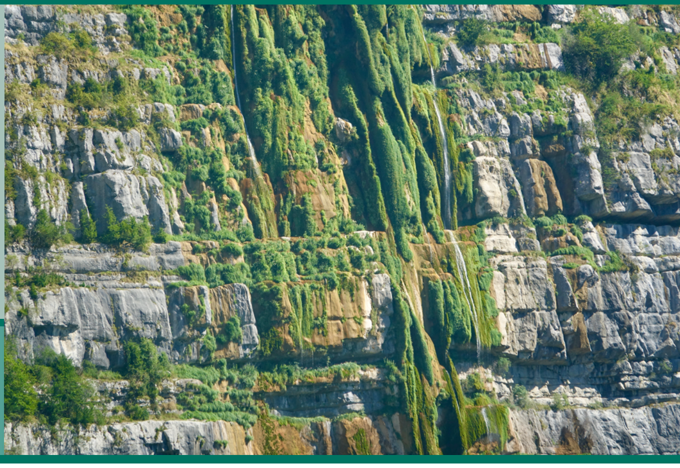

Integrated surface-subsurface, multi-continuum flow model of the Western Mountain Aquifer

Key findings

- We simulate flow in the variably saturated fractured-porous subsurface, accounting for the duality of karstic flow in the vadose and phreatic zone, and 2-D friction-based overland flow due to infiltration excess.
- The model demonstrates that altered precipitation because of climate change requires dedicated adaptation of water management practices due to 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 a parallelized computing environment.

Motivation

Climate change is expected to have a significant impact on the water budget of Mediterranean karst aquifers due to the expected decrease in average precipitation, while intensity and frequency of short-duration extreme rainfall might increase. The reduced total annual precipitation may not necessarily result in a decrease in recharge since karst features provide high infiltration capacities, reducing the amount of water exposed to solar radiation. 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 sub-project is to simulate the temporal and spatial discharge dynamics of the WMA considering the storage properties of the phreatic and vadose zones as well as the characteristics of the karst system, composed of the conduit network and the adjacent permeable matrix blocks.

Methodology

We employ the flow simulator HydroGeoSphere (HGS) on a high-performance-computing platform to simulate the hydrological-hydrogeological cycle of the WMA. A double-continuum approach based on the volume-effective Richards' equation with Van-Genuchten parameters is applied in order to simulate flow in the variably saturated fractured-porous subsurface (Figure 1b), accounting for the duality of karstic flow, both in the vadose and phreatic zones, with rapid flow through conduits and slow flow through the rock matrix. Overland

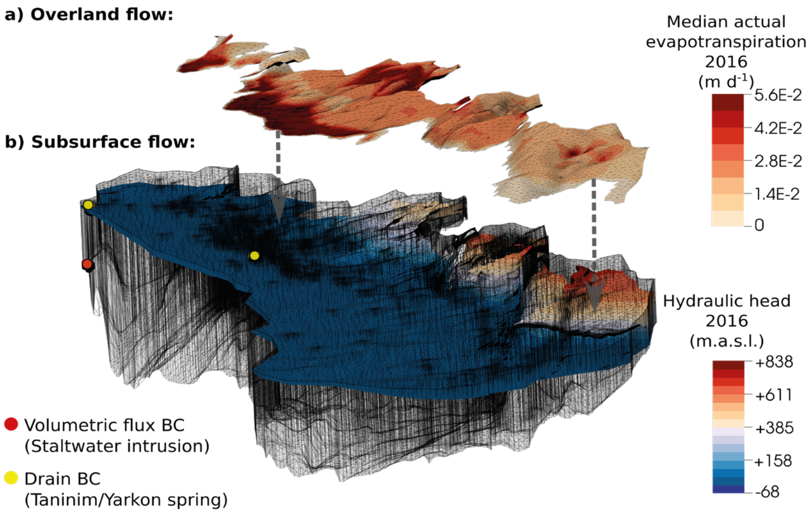

Figure 1 : Spatial discretization and simulation results for the year 2016

MedWater – Sustainable management of politically and economically highly relevant water resources in hydraulically, climatically, and ecologically dynamic carbonate aquifers of the Mediterranean.
Funding code: 02WGR1428A
SPONSORED BY THE Federal Ministry of Education and Research
FONA Research for Sustainable Development BMBF
An Initiative of the Federal Ministry of Education and Research GRoW WATER AS A GLOBAL RESOURCE

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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 for rainfall to naturally partition into overland flow and multi-continuum infiltration.

flow due to infiltration excess is accounted for via a 2-D friction-based overland flow continuum (Figure1a), coupled by a first-order exchange term to the subsurface. Precipitation is directly fed to the overland flow continuum. HGS simultaneously computes actual evapotranspiration by reducing the reference evapotranspiration according to surface-specific conditions such as land cover, leaf area index, root depth, water content, and rainfall distribution. The a priori computed Penman-Monteith reference evapotranspiration serves as a boundary condition to the model. To cope with the high computational demand and instability in convergence, optimized unstructured triangular meshes with refinement in the vicinity of wells, streams, and springs were defined.

Results

With the ability of simulating rapid infiltration, the change in storage in the vadose and the phreatic zone as well as the characteristics of the karst system dynamics, the flow model constructed has considerable advantages compared to currently available models, providing Israeli stakeholders with the option of predicting spatio-temporally distributed groundwater recharge, i.e. groundwater available for sustainable abstraction. The non-linear response of groundwater recharge to transient climatic inputs requires a daily resolution for the analysis. The integrated surface-subsurface flow model provides a physically-based approach to account for the exchange between surface and subsurface flows, accounting for the temporal transformation and partitioning of rainfall. The recharge area is characterized by a thin cover of soil and bare karstified carbonate rock, providing pathways for fast direct infiltration along karst features (e.g., sinkholes and dolines). In the mountainous regions towards the East, the vadose zone has a thickness of several hundreds of meters emphasizing the importance of accounting for variably saturated flow and of evaluating spatio-temporally distributed recharge to quantify the impact of climatic changes on groundwater resources. Lastly, the flow model provides insight into the infiltration dynamics on the catchment scale, i.e., mean residence time in the vadose zone characterized by potential-dependent exchange between the slow/diffuse and fast flow system and hence the ability to affect the long-term release of water.

Application

The flow model exhibits an unprecedented level of detail with respect to modeled processes and spatial information and hence heavily increases the predictive power. The tool will assist the local water authority in the adoption of strategies to limit abstraction to the 5-year moving average of recharge in the context of climate change. Richard's equation due to its non-linear constitutive relation may only apply on certain spatial length scales and is purely capillary driven, neglecting gravity-driven infiltration. However, no approach currently exists capable of accounting for this on a catchment scale. Multiple follow-up studies may be conducted, such as predicting flood routing, flood-runoff forecasts in wadis, quantifying the relevance for transmission losses in wadis for groundwater recharge, or improving the process understanding of managed aquifer recharge applications.

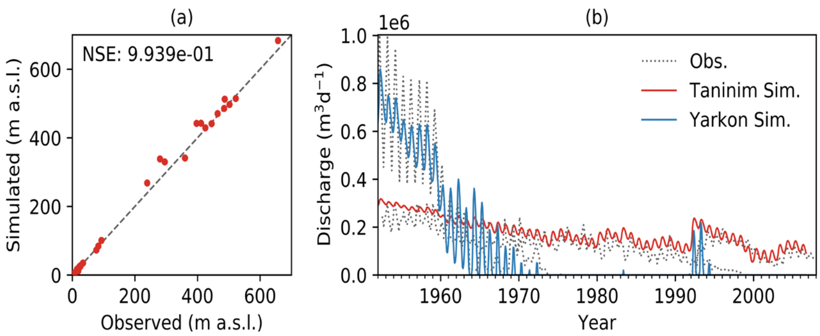

Figure 2: Calibration of the a) steady-state and b) transient, variably saturated, dual-continuum flow model

References

Aquanty Inc. (2019). HydroGeoSphere (Version 1977) [Computer software]. Retrieved from https://www.aquanty.com/hgs-download

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