
Lower Jordan Valley ©Xanke

Groundwater Models of the Lower Jordan Valley Aquifer

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KEY FINDINGS

The main input flow component of the Lower Jordan Valley alluvial aquifer is lateral groundwater inflow from the adjacent mountain flanks to the east (Jordan) and west (Palestine) of the Valley.

Abstraction by wells is the main flow component for the depletion of stored groundwater on both sides. A sharp decline in groundwater levels has been observed over the past 20 years in the central and southern parts of the valley on the Jordanian side as well as in Jericho and Auja areas on the Palestinian side.

There is potential for managed aquifer recharge (MAR) on both sides of the valley, which would increase groundwater resources availability and enhance managing the supply-demand in both areas.

MOTIVATION

Hydrogeological understanding of the aquifer system is a key aspect for sustainable groundwater management in the Lower Jordan Valley (LJV). The heterogeneous geological structure of the Quaternary sediments results from lacustrine and fluvial deposits, ranging from fine evaporite-bearing layers to coarse gravel. Groundwater quality ranges between freshwater and brackish water, the latter mainly due to groundwater overuse and leaching of evaporites. Two three-dimensional numerical groundwater models were developed to determine the groundwater fluxes and aquifer overuse in the past decades (Figure 1). The investigations include quantifying the groundwater balance, including lateral inflow from the mountain bedrocks and Lake Tiberias, while considering hydraulic exchange with the Jordan River and seepage to the Dead Sea. The models assess groundwater storage capacity and its change due to climate change and groundwater abstraction. Furthermore, the models can be employed to show the impact of different scenarios on the groundwater budget, e.g. increases or decreases in groundwater abstraction rates and/or through managed aquifer recharge (MAR). The eastern and western sides of the valley were investigated using two different groundwater models, as one model already existed on the Palestinian side and was further developed, and as the input data for calibration originated from different time spans. However, the models were created with similar parameters and boundary conditions to be comparable (see Table 1).

Model	Software package and numerical method	Number of layers	Model thickness [meter]	Hydraulic conductivity [m/d]	Boundary conditions			
					Jordan River	Dead Sea	Mountain range	Lake Tiberias
Jordanian	FEFLOW, finte element	10	200	1-2	Cauchy	Hydraulic head	Hydraulic head	Hydraulic head
Palestinian	MODFLOW, finite difference	9	200	0-8	Hydraulic head	Hydraulic head	Cauchy	-

Table 1: Comparison of the two model configurations.

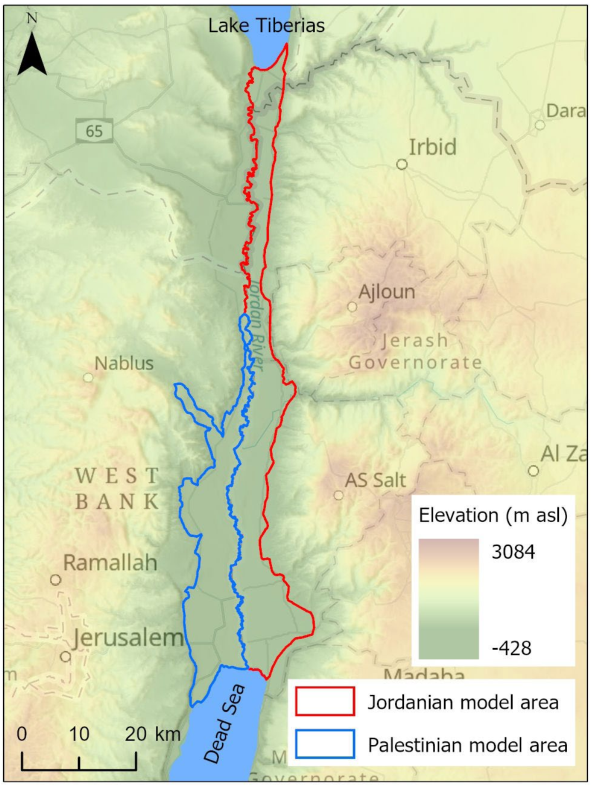

Figure 1: Location of the two model areas in the Lower Jordan Valley.

JORDANIAN SIDE

Methodology

Work steps included an evaluation of the lateral and vertical geometry of the upper unconsolidated aquifer, spatial analysis of hydraulic parameters, groundwater levels, and their regionalization, estimation of the inflow, and evaluation of available groundwater data from MWI (2019).

The model was implemented with FEFLOW software and covers the entire Jordanian part of the LJV with a length of 116 km and a width of up to 15 km (Figure 2). The model boundaries at Lake Tiberias (north), the Dead Sea (south), and the bedrock of the Jordan Highlands (east) were implemented as 1st kind/Dirichlet boundary condition. The Jordan River in the west was implemented as 3rd kind/Cauchy boundary condition. The model has an average thickness of 200 m.

The model was calibrated for steady-state conditions based on the groundwater levels of 1998 (best data coverage). For the calibration process, hydraulic conductivities of the Lisan-Formation, the Alluvium, and the interfingering area is estimated with PEST, an automatic parameter estimation software. Subsequently, the boundary conditions were adapted according to 2020 water levels from Lake Tiberias and the Dead Sea to represent the current groundwater conditions..

Results

Simulated groundwater levels show a very good correlation with observed groundwater levels from 1998 with a correlation coefficient of 0.95, which is satisfactory for a model of this size. Although, the simulated groundwater levels reproduce the observed groundwater levels well, in the southern area, the model indicates much lower groundwater levels compared to the contour map produced by

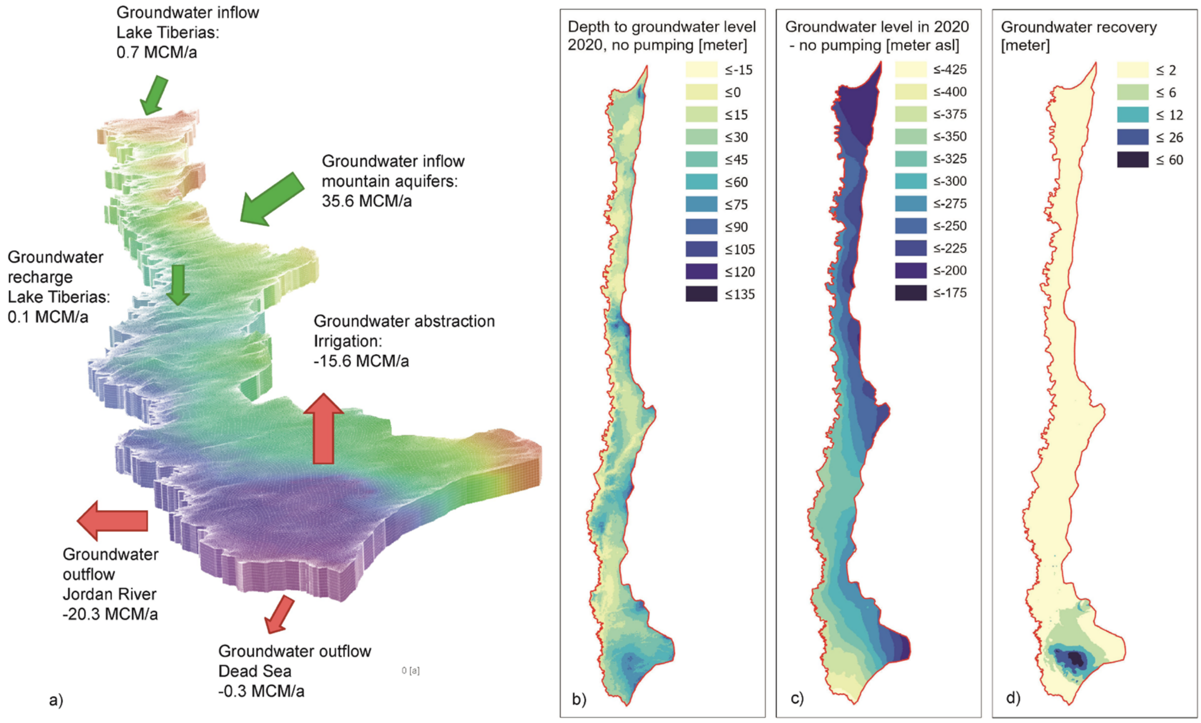

Figure 2: a) Numerical groundwater model of the Jordanian side with simulated in- and outflow components, b) depth to groundwater level and c) groundwater level in 2020 without pumping activities, and d) resulting groundwater recovery.

interpolation. It is assumed that excessive groundwater withdrawals cause local cones of depression not captured by the interpolated groundwater contour map.

A comparison of simulated groundwater levels with and without groundwater abstraction shows storage volume differences of 72 Mio. m^3/a. The results indicate that a combined groundwater management approach of reducing abstractions and increasing MAR would allow the aquifer long-term storage volume to increase significantly, positively affecting groundwater discharge to the Jordan River, favouring floodplain restoration and annual inflow to the Dead Sea.

PALESTINIAN SIDE

Methodology

A steady-state finite difference approach and inverse modeling were used to determine hydraulic conductivities, hydraulic heads, and groundwater budget on the Palestinian section of the Lower Jordan Valley Alluvial Aquifer (Figure 3). A geological map, a digital elevation model, precipitation data, and data from about 100 abstraction wells and 26 observation wells were used as input data. The simulation was performed using Aquaveo's GMS software, which includes the code of the finite-difference flow modeling program MODFLOW and a graphical user interface. As on the Jordanian side, model thickness is set at 200 m, assuming insignificant flow below this depth. The model is divided into 8 layers and extends about 60 km in the N-S direction and 10 km in the E-W direction. The hydraulic heads in the south and the east are defined as fixed-head boundaries at water levels of the Dead Sea and the Jordan River, respectively. In the west, towards the Eastern Mountain Aquifer, a variable general head boundary was implemented, controlled by measured groundwater levels in the adjacent carbonate aquifers.

Results

Trial and error calibration obtained a map of the spatial distribution of hydraulic conductivities in the model area (Figure 3a). Higher conductivities occur primarily in the west

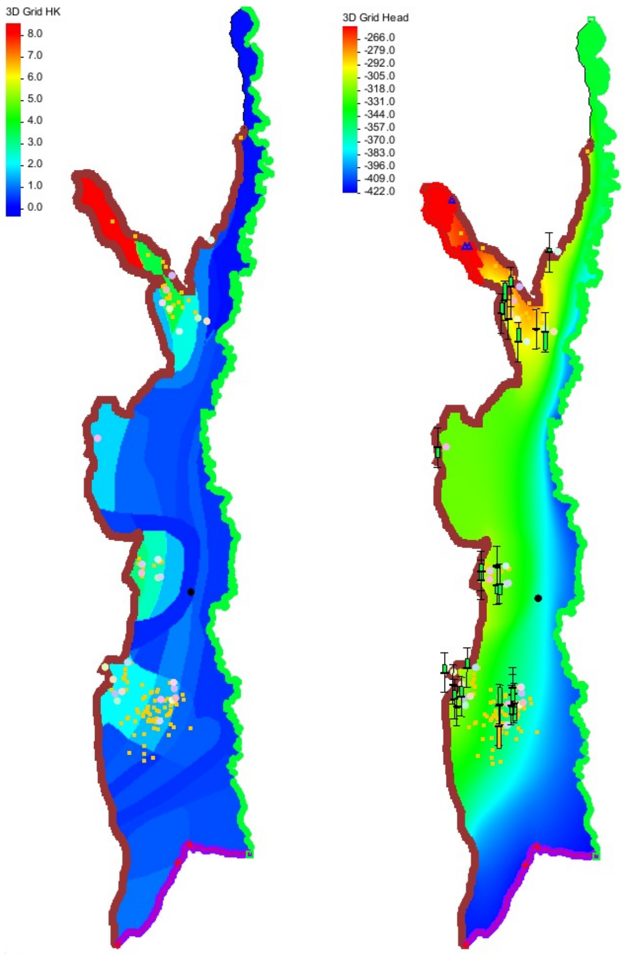

Figure 3: Hydraulic conductivities (left, in m/day) and hydraulic heads (right, in m asl) of the groundwater model at the Palestinian side.

and are concentrated around the major wadi exits to the LJV, consistent with the higher grain size expected in these areas. The hydraulic heads could be optimized to be within +/- 22 m compared to the observed heads, which appears large at first glance (Figure 3). More accurate calibration proved difficult because only a few observation wells are available. The available observation wells are located within a few clusters. The estimated hydraulic conductivities show a very heterogeneous distribution. A total of 11.3 Mio. m^3/a is withdrawn by wells, while 3.2 Mio. m^3/a discharges towards the Dead Sea. Recharge by precipitation is only 3.4 Mio. m^3/a. Inflow from the Eastern Mountain Aquifer can only be estimated by model calibration, thus implying some uncertainty. The final model can be used for forward modeling approaches to simulate the effect of MAR and the freshening process of brackish groundwater.

CONCLUSION AND NEXT STEPS

The large-scale groundwater models of the Lower Jordan Valley are well suited to simulate the inflowing and outflowing water volumes. Simple scenarios such as reservoir changes are feasible and allow conclusions about available groundwater volumes and groundwater management. For small-scale, local simulations, the model is rather unsuitable for drawing conclusions due to its size and generalized input parameters. Consequently, further numerical models are still needed to understand the flow dynamics between the mountain aquifers and the Lower Jordan Valley on both sides as well as the impact of climate change, pumping and managed aquifer recharge on the water quality in the aquifer systems.

MODELING SOFTWARE

Based on the hydrogeological conceptual models of the Lower Jordan Valley, two three-dimensional numerical groundwater models were created. The model for the Jordanian side was implemented using the FEFLOW software by DHY Wasy (Diersch, 2013). Model calibration was accomplished using FEPEST, which uses the Gauss-Levenberg-Marquardt algorithm (GLMA), which iteratively optimizes the model parameters to improve its fit to the observed data. The model for the Palestinian side was created using the GMS software by Aquaveo, which includes the code of the finite differences flow modeling tool 'MODFLOW' and a graphical user interface. Model calibration was done manually.

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References

Diersch HJG (2013) FEFLOW: finite element modeling of flow, mass and heat transport in porous and fractured media. Springer Science & Business Media.