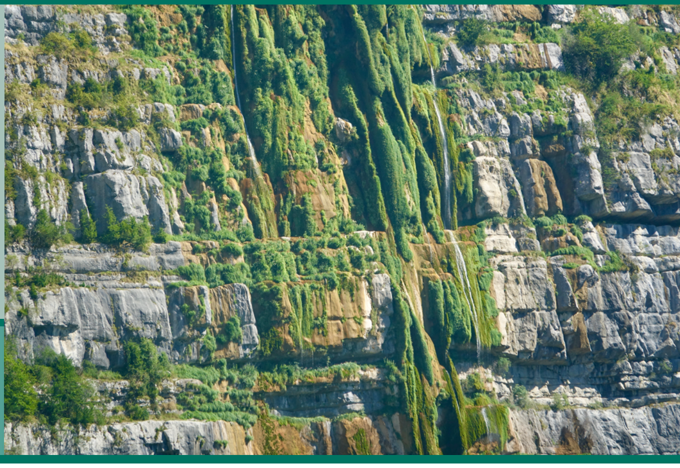

Variably saturated dual-continuum flow modeling to assess distributed infiltration and storage in the vadose zone

Key findings

- We simulate flow in the variably saturated fractured-porous subsurface, accounting for the storage capacity of a several hundred meters thick vadose zone and the duality of karstic flow in the vadose and phreatic zone.
- The model demonstrates that altered precipitation patterns due to climate change require careful adaptation of water management practices to account for the complex interaction between rapid infiltration and long-term groundwater storage patterns.
- Modeling spatially distributed dynamics at sufficiently high temporal resolution and in the context of climate change simulations on a catchment scale requires substantial computational power and a parallelized computing environment.

Motivation

Climate change is expected to significantly impact water resources in Mediterranean karst aquifers due to the expected overall decrease in average precipitation depth, while the intensity and frequency of short-duration extreme rainfall might increase. The reduced total annual precipitation may not necessarily decrease recharge since karst features, such as dolines and dissolution shafts, provide high infiltration capacities, reducing the total volume of water exposed to evapotranspiration. With its expected large variability in recharge and its complex geometric structure and hydraulic properties, the management of the Western Mountain Aquifer (WMA) in Israel and the West Bank requires appropriate management strategies and therefore adapted groundwater modeling tools. The main objective of this subproject is to simulate the temporal and spatial discharge dynamics of the WMA taking into account the storage properties of the phreatic and vadose zones as well as the geometric and hydraulic characteristics of the karst system, composed of a draining conduit network and the adjacent porous matrix storage system.

Methodology

We employ the parallelized flow simulator HydroGeoSphere (HGS) on a high-performance-computing platform to simulate transient, variably saturated water flows on the catchment scale. A double-continuum approach based on the volume-effective Richards equation with Van-Genuchten parameters is applied to simulate flow in the variably saturated fractured/karstic-porous subsurface (Figure 1b), accounting for the duality of karstic flow, both in the vadose and phreatic zones, with rapid flow

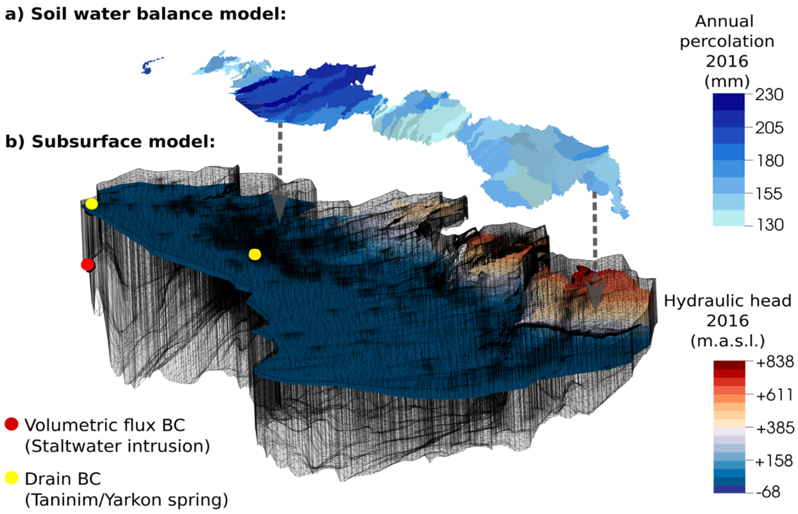

Figure 1: Spatial discretization and simulation results for the year 2016

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MedWater

HydroGeoSphere (HGS)

HydroGeoSphere (Aquanty Inc., 2019) is a three-dimensional, physics-based, integrated surface-subsurface, multi-continuum flow simulator that can be run on parallelized high-performance-computing platforms, facilitating the computation of large-scale complex representations of catchments. It simultaneously solves the 2D overland flow and 3D subsurface equations, allowing rainfall to partition into overland flow and dual-continuum infiltration naturally.

through conduits and slow flow through the rock matrix. We apply optimized unstructured triangular meshes with refinement near wells, streams, and springs to deal with the high computational demand and potential numerical convergence issues. We compute daily infiltration at the level of the Zero-Flux-Plane as input a priori by a semi-distributed water balance model (Schmidt et al., 2014). This model considers separate soil moisture balances for two types of "soils", actual soil and bare carbonate rock, with the relative areal proportions controlling the relative contributions to overall infiltration input. We calibrated the soil moisture balance model spatially distributed on sub-basin level.

Results

With the ability to simulate rapid infiltration, the change in storage in the vadose and the phreatic zone, and the characteristics of the karst system dynamics, the constructed flow model has considerable advantages compared to currently available models, providing Israeli stakeholders with the option of predicting spatiotemporally distributed groundwater recharge, i.e., the available groundwater for sustainable abstraction. The non-linear response of groundwater recharge to transient climatic inputs requires a daily resolution for the analysis. The recharge area comprises a thin cover of soil and bare karstified carbonate rock, providing fast, direct infiltration pathways along karst features (e.g., sinkholes and dolines). In the hilly regions towards the East, the vadose zone displays a thickness of several hundred meters, emphasizing the importance of variably saturated flow and the evaluation of spatiotemporally distributed recharge to quantify the impact of climate change on groundwater resources. Lastly, the flow model provides insight into the infiltration dynamics at the catchment scale, i.e., mean residence times in the vadose zone characterized by a potential-dependent exchange between slow/diffuse and fast flow system, hence the ability to control the long-term release of water.

Application

The flow model exhibits a new level of detail with respect to modeled processes and spatial information, increasing predictive power considerably. The tool will assist the local water authority in adopting strategies to plan abstraction within a 5-year window accounting for changed recharge dynamics following climate change effects on precipitation patterns. However, due to its nonlinear constitutive relationship, the Richards equation only applies on specific spatial length scales, and since the process described is capillary driven, it neglects gravity-driven infiltration. The developed model allows for a number of follow-up studies, such as the prediction of flood routing, flood-runoff forecasts in wadis, the quantification of the relevance of channel infiltration along the wadi courses, i.e., direct groundwater recharge, the quantification of the relevance of vadose zone storage, or the improvement of process understanding for Managed Aquifer Recharge applications.

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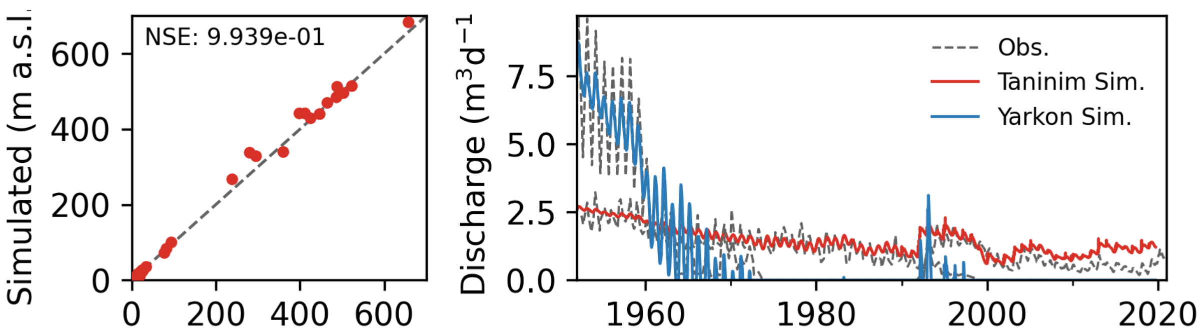

Figure 2: Calibration of the a) steady-state and b) transient, variably saturated dual-continuum flow model

Authors	Affiliation	Department	Email
Lysander Bresinsky	University of Göttingen	Geoscience Center	lbresin@gwdg.de
Jannes Kordilla	University of Göttingen	Geoscience Center	jkordil@gwdg.de
Martin Sauter	University of Göttingen	Geoscience Center	msauter1@gwdg.de