



Single-continuum MODFLOW model of the Western Mountain Aquifer

Key findings

- The complex geological system of the karstified Western Mountain Aquifer (WMA) was simplified in a single-continuum MODFLOW model.
- The model accurately simulates the extensive exploitation of the WMA and the drying out of the historically most productive Yarkon spring.
- Due to great spatial differences in hydraulic conductivity, areas with a higher/lower density of conduits can be isolated.
- The model shows quick responses of the aquifer to external factors such as seasonal differences in recharge.

Motivation

The Western Mountain Aquifer (WMA) is Israel's most important groundwater source and has been heavily exploited since the early 1950s. The aquifer experiences significant changes in the pressure head throughout the seasons and long-term changes caused by wet or dry years. These quick responses of the aquifer to climatic changes can cause water shortages if not addressed early on. Sustainable aquifer management can be supported by hydrogeological modeling. We crea-

ted a fully calibrated MODFLOW model (Harbaugh, 2005) that can simulate groundwater flow in the WMA. In addition, the model simulates possible future water stress by integrating the results of high-resolution projections of climate and groundwater recharge until 2070. A good management plan can adjust groundwater extraction, i.e. pumping rates, before shortages even appear.

Methodology

The necessary files for the MODFLOW model were prepared in python scripts, where the geometry of four georeferenced layers forms two confined aquifers divided by a semi-conductive aquitard. Each formation has specific initial hydraulic properties within defined zones that stretch mostly from north to south. These zones were defined with regard to the great drop of hydraulic head around faults and the mountains of the recharge area as well as increased transmissivities measured in boreholes. After the geometry of the model was set up, the boundary conditions of pumping wells, springs, groundwater recharge in the outcrops of the WMA, and the saline intrusion near the Taninim spring were added to account for temporal changes in the system. The model implements the recharge calculations by a SWAT-model from 1979-2019,

MODFLOW

MODFLOW is a finite difference model (Harbaugh, 2005) that is able to simulate the groundwater flow process through an aquifer. It was developed and has been updated since the 1980s by the United States Geological Survey (USGS). It is a single-continuum model that is suitable for applications to karst aquifers.

previous years are simulated with recharge rates calculated by Abusaada (2011). The groundwater model can run in the steady-state and transient mode. Calibration of the model was done with PEST, an object-oriented parameter estimation code.

Results

The complex karst aquifer can be modeled as a single continuum in MODFLOW if enough zones are delineated. The fast flow component of karst aquifers occurring in conduits cannot be accurately simulated due to the limitations of the software, but high transmissivities can be achieved well. The calibrated pressure head shows the same trends and water table as the observed values. Figure 1 compares the observed and simulated head at selected observation wells across the confined upper aquifer for the period 1970-2019. From 1990 to 1995, the selected observation wells

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show an increase of pressure head due to the extremely wet year 1992. The seasonal change on the other hand is visible in the fluctuation of the pressure head, which is the strongest in the confined area of the north-west lowlands and an indicator of the storage capacity and temporal differences in groundwater recharge. In recent years, simulated and observed observation wells show different trends. The increase in simulated pressure head is caused by the Israeli pumping rate reduction of $\sim 100 \text{ Mm}^3/\text{a}$. Assuming the groundwater recharge is simulated correctly as before, additional water must be extracted that is currently unaccounted for.

Application

The MODFLOW model will help to make educated management decisions to reduce water stress by avoiding overexploitation and preparing for future changes caused by less annual precipitation and therefore reduced groundwater recharge. Figure 2 shows a nature conservative scenario with a reduction of pumping rates to 80% of the 5 year mean recharge, which would guarantee that groundwater levels stay above the red lines. The model can also help to find unnoticed water abstractions as shown above. A Karst Probability Map developed with the Stochastic Karst Simulator can be implemented in the model to increase the accuracy and provide information about the karst network and its state. This additional information will help to simulate the aquifer's fast flow component. The calibrated MODFLOW model is used as the basis for a Multi-Objective Optimization framework and a Decision Support System for the WMA.

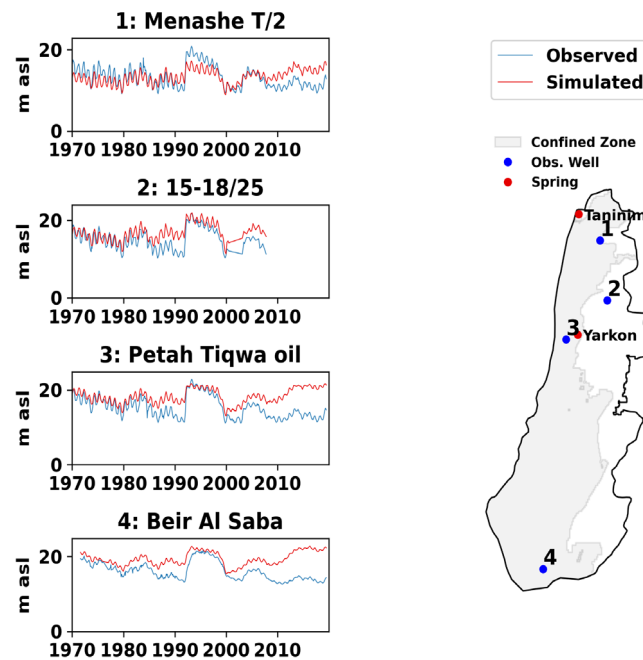


Figure 1: Comparison of the simulated and observed pressure head at selected observation wells across the confined upper aquifer

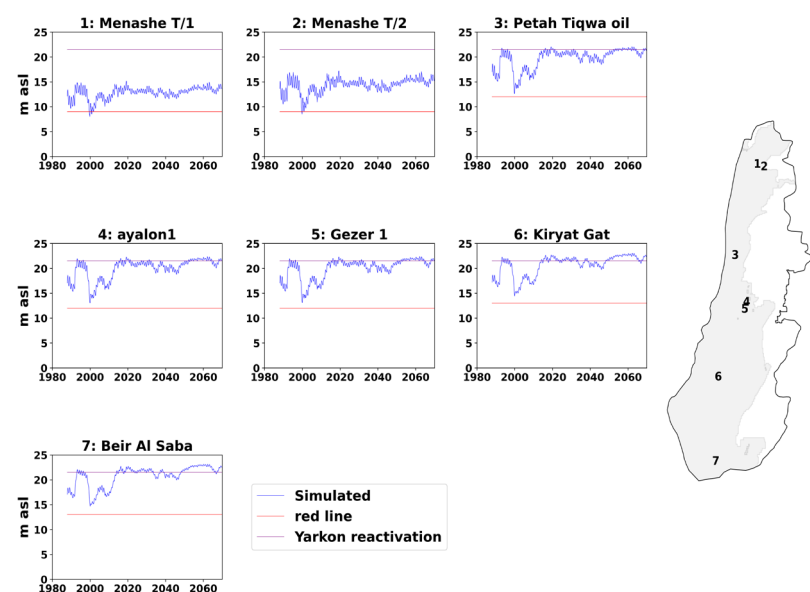


Figure 2: Selected simulated observation wells until 2070, compared with the Hydrological Service's corresponding red lines for maximum pumping

References

- Abusaada, M.J. (2011). *Flow dynamics and management options in stressed carbonate aquifer system, the Western Aquifer Basin, Palestine* (Doctoral dissertation). Retrieved from Georg-August-Universität Göttingen eDiss. (<http://hdl.handle.net/11858/00-1735-0000-0006-B2FD-2>)
- Harbaugh, A.W. (2005). *MODFLOW-2005: The U.S. Geological Survey modular ground-water model: The ground-water flow process*. United States Geological Survey. <https://pubs.er.usgs.gov/publication/tm6A16>

