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

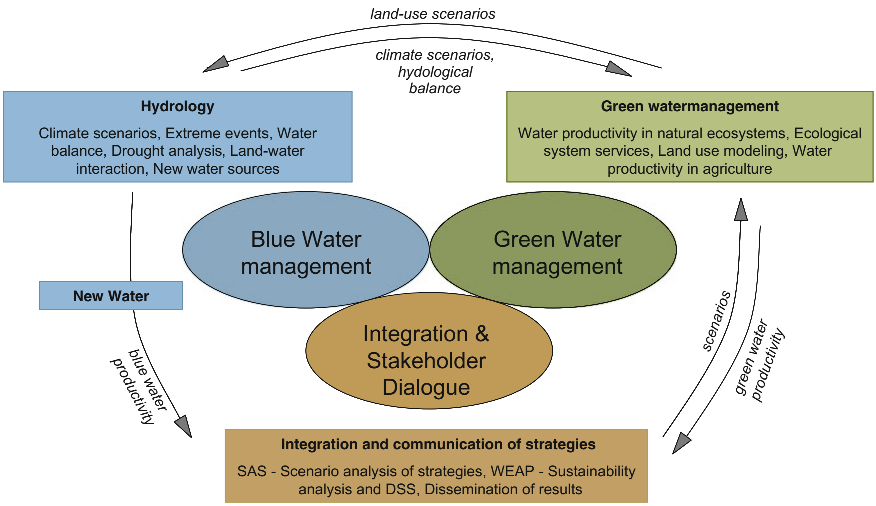

Fig. 27.2 Structure of GLOWA JR in the last project phase (2008–2012). *SAS* Story and simulation approach, *DSS* Decision support system, *WEAP* Water Evaluation and Planning tool

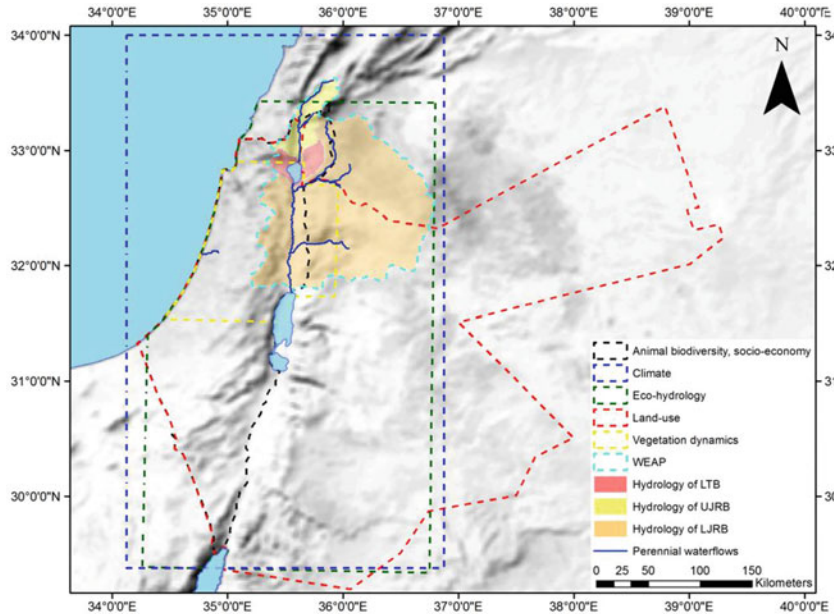

Fig. 27.3 Geographical domains of models developed in GLOWA JR (adapted from the GLOWA JR Atlas, Claus et al. 2014). *WEAP* Water Evaluation and Planning tool, *LTB* Lake Tiberias basin, *UJRB* Upper Jordan River basin, *LJRB* Lower Jordan River basin

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

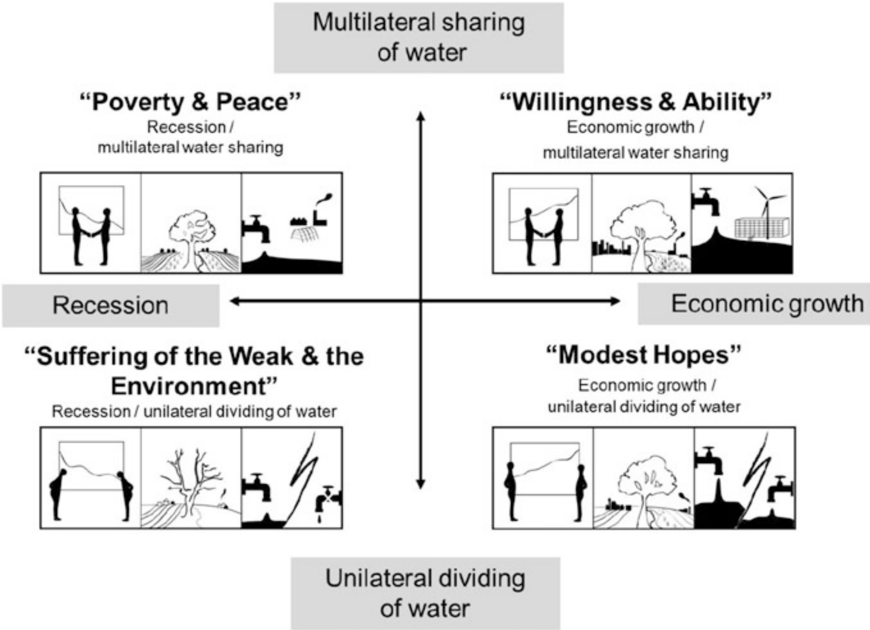

Fig. 27.4 The GLOWA JR regional development scenarios—a schematic presentation

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

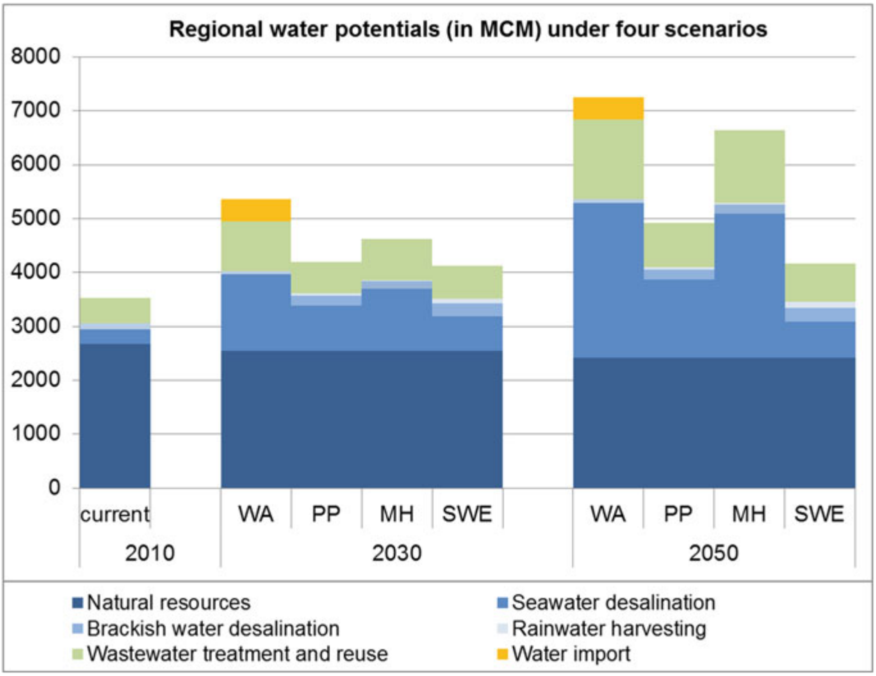

Fig. 27.5 Regional water resources (in MCM: million cubic meter) including potential new water sources assumed to be maximally realizable as part of the water strategies under the four Regional Development Scenarios (*WA* Willingness and ability, *PP* Poverty and peace, *MH* Modest hopes, *SWE* Suffering 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

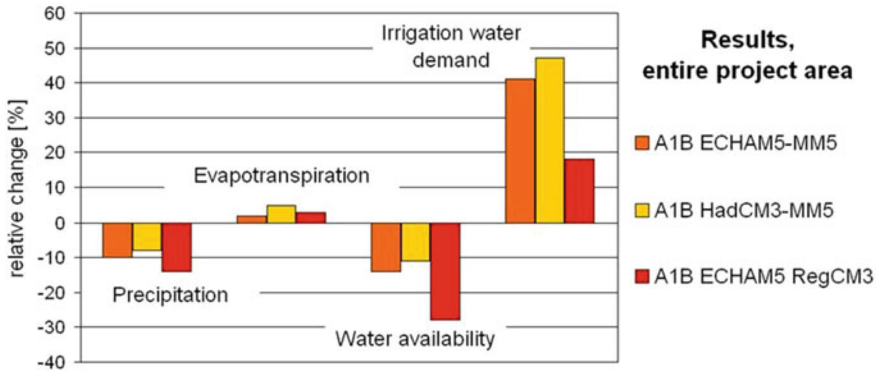

Fig. 27.6 Relative changes (%) of precipitation, evapotranspiration, blue water availability and irrigation water demand between current (1961–1990) and future (2031–2060) conditions for the Jordan River region, based on the three different climate scenarios (Menzel and Törnros 2012)

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

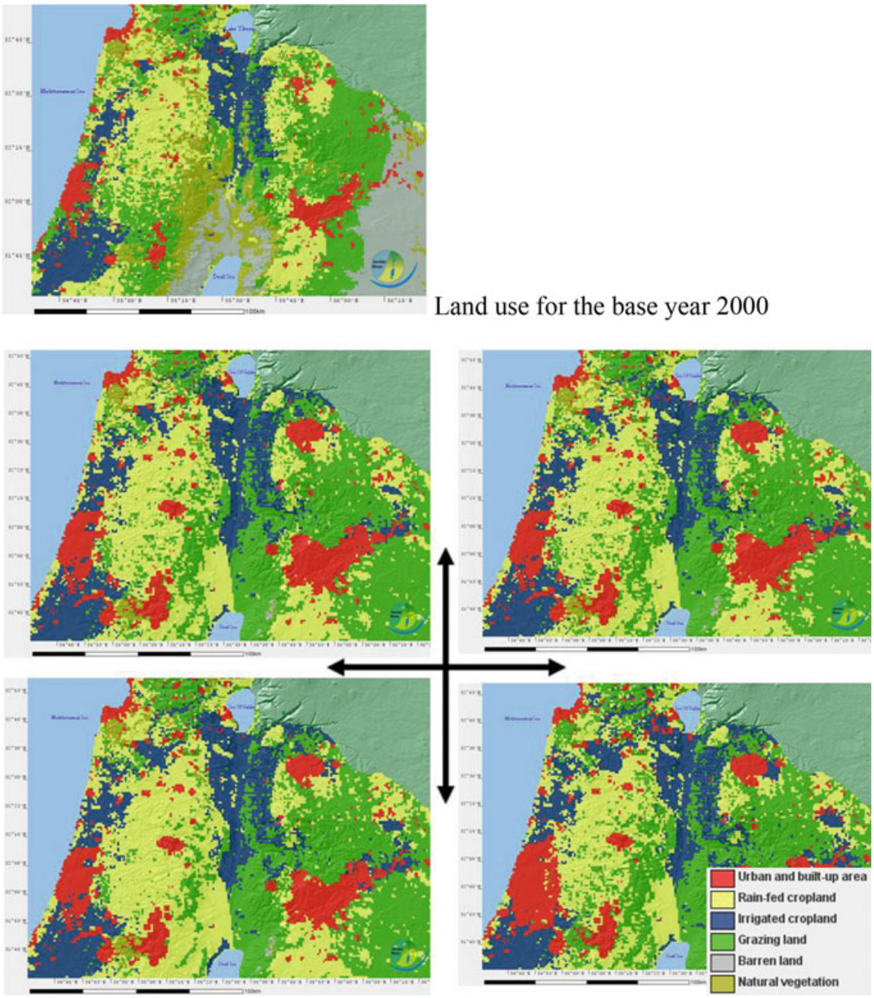

Fig. 27.7 Land use for the base year 2000 (above) as well as land use change simulations for the year 2050 computed with LandSHIFT.JR for the four GLOWA JR scenarios (see Fig. 27.4) assuming no climate change conditions (GLOWA JR Atlas, Claus et al. 2014; Volland et al. 2014)

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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