Assessment of groundwater recharge processes in a carbonate aquifer under semi-arid climate by an integrated surface-subsurface, multi-continuum model

Lysander Bresinsky[1], Jannes Kordilla[1], Irina Engelhardt[2], Martin Sauter[1]

[1]University of Göttingen, Dept. of Applied Geology, Germany <lbresin@gwdg.de>

[2]Technical University of Berlin, Dept. of Hydrogeology, Germany

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

I. Introduction

Motivation

- Karst groundwater resources constitute a major freshwater resource in the Mediterranean.
- Mediterranean groundwater resources are possibly to decrease due to a projected increase in temperature and the change in temporal precipitation patterns.
- Highly non-linear and rapid flow processes (i.e. preferential flow) make it nearly impossible to find an adequate single REV.
- Recharge estimations based on cumulative annual or monthly precipitation do not consider temporal patterns and various rainfall intensities.

Key Objectives:

- Estimate groundwater recharge based on a rigorous implementation of surface-hydrological processes, that account for:
  - the particularities of rock-soil landscape,
  - focussed recharge along karst features (i.e., sinkholes),
  - transmission losses of ephemeral streams (i.e., wadis) (Messerschmid, 2018),
  - specific climate conditions as well as the different precipitation patterns.
- Simulation of the effect of infiltration through a thick (several hundreds of meters) vadose zone on groundwater flow dynamics in a semi-arid environment.

II. Area of study

The study is conducted for the Western Mountain Aquifer (WMA), located in Israel and the Palestinian territories.

Geological and hydrogeological setting:

- The WMA is a highly karstified and fractured Cretaceous carbonate aquifer (mainly calcite and dolomite).

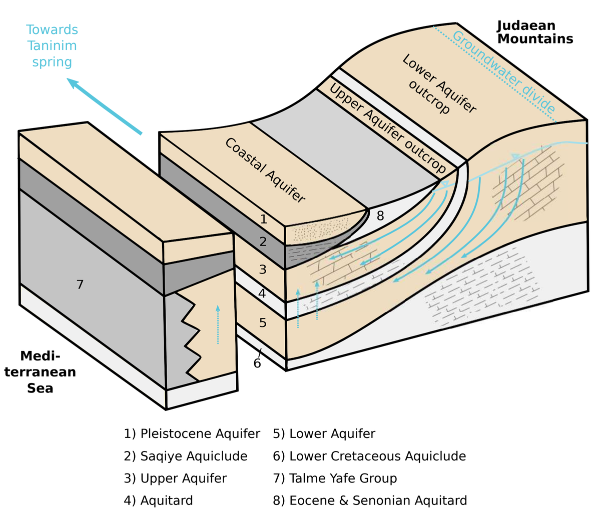

Figure 1: Schematic representation of the hydrogeological setting (after Weinberger, 1994)

- Composed of two sub-aquifers (Upper & Lower Judean Aquifer) divided by chalk and marl of the Moza Formation.
- Unconfined in the East and confined in the West (Fig. 1)

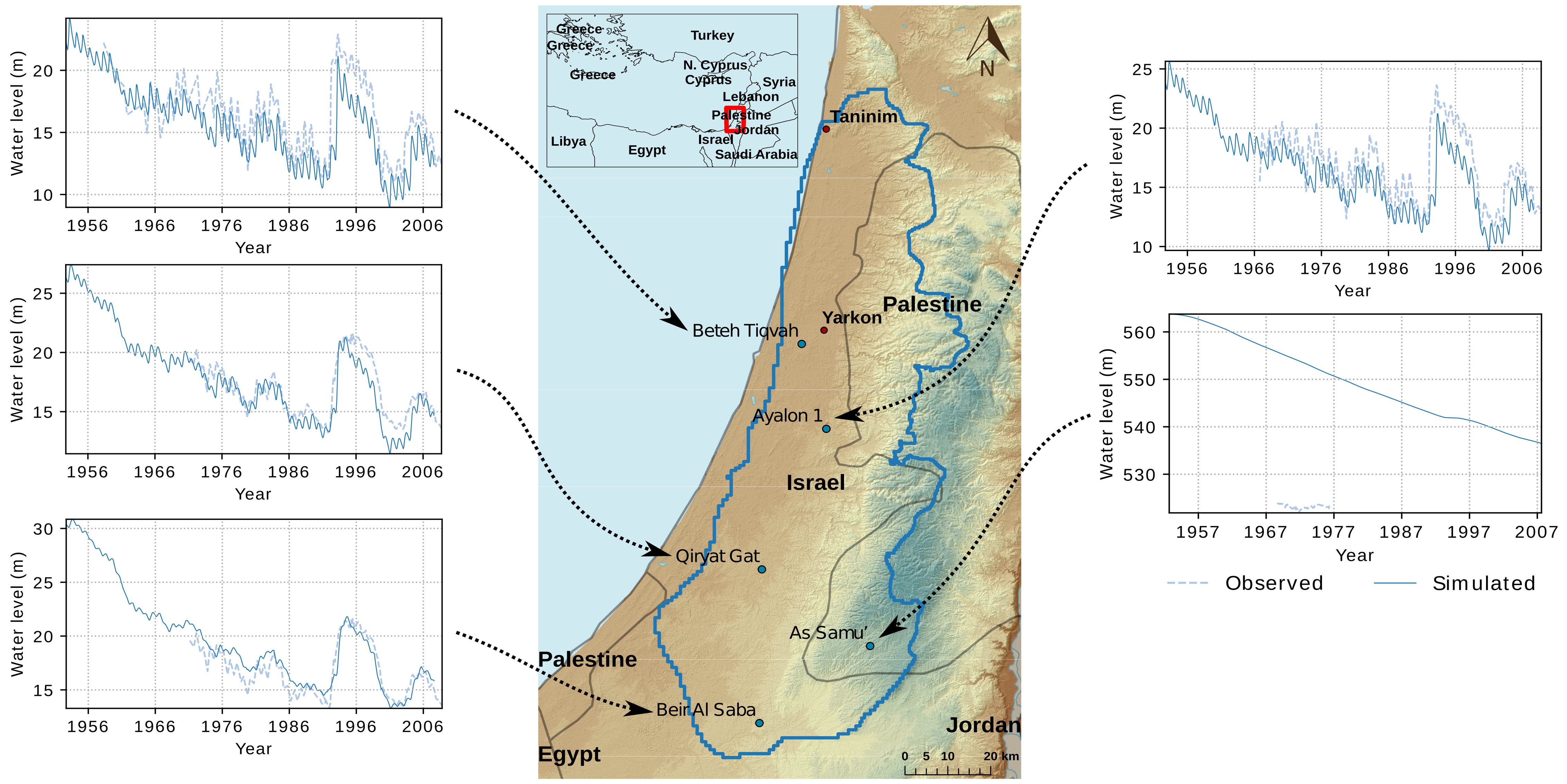

Figure 2: Catchment of the Western Mountain Aquifer and computed/observed transient hydraulic heads of selected wells

- The rocks of the WMA are exposed due to an anticline structure in the Judean and Samarian Mountains (East)
- The aquifer drains at the Yarkon (till the 70s) and Taninim springs (Fig. 2)
- Little interaction with saline Mediterranean waters due to impermeable layers of the Talme Yafe Group.

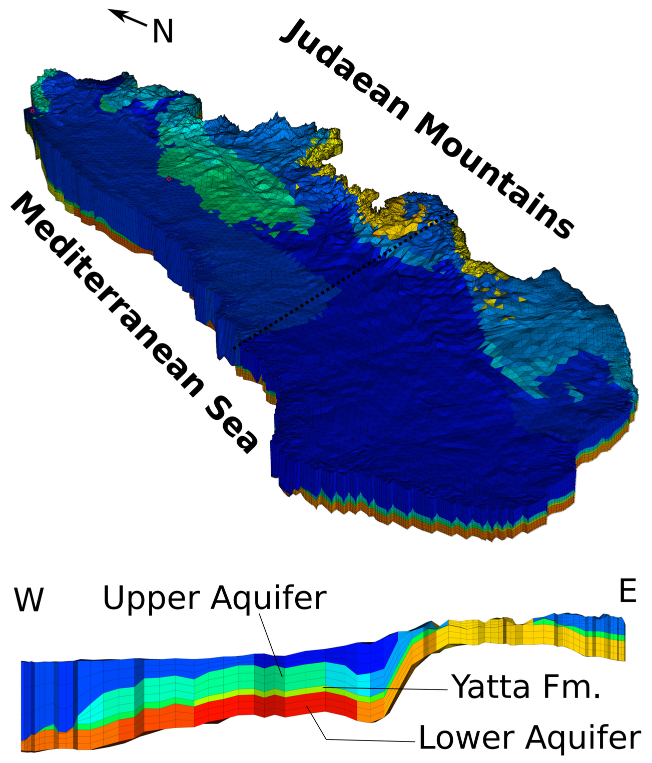

Figure 3: Model discretisation.

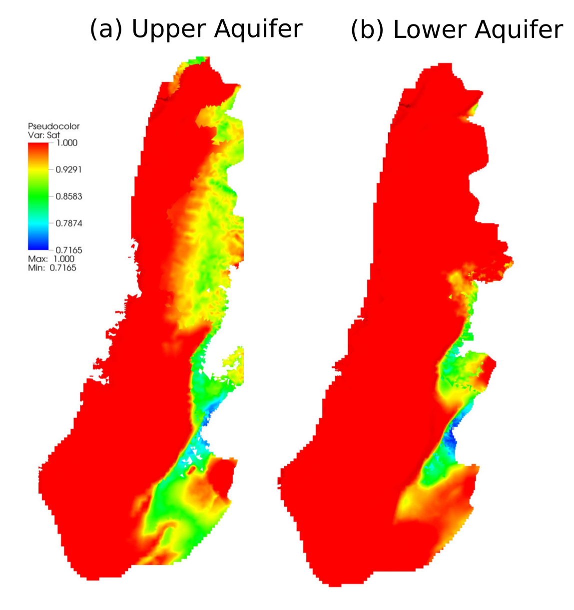

Figure 4: Spatial saturation distribution of a preliminary model

- High annual and seasonal variability of rainfall (mainly from December to February).
- Large drop of groundwater levels due pumping since the 1960s (major discharge component).

III. Methods

- HydroGeoSphere (HGS) is utilized on a high-performance-computing platform: Richards' equation is applied for both continua (Aquanty, 2015):

$$-\nabla \cdot (w\boldsymbol{q}) + \sum \Gamma_{ex} \pm Q = w\frac{\partial}{\partial t}(\theta_s S_w), \quad (1)$$

where the fluid flux q is defined as:

$$\boldsymbol{q} = -\boldsymbol{K} \cdot k_r \nabla(\psi + z). \quad (2)$$

w: volumetric fraction of the total porosity occupied the continuum; Q: volumetric fluid flux (bcs); S_w: water saturation ($S_w = \frac{\theta}{\theta_s}$); $\mathbf{q}$: fluid flux; θ_s: saturated water content; Γ: exchange term; $\mathbf{K}$: hydraulic conductivity; k_r: relative permeability; ψ: pressure head; z: elevation head

- Exchange flow between the continua via a Darcy-type term:

$$\Gamma_d = \frac{\beta_d}{a^2}\gamma_w K_\alpha k_{ra}(\psi_d - \psi) \quad (3)$$

β_d: geometrical shape factor; a: inter-continuum skin thickness; γ_w: empirical coefficient

- 2D overland flow via the Saint Venant equation:

$$-\nabla \cdot (d_o\boldsymbol{q_o}) - d_o\Gamma_o \pm Q_o = \frac{\partial \phi_o h_o}{\partial t}, \quad (4)$$

where the fluid flux $\boldsymbol{q_o}$ yields:

$$\boldsymbol{q_o} = -\boldsymbol{K_o} \cdot k_{ro}\nabla(d_o + z_o). \quad (5)$$

ϕ_o: surface flow domain porosity; h_0: water surface elevation; k_{ro}: horizontal conductance reduction from obstruction storage exclusion

- Coupling of surface and subsurface flow:

$$d_o\Gamma_o = w_m\frac{k_r K_{zz}}{l_{ex}}(h - h_o) + w_d\frac{k_{dr}K_{dzz}}{l_{ex}}(h_d - h_o) \quad (6)$$

h/h_d: subsurface porous medium/ dual medium heads; K_{zz}/K_{dzz}: vertical saturated hydraulic conductivties (porous/dual media); k_r/k_dr: relative permeability

IV. Model calibration

- During the pre-development period the aquifer exclusively discharged via two springs (Yarkon & Taninim).
- The steady state simulation was configured to represent the water-level and discharge rate of the pre-development period (Fig. 5a).

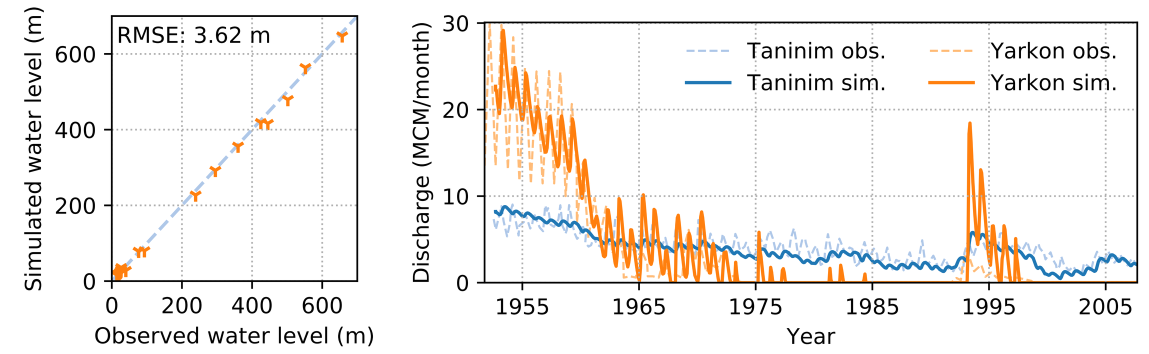

Figure 5: Computed vs. observed spring discharge and stationary well heads

- Employing a single continuum model within the period 09/15/1950 to 09/15/2007 that reflects the observed spring discharge at the Taninim and Yarkon spring and well heads.
- The simulated discharge reproduces the drying up of the Yarkon spring in the 1970s (Fig. 5 & 2).
- In 1991/92 the Yarkon spring was reactivated due to an extremely wet year. The simulation replicates this event.

V. Conclusion & Outlook

Conclusion:

- A fully-coupled dual-continuum model of the subsurface and surface is expected to better represent the fast response to recharge events accompanied by a high variability of flow rates, flow velocities and water level fluctuations.
- This study demonstrates that an integrated surface-subsurface hydrologic model is capable to capture the dynamics on an increased spatial and temporal scale.

Outlook:

- Definition of suitable unsaturated parameters (i.e., Van-Genuchten parametrization).
- Implementation of a second continuum to account for the duality of flow,
- and of a 2D surface routing domain to account for transmission losses in ephemeral streams and focused recharge induced by karst landscape characteristics (i.e., dolines).

Acknowledgement: This work was funded by the Federal Ministry of Education and Research of Germany (BMBF) within the context of the MedWater project (GROW programme)

References: Weinberger (1994): Journal of Hydrology **(161)**; Messerschmid (2018): Hydrological Processes **(32)**; Aquanty (2015): HGS User Manual - Theory