

Chapter 16

Analysing Stakeholder Driven Scenarios with a Transboundary Water Planning Tool for IWRM in the Jordan River Basin

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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 |

^aFor PA = 2005 US\$, ^bPA = 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

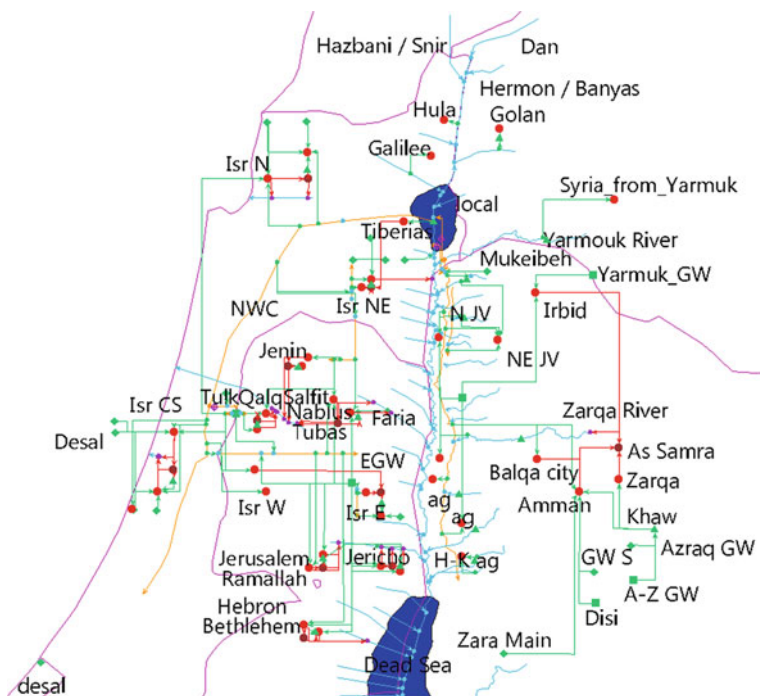


Fig. 16.1 Conceptual representation of the JRB WEAP model showing supply nodes and transmission lines in *green*, water diversions in *yellow*, and demand nodes and return flows in *red*

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 $50 \text{ m}^3/\text{s}$. 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 m³ (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 |

^aNote 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 economically favorable scenarios, which assume a better infrastructure for the distribution of TWW (Table 16.3) to the economically 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

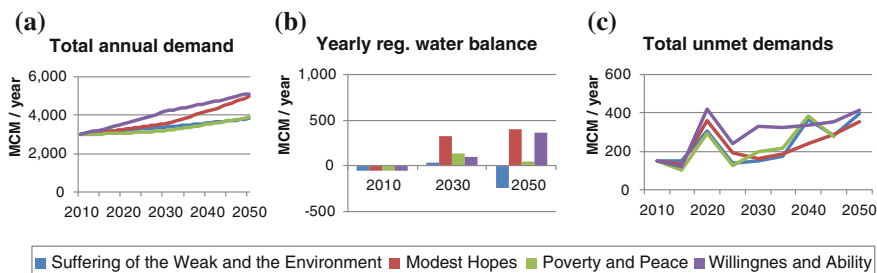


Fig. 16.2 a JRB WEAP model results showing transient demand development; b regional water balance comparing all water resources and demands for 1 year (supply minus demand for the baseline year (2010) and every 20 years thereafter); c JRB WEAP model results showing aggregated yearly demands for the whole 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 economically 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.

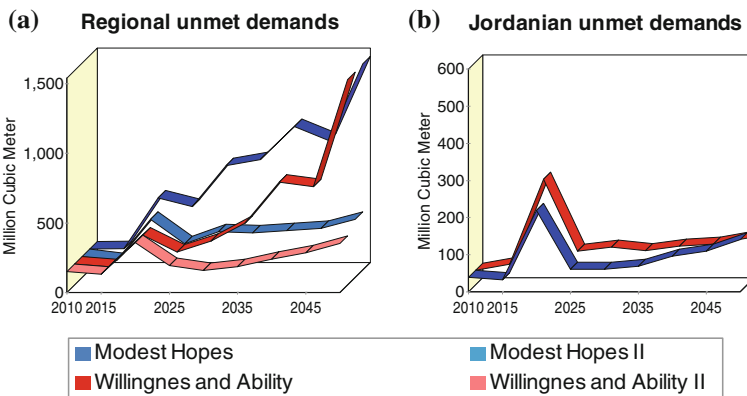


Fig. 16.3 **a** Regional unmet demand in the ‘Modest Hope’ (blue) and the ‘Willingness and Ability’ (red) scenarios. The dark coloured lines (marked II) represent the scenario-versions without large desalination capacities. **b** Unmet demands for all Jordanian demand nodes in the two economic growth scenarios

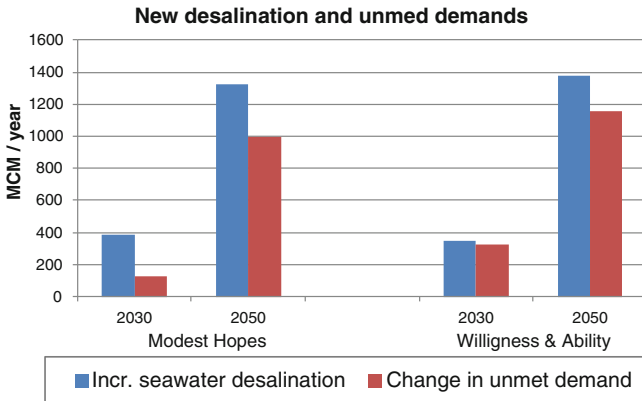


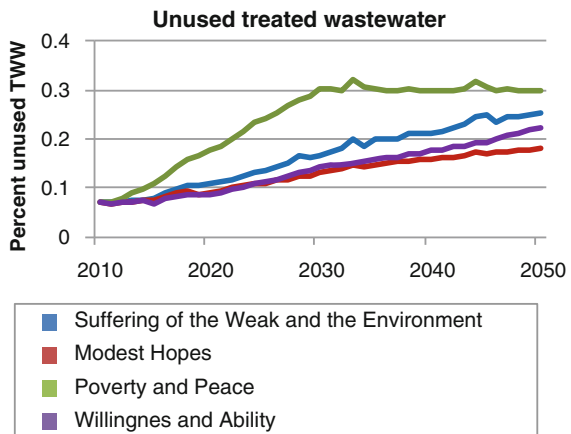
Fig. 16.4 The comparison of the amount of desalinated water entering the system and the reduction in unmet demands in the corresponding scenarios

(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



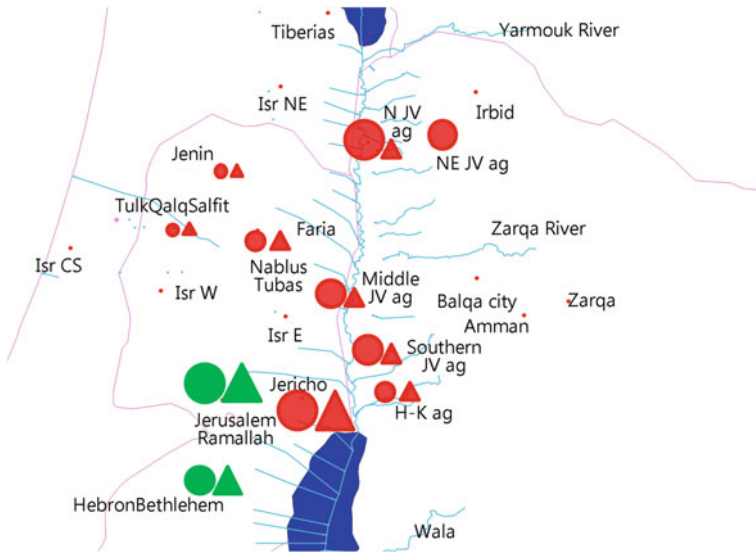
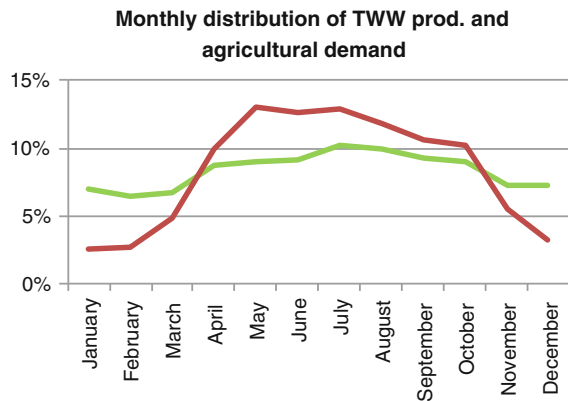


Fig. 16.6 Spatial distribution of unused treated wastewater, size of nodes indicates the amount of unused treated wastewater (*green*) and agricultural unmet demands (*red*) for the years 2030 (*triangle*) and 2050 (*circle*) under the ‘Suffering of the Weak and Environment’ scenario

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 wastewater. 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 agriculture (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 stepped 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. IWRM 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 are 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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References

- Abu Sadah M (2009) Application of WEAP-MODFLOW in the Western Aquifer Basin, Palestine. In: Paper presented at the First Arab WEAP conference, Damascus, Syria, 25–27 May 2009
- Al-Omari A, Al-Quraan S, Al-Salihi A, Abdulla F (2009) A water management support system for Amman Zarqa Basin in Jordan. *Water Resour Manage* 23(15):3165–3189. doi:[10.1007/s11269-009-9428-z](https://doi.org/10.1007/s11269-009-9428-z)

- Alcamo J (2008) The SAS approach: combining qualitative and quantitative knowledge in environmental scenarios. In: Alcamo J (ed) *Environmental futures: the practice of environmental scenario analysis*. Developments in integrated environmental assessment, vol 2. Elsevier, Amsterdam, pp 123–150. doi:[10.1016/S1574-101X\(08\)00406-7](https://doi.org/10.1016/S1574-101X(08)00406-7)
- Alfarra A, Kamp-Benedict E, Hötzl H, Sader N, Sonneveld B (2012) Modeling water supply and demand for effective water management allocation in the Jordan Valley. *J Agric Sci Appl* 1 (1):1–7. doi:[10.14511/jasa.2227.6475](https://doi.org/10.14511/jasa.2227.6475)
- Biswas AK (2004) Integrated water resources management: a reassessment—a water forum contribution. *Water Int* 29(2):248–256
- Biswas AK (2008) Integrated water resources management: is it working? *Int J Water Resour D* 24 (1):5–22. doi:[10.1080/07900620701871718](https://doi.org/10.1080/07900620701871718)
- Bonzi C, Hoff H, Stork J, Subah A, Wolf L, Tielbörger K (2010) WEAP for IWRM in the Jordan River region; bridging between scientific complexity and application. In: *Integrated water resources management*, Karlsruhe, 24–25 Nov 2010, pp 397–403
- Brooks D, Trottier J (2010) A modern agreement to share water between Israelis and Palestinians. The Friends of the Earth (FoEME) Proposal. FOEME. Amman, Jordan. www.foeme.org/www/?module=publications&project_id=54
- Comair G, McKinney D, Maidment D, Espinoza G, Sangiredy H, Fayad A, Salas F (2014) Hydrology of the Jordan River basin: a GIS-based system to better guide water resources management and decision making. *Water Resour Manage* 28(4):933–946. doi:[10.1007/s11269-014-0525-2](https://doi.org/10.1007/s11269-014-0525-2)
- EXACT (ed) (1998) Overview of middle east water resources: water resources of Palestinian, Jordanian and Israelie interest. Executive Action Team MEDBPE. <http://exact-me.org/>
- Hoff H, Bonzi C, Joyce B, Tielboerger K (2011) A water resources planning tool for the Jordan River basin. *Water* 3(3):718–736. doi:[10.3390/w3030718](https://doi.org/10.3390/w3030718)
- Isendahl N, Dewulf A, Brugnach M, François G, Möllenkamp S, Pahl-Wostl C (2009) Assessing framing of uncertainties in water management practice. *Water Resour Manage* 23(15):3191–3205. doi:[10.1007/s11269-009-9429-y](https://doi.org/10.1007/s11269-009-9429-y)
- Israel-Jordan (1994) Treaty of peace between the state of Israel the Hasemite Kingdom of Jordan; Water related matters. ANNEX II, 1a/1b, Allocation
- Jayyousi AF, Almasri MN (2010) The use of water allocation models in managing trans-boundary water resources: a case from Palestine. In: Paper presented at the international conference “transboundary aquifers: challenges and new directions”(ISARM 2010), Paris, France
- Jonch-Clausen T, Fugl J (2001) Firming up the conceptual basis of integrated water resources management. *Int J Water Resour D* 17(4):501–510. doi:[10.1080/07900620120094055](https://doi.org/10.1080/07900620120094055)
- Pahl-Wostl C (2007) Transitions towards adaptive management of water facing climate and global change. *Water Resour Manage* 21(1):49–62. doi:[10.1007/s11269-006-9040-4](https://doi.org/10.1007/s11269-006-9040-4)
- Randall D, Cleland L, Kuehne C, Link G, Sheer D (1997) Water supply planning simulation model using mixed-integer linear programming “engine”. *J Water Resour Plann Manage* 123(2):116–124
- Samuels R, Rimmer A, Hartmann A, Krichak S, Alpert P (2010) Climate change impacts on Jordan River flow: downscaling application from a regional climate model. *J Hydrometeorol* 11(4):860–879. doi:[10.1175/2010JHM1177.1](https://doi.org/10.1175/2010JHM1177.1)
- Schaldach R, Alcamo J, Koch J, Kolking C, Lapola DM, Schungel J, Priess JA (2011) An integrated approach to modelling land-use change on continental and global scales. *Environ Model Softw* 26(8):1041–1051. doi:[10.1016/j.envsoft.2011.02.013](https://doi.org/10.1016/j.envsoft.2011.02.013)
- SEI (ongoing) Webpage: the water evaluation and planning system (WEAP). Stockholm Environmental Institute. www.weap21.org
- Sigel K, Klauer B, Pahl-Wostl C (2010) Conceptualising uncertainty in environmental decision-making: the example of the EU water framework directive. *Ecol Econ* 69(3):502–510. doi:[10.1016/j.ecolecon.2009.11.012](https://doi.org/10.1016/j.ecolecon.2009.11.012)
- Sivan I, Salingar Y, Rimmer A (2007) A WEAP model for the Sea of Galilee (Lake Kinneret) Basin—water resources and consumers by sub-basins. *Water Eng* 53:50–58

- Törnros T, Menzel L (2013) Characterizing droughts under current and future climates in the Jordan River region. *Hydrol Earth Syst Sci Dis*. doi:[10.5194/hessd-10-5875-2013](https://doi.org/10.5194/hessd-10-5875-2013)
- United Nations DoEaSA, Population Division (2013) World population prospects: the 2012 revision, key findings and advance tables. Working Paper ESA/P/WP.227
- Yates D, Sieber J, Purkey D, Huber-Lee A (2005) WEAP21—a demand-, priority-, and preference-driven water planning model Part 1: Model characteristics. *Water Int* 30(4):487–500
- Zagona EA, Fulp TJ, Shane R, Magee T, Goranflo HM (2001) Riverware. A generalized tool for complex reservoir systems modeling. *JAWRA J Am Water Resour Assoc* 37(4):913–929. doi:[10.1111/j.1752-1688.2001.tb05522.x](https://doi.org/10.1111/j.1752-1688.2001.tb05522.x)