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. Our goal is to create a fully calibrated MODFLOW model (Harbaugh, 2005) that can simulate groundwater flow in the WMA. In addition, the model is expected to simulate possible future water stress by integrating the results of climate models until 2070. A good management plan can adjust groundwater extraction, i.e. pumping rates, before shortages even appear.

MODFLOW

MODFLOW is a finite difference model 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.

Methodology

The necessary files for the MODFLOW model were prepared in python scripts (Bakker et al., 2016), where the geometry of four georeferenced layers form 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 in regard to the great drop of hydraulic head around faults and the mountains of the recharge area as well as increased transmissivities

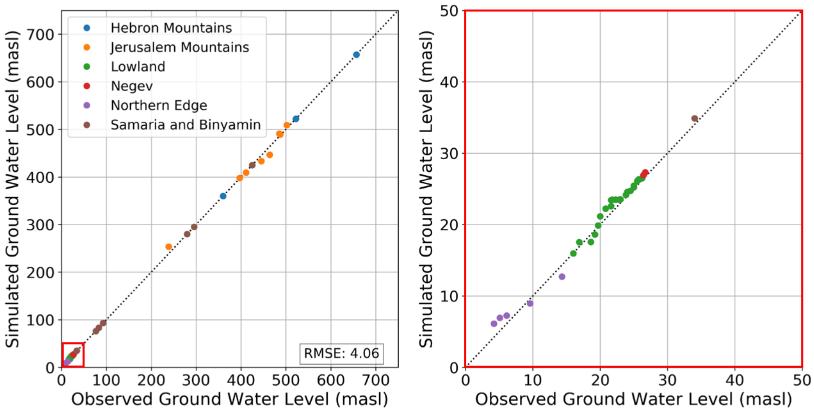

Figure 1: Comparison of the simulated and observed pressure head of several observation wells, plotted to show deviations of the current steady-state model

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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 groundwater model can run in the steady-state and transient mode. Calibration of the model is done with PEST, an object-oriented parameter estimation code. The steady-state version of the model is used to calibrate the hydraulic conductivity, while the transient version is used to calibrate the storage coefficients.

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 calibration of the steady-state system shows good results of the pressure head for low elevated areas (Figure 1). With increasing surface elevation, the simulated and observed pressure heads are showing small discrepancies (Figure 2), especially in the Jerusalem Mountains. The seasonal change in the water table as well as the influence of wet years is visible in the quick response of the water table in the simulated aquifer (Figure 3). From 1990 to 1995, selected observation wells 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. The strongest discrepancy between observed and simulated pressure head is shown for well 4 in Figure 3. The simulated head is constantly overestimated and could be adjusted by an increased storage coefficient.

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. The model will also help to understand the aquifer better by highlighting areas of high conductivity. A Karst Probability Map developed with the Stochastic Karst Simulator will 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. Therefore, new zones will be defined and calibrated. The calibrated MODFLOW model is used as the basis for a Multi-Objective Optimization framework and a Decision Support System for the WMA.

References

Bakker, M., Post, V., Langevin, C.D., Hughes, J.D., White, J.T., Starn, J.J., & Fienen, M.N. (2016). Scripting MODFLOW model development using Python and FloPy. *Groundwater, 54*(5), 733-739. https://doi.org/10.1111/gwat.12413

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

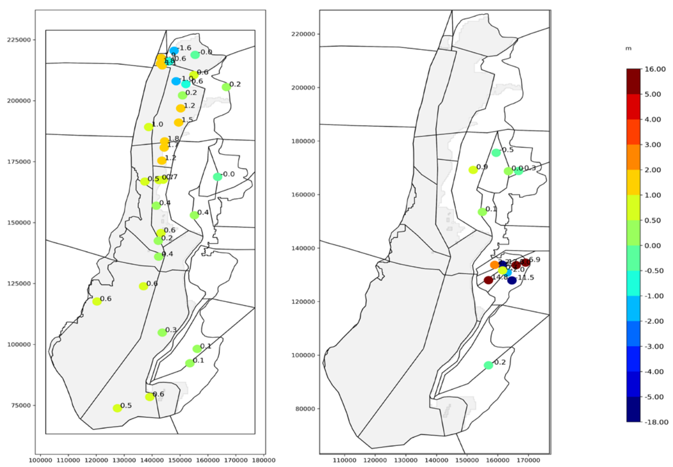

Figure 2: Differences of simulated and observed pressure heads in the upper (left) and lower (right) aquifer, as represented by their dot color. The greatest deviations occur in the mountainous area.

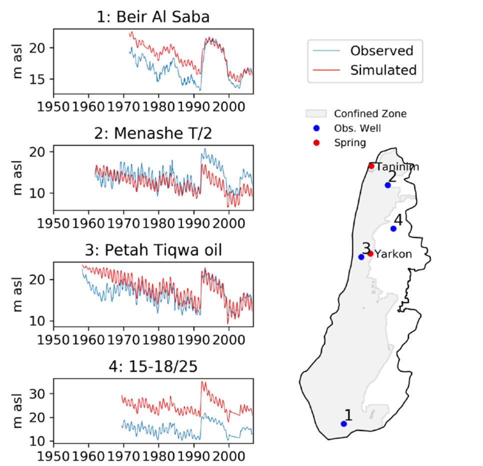

Figure 3: Comparison of the simulated and observed pressure head of selected observation wells

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