence of hepatitis A and enteroviruses observed in the ger areas of different cities are at least partly due to poor sanitation and water supply (Kuramitsu et al. 2005; Karthe et al. 2012b).

25.2 A Modular Municipal Water Management Concept for Mongolia

According to the Global Water Partnership (2000) definition, integrated water resources management is "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP-TAC 2010). A key prerequisite for the operationalization of IWRM is a transdisciplinary assessment of the environmental and socio-economic conditions in regional context (Borchardt et al. 2013).

In Mongolia, urban areas play an important role for IWRM because (1) in a sparsely populated country, they represent areas where water use and pollution are concentrated; (2) there are significant deficits in urban water supply and wastewater disposal which have negative impacts on human health and the environment. At the same time, due to the dry continental climate, urban areas are dependent on water resources originating from a large hinterland. Therefore, efforts to preserve aquatic resources need to incorporate a wider perspective going well beyond urban limits (Karthe et al. 2015).

Integrated urban water management addresses this dual focus on urban areas and their surrounding watersheds (Anthonj et al. 2014) through an "alignment of urban development and basin management" (GWP-TEC 2012). One specific focus lies on closing the loop between water supply and wastewater disposal, which does not only require "forward-looking planning, a supportive institutional setting, […] and public acceptance and participation" (GWP-TEC 2012), but also multipurpose infrastructures aiming at social, economic and environmental benefits (Borchardt et al. 2013).

The IWRM MoMo project selected the Kharaa River Basin for the development of a science-based IWRM (Karthe et al. 2015) that includes modular but inter-linkable components for urban water management aiming at a more efficient water distribution and an integrated wastewater management concept (see Fig. 25.2). Technical solutions, which were adapted to local conditions and always accompanied by capacity development, were implemented at pilot scale, tested under realistic operational conditions and improved stepwise.

An integrated concept for urban water management requires a clearly defined strategy for priority setting (Rost et al. 2015). This is particularly relevant in the

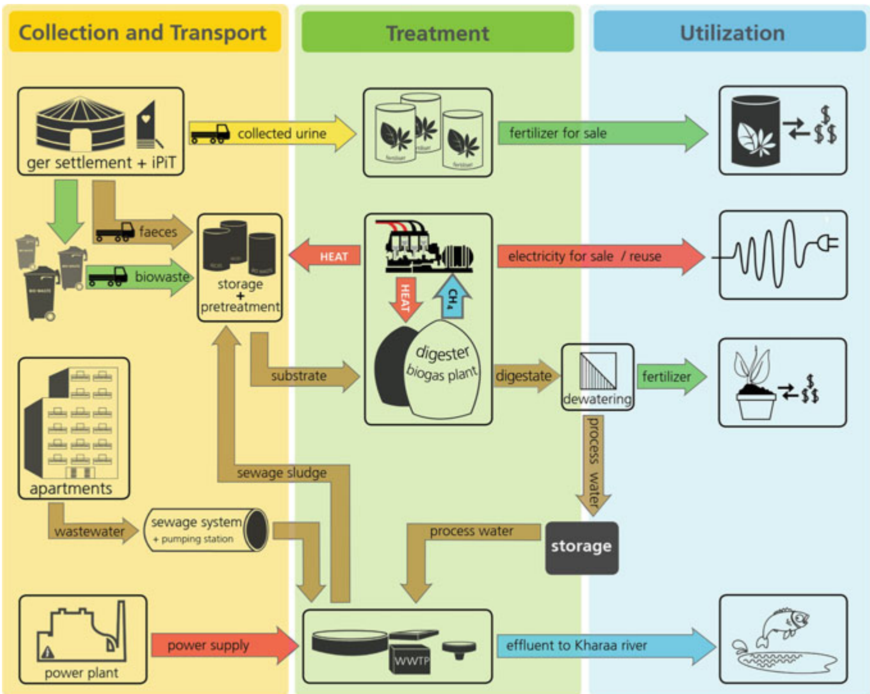

Fig. 25.2 Integrated sanitation system for the city of Darkhan. *Source* Bauhaus-Universität Weimar

context of transition countries like Mongolia experiencing a rapid urbanization which often outpaces urban planning and development. Urban water services like water supply, transport, use, reuse and treatment are embedded in a physical system with water and material flows. Urban areas are not only focal points of water abstractions, but within the urban water cycle the water quality changes depending on its use or treatment. The resulting material flows should, however, not only be seen as a problem ("contaminants"), but considered in the light of reusable resources. In this way, negative impacts on natural ecosystems can be avoided while resources, such as nutrients contained in domestic sewage, can be recycled. The specific framework for integrated urban water management (IUWM) in Darkhan and Orkhon Sum, including linkages with external factors, are shown in Table 25.1.

25.2.1 Module 1: Minimization of Water Losses in the Distribution System

Leakage in water distribution systems and therefore the waste of valuable resources is a problem in many countries. In Mongolia, where water is scarce, any unnecessary loss should be avoided. Since urban areas are among the largest water consumers, leak detection and network rehabilitation are therefore a key strategy to save both water and energy. For the Mongolian city of Darkhan, an optimized leak detection procedure was developed based on the combination of online sensors and hydraulic network modeling (Scharaw and Westerhoff 2011). Until 2006, the water losses in Darkhan's drinking water network accounted for about 50 % of the amount entering the distribution system.

Leak detection in Darkhan is complicated by the fact that pipes are installed at a depth of 4.5–5 m below the ground, thus leading to high excavation costs in case of repairs, and also increasing the cost of standard approaches using correlators. Using a set of multi-parameter sensors (measuring pressure, flow and noise) at selected nodes distributed over the supply network, the positions of leaks were determined based on online sensor data and a hydraulic model of an ideal, leakage-free network. The principle is relatively simple: network inflow from tanks and network outflow (consumer demands, leakages) produce typical but dynamic pattern of pressure, flow and noise which can be measured at network nodes. With knowledge of measured water demand changes (or typical demand profiles during the day), and the leak flow which depends on the net's pressure it is possible to estimate the approximate position of leaks by using evolutionary optimization algorithms in combination with a hydraulic simulation. Because the network is monitored 24/7, upcoming leaks can be identified immediately. The typical change in flow and pressure caused by the leak are detected by the sensors and generate an alarm signal which starts the computational (model based) pre-localization of the leak. Higher accuracy of the hydraulic network model and more sensors within the network provide better results of the pre-localization. Prolongued water losses, which are a risk with classical approaches based on annual DMA (district metered area)

Table 25.1 General framework for IUWM components in Darkhan and Orkhon Sum

Component	Relevance in the Kharaa River Basin
Climate trends Climate change may alter water availability in general and lead to an increase in extreme weather events which may be challenging for managing urban water infrastructure	• Temperatures rising faster than the global average will result in higher water demand (e.g. in agriculture) and lead to increased evaporation losses, thereby potentially reducing water availability for urban areas (Karthe et al. 2013) • This results in the need for an intelligent urban water management that features adapted technologies aiming at efficient water distribution and wastewater reuse
Land use and cover change Land cover is not only an important determinant of hydrological processes such as infiltration and surface runoff generation, but also governs nutrient influxes into the river system (erosion susceptibility; impact on soil fertility/application of fertilizers). Nutrients from the urban water cycle may be reused for agricultural purposes	• Nutrient imbalance between urban and rural areas, i.e. depletion of fertile soils in rural areas versus nutrient surplus in urban areas caused by sewage and organic waste (Hofmann et al. 2010, 2011). Nutrient surpluses generated in urban areas could be used for fertilization in rural areas • Natural forest and steppe vegetation is degraded due to forest fires and livestock farming exceeding natural grazing capacities (Schweitzer and Priess 2010; Schweitzer 2012), with negative effects on water availability further downstream (Minderlein and Menzel 2015)
Water availability and quality Sufficient availability of raw water forms the backbone of urban water supply systems. The management of both factors typically has to include regions further upstream. Environmental impacts related to urban water use may be related to water abstractions (including hydromorphological alterations such as dams) and wastewater discharge. These processes contribute to the depletion and qualitative degradation of ground and surface water bodies and may interfere with aquatic and terrestrial ecosystems	• Local surface and groundwater generation in urban areas located along the mid- and downstream sections of the Kharaa river is very limited. These areas are mainly fed by water resources from the headwater regions in the Khentii Mountains (Menzel et al. 2011; Karthe et al. 2013) • Due to their poor state and obsolete technology, wastewater treatment plants are hot spots for water pollution (Hofmann et al. 2011). Moreover, contamination is aggravated by the release of toxic substances including heavy metals from mines or industry (Avlyush 2011; Hofmann et al. 2010)
Basin-wide water use At a river basin scale, water users such as urban areas, agriculture or industry have distinct interests and may be in competition with each other. Typically, the role of these sectors is not stable but subject to temporal and spatial trends	• Economic growth (especially of the mining sector), increases of irrigated agriculture and population growth (Karthe et al. 2015) result in a higher competition and need for intelligent water reuse

(continued)

Table 25.1 (continued)

Component	Relevance in the Kharaa River Basin
Urban water infrastructure The types and state of urban water infrastructure and their management play an essential role for the economic efficiency and environmental sustainability of urban water use	• In central parts of Darkhan, water losses of up to 50 % are caused by leakages in the supply system (Scharaw and Dietze 2010) and need to be minimized • For Darkhan and Orkhon Sum, wastewater treatment needs to be improved • In ger areas, no water supply and wastewater disposal system exists to date. Water procurement is costly, time and energy consuming (water kiosks) or associated with health risks (shallow wells). Improvements need to be accepted by the local population and place a high priority on safe sanitation (Sigel et al. 2012, UNICEF and WHO 2008)
Socioeconomic situation The urban water cycle is highly dependant on socioeconomic factors, including demographic development, payment for services, and behavioral aspects (e.g. willingness to save water). A sustainable urban water management needs to take into account both present conditions and future trends	• Rapid demographic changes involving both urbanization and rural desertification, a rising disparity between poor and rich (Gardemann and Stadelbauer 2012; Genté 2012; Taraschewski 2012) and a shortage of qualified staff are challenges for municipal water management • High water consumption in urban areas is caused by lacking incentives for responsible water use (inadequate water pricing and metering) (MoMo Consortium 2009) •The booming mining sector requires high amounts of water and infrastructure in (formerly) remote areas (Sandmann 2012)
Water governance In practice, urban water management is closely related to both the general legal framework and the institutionalization of responsibilities. Advanced resource-oriented and integrated concepts for urban water management require appropriate legal and institutional structures	• Water governance in Mongolia is still characterized sectoral approaches and overlapping responsibilities of a multitude of actors • Recently, IWRM and river basin management have been adopted as guidelines for water policy reforms. However, more responsibilities and capacities need to be decentralized and assigned to local/regional levels of administration (Houdret et al. 2013)

measurement campaigns, can therefore be avoided. Given a pre-located position, the approach with correlators is more efficient because the search area is smaller.

The centralized water supply system of Darkhan consists of two main branches. Hot water is produced by the thermal power plant, which uses its own wells and provides it to both industrial and domestic users. The cold water comes from 18 wells operated by Darkhan's municipal water supply company USAG. There are different distribution systems, and hot water is partially recirculated. Darkhan's daily water demand totals about 18.900 m^3/d for the period 2010/2011 (see Fig. 25.3).

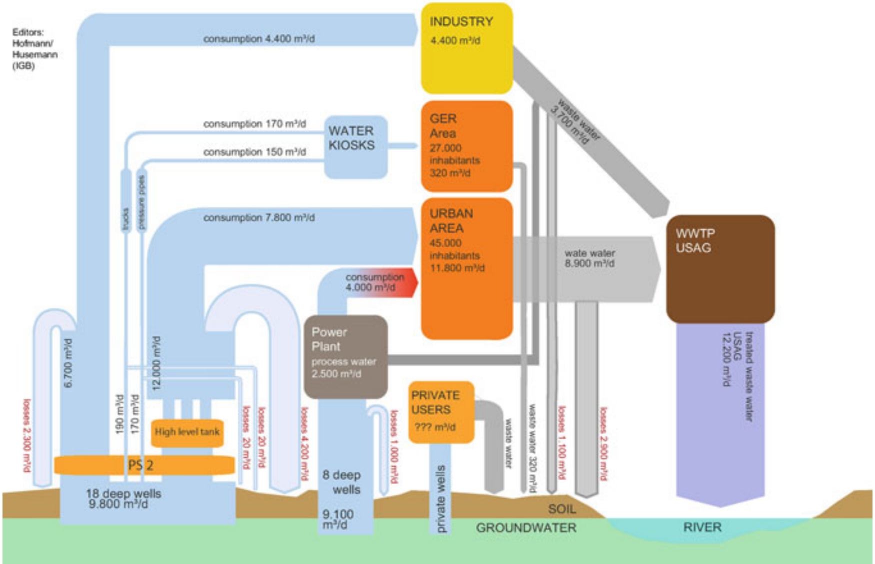

Fig. 25.3 Water supply scheme of Darkhan city for the period 2010/2011. *Source* Hofmann and Husemann 2012

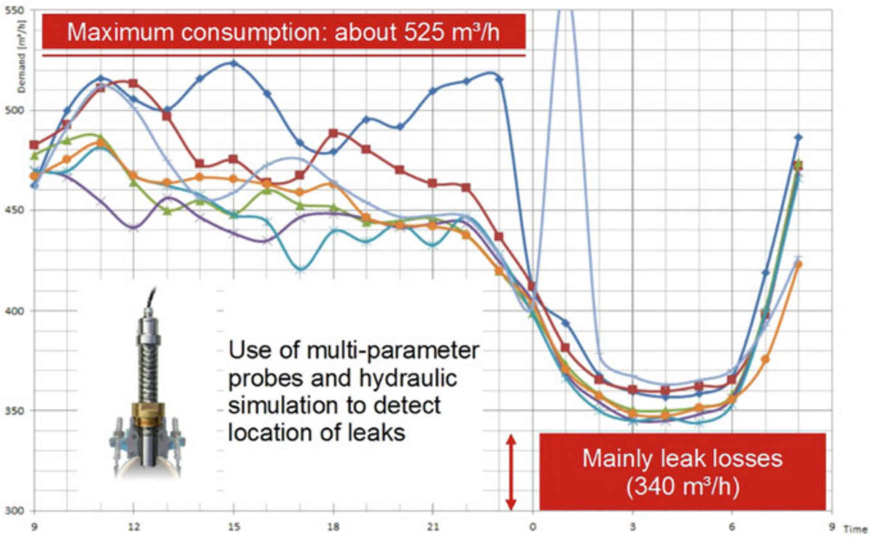

Fig. 25.4 Water consumption and leak losses in Darkhan. *Source* Fraunhofer AST (modified)

Supply data during the night, when there is almost no consumption, show that in Darkhan leakage losses are in the order of 50 % of the water pumped from the city's supply wells (see Fig. 25.4).

Fig. 25.5 Exchange of pipelines in Darkhan. *Photo* Daniel Karthe

Based on the results of the leak detection, USAG Darkhan began in 2012 to exchange those pipelines (see Fig. 25.5) that have the highest leakage losses. In 2013, for example, more than 6 km of pipes were rehabilitated. The decision for pipeline replacement rather than repair was politically-driven, and based on the considerations that (1) due to poor state of the pipes, future leaks would be likely in case of repair; (2) due to the depths of pipelines, a network rehabilitation should lead to a long-term solution and (3) the use of inliners was not an option because of a growing water demand. As an incentive to reduce water consumption, USAG Darkhan is currently beginning to introduce water metering. Moreover, the present water tariffs are under reconsideration.

25.2.2 Module 2: Providing the Scientific Basis for Improvements of Peri-urban Water Supply

In Darkhan's ger areas, a lack of adequate water supply and sanitation leads to environmental pollution and negatively impacts the hygiene and health of the population, especially children. Morbidity patterns in ger areas in Mongolia reveal a high rate of waterborne diseases and those related to poor environmental living conditions, such as diarrhoea and hepatitis A (Basandorj and Altanzagas 2007; City of Ulaanbaatar 2006). However, for ger areas in Darkhan there is no data available in this regard.

For the groundwater situation in Darkhan two different groundwater bodies could be distinguished: the unconfined porous aquifer with shallow water table (<3 m) in alluvial sands and gravels in the floodplains of the Kharaa river and fissured bedrock aquifer in magmatic/metamorphic rocks with deep groundwater table (>5 m) in the higher relief parts of Darkhan city (Hofmann et al. 2015). Table 25.2 shows selected analytical results of five different wells located in the informal settlement areas in Darkhan (so-called Ger areas) in comparison with reference conditions. The “reference conditions” indicated in Table 25.2 refer to subcatchments in the upper part of the Kharaa river basin with natural or near-natural background conditions (following reference conditions guidance in the context of the EU Water Framework Directive by Wallin et al. (2003), e.g., absence of point source pollution and agricultural activities, more than 90 % natural land cover, low population density with less than 4 inhabitants/km^2, lack of morphological alterations and water abstractions). Against these reference conditions, it can be stated that especially the wells of Bag 7 (sampling location 1 in Table 25.2) and Mangirt (sampling location 4) have strong impacts on groundwater quality. Chloride and boron concentrations as reliable pollution indicators are 9–17 fold and chloride concentrations are 5–8 fold higher than in natural groundwaters of Kharaa river basin. Statistical regression analysis confirms a significant correlation (R^2 = 0.9048, N = 17) between electrical conductivity (EC) and chloride concentrations in all investigated groundwater bodies (Hofmann et al. 2015). Since EC measurements were performed more frequently than water samplings including

Table 25.2 Selected indicators for groundwater contamination in Darkhan as compared to Mongolian and WHO guidelines for drinking water and natural reference conditions

	B (µg/l)				Cl (µg/l)			
MNS 900:2005	500				350			
WHO 2011	2400				–			
	N	Mean	Min	Max	N	Mean	Min	Max
Reference conditions	25	10	5	12	33	1.6	1.0	2.7
Bag 2 well	1	29			1	33.4		
Bag 3 well	3	35.7	35	37	2	11.2	10.3	12.1
Bag 7 well	3	229	205	260	2	78.2	74.2	82.1
Mangirt well	3	126	112	140	2	52.8	52.1	53.5
Mangirt water kiosk	1	88			1	34.2		
	Sulfate (mg/l)				Nitrate (mg/l)			
MNS 900:2005	500				50			
WHO 2011	–				50			
	N	Mean	Min	Max	N	Mean	Min	Max
Reference conditions	18	5.1	1.9	10.5	18	1.6	0.2	3.4
Bag 3 well	2	3.5	3	4	0	–	–	–
Bag 7 well	2	112	98	126	2	169	156	182
Mangirt well	2	451	449	453	2	113	109	117

analyses of chloride, it is possible to extrapolate the chloride concentration based on EC measurement results. Although the low number of analysed samples in Table 25.2 can only provide a "snapshot" of the current situation, the frequent EC measurements suggest elevated levels of chloride concentration and thus more wide-spread and persistent groundwater pollution. Moreover the nitrate concentrations reach peaks up to 113–169 folds of the natural background levels. The impacts of boron, chloride and nitrate concentrations are also detectable in the shallow groundwaters (sampling locations 2 and 3) with a less pronounced trend. For heavy metals only iron and manganese showed levels close to the maximum tolerable concentrations of drinking water. The initial risk assessment revealed that groundwater around and in the city of Darkhan has a significant risk of failing to reach a good chemical status of groundwater as an environmental objective. A more detailed description of the groundwater quality and initial risk assessment is presented in Hofmann et al. (2015).

Another key problem is the emerging under-consumption of kiosk water. A household survey conducted in a selected ger area district in Darkhan in 2009 revealed an average water consumption of 12 l per capita per day, less than the lowest international standard stated in the literature (Sigel et al. 2012). This raises the question of whether the people have sufficient water to meet basic needs. The under-consumption of kiosk water can partially be explained by the fact that some ger residents use water from additional sources and generally have their shower or bath elsewhere, e.g. with relatives living in apartment buildings and/or at a public bathhouse (Sigel et al. 2012; Kuramitsu et al. 2005). In addition, based on the data of the household survey and theoretical research it can be argued that there might be a problem of non-affordability, superposed by two adjacent problems: the problem of poverty and the problem of access (Gawel et al. 2013). The latter includes the effort to go to the kiosk and carry water, and constraints regarding water availability (limited opening hours of the kiosks, service break-downs etc.).

To improve the water supply situation in Darkhan's ger areas in a sustained manner it is crucial to tackle also adjacent problems like sanitation, stormwater management and waste management. Technical measures should be embedded within a comprehensive political action program, including educational and awareness-raising measures (e.g. in the field of water and hygiene), social measures (e.g. to reduce poverty), economic measures (e.g. to redesign water tariffs), and institutional measures (e.g. to improve access to water kiosks).

25.2.3 Module 3: Modernization of the Centralized Wastewater Treatment Plant

The City of Darkhan has been selected in 2012 as a model city for public infrastructure development in Mongolia with the intention to be duplicated in 22 of other province capitals (Scharaw and Westerhoff 2011).

Fig. 25.6 Current state of Darkhan's central wastewater treatment plant

The desolate repair status of Darkhan's central wastewater treatment plant (WWTP; see Fig. 25.6) is typical for most central WWTPs in Mongolia.

Since its commissioning in 1968, no constructional changes besides some minor works in 1978 and 1998 have been undertaken at Darkhan's WWTP (Heppeler 2012). The plant was not designed to eliminate nitrogen and phosphorous nor is there an operational disinfection. Therefore, oxygen depletion and the risk of eutrophication of the receiving waters, the River Kharaa, are likely. Darkhan's urban population is expected to double to more than 160,000 inhabitants by 2040, a fact which underlines the urgent need for action.

Due to the constructional and technological shortcomings, the construction of a new WWTP is considered the only feasible option. The decision for SBR technology was supported by several arguments: (a) the SBR brings along a high degree of flexibility, (b) it allows a compact arrangement thereby reducing the surface area and exposure to climatic conditions due to rectangular reactors, (c) the technology is less sensitive against hydraulic and organic shock loadings as compared to many alternative technologies.

In contrast to continuous-flow systems, the fill and draw principle being the basic for the SBR, removes nutrients and separates the activated sludge from the supernatant in the same reactor in a temporal arrangement. The time management allows a maximum degree of control, e.g. of the effluent quality or the treated wastewater quantity. The sequence of various treatment phases (filling, aeration, stirring) enables the elimination of carbon compounds, nitrogen and phosphorous.

To proof the functionality and to pioneer for large-scale plants in Mongolia, the pilot reactor has been loaded with Darkhan's wastewater for 2 years. The SBR

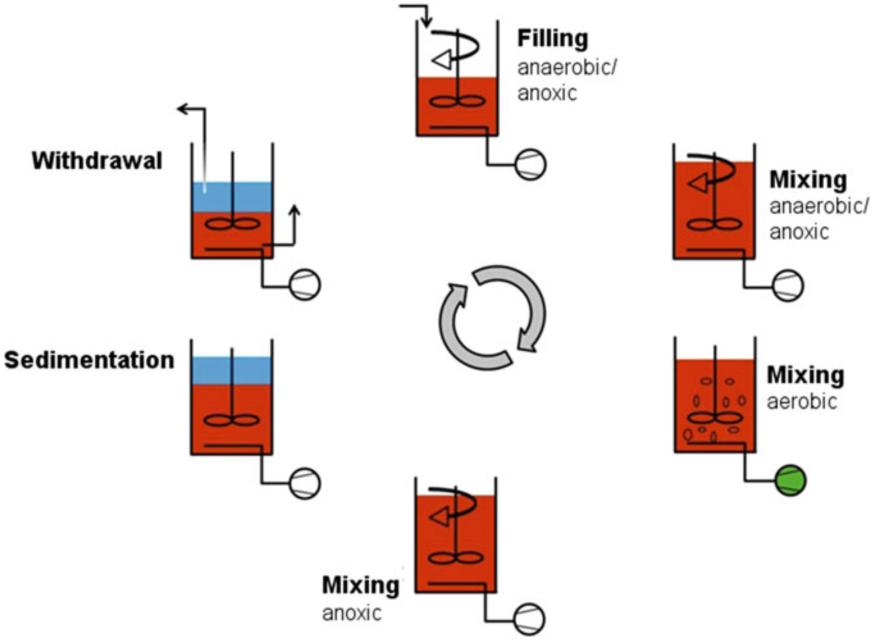

Fig. 25.7 The SBR cycle: different stages of the treatment process take place in a single tank. *Source* p2m berlin GmbH (modified)

principle (see Fig. 25.7) is a state-of-the-art technology in many countries. In Mongolia, however, the SBR principle had not been implemented and evaluated previously.

In 2011 the SBR pilot plant (see Fig. 25.8) was built at the WWTP of Darkhan. The plant then began operating and receiving the wastewater of the city.

The operation of the pilot SBR was done by p2m berlin GmbH, a German engineering consultancy in cooperation with Darkhan Us Suvag Joint Stock Company (USAG), as the local wastewater treatment operator and the Fraunhofer IOSB-AST Ilmenau. During the operation phase valuable process data was assembled via the analysis of grab samples, online sensors (pH, oxygen, suspended solids, temperature) and flow measurements. Repeatedly, the plant was visited and the process controlled. After the first winter, optimization works were implemented to exchange frost prone installations, such as the magnetic membrane valve of the aeration.

The data of the online sensors was transferred to Germany and evaluated. In doing so, the local operator could be supported effectively.

The inflow wastewater analyses during operation revealed much higher carbon and nutrient concentrations than initially reported by the local operator. This called for the extension of the treatment cycle from 3 to about 6 h. Furthermore, the adverse carbon to nutrient ratio (especially C:N, which was 6.5:1 as opposed to an optimum of about 12:1 for aerobic treatment) required the adaptation of the treatment cycle sequence. High efficiency rates have been achieved by the intermittent

Fig. 25.8 View into the reactor while aeration testing in August 2011. At the bottom membrane tube aerators, above four-bladed stirrer, aside online sensors and inflow pipes. *Photo* Martin Vocks

treatment as indicated in Fig. 25.9. In this regard the flexibility proved meaningful as all amendments could be implemented without constructional changes.

Throughout the operation phase the pilot reactor achieved considerable elimination rates. Table 25.3 summarizes the maximum values by comparing the inflow and the corresponding outflow concentrations. For the operation of a large scale SBR plant an even higher elimination rate can be anticipated for the carbon compounds while the nitrogen and phosphorous parameters should range between 80 and 90 %.

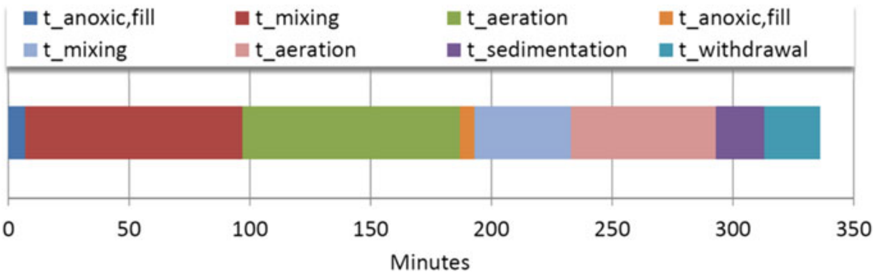

Fig. 25.9 Phase sequence of treatment cycle with a total duration of 336 min. The sequence shows an intermittent filling and treatment (Heppeler 2012)

Table 25.3 Average and maximum elimination rates achieved by the pilot SBR at Darkhan during the optimization phase between April and August 2012 based on random samples (n = 13) of the inflow and corresponding composite samples of the outflow without filtration. The composite samples were taken during t_withdrawal (n = 5)

Parameter	Average reduction of concentration (%)	Maximum reduction of concentration (%)	Reference elimination rates for 172 SBR plants in Germany (DWA 2012) (%)
COD	72	86	94…96
TN	40	73	87…92
TP	61	94	

Source Heppeler (2012)

Due to various reasons, the performance of the pilot reactor was unsatisfying in the beginning. The average elimination rates of COD, TN, and TP were below the demands of the EU Directive concerning urban wastewater treatment (91/271/EEC). Therein the demanded minimum percentage of reduction for COD is 75 %, for TN 70–80 % and for TP 80 %. A direct comparison of these demands with the observed results in Darkhan is problematic, as the data is available for several months while the reduction rates in the EU directive refer to annual mean values. The Mongolian wastewater standard for treated effluents (MNS 4943:2011) sets the following limits for effluents and elimination rates, respectively: CSB 50 mg/l; TN 15 mg/l (minimum elimination rate 80 %); TP 1.5 mg/l (minimum elimination rate 80 %). Considering the scale of the pilot reactor, however, the achieved elimination rates appear favorable and support the potential application of such technology in Darkhan and in similar settings. Due to the limited data basis, further investigations are necessary in order to come to a science-based assessment.

The learning process at the pilot SBR, in particular of the winter seasons, is considered of high value with regard to any prospective planned large-scale SBR in Mongolia. Additionally, the biennial operation provided the advantage for USAG's staff to experience the technology and the operation mode under real conditions. After the operation's termination, USAG's management expressed their continued interest in the technology. Obviously beneficial, the SBR principle was introduced in a slow and understandable way. During the entire process, the local water supply and waste water treatment operator was supported by external experts, a factor that is highly relevant for the introduction of any new technology in a developing country.

Beyond the pilot plant, the intensive cooperation of p2m berlin and USAG triggered the latter to question the treatment process and parameters of the existing WWTP, to experience latest measuring and control technology and to compare the analyzing processes of Mongolian to German chemical investigations.

National and local authorities followed the investigations at the pilot SBR and consumed the findings in order to advance the replacement of the existing WWTP. After the completion of the MoMo project, Mongolia brought the need for action forward to the Asian Development Bank (ADB) successfully. Subsequently pre-feasibility and feasibility studies for the rehabilitation of the central WWTP of Darkhan were granted, to which the results of the pilot SBR contributed.

Concluding, the pilot plant is operated under real conditions for 2 years being an important prerequisite for the construction of a new WWTP. The gained experience is very valuable for the Mongolian and German partners with regard to an integrated urban wastewater management. The findings of the pilot plant at the site of the existing central WWTP confirm the initial intention: the SBR process shows a high flexibility and taking appropriate measures, cold winter temperatures are uncritical. In this regard the SBR plant represents a feasible option for the construction of the new large-scale WWTP.

25.2.4 Module 4: Introduction of Decentralized Wastewater Treatment Systems

Mongolia currently experiences a fast urbanization that is paralleled by an exodus of people from rural areas. To counteract this trend, rural living conditions must be improved drastically. In this context, the development of adapted water infrastructure plays a central role. Currently, the situation of wastewater management in rural Mongolia is insufficient. While some existing treatment plants need to be urgently rehabilitated and modernized in the near future, there are also numerous small communities that are completely lacking wastewater treatment technologies. If solutions exist at all, this usually involves only simple wastewater collection systems without any or with insufficient biological treatment. Primary treated wastewater is often discharged into basins for infiltration or directly into rivers. The low temperatures present challenges to potential wastewater treatment technologies that rely on biological removal and conversion of wastewater pollutants. The practices of burying infrastructure at depth, insulating and heating are potential solutions to the cold climate issue; however, they come with additional construction and operation costs.

In accordance with the IWRM focus of the project, one MoMo subproject aimed at the identification of a wastewater treatment approach that is appropriate for the local context while utilizing the wastewater components for local economic and environmental benefits. In response to the objective, a willow-based wastewater treatment system was investigated as an appropriate wastewater treatment solution. Willow or tree based systems have been implemented in a variety of regions including several with cold climates. The work completed by Gregerson and Brix (2001) and Brix and Arias (2005) is of particular interest here as they describe a zero-outflow willow-based system that has been developed and implemented in Denmark and surrounding regions. The system incorporates internal winter storage of wastewater and therefore eliminates the requirement and economic cost associated with the provision of external winter storage. In addition to providing wastewater and sludge treatment willow based coppices have been investigated as an alternate fuel source in a variety of regions.

Willow-based wastewater treatment systems are an attractive option for Mongolia for the following reasons:

1. Robustness of the technology as compared to conventional biological treatment plants (in particular regarding exposure to cold temperatures and variations in loading);
2. Low need of maintenance, making the technology ideal for small communities where there is neither qualified staff nor the capital investment needed for high-tech solutions;
3. Low energy demand (no aeration or other energy-intensive components)
4. Integrated wood production, i.e. financial returns from biomass yield combined with a reduction of the carbon footprint

For investigating the feasibility of the willow-based system under Mongolian conditions, four beds in different configurations have been tested in a pilot system located on the Campus of the Mongolian University of Science and Technology (MUST) in Darkhan in the summer of 2011. Four beds of 16 m^2 were excavated to a depth of 2.20 m and covered with a PVC liner sandwiched between two geo-textile layers. A 100 mm slotted collection pipework was then placed in the beds. This was then surrounded with a 150 mm drainage layer consisting of 32–64 mm crushed river gravel. A 50 mm intermediate layer consisting of approximately 8–16 mm gravel was then placed on top before the bed was filled with 1000 mm of endemic sandy loam soil. The beds were then planted with a mixture of 1 year old endemic *Salix* and *Populus* species at a spacing of approximately 700 mm. The beds were then left to rest during the winter period. An existing sewer system was accessed to provide wastewater for the trial beds. The sewer was penetrated with a 100 mm steel pipe and the water was directed via gravity flow to a 6 KL three stage septic tank. Three submersible pumps were placed in the final stage and timers used to deliver specific loading rates for the irrigation of the beds with primary treated wastewater.

Four different experimental setups were defined in order to test the impact of loading rates and seasonal loading regimes on water balance, water quality, tree health and productivity. The experimental design is illustrated in Figs. 25.10 and 25.11.

Leachate received from the beds is drained to a collection manhole where flow volumes are measured with tipping buckets. Analysis for a variety of physico-chemical parameters was undertaken on a weekly basis for an initial period of 12 months. The parameters under analysis include chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (TN), ammonium, nitrate, nitrite, total phosphorous (TP) and E. coli. Initial data acquired from the trial system suggests that both *Salix* and *Populus* species can survive inundation with frozen wastewater to approximately 1 m over the winter period. The presence of ice does however, have an impact on tree growth for both species when compared to alternative treatment approaches. The preliminary results of the first year showed that depending on the above mentioned treatment approaches, the willow system

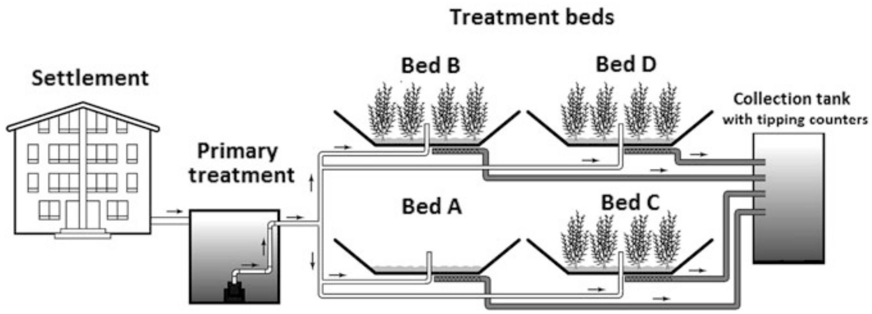

Fig. 25.10 Experimental design of the willow based pilot plant for wastewater treatment and wood production (annual irrigation period: bed A/B/C 12 months, bed D 4 summer months; daily loading rate: bed A/B 5 mm, bed C/D 15 mm)

Fig. 25.11 Construction of the willow-based treatment beds

can recycle between 15 and 47 % of the primary treated water applied to the system for tree irrigation.

The treatment efficiencies of the beds were calculated by comparing the annual pollutant loads of the applied wastewater with the loads of the collected leachates. BOD_5 and COD removal rates vary between the treatment approaches ranging

Table 25.4 Treatment costs of the WSB system

Capacity (PE)	5	10	50
1. Investment costs[a] (€)	6000.00	9000.00	30000.00
2. Operation costs			
2.1 Energy costs[b] (€/a)	20.44	28.47	84.68
2.2 Maintenance costs[c] (€/a)	23.75	27.50	63.75
2.3 Repair and wear part costs (€/a)	82.83	116.17	269.50
2.4 Sludge removal costs[d] (€/a)	9.13	14.60	73.00
2.5 Depreciation[e] (€/a)	160.00	240.00	800.00
2.6 Total costs (€/a)	316.59	455.21	1375.61
3. Inflow per day			
250 L/PE•d per person (m^3/d)	1.25	2.50	12.50
150 L/PE•d per person (m^3/d)	0.75	1.50	7.50
4. Treatment costs			
250 L/PE•d per person (€/m^3)	0.69	0.50	0.30
150 L/PE•d per person (€/m^3)	1.16	0.83	0.50

[a]Investment costs: equipment, tank, construction and installation on-site, initial operation
[b]Energy costs with 0,05 €/kWh or 95Mongolian Tugrik/kWh
[c]Maintenance costs 25 % of costs in Germany (1x/year)
[d]Sludge removal costs (10€/m^3)
[e]Depreciation of technical equipment over 7.5 years

between 79–93 and 60–87 % respectively. Removal rates of TN and TP vary between 38–77 and 42–89 % respectively.

The biomass yield of the system was estimated for the first year and varied from 11 to 24 t of organic dried matter (ODM) per ha per year, which demonstrated the potential to use biomass as energy fuels for the long and harsh winters of Mongolia. The control bed without any wastewater application yielded only close to 0 ODM/ha*a, which demonstrates one of several benefits of this system. Using willow and/or poplar as fuel for heating can help reduce the smog problems in urban areas caused by heavy usage of coal and simultaneously reduce the carbon footprint.

These results underline the potential benefits of willow based wastewater treatment systems in Mongolia. Due to the fact that the treatment performance and biomass yield of such treatment systems depend on the natural growth of the trees, these preliminary results have to be confirmed over a longer time period.

Another technical solution that was selected as pilot measure for the decentralized wastewater management in rural areas is the WSB® clean system (**W**irbel-**S**chwebebett-**B**iofilm, a special moving bed/biofilm carrier-based technology), which was developed in the 1990s by the Bergmann group in Germany. The system has been introduced in many European countries, the Middle East and Northern America during the last 10 years. In the MoMo project, the system was adapted for the typical demands of rural areas in Mongolia (see table 25.4).

WSB® clean offers the possibility of different designs for private, industrial and municipal usage and works efficiently for 4 up to 5,000 users. It is a pure biofilm technology and uses a specifically developed carrier material. Incoming wastewater passes by gravity through the pretreatment step where coarse particles settle. Preprocessed wastewater is then fed into the biological stage which contains the carrier media (see Fig. 25.12). Microorganisms settle on the media and consume the organic material in the wastewater. Oxygen is needed for the biological cleaning process. Due to the small size of the carrier material the microorganisms have a large surface area to form the biofilm that is responsible for the long-term high cleaning performance. Even at a wastewater temperature of 4 °C, which is not uncommon during Mongolian winters, the fully biological process performs reliably. The technology is also suitable for prolonged non-utilization periods, e.g. when users are on vacation, and for cases when the actually required capacity (periodically or permanently) falls below the installed capacity. In other clarification technologies, both cases can cause the collapse of the existing biology (autolysis) and thus lead to costly plant outages.

In the framework of the MoMo project, a pilot plant was constructed on the site of a kindergarden in Orkhon Sum and tested under different conditions including extremely cold temperatures during winter. The treatment plant was designed with a capacity 50 PE. The formerly existing treatment plant consisted of an old septic tank system without biological treatment. The objective of the pilot's 2 year

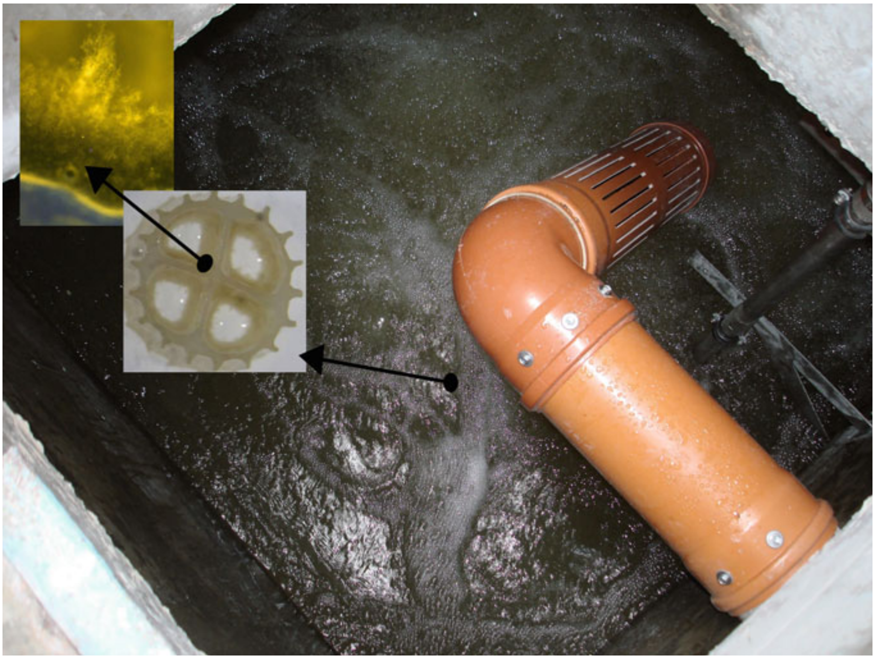

Fig. 25.12 Biological stage with plastic carrier media and biofilm. *Source* Bergmann Beton + Abwassertechnik GmbH

operation period was the adaptation of this flexible technology to the varying sewage loads under extreme climatic conditions. The treatment process was optimized for low energy consumption and minimal operating costs.

During the research period, it was found that the system works with a low-maintenance demand and a high cleaning performance. Outflow concentrations of COD under 75 mg/l and NH_4–N under 5 mg/l were achieved. Figure 25.13 shows the NH_4–N of in- and effluent concentrations and water temperatures over an 8 month-monitoring period in 2012/13.

The treatment costs for the smallest plant, a 5 PE plant for a single house and the costs for a 10 PE and a 50 PE plant for small group solutions are shown in Table 25.4.

The costs are estimates based on both the pilot operation in Mongolia and experience with WSB® plants in Germany. For the pilot plant in Orkhon Sum, treatment costs from 0.3 to 0.5 €/m^3 could be determined.

Following the pilot operation, the plant continues to treat the waste water of Orkhon Sum's kindergarten where the existing old plant caused operational problems and even posed safety risks. The plant is now being operated by the employees of the community who had been trained during the MoMo project.

Several advantages of the system are particularly relevant in the Mongolian context (see Table 25.5).

The results of the trial operation will in the future be transferred to the basic design of a standardized series for single houses and group solution from 5 to 5,000 PE. The technology has already been standardized by the Mongolian Ministry of Construction and Urban Development (MCUD), thus allowing its duplication in rural regions of Mongolia.

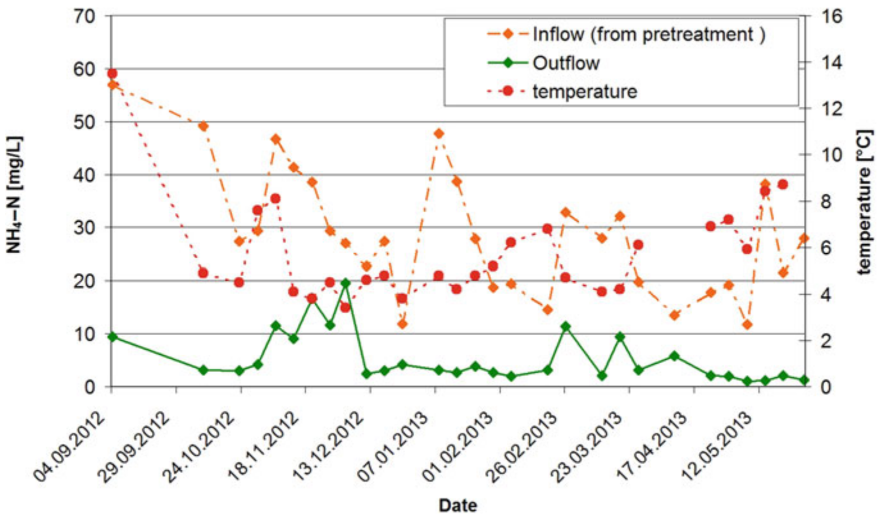

Fig. 25.13 NH_4–N in- and effluent concentrations and water temperature during winter operation of the WSB pilot WWTP. *Source* Bergmann Beton + Abwassertechnik GmbH

Table 25.5 Advantages of the WSB system in the Mongolian context

General advantage	Relevance in Mongolia
• free-flow-system capable of handling low flows and shock loadings (no backflow, no emergency overflow)	• highly variable wastewater loads and environmental conditions (changing groundwater tables, freezing of soil)
• less electrical, mechanical or moving parts in the tank	• little need for maintenance, therefore ideal for underground construction
• self-cleaning bio media (20 years in operation)	• little need for maintenance, therefore ideal for underground construction
• biofilm process works on temperatures from 4 to 30 °C	• wastewater temperatures in Mongolia are within this range

The willow-based approach and the small WWTP using WSB® technology are solutions for decentral wastewater treatment in different contexts: while the latter requires little space (making it ideal for realization in built up areas and frost-protected construction), the former has the added benefit of producing wood as a renewable resource.

25.2.5 Module 5: The Integrated Personal Innovative Toilet (iPiT) as a Component of an Integrated Sanitation Concept for Ger Areas

Another pilot solution that was developed and implemented within the MoMo project is an integrated sanitation concept which aims at improvements in hygiene and comfortable access to sanitation in the peripheral ger areas. The system is designed in a way that enables the separate collection of the different material flows (urine, faeces, organic waste, solid waste and greywater) of households in ger areas and is adapted to local environmental and socio-economic conditions (Londong et al. 2014).

The technological key components of the integrated sanitation system are (i) a urine diversion dry toilet (iPiT®), (ii) a transport system for urine, faeces and organic waste in ger areas and (iii) a biogas plant for the digestion of faecal matter and sewage sludge located in close proximity to a new WWTP based on the SBR principle (Schuster 2012; Stäudel et al. 2012).

Because it directly involves the population as end users, the sanitation system itself has been developed in an iterative way and with community participation. In order to ensure an effective stakeholder involvement a so-called demand-responsive, participatory planning approach has been chosen for the Darkhan case, which is called *community-led urban environmental sanitation* (CLUES). According to CLUES, the residents and the local administration had a crucial role and their ideas and needs should be included in the design of the system, right from the start of the project (Lüthi et al. 2011). In several practical workshops the experts and residents had the possibility to address their most important problems. Cultural habits, climate

Fig. 25.14 The iPiT and collection and transport by a local service provider (*Photo* Jürgen Städel)

and further socio-economic conditions influenced the development of the overall system. For instance, it has been the residents themselves, who decided on the type of toilet, which they thought was the most appropriate for their needs and circumstances (Sigel et al. 2014). As a result of this process 12 toilets (iPiT®) have been constructed at different households (see Fig. 25.14) and were tested from 2011 to 2013 in a first pilot phase (Londong et al. 2014).

In contrast to conventional wastewater systems, the domestic material-flows (such as urine, faeces, organic waste) are *not* considered as liquid or solid waste, but as a resource, which can be reused in a value-added way. This will contribute to the financial affordability of the system: Examples are (a) the sale of quality fertiliser derived from urine and composted sludge from the treatment processes and (b) the reduction of external energy for the wastewater treatment processes by utilisation of biogas which is produced in the biogas digester and further sale of excess energy. In the case of Darkhan with its extreme climatic conditions, calculations done by Bruski show that external thermal energy supply for the anaerobic treatment steps could completely be replaced by the energy produced in the biogas plant. The calculations are based on operational experiences with the pilot plant. Depending on the process steering, the co-fermenting of sewage sludge and feces shows a positive thermal balance with 15.000 PE connected for the continuous operation and 30.000 PE connected for the discontinuous operation (e.g. only summer months) respectively (Bruski 2015).

Mongolia's agricultural sector increasingly has to deal with a depletion of soil nutrients, organic matter and topsoil. Due to expensive fertilizer, increasingly large areas have to be cultivated in order to maintain the yield (Rost et al. 2015). In the reach of Darkhan the cultivated agricultural area covers currently about 60.000 ha. Therefore there is a large potential value that can be derived from the application of fertilizer, which is produced from human waste (Hofmann et al. 2015; Hofmann et al., Chap. 19).

A collection and transport system has been established to ensure the reliable operation of the system. In an up-scaled future project private or communal companies (as a local service provider) could be in charge of (i) the maintenance of the iPiT, (ii) the operation of the treatment facilities and (iii) the marketing and sale of organic fertilizer.

In this way it is possible to keep the sanitation costs in ger areas low and avoid barriers for the financial weak users. Waste, drinking water and wastewater fees have to be calculated on basis of the integrated system including the revenues. The costs for transport, maintenance and general operation of the system shall be included in the regular fee system.

A survey in one of Darkhan's administrative districts that is almost exclusively covered by gers (Bag 7) showed that the residents would be willing to contribute between 2 and 4€ per month for this service. According to Badran et al. (2010), poor families in Egypt could contribute around 2–5 % of their annual income to water and sanitation infrastructure. With regard to the average income of families in ger areas in Darkhan this would raise the theoretical monthly expenses to more than 6€ (including drinking water). Different alternative financing models have been examined for these ger areas. However, the selection of a future applied model is mainly based on political decisions (Gutjahr 2013).

The monitoring program of the pilot project throughout the period of 2 years revealed that the acceptance level of the iPiT and the integrated system itself is remarkably high among the involved population and stakeholders. It offers an affordable and quick solution for the challenging sanitation problems in ger areas. The system is flexible and adaptable to the rapid urban development (positive and negative growth) and climatic alterations (Stäudel et al. 2012). Interestingly, the environmental benefits of this system were also appealing to the local population and contributed to the high public interest and the high level of acceptance among the residents, who took part in the pilot project. However, intensive capacity development measures for the local stakeholders are needed in the future to ensure the self-contained continuation of the new sanitation system (Londong et al. 2014).

In order to examine the economic efficiency of the iPiT® sanitation system in Bag 7 (Darkhan), a dynamic cost comparison has been undertaken using an international standardized method. Different sanitation concepts and depreciation times up to 40 years have been evaluated, whereby the collection and transport of domestic solid waste has been included additionally in all the examined sanitation concepts. All investment costs, costs for planning, collection, transport, salary of staff, ad-ministration, capacity development, re-investments, inflation, maintenance etc. were considered. The results showed that the iPiT® sanitation system is most cost-effective among all the considered sanitation concepts and over different depreciation periods (Schuster 2012).

In a further step, a preliminary planning for a conventional sewage system for Bag 7 was undertaken (see Fig. 25.15). Following a survey of requirements, several construction companies in Mongolia were asked to provide bids in a tender process. However, the companies were informed that the tender process would not lead to an assignment in order to avoid price dumping. The information gained was used to come to a realistic estimate of construction costs.

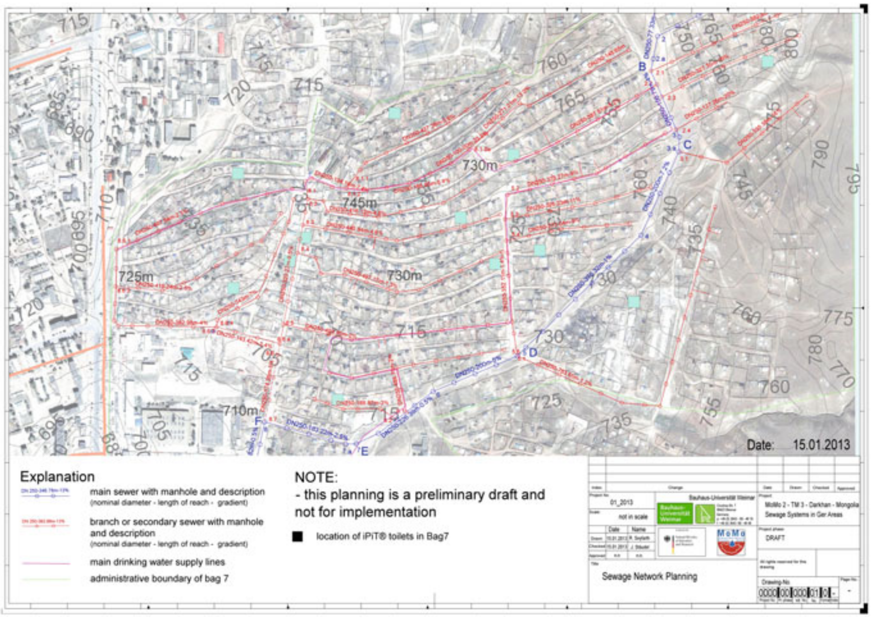

Fig. 25.15 Preliminary sewage network in Bag 7, Darkhan. (*Source* Bauhaus-Universität Weimar)

The evaluation of the tender documents showed that the investment costs alone for a conventional sewage system for Bag 7 would be at least 10 times higher than the investment costs for the iPiT sanitation system developed in the MoMo project. With the help of the dynamic cost comparison model it became apparent that the overall costs for the iPiT sanitation system for bag 7 including its complete operation over 40 years are lower than the investment costs of a conventional sewage system alone.

According to the municipality of Darkhan ger areas are expected to persist at least another 20–30 years before they might be replaced by modern urban structures. The housing density in ger areas is very low in Darkhan and sewage pipelines have to be laid in a depth of 4–5 m in order to be frost-protected. Furthermore, each house or ger would need a separate heated toilet room, which most of the people could not afford to build. Therefore, with regard to the results of the economic research of different sanitation systems, it has to be stated that all pipeline-bound sewage systems are highly uneconomical, irrespective if the concepts are centralised or decentralised (Schuster 2012; Braun 2014; Londong et al. 2014).

25.3 Conclusions

In Mongolia and neighboring parts of Central Asia, an extremely continental climate leads to very harsh winters and limited water availability. The key challenges for municipal water management include very heterogenous settlement structures, an increasing sectoral competition over water resources, a frequently poor state of water infrastructures and a lack of qualified staff. This situation necessitates robust and adaptive solutions which address the local conditions and at the same time are coherent parts of a catchment-based integrated management concept. The core aspects are vast disparities between urban centers, peri-urban areas and very sparsely settled rural regions. Therefore, there cannot be any universal solution. Both drinking water supply and wastewater management need to take into account the contrasts between central and decentral settlement structures and their specific characteristics with regard to existing infrastructures, socioeconomic and demographic development, including differences in the attitudes of the local population and relevant stakeholders.

Against this background, the IWRM MoMo project developed a modular concept for municipal water management. While the concept is integrative in the sense that it considers all technical and non-technical measures in the context of a sustainable water resources management at river basin scale, it is modular in the sense that it is made up of different components which on their own have a duplication potential for comparable settings. Both in the contexts of drinking water supply and wastewater management, there are different challenges and thus solutions for central and decentral settings.

For urban centers, high leakage losses in a distribution system which is laid deep below the surface require intelligent detection methods such as model-based approaches which need only a minimum number of sensors. Since the urban population tends to grow, outdated or dysfunctional wastewater treatment systems need to be replaced in order to ensure drinking water safety downstream and to protect aquatic ecosystems. Both the dynamic population development and extremely cold winter temperatures mean that the easily scalable and compact SBR technology is a promising approach when it is adapted to local conditions.

For more peripheral urban and rural areas, the drinking water supply depends on a combination of pipe- or well-fed water kiosks, private wells and the utilization of surface water sources. While water kiosks tend to be relatively expensive, leading to affordability problems and under-consumption, shallow wells and surface water sources are prone to contamination by livestock and domestic wastewater. A key issue for the protection of these water sources lies in improved sanitation and wastewater handling and represents a necessary precaution against the outbreak of water-associated borne or related diseases. The dry separation toilet system iPiT is one concept that does not only improve sanitation, but that can be ideally integrated into recycling concepts, which include biogas production through fermentation and nutrient reuse. Other feasible options consist of robust and energy-effective small wastewater treatment plants, such as those using the WSB® clean moving bed/biofilm carrier-based technology, and so-called constructed wetlands. In the latter case, wastewater treatment is combined with the production of wood, which is in high demand. Therefore, such systems have the added advantage of reducing the pressures on the woody floodplain vegetation, which is already heavily degraded.

While each component of the modular concept has specific advantages and a duplication potential on its own, their intelligent combination and consideration in the holistic perspective of an integrated water resources management will lead to the greatest environmental and socioeconomic benefits in a given regional context.

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Chapter 26
From the Concept to the Tap—Integrated Water Resources Management in Northern Namibia

Stefan Liehr, Marian Brenda, Peter Cornel, Jutta Deffner, Jörg Felmeden, Alexander Jokisch, Thomas Kluge, Katharina Müller, Julia Röhrig, Vanessa Stibitz and Wilhelm Urban

Abstract Namibia is the most arid country in Sub-Saharan Africa. The Cuvelai-Etosha Basin (CEB) in central northern Namibia in particular is experiencing various ecological and social-ecological challenges such as high climate variability, saline groundwater, dependence on Angola for freshwater supply, high population growth and density, and increasing urbanisation. These challenges make water supply and management difficult and threaten the livelihood of the local population and the health of the ecosystem. Facing up to these challenges, the German-Namibian research project CuveWaters has developed, adapted and set up different technologies as pilot plants. The Integrated Water Resources Management (IWRM) concept of CuveWaters is based on a multi-resource-mix in which water is obtained from different sources (rainwater, floodwater, groundwater and wastewater) and used for various purposes. High quality water is used as drinking water; water of a relatively low quality is used for irrigation. In cooperation with the residents of four villages and one small town, the project partners are implementing different technologies to collect and store, produce, treat and reuse water. The implemented technologies are rain- and floodwater harvesting, groundwater desalination, and the combination of sanitation, wastewater treatment and water reuse. The aim is to improve peoples' livelihood through research on innovative and adapted solutions which contribute to a successful and adapted application of IWRM. To this end, the project integrates science, technology and societal aspects in a transdisciplinary research approach by linking scientific knowledge from natural, engineering and social sciences with the everyday practices and know-how of the stakeholders involved. Thus, the technical aspects are complemented by a wide

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range of societal and scientific components, such as capacity development, monitoring, participation or knowledge management. These ensure societal embedding of the technologies and knowledge transfer. This paper will illustrate the transdisciplinary approach, implemented technologies and accompanying measures as well as key results.

Keywords Multi-resource-mix · Rainwater and floodwater harvesting · Solar-coupled groundwater desalination · Sanitation and water reuse · Transdisciplinarity

26.1 Introduction

Namibia is the most arid country in Southern Africa, so water and fertile soil are scarce resources (Heyns 2005; Mendelsohn et al. 2013). The water supply is highly dependent on water from Angola, particularly in the Cuvelai-Etosha Basin (CEB), the southern and downstream part of the transboundary Cuvelai Basin (ibid.). Hydrologically, the region is characterized by the flow regime of the ephemeral Cuvelai River, which flows through the project area from north to south into the Etosha salt pan in a multitude of shallow ephemeral streams locally known as 'oshanas' (Bittner and Plöthner 2001). In the basin, pronounced rainy and dry seasons determine the pattern of life, but rainfall is highly variable (Mendelsohn et al. 2013). This circumstance, combined with contrasting extremes such as floods and droughts, threaten the populations food supply and income (ibid.). Thus, water-related problems are closely linked to land use, agricultural production, demography and economy. Additional challenges for water management arise from the impacts of climate change, increasing urbanisation, lack of sanitation, and groundwater which often has a very high salinity (Kluge et al. 2008; Liehr 2008).

The CEB in central northern Namibia can be taken as an example for many semi-arid regions which face similar manifold and complex problems. The fact that nearly half of the Namibian population lives in the CEB (NSA 2013) makes implementing integrated management approaches, which ensure that the basic needs for safeguarding people's livelihood are met, a demanding but simultaneously vital task. Access to clean water and to sanitation are crucial for social welfare, health, economic development, and nature conservation. The United Nations have acknowledged the importance of these aspects within the framework of the Millennium Development Goals (MDGs) and since 2015 in the Sustainable Development Goals (SDGs). Also the Namibian government is addressing these problems and challenges in their strategic documents (GRN 2004b; MAWRD 2000; NPC 2013). Nevertheless, the rates of progress in the respective indicators 'safe drinking water' and 'basic sanitation' have been recently assessed to have slowed down in Namibia (AUC et al. 2013) and staying on track still remains a critical issue. Within the paradigm of Integrated Water Resources Management

(IWRM), Namibia fosters the sustainable and efficient management of water and land resources in order to safeguard people's livelihood and ecosystem integrity (MAWRD 2000). Integrated concepts and solutions are necessary to achieve these goals, while taking socio-economic and cultural dimensions in particular into account.

The development of the concept of Integrated Water Management goes back to the mid-20th century before it was taken up in the Dublin Principles and the Rio Conference 1992 and resulted in the definition of Integrated Water Resources Management (IWRM) by the Global Water Partnership (GWP 2000). Being a subject in numerous international debates, it has been considered and assessed from varying perspectives. On the one hand, it is discussed as a very vague and—in contrast to its new-found popularity—little innovative concept, of which the transfer into practice seems hardly possible due to its indeterminacy (Biswas 2008). With the designation 'Nirvana concept' an idealized vision is addressed which masks the political nature of resource management and allows to conceal political agendas (Molle 2008). On the other hand, emphasis is given to the advantage of universality of the IWRM-concept, since it leaves room to contextual configuration, integration and adaptation by stating the basic principles and ideas. In view of the foregoing, success or failure cannot be attributed to IWRM as programmatic framework, but primarily to the specific conditions of implementation and constraints. IWRM is also discussed in connection with the concept of ecosystem services against the background of a similar criticism on both. It is argued that both concepts should not address their weaknesses but built upon their strength in order to be tools which help to traverse the implementation gap (Cook and Spray 2012).

In Namibia, quite promising conditions for a targeted implementation are given, because, as already mentioned, there is a coherent strategic framework and an ongoing implementation process. A roadmap has already been accomplished to bring the IWRM Strategy and Action Plan for Namibia into practice (MAWF 2010). Legislation and investment build the basis to promote capacity building and stakeholder involvement and thus ensuring resource management for future resource security.

The CuveWaters project has been contributing to these goals in central northern Namibia since 2006 after successfully finalizing a preparatory phase in 2004/2005. Being within the last of its three main project phases (1st: initial phase, 2nd: pilot phase, 3rd: diffusion phase) CuveWaters will be finalised in 2015. The international joint research project is being led by the Institute for Social-Ecological Research (ISOE) in cooperation with the Technical University Darmstadt in Germany and German industry partners, the Namibian Ministry of Agriculture, Water and Forestry (MAWF), the Outapi Town Council (OTC), the Desert Research Foundation of Namibia (DRFN), the Polytechnic of Namibia (PoN), the University of Namibia (UNAM), the German Federal Institute for Geosciences and Natural Resources (BGR), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Africa AHEAD, Development Aid People for People (DAPP) and One World Consultants. The project is being funded by the German Federal Ministry of Education and Research (BMBF) under the Framework Programme Research for

Sustainable Development (FONA). The project develops and implements solutions for IWRM in a form tailored to the Cuvelai-Etosha Basin. Its central goal is to strengthen the potential of the region's resources by developing, adapting and implementing innovative technologies for water supply and sanitation as pilot plants (see Fig. 26.1).

The implemented technologies comprise pilot plants for rain- and floodwater harvesting, groundwater desalination, as well as a combination of sanitation, wastewater treatment and water reuse. Depending on its quality, the water is used as drinking water or to irrigate vegetable gardens. Technologically sophisticated concepts can, however, easily clash with users' socio-cultural needs and everyday behaviour. So from the very beginning, the project applied a transdisciplinary approach based on research centred on the described challenges and on integrating science, technology and society (Kluge et al. 2010). This approach is reflected in the project's structure: scientific and technological components as well as empirical studies are closely interlocked with integrative societal components. For instance, the project has been cooperating closely with the population and institutions on a local, regional and national level. This started with the selection of the technological concepts and design, continued with planning and implementation, and finalises with handing-over and scaling-up activities. However, in the long run, technological innovations alone are not sufficient to significantly alter the sustainability of

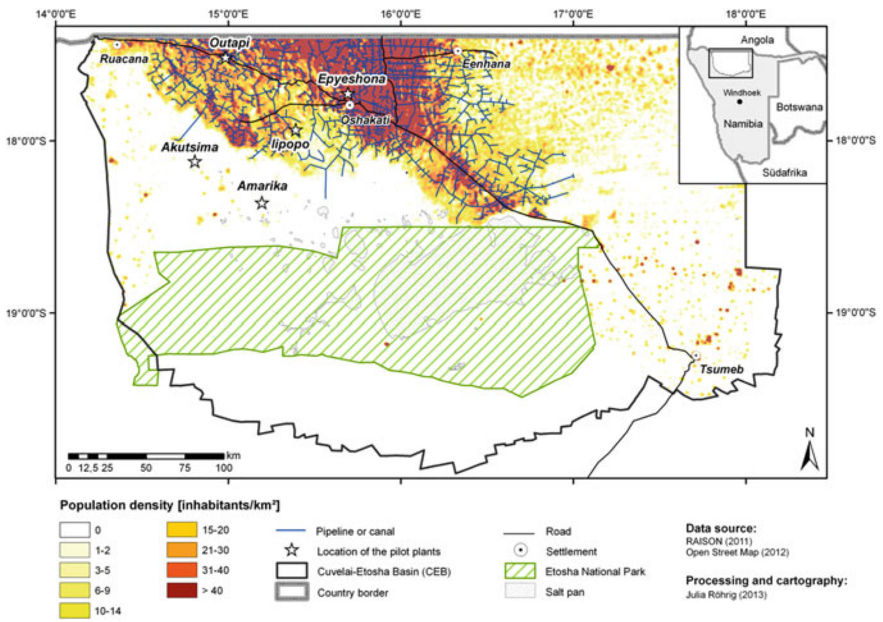

Fig. 26.1 The Cuvelai-Etosha Basin (CEB) and the location of the pilot plants. In addition, the population density and water supply network is shown

natural resources management. For this reason, the technological components are supplemented by various flanking activities such as participation, governance, and knowledge transfer.

In the subsequent parts of this chapter, the description of the social-ecological challenges in central northern Namibia (Sect. 26.2) outlines the rationale for the transdisciplinary approach chosen for this research and development project (Sect. 26.3). Then the project's achievements are presented, with an overview of the results with regard to research and practice (Sect. 26.4). This includes subsections on the various different technologies of the multi-resource-mix, as well as contributions on policy and cross-sectional issues. Finally, the chapter concludes with the conditions necessary to transfer the technological solutions to other sites in Namibia and beyond (Sect. 26.5).

26.2 Social-Ecological Challenges

The Cuvelai-Etosha Basin as the project region of CuveWaters is faced with various highly dynamic developments in several fields: resource constraints and climate conditions, demographics and the social situation, and finally the economy are subject to constant change. The different developments are closely interwoven and integrated responses to the associated challenges are therefore essential.

Resource constraints and climate conditions strongly affect the population of central northern Namibia (Mendelsohn et al. 2013). The region's society and ecosystem are particularly vulnerable to impacts from changing climate conditions and the consequences of an intense use of natural resources (Zeidler et al. 2010). Seasonal alternations of droughts and heavy rainfall, mostly saline groundwater and a lack of permanent rivers aggravate the risks to the livelihood of the local population (Bittner and Plöthner 2001; Zeidler et al. 2010). Even during the rainy season, dry spells occur regularly and carry the risk of crop failure even during this favourable period of the year. Potential evaporation rates exceed annual rainfall by about factor four to six (Mendelsohn et al. 2013) and extreme weather events are likely to compound the strained situation of local and regional water availability. Climate change is expected to intensify these threats. According to the Fifth Assessment Report of IPCC (2014), observed warming trends in this region are projected to hold on above the global trend and with regard to precipitation, GCM projections show a drying signal in the annual mean over the climatologically dry southwest, extending northeastward from the desert areas in Namibia and Botswana.

Demographic and social developments play an important role for resource demands in the region. According to the main census report of the year 2011, about 850,000 people, who resemble 40 % of Namibia's population, live in this part of the country and 83 % of this group live in rural areas (NSA 2013). The census shows a considerable annual population growth in the region of about 1.5 %[1] since 1991 and a constant migration towards rapidly growing urban areas (urbanisation increases from 9 % in 2001 to 17 % in 2011). Both factors increase the demand for water. This is supported by studies showing that the higher reliability and better access to water services in urbanised areas implicate a higher per-capita demand for water (Jacobsen et al. 2012). Furthermore, the country's second largest share of jobs is held from non-paid subsistence farmers (NSA 2013). Thus the livelihood of the Namibian population depends strongly on subsistence agriculture, practised on non-freehold or communal land. Livestock and crop farming is strongly influenced by low and highly variable annual rainfall and is a major consumer of water. However, studies show that the population and livestock density already exceed the present rangeland carrying capacity (Mendelsohn et al. 2002) and the Namibian Government recognizes degradation due to deforestation, overgrazing, overstocking, high population pressure, unsustainable farming practices and clearing for crop farming as a major threat for development (Nangolo et al. 2006). In consequence, local communities observe sinking groundwater tables (Zimmermann 2013) which makes it more difficult to maintain rural livelihood with the traditional way of farming. Households without access to the water supply network are threatened by increasingly insecure water sources like hand-dug wells which deplete due to lower water availability or deteriorate due to pollution by floods and the conflicting use by humans and livestock (Bittner and Plöthner 2001).

An analysis of data on household distribution and water resources (pipeline, boreholes and oshanas) shows that the majority of the population living in remote areas is not connected to the water pipeline distributing water from the neighbouring Kunene catchment (Hähnel 2009, see also Fig. 26.2). They only have access to water from traditional boreholes and hand-dug wells with low-quality and mostly saline groundwater. This situation bears the risk for a poor health status of the affected population. A similar situation holds true for the widespread problem of open defecation. Inadequate sanitation, wastewater treatment and disposal infrastructures have shown considerable effects on people's health. Improvement in water, sanitation and hygiene (WASH) are proven to lead to positive effects on physical and mental health, in particular for children's development (Strunz et al. 2014), but also on economic development (Sanctuary et al. 2005). Additionally, without a proper sanitation, treatment and reuse system, valuable resources are wasted, since water, nutrients and energy are not recycled. Water infrastructure is therefore a pressing issue.

The economic development is characterised by a vivid exchange with Angola. With trade and commerce, industry and services like tourism, the secondary and tertiary economic sectors exhibit considerable dynamics. This enforces the urbanisation process and also generates new patterns of water demand due to these economic activities (Liehr 2008).

[1]Exponential rate of growth.

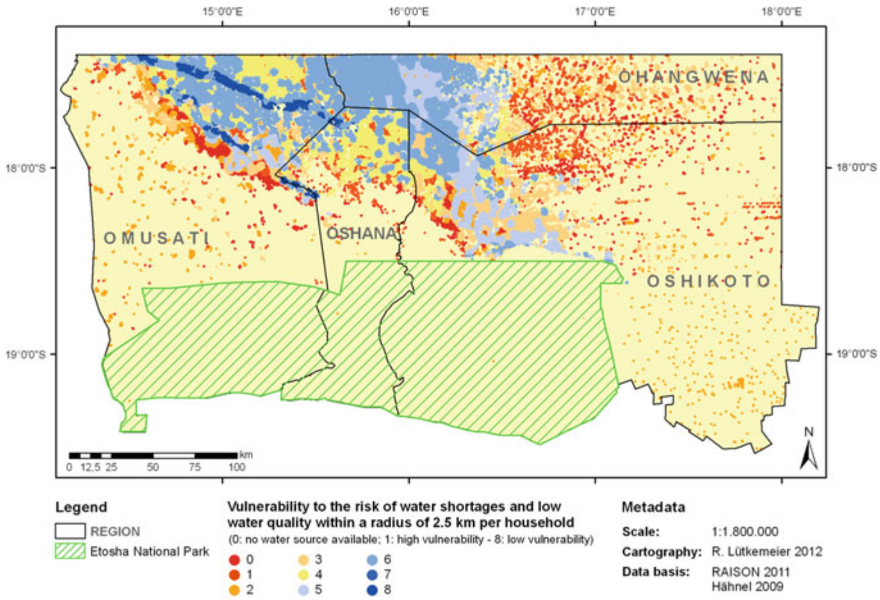

Fig. 26.2 Vulnerability analysis of households on the basis of access and quality of locally available water sources. The *colours* indicate the degree of vulnerability to water shortages and poor water quality. It is assumed that the different natural resources are substantially more prone to the risk of shortage (running dry) or quality deterioration than the pipeline network (Hähnel 2009)

Effective measures within the framework of IWRM are therefore of great importance for both the urban and rural populations in central northern Namibia.

26.3 Project Approach

The main goal of CuveWaters is to address these challenges and to improve the living conditions of people in the project region and beyond, taking ecological, social, economic and institutional aspects into account. The project provides solutions for adapting and implementing innovative water supply and sanitation technologies under different local conditions.

The project is based on the principles of Integrated Water Resources Management (IWRM), thus internalising the idea that water is a fundamental resource for life and making holistic management as well as the integration of land and water use indispensable (GWP 2000). Water in this sense is to be understood as a cross-cutting issue that is closely linked to other natural resources like land, energy or biodiversity and consequently interrelates with various policy fields and their corresponding stakeholders (GWP and INBO 2009; Kluge et al. 2008/2010; UNEP 2009).

The central idea behind the project is the identification and targeted utilisation of a variety of endogenous water resources for different purposes. Based on this idea, a multi-resource-mix (MRM) was established that enhances the use of water of different quality levels according to specific purposes (see Fig. 26.3). In other words, water from a certain technology is used either as drinking or irrigation water depending on its respective quality. This is done to ensure the efficient utilisation of water resources. The use of endogenous water resources in particular is promoted, in order to endorse the use of local water sources above and beyond the piped water supply. The term ‘endogenous’ emphasises those water resources which are available naturally within the region, as opposed to water distributed via the pipeline network. The latter system is part of an interbasin water transfer scheme that collects water from the Kunene River and is therefore ‘exogenous’ with respect to the Cuvelai-Etosha Basin. Consequently, the approach of combining different technologies addresses the social-ecological challenges with specific and adapted solutions under one roof.

Together with Namibian stakeholders, three technologies were identified during the project’s preparatory feasibility phase of agreeing upon a joint viewpoint about the problem and identifying potential solutions: rain- and floodwater harvesting, groundwater desalination, and wastewater treatment and water reuse.

Rain- and floodwater harvesting (RFWH) systems buffer precipitation and surface run-off during the rainy season with different technical solution. The underlying intention is to increase water productivity and introduce gardening as a culturally neglected or even unknown activity. Harvesting and storing water thus mitigates the risk of dry spells during the rainy season and allows almost continuous

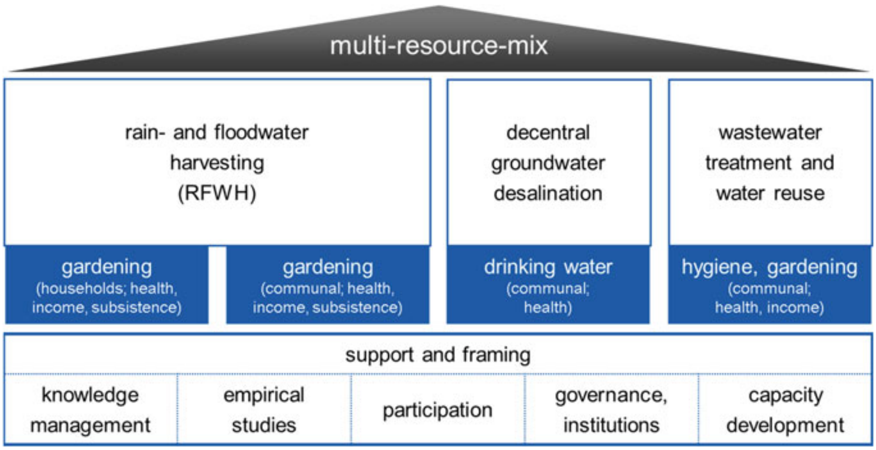

Fig. 26.3 The ‘multi-resource-mix’ as the overarching project approach with three types of technology options, their application purposes and flanking activities for support and framing

vegetable crop production during the dry season. The technology is innovative for the region although it's quite simple, as it introduces new and highly demanded options of productive water use.

Groundwater desalination provides clean and healthy drinking water for the inhabitants who formerly only depended on low-quality water from hand-dug wells. Research on feasible technological options and their implementation has been of high interest for Namibian governmental stakeholders. The project's technological concepts for desalination are characterized by its small-scale dimension, low maintenance requirements, its chemical-free and highly salt-tolerant implementation and its linkage to the solar energy supply system.

The wastewater treatment and water reuse concept includes sanitation facilities, a vacuum sewer system, a wastewater treatment plant and irrigated agricultural areas. The closed vacuum sewer system helps to overcome the health threats posed by inundation of evaporation ponds, pit latrines, gravity sewers and open defecation during rainy season. Additionally, the vacuum system exhibits advantages compared to gravitational systems particularly due to the region's flat topography (lower excavation costs through shallower trenching, smaller diameter pipes, and no manholes need, see e.g. Little 2004). The reuse of water, nutrients and energy is enabled by an aerobic-anaerobic treatment process including a microsieve for helminth eggs removal and UV-disinfection. Even if the different components are well-known, their combined implementation in a systemic kind of way and the integration within a strongly participative approach, show new insights on how such systems can be adapted and implemented in the development context.

Rain- and floodwater harvesting as well as the collection, treatment and reuse of wastewater increase water use efficiency. This becomes clear when looking at the newly introduced water productivity in comparison to the former non-usage of rain, flood and wastewater with unproductive evaporation. Further, by implementing these technologies, the project aims at the improvement of the health and food security situation as well as poverty alleviation by stimulating the regional economy (Kluge et al. 2008; Lux and Janowicz 2009; Röhrig and Werner 2011). The productive use of water in gardening but also the development of competences on construction, operation and maintenance of the technologies itself generate new job opportunities and new sources of income.

Research which aims at achieving a sustainable implementation of this idea needs a linkage of different scientific domains as well as practice, which has to be realised on a methodological sound basis (Keil et al. 2007). From the beginning, CuveWaters followed a transdisciplinary research approach based on the integration of science, technology and society. The transdisciplinary approach reverberates in the project's design and structure: scientific components like empirical studies and technical developments are closely interconnected with integrative societal components by involving all relevant stakeholders in the research, planning and implementation process. The stakeholder groups are specific to each technology and in general comprise users and technicians, economic operators like service providers and farmer cooperatives, as well as representatives and decision-makers from local, regional and national institutions.

To safeguard a strong involvement of these stakeholders, the project team is committed to a community-based and participatory approach (Deffner et al. 2012; Deffner and Mazambani 2010). The communities addressed by the project have been seen not only as informants of how to gather empirical data, but as actors in an implementation process. Their knowledge has the role of everyday experts. The interdisciplinary team of German and Namibian research partners developed the ‘demand-responsive approach’ in order to include the local knowledge meeting local demands and also to generate an understanding of the living conditions of the stakeholders (see Fig. 26.4). The debate on participatory planning methods shows that these methods sometimes lack efficiency and quality criteria (Brown et al. 2002). Therefore, social science methods were combined with community-based planning instruments. This approach takes into account that technologies only unfold their potential for sustainable development and establish themselves on the market when they are accepted by their users, are practicable for everyday use and are ecologically, politically and financially viable. As an outcome, a broad range of knowledge on the system, normative orientations and practical know-how is generated through this integrative approach (Deffner et al. 2008; Jahn et al. 2012). By developing and applying this demand-responsive approach, results can be achieved that are not only important for a sustainable implementation but which also make a fruitful contribution to the academic and societal discourse.

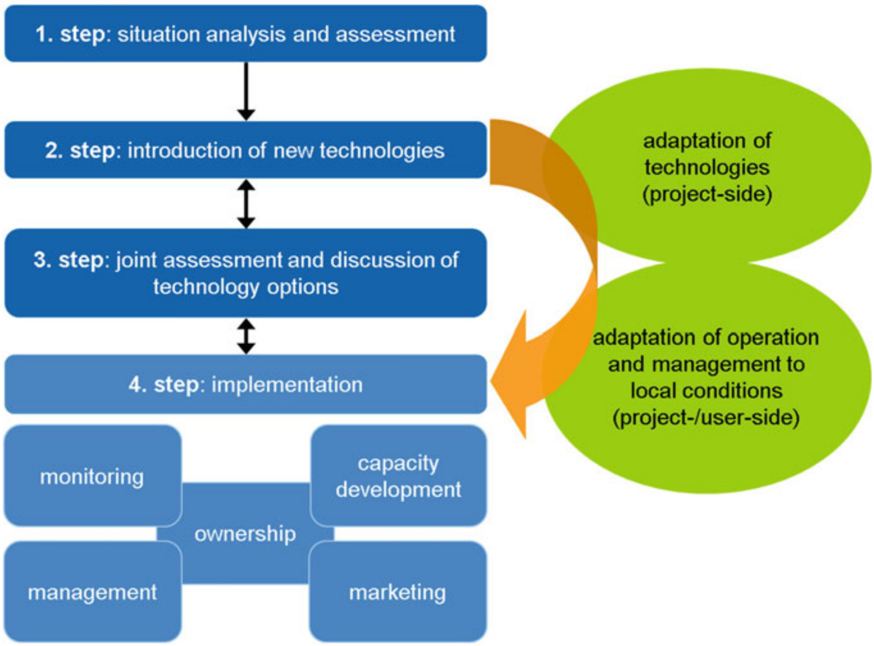

Fig. 26.4 Methodological scheme of the ‘demand-responsive approach’ for demand-oriented participation (own figure Deffner and Mazambani 2010 adapted in Deffner et al. 2012)

The implementation of the project is divided into three phases: after a preparatory feasibility study including problem definition and general concept development done in 2004/2005, the initial phase started in 2006. At the end of this phase, in 2009, the concrete concepts of adapted technological solutions and the identification of suitable pilot sites were completed. The subsequent pilot phase had the goal of implementing the respective pilot plants and accompanying monitoring activities, and included preliminary evaluation and assessment of their impact. The final diffusion phase began in 2013 and aims at officially handing-over the technologies and empowering the Namibian partners to operate the plants autonomously in the future. Furthermore, the dissemination and replication of the results will be initiated. During this final phase, the functional character of the plants will change from 'pilot' to 'demonstration'. They will thus serve as a location for training on a local level, for scientific education of young researchers and as a showpiece for decision-makers and potential users.

As shown in Fig. 26.4, the technology-oriented project activities are flanked by supporting activities in knowledge management, empirical studies, participation, governance and institutional development as well as capacity development. Knowledge management comprises the development of a Digital Multimedia Atlas and Toolkits on RFWH and IWRM in general. These instruments document the project knowledge and aim to support planning and decision-making processes. This is complemented by impact assessments looking on effects on ecology, hydrogeological cycle, land use, and regional economy. Empirical studies started from the beginning with situation assessments and continued after implementation with technical, environmental and social monitoring. This allowed the generation of site-related data, supported optimisation and adaptation processes. Data and information from monitoring also build the ground for conclusions regarding future scaling-up activities in the project region and beyond because they give valuable evidence on experiences with technical, socio-economic, political/institutional, hydrological and ecological issues. Participation has taken place throughout the whole process for embedding the technologies into respective social and institutional settings, for creating ownership and preparing the handing-over to Namibian stakeholders. In particular the latter has required adapted forms of regulatory structures but also financial means and staff which have been addressed by developments in governance and institutionalisation. The conceptualisation and implementation of trainings and vocational education programmes, the provision of academic teaching materials and supervision of examination works accompany the technological innovations.

The main research question that guided the activities of CuveWaters was how the technologies can be embedded in and adapted to the social-ecological context to exploit their whole beneficial potential and thus foster their scaling-up. The processes mentioned above form the basis for adapted problem-solving, since they promote social embedding of the technologies and active involvement of the institutional stakeholders and the local population. This aims to make use of the mentioned endogenous water resources and associated ecosystem services through innovative technology-based options, thus complementing the current infrastructure and management strategies. CuveWaters' approach takes into account the complex challenges at the interface of water scarcity, climate change, urbanisation and other societal dynamics in the region, and the IWRM approach is implemented at a practical level. Furthermore, the MDGs and the concept of sustainability are promoted on a local scale by strengthening capacities and structures on site. The ultimate aim is to expand knowledge and practice, as well as technologies and institutions as the backbone of sustainable development above and beyond the project region.

26.4 Achievements in Research and Practice

26.4.1 Rain- and Floodwater Harvesting (RFWH)

The technology of rain- and floodwater harvesting can be defined as the collection of rainwater on impermeable surfaces such as roofs or concrete, as well as floodwater from the oshana water system during the rainy season. Both types include the storage of the collected water in covered reservoirs to prevent evaporation and quality degradation over the storage period. The stored water is used only for irrigation, since the drinking water supply in the project region is ensured by a long-distance drinking water supply network. This technology has huge potential and has been tested in climatically similar regions in Sub-Saharan Africa (Gould and Nissen-Petersen 2006; Mwenge Kahinda et al. 2007). Despite this fact, the technology including its usage for the irrigation of vegetable gardens is not commonly used in the project region and introduces new practices and knowledge to the people.

Four different technological adaptations of rainwater harvesting were tested in the pilot village of Epyeshona, located approximately 10 km outside of Oshakati. Three of them belong to the household approach of rainwater harvesting, where rainfall is collected on already existing roofs made of corrugated iron sheets. At three different locations within the village different tank materials were used, namely ferrocement, bricks and polyethylene. The storage capacity of each tank is 30 m^3. All households with rainwater harvesting tanks were also equipped with gardens (150 m^2) and water-saving drip irrigation systems so that the rainwater can be used for irrigation during the dry season. The fourth option for rainwater harvesting operates on a communal level. In this case, five households work together. This pilot plant consists of a ground catchment made of concrete (480 m^2), an underground tank with a water storage capacity of 120 m^3, a covered pond (80 m^3) where the rainwater from the roof of a greenhouse (160 m^2) is collected, and outside gardens with a combined size of 900 m^2. Both the greenhouse and the outside gardens are equipped with water-saving drip irrigation systems (see Figs. 26.5 and 26.7). While the greenhouse is jointly managed by all participating households, each household has an individual share of the outside garden (Fig. 26.6).

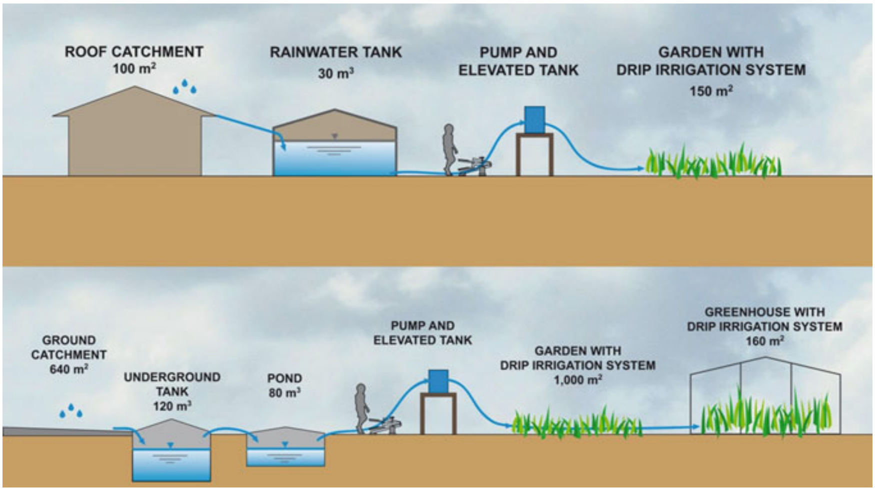

Fig. 26.5 Concepts for rainwater harvesting at the household (*top*) and the communal level (*bottom*)

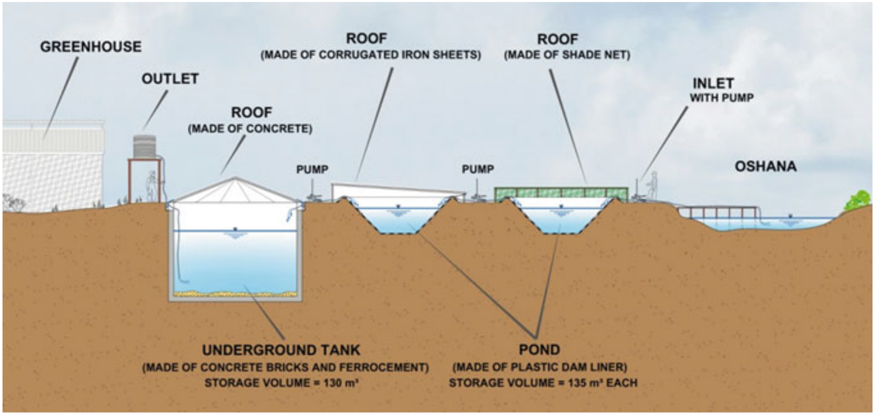

Fig. 26.6 Concept for floodwater harvesting which is realized at communal level

A system for floodwater harvesting from the oshana water system was also developed, based on research results from the rainwater harvesting plants and in cooperation with numerous Namibian experts. The aim is to store some of the surface water runoff that flows through central northern Namibia once a year towards the end of the rainy season. In contrast to these phases of water abundance, there is almost no precipitation between April and October. Surface water in the oshana water system is affected by evaporation and rapid quality degradation, caused by both humans and animals. The technology of floodwater harvesting developed within the project thus aims to store the floodwater over the course of the

Fig. 26.7 Rainwater harvesting pilot plants (from *top left clockwise*: Green Village with greenhouse and outside garden, Green Village ground catchment with underground tank, household ferrocement tank with garden, spinach inside household greenhouse)

dry season and provide a source of good quality irrigation water throughout the period of water scarcity. To this end, tanks made of different materials were constructed on the banks of the local oshana in the centre of the pilot village of Iipopo located approximately 40 km south-west of Oshakati. Good quality water is pumped from the oshana at the height of the rainy season and stored in two covered ponds with a storage capacity of 135 m^3 each and in an underground tank made of bricks and ferrocement, with a storage capacity of 130 m^3 (combined storage capacity 400 m^3). The pilot plant also encompasses a greenhouse (176 m^2) and an outside garden area of approximately 1200 m^2, all equipped with drip irrigation systems (see Figs. 26.6 and 26.8). The compound is fenced in and surrounded by more than 150 fruit trees. The pilot plant is operated cooperatively by ten user households from the pilot village who jointly manage the greenhouse and each have a private share of the outside garden.

Both communal approaches for rainwater and floodwater harvesting are known as “Green Villages” within and beyond the region.

26.4.2 Capacity Development

The planning for the implementation of rainwater harvesting tanks in the village of Epyeshona began 2 years before construction commenced, with participatory workshops and surveys of the local population. During these workshops, target households for rainwater harvesting sites and also trainees for the construction

Fig. 26.8 Floodwater harvesting pilot plant (from *top left clockwise*: covered ponds, greenhouse, crops from outside gardens, underground tank and outside gardens)

process were selected. The construction of both tanks and gardens was supervised by experts from Kenya and Germany and was carried out by trainees from the local community. In 6- to 10-week training sessions, the individuals selected learned all the skills necessary to design and construct rainwater harvesting tanks with attached gardens. After construction of the pilot plants, they were able to use this knowledge to design, construct and maintain rainwater harvesting tanks on their own. The users of the gardens were also trained in all important aspects of gardening, ranging from soil preparation, plant care and harvesting, to the sale of fruits and vegetables, as well as book-keeping and other management skills (Zimmermann et al. 2012).

Like the rainwater harvesting approach, the concept for floodwater harvesting was discussed with the local community at regular workshops held within the pilot village of Iipopo. This gave the community members the opportunity to express their ideas and opinions with regard to the technology and its mode of operation. The construction of the plant took 6 weeks in which more than 30 people from the community were involved in construction work, and several more in framing activities such as supplying material and cooking. Ten trainees learned all the skills necessary to design, construct and maintain similar tanks and greenhouses elsewhere and have already demonstrated their expertise during construction work in other regions. In a further training phase, the ten pilot plant operators learned all the skills necessary to operate the plant, ranging from economical water consumption, the use of drip irrigation systems, soil preparation and plant care, to the sale of fruits and vegetables at local markets.

26.4.3 Monitoring

For more than 3 years, the performance of RFWH small-scale irrigation farming was monitored using various different methods. The monitoring consisted of a natural-scientific-technical and a socio-cultural part which were conducted integrative. A good example for the integrative procedure is that daily operations of the plant were assessed by the users themselves. They were equipped with so-called 'monitoring booklets' which were developed together by the project team and the users. Water quality and soil were monitored on a regular basis (e.g. quarterly, annually) as well as other aspects such as the technical performance of the tanks. All the tanks and the irrigation systems were equipped with water metres. The floodwater harvesting pilot plant was also equipped with flow measurement facilities in the oshana and with a weather station. The aim of the social and cultural monitoring was to discover what impact RFWH farming has on everyday behaviour as well as on management and livelihood strategies. To this end, qualitative guideline-based interviews were conducted on an annual rotation basis with all the farmers involved and with members of the construction team.

One important outcome of the social monitoring is the importance of maintaining the farmers' capacities with regard to technical and social management and to marketing. The household-based plants are used much less continuously than the communally-owned ones. In general, the adoption of the technologies in the two villages has a positive impact: farmers improve their livelihood strategies by selling produce and through subsistence use. This leads to a healthier diet in farmers' families. Aspects such as personal pride in having a meaningful occupation have also been observed as positive effects. When rainfall is not abundant enough, maintaining the farming groups can pose a challenge. In addition, cost-benefit analyses were performed in which the investments into and the running costs of the tanks and gardens were compared to the income derived on local markets from the sale of fruits and vegetables.

The different storage technologies implemented within the project were compared by an economic analysis in which the dynamic generation costs of the water stored were estimated. This estimation includes material as well as labour costs and shows that the dynamic generation costs for the different tank solutions (polyethylene, ferrocement, brick) are in the range of 47–52 NAD[2]/m^3 (3.20–3.54 €/m^3) if lifetimes between 25 and 35 years are assumed. The alternative pond solutions with iron sheet or shade net roof show respective costs of about 30 NAD/m^3 (2.04 €/m^3) based on

[2]NAD = Namibian Dollar; exchange rate: 10 NAD = 0.68 € (15 Dec 2014).

lifetimes between 12.5 and 20 years. These figures are assuming that households already have iron sheet roofs for water collection, if this is not the case costs will be between 10–15 NAD/m^3 (0.68–1.02 €/m^3) higher.

Solely based on this economic estimation the project therefore recommends the construction of ponds for rainwater harvesting in Namibia. Nevertheless, there are also several positive aspects related to the construction of tanks in comparison to ponds such as the possibility to use only local materials and local labour, having positive effects on job and income generation.

26.4.4 Recommendations from Impact Assessment

For rainwater harvesting, model-based assessments based on the example of the Okatana Sub-Region show that if the household and communal solution spreads to all households and schools, less than 0.3 % of the precipitation will be retained and thus temporarily withheld from the hydrological cycle (Klintenberg et al. 2014). Later, the water is re-introduced into the natural system via irrigation. Adapted and optimised crop rotation systems are an essential factor of productivity (Woltersdorf et al. 2014). In this context it was possible to develop optimised cultivation strategies for various climate scenarios and purposes of use (ibid.). It is hardly avoidable to use fertiliser and pesticides, because of the natural conditions, but this should be flanked by training and monitoring due to risks. With regard to the access to technology, the socio-economic aspect of high investment costs poses a substantive challenge (ibid.). Essential factors for the successful diffusion of the technology are awareness building and the training of users and service providers (plant construction) as well as political support through appropriate policies (ibid.).

Klintenberg et al. (2014) conclude that the floodwater harvesting plant extracts and stores between 0.31 to 1.65 % of the surface runoff from the oshana, assuming a captured floodwater volume of 500 m^3/a, an area of 1,650,000 m^2 contributing to runoff (derived from the catchment's topography), a runoff coefficient of 10 % and assuming annual rainfall between 184 mm/a (minimum scenario) and 982 mm/a (maximum scenario). Although this estimation indicates no substantial interference with the surface runoff, the interaction of such a withdrawal of floodwater with the partly fragile ecosystem should be monitored in the long run. In future, the potential attractive force of the availability of additional water on population movements should also be taken into account, since this bears the risk of social conflicts or overuse of water and land resources. With regard to access to the technology, support through appropriate policies in particular, clear cut legal-institutional integration as well as adapted funding, cost coverage and ownership models are crucial factors for success on the farmers side as well as for a multiplication of the concept.

26.4.5 Desalination

The lack of perennial surface water bodies is another challenge in this region. People traditionally use water from hand-dug wells which fill up in the rainy season and dry out during the dry season due to evaporation and usage. These hand-dug wells are contaminated by algae, faeces and parasites and they turn salty during the dry season, making them unsafe sources for drinking water. The groundwater is saline, so desalination becomes an option for producing safe drinking water.

Both villages, Amarika and Akutsima, are located in remote rural areas without access to electricity or water network and no access to tarred roads. All the desalination plants are solar-driven for several reasons (see Fig. 26.9). Firstly, the solar radiation in northern Namibia is quite high: over 6 kWh/(m^2d) (or 250 W/m^2). Secondly, it is difficult to supply remote areas with conventional energy sources like fuel or gas. Last but not least, the environmental impact due to the combustion of conventional energy sources is high, since the desalination process has a high energy demand.

Four different desalination pilot plants (prototypes) were installed in the villages of Amarika and Akutsima: reverse osmosis (pro|aqua), membrane distillation

Fig. 26.9 Different types of desalination plants at Amarika and Akutsima (from *top left clockwise*: IBEU/SIJ, Terrawater, pro|aqua, people at the water point fetching desalinated water)

(Fraunhofer ISE[3]), evaporation (Terrawater), multi-stage-desalination (IBEU/SIJ[4]).

The reverse osmosis plant from pro|aqua operates without chemicals, since it is difficult to supply plants in remote areas with them on a regular basis. For pre-treatment, an electro-chemical scale remover is used to prevent scaling and fouling. On average, the plant produced 3.3 m^3/d of drinking water from 14.1 m^3/d of raw water, with a specific electrical energy demand of less than 10 kWh/m^3. The operating pressure was 30 bar.

The membrane distillation plant from the Fraunhofer ISE is a new system which heats the raw water up to 70 °C. The vapour passes through a membrane and condenses. This process needs electrical and thermal energy which is provided by solar collectors. The average production in 2011 was about 0.8 m^3/d of freshwater from 6.7 m^3/d of raw water. The specific thermal energy demand can be expressed by the fact that per m^2 of thermal solar collector area a maximal volume of 11 l distillate has been produced per day. Additional electrical energy is needed.

The evaporation plant from Terrawater operates with evaporation and condensation on a chemical-free basis. The raw water is heated by thermal solar collectors and humidifies air in the humidifier. The humid air condenses in another chamber, producing pure distillate (6 µS/cm). On average, the plant produced 1.4 m^3/d of freshwater from 16.7 m^3/d of raw water. The modules are made from plastic which is robust against scaling and cheaper than using stainless steel. The specific thermal energy demand can be expressed by the fact that per m^2 of thermal solar collector area a maximal volume of 11 l distillate has been produced per day. Additional electrical energy is needed.

The multi-stage-desalination plant from IBEU/SIJ is the smallest plant and operates without chemicals or electricity. The raw water is heated by thermal solar collectors and evaporates and condenses in seven stages. Because it is simple to operate, it can also be used on a household level. One module produces up to 85 l/d of pure distillate. Six modules have been installed in Akutsima which have a production capacity of about 500 l/d of freshwater from 1.2 m^3/d of raw water. The specific thermal energy demand can be expressed by the fact that per m^2 of thermal solar collector area a maximal volume of 15 l distillate has been produced per day. No electrical energy is needed.

26.4.6 Capacity Development

The operational concept includes a local caretaker and guards who are residents of the villages and who are elected by the community. They are responsible for daily operations and security. Water Point Committees (WPC) have also been nominated throughout Namibia which are responsible for administration and for selling the

[3]Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE).

[4]Ingenieurbüro für Energie- und Umwelttechnik (IBEU)/Solar-Institute Jülich (SIJ).

water (Werner 2009). A professional service provider (Aqua Services and Engineering) was responsible for major repairs, maintenance and regular monitoring, with handing-over of the plants to the MAWF this duty has been taken over by the Directorate of Water Supply and Sanitation Coordination (DWSSC). Everyone was trained directly by the plant manufacturers during the installation of the plants. The local caretaker received additional training, and it became obvious that there is a lack of institutionalised training for water operators in Namibia in general. So together with the Polytechnic of Namibia, Aqua Services and Engineering, and the Ministry of Agriculture, Water and Forestry, the project initiated the implementation of a certified training programme for water operators. During service operations it became clear that communication via satellite phone and data transmission with the manufacturers in Germany was vital.

26.4.7 Monitoring

For approximately 3 years, the performance of the desalination plants was monitored using different methods. As mentioned above, monitoring was made up of a natural-scientific-technical part and a socio-cultural part which were conducted in an integrated way.

Technical monitoring of the plants was conducted via satellite data transmission and with the help of the reports from the service provider (on water quantity and quality, operation and malfunctions). Ecological monitoring was conducted during several visits in the field. In particular, brine disposal in deep wells was monitored by measuring salinity and water levels in the boreholes to prevent an adverse ecological impact.

The aim of the social and cultural monitoring was to find out what impact the new water source has on everyday behaviour, especially on water use patterns and health. To this end, two standardised surveys were conducted in 2010 and 2011, covering about 60–70 % of all households in the two pilot villages. In addition, field observations, qualitative interviews and the hands-on experience of the field facilitator rounded off the picture.

The results of the monitoring show, that overall the new water source is well accepted in the two communities. However, consumption varies widely, depending on several factors. One factor is the willingness and ability to pay. The comparison of both villages shows that similar economic backgrounds are reshaped by the particular social structures within the community which create very different levels of engagements and motivations. This is also linked to functioning and reliability of the WPC which can stimulate or even curtail and deter users from access and payment of the water. Another factor is knowledge about waterborne diseases, water storage techniques and the benefits of better drinking water in general. There also seem to be concerns to use the freshwater to brew traditional drinks. On the other hand, access to the improved water is highly valued and many households use a mix of the various water sources. The subjective health assessment of users is positive, and the existence of the plants has a positive impact on both communities (with ‘pride’ being a symbolic effect).

The economic analysis indicates a range of estimated dynamic generation costs for the market case between 13 and 15 €/m^3 including costs[5] for investment, operation and maintenance. This is within the same range as the estimated costs for alternative supply options to the villages like the extension of the pipeline grid or the provision with water tankers. Excluding the investment, the estimated dynamic generation costs for operation and maintenance are between 5 and 9 €/m^3. The multi-stage-desalination plant is in particular favourable for local production at household or farm level which would reduce service and personnel costs significantly and lead to operation and maintenance costs clearly lower than 5 €/m^3.

26.4.8 Recommendations from Impact Assessment

Two aspects of the project’s desalination technology can have a direct impact on the environment: the groundwater extracted and the brine produced in the process. Since the start of the pilot operation no negative environmental impacts have been observed so far. In any case it is vital to gain a clear picture of the hydrogeological situation in order to examine the best options for abstraction and brine disposal (see Mickley 1993).

Estimates show that the influence zones of groundwater abstraction can lie in a considerable range, strongly depending on local conditions. Calculations indicate that for the worst-case scenario, the radius of the influenced area around the abstraction well is less than 650 m. This offers a first criterion for the minimal distance between desalination abstraction holes which needs to be empirically validated with regard to the local hydrogeological situation (Klintenberg et al. 2014).

The re-injection of brine in Amarika takes place in deep aquifers with a high salinity (higher than the salinity of the brine). Aquitards prevent hydraulic short circuits with aquifers near the surface, which are used for water supply (extraction borehole or hand-dug wells). It is also important to construct the boreholes in a way that different aquifers are not connected, which is done with bentonite lining in the annulus of the re-injection boreholes. The brine contains no chemicals like antiscalants. To prove the function of the brine disposal concept an ongoing monitoring was conducted. The re-injection boreholes were less expensive than the evaporation ponds, but as shown in Akutsima one can resign the expensive lining when there is a natural lining and no aquifer exists nearby.

[5]The costs include the desalination plant, solar energy components, data transmission for monitoring, services and salaries for local personnel.

26.4.9 Wastewater Treatment and Water Reuse

The technology is subdivided into the components of sanitation, wastewater treatment and water reuse as shown in Fig. 26.10. A water-based vacuum sewer system was chosen for sewage conveyance from the informal settlements to a wastewater treatment plant. During the rainy season, waterborne diseases may occur in the Cuvelai-Etosha Basin and the 'closed' vacuum sewer system thus helps to overcome the threats posed by seasonal floods in the area. Further advantages of the vacuum system over conventional gravity sewer systems lie on the energetic and water efficiency side due to the flat landscape and the low water demand.

It was clear from the beginning that one single type of sanitation facility would not be able to serve the needs of all the residents and suit all the stages of development of the settlements in the project area (Deffner et al. 2012; Deffner and Kluge 2013). Therefore, three different types of sanitation facilities in three differently developed areas of Outapi are implemented (see Fig. 26.11). Between 1,000 and 1,500 inhabitants will be provided with this infrastructure.

- 66 households are "individually connected" to the water supply and sewage system. The Shack Dwellers settlement consists of modularly constructed brick houses that are already equipped with a bathroom.
- 30 small "cluster washhouses" with a shower, a toilet, a hand wash basin and a large sink are shared by four to five families in Tobias Hainyeko. In this area, most people live in zinc huts, but some brick houses are also being built.

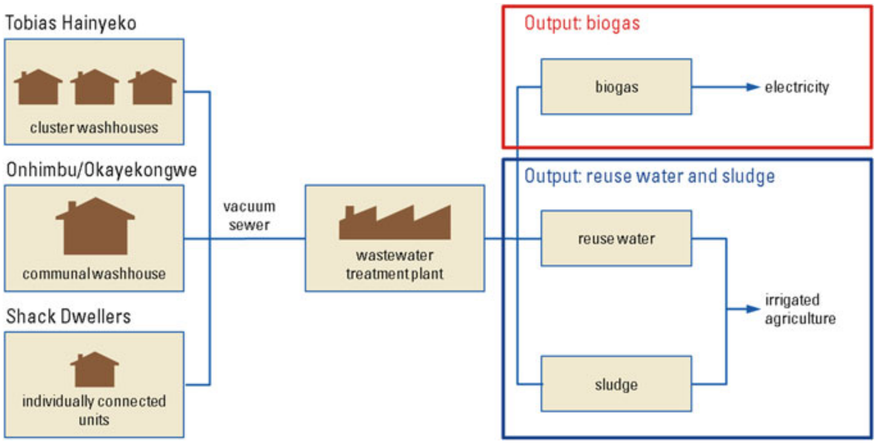

Fig. 26.10 Illustration of the interlinked components sanitation, wastewater treatment and water reuse. Three different sanitation concepts are connected by a vacuum sewer system with the treatment plant. Besides irrigation water, the output includes also nutrients and biogas

Fig. 26.11 A cluster washhouse (*left*) in Tobias Hainyeko settlement and the communal washhouse (*right*) in Okayekongwe settlement of Outapi

- A "communal washhouse" for 250 users offers toilets, showers, hand wash basins and sinks for laundry and dish washing. It is situated between the settlements of Onhimbu and Okayekongwe. Onhimbu is a rather old part of Outapi, with a lively market. The zinc shacks in the new settlement of Okayekongwe were installed from 2010 onwards.

After the wastewater has been transported from the sanitation facilities to a vacuum station, it is initially pre-treated and then further purified with rotating biological contactors (see Fig. 26.12). Organic compounds are oxidised and nutrients largely remain in the water for fertigation purposes. Finally, solids and pathogens are removed via a microsieve and UV radiation before the water is stored in a pond for reuse in agricultural irrigation. Wastewater is generated daily all year in more or less equal quantities. Irrigation demand in agriculture is high during the dry season and low during the rainy season or harvest. Therefore, a pond with a capacity of 3,000 m^3 is used for water storage. The biogas produced from thermophile anaerobic digestion of the wastewater sludge and residual biomass from

Fig. 26.12 View into the main building of the wastewater treatment plant and on the irrigation site for agricultural production under reusing water and nutrients

the agricultural irrigation site is used to generate electricity and heat. The stabilised sludge is dried on sludge beds and can then be used for soil improvement and as an additional fertiliser.

The agricultural irrigation area (see Fig. 26.12) consists of two greenhouses and several open fields equipped with surface and subsurface drip lines. In order to avoid soil salinisation, the fields are flushed intermittently and the leaching water is collected by a drainage system. The crops like maize, tomatoes, green peppers and melons are sold on-site directly at the farm or at local markets. If all the fresh vegetables can not be sold, a drying unit can be used for conservation/further processing.

26.4.10 Capacity Development

The Outapi Town Council (OTC) has capacities available for managing the existing gravity sewer system. To manage the infrastructure introduced by CuveWaters, supplemental training is necessary. With regard to agriculture, the local population has little or no knowledge, so capacity development is also necessary.

For capacity development on a technical level, CuveWaters initiated an operator training programme in 2011. In mid-2012, the German industrial partner Bilfinger Water Technologies conducted vacuum sewer training with two representatives from OTC. During the start-up phase of the vacuum sewer system and the wastewater treatment plant, the technicians received further training by the German industrial partner. During the first months of operation, CuveWaters provided additional support through a wastewater technician who assisted OTC with operation and maintenance. Further support is given by providing analytical monitoring as well as by remote control and assistance via mail and help hotline.

Capacity development measures were also implemented with regard to agriculture by training EKOTI (farmers group that currently manages the irrigation site) in September/October 2011, during the main construction and start-up phase, and in April 2012 after half a year of operation. Initial and refresh courses addressed topics such as operation and maintenance of the irrigation system, water budgeting and management, crop husbandry, identification of diseases, pest control, group dynamics, and record keeping.

From its inception in 2008, the project has integrated the communities into all the planning phases. Before implementation, special attention was paid to changing hygiene behaviour. To achieve this, the community-based approach was continued by setting up so-called Community Health Clubs (CHC) (Deffner and Böff 2012; Waterkeyn 2010). The main aims were:

- A long-lasting change of hygiene behaviour, particularly to reduce health risks;
- To establish a routine of and demand for toilets, showers and wash basins;
- To communicate the benefits of the sanitation facilities and to embed them into everyday life;
- To communicate adequate use of the new facilities.

This approach was developed in the early 2000s by the NGO AfricaAHEAD and is based on a scientific understanding of behavioural change and social learning. It aims to change norms and values in health and hygiene behaviour. The residents need to be able to see, feel and understand the difference that improved sanitary conditions can make. This calls for a rapid social and cultural learning process. By way of comparison: In Europe, the development from open urination and defecation to water closets and sewage systems took several hundred years, as opposed to just a few years here.

The first step to this end was a 6-month community-based and discursive learning scheme in the Community Health Clubs to impart proper use in terms of knowledge and everyday practices. Starting with issues such as avoidable diseases, cooking, household and personal hygiene, it went on to teach the correct use and maintenance of the new sanitary installations and to provide support for the transfer of ownership. The facilitators of the Health Clubs were trained beforehand by AfricaAHEAD and were recruited from the communities and a nearby vocational training centre with a class of community development.

26.4.11 Monitoring

Monitoring of the sanitation facilities, vacuum sewers and the wastewater treatment plant has been carried out since April 2013. Parameters monitored include the number of users of the sanitation facilities, water volumes, electric conductivity, pH, turbidity, COD, nutrients (P and N), microbial parameters, biogas volumes produced and biogas composition.

In order to assess the preliminary situation of the user households, a Household Inventory Survey (HIS) was performed in the three pilot settlements in 2011. The aim of the survey was to assess the households' conditions with regard to sanitation, water, health status, socio-economic situation and water-related household practises. The survey results confirm the necessity for implementation: 96, 60, 52 and 10 % respectively of the residents questioned in the four settlements said that they practice open defecation. Half of the people surveyed have no access to latrines. The incidence of diarrhoea is rather high.

The following preliminary conclusions can be drawn after the monitoring interviews and the daily counts at the communal washhouse were performed so far: in the washhouse, men primarily use the showers, whereas women mainly use the toilets. Laundry washing is popular. Till now, managing the washhouse has usually run smoothly; however, it is obvious that supplementary training of the end users would be helpful. Maintenance of the ongoing repairs is a challenge for the management capacity of OTC. Observations the team conducted within the social monitoring show that there is a combination of partial misuse and irregular repairs. OTC is planning to raise the tariffs as a combined measure to increase the cost efficiency and to symbolize the value of the provided service.

Regarding the agricultural irrigation area, monitoring includes parameters such as the volume of water used for irrigation and other purposes (cooking etc.), the amount of harvested and sold products, the costs and revenues as well as the use of fertilisers and pesticides. More qualitative parameters regarding general activities at the farm (e.g. visitors, exchange with other farmers, group development) are also collected.

At the time of finalisation of this chapter, the financial analysis is still on-going and no figures can be given here.

26.4.12 Recommendations from Impact Assessment

According to initial assessments, in its current dimensioning the outlined solution has only a minimal impact on the hydrological cycle. It is estimated that a maximum of 0.1 % of the water runoff from the Kunene is used in the sanitary system. Ecologically, the risk of contamination due to sewage malfunctions and irrigation agriculture are relevant but this has to be compared to the high risks of the current system (evaporation ponds) or even the threats by open defecation. In order to ensure socially viable access to the technology, adapted tariff and cost coverage models are very important. The substantial need for political support due to the considerable impact on institutional accountabilities needs to be stressed.

26.4.13 Contribution to Policy Implementation

Since the beginning of the project, the integration of CuveWaters into Namibian policies has been achieved with the help of a multi-level governance approach (Polak and Liehr 2012). Firstly, there is the national institutional level of Namibian water policy as recorded in the National Water Policy White Paper of 2000 (MAWRD 2000) and the Water Resources Management Act of 2004 (GRN 2004a). The latter repealed the Water Act of 1956 (GRN 1956). Within this context, the project had already been authorised to work in the Cuvelai-Etosha Basin by the Namibian government in 2006. In order to transfer the results from the pilot-like implementations onto the national level, technology-specific policy papers are being worked on in a discussion process with Namibian stakeholders. The CuveWaters project does not just integrate itself into the Namibian IWRM-strategy, but is also closely linked to the National Sanitation Strategy Namibia 2010/11–2014/15 (GRN 2009) and the National Development Plan (NDP3) 2007/2008–2011/2012 (GRN 2008). Among other things, the project's participation in the national Water and Sanitation Forum (WatSan) and the WASH-IEC (Water and Sanitation Information and Education) task force are visible signs of this integration.

In addition to this national level, the project is also active on a regional level via its integration into the activities of the Regional Councils (RC). These are responsible for infrastructure planning in Namibia, and thus also for the water supply and sanitation. In areas with an urban character, these RCs work hand-in-hand with the Village Development Committees, and in more rural areas with the Constituency Development Centres. In this context, CuveWaters is in close contact with the City Development Centre of the Okatana Constituency (Okatana-CDC).

Within the context of integration on a regional level, the following aspect is of key significance: the Cuvelai-Etosha Basin is divided into several sub-basins with corresponding Basin Management Committees (BMCs). Once a year, all the BMCs of the Cuvelai-Etosha Basin meet in an exchange and steering forum which is organised together with the Namibian water ministry (national level) and with close involvement of the RC (regional level). CuveWaters has continuously taken part in these meetings with a seat and a vote. It has contributed project results, liaised with other sector initiatives and has thus disseminated its approach in the region via the corresponding institutions. A vital aspect on a local-institutional level is the fact that after gaining independence, Namibia anchored key decentralisation strategies in its water legislation. In addition to the IWRM-connected Basin Management Committees, the lowest decision-making level is the Water Point Committee (WPC) (Werner 2009). It is responsible for water distribution and fee collection, but also for repairs. For CuveWaters, these WPCs were set up at the desalination and water collection sites, in each case with the assistance of the responsible directorate of the ministry. This legal structure, collectively set up and geared towards self-organisation, is extremely unique because in the communal areas, legislation in Namibia still depends on the established authorities.

On a local level the Community Health Clubs (CHC), which were newly introduced by the project, also contribute to the dissemination of behavioural changes in the field of sanitation/hygiene. While developing tools for planning and implementation processes, Namibian protagonists on a national (MAWF, NPC) and regional (RCs and BMCs) level were closely involved. This enabled the connection to Namibian developments towards an integrated data and information platform, even into the operative level, and also its strategic preservation via a clearly delineated accountability structure. These aspects all demonstrate the multi-level integration of the CuveWaters project into Namibian policies.

26.4.14 Cross-Cutting Issues

CuveWaters combines technologies for the sustainable management of water and land resources with the basic needs of food, health, employment, education and living. Its central theme is the idea, that technologies can only develop their potential for sustainable development and establish themselves on the market, if they are accepted by their users, are suitable for everyday life and are ecologically, politically and financially viable. The general IWRM-concept and the Dublin principles as well as the Namibian developments towards an "IWRM Plan for Namibia", as part of a "National Water Development Strategy and Action Plan" are important benchmarks: the multi-resource-mix with its technologies is an integrated response to the complex problems on the ground and, for the transfer, offers a flexible solution for adaptations to varying conditions. Different levels of knowledge are integrated as a basic requirement for successful implementation. Interdisciplinary cooperation, participation and demand-orientation, as well as academic and non-academic capacity development form the basis of the project's concept. In accordance with the IWRM-concept, societal issues such as the economy, society, institutions and policies are factored in just as much as ecological issues regarding resource efficiency and a close interconnection of water and land resources. For CuveWaters and within this context, climate change, demographic developments and urbanisation form the framework for the development of strategies and the assessment of room for adaptation.

The relationship between water and poverty (UNDP 2006) was the initial starting point and improving the water security situation while contributing to poverty reduction is also a part of CuveWaters' goal. Depending on the economic situation, there are clear differences in access to various water sources and sanitary facilities in Namibia (CBS 2006). This fact is integrated into the project's concept in a variety of ways: (a) the choice of technologies (e.g. provision of drinking water to improve health), (b) suitably adapting the concepts to the technologies (e.g. sanitary systems for three different settlement structures) and kinds of usage (e.g. individual and communal gardening), (c) training, as well as implementation, business and funding models.

In view of the overarching integrative effect of the technologies with regard to water supply and sanitation, water and land management, and the reuse of resources such as water, nutrients and energy, the current discussion on the water-energy-food nexus (Gupta et al. 2013; Ringler et al. 2013) is particularly relevant to the CuveWaters project. By combining the technologies RFWH and wastewater treatment with agricultural production, the link between water and food immediately becomes clear (Röhrig and Werner 2011); in the case of sanitation, energy recovery also becomes relevant. More efficient and thus more productive uses of water and land, energy and nutrient resources are central, especially with regard to wastewater treatment and water reuse, together with its implications for hygiene. With regard to desalination, the availability of freshwater is also linked to issues of domestic diet; the decentralised, solar-linked power supply of the plants highlights the relevance of the energy issue.

Capacity development measures and the development of tools for planning and decision-making processes, play a key role in sustainably anchoring the project results locally, above and beyond the duration of the project. In the field of academic education, there is an established relationship of scholarly exchange between the German and Namibian project partners, especially with the University of Namibia (UNAM) and the Polytechnic of Namibia (PoN). In addition, there are cooperations with German and European universities, with the goal of establishing sustainable and long-term research and teaching capacities. To this end, the project supports strategic networking, a summer school programme (vacational school), academic qualification papers, internships, scientific exchange and eLearning[6] (distance learning).

Non-academic training ensures the long-term operation, maintenance and also the transfer of the various technologies. In basic training and continuing education, technology-specific know-how on construction, gardening and irrigation, operation and maintenance, marketing and communal management was imparted. In accordance with the multi-level approach, farmers and users, staff of local construction teams, caretakers/operators and technicians, service providers and extension officers as well as administrative decision-makers are targeted. Partly independent decision-structures and clear hierarchical structures for communication and responsibility reflect an adaptation to the diverging degrees of complexity of the different technologies (Polak and Liehr 2012). Among other things, this approach supports the new local structures of the Water Point Committees (WPC), which the project has initiated and which are mainly run by volunteers. It is proving a particular challenge to cement their functionality within the context of a difficult training and knowledge situation and in view of the fact that traditional and formal institutions and structures are colliding (Faschina 2011; Werner 2009).

Another form of knowledge transfer is achieved by developing tools to support planning and decision-making processes. The development is based on an ongoing active participation of Namibian stakeholders in choosing and developing the tools, their training for further future development and a final handing-over of the tools to institutions in Namibia. During several workshops, three tools were chosen on this basis, drafts and pilot versions were developed together and preliminary arrangements were made with regard to the issue of Namibian ownership. The three tools include a Technology Toolkit for Rainwater Harvesting (RWH-Toolkit), a Digital Multimedia-Atlas and an IWRM-Toolkit.[7] These are tools with focused content, a rather low degree of complexity and, in addition to software applications, various physical realisations also. The tools have been developed separately, but are connected to one another and also pick up GIS- or model-based project activities.

26.5 Conclusion for Transfer

It is one of the project's key tasks to ensure the transferability of overarching insights. Within the framework of CuveWaters' networking with various different initiatives in the SADC-region, possibilities for the exchange, generalisation and

[6]In cooperation with IWAS and IHP/HWRP (Liehr and Röhrig 2012), see www.iwrm-education.de.

[7]An integration of the Digital Multimedia-Atlas into the Namibian Environment Information System (EIS, www.the-eis.com, accessed 15 Aug 2014) as an Interactive Water Information and Planning Tool (IWIP) of the Cuvelai-Etosha Basin and of the IWRM-Toolkit and the Digital Multimedia-Atlas on the Namibian online knowledge platform on IWRM (www.iwrm-namibia.info.na, accessed 15 Aug 2014) has already taken place outside of the scope of the project. The RWH-Toolkit is integrated in ongoing capacity development measures and will be handed-over to the BMCs.

transfer of the project's results with regard to content and method are already arising. These measures must impact on decisions and actions on every level (Krug von Nidda and Kluge 2011).

Monitoring RFWH over the course of several years captures long-term experience with the plants, thus offering valuable input for future projects, also within the framework of international development cooperation and measures to adapt to climate change. With the help of the results and insights gained so far, and taking socio-cultural and economic as well as ecological aspects into account, feasibility in semi-arid regions has been demonstrated and the harvested water has been shown to have a clear benefit. In this respect, German organisations working in this field (e.g. GIZ) can receive vital support. Examples for replications which have already been successfully implemented are the construction of a Green Village in Onamishu (Oshikoto Region) by the NDT/Okatana Rural Development Centre and the construction of greenhouses by irrigation farmers at the Olushandja Dam. In the case of broad diffusion, relatively high investment costs come face to face with multi-faceted positive effects (e.g. on income, nutrition, resource efficiency, local economy).

For the desalination plants, operating independently in rural regions without any additional infrastructure poses a huge challenge. CuveWaters' pilot plants are characterised by the fact that due to the design of the plants (chemical-free operation, remote monitoring, suitable for high degrees of salinity) and the operating concept tailored to it, three of four desalination plants can be run reliably in remote areas over the long term. One plant could not be adapted to the Namibian conditions with the available resources, mainly because it was not designed for the prevailing high degrees of hardening components of calcium and magnesium, in particular gypsum[8]; this plant needed to be deconstructed. However, due to the complexity of the plants, a functioning framework for operation and maintenance across all scales is in the process to be established, in spite of a high degree of operational reliability and low maintenance needs. Local accountability for operations, maintenance and fees need to be backed by service providers and higher-level decision-making and budgeting on a regional and national level. Further criteria for transfer are the hydrogeological conditions with accessible groundwater in suitable quantity and quality range as well as low-impact options for brine disposal.

The integrated concept of wastewater treatment and water reuse developed within the CuveWaters project breaches a needs gap in this field. Overall it has become clear that, in addition to technical requirements including a quality-assured implementation, the so-called "soft" factors in particular play a key role for the transfer. Essential tasks for strengthening the transfer are consolidating and communicating the results of cost-benefit and economic feasibility studies, developing funding options and business plans, demonstrating regional-economic potential,

[8]Total Dissolved Solids (TDS) of 23,650 mg/l including Sulphate of 8,170 mg SO_4^{2-} per l.

professionalising the management and sale of products as well as mobilising resources along the value-added chain like drying of fruits, generation of compost and marketing. Flanking with adapted trainings in hygiene and health issues and taking user needs into account would be a further precondition for a successful transfer. By this, the pilot plant at the city of Outapi will set a stimulus for national and municipal authorities but also for financing agencies in order to transfer the concept in Namibia and beyond.

The project is running since about 10 years from the first idea to the handing-over of three technologically totally different types of facilities to the respective Namibian stakeholders A broad transdisciplinary approach has provided the basis for addressing the complex interplay of scientific and societal actors (Jahn et al. 2012). Water-related risks were identified as a starting point for the demand-based development of adapted solutions. Subsequent technological interventions have gone along with the integration of expert and everyday knowledge, the promotion of adaptive governance structures across institutional levels and with the development of long-term capacities supporting the consolidation of new practices and knowledge. Based on a clearly defined methodological guidance (Deffer and Kluge 2013; Kluge et al. 2010) the transdisciplinary approach structured the whole research process and has led to new impulses for development in the region.

Within this process, the IWRM concept showed its two faces: its vagueness and abstraction bears the risk that effective implementation is hardly possible without sufficient training, instruments, structures and capacities. The project showed that not the technological solutions themselves are the crucial success factors, but how they are implemented in the social, cultural and institutional environment. The term 'IWRM' is an important anchor on a higher strategic level but needs to be filled with concrete management and operational issues on the ground. The necessary processes of institutionalisation and capacity development easily go beyond the scope of a research and development project. Therefore, the cooperation with actors like national authorities or agencies of international cooperation are a decisive factor to create synergies and pick scientific and non-scientific actors up at their respective core competences. This supports the sustainability of such projects at the interface of research and development.

Looking at the other face of the IWRM concept, its vagueness opens a very useful space for integrating different scientific disciplines and societal stakeholders across sectors and hierarchical levels. They all act with different motivations, focusses and interpretations which depend on their respective area of responsibility and competence. The Namibian case and the project show, that this programmatic approach given with the IWRM concept creates the potential for discussion and for solutions which are jointly agreed. Important drivers for those solutions are interfaces where the involved actors exhibit shared interests and risks. Contributing to IWRM and creating success stories therefore strongly depend on how a problem-centred, demand-based and integrated approach can identify these interfaces and can bring this into a process which is substantiated by the specific contextual conditions.

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Part X
Transboundary Case Studies

Chapter 27
Sustainable Water and Land Management Under Global Change—The GLOWA Jordan River Project

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Abstract Water scarcity has been a feature of life in the Jordan River basin from time immemorial. Over the last century the situation has become gradually worse because of the increasing population, its development for agriculture and changes in rainfall patterns and consequent droughts. The potential impact of global change on the region is likely to be very damaging unless steps are taken to adapt. The roughly forty interdisciplinary research teams taking part in the GLOWA Jordan River Project, whose membership is made up of scientists and stakeholders from Germany, Israel, Jordan and Palestine, produced numerous results of applied and basic research about the effects of global change and alternative options for responding to them. The results included regional climate change scenarios, scenarios for regional development under global change, improved understanding of the hydrological conditions in the region, and water management application tools such as the Water Evaluation and Planning (WEAP) tool. The project developed strategies and guidelines for sustainable water and land management under global change. It integrated among many different disciplines like climatology, hydrology, ecology, socio-economy, and agriculture and supported an active transboundary dialogue between science and stakeholders in the Jordan River region. A transdisciplinary approach was realized by developing jointly with stakeholders scenarios of the water situation and potential adaptation strategies via a scenario

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analysis approach, as well as by developing and establishing WEAP usage with regional stakeholders. The project can serve as an example for successful transboundary IWRM even in the most contentious setting.

Keywords Jordan river · Global change · Water management · Land management · Regional cooperation

27.1 Introduction: The GLOWA Programme

Global change alters the earth system and directly impacts the well-being of human society by affecting availability and distribution of natural resources. The modification of the hydrological cycle is a key aspect of global change, whose main drivers include climate change, land use change, population growth, development of industry and agriculture, energy consumption and globalization. Due to the large impact that global change will have on the livelihood of people (IPCC 2007), scientific and public interest in global change issues has increased in the last decades (Klepper 2011). International conventions aim to focus the attention of the international community on social and institutional solutions, and regular reports have summarized our knowledge about impacts and adaptation options (IPCC 2007).

The German Government has recognised at an early stage the need for an integrated approach to studying global change effects on the hydrological cycle. This idea obviously relied on concepts from the classical IWRM approach (Chap. 1) but took into account that IWRM is an holistic approach urgently needing to include land use and ecosystem management (FAO 2000; Falkenmark 2003) as well as to incorporate climate change (Ludwig et al. 2013). Additionally, the idea aimed to bring together decision-makers and researchers to find scientifically sound solutions to the challenges imposed by climate and land-use change for water management (von Witsch 2008). To this end, the German Federal Ministry of Education and Research (BMBF) launched a programme called "GLOWA—Global Change and the Hydrological Cycle" in 1998 (Rieland 2004). As part of the BMBF framework programme on research for sustainable development (FONA), the GLOWA programme aimed at developing, testing and applying integrative, interdisciplinary methods and models to understand and predict the effects of global change on a regional scale. GLOWA focused on the development of sustainable development under global change conditions by capitalizing on interactions between the hydrological cycle, climate change and land use change. As access to safe drinking water is one of the most important factors within sustainable development (UNDP 2013) a main focus was on the availability of fresh water for domestic use. However, many other related areas of concern have been studied, including agricultural development, soil quality, and urbanization. Among the main end-products of the GLOWA programme were decision support systems for improving the management of water resources on a national and river basin scale (von Witsch 2008; Klepper 2011), but also novel approaches to transdisciplinary science that can serve as a model for future projects.

The GLOWA Jordan River Project (GLOWA JR) is one of five case studies of the GLOWA programme, each of which has focused on a separate river catchment. The projects included catchments in Europe (Elbe, Danube, Wechsung et al. 2008; Mauser et al. 2008), and North and Central Africa (Draa—Morocco, Oueme—Benin, Volta—Burkina Faso, Speth et al. 2010; Liebe et al. 2008), and the Middle East. Though the Jordan River basin is the smallest of the GLOWA basins, it has posed by far the largest challenge to integrated water resources management. This is due to a combination of a current water crisis and the aggravation of the situation in the future. Namely, natural water scarcity hardly compares to any other region in the world, i.e. the region is characterized by world record lows in per-capita water availability (FAO 2003). Furthermore, environmental degradation and the existing water gap is bound to rapidly increase in the future due to climate change and population growth. Finally, natural resources are transboundary in a region where regional cooperation is often hampered by political conflict. This water crisis was a tremendous challenge which GLOWA JR set out to address during the course of its existence. Due to this challenge, GLOWA JR solutions are most likely to be applicable to other, less difficult, transboundary cases.

In the following article, we summarize the current challenges posed to transboundary IWRM research in the Jordan River Basin, their possible future development, the approach taken by GLOWA JR to meet these challenges, and key findings and development recommendations supported by the project results.

27.2 The Challenge—The Water Crisis in the Jordan River Basin

The Jordan River basin is transboundary and shared among five countries. Syria and Lebanon contribute water resources to the basin, but rely much less heavily upon it for water supply than Jordan, Palestine and Israel, for which the river is a main source of renewable fresh water (SIWI 2007). By the end of the last century, i.e. before onset of the project, the region had already been classified as one of the most water-scarce regions of the world (FAO 2003). The total renewable per-capita water resources decreased dramatically during the second half of the last century in the three focal countries, Israel, Jordan and Palestine, from >500 m^3/a to 280–190 m^3/a in 2002 (FAOSTAT 2013). Therefore, the region has been categorized as suffering from absolute water scarcity (sensu Falkenmark 1986), i.e. “an insufficiency of supply to satisfy total demand after all feasible options to enhance supply and manage demand have been implemented” (FAOSTAT 2013). Since the beginning of the century, the pressure on the renewable water resources has further increased. For example, by the year 2000, the freshwater withdrawal in Jordan equalled the total actual renewable water resources (FAOSTAT 2013). Therefore, non-renewable water reserves have been increasingly exploited to meet the deficit (Nortcliff 2011), a situation that is further aggravated by the influx of refugees from the neighbouring countries.

The population in Israel, Jordan and Palestine, has grown at an annual rate of 4.9 % between 1970 and 2000, from 5.6 to 14.0 million people, and the population is expected to double in less than 20 years (UN 2013). This is dramatically increasing the water gap and land degradation, and thus population growth needs to be addressed in an IWRM context (Fig. 27.1).

Population growth has also important consequences for the intensity and extent of agriculture. As most of the agriculture in the region is irrigated, direct relationships between land use and water demand emerge. For example, in the last four decades, irrigated agriculture has expanded by 30 % in Israel and by 50 % in Jordan, further enhancing the unmet water demand (FAOSTAT 2013). Land-use related overexploitation of natural resources includes also overgrazing and associated land degradation. For example, livestock numbers (cattle, sheep and goats) have increased by roughly 30 % in Israel and by 230 % in Jordan between 1970 and 2000 only (FAOSTAT 2013), leading to severe overgrazing especially East of the Jordan River. As vegetation cover directly affects the hydrological cycle, any attempt to develop integrated water management strategies must also include management of land use practices, and it has been proposed to expand the IWRM concept to IWRLM, where the L stands for land, i.e. Integrated water resources and land management (FAO 2000; Falkenmark 2003).

Fig. 27.1 Landscape of the lower Jordan River basin

Apart from the highly important effects of socio-economic development (i.e. population growth, technological development, land use change), climate change may further add to the current water crisis. At the onset of the GLOWA JR project, only global circulation models (GCMs) of low spatial resolution and thus high uncertainty, were available for the region (Giorgi et al. 2001). These suggested a decrease in precipitation, and increase in temperatures and an increased frequency of extreme climatic events. This was corroborated by trend analyses conducted between 1970 and 2000, suggesting rising temperatures of around 2.7 °C and a reduction of rainfall of around 12 % (Verner et al. 2013). In a region with highly variable and limited water resources, this has tremendous impact on the hydrological cycle, highlighting the need to integrate climate change into IWRM in the region. Due to the unsatisfactory resolution of the GCMs, the generation of downscaled regional scenarios was urgently needed.

Until now, IWRM, failed in fully appraising new future related pressures on the water system such as climate change (Ludwig et al. 2013). With our study, we intended to fill that gap. GLOWA JR approached the transboundary IWRM concept for the Jordan River basin by taking all of the above aspects into account. Namely, integrated water management was approached by addressing climate change, land use change and changes in the socio-economic and political situation, including demographic changes.

27.3 Addressing the Challenge: The GLOWA Jordan River Project

The overall goal of GLOWA JR has been to provide scientific support for sustainable water and land management in a highly water stressed region, with the central question: "How can the benefits from the region's water be maximized for humans and ecosystems, under global change?" In an interdisciplinary approach German, Israeli, Jordanian and Palestinian scientists and stakeholders have worked together from 2001 to 2012 with the dedication that their findings will help ensure that future regional management of water and land resources is effective.

The rationale of the project was that quantification of the water crisis, analyses of future changes, and development of adaptation options need to be addressed in an integrated manner. These aspects were studied in three subsequent project phases. Phase 1 (2001–2005) provided new process understanding and a wealth of new water and land use related data for specific locations, mostly through experiments and data collection. Phase 2 (2005–2008) synthesized and consolidated this information and regionalized methods and findings, mostly via modelling for improving scenarios in relation to global and regional change. Phase 3 (2008–2012) focused on evaluating strategies for water and under water scarcity and global change, looking at potential additional water resources, disseminating the knowledge of the project and introducing new management tools.

The project included various integrated topics, all related to water and land management (Fig. 27.2). Projects dealing with 'blue water' investigated climate change and its impact on water quantity and quality, as well as management options (so-called New Water) for increasing water supply.

A second focus was on so-called 'green water' management, i.e. management of water stored in plants and soil through adaptive land use. Land management was investigated under various socio-economic and climate scenarios and impacts on agro-ecosystems assessed. An active science-stakeholder dialogue, as well as decision-support and dissemination guaranteed continuous interaction between scientists and decision-makers. Details about these activities as well as specific linkages between work packages and models can be found below.

The geographical core region studied was the Jordan River Basin in Israel, Palestine and Jordan, but the exact focal region varied according to the different disciplines (Fig. 27.3). The areas of the Jordan River watershed within Lebanon and Syria, which make up to 14 % of the Jordan River basin (FAO 2009), were not considered in detail.

Taking into account the geopolitical situation of the Jordan River region, global change research and transdisciplinary approaches were in its fledging stages in the beginning of the GLOWA JR project. Nevertheless, GLOWA JR's integrated approach has evolved from phase 1 to phase 3 and close linkages between three main elements were successfully established using qualitative and quantitative model coupling (Table 27.1):

(1) **Drivers** of change were identified, quantified and their change simulated for the next decades, a time frame defined by the stakeholders in the project. The simulated drivers included climate change, land use change and socio-economic

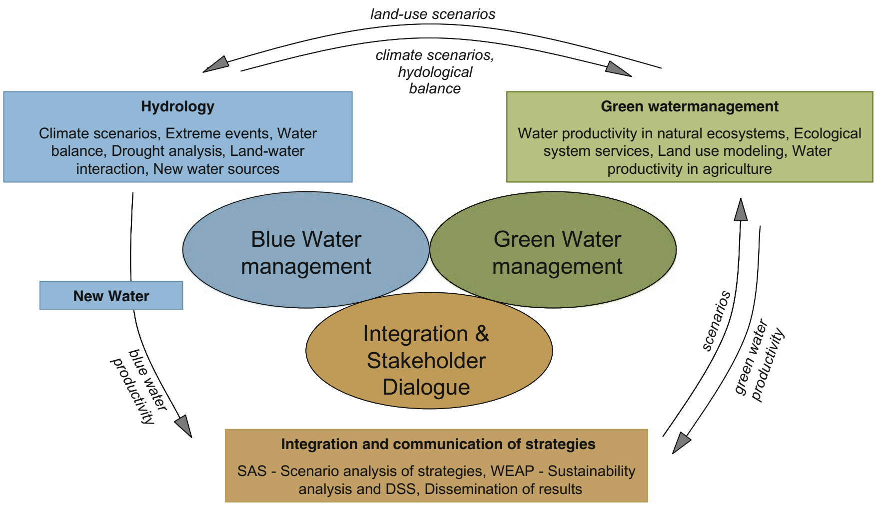

Fig. 27.2 Structure of GLOWA JR in the last project phase (2008–2012). *SAS* Story and simulation approach, *DSS* Decision support system, *WEAP* Water Evaluation and Planning tool

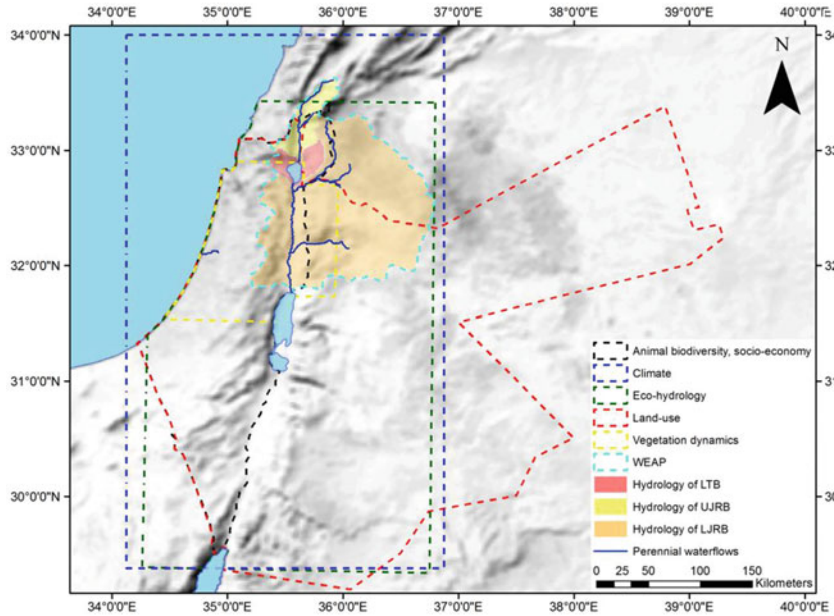

Fig. 27.3 Geographical domains of models developed in GLOWA JR (adapted from the GLOWA JR Atlas, Claus et al. 2014). *WEAP* Water Evaluation and Planning tool, *LTB* Lake Tiberias basin, *UJRB* Upper Jordan River basin, *LJRB* Lower Jordan River basin

changes such as population growth, technology development, or economic growth. The uncertainty inherent in socio-economic developments were addressed through the development of alternative regional scenarios.

(2) **Impacts** of the various drivers on hydrological, ecological, and agricultural systems as well as on society were quantified using model outputs of drivers as direct input into impact modelling or experimental studies. Vice versa, some impact model results served as driver for other models.

(3) **Strategies** for dealing with the impacts of global change, such as non-conventional water sources or adaptive land management, were analysed in an iterative process between scenario analyses and impact modelling, providing flexible decision-support in the shape of tools, option sets for management, or user-friendly data bases.

The summary of models and applications (Table 27.1) indicate the close interrelationship among science and application that has been characteristic for GLOWA JR. This transdisciplinary approach became most obvious in two aspects of the project. First, the Story and Simulation approach (SAS, Alcamo 2009), developed regional scenarios of socio-economic development in a four-year iterative process between scientists and stakeholders (see Onigkeit et al., Chap. 12). As can be seen in Table 27.1, the scenarios fed into a variety of models and were, vice

Table 27.1 Models and methods used within GLOWA JR to produce scenarios for drivers, their impacts, and selected applications in IWRM

	Used models/methods	Simulated variables and parameters, linked driver and impact models
Drivers		
Regional climate change	MM5, RegCM3, boundary conditions: ECHAM5, HadCM3 (Samuels et al. 2011; Smiatek et al. 2011) and more	Precipitation, temperature, wind speed, air pressure, and other climatic variables
Regional development	SAS—Story and simulation approach (Onigkeit et al., Chap. 12)	Population growth, economic growth, water technology development (e.g. treated wastewater (TWW), desalination)
Land use change*	LandSHIFT.JR—Land simulation to harmonize and integrate freshwater availability and the terrestrial environment—Jordan River (Koch et al. 2012)	Land use and land cover changes; impacted by climate, demand for land intensive commodities, the GLOWA JR regional development scenarios
		Driver for regional development, (eco-) hydrological models, vegetation models
Impacts		
Hydrological systems	Eco-hydrological modeling: TRAIN* (Menzel et al. 2009)	Evapotranspiration, soil moisture, groundwater recharge, surface runoff, irrigation water demand; driven by climate and land use, vegetation cover, driver for land use model
	HYMKE—Hydrological model for karst environment (Rimmer et al. 2011)	Stream flow of upper Jordan River catchment tributaries
	Lake salinity model (LSM), lake evaporation model (LEM) (Samuels et al. 2009; Rimmer and Salinger 2006)	Lake solute storage, solute concentration, evaporation rates
	TRAIN-ZIN (Gunkel and Lange 2012)	Overland flow generation in Lower Jordan River Basin, water percolation, channel transmission losses, wadi runoff; driven by climate
Semi-natural and natural vegetation dynamics*	WADISCAPE—Wadi landscape (Köchy et al. 2008; Köchy 2008)	Biomass production, growth form structure of semi natural vegetation, biodiversity, ecosystem function; driver for land use model and economic models, driven by climate and land use model

(continued)

Table 27.1 (continued)

	Used models/methods	Simulated variables and parameters, linked driver and impact models
Animal biodiversity	MaxEnt—Maximum entropy (Phillips et al. 2006)	Distribution of animal species, driven by climate change and land planning scenarios
Agricultural and farming systems and adaptation options	Israel: VALUE—vegetative agricultural land use economics (Kan and Zeitouni 2013)	Farming profits, farm characteristics and irrigation water; optimal allocation of land and water among crops; driven by climate change, driver for land use model
	Jordanian farming system model (Doppler et al. 2002; Al-Assaf et al. 2007); Palestinian farming system model (Hijawi 2003)	Net farm income, cropping pattern, contribution of agriculture to gross domestic product (GDP); driven by climate change and development scenarios
	Jordan Valley (east): WAM—Water allocation model	Efficient land and water use in agriculture for maximization of farming income under climate change conditions
Ecosystem services	Israel and Jordan: MEVES—*M*acro *E*conomic *V*aluation of *E*cosystem *S*ervices	Ecosystem services provided by natural stocks like green biomass, soil deposition
		Adjusted Net Saving Index (index of sustainability of the World Bank); driven by climate change and vegetation models, driver for land use models and scenarios
	Various ecosystem service assessment models, like contingent valuation method, Willingness to Pay (WTP), Agricultural productivity valuation method (e.g. Fleischer and Sternberg 2006)	Ecosystem services provided by forests and rangelands, changes in welfare;
		Driven by climate change, development scenarios and semi-natural vegetation dynamics
		Environmental, economic, social and heritage values of endangered and rare plant species;
		Driven by land use change
Application and strategies (selection)		
Decision-support system	WEAP—Water Evaluation and Planning (Bonzi et al., Chap. 16)	Region-wide and subregion-specific water supply and demand, driven by development scenarios, driver for development scenarios

(continued)

Table 27.1 (continued)

	Used models/methods	Simulated variables and parameters, linked driver and impact models
Soil risk assessment for treated wastewater (TWW) irrigation	Geographical information system (GIS) analysis (Schacht et al. 2011)	Soil sensitivity towards six major agricultural risks, soil and groundwater deterioration associated with TWW irrigation; overall soil sensitivity (Schacht et al., Chap. 18)
Rainwater harvesting and groundwater recharge	GIS analyses and radar data (Lange et al. 2012a, b)	Spatial analysis of suitability for rainwater harvesting (RWH) and managed aquifer recharge (MAR) recharge, driven by TRAIN-ZIN

Asterisks denote models that were used both for simulating drivers as well as impacts

versa, continuously influenced and refined by the model outputs, ensuring a continuous dialogue between scientists and stakeholders.

Another core meeting point for science and application was WEAP, the Water Evaluation and Planning tool (Yates et al. 2005), which has been established as a major decision-support tool in all three water ministries during the course of the project. With direct input by end-users and permanent update with model results from the scientific subprojects, WEAP models of the Jordan River watershed were developed representing current and future water demand and supply and possible water management options taking into account non-conventional water sources (see Bonzi et al., Chap. 16).

Table 27.2 The most important GLOWA JR transdisciplinary products

Transdisciplinary publication or product	Description
Digital GLOWA JR Atlas (Claus et al. 2014) https://publikationen.uni-tuebingen.de/xmlui/handle/10900/53308	Publicly accessible transnational end-user geographical information system (GIS), presents all spatial results of the project, visualises, organises, analyses and presents data
GLOWA JR Briefings series https://publikationen.uni-tuebingen.de/xmlui/handle/10900/53308	Key applications of scientific results summarized for stakeholders, e.g. about effects of climate, global and regional change in the Jordan River basin on natural resources and their management
GLOWA JR homepage http://www.glowa-jordan-river.de	News about the project, project team, activities, and results, link to sustainable products
Scenario analysis https://publikationen.uni-tuebingen.de/xmlui/handle/10900/53308	Description of scenario analysis and strategies

Through WEAP and SAS and their interaction with science and application, a number of transdisciplinary products have been published which are freely accessible for stakeholders and scientists alike (Table 27.2).

27.4 Core Activities, Key Results and Application

GLOWA JR produced numerous results of applied and basic research about the effects of global change and alternative options for responding to them. In the following, we will review the most important approaches, their findings and applications. These will be kept brief where related chapters in this book provide more detail.

27.4.1 Scenarios of Regional Development Under Global Change

The "Story and Simulation" (SAS) approach (Onigkeit et al., Chap. 12) was applied within GLOWA JR to integrate quantitative information, resulting from scientific model simulations, and qualitative information. The latter was compiled by stakeholders from various ministries and non-governmental organizations from the region during a number of Scenario Panel meetings. Four Regional Development Scenarios evolved in an iterative process between inputs from the stakeholder side and scientists. Together they serve as a basis for the development of water management strategies to cope with the impact of socio-economic and climatic changes in the Jordan River region (Fig. 27.4). The most important uncertainties identified by stakeholders were the future of economic development and the way in which the potential for regional cooperation in water management and climate change can be realised. These two axes defined the space in which the four GLOWA JR scenarios were developed.

The "Poverty and Peace" (PP) and "Suffering of the Weak and the Environment" (SWE) scenarios assume economic stagnation while the scenarios "Willingness and Ability" (WA) and "Modest Hopes" (MH) anticipate a prospering economy. The assumption of a multilateral sharing of water resources builds the frame for the PP and WA scenario while SWE and MH assume unilateral division of water (see Fig. 27.4, Onigkeit et al., Chap. 12).

During the scenario development process, a wide range of measures have been elaborated so as to provide for adaptation to future water scarcity under changing socio-economic trends (details see Onigkeit et al., Chap.12). In brief, the scenarios differ in the ability of the society to apply costly high tech solutions (possible only under economic growth) and in the likelihood for technology transfer and cooperation (in the 'peaceful' scenarios). For example, desalination and reuse of treated

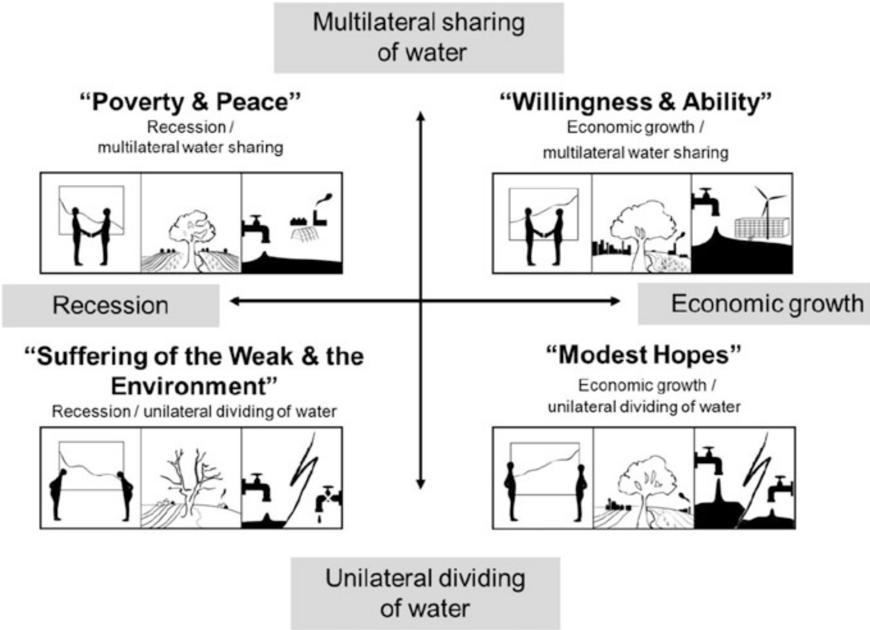

Fig. 27.4 The GLOWA JR regional development scenarios—a schematic presentation

wastewater (TWW) were shown to have a high potential to augment the scarce water resources, but as both these options are costly, they were assumed to be realized mainly in the economic growth scenarios, while water imports e.g. from Turkey, an option that is both costly and requires a high level of regional cooperation, could be realized only under the Willingness and Ability scenario (Fig. 27.5).

The scenario exercise served two main purposes. First, scenario development was used as an integration tool within GLOWA JR. The impact models integrated quantified scenario drivers and qualitative aspects of the Regional Development Scenarios and generated scenario-specific outputs (e.g. water demand *vs*. supply in WEAP) which in turn fed back into the scenario exercise (e.g. as efficiency of a particular management strategy). For example, our decision support tool WEAP used the scenarios to compare the feasibility and effectiveness of various management options in order to identify options that could be possible irrespective of the socio-economic development (Bonzi et al., Chap. 16).

A second important result of the scenario process was to develop and sustain a forum for scientists and stakeholders from all countries involved in GLOWA JR. This not only enhanced the transdisciplinary dialogue but, more importantly, the dialogue among representatives from Israel, Jordan and Palestine. As such, friendly working relationships among top scientists and stakeholders from the region were

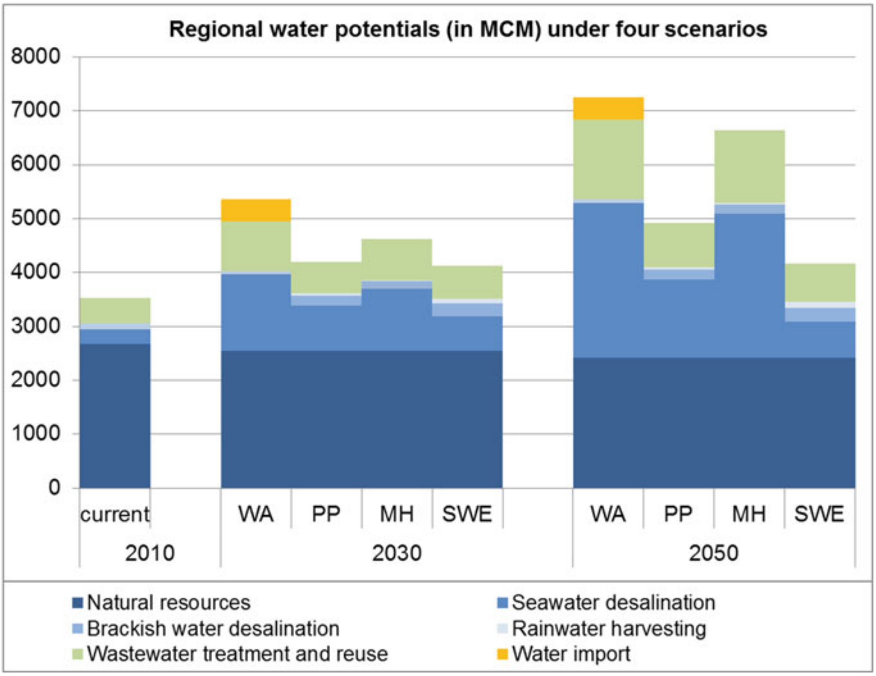

Fig. 27.5 Regional water resources (in MCM: million cubic meter) including potential new water sources assumed to be maximally realizable as part of the water strategies under the four Regional Development Scenarios (*WA* Willingness and ability, *PP* Poverty and peace, *MH* Modest hopes, *SWE* Suffering of the weak and the environment). Natural water resources are long-term averages assuming a climate induced average decline of 10 % until 2050

established over the course of time. This achievement cannot be over-rated in an era where such relationships are rare and fragile but also urgently needed for addressing the challenges of global change.

27.4.2 Scenarios of Regional Climate Change

Predictions of future climate conditions, including future spatial and temporal distribution of temperature and precipitation are an indispensable basis for decision makers in the Eastern Mediterranean if they are to develop adaptation and mitigation strategies. The steep climatic gradient that is characteristic for the region (EXACT 1998) made it necessary to develop downscaled regional climate models of high spatial resolution. Furthermore, the scenario exercise (Onigkeit et al., Chap. 12) dealing with the development of water management strategies has shown that also the time period originally covered by most of the global circulation models (i.e. 2070–2099) and consequently in our non-transient first regional climate model

(RCM) runs (e.g. Alpert et al. 2008), was found to be less relevant for the purpose of water planning. In order to meet the need of the stakeholders, an ensemble of 27 high-resolution transient (now to different time steps until 2099) regional climate models was developed during the entire course of the project by a team of Israeli, German and Palestinian scientists (e.g. Kunstmann 2010; Samuels et al. 2011; Smiatek et al. 2011; Krichak et al. 2011). The ensemble consisted of various combinations of methods (statistical vs. dynamical downscaling), different global models (e.g. ECHAM 5, HadCM3), different regional models (e.g. MM5, RegCM3), different domains and different emission scenarios. Recently, a first summary analysis of an RCM ensemble consisting of five members to assess expected future trends of temperatures, precipitation and other climatic variables and their respective uncertainty has been conducted (see Table 27.3, Samuels et al. 2011).

While the outputs of particular ensemble members differed, there were obvious trends common to all applied RCMs (see Table 27.3). Namely, until the year 2060 an increase of mean annual temperatures of up to 2 °C was accompanied by an increase in warm spell length. All RCM simulations revealed a future reduction of rainfall by 10 % until 2060 as well as a higher inter-annual variability for large parts of the study region (Krichak et al. 2011; Smiatek et al. 2011; Samuels et al. 2011).

Additional effects, relevant for e.g. for human health, included an increase of up to 5 days in the duration and intensity of heat spells (Smiatek et al. 2011, Samuels et al. 2011).

A main outcome of GLOWA JR and the climate scenarios was to put climate change on the national agendas of all three countries involved. National committees dealing with climate change impacts and adaptation have been established. These are largely composed of GLOWA JR scientists and stakeholders. All three countries have drawn knowledge from the GLOWA JR project for developing their climate change adaptation strategies. An early example of this change in attitude leading to direct application stems from the Israeli Water Authority. When negative climate

Table 27.3 Summary of mean climatic variables calculated from an ensemble of five downscaled GLOWA JR climate scenarios for the region

Index	Dec–Feb	June–Aug	Oct–April	Annual mean
Daily mean temperature (°C)	1.31	1.97	–	1.58
Daily maximum temperature (°C)	1.52	1.97	–	1.70
Monthly minimum value of daily minimum temperature (°C)	1.18	2.01	–	1.50
Mean precipitation change (%)	–	–	−5.10	–
Consecutive number of dry days	–	–	4.27	–
Consecutive number of wet days	–	–	−0.06	–

The five scenarios were: MM5 version 3.5 and 3.7 (RCMs) with ECHAM5 and HadCM3 boundary conditions, and RegCM3 (RCM) with ECHAM5 boundary conditions. Changes were calculated by comparing modelled future (2021–2050) and observed past (1961–1990) climatic conditions (Samuels et al. 2011; Smiatek et al. 2011, G. Smiatek pers. comm.)

change impacts on water availability had become apparent through GLOWA JR, the assumed available amount of water had been corrected to considerably lower amounts for planning, thus indirectly supporting the investment into new technologies (e.g. desalination).

27.4.3 Impact of Global Change on the Hydrological System

Through decreased precipitation, increased evapotranspiration and changes in intensity and frequency of climate extremes, climate change will have a direct impact on the hydrological cycle. Therefore, a main focus of GLOWA JR was on modelling the consequences of global change on water quality and quantity. This was done with a variety of models focusing on different areas or modelling vertical or horizontal water fluxes. Investigations focused on the entire Jordan River Region (JRR) using TRAIN (Menzel et al. 2009), on the Lower Jordan River Basin (LJRB) using TRAIN-ZIN (Gunkel and Lange 2012), the Upper Jordan River (UJRB) and Lake Tiberias (Kinneret) Basin (LTB) using HYMKE, LSM and LEM (Sade et al., Chap. 6; Rimmer 2007; Rimmer et al. 2011, Table 27.1), utilizing data from field observations, climate stations, radars and remote sensors. To assess future conditions, the combined impact of a range of climate scenarios and land-use scenarios based on SAS were considered. The results give a broad overview of the vertical and horizontal fluxes over various land use types during normal, as well as especially dry and wet years. Particular attention was paid to current and future frequency and intensity of droughts and their impact on land-use and irrigation (Menzel et al. 2009; Törnros and Menzel 2013).

The effects of climate change and water usage management of the Lake Tiberias Basin are described in chapter 2 in this book (Sade et al. Chap. 2). That work concludes that the effect of reduced precipitation due to climate change on the future water availability in the lake is small compared to local changes due to human intervention. Furthermore, water quality issues will be increasingly important due to intensified land use and more frequent high-flow events (Reichmann et al., Chap. 6).

As the hydrological work was particularly extensive, we only highlight a single example, i.e. aggregated results from TRAIN applications to the entire basin. TRAIN models vertical water fluxes through soils and plants and thus directly connects to land management. A main finding was that a relatively small decrease in precipitation may translate into a disproportional decrease in water availability, due to the temporal distribution of rainfall changes (Fig. 27.6, Menzel and Törnros 2012). Estimates of additional demand for water for irrigation amounted to 15 % up to almost 50 %, depending on the specific climate model applied. This was a striking example of the direct impacts of climate change on the regional economy.

Another important finding was that the frequency, length and severity of 'hydrological droughts', i.e. periods with particularly large demand for irrigation water, are expected to increase. For example, the average length of current droughts could increase by up to 46 days, and the frequency of extreme droughts could be doubled

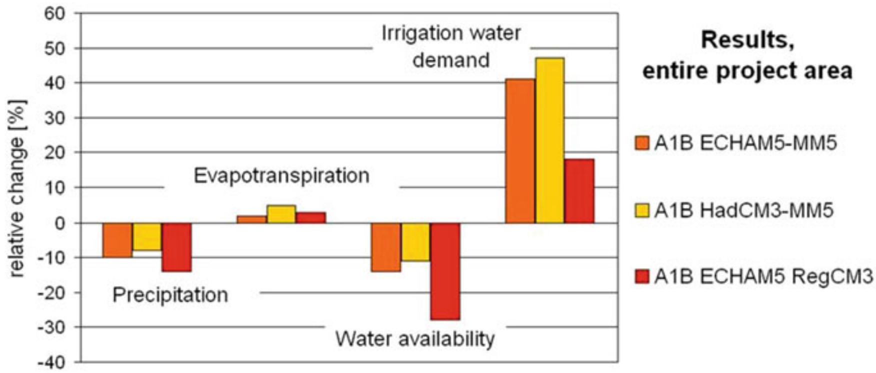

Fig. 27.6 Relative changes (%) of precipitation, evapotranspiration, blue water availability and irrigation water demand between current (1961–1990) and future (2031–2060) conditions for the Jordan River region, based on the three different climate scenarios (Menzel and Törnros 2012)

in the future (Törnros and Menzel 2013). The finding that rainfall variability may strongly amplify within the hydrological cycle was confirmed for the Lower Catchment using TRAIN-ZIN, a coupled model of vertical and horizontal water fluxes (Gunkel and Lange 2012). This result is characteristic of the non-linear behaviour of (semi-) arid systems. Because TRAIN-ZIN evaluated overland flows and local water availability in the upper soil surface, it could be used for direct applications in adaptive water management. On the one hand, boundary conditions for rainfed agriculture were evaluated and the spatial extent of current and future areas suitable for rainfed practices communicated to stakeholders (now available in the GLOWA JR Atlas, Claus et al. 2014). A second product, which has been particularly valued by the stakeholders, was a spatial assessment of the suitability of the area for rainwater harvesting (RWH) and managed aquifer recharge (MAR). Rural and urban RWH techniques are interesting because they provide a large potential for decentralised water supply at relatively low cost, i.e. they can be realized under all GLOWA JR scenarios, albeit with an increased importance in the 'poor' scenarios (Fig. 27.4). Our models indicate that the potential of RWH will increase in the future due to population growth and projected urbanisation. However, this unconventional water source exhibits a high temporal variability, making it somewhat unreliable. For example, the modelling indicated that in an average rainfall year 195 MCM, in a dry year only 48 MCM can be harvested in the LJRB (not including Yarmuk and Zarqa basins, nor runoff generated in the Jordan Valley itself) (Lange et al. 2012a, maps see GLOWR JR Atlas, Claus et al. 2014).

Other unconventional water sources assessed in GLOWA JR include desalination (see Bonzi et al., Chap. 16), and the use of TWW for irrigation (Fig. 27.5). Availability and costs of TWW under scenario conditions were evaluated using economic models (e.g. VALUE model, Table 27.1) while hydrological models in combination with soil studies and yield models were used for soil risk assessment (Schacht et al. 2011, Schacht et al., Chap. 18). Namely, GIS analyses showed for most soils in the entire region a high or moderate suitability for irrigation with TWW. High soil sensitivities were found mainly for sandy soils near the coast and shallow heavy soils of the mountains, where soil salinization and groundwater pollution pose a great risk (see Schacht et al., Chap. 18 and Schacht et al. 2011).

In summary, the results of the climate change models are used as an input to the hydrological models to develop hands-on solutions to adaptive land and water management, i.e. the hydrologic models translate climatic droughts into actual water availability and therefore suitability of certain areas for particular types of land use.

27.4.4 Impact of Global Change on Ecosystem Function and Services

The study area is a biodiversity hotspot of global concern (Myers et al. 2000). At the same time, biodiversity provides many important services to society, while being increasingly threatened by human impact. Therefore, we studied the impact of climate change and land use change on semi-natural ecosystems in the region to assess the value of these systems for society under current and future conditions. To this end, we relied on long term experiments and on models that were calibrated with field data. Several long term research sites were established along the steep climatic gradient which is characteristic of the region. Both, rainfall (Tielbörger et al. 2014) and grazing were manipulated in these sites through experimental treatments either increasing or reducing the amount of rainfall and/or the grazing pressure. The experimental results suggest that productivity, structure and biodiversity of semi-natural ecosystems are likely to be resistant to climate change (Tielbörger et al. 2010), but that grazing may have an immediate and large impact on ecosystem function. Most interestingly, the observed resistance to climate change applied only to systems that were under no or low grazing pressure. This has two main implications: On the one hand, current stocking rates in many regions in Jordan are above the level which will permit the diversity and services provided by these systems to be maintained and to effectively resist climate change. On the other hand, a clear recommendation can be drawn from these findings: a reduction in grazing pressure in regions with very high stocking rates will greatly help maintaining the function and associated services in the future.

In Jordan, an in-depth assessment of socioeconomic benefits of ecosystem services was conducted under climate change conditions and indicated that the recreational benefits of ecosystem services generated by climate change can be tremendous (Table 27.4). The costs of environmental degradation are estimated based on approximation of return to land. The ecosystem services generated by urban areas are expected to drop to 1/3 of the 2000 level as a result of climate change. The estimated value of degradation of different ecosystem services could be used for further adaptation policy.

Table 27.4 Changes in land values of ecosystem services measured as gross margin, profit or market value (US$/ha)

Land-use/land-cover type	Year 2000	Year 2050
Evergreen needle leaf forest	153.5	392.8
Evergreen broadleaf forest	207.7	387.1
Deciduous needle leaf forest	98.2	282.8
Deciduous broadleaf forest	173.1	361.1
Mixed forests	192.6	291.7
Closed shrublands	30.6	77.8
Open shrublands	2.2	8.84
Permanent wetlands	81	645.0
Urban and built-up	1,118,800	304,566
Barren or sparsely vegetated	1.2	3.54

The ecosystem service values were used as input into the LandSHIFT.JR model (see maps in GLOWA JR Atlas, Claus et al. 2014; Volland et al. 2014) which aimed at exploring the effects of socio-economic, climatic and biophysical changes on land use allocation, including natural and semi-natural ecosystems (see below).

An intriguing conclusion which may seem against ‘conventional wisdom’ was obtained from combining the findings from the ecological studies (Tielbörger et al. 2014) with the economic analyses of ecosystem service provisioning (Fleischer and Sternberg 2006): a main application was that in terms of revenue from ecosystem services, rainfed land-use should be favoured over irrigated agriculture because it is more sustainable and may yield, in a changing climate, higher returns (Tielbörger et al. 2010). Therefore, protecting open space may maximize the benefit to society, because non-market values can be much larger than profit from agriculture (Fleischer and Sternberg 2006; Tielbörger et al. 2010). In combination with findings where intercropping with wild plants in rainfed fields was shown to yield high revenues (Salah 2008), we can conclude that an expansion of rainfed land use at the expense of irrigated land use may help to meet the challenges posed to the water cycle in the region in an era of global change. Such a shift in land use patterns will require fundamental shifts in priorities regarding land allocation but will eventually yield large economic benefits.

Further impact of the ecological work was that before GLOWA JR, the idea of allocating water for nature was unthinkable for water managers. According to key stakeholders in Jordan (pers. comm.) the project caused them to place nature conservation on their agenda and reallocate water from direct human consumption to natural ecosystems and the remnants of the Jordan River.

27.4.5 Impact of Global Change on Agricultural Systems

Most of the agriculture in the region relies on irrigation. Therefore, agriculture will be directly affected by global change (see Fig. 27.6 for irrigation demand). It is thus not surprising that considerable attention went into studying adaptation options and impacts of climate change on agricultural systems. These studies were done separately for Israel, Jordan and Palestine though similar methods were applied.

Simulations show that the impact of climate change on the decrease of wheat yields was significant. The use of adaptation techniques, like mulching or screening mesh, reduced evaporation and therefore total water use considerably (GLOWA JR Atlas, Claus et al. 2014).

The simulated impact of climate change on the growth of fruits and vegetables in Israel indicated a reduction of about 15 % in the cultivated land and of 5–7 % in profits (Kan and Zeitouni 2013) with precipitation as the main driver of change. Overall, a reduction of farm profitability was observed due to an increase in input costs, a reduction in cultivated land, a shift from rain-fed to high technological agriculture, and a reduction in farmland landscape value (Kaminski et al. 2012).

Similar trends were observed for the Jordanian side of the Jordan Valley in that the suggested reduction of water supply yielded a reduction in the area of highly water consumptive crops and a reduction in the total farm net income. The relative fraction of cultivated area of more profitable crops such as fruit trees was found to increase at the expense of field crops. Furthermore, indirect negative effects on the livelihood subsistence (such as decreasing employment opportunities and source of income) of the agricultural communities could be observed (Salman et al. 2013).

27.4.6 Scenarios of Land Use Change

Adaptive management under climate change may capitalize on two sides of the same coin. On the one hand, reduced water availability may be augmented by new (blue) water sources such as desalination, TWW, RWH and others (see above), or by reducing demand. The latter can be most effectively achieved by 'green water management', i.e. adaptive management of land use, an idea that has led to the concept of IWRLM or ILWRM (L = land) (Calder 2005; Falkenmark and Rockström 2006; Rockström et al. 2007). Namely, a shift from water intensive irrigated agriculture towards more rainfed practices seems a must under the predicted water gap. However, the considerations of which land use practice to apply and where to do so is rather complex and depends on physical land characteristics (e.g. soil types or local climate), accessibility, cultural factors (e.g. cultural preference for certain land use types, such as grazing), socio-economic factors (e.g. market, Fleischer et al. 2008, 2011), and many more. Therefore, results of almost all above subprojects were used to model adaptive land use under climate change and the four GLOWA JR scenarios.

The regional land-use model LandSHIFT.JR was developed and refined to generate comprehensive integrated land use scenarios for the Jordan River region (Koch et al. 2012). Calculations considered the SAS socio-economic scenario drivers such as population growth, amounts of crop production under rainfed and irrigated agriculture, and information about soils and climate provided by other GLOWA JR subprojects.

Without climate change, simulations of land use change which only considered regional development scenarios indicated that both urban areas as well as agricultural areas will increase considerable until 2050. For example, urban land cover may increase to 44 % (SWE) and to 59 % (WA), respectively, irrigated agriculture may be expanded by 36 % (PP) to 184 % (WA), and the largest increases were simulated for rangeland (168 % (SWE) to 425 % (WA)) (Fig. 27.7).

A consequence of increased land demand for urban areas and agriculture, would be a strong reduction in the area of (semi) natural vegetation. Though much of the

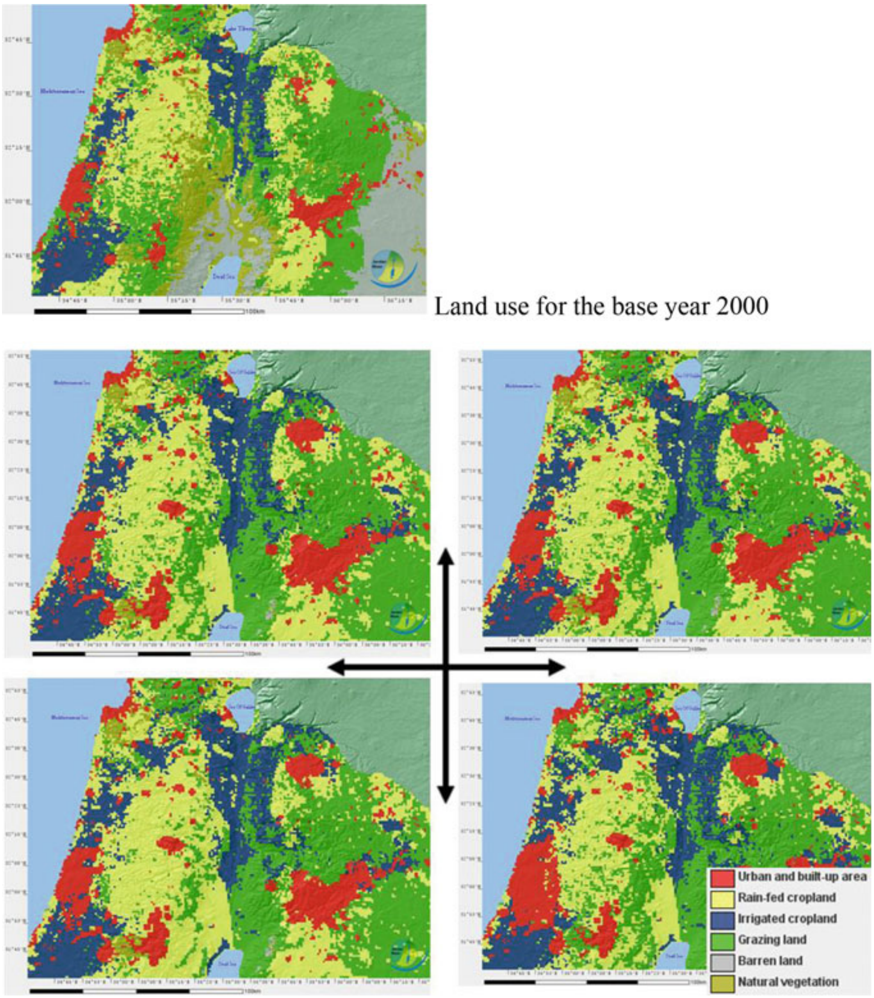

Fig. 27.7 Land use for the base year 2000 (above) as well as land use change simulations for the year 2050 computed with LandSHIFT.JR for the four GLOWA JR scenarios (see Fig. 27.4) assuming no climate change conditions (GLOWA JR Atlas, Claus et al. 2014; Volland et al. 2014)

grazing will actually be done in such semi-natural areas, overgrazing may lead to considerable degradation of these regions and the predicted forage production will not meet the feed demand of grazing livestock (Koch et al. 2012). Hence there could be a shortfall in forage production between 58.000 t/a (MH) and 364.000 t/a (WA) by 2050.

For all simulations taking into account climate change, the expansion of irrigated and rainfed cropland as well as rangeland was somewhat more pronounced but overall, spatial land-use patterns did not differ largely between scenarios with and without climate change. The main impact on increased urbanization and agricultural land, which was predicted for all scenarios was due to population growth, highlighting again the need to manage demand rather than supply of water.

27.4.7 Decision Support Tool WEAP

The central decision support tool applied and introduced into the region by GLOWA JR is the Water Evaluation and Planning (WEAP) tool, a computer model based on water balance accounting principles that integrates many different scientific results (Bonzi et al., Chap. 16) and thus transferred the scientific project results into application. The WEAP applications reproduced the water system in the Jordan River Basin and allowed comprehensive testing of joint management options of green and blue water resources and trade-off analyses such as allocation of water from irrigated agriculture to rain-fed land use (e.g. open space, rain-fed crops). Furthermore, WEAP addressed conjunctive surface and groundwater management by incorporating the groundwater model MODFLOW (Abusaada 2011). Besides, the model for the entire Lake Tiberias Basin was build using two modules: WEAP and the karst hydrology model HYMKE (Rimmer and Salinger 2006). Lake water balance calculations and artificial rain generation tool were used in order to create the combined model structure (Sade et al. 2016). Finally, WEAP was used to evaluate the effectiveness of contentious mega-projects such as the Red Sea-Dead Sea Canal (Al-Omari et al. 2014).

Regional stakeholders have been closely involved in WEAP development to meet local demands and guarantee the regional implementation of the tool. WEAP was therefore ideal to support regional water planners in analysing management options and water allocation schemes under global change. This has made WEAP a key water management tool in the entire region with important applications in the Jordanian Ministry of Water and Irrigation, and the Palestinian and Israeli Water Authorities.

Although WEAP is a very capable IWRM-tool it has, as all models, certain limitations. For example, the results of the WEAP models are only as good as their input data. In that context, it is important to remember that data availability in the region is often limited and that data from different sources is often not compatible.

In addition, the fact that some input, e.g. about climate, land use (e.g. cropping patterns) or impact, are generated by models and thus, introduces another level of uncertainty to WEAP results (Yates et al. 2009; Ludwig et al. 2013). Further uncertainty arises from 'soft' information or lack thereof, such as static cropping pattern, unique water rights, demand preferences, and mechanisms.

27.5 Transboundary Cooperation in GLOWA JR

Alongside of the above described intention of the German Government in deciding to finance GLOWA JR went a second, to promote peace and understanding in a region driven by conflict through the creation of working relationships among the people of the region in general, and the scientific community in particular.

From the outset, the project was driven by an acute awareness that climate change posed a threat to Israelis, Jordanians and Palestinians alike. As it developed, the research was co-designed by the scientists involved together with significant regional stakeholders such as the various water authorities and other relevant ministries, notably those of Agriculture and Environment, and representatives of civil society. While the day-to-day leadership of the project was taken care by the University of Tübingen, decisions as to policy and research to be undertaken, were made at a series of meetings (approx. 30), which involved the participation of a significant number of lead researchers and stakeholders. These meetings were significant in that they enabled face-to-face contact between those involved to take place and thus fostered confidence building, but they were not the only manifestations of cooperation. Articles written jointly by scientists from the various countries involved were published in a wide variety of professional journals (e.g. Tielbörger et al. 2010; Grodek et al. 2011; Schacht et al. 2011; Lange et al. 2012a, b) while the results of the project were made known in electronic and conventional media. In all these instances it was clear that the work being undertaken was cooperative in character, the scientists involved were working together regardless of their nationality. The project managed to prevent the political situation in the region from impeding its work and this required careful professional facilitation and understanding from all concerned that they should avoid letting the conflict hamper their work.

The long term value of such cooperation is evident. Even when political tensions scar the region, professionals can work together over environmental issues of mutual concern. The role of the German participants was of value in providing a neutral presence as well as making a major scientific contribution. Such links between scientists can survive even if the political situation in the region is difficult, provided there is not outright violent conflict, because water and other natural resources know no borders.

27.6 Sustainability of GLOWA JR

It is imperative that the outcome of a project such as GLOWA JR should be sustainable. A key factor in ensuring this is the availability of the results of the research undertaken during the course of the project. Every effort has been made to ensure that, e.g. through publication of results in professional journals (to date more than 340), through distribution of results and tools to key stakeholders in the region and internationally (Table 27.2), and through contribution to international conferences and meetings. In addition, the project has during its existence provided opportunities for training and obtaining additional academic qualifications to hundreds of students at all levels, many of whom have found positions in their respective governments.

The experience of GLOWA JR showed that there is still a need in developing methods to communicate the large range of possible futures and the resulting uncertainty from climate and impact model runs to decision makers (Ludwig et al. 2013). Two further important elements in securing sustainability have been the introduction of the WEAP water management tool into the region and the preparation of alternative regional scenarios designed to assist decision makers in Government determine how best to adapt to climate change. WEAP has been adopted in Jordan as a major element in national water planning and it being widely used in Israel and Palestine. The scenarios have provided stimulus to creative thinking in Ministries and other Governmental bodies in the region.

It is in great part due to the impetus provided by GLOWA JR that climate change has steadily gained recognition as an important factor in national environmental planning in the region. This has been most clearly demonstrated by the effort currently being made to establish a regional centre for sustainable adaptation to global change. This will, if it materializes, allow substantial additional transboundary research, and stimulate both Governments and civil society to much needed action to adapt effectively to global environmental challenges. The concept has Government support from the region and is now being actively considered by all the concerned parties.

If an effective and cooperative response to climate change is sustained, a large part of the credit should be given to the work done within GLOWA JR over the 12 years of its existence.

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Chapter 28
Challenges of Implementing IWRM in the Lower Jordan Valley

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28.1 Introduction

The Lower Jordan Valley (LJV) (Fig. 28.1) comprises parts of Israel, Jordan, and the Palestinian Territories and, in terms of per capita freshwater availability, is among the water scarcest regions worldwide. The current overexploitation of the

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Fig. 28.1 The Lower Jordan Valley (picture taken from the eastern escarpment in Jordan with view to the West Bank, *photo* J. Klinger)

natural surface and groundwater resources already shows severe impacts on environment and society. According to the observed trends of population growth and demand, the conditions are likely to be aggravated in the coming years.

On a regional scale, capacious seawater desalination and import schemes are presented as potential solutions. However, even if political and economic constraints and environmental concerns over such mega-projects can be overcome, the effective management and protection of the basins internal resources still remains a key requirement for the future water security in the LJV.

In response to this situation, the responsible governments have already stated their commitment to foster IWRM (integrated water resources management) as well as the required major water sector reforms. However, each of the riparian states is vastly different in terms of institutional setting and capacity, awareness, economics, and water policy. Therefore, at present, there is no universally applicable basin-wide IWRM implementation concept for the LJV. In spite of this, there are common denominators that unite the different riparian states. Aside from the need for reliable and comprehensive information on the temporal and spatial availability of the regions' conventional water resources, the understanding of treated wastewater, brackish groundwater, and storm runoff as genuine parts of the water management cycle highlights the importance for IWRM in such water stressed regions. The critical challenges in this regard are the establishment of measures that are technically adapted to local physical conditions as well as conceptually adapted to the respective socio-economic realities.

The multilateral research and development project SMART (**S**ustainable **M**anagement of **A**vailable **R**esources with Innovative **T**echnologies) was a research initiative with partners from Germany, Israel, Jordan and the Palestinian Territories. Through a series of local pilot studies and demonstration sites in sub-catchments in the LJV within this project, these topics have been investigated.

28.2 The Lower Jordan Valley

28.2.1 Geographical, Hydro-geological Settings and Climate

The LJV in the Middle East is part of an extensive geological transform fault system and is shared by Israel, Jordan, and the Palestinian Territories. It extends over 100 km from Lake Tiberias in the north to the mouth of River Jordan at the Dead Sea in the south. As part of the LJV, the SMART project region encloses an area of approximately 5,000 km^2 including the valley floor with a width of 8–15 km as well as numerous tributary sub-basins (called 'wadis') east and west of the River Jordan (Flexer et al. 2009). The project area is bordered by mountain ridges on the eastern side along the cities of Irbid, Amman, and Madaba, and on the western side along the cities of Nablus, Ramallah, Jerusalem, and Hebron (Fig. 28.2).

The Dead Sea is the lowest area topographically and lies currently at about 420 m below sea level, while the surrounding mountain ridges reach altitudes of 1,200 m above sea level.

The climate in the project region is arid to Mediterranean. Arid conditions prevail down in the Jordan Valley with precipitations below 150 mm/a, whereas the potential evaporation can exceed 2,600 mm/year. Along the mountain ridges, Mediterranean climate dominates with precipitation of 600–800 mm/year and a potential evaporation of 1,600–1,900 mm/year (Flexer et al. 2009).

28.2.2 Water Resources in the Lower Jordan Valley

The LJV lies within a region where water demands frequently exceed the availability of resources. As such, water shortage is a problem for daily life, especially in dry periods. As the average water available per person is below 150 m^3/year, this region is facing absolute water scarcity according to the FAO (see FAO 2012). This situation is aggravated by declining natural groundwater recharge and the constant population growth. Based on this indicator, Jordan and the Palestinian Territories can be described as regions suffering extreme water shortage. The deficit of water demand and water availability is already significant and will face an aggravated increase in the next 10–15 years. Table 28.1 provides a water budget for both present and future conditions in the riparian states of the LJV.

Fig. 28.2 Overview of the SMART project area in the LJV. The *green* and *red coloured* areas display the study areas and the trans-boundary groundwater model is shown by the hatched area

Table 28.1 Current and projected water availability and demand in adjacent countries in the LJV according to the respective water strategies

	Israel		Jordan		Palestinian Territories(West Bank)	
Year	2010	2020	2010	2025	2010	2022
Freshwater resources (MCM/year)	1,170[(3)]	1,170[(3)]	780[(7)]	483[(8)]	127[(4)]	>127[(6)]
Inland brackish water desalination (MCM/year)	25	75[(1)]	57	82	0.5	22
Seawater desalination (MCM/year)	270	650[(2)]	–	370	–	–
TWW reuse in agriculture (MCM/year)	400	570[(1)]	100	247	–	30.6
Population (million)	7.7	9.1	6.1	8.5	2.65[(5)]	5.7
Total water demand (MCM/year)	1,994	2,596	1,315	1,652	125[(5)]	712[(9)]
Deficit of water (demand—resources) (MCM/year)	129	131	361	470	2	≫2

Abbreviations: *TWW* Treated wastewater; *MCM* Million cubic meters
Superscript numbers: [(1)]2015 value, [(2)]2017 value, [(3)]Pumped water, [(4)]Domestic and agricultural water supply, including purchases from Mekorot utility, [(5)]2012 value, [(6)]Depends on the access to water resources, [(7)]Estimated natural groundwater and surface water resources, [(8)]Renewable and non-renewable groundwater only, [(9)]Long-term water strategy of 2022
Sources Guttman (2011), Rosenthal and Katz (2010), Palestinian Water Authority (2012), RCW and MWI (2009)

The table reflects that all riparian states include prospective increasing water demand in their water strategies. The reuse of treated wastewater, the inland brackish water desalination, and seawater desalination is planned to be reinforced so that the water demand deficit can be mitigated. For instance, in case of Israel, reuse of treated wastewater is being practiced at a large scale e.g. at Shafdan (Cikurel et al. 2012), and the government is currently implementing a large seawater desalination program along the Mediterranean coastline (Dreizin 2006).

In Jordan, water reuse, especially for irrigation purposes in agriculture, is being practiced as well. Major infrastructural projects like the Disi water conveyance pipeline or the Red Sea—Dead Sea water conveyance project represent two of the main future options. In the northern part of Jordan, the water situation is getting particularly worse due to the crises in Syria. The UNHCR (October 2014) indicate almost 3.2 million Syrian refugees in the Middle East, 620,000 refugees are officially registered in Jordan. Jordan's Ministry of Water and Irrigation announced estimates up to 1.3 million Syrian refugees in Jordan by the end of 2014. As such, the country has experienced a defacto population growth of more than 20 % within the last 2 years, compared to the total population of 6.3 million (in 2012).

The situation in the Palestinian Territories, especially at the West Bank, is characterized by the limited access to natural resources and on-going conflict with Israel. The availability of water per capita ranges from 29 to 150 l/d, but is mostly below 80 l/d, with widespread seasonal water cut-offs, mainly during dry summers.

30 % of the communities or 700,000 people are currently not served by any water network. In these areas, purchasing water from trucks and hauling water from standpipes are typical practices. Due to the lack of water, many people use untreated wastewater to irrigate their farms and gardens without taking into consideration health and environmental risks especially to children and pregnant women. The gap between supply and demand will increase dramatically in the coming years.

In all three regions, by adjusting the allocation of water among the three riparian countries together with additional measures, such as water reuse, brackish water desalination and storm water harvesting, the insufficient water supply could be radically improved. The development and application of an approach addressing IWRM principles could provide a way towards an efficient, equitable and sustainable development and management of the scarce water resource in the LJV (Hötzl et al. 2009).

28.3 The SMART Project: Objectives and Major Outcomes

The SMART project represents a multilateral and interdisciplinary research initiative with 23 partners from universities, research centres, water authorities, decision relevant institutions, external experts as well as partners from the industry from Germany, Israel, the Palestinian Territories and Jordan. The project was funded by the German Federal Ministry of Education and Research (BMBF) from 2006 to 2014 (Wolf and Hötzl 2011; Klinger and Goldscheider 2014). The overall goal was to develop a concept for integrated water resource management for the LJV to ensure an optimized and sustainable use of all water resources in the region. It was the aim that the developed, applied and validated concepts throughout the project should be transferable to other regions suffering from natural and/or anthropogenic water scarcity (DoW 2010; Klinger et al. 2015).

Under the umbrella of an integrated water resource management scheme, the study addressed relevant ecologic, economic, and social issues and built upon the assessment of conventional water resources as well as unconventional water resources. This was based on the investigation and evaluation of water resources that were not taken into account for use due to qualitative or storage deficits. Therefore, suitable techniques had been developed, demonstrated and in parts implemented. Figure 28.3 illustrates the project structure and reflects the interlinkage of work packages (WP). The following text summarizes the outcomes of each work package.

For decision-making in natural resources management, a detailed database of all available variables and measurements is essential. As seen in Fig. 28.3, WP 2 included the development of a comprehensive database management system called DAISY (DAta and Information SYstem) (Geyer 2014). Partners of the riparian

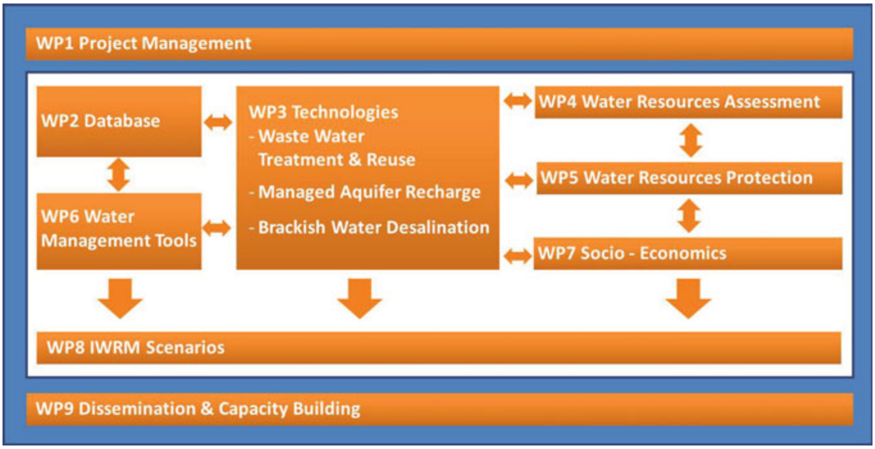

Fig. 28.3 Project structure of the SMART project

states of the LJV contributed data to the database, which continues to operate. Currently, approximately 2 million data records exist within the database, which underlines the success of the transboundary approach of the project. The database's interface, which can be used to display and download data, can be found at: https://www.ufz.de/daisy_harvester/.

In the field of waste water treatment (WP 3-1), five different technologies towards the reuse of wastewater had been developed and adapted, complying with the Jordanian Standard (JS 893-2006). In total, seven decentralised waste water treatment (DWWT) systems for individual households and multi-family houses had been implemented in Jordan (Mueller and Abbassi 2014; Van Afferden et al. 2010; Boog et al. 2014). With regard to Managed Aquifer Recharge (MAR, WP 3-2) an evaluation of relevant biogeochemical processes during the vertical infiltration, as well as socio-economic considerations concerning the feasibility of MAR implementation was performed and six test sites were studied (Tiehm et al. 2011; Zemann et al. 2014; Xanke et al. 2015). Suitable sites for the desalination of brackish groundwater (WP 3-3) were identified by geophysical and analytical methods along the Jordan Valley (JV) (Salameh and Frimmel 2010; Saravia et al. 2013). An innovative water treatment plant, which uses low pressure reverse osmosis membranes to treat the challenging groundwater, was built in Karameh, Jordan. This facility has the potential to generate 10 m^3/h of treated water (Frimmel and Flexer 2014).

In the long-term planning of an integrated water management scheme, the assessment of surface water and groundwater resources (WP 4) are the most important components. Within the project, direct measurements of discharge components (surface, groundwater and waste water) components, water budgeting, forward modelling with hydrological models have been performed on catchment scale along the JV. The measurements provided improved estimates of these water resources in the region (Schmidt et al. 2013).

With regard to groundwater protection (WP 5), detailed evaluation of water quality and trace contaminants in the LJV and adjacent Wadis was performed, with a focus on wastewater impacts on groundwater resources (Zemann et al. 2015; Tiehm et al. 2012). The development and initial implementation of continuous monitoring techniques at a karst spring in Jordan could be connected to the regional drinking water network. A sustainable outcome of SMART is the advancement of groundwater protection zoning concepts, with initial implementation in the Palestine Territories (Goldscheider and Guttman 2014).

The focus in WP 6 (IWRM tools) was on the development, deployment, and application of state of the art tools for IWRM, including a web-based set of visual tools for water resources management, a platform for risk assessment (see http://www.ewre.com/smartdss/publish.htm) as well as a web-based visual platform for knowledge management (DROPEDIA, see http://www.dropedia.iwrm-smart2.org (Riepl 2013; Kämpgen et al. 2014; Bensabat et al. 2014).

The works in WP 7 (socio-economics) focussed on tools for cost benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), financial feasibility analysis, social acceptance analysis, and hydro-economic models that aimed to increase the economic efficiency of water management projects at basin level (Heinz et al. 2014).

The WP IWRM scenarios (WP 8) focussed on the provision of planning criteria on the sub-basin level and the integration of results from other work packages into combined IWRM approaches (Wolff et al. 2012).

The WP 9 encompassed all work packages and addressed the dissemination and capacity development of each individual work package. The direct outcome of this work was the knowledge transfer and training in schools, including teachers and technicians. The teaching materials and booklets were published in English and Arabic language (http://www.waterfunforlife.de/projects-partners-promoters.html).

Furthermore, academic capacities were built within a doctorate program, in which 26 doctoral students from Israel, Jordan, the Palestinian Territories and Germany participated. Scientific advanced training for researchers from the region ensured the preservation of a sustainable development and supported the transboundary cooperation. The publication and dissemination of the results are documented in more than 35 papers in international journals (van Afferden and Ali 2014).

The studies in SMART are multifaceted and were performed on almost all spatial, technical and institutional levels reaching from field investigations and technology demonstration, to stakeholder consultations. However, the focus of this chapter is on local IWRM studies as they incorporate the experiences within the course of the project.

28.4 IWRM in the Lower Jordan Valley

28.4.1 Basic Requirements for IWRM Implementation

IWRM is a framework which promotes a coordinated development and management of water (GWP 2004). However, IWRM can only be effectively implemented if the affected regions adapt their water policies continuously to the changing boundary conditions (Wolff et al. 2012; Biswas 2004; Riepl 2013). The riparian states of the LJV have declared to incorporate IWRM principles in their water strategies and numerous studies to support the decision making process have been published. As an example, innovative water management options like sea water desalination, water trading, brackish water desalination in the Middle East (Fischer and Lee 2011; Mohsen and Jaber 2001) have been described within publications in terms of economic assessments of such alternative options. Other studies focused on economically efficient measures in the agricultural sector (Ramirez et al. 2009), as most of the water is consumed by irrigated agriculture to ensure food security (in Jordan approximately 75 %). Proposals for the integrated management of the shared transboundary water resources of the Jordan River Basin were discussed previously in the 1990s by Shuval (1994). These studies are valuable as they describe the process of the implementation of important IWRM elements.

In the following sections, the authors illustrate how SMART accomplished water management assessments of the riparian countries taking basic IWRM principles into consideration. First, the local IWRM studies within the project are introduced and the stepwise approach is presented (Sect. 28.4.2). Based on a profound analysis of the different national water strategies in the LJV (Sect. 28.4.3) and the dynamics of the water sectors' changes, e.g. due to population growth, detailed scenarios have been compiled to take the specific boundary conditions into account (Sect. 28.4.4).

The relevant components of the water strategies, including the applied water management options and developed scenarios had been incorporated into a framework (Sect. 28.4.6) for the assessment of the respective water strategy by the use of defined performance indicators. The indicators are introduced and discussed in Sect. 28.4.5.

28.4.2 Introduction and Overview About Local IWRM Studies in the LJV on Sub-basin Scale

The principles of the Global Water Partnership postulate that integrated water resource management is built upon a clear understanding of the river basin processes (GWP 2009; FAO 2012). In accordance to these principles, adapted water management strategies are the prerequisite to reach the long term goals. The processes of defining how these goals can be reached are described in individual strategies covering periods of 10–20 years. Within the SMART project, comprehensive studies on the development of adapted IWRM concepts have been conducted on the sub-basin scale for the identification of water related problems to provide technically feasible solutions. The involvement of local stakeholders, through scientific steering project meetings and workshops, as well as representatives of international development cooperations, ensured realistic assumptions and input in developing water management options and scenarios. This involvement is a prerequisite for the sustainability of IWRM concepts.

Local IWRM studies have been developed and applied in four different areas on the sub-basin and settlement scale: Wadi Cluster Auja, Nuema and Quilt (see Rusteberg et al. 2014) as well as the local study Kalya (Guttman and Bensabat 2013) on the western side of the Jordan River and Wadi Al-Arab (Rödiger 2014) and Wadi Shueib (Riepl 2013) in Jordan. The main characteristics reflecting this integrated approach are displayed in Table 28.2.

Table 28.2 Overview of the local IWRM studies and their main characteristics

Properties	Wadi cluster Auja/Nuema/Quilt	Kalya	Wadi Al-Arab	Wadi Shueib
Location of sub-basin/study area	West Bank	West Bank	Jordan	Jordan
Area (km^2)	577	<10	300	190
Time line: current status	2010	2010	1980–2008	1994–2009
Time line scenario	2050	No scenarios defined	No scenarios defined	2010–2025
IWRM measures rely on	Participative approach, interaction of water experts and stakeholders	Participative approach, interaction of water experts and stakeholders	Hydrological assessment—artificial recharge as key technology	Jordan's water strategy water for life
Ranking of measures, setting of priorities and definition of scenarios	AHP, multi-criteria analysis; local IWRM strategies as combined water management measures	AHP, definition of alternative water management options using multi-criteria decision procedure	Multi-response calibration, scenario: recharge of TWW and storm water	Based on Jordan's water strategy water for life and action plan
Scenario modelling/optimise strategy	Multi-objective optimization/Pareto-Frontier	–	J2000g; FEFLOW	WEAP21
Involved stakeholder, decision maker	PWA, PHG, MoA, MEKOROT	MEKOROT	MWI, WAJ, JVA	MWI, WAJ, JVA

Abbreviations used: *AHP* Analytical hierarchy process, *J2000g* proper name; *FEFLOW* Finite element flow, *WEAP21* Water evaluation and planning system, *PWA* Palestinian water authority, *PHG* Palestinian hydrology group, *MoA* Palestinian Ministry of Agriculture, MEKOROT Israel National Water Company, *MWI* Ministry of Water and Irrigation (including Water Authority of Jordan (WAJ) and Jordan Valley Authority (JVA)

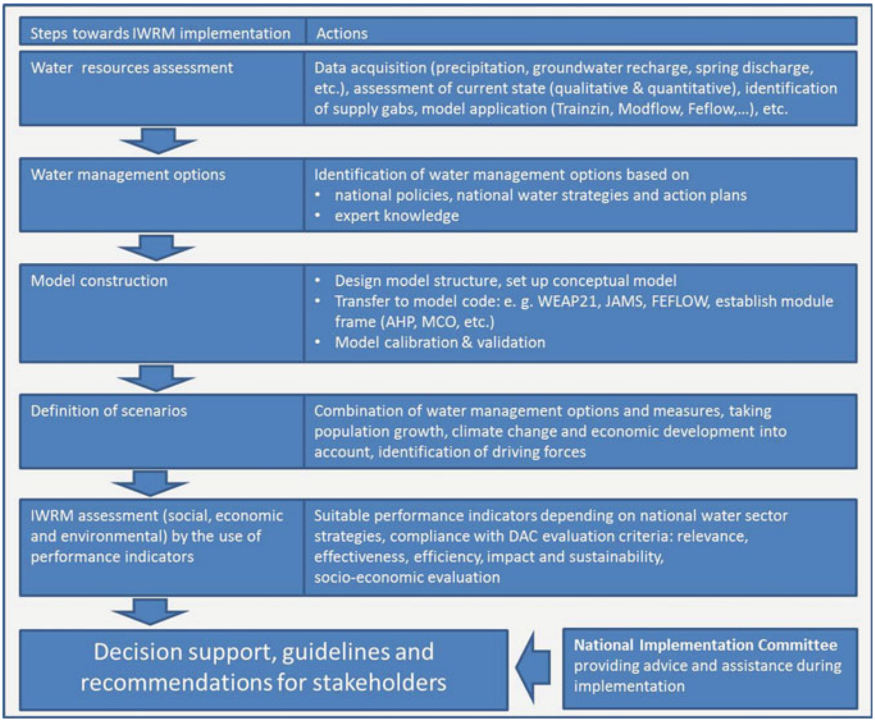

Fig. 28.4 Scheme for the setup of an IWRM approach developed for the Wadi Shueib

Due to the significant differences in water strategies and the economic and social development within each state, an up-scaled concept on IWRM for the Lower Jordan River basin could not be formulated in that stage. Hence, a set of three different approaches have been applied and partly developed, assessing the socio-economic as well as the environmental impact on sub-basin scale. Each of the approaches were based on a detailed water balance that allowed the evaluation of the current situation, the water management in the respective sub-basin, and the water management options in the context of population growth and climate change. The basic steps for the set-up of the local IWRM studies are summarised in Fig. 28.4. The process scheme serves as a guide for the construction of a framework for water resources planning towards implementation.

28.4.3 Water Strategies in the Region and Integration of IWRM into the Respective Policies

Water management plans for the use of regional water resources in the Jordan River Basin have been developed since 1900 when Abraham Burkart first developed proposals for water distribution. Within the Frangia Plan (1913), recommendations were made to transfer Yarmouk River flows to Tiberias for storage and for generating electricity. Since then, numerous plans targeting the water distribution in the Middle East had been developed e.g. Ionides Plan (1939), Hays (1947), United Nations Partition Plan (1947) (Attili etl al. 2014; Bassat and Ginio 2011).

After the declaration of the State of Israel in 1948, the governments in the region began to pursue of national plans for water resources exploitation of the Jordan River Basin (Haddadin 2002). However, these unilateral activities soon led to water-related disputes and conflicts between the riparian countries. In 1953, and as a response to the USA initiatives, Lebanon, Syria, Jordan, and Israel commenced the "Johnston Plan", with the goal of a multilateral agreement on water use rights for the Jordan River (Smith 1966). Although the plan was technically accepted, it was never ratified by the Arab League due to politically motivated reasons related to the Arab-Israeli tensions (Wishart 1990). Infrastructural activities on both sides of the Jordan River, such as the construction of National Water Carrier in Israel or the East Ghor Kanal in Jordan resulted in smaller military conflicts (Al-Kloub and Abu-Taleb 1998).

Despite the persistent potential for conflict, the countries of the Jordan River Basin have also realized their urgent need for cooperation during the last decades. During the 1990s the riparian states began serious negotiations, foremost with bilateral legal agreements on the distribution of the water resources (surface water and groundwater) in the Jordan River Basin (Haddadin 2002; Jägerskog 2003). The two central agreements in this respect are the Israel–Jordan Treaty of Peace signed in 1994 and the Israeli-Palestinian Interim Agreement (also: Oslo II) from 1995 (Interim Agreement 1995; Treaty of Peace 1994).

Until the 1990s, the developed water plans negotiated mainly water management matters, e.g. water rights and water distribution among the riparian countries and did not take social, economic, and ecological effects on the long run into account (Riepl 2013). A significant paradigm shift evolved after the International Conference on Water and the Environment in Dublin in 1992, where the principles of IWRM were clearly formulated.

The Jordanian Ministry of Water and Irrigation (MWI) started to adapt integrated management principles within its national water policies during the 1990s (Riepl 2013). The latest long term strategy was published in 2009 (MWI 2009). However, this strategy is still subject to discussion within the national administration. The authorities in Israel and Palestine are in the final stage of developing and approving comprehensive strategy papers after years of intermediary targets and temporary declarations of intent. The objectives of this strategy can be grouped into three categories:

- Continuous supply of water for a growing population for the purpose of securing and improving current living standards, which includes water for domestic purposes as well as for economic activities in industry, trade, and agriculture;

- Improving the sustainability of available water and water resources in terms of quality and quantity;
- Independence from water imports under the politically sensitive regional settings.

All three states support IWRM, in particular with respect to the second objective, but their current water policies clearly assign the highest priority to the mobilization of all potential water resources through advanced technologies (Bein Committee 2010; MWI 2009; MOPAD 2010). Expectations in Israel and Jordan focus predominately on the scheduled development of capacities in seawater desalination, while the Palestinian national plan for the West Bank relies primarily on water recycling and larger shares from local water resources.

The adoption of IWRM into the national strategies originates from the riparian states' acknowledgement of the need to adapt current water cycles into conceivable changes in their water balances. These changes include anticipated impacts from climate change, as well as the effects of increased water supply. Prognoses on effects from climate change in the LJRV predict a decrease of 10–20 % in annual precipitation, a seasonal shift and shortening of the rainy season, higher temperatures, and an increasing occurrence of extreme weather events, such as droughts and flash floods. Estimations of the timing of the onset of significant changes vary between the expectation of first effects towards the end of the ongoing decade and the established change of overall climatic conditions until the end of the 21st century (UNDP 2009; Samuels et al. 2011). The task of IWRM in the existing strategies is therefore threefold:

- Bridge the gap in water availability between the current situation of growing water scarcity and anticipated future conditions by the mobilization and better management of local water resources;
- Guide and design the transformation process in a way that minimizes potential hazards while incorporating the expected changes in water balances; and
- Adjust the currently applied approaches to water resources management to the requirements of achieving the strategic objectives in the long run.

To date, however, the existing concepts and planning still rely on more general ideas of IWRM and define practical solutions only for selected elements. One reason for the lack of comprehensive designs of IWRM set-ups are deficiencies in applying technical knowledge regarding integrated solutions to specific problems. Another major reason is the strong dependency of water sector strategies with strategies from other sectors, such as urbanization, industry, rural development, agriculture, and environment as well as the financial sector.

The consideration of these dependencies, which are defined under the term 'water coherence' in the international discussion (OECD 2012), require that decision makers and researchers first align their contributions to the existing national strategies, even if those topics may not always constitute the highest priorities from the viewpoint of IWRM. Introducing IWRM priorities, which are not already part of the national strategies, is a mid- to long-term task, as this task demands thorough appreciation of values from all sectors of the national economy and goes far beyond the scope of exclusive decision making by water scientists.

28.4.4 Scenarios—Valuable Tools for Quantitative Impact Assessments of IWRM Measures in Jordan, the Palestinian Territories and Israel

The objective of the scenario development was to provide a baseline for quantitative impact assessments of IWRM measures and strategies in local IWRM studies. This included the quantification of anticipated developments in the water sector under "most likely" assumptions relating to the future conditions and potential variation within those conditions. Direct downscaling from the available regional scenarios by multiple organizations and projects proved to be unsatisfactory due to the strong heterogeneity of the sub-regions. Therefore, the scenarios needed to be completed or even replaced by data and information from the respective national and local water administrations as well as from local scenario exercises. The local approaches for both sides of the river Jordan had been coached by SMART partners during the period of the project (Wolff et al. 2013; AFD/PHG 2011) and its results are summarized below.

Study areas in Jordan: The development of scenarios for Jordan was based on a series of workshops with experts and stakeholders from MWI, WAJ and JVA in 2010 and 2011 and took place under the umbrella of Jordan's planning mission on water demand management (MWI/AFD 2011). Results focused on a time projection until 2025 and considered demographic development and economic development as major drivers in Jordan's water sector.

In Jordan, the potential of wastewater recycling would satisfy the current agricultural water demand in Wadi Shueib as well as in Wadi Arab, while freshwater for domestic purposes will always rely on water imports under the current settlement structure. However, it is likely that the increased availability of water would result in an extension of irrigation areas.

The amount of treated wastewater, which may be alternatively allocated to aquifer recharge, depends at least as much on the aforementioned capacities of farming systems as on its quality. The increasing amount of wastewater is the result of increasing water imports in both areas. Potential from wastewater treatment will therefore depend on the overall development of Jordan's freshwater conveyor infrastructure and water production in other regions. Any sustainable planning of local wastewater treatment coverage will crucially rely on the inclusion of these supra-regional interdependencies in the planning process. Figure 28.5 displays the situation in Wadi Shueib as an example for the situation in the Jordanian areas of interest.

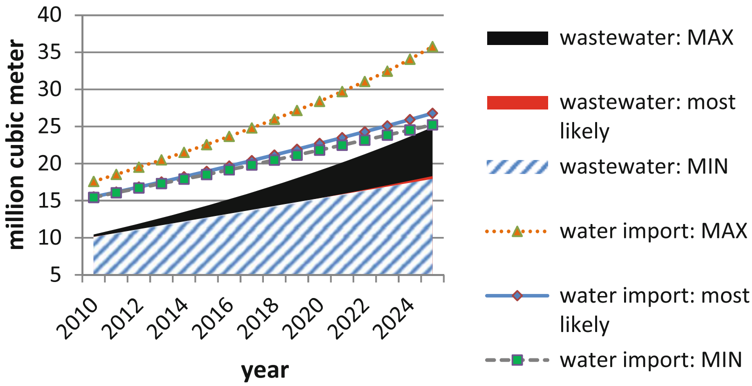

Fig. 28.5 Water supply scenarios and relationship to wastewater availability, Wadi Shueib

Study areas in the West Bank:
Scenarios for the Palestinian research areas relied on workshops for the development of the Water Master Plan for Jericho City and focused on the same time horizon, i.e. until 2025. The stakeholders in Jericho identified “management and coordination among stakeholders” and “resource availability under climate change” as the two most significant drivers for future developments in the water sector (AFD/PHG 2011). The governorate of Jericho is not driven by natural water scarcity, but water availability. Water consumption in urban areas is significantly higher than in comparable communities on the East Bank, but also significantly lower than in Israeli settlements. Water availability restricts the potential of agricultural production and forces Palestinian farmers to leave large areas of cultivated land as fallow land. The start of operations of the large-scale wastewater treatment plant in Jericho East will provide sufficient capacity for the full sanitation of the Jericho governorate beyond the scenario period until 2025.

The current estimations of the stakeholders in Jericho indicate that desalinization of brackish groundwater from wells in Jericho East will become a potential contributor to local water supply after 2025. The potential, alternative development of these factors lead to the specification of the two scenarios “optimal development”, which assumes the successful implementation of managerial and technical improvements, and “business as usual”, which assumes no changes in resource availability and the current water governance (Fig. 28.6).

This estimation relies on the current technological state of the art of desalinization plants and may change if technical innovation leads to economically sound solutions before that date. Scenarios for the Israeli settlement of Kalya relied on information from local SMART partners, since recent official scenario exercises were not available.

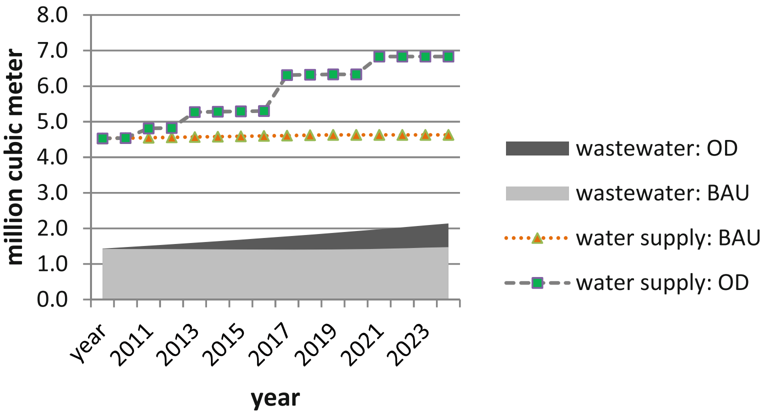

Fig. 28.6 Water supply scenarios, research region Jericho (acronyms: *BAU* Business as usual, *OD* Optimal development)

28.4.5 Indicators for IWRM Assessment

In general, suitable indicators for the performance of IWRM depend on its contributions to the strategic objectives of the national water sector strategies. A further recommendation is the compliance with the DAC evaluation criteria, stipulated by the Development Assistance Committee of the Organization for Economic Co-operation and Development (DAC, see OECD 1991), which focus on the five basic fields: relevance, effectiveness, efficiency, impact, and sustainability. The importance of the DAC criteria lies not only in the provision of a professional framework for evaluations, but also has relevance in regard to requests for support and funding from European donors and others. The third constraint that determines the suitability of indicators is the required costs for collecting information about the indicators, which may force monitoring and evaluation (M&E) to find a compromise between ideal and feasible analyses.

Comparatively straightforward performance indicators (e.g. the provision of water quantities of a given quality at a certain point in time with minimal costs) are typical project and operational process measurements. Such indicators help in assessing the merit of technical and managerial components, but only constitute one component in the evaluation of comprehensive IWRM strategies (Wolff et al. 2012). It is due to the third constraint, the costs of information gathering and measurements, that an equally comprehensive set of suitable indicators is rarely practicable for continuous M&E systems.

The research under SMART led to the definition of three IWRM-specific areas of indicators (Wolff et al. 2012), which have analogous indicators in the national water strategies of all three riparian states and in the DAC criteria. Discussions among the participating scientists and stakeholders within the frame of separate sessions allowed a second step for the identification of the most meaningful, although not comprehensive, individual indicators from each of these three sets. The development of these indicators was rated as central first step in assessing the success of IWRM approaches and the selection between alternative IWRM strategies.

- Indicator 1: Closure of gaps in municipal water demand. IWRM-specific area: potential additional water supply, DAC-criteria: relevance, effectiveness and impact
- Indicator 2: Recuperation of total costs for water services (supply and sanitation). IWRM-specific area: costs of additional water through improved technologies, DAC-criterion: efficiency and sustainability
- Indicator 3: Environmental Water Stress (EWS). IWRM-specific area: controlled mass flows, pollutants in water and land, DAC-criterion: relevance, effectiveness and sustainability

The local IWRM studies presented below show that the outcomes of alternative IWRM strategies can be assessed by using most of the above mentioned performance indicators.

28.4.6 Local IWRM Studies in the Lower Jordan Valley

28.4.6.1 Introduction

The IWRM approach which was developed on the western side of the Jordan River, i.e. the local IWRM study on the Wadi cluster Auja, Nuema and Quilt in the Palestinian Territories (see Fig. 28.2) is briefly summarised in Sect. 28.4.6.2. Parts of the framework had been promoted for many years and, in the meantime, are partially implemented within the Ministry of Water and Irrigation, Amman. The local IWRM study on Wadi Shueib in Jordan is therefore described in more detail (see Sect. 28.4.6.3).

28.4.6.2 IWRM Study Wadi Cluster Auja, Nuema, Quilt

In the western sub-catchment cluster of the LJV, comprising the Wadis Auja, Nueimah and Qilt, a methodological approach (concept) has been developed which leads to an integrated water resources development plan. The approach is characterized as a water resources planning and is strictly participative, involving the relevant stakeholders. The final water resources development plan indicates clearly how priority interventions in terms of structural measures (e.g. pipelines, surface water retention structures, shallow or deep wells) and management measures (e.g. subsurface water storage and recovery by Managed Aquifer Recharge, demand management or water mixing) should be combined. The final water development plan, specified as a IWRM strategy, presents the best balanced solution between the most relevant social, environmental and economic water development objectives and stakeholder preferences. Software tools, including e.g. a Multi-Criteria-Optimisation algorithm, have been developed within the SMART project to support the decision making process (see Wolf et al. 2010; Kämpgen et al. 2014), e.g. with regards to the identification of satisfactory compromise solutions between conflicting development objectives and ranking of alternative IWRM strategies (software may be downloaded and installed: http://www.ewre.com/smartdss/publish.htm).

The approach schematically displayed in Fig. 28.7 has been applied for the typical rural sub-basin of Wadi Auja in cooperation with stakeholders, such as the

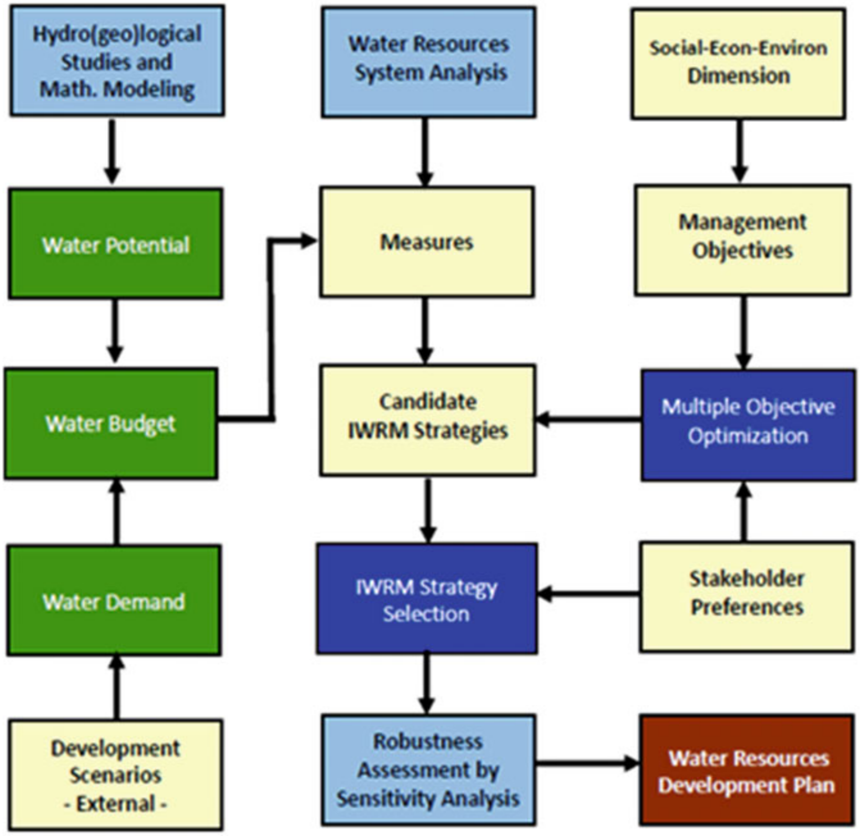

Fig. 28.7 Scheme for the local IWRM study applied at the Wadi Cluster Auja, Nuema, Quilt in the LJV (Rusteberg et al. 2014)

Palestinian Water Authority (PWA), the Palestinian Ministry of Agriculture (MoA), the Israeli Water Supply Company (MEKOROT) and the Palestinian Hydrology Group (PHG) (further details see Rusteberg et al. 2014).

28.4.6.3 IWRM Study Wadi Shueib, Jordan

Study area and water resources

The Wadi Shueib is a Jordanian side valley incised into the eastern rift shoulder of the Lower Jordan River Basin (see Fig. 28.2) with a catchment area of 198 km^2 upstream of the 1.4 MCM (million cubic meters) Shueib Reservoir. The karstified Upper Cretaceous Aquifer Complex is the primary source of fresh water and feeds several springs with a combined average discharge of about 10 MCM/year. However, the aquifer also receives unintentional recharge and is particularly vulnerable to pollution from abundant domestic sewage leakages (Abu-Jaber et al. 1997; BGR and MWI 2010; Werz 2006). Thus, growing demand is combined with pollution-induced yield reduction and high physical losses (28 %) in the supply infrastructure (MWI 2004). As a consequence, water imports have increased considerably during the last years, although the quantity of local freshwater could be still sufficient to cover the officially anticipated supply of 100 l/c/d for the approximately 120,000 domestic users.

Future projections based on official demographic scenarios (HPC 2009) would result in almost 50 % imported water for the drinking water supply until 2025, if less mitigation actions are taken. However, increased imports would compete with neighbouring demand sites, particularly the nearby Jordanian capital Amman. Downstream farms in the Jordan Valley receive irrigation water from the Shueib Reservoir and any alteration of the allocation system must also consider the impact on these communities.

Objectives of the local IWRM study for Wadi Shueib

With the involvement of local stakeholders, a specific concept was taken as the basis for the management strategy of the Wadi Shueib catchment. The concept is outlined by the following steps:

(1) Identification of the basic IWRM components for the specific sub-basin;
(2) Reporting the gaps between existing water technologies and modern technologies that could be introduced;
(3) Definition of the needs and challenges of the specific water management plan;
(4) Determination if alternative water management options can be integrated into the IWRM plan;
(5) Development of a transparent framework for the quantitative downscaling of regional scenarios to sub-basin scale.

The primary objective of the modelling approach was to develop a local IWRM study to test the IWRM planning possibilities provided by the local decision makers (Riepl 2013). The data were received directly from water sector institutions (WAJ, laboratories, etc.) in Jordan and their respective monitoring programs. For the model construction, the WEAP21 Water Evaluation and Planning (WEAP) tool was used. The location and schematic processes are shown in Fig. 28.8.

After the model was satisfactorily conceptualized, calibrated and validated (Riepl 2013), it was used to simulate various scenarios. Planning alternatives were derived from the Jordanian National Water Strategy (MWI 2009) as a subset of appropriate goals and measures for the local water sector challenges (Table 28.3).

For the scenarios, the identified alternatives were combined in two action plans for the Wadi Shueib area: a *Business as Usual* (BAU) strategy assuming the currently active projects are continued and finished until 2025 (projects marked as bold in the second column of Table 28.3); and a *Full Implementation* (FI) development scenario assuming the full range of stated implementation approaches is realized until 2025 (the complete second column of Table 28.3). Both planning alternatives were set in a 15-year horizon considering two alternative sets of external driving forces. Driving forces were chosen to agree with the official projections for climatic conditions (MWI 2009), demographic growth (HPC 2009) and water demand development (RCW and MWI 2009) as recognized by the Jordanian water sector institutions. The driving forces grouped in a set of four planning scenarios are depicted Fig. 28.9.

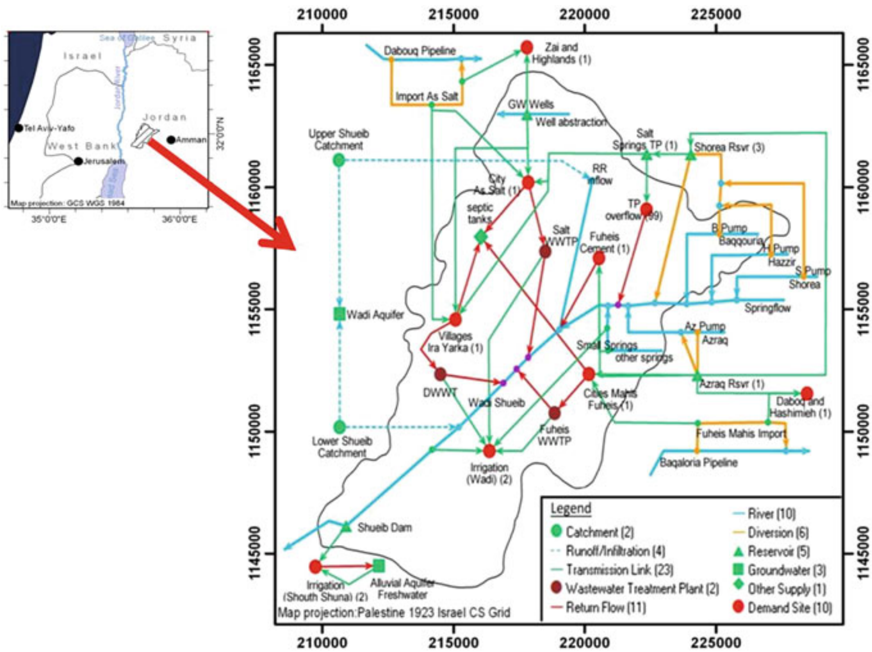

Fig. 28.8 Location and schematic WEAP21 presentation of the Wadi Shueib catchment (Riepl 2013)

Table 28.3 Strategic objectives of the Jordanian Water Strategy, implementation in the Wadi Shueib area, and selected indicators for performance evaluation

National IWRM objective	Implementation in the Wadi Shueib model	Performance indicator
Increase volume of captured and treated wastewater	**Increase the sewer connection ratio in as salt**, Fuheis and Mahis (i.e. major cities in Wadi Shueib)	I.1b: Municipal wastewater recharge ratio (%) (WWrecharge)
	Leakage reduction from municipal wastewater	
	Install decentralized wastewater treatment units for rural communities	
	Decrease the losses from septic tanks	
Maximize resources availability	Increase amount of treated wastewater directly allocated to agriculture	I.2a: Available groundwater for internal use (m^3/c/y) (AWRinternal/gw)
	Cement factory builds rainwater harvesting pool	
Secure constant drinking water supply	Increase capacity and efficiency of pumping stations and Salt Springs microfiltration plant to meet needs	I.3a: Municipal water supply shortage index (–) (WSSmunicipal)
Demand management	**Reduction of physical supply losses**	I.4a: Municipal water supply requirement (m^3/time step) (WSRmunicipal)
	Per capita domestic consumption does not rise above 120 l/c/d	
Improve cost efficiency of water services	Increases of revenue per supplied m^3 from the water treatment plants and the water imports	I.5: Full water service cost (JD/m^3) (FSCuc/municipal)
Protect water resources and environment	Spring protection zones	I.6: Environmental water stress (–) (WSIrf)
	Monitor minimum flow requirement for wadi stream	

The scenario simulations conclude that only an increased effort (Full implementation scenarios) will enable a progress towards the goals of the national water strategy and a successful IWRM process in the Wadi Shueib area. The current projects in the area, even when extended into the near future (BAU scenarios), appear to be incapable of relieving water supply problems. Furthermore, meeting future requirements is strongly dependent on the uncertainty of near to mid-future climatic, population growth and water demand development.

The modelled and standardized performance scores for the most significant indicators for the planning scenarios are plotted for comparison (Fig. 28.10). The major downside of the FI alternative is that considerable investment costs are involved. Due to the reduction of expensive water import volumes, the unit cost of water services does not rise linear with the anticipated investments. Yet, it was still simulated to significantly increase from the current 0.595–0.958 Jordanian Dinar/m^3 in the LRP-FI scenario in 2025 (Note: 1 JD corresponds to approximately 1.4 US Dollar). However, in the light of the current water sector expenditures (including MWI, WAJ, JVA, Aqaba Water Company, and Miyahuna) that were

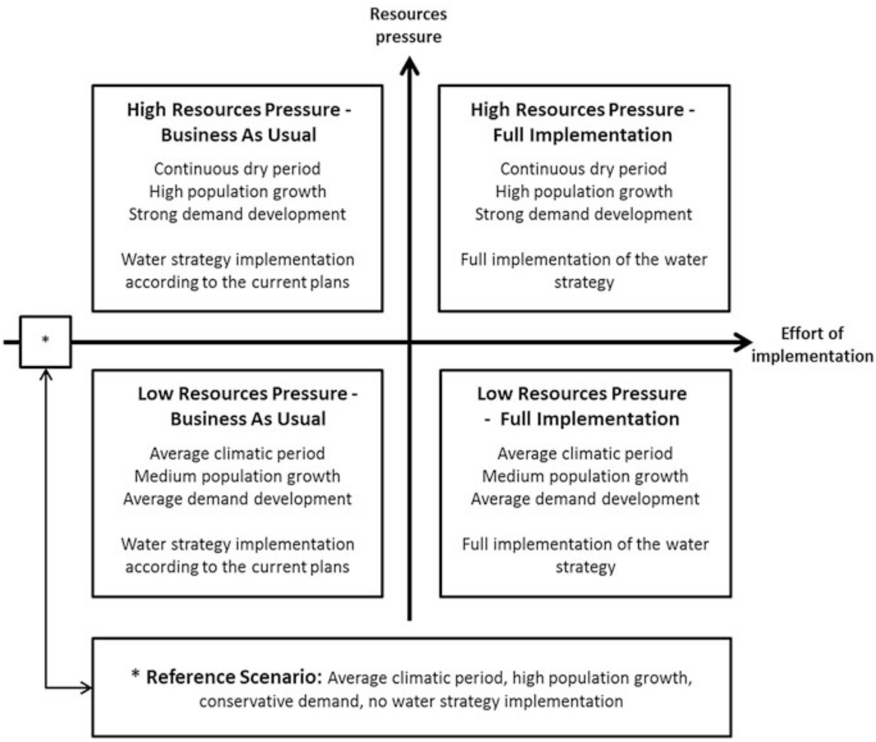

Fig. 28.9 Alternative development scenarios until 2025. The scenarios are characterised by the development of the drivers towards a future of high or low resources pressure (HRP or LRP) and towards a business as usual or a full implementation of the water strategy objectives (BAU or FI) (Riepl 2013).

estimated at approximately 500 million Jordanian Dinar (JD) in 2010 (Sommaripa 2011), the anticipated investment costs for the FI scenarios (~94 million JD over 15 years in a region with 2–3 % of the country's population) are not overambitious. This is particularly the case with aspiring mega-projects like the Red-Sea-Dead-Sea canal with currently estimated costs of approximately 4–8 billion JD (World Bank 2009).

Regardless of this major infrastructural projects, it is expected that further water tariff reforms will be necessary to progress towards the objective of cost recovery in the water sector; considering that currently, the revenues of the WAJ and the public companies do not cover their annual expenditures (Segura/IP3 Partners LLC 2009).

The simulation results in the Wadi Shueib study also reflect the general Jordanian situation. During the last decade, the water sector has mostly focused on the maximization and development of resources, as well as the extension of sanitation services. Until recently, the reduction of the tremendous water losses and the

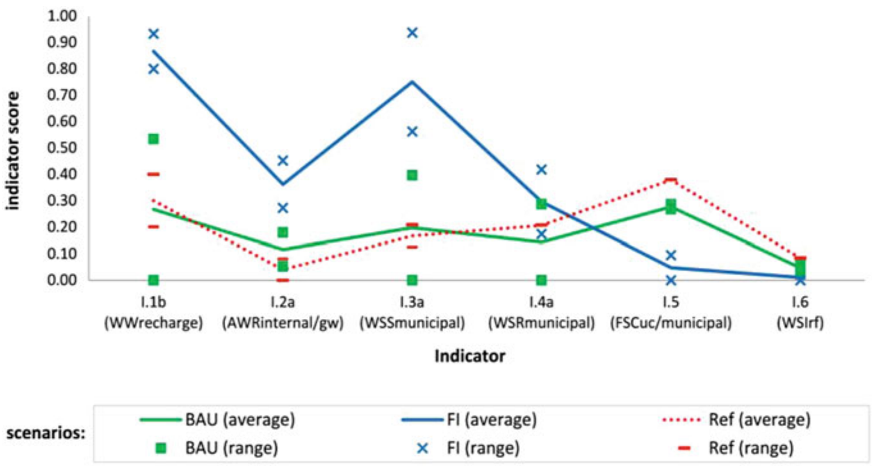

Fig. 28.10 Summary of the standardized scenario simulation results for the BAU and FI planning alternatives. Higher score indicates a better performance. A broad range in scores expresses sensitivity to the external scenario driving forces (LRP/HRP). Acronyms: *BAU* Business as usual, *FI* Full implementation, *Ref* Reference scenario; *I.1b*, *I.2-4a*, *I.5* and *I.6* Performance indicators, detailed description see Table 28.3

realization of efficient demand management and water awareness campaigns have played secondary roles.

Limitations and Uncertainties

The presented study provides valuable quantification for items such as water costs, but does not give any insight about the difficulties experienced during approach setup. Obstacles arise throughout the data acquisition, quality control, and data processing. These are extensive, time consuming tasks due to the widespread distribution of data over several competent authorities. Moreover, a significant discrepancy in data format throughout collection needed to be managed. While some data were available in digital form and therefore relatively easy to process and incorporate, there was also other data still stored in rudimentary formats, i.e. handwritten notes, which required transcription and standardization into digital formats.

The quality of the input data was identified as a limiting factor as the accuracy of the results is always highly dependent on quality input. Some of the provided parameters are only available as aggregated values (i.e. daily to monthly averages), which requires interpolation of data to maintain temporal consistency. This interpolation increases the uncertainty of the calculated results, e.g. groundwater recharge.

Further limitations are inherent within the WEAP code itself, which represents the groundwater component in the catchment as a relatively simple bucket model. To obtain a more holistic and comprehensive assessment in the future, the coupling of WEAP with numerical groundwater models is necessary.

A basic requirement for the implementation of planning tools and technologies is the economic assessment of the results. The presented IWRM study Wadi Shueib included a cost calculation and provided a first estimate of the economic effects and costs of the water management options. Nevertheless, decision makers and donors need to be provided with a solid economic assessment. Cost Benefit Analyses, Multi-Criteria-Analyses (Bensabat et al. 2014; Heinz et al. 2014) or the calculation with MYWAS (Multi Year Water Allocation), which is based on the WEAP model, employ a wide range of highly sophisticated economic methodologies and aim to deriving appropriate water prices and economically efficient IWRM strategies to tackle particularly water scarcity problems (Fisher and Huber-Lee 2012; Fisher et al. 2005).

For a sustainable transfer of knowledge from research to implementation, an interface between the project and the competent authorities is a fundamental prerequisite. In SMART, a national implementation committee (NICE) could be established directly at the MWI in Amman, Jordan. The focus of NICE is directed on the implementation of decentralized wastewater treatment plants in Jordan. The mission of a national implementation committee needs to be adapted to the project outcomes.

Above all, IWRM and its implementation is not just a task at the end of the research and development project but should be viewed as vigorous and long term process that requires competent consultation and highly motivated staff.

In SMART it was experienced that successful implementation should be started with the beginning of the project. Meaning the dialog with development banks and stakeholders needs to be initiated from the beginning of the project.

28.5 Summary and Recommendations

SMART is an IWRM project in the water scarce region of the LJV with the objective to support the stakeholders with the development and implementation of adapted water strategies. The project is taking into account both conventional and non-conventional water resources and was conducted at numerous demonstration sites for decentralised wastewater treatment and reuse, managed aquifer recharge and brackish water desalination.

Local studies integrating basic elements of IWRM have been developed and applied on sub-basin scale on the eastern and western side of the Jordan River. Each of the studies includes the evaluation of existing water management systems as well as an assessment of future development scenarios including the aforementioned technology implementation. The basic steps were derived and incorporated into a process scheme for the set-up of a framework for water resources planning and implementation (see Fig. 28.4). This scheme may serve as a guideline for other regions facing water scarcity.

The approach for the Wadi Shueib, which was already in parts implemented and in use by the stakeholders in Jordan, consisted of a combined modelling and scenario planning framework describing a potential path towards an operational realization of the ambitious IWRM concept on the sub-basin scale. The modular framework is based on the analysis of the water strategy, planned water management options and scenario definition. As such, the framework appears to be viable for expansion and continuous development. The detailed analysis of the standard objectives with regard to implementation options and suitable performance measures (indicators) is an important contribution to the local IWRM planning endeavours. In this regard, the study offers a proof of concept and a methodological framework for the application in other sub-basin scale sites.

The established scenarios are only a subset of options that provide a basic framework. For the further application in planning and strategy decisions, the development of other scenarios is recommended, for example, isolating selected aspects of the full implementation of options or other combinations of conditions. The model presented in this study is flexible enough to implement such changes in relatively short time.

The modelling framework for Wadi Shueib presented here successfully illustrates the objective to provide decision makers with interdisciplinary and integrated planning support that is equally based on national IWRM policies as well as on sound science. It is therefore a viable instrument to progress towards operational IWRM and may be transferred to other regions suffering water scarcity.

While the framework provided by SMART has been proven on catchment scale, it would be necessary in a next step to upscale it to cluster scales relevant to water management to derive a generalized IWRM concept.

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