

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

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).
- 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)

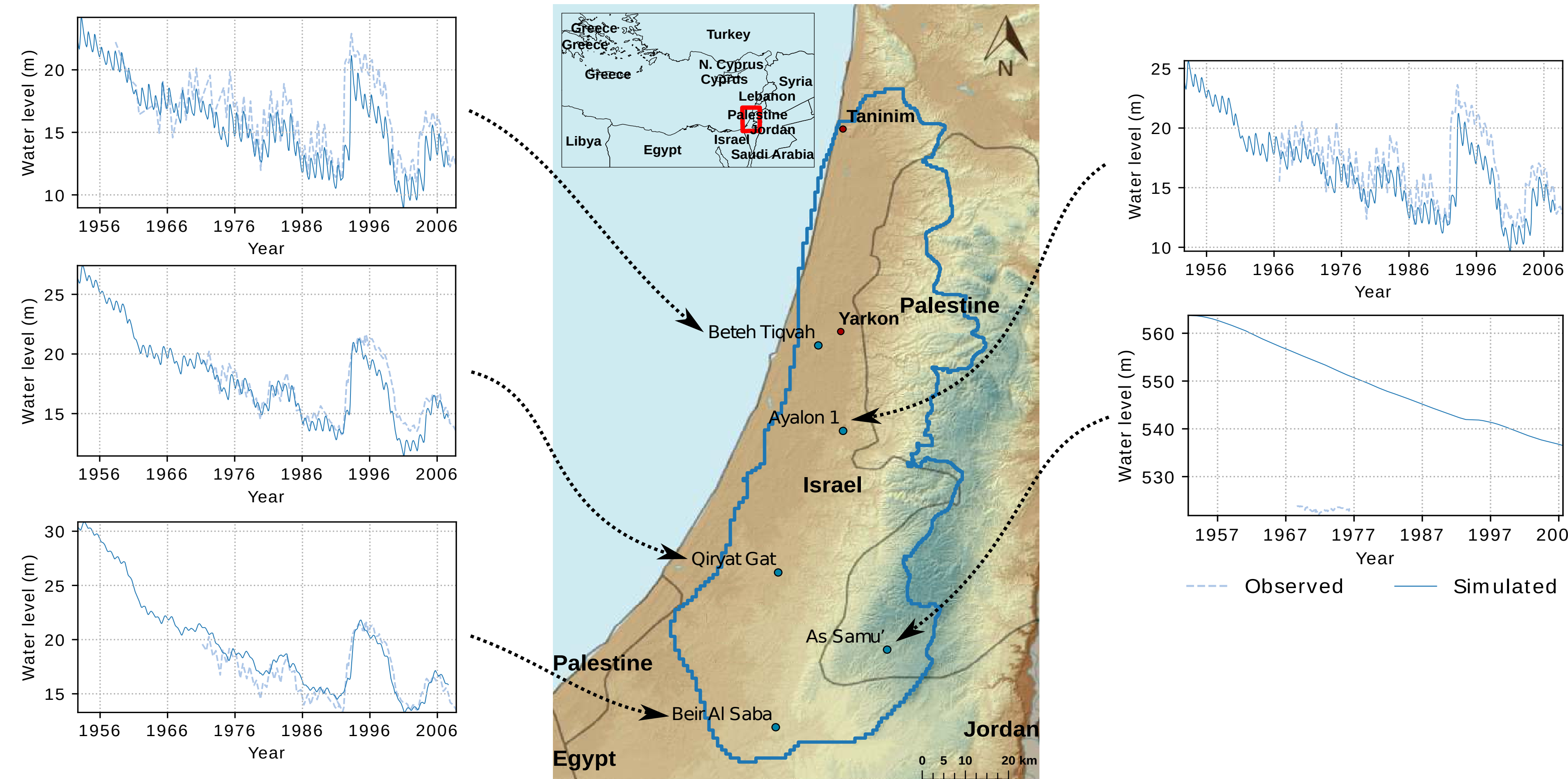
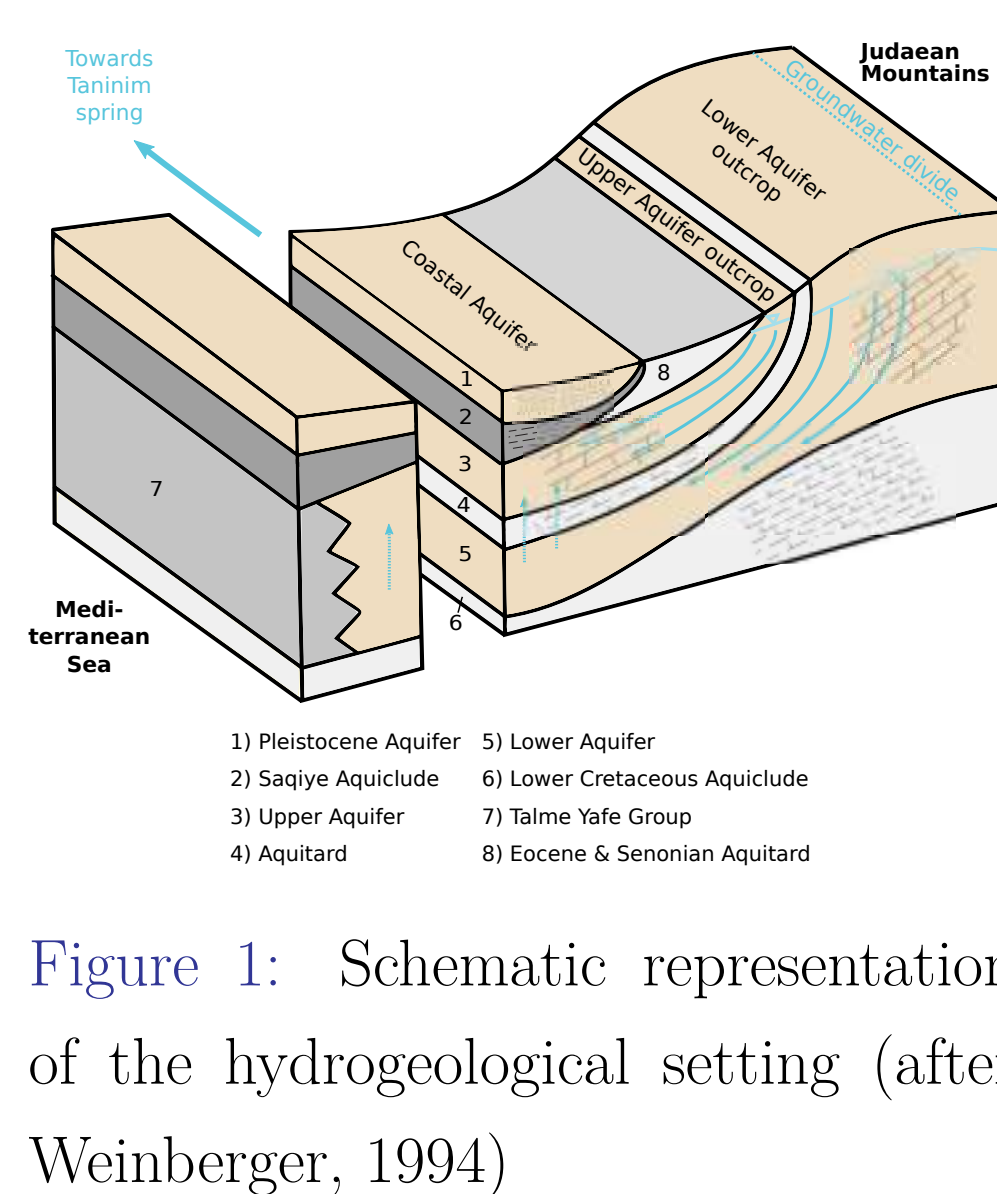


Figure 2: Catchment of the Western Mountain Aquifer and computed/observed transient hydraulic heads of selected wells

- 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 Tananim springs (Fig. 2)
- Little interaction with saline Mediterranean waters due to impermeable layers of the Talme Yafe Group.

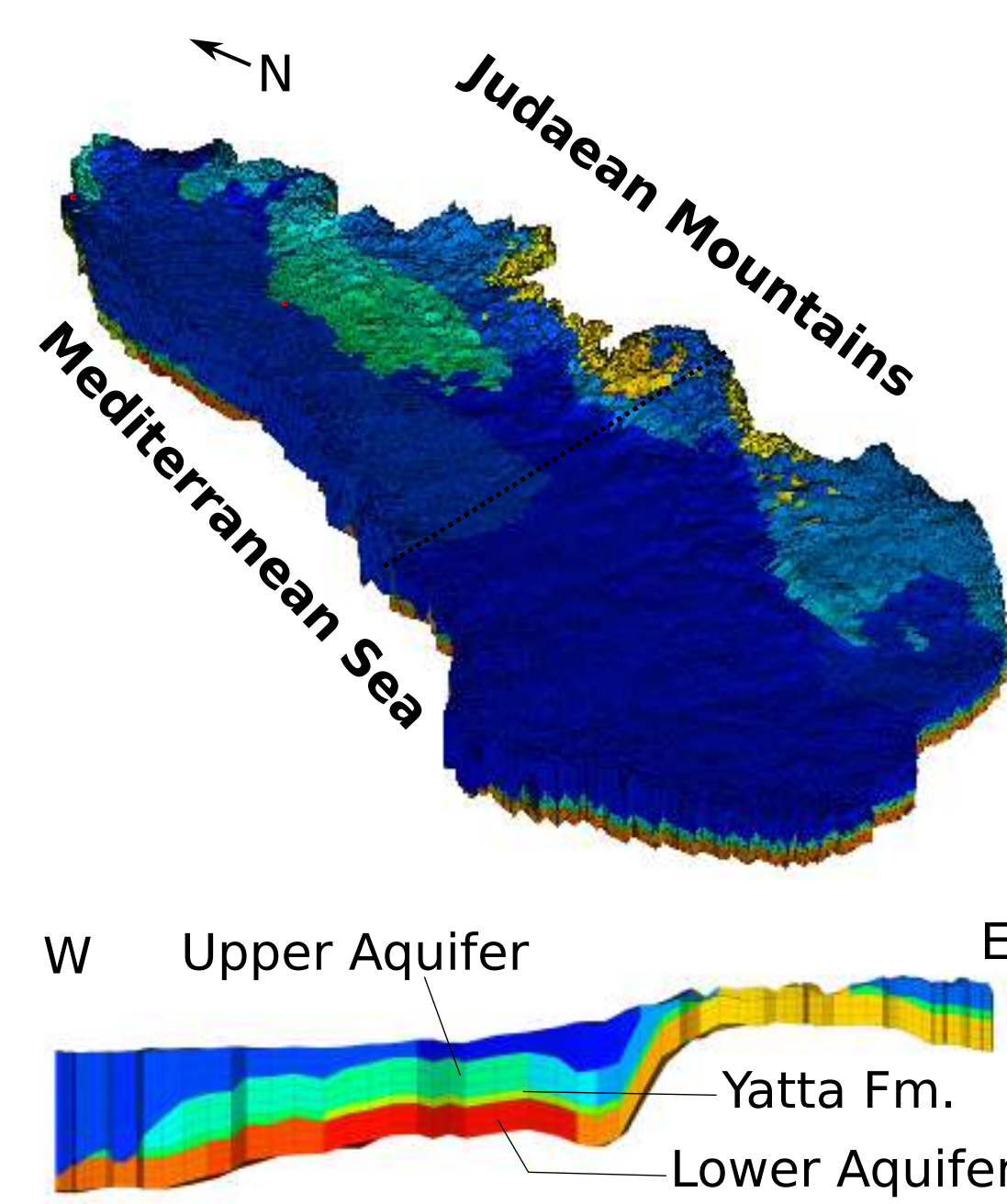


Figure 3: Model discretisation.

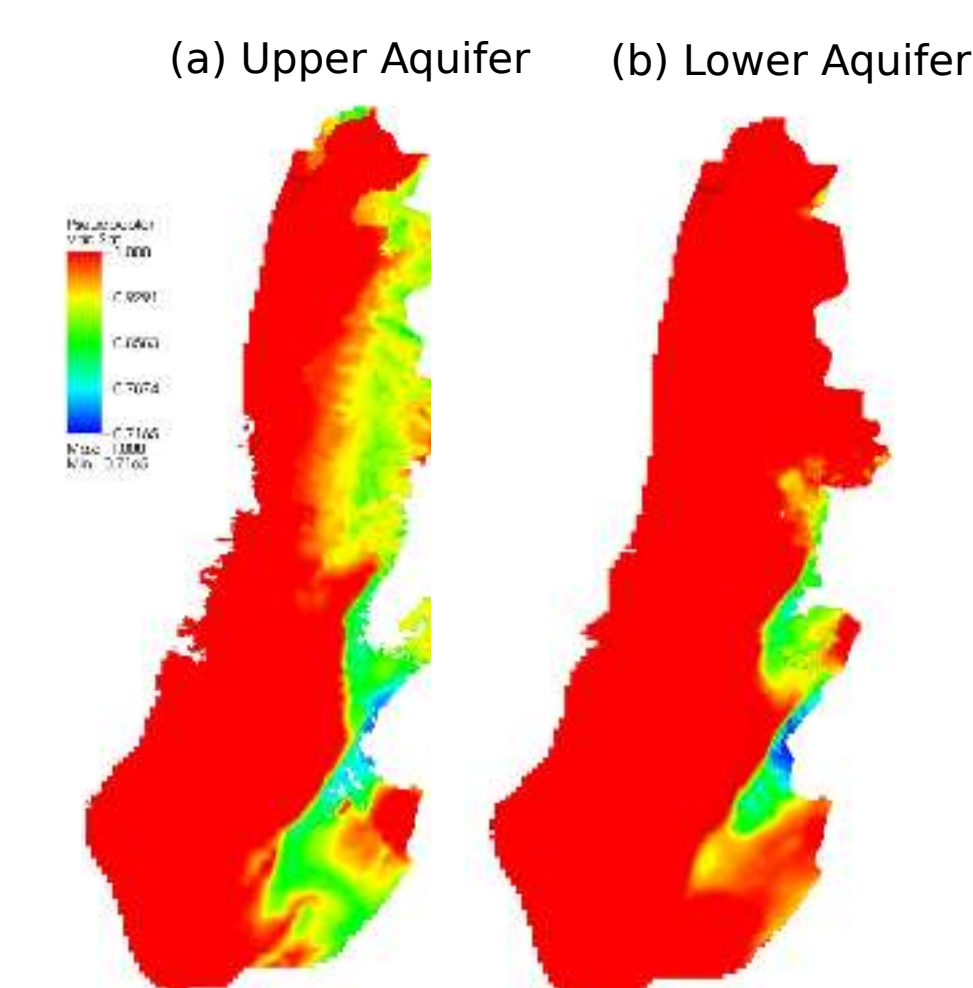


Figure 4: Spatial saturation distribution of a preliminary model

- High annual and seasonal variability of rainfall (mainly from December to February).
- Large drop of groundwater levels due to 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):

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

where the fluid flux \mathbf{q} is defined as:

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

w : volumetric fraction of the total porosity occupied the continuum
 \mathbf{q} : fluid flux
 \mathbf{K} : hydraulic conductivity
 z : elevation head

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

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

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

- 2D overland flow via the Saint Venant equation:

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

where the fluid flux \mathbf{q}_o yields:

$$\mathbf{q}_o = -\mathbf{K}_o \cdot k_{ro} \nabla (d_o + z_o). \quad (5)$$

ϕ_o : surface flow domain porosity
 h_o : 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 conductivities (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 & Tananim).
- The steady state simulation was configured to represent the water-level and discharge rate of the pre-development period (Fig. 5a).

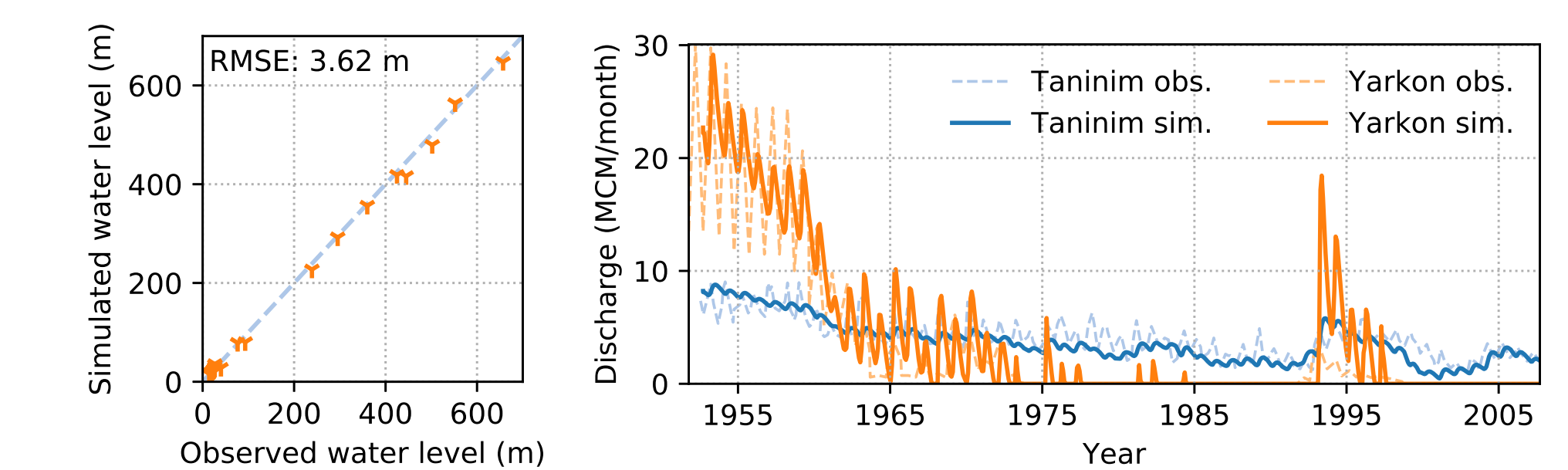


Figure 5: Computed vs. observed spring discharge and stationary well heads

- Employing a single continuum model within the period 09/15/1950 to 09/15/2007 that reflects the observed spring discharge at the Tananim 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).

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