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Extended Abstracts

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title: **WEAP-MODFLOW as a Decision Support System (DSS) for integrated water resources management: Design of the coupled model and results from a pilot study in Syria**

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INTRODUCTION

The situation of the water supply in the Arab region is characterized by water scarcity and, at the same time, by increasing demand caused by population growth as well as expanding economy and agriculture. Furthermore, climate change models predict even more severe conditions in the water sector, associated with rising temperatures and decreasing precipitation. The decision makers have to respond to the most urgent questions: How will the water balance change in time and which action is required to achieve a sustainable water supply?

To answer these questions an integrated approach is obligatory. In addition to the evolution of the availability of water resources and of the demands, the whole social, economic, cultural and environmental framework has to be taken into account. To understand such a complex interacting system and the outcomes of any changes, a Decision Support System (DSS), based on computational models, renders assistance.

Within the framework of a technical cooperation project, ACSAD and BGR, supported by the SEI (Stockholm Environment Institute), have jointly worked on the development, application and dissemination of a DSS software for water resources management (Droubi et al., 2008). This system has been successfully applied in several pilot areas in the Arab region, e.g. in the Zabadani Basin, Syria.

WEAP-MODFLOW DECISION SUPPORT SYSTEM (DSS)

The DSS itself is a software product that gives the user the capability to calculate and visualize the time-dependent behavior of a hydraulic system, if one or many of the system's parameters change. The modeling components are a combination of the two preexisting software products: MODFLOW and WEAP. MODFLOW, developed by the U.S. Geological Survey (Harbaugh et al., 2000), numerically solves the three-dimensional groundwater flow equation for a porous medium by using the finite-difference method. It is based on Darcy's law for laminar flow and the conservation of the water volume. The water evaluation and planning system WEAP (<http://www.weap21.org>) has been developed by the SEI (Yates et al., 2005). Based on groundwater and surface water balances in a catchment, subcatchment or landuse class level, WEAP calculates current and future demands as well as the development of the resources.

A dynamic link between WEAP and MODFLOW has been developed. For each time-step, results of the one model are transferred as input data to the other (Fig. 1). Groundwater recharge, abstraction rates, and river stages are calculated by WEAP. This data act as boundary conditions for MODFLOW, which calculates hydraulic heads, storage volumes and flows in the groundwater system. These values are used in turn by WEAP.

Contrary to MODFLOW, WEAP does not take into account any spatial relationship. In order to ensure that WEAP results address to MODFLOW cells correctly and vice versa, a linkage has been developed, which acts like a dictionary between the two models.

Thus, river-groundwater interaction, spring discharge or recharge as well as management constraints regarding the groundwater head or discharge can be considered (Al-Sibai et al., 2009).

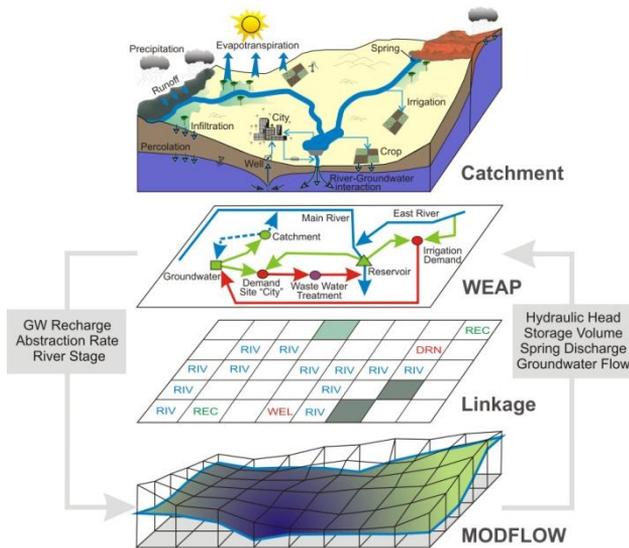


Figure 1. Schematic setup of the WEAP-MODFLOW DSS.

The calibrated DSS provides the capacity to investigate, compare and evaluate various water management scenarios. Future constraints, as changes in demography, economy, climate, land-use, irrigation efficiency, or return flow, can easily be taken into account. The results are visualized as graphs, maps, and tables. They depict the impacts of the scenarios on the water balance in a whole watershed or in detail, e.g. in terms of hydraulic heads, flow rates or irrigation amounts. Thanks to the coupling with MODFLOW, the reactions and dynamics of the groundwater system, discretized in time and space, can be predicted and evaluated.

The WEAP-MODFLOW DSS has been improved continuously. Recent developments aim at the integration of the simple particle tracking model MODPATH (Pollok, 1994), the optimization of abstraction rates and pumping allocation with consideration of water quality, drawdown and cost, and an additional soil water balance model called MABIA (Sahli, Jabloun, 2005). MABIA is based on the FAO-56 dual crop coefficient approach. It provides the use of real world field data as well as FAO reference parameters.

PILOTSTUDY ZABADANI BASIN, SYRIA

The Zabadani Basin is located in the Antilebanon Mountains in the NW of Damascus, Syria. It covers an area of about 140 km². Geomorphologically and hydrogeologically it can be divided into three NNE-SSW trending blocks (Fig. 2): 1) the Chir Mansour Mountain range in the W, reaching up to 1884 m a.s.l., characterized by faulting, intensive karstification and very high transmissivities; 2) the Zabadani graben, ranging from 1080 to 1400 m a.s.l., with moderate transmissivities; 3) the Cheqif mountain range in the E, reaching up to 2466 m a.s.l., with minor karstification and high transmissivities.

In the basin rises the Barada River representing the only perennial stream in the region. The mean annual rainfall is about 700 mm. About 48,000 people are living permanently in the area; however, during summer time the population increases significantly due to tourists.

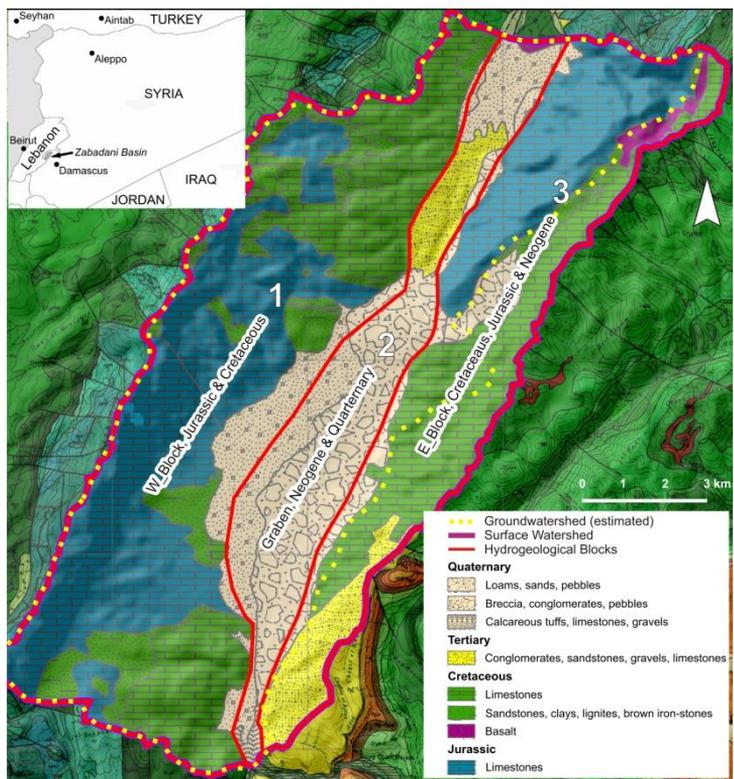


Figure 2. Location and geology of the Zabadani Basin.

In the Zabadani Basin exists already a water competition between local drinking water suppliers, Damascus water supply authority as well as agriculture and touristic activities. Since the very beginning of the project, a steering committee has been set up, integrating all relevant stakeholders into the DSS development, data acquisition and future scenario planning.

The numerical MODFLOW groundwater flow model of the Zabadani Basin consists of 10,044 cells, each with an equal length and width of 200 m. The regional aquifer has been subdivided into three layers, which have different hydraulic properties but are hydraulically connected. The anisotropic permeability varies in the range between 0.01 to 60.0 m/day, mainly according to the type of formation, density of lineaments and dipping of the formation. The boundaries have been set as no flow Neumann boundaries, except in the south where groundwater inflow is assumed. Groundwater recharge is calculated by WEAP, applying a soil water model on 48 landuse classes. Groundwater abstractions from well fields for domestic use and from rural wells for irrigation are considered. Furthermore, surface water-groundwater interactions at the Barada River and Barada spring have been modeled by Cauchy boundary conditions.

Since the hydrological year 2004/2005 was a year with an average precipitation leading to full recovery of the groundwater table after the winter rains, it was used for steady state and transient calibration of the hydraulic properties and the groundwater inflow from the south in order to fit the Barada spring discharge and the measured groundwater heads.

The WEAP21 software was used to build a planning and evaluation model, which then has been linked to the MODFLOW groundwater flow model as component of the DSS. Within WEAP, the basin has been divided into 11 subcatchments, based on the location of the major drinking water well fields and surface watersheds. In addition to areal data, climate data are also assigned at subcatchment level. In the next step, each subcatchment was further subdivided into respective landuse classes. Irrigation pattern, crop coefficient, leaf area index, root zone conductivity and soil water capacity values have been assigned to them. The basis for the landuse mapping was provided by aerial photographs, geological information (Kurbanov et al., 1968) and data from ministries as well as local farmers. Figure 3 depicts the WEAP schematic with integrated nodes as demand and supply sites as well as the connections between them.

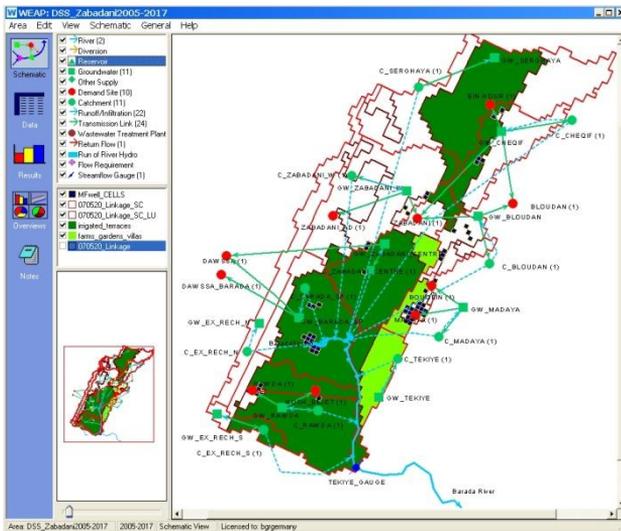


Figure 3. WEAP schematic of the Zabadani Basin (screenshot).

With the linked WEAP-MODFLOW model realistic surface-, soil- and groundwater balances as well as hydraulic heads for the reference year 2004/2005 could be calculated. The results can be visualized by WEAP at different scales in various charts, tables and maps, as shown in Fig. 4 exemplary.

Based on this initial model setup, different scenarios have been investigated dealing with realistic assumptions on domestic and agricultural demands as well as influences of climate change. As an example, results of two scenarios are depicted in Fig. 5. For scenario A, the demand of drinking water has been doubled whereas the irrigation demand has decreased by 30%, assuming population growth on one hand and a change to drip irrigation on the other hand. Influences of climate change are considered in scenario B, based on predictions of the climate model ECHAM4. Here, preliminary calculation results of daily precipitation data have been compared for two thirty year time periods (1961–1990 and 2070–2099). By averaging the yearly precipitation in the two time periods, a decrease in precipitation of twenty percent can be derived. This decrease was applied to the planning scenario 2005–2017 in order to see on an even shorter time scale the impact of climate change.

Both scenarios lead to a negative water balance within the basin. As a consequence of this, groundwater drawdown can be expected.

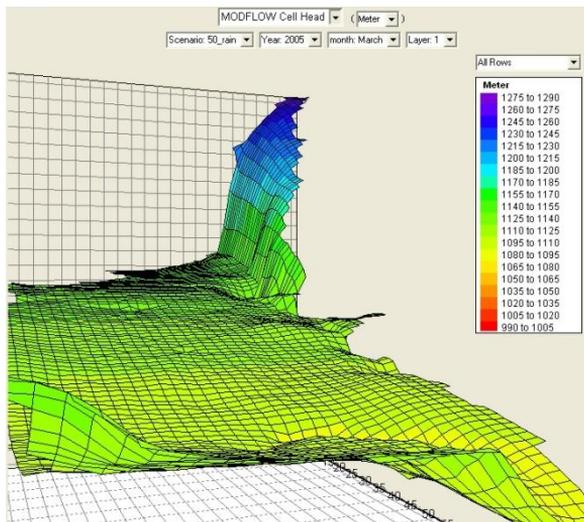


Figure 4. WEAP-MODFLOW DSS result: Hydraulic heads in the Zabadani Basin.

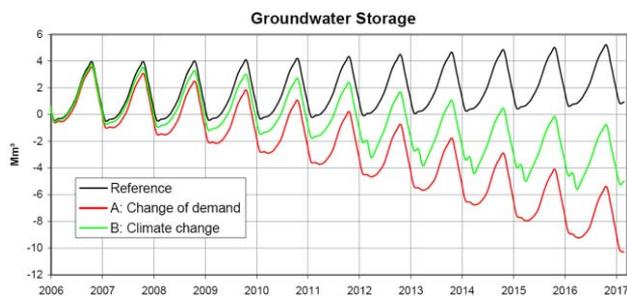


Figure 5. WEAP-MODFLOW DSS result: Comparison of scenarios.

CONCLUSIONS

Within the framework of a technical cooperation project, a user-friendly, inexpensive, efficient and easily shareable Decision Support System (DSS) for integrated water resources management has been developed incorporating MODFLOW and WEAP as modeling components. The user can manipulate inputs and evaluate and compare results of various scenarios with respect to current as well as future water management strategies in the target area, considering human activities (population growth, urbanization, domestic demand), agriculture (landuse, crop types, irrigation practices), climate impacts (climate change models, regional climate cycles), network characteristics (transmission link losses and limits, well field characteristics, well depths), and additional resources (artificial recharge, waste water reuse).

The results are visualized as graphs, maps and tables (hydraulic heads, water balances, etc.) and support the decision making process among relevant stakeholders and decision makers. The DSS has been successfully tested in the Zabadani Basin, Syria. For different water planning scenarios, realistic results (hydraulic heads, surface and groundwater balances, etc.) on different scales (MODFLOW cell, landuse class, subcatchment or catchment) could be calculated. The

DSS is already established in several institutions within the Arab region in Morocco, Tunisia, Palestine, Syria and Jordan.

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