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WATER MANAGEMENT UNDER EXTREME WATER SCARCITY: SCENARIO ANALYSES FOR THE JORDAN RIVER BASIN, USING WEAP21

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SUMMARY- We have developed a scenario analysis and decision support tool for adaptive water management in the Jordan River basin. The WEAP (Water Evaluation and Planning) tool (see www.weap21.org) provides a consistent framework for integrating water availability, water demand, water quality, and water use efficiency information from a range of sources from all riparian countries in the basin. This framework allows environmental, technical, socio-economic, institutional and political aspects of water management to be considered in tandem toward evaluating scenarios that explore various drivers and adaptation options.
With WEAP we assess different climate, land use and population scenarios and adaptation options and combinations thereof, for their individual and overall effect on future water scarcity. By taking into account transboundary surface and ground water resources, we also assess the benefits from co-operative water management compared to separate national management.
We find that climate change effects, as predicted by regional climate models for A2 and B2 scenarios, considerably constrain future water availability, while concomitant population growth, as derived from regional and global projections, greatly increases water demand. Several adaptation options are assessed and compared for their potential to close the widening gap. These include wastewater reuse, desalination, rainwater harvesting and artificial groundwater recharge, as well as demand management in different sectors.
We are presently integrating green water and land management concepts into WEAP scenarios of sustainable development strategies, by including resulting changes in evapotranspiration and water productivity using both external eco-hydrological models as well as internal simulation capabilities within WEAP.

Key words: Jordan River basin, WEAP21, scenarios, wastewater reuse, rainwater harvesting

INTRODUCTION

As in most semi-arid regions, high natural spatial and temporal climate variability and uncertainty pose severe challenges to water management in the Jordan River basin, e.g. through pronounced dry seasons, high inter-annual variability in precipitation and steep precipitation gradients away from the coast and from the highlands. Water scarcity in the Middle East is among the highest in the world. Groundwater and surface water resources are fully used or overused. Per-capita water availability in Israel is currently at 265 m^3 per year, in Jordan at 170 m^3 (WRI 2006), and in the Palestinian Autonomy even lower, which exceeds all typical thresholds of water scarcity (e.g. 1700 m^3 or 1000 m^3 per capita and year, Falkenmark, 1999).

Regional water scarcity will increase further due to internal and external trends, including:

- Global climate models generally agree that total annual precipitation in the eastern Mediterranean will decrease, while temperatures and hence evaporative demands will increase, accompanied by generally higher future climate variability (Arnell, 2004; Milly, 2005; Giorgi, 2006);
- In parallel, population growth rates remain among the highest in the world (WRI, 2004), due in part to repeated waves of refugees coming into the region, so that water demand is rapidly increasing.

Potential for conflicts stems also from very unequal distribution of water resources in the region - between the different riparian states as well as between different population groups. This inequity is due in part to natural and climatological factors but largely due to the political and economic situation as well. Resulting water use conflicts are closely related to the political situation. Conflict resolution almost always has a political component or political implications (Jägerskog, 2001; Allan, 2003). Sustainable solutions to the water crisis are difficult to achieve under the current political situation. However, progress in resolving water issues can facilitate the overall political process. The special role of the water sector is also evident from the continuous activities of the Palestinian-Israeli Joint Water Committee and the agreement of both parties to keep water infrastructure intact despite the conflict.

Adaptation to water scarcity and high climate variability has a long history in the region, which has been called the "cradle of agriculture" (Issar, 2004). Water harvesting technologies for runoff agriculture under very low rainfall (down to 100 mm/a) have been applied for many centuries or even millennia, and drought resistant crops have been developed (Evenari *et al*., 1982). In the past decades, water productivity in irrigated agriculture (biomass production per liter of water used) has increased several times (Tal, 2004). The region is leading in use of technologies such as drip irrigation, green house agriculture, wastewater reuse and most recently also seawater desalination, all of which contribute to the mitigation of increasing water scarcity. By the end of this decade, reuse of wastewater is expected to exceed the use of freshwater in agriculture. In parallel, a chain of desalination plants is expected to be operated along the Mediterranean coast with a total capacity of about 500 million m^3 per year (Water Commission, 2003).

A feasibility study for the Red Sea – Dead Sea canal has recently been commissioned, in addition to further increases in water use efficiencies (El-Naser, 2004; World Bank, 2006). In this canal, the energy from the elevation gradient (from sea level to 400 m below sea level) is to be used to produce for the regional water system about 800 million m^3 per year of desalinated water.

Despite all measures taken so far, the region "has run out of water" since the 1970s and can no longer be food self-sufficient (Allan, 2001). In adapting to this water scarcity, the region has substituted food imports for local food production like no other region in the world. Food demand in Israel and Jordan is currently met through annual food imports that contain 2-3 times more virtual water than the total renewable resources of these two countries (Hoekstra *et al*., 2002).

The wide range of measures and proposed and implemented projects, often supported by international donors, have not been able to solve the water crisis. We believe that a new approach for a joint and integrated water resource management strategy with all riparian partners is required, supported by an IWRM tool that allows decision-makers to compare and evaluate different development scenarios, including efficiency and equity aspects as well as effects of climate and other global changes.

BACKGROUND ON WEAP21

The WEAP21 platform crystallized from the recognition of a critical need in water resources planning and management tools - the need for a decision support tool that integrates the complex array of hydrologic, water quality, economic, and social factors that control the availability of water and influence the priorities set for its use. Whereas water resource planning and management has been dominated historically by tools that emphasize components of either the engineered (e.g., Riverware™ *;* Zagona *et al.,* 2001) or natural (e.g., SWAT; Arnold and Allen, 1993) systems, the WEAP21 platform (Raskin and Zhu, 1992; Yates *et al.,* 2005a,b) is among a new generation of water management DSS tools developed with the objective and guiding principle to provide, for planning purposes, the balanced integration of both the engineered and natural components of a watershed, as water managers are increasingly called upon to do (Biswas, 1981; Bouwer, 2000; Westphal *et al.,* 2003).

WEAP21 is a multifaceted database, forecasting, policy analysis, and resource management tool. As a database, it provides a framework for maintaining spatially and temporally varying hydrologic, demand and supply information. As a forecasting tool, WEAP21 simulates a broad range of engineered parameters (e.g., reservoir storage, hydro-power generation, pollution generation) and hydrologic processes (e.g., precipitation, runoff, evapotranspiration, groundwater/surface water interactions). It can also be used to simulate river water quality; it is coded to handle biological oxygen demand (BOD), dissolved oxygen (DO), and temperature explicitly, and other user-defined parameters can be simulated upon specifying conservative or first order decay behavior. As a scenario-driven policy analysis tool, WEAP21 allows stakeholders the opportunity to evaluate tradeoffs among a full range of water development and management options. The model's graphical user interface supports the construction of a watershed's network representation and the water system contained within it, and facilitates multi-stakeholder water management dialogues organized around scenario development, analysis, and evaluation of the full range of issues and uncertainties faced by water planners, including those related to climate, watershed condition, anticipated demand, ecosystem needs, regulatory climate, operational objectives and infrastructure. Perhaps most importantly, WEAP21 performs these functions in a manner that emphasizes transparency of process and recognizes that planners and policy professionals may have non-technical backgrounds.

During its 15 years of development, implementation and refinement, WEAP21 has evolved as a decision support tool applied in more than thirty applications around the world, with its international adoption signaled by an increasing number of available translated versions (currently Korean, Chinese, French, and Portuguese – Spanish and Arabic are in progress). At present, WEAP21 is being applied in a number of international contexts in addition to the Jordan River basin, including study of the hydrologic, economic, ecological, health, and institutional dimensions of small reservoir ensemble planning and management in the Volta (Ghana), Limpopo (Southern Africa), and Sao Francisco (Brazil) basins. Tradeoffs for ecosystems services under scenarios of climate and land use change are being explored in the Sacramento River basin, California, USA using WEAP21 (Yates *et al*., 2005a; Yates *et al*., 2005b). WEAP21 has also been utilized as the water management DSS for a European Union-funded study, Rivertwin, that sought to understand how the processes and lessons learned from developing an integrated regional water resources management model in a data-rich river basin (Neckar basin, Germany) can be translated to that of a data-scarce region (Oueme, Benin). WEAP21 also played an integral role in an analysis of planning and decision-making processes that influence upstream-downstream cooperation around water in the water-scarce Beijing-Hebei region of Northeast China.

HOW WEAP21 WORKS

WEAP21 balances water supplies and multiple water demands and environmental requirements characterized by spatially and temporally variable allocation priorities and supply preferences. It employs a priority-based optimization algorithm as an alternative to hierarchical rule-based logic, and uses the concept of Equity Groups to allocate water in times of insufficient supply.

Operating on the basic principle of water balance accounting, where total inflows equal total outflows net of any change in storage (in reservoirs, aquifers, or the soil column), it is possible to address a range of inter-related water issues facing a water system with this decision support tool. WEAP21 data objects and the model framework are graphically oriented, with the software built using the Delphi Studio® programming language (Borland Software Corporation), and also utilizing MapObjects® software libraries from the Environmental Systems Research Institute (ESRI) to allow for spatial referencing of watershed attributes (e.g. river and groundwater systems, demand sites, wastewater treatment plants, watershed and political boundaries, and river reach lengths) (Yates *et al.*, 2005a).

WEAP21 applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. While the model can be run on any time-step where routing is not a consideration, the model description described here assumes a monthly time-step. The foundational dataset for any application is the *Current Accounts*, which provides a snapshot of actual water demand, pollution loads, resources and supplies for the system during the current or a baseline year. Scenarios based on assumptions about climate change, population development, policies, costs and other factors that affect demand, supply and hydrology are then developed within the application; these drivers are able to change at varying rates over the planning horizon of the study. The time horizon for these scenarios can be set by the user, from as short as a single year to more than 100 years. Scenario results are then evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

The management of the system is represented in terms of its various supply sources (e.g., surface water, groundwater, desalinization plants, and water re-use elements); withdrawal, transmission and wastewater treatment facilities; water demands, and pollution generation associated with these activities. The WEAP21 structure allows the user to consider watershed water supplies at their origin – the precipitation that falls on the watershed. If the hydrological functions in WEAP are used, rainfall will be depleted first among natural and agricultural evapotranspirative demands dictated by land cover characteristics (Mahmood and Hubbard, 2002) or transmitted via runoff and soil infiltration to soil moisture reserves, the watershed river network and groundwater aquifers, following a semi-distributed, parsimonious hydrologic model; these elements are linked via the user-defined water allocation components input through the WEAP21 interface (Yates *et al*., 2005a).

The water allocation problem – to distribute the supply remaining after the satisfaction of watershed demand – is solved using an iterative Linear Programming algorithm, whose objective is to maximize water delivered to demands and instream flow requirements according to their ranked priority, with demands of the same priority referred to as Equity Groups. These Equity Groups are indicated in the interface with a number in parentheses from 1 to 99, with the number 1 having the highest priority and 99 the lowest. The LP is formulated to allocate equal percentages of water to the members of the same Equity Group when the system is supply-limited (Yates *et al*., 2005a).

A WEAP MODEL FOR THE JORDAN RIVER BASIN

An initial WEAP application has been developed for the Jordan region, as part of the GLOWA Jordan River project (see www.glowa-jordan-river.de). Given the mandate of the GLOWA project to scientifically support regional water management, WEAP has been jointly developed by GLOWA scientists and regional stakeholders as tool for scenario evaluation and decision support. Key questions of current and future national and transboundary water management were formulated by water managers and policy makers from Israel, Jordan and PA., so they can be addressed in WEAP.

We would like to emphasize that this WEAP development for the Jordan River basin is still at an early stage, and that the initial results presented below have not been discussed in detail with all stakeholders. Also the current regional WEAP model for the Jordan region is based upon selected input data only. The ability of our project partners to make available and share their respective national data beyond their country boundaries is very limited. Any use of hydrological and water resource data comes with associated political sensitivities, closely related to the current overall situation.

Hence, the following presentation will demonstrate the functionality of WEAP and some general results derived from this WEAP application for the Jordan region. It will also discuss how WEAP can further be developed and used in support of regional water management, quantifying the costs and benefits of different development options and pathways. We do not claim that our WEAP results at this stage are sufficiently accurate to be used immediately in regional water management. However, as part of the GLOWA Jordan River project, we have established a continuous dialogue between scientists and stakeholders which over the coming months will further refine the regional WEAP model by iteratively assimilating new data and information and by refocusing the guiding questions according to stakeholder priorities. As such, the results of this WEAP application are expected to become increasingly useful in cooperative and trans-boundary water management in the Jordan region.

While GLOWA project scientists in each of the three riparian countries, Israel, Jordan and PA, have developed detailed WEAP models for sub-catchments (upper Jordan River, West-Bank, East-Bank), we present here a regionally synthesized, aggregate WEAP model, representing the water system and its characteristics at basin level. This regional WEAP model simulates the system and its interlinkages with a limited level of detail and complexity by aggregating demand and supply sites while maintaining a representation of the current and future situation that is adequate for scenario analysis.

Figure 1 shows the WEAP schematic, which represents the system's demand and supply nodes and their interlinkages. Surface water resources are represented in aggregated form for:

- the Jordan River,
- its three main headwaters, Dan, Hazbani and Hermon,
- the Yarmuk, and
- a few side wadis from the eastern Bank.

The West Bank runoff to the Jordan Valley is represented by only one tributary in this preliminary WEAP model. Groundwater resources are also represented with limited detail, mainly through the three parts of the Mountain Aquifer, i.e. the Western, Eastern and North-Eastern Aquifer. Some other aquifers in the basin are currently being implemented and are not yet active in the WEAP model presented here.

Demand nodes are also highly aggregated in this regional WEAP model, to the extent that Jordan's demands are represented by only 3 irrigation districts (northern, middle, southern Ghor) and 2 cities (Amman and Zarqa), which depend to a large degree on Jordan / Yarmuk River water.

Similarly, demands in Israel (only 4% of Israel's population live in the Jordan River basin) that depend on Jordan basin surface and ground waters are represented by five demand nodes.

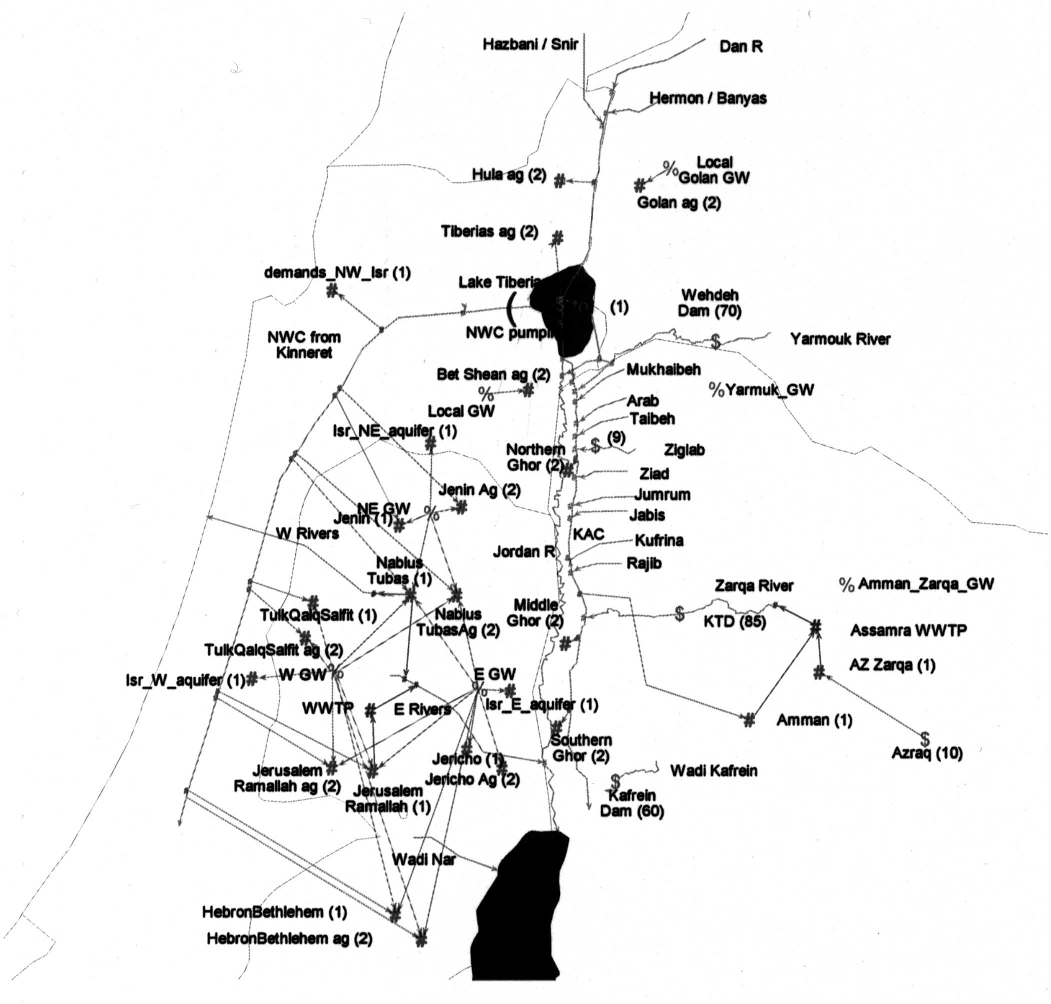

Fig. 1. Schematic of the regional WEAP model, with supply and demand components defined for those parts of the respective national water systems that are connected to the (surface and ground) waters of the Jordan River basin.

TESTING SELECTED WATER MANAGEMENT SCENARIOS IN WEAP

After extensive dialogues with many stakeholders throughout the basin, we concluded that initial WEAP scenario analysis should focus on the effects of:

1. increasing water demand from population growth, and

2. changing water availability from projected climate change.

Both of these drivers have been represented in this preliminary regional WEAP model in a simple and uniform way. Population growth rate was set to 1.5% per year across the basin and all countries, and that growth rate was applied to all demand nodes, i.e. municipal population as well as irrigated areas. Figure 2 shows the resulting total Palestinian population in the West Bank for the coming decades, as calculated in the WEAP scenarios. WEAP calculates total water demands for each node by multiplying the actual population (for municipal demand) or area (for irrigation demand) by the respective per unit water demand, as specified by the user.

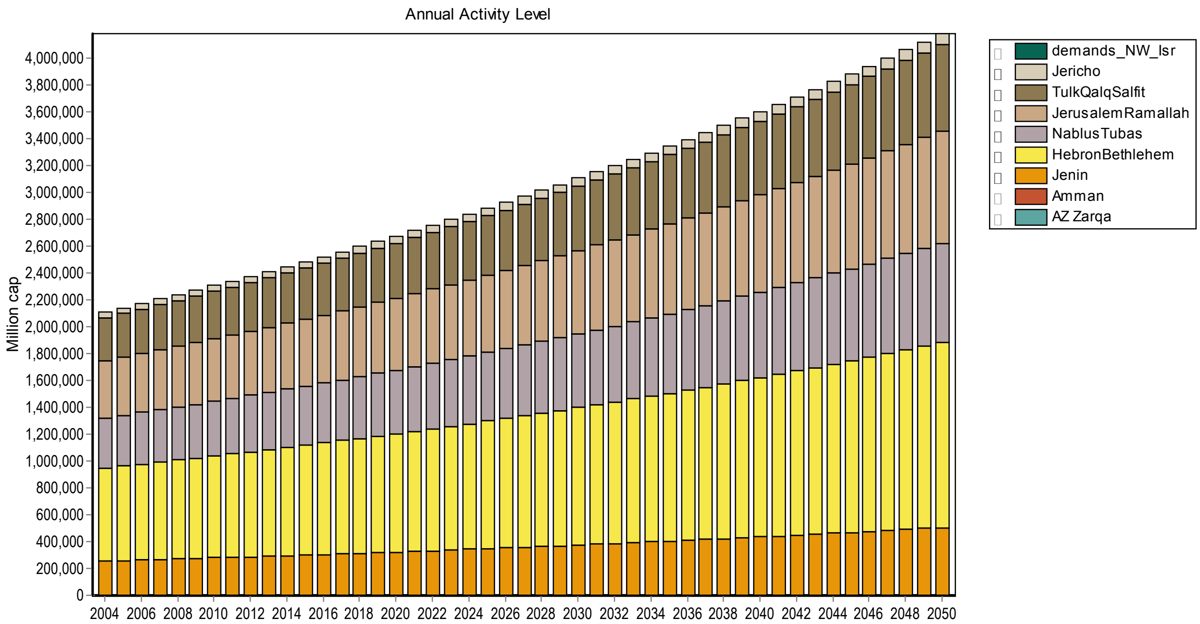

Fig. 2. A scenario of doubling in Palestinian West-Bank population by 2050.

In order to simulate seasonal variation in water demand, relative demands per months are entered in WEAP, as represented in Figure 3 for two agricultural and one municipal demand node for the base year 2004.

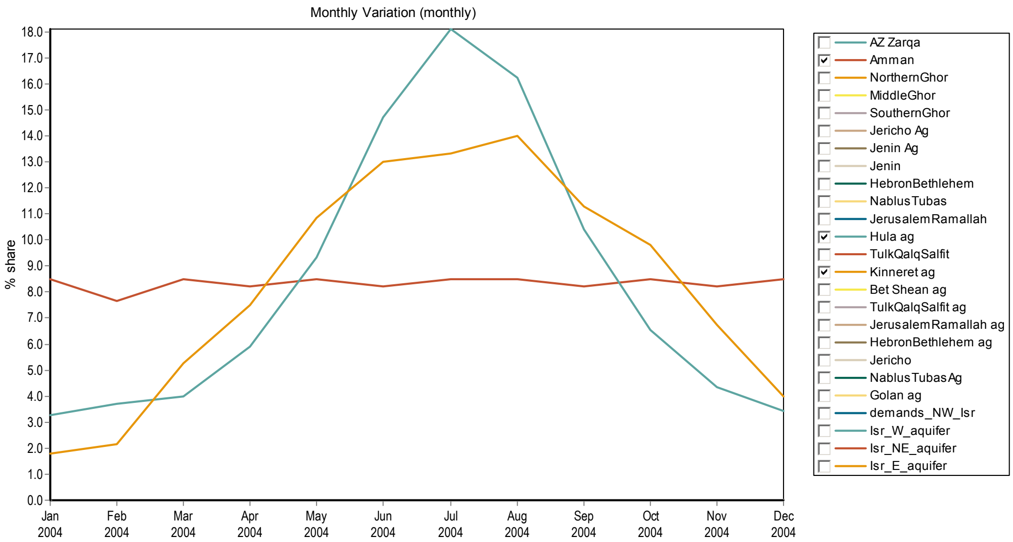

Fig 3. Fractional water demand per month for two agricultural demand nodes (Hula Valley and Kinneret) and one municipal node (Amman) for the base year 2004.

The second scenario driver, climate change, has been implemented in the preliminary regional WEAP model in a simple and uniform way, by reducing runoff and groundwater recharge with an annual rate of 1 % across the basin. Our assumption here - supported by regional climate modeling in the GLOWA project – is that with increasing temperatures and reduced total precipitation, runoff and groundwater recharge will be reduced by about 20 – 30 % over the coming decades.

Resulting overall effects for future runoff are presented in Figure 4. This graph demonstrates the additive effect of uniform runoff reduction across all tributaries, i.e. the cumulative runoff reduction in the Jordan mainstem when moving further downstream along the upper catchment towards Lake Tiberias.

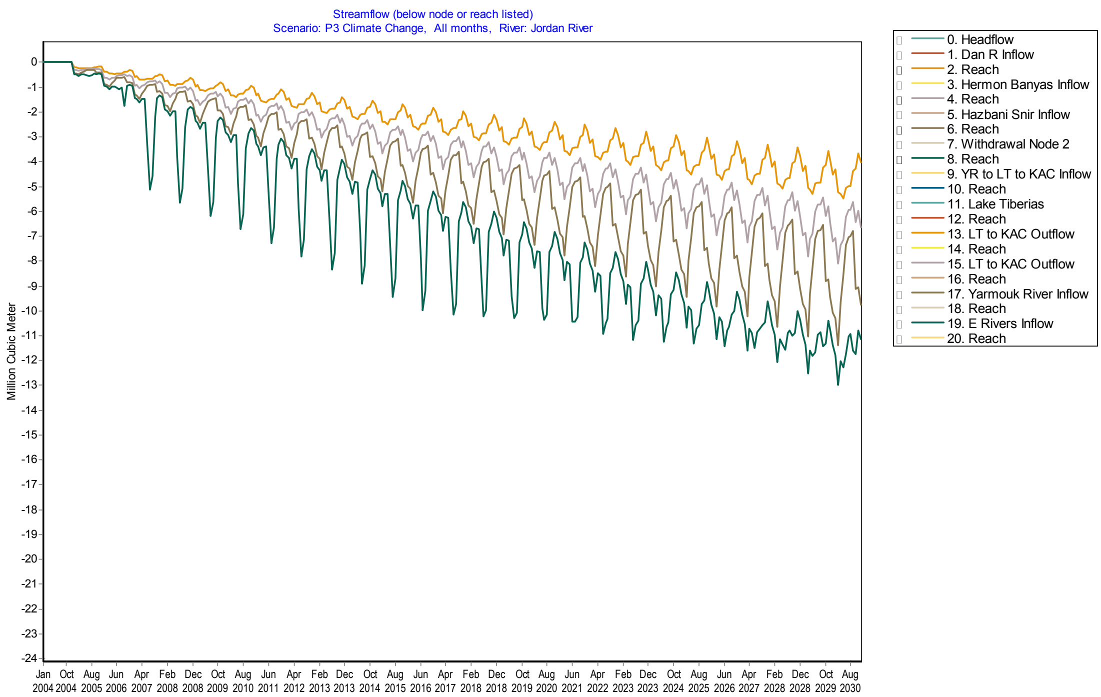

Fig. 4. Changes in monthly flow rates for different stretches along the upper Jordan River, for the climate change scenario (1% flow reduction per year), relative to the reference scenario without climate change effects.

Figure 5 overlays our assumption of a 1% annual reduction in groundwater recharge due to climate change with the current seasonality of recharge for the Western, Eastern and North-eastern Mountain aquifer, demonstrating the resulting temporal pattern for the coming decades.

In both cases the strong seasonal climate signal is clearly visible, indicating the increasing risk of severe water scarcity in summer, when total water availability decreases. We are currently implementing in this regional WEAP model the additional summer-time evaporative losses in the main regional water storage – Lake Tiberias; these losses amount to approximately 300 million m^3 per year and will increase further with rising temperatures.

Note that projected increasing climate variability for the eastern Mediterranean, with more frequent and severe dry periods and droughts, is not yet represented in our initial WEAP model. At present, we have implemented only a uniform decrease in annual runoff and groundwater recharge. We believe this is a simplified, but fair, representation of hydro-meteorological modeling results, such as those produced within the GLOWA Jordan River project. Critical water shortages in summer are likely to be amplified by the increasing climate variability, an effect which we will include in our regional WEAP model over the coming months.

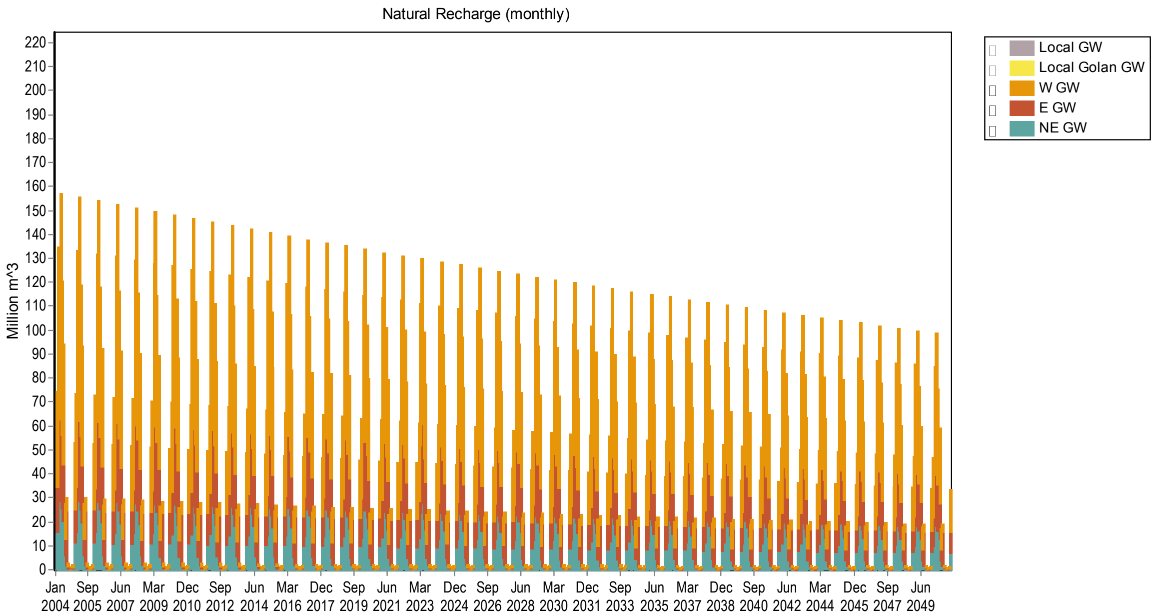

Fig 5. Time series of monthly recharge for the Western , Eastern and North-Eastern Mountain Aquifers, integrating current seasonality with our future climate change assumption of a 1% decrease in recharge per year.

Figure 6 shows the resulting change in groundwater storage due to changes in climate and recharge for the Western, Eastern and North-Eastern Mountain Aquifers; these results are dependent on total and initial storage volumes specified by the user. Storage in the Western Aquifer drops most rapidly, due to the highest degree of exploitation prescribed in this preliminary model.

A comparison of Figures 4 (runoff), 5 (groundwater recharge), and 6 (groundwater storage) demonstrates the buffering effect of large aquifers to seasonal fluctuations and hence the urgent need for sustainable management in order to cope with future drought situations. Note that these preliminary results do not consider increasing pumping due to increasing demand. We were not able to obtain reliable estimates of safe yields for these aquifers nor current pumping rates, again due to the restrictive data policies of the respective parties. In the coming months, we hope to be able to integrate the effects on groundwater storage in the respective aquifers from climate change with those from pumping and over pumping.

WEAP can be used to assess and compare different adaptation options and their system-wide implications. For the Jordan basin, demand management plays a key role. In Figure 7, results simulate the overall effect of successively introducing demand management measures that increase water use efficiency by 25%. Here we assumed that all municipal and agricultural demands can be reduced by 25% without reducing water-related services and productivity, achieved for domestic demands e.g. by reducing or eliminating unaccounted for water or leakages (currently 50% in Amman) or for agriculture by introducing drip irrigation. Jordan currently upgrades its sewage treatment plants for unrestricted reuse of wastewater, including drip irrigation. Figure 7 shows the aggregate effects of introducing such measures across all Jordanian demand nodes in our regional WEAP system. Again, strong seasonal variability is driving water scarcity for the agricultural demand nodes.

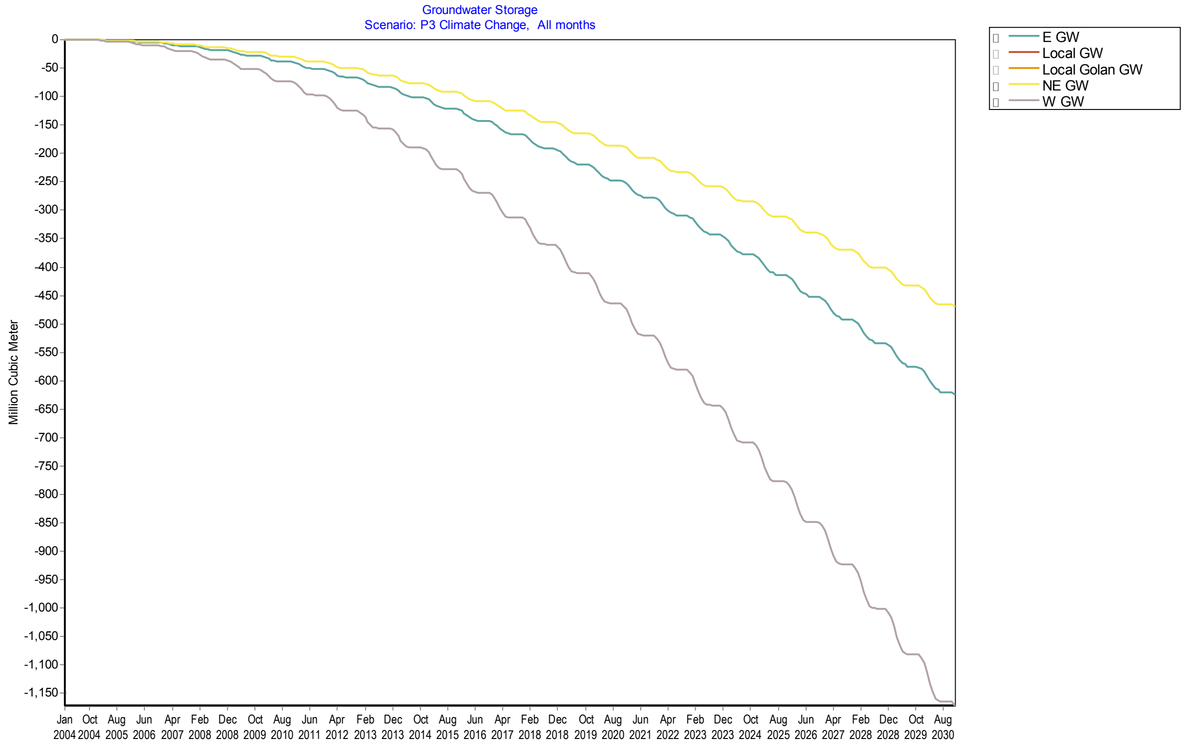

Fig. 6. Reduction in groundwater storage for the Eastern, North-Eastern and Western Mountain Aquifer, due to climate change, here relative to the no-climate-change scenario.

Over the coming months, we will specify jointly with stakeholders, e.g. from Ministries of Water and Irrigation and Agriculture, more realistic potential water saving strategies for different uses and compare them to supply side measures. As part of this improvement of our WEAP model, we will also introduce costs for different demand and supply measures; this will allow the derivation of per unit costs of water savings or increases in water supply.

DISCUSSION AND CONCLUSIONS

This work demonstrates the utility of WEAP as a data management, scenario analysis and decision support tool in water management in the Jordan region. This tool provides integrated information in a new and intuitive way to inform policy and decision makers.

The development of WEAP, a water balance model of limited complexity, is very straightforward, allowing iterative integration of new and more detailed information as it becomes available. Data entry, scenario analysis and revision of scenario assumptions are performed in a quick and very transparent manner. With that, stakeholders in water management are able to quickly learn how to use WEAP for their specific questions, in particular for comparing different scenarios and development alternatives, without having to rely on constant support from academic institutions (which is quite different for other water resources modeling tools). Once the benefits of using WEAP, in particular for co-operative, trans-boundary assessments and planning are recognized, it should be possible to share data more freely between the riparian partners. When that is achieved, WEAP will also serve as a useful tool to make previously static data bases dynamic and hence much more useful for future planning, as in the case of the joint Israeli-Jordanian-Palestinian EXACT database (see http://exact-me.org).

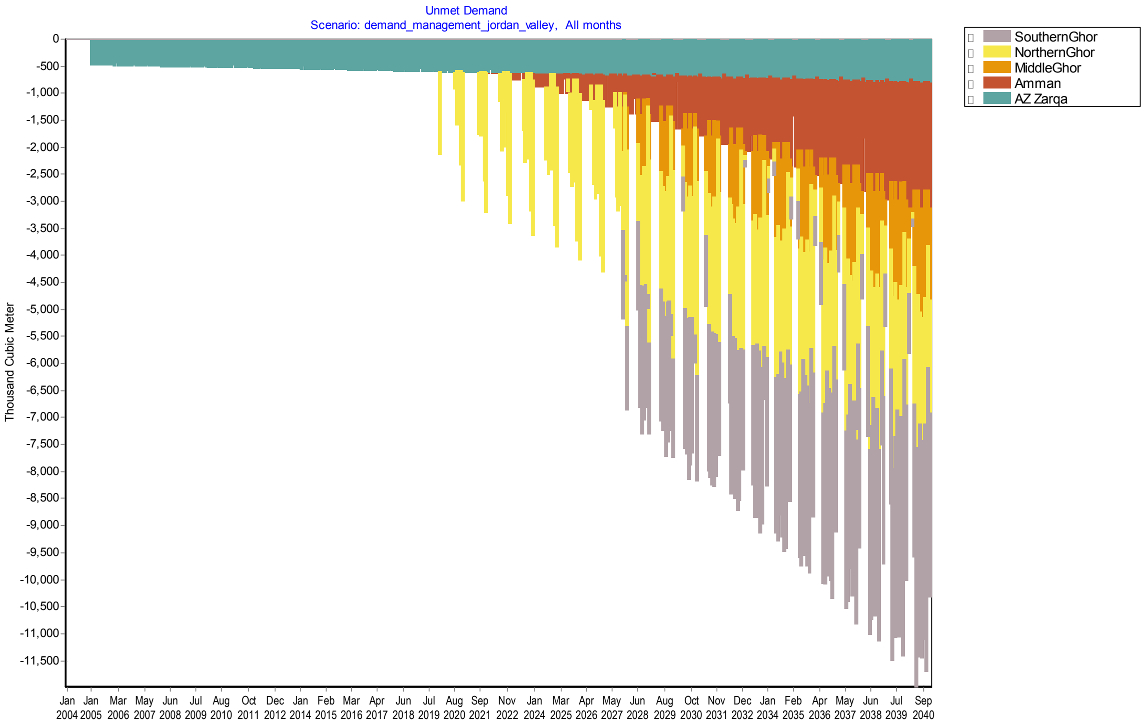

Fig. 7. Potential for water savings from the successive implementation of demand management strategies in Jordan (25% demand reductions for municipal and agricultural demands); here unmet demand for the demand management scenario is shown relative to unmet demand for the population doubles scenario

In the context of the GLOWA Jordan River project, we will refine the preliminary WEAP model for the Jordan River basin presented here through continuous dialogue between project scientists and stakeholders, in order to target the respective questions they pose for different development scenarios. This WEAP model for the Jordan region will be fully validated with in-situ and remotely sensed measurements as well as results from process-based models, and initial scenario assumptions will iteratively be replaced with better information as it becomes available. GLOWA model simulations, such as coupled hydro-meteorological modeling (MM5-WASIM), and coupled green and blue water modeling (TRAIN-ZIN) will play a key role in this revision.

Green water modeling, or the simulation of land use and climate change effects on runoff generation and groundwater recharge, will be consistently integrated in this WEAP model via implementation of WEAP's internal hydrology module. Using spatial aggregation, WEAP will also allow assessment of system-wide effects of different water and land management interventions, such as rainwater harvesting, artificial groundwater recharge or afforestions, when these are applied at larger scale. Furthermore, ongoing efforts to couple WEAP with a groundwater flow model (Modflow) for the MENA region will further support the application of scientific data and information in water management.

Iteratively we will also introduce costs of different supply side and demand side measures into our WEAP model, in order to compare per-unit-costs (of additional water in the case of supply side measures, or saved water in the case of demand side measures).

Eventually we hope to establish WEAP as a standard tool for co-operative and trans-boundary water management; one that will provide integrated assessments of social and economic costs and benefits and efficiency and which can explore equity issues concerning different water management and development trajectories. A concrete example would be the assessment of costs and benefits of the planned Red Sea – Dead Sea Canal, which could be compared to measures further upstream that increase green water use or water productivity in irrigation or reduced municipal water demands for example.

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