Taninim Spring, Israel ©Bresinsky

Regional Models of Large-Scale Storage of Desalinated Seawater

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KEY FINDINGS

Storage occurs in the vadose and phreatic zone at different temporal scales due to the contrast in hydraulic properties between the conduit network and the fractured rock matrix.

Model results show that hydraulic losses are below 10% for the first 14 years for the Western Mountain Aquifer. Cumulative hydraulic losses during that time are estimated at ca. 3%.

The regional water balance reveals that only a small fraction of the recharged water discharges to springs. Most of the groundwater is abstracted by wells.

MOTIVATION

Managed aquifer recharge (MAR) with desalinated seawater is a promising storage option in the Mediterranean region. Desalinated water being expensive and of very high quality, it is necessary to minimize water losses and prevent quality impairments during MAR. Numerical models provide quantitative support in the spatial optimization of MAR and the recovery of recharged water by simulating the storage system response to proposed MAR strategies. MAR applications can be examined a priori by employing process-based numerical models that provide quantitative measures of different injection/infiltration schemes, storage time, storage capacities, and potential losses because of quality impairment or uncontrolled discharge. Here, we assess the suitability of the Western Mountain Aquifer (WMA), shared by Israel and Palestine. The necessity of employing a numerical model is a result of the complex flow system of the WMA (i.e. duality of flow in karst), considering vadose and phreatic flow. Distributed numerical models allow to estimate the effects of the vadose zone on the storage and the residence time (and consequently the recovery efficiency) of the recharged water in the aquifer considering the rapid flow behavior of karst aquifers.

METHODOLOGY

The WMA is characterized by a vadose zone several hundred meters thick and its dual flow dynamics, i.e., diffuse matrix and rapid fracture/conduit flow. To account for these aspects, the WMA is represented as a variably saturated dual-continuum model (Bresinsky et al., n.d.) simulating the vadose and phreatic storage dynamics. The domain is discretized by two separate overlapping continua and coupled by a head-dependent exchange term representing flow through the rock matrix and all additional flow domains (i.e., conduits and fractures). The employed modeling software HydroGeoSphere (Brunner & Simons, 2012) uses the bulk-effective Richards' equation parameterized by the Van Genuchten material model to predict variably saturated conductivity. We heuristically approximate inertia-driven infiltration through the second continuum by employing a minimum relative conductivity at nearly dry conditions since capillary-driven approaches cannot resolve non-equilibrium infiltration. Net infiltration at the soil level is calculated by a soil-epikarst water balance model based on Schmidt et al. (2014). The serial model arrangement is shown in Figure 1. The methodology applied allows to predict spatiotemporally distributed storage at catchment scale and therefore enables to optimize the application of MAR.

RESULTS

The simulation of phreatic and vadose flow indicates that the WMA has considerable potential for long-term storage

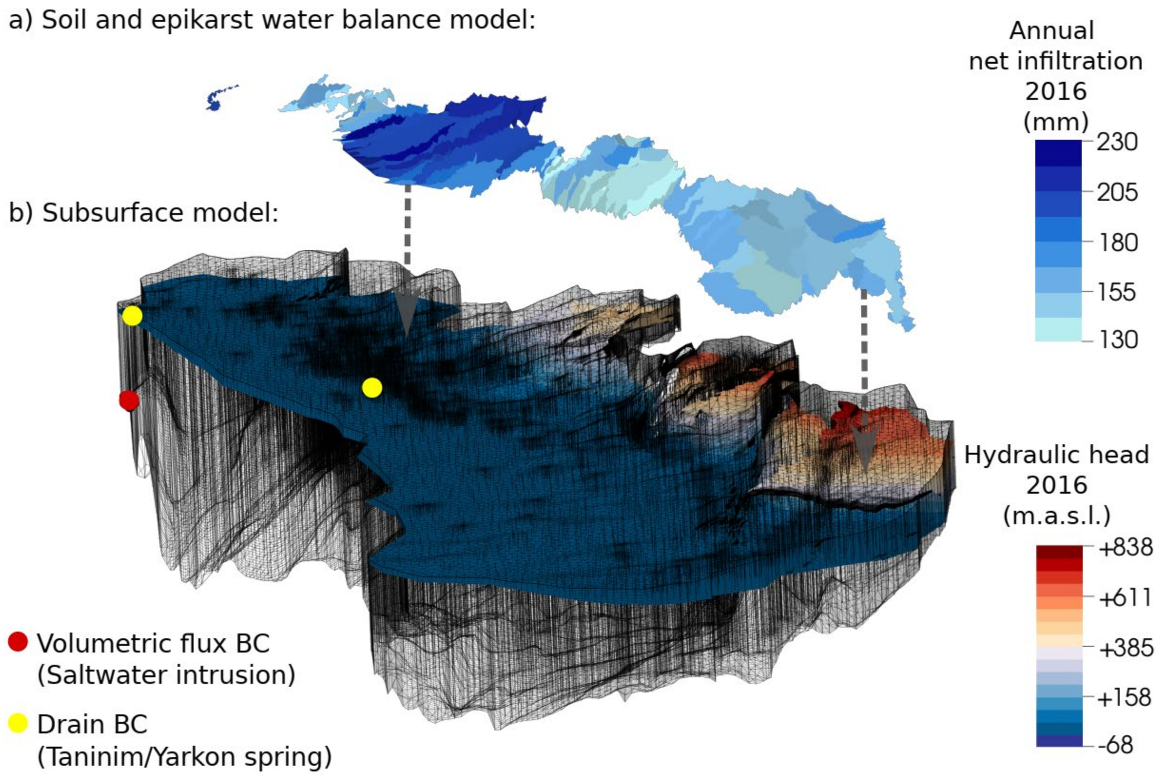

Figure 1: Recharge calculated by a soil-epikarst water balance model and variable saturated dual-continuum subsurface flow model for 15-09-2016.

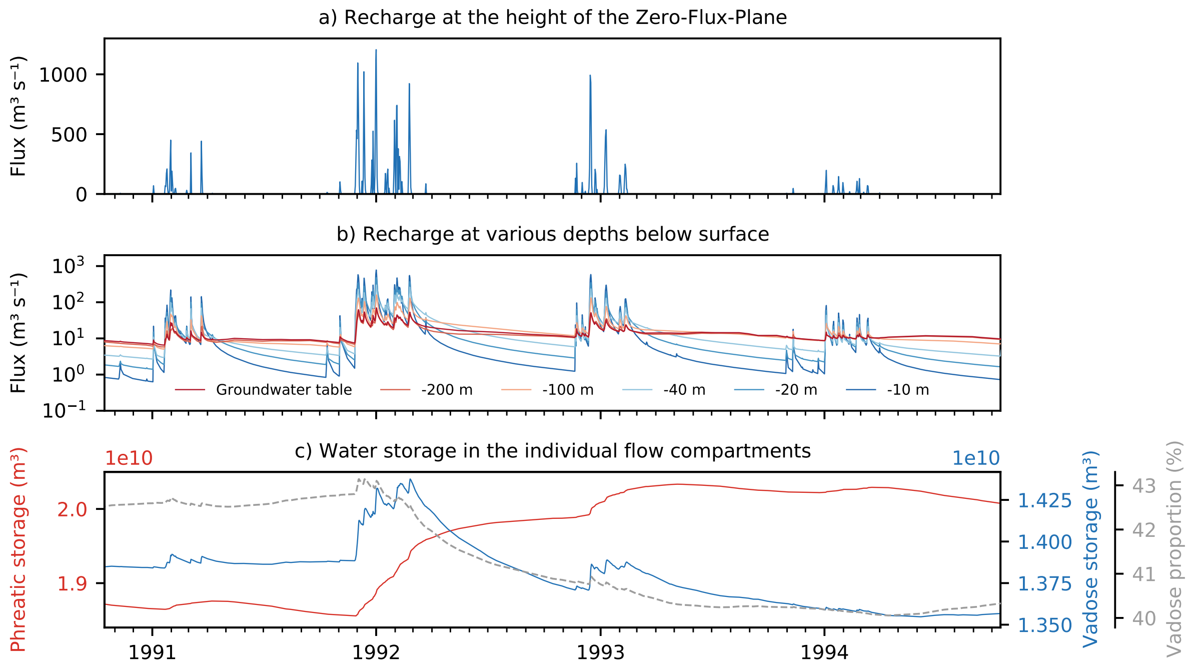

Figure 2: Simulation results for the Western Mountain Aquifer (WMA) of a) shallow recharge, b) deep recharge at various control planes below surface, and c) the change in water storage in the individual flow compartments following recharge events.

despite being a well-matured karst aquifer. This can be explained by the fact that the aquifer is enclosed largely by non-permeable geological units of the Talme Yafne Formation towards the Mediterranean, which prevent rapid discharge (i.e., dammed karst system). Natural groundwater discharge is confined to artesian discharge at the Taninim spring. However, due to heavy anthropogenic abstraction, only a small fraction of the recharged water discharges naturally, and ca. 90% of the water is abstracted at many production wells, inducing a regional cone of depression. Model simulations demonstrate that the thick vadose zone provides additional short-term storage. This is apparent from the delayed long-term recession of the hydraulic signal (spring discharge, groundwater levels) for ca. 600 days following the wet winter of 1991/1992 (Figure 2). Still, a large fraction of recharge reaches the groundwater table along preferential flow paths after circa 100 days. Natural recharge of the wet winter of 1991/1992 shows residence times of almost 1.5 years in the vadose zone and up to 7 years in the phreatic zone. Figure 3 shows how much water is lost per year if 100 Mio. m^3/a are artificially recharged in the upgradient Jerusalem district. As losses stay low (<10%) for up to 10 years, it highlights that the WMA can be used for long-term storage, while keeping the recovery efficiency high. Therefore, the combined storage capacity of the vadose and phreatic zones may be utilized for compensating increased water demands during multi-annual droughts.

CONCLUSIONS

This feasibility analysis shows that MAR can be used even in karst aquifers for long-term water storage while achieving high recovery efficiencies. However, the investigation of management scenarios for optimization remains an open task. Thus, this study may serve as a basis for future research dealing with optimization strategies, which in turn should be tested through field studies/experiments. A further study should consider substituting the soil-epikarst water balance model by a numerical model approach that discretely simulates surface runoff processes. It would allow to investigate the recharge potential of infiltration schemes along wadis, dolines and other infiltration hotspots. The model employed is particularly suited for coupling surface and subsurface processes, because the utilized spatial discretization method of mimetic finite differences was shown to be advantageous for such coupled simulation tasks (Coon et al., 2020).

MODELING TRADE-OFFS

Numerical models representing a natural flow system are subject to a trade-off between parametric ambiguity and structural uncertainty. When incorporating more physical processes into a numerical model, the number of unknown parameters increases, making it more difficult to obtain them via field measurements. In contrast, lumping physical processes carries the risk of having oversimplified model structures. Such oversimplified models do not account for relevant physical processes or the spatial variability of hydraulic parameters of carbonate aquifers, resulting in an overall low predictive power.

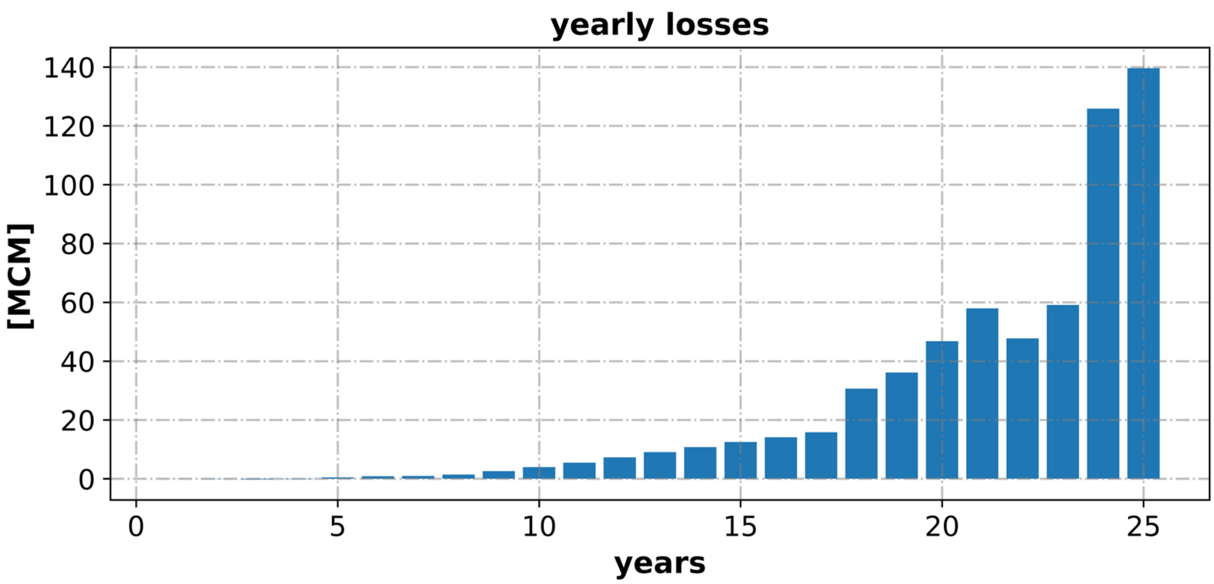

Figure 3: Annual losses in million cubic meters (Mio. m^3MCM) in case of an artificial recharge of 100 Mio. m^3/aMCM/a.

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Funding code: 02WM1533A

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