

## ***Interactive comment on “Recharge estimation and soil moisture dynamics in a Mediterranean karst aquifer” by F. Ries et al.***

**F. Ries et al.**

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We are grateful for the constructive comments in the anonymous review of referee 3. Please find below our replies to the reviewer's comments.

**Comment 1:** However, the hydrological and hydraulic parameters of the soil zone and other variables relevant to the formulation of the van Genuchten-Mualem model are not physically based, and their calibration was performed using the Shuffled Complex Evolution Metropolis algorithm and Kling- Gupta Efficiency as optimization criteria. Therefore, the model ability to correctly predict soil water percolation and groundwater recharge rates is clearly affected by the reliability of the hydraulic-physic parameters

C4155

assumed and included in the model Hydrus-1D, which are not physically based.

**Reply:** We fully agree with this statement and will modify our updated manuscript accordingly. Our unimodal HYDRUS version was not meant to be a physically-based soil water model but rather a tool to translate soil moisture values into soil water percolation. Please also refer to our replies to the comments of referee 1.

**Comment 2:** Page 4, Lines 1-8 is given a general description of the karst aquifer and soil cover. A more detailed description of the hydrogeological conceptual site model is necessary. In this regard, the Figure 1 is not very detailed, and it should be integrated with: i) a hydrogeological model of the perched karst aquifer (indicating the outcropping lithologies and soils, and the groundwater flow), ii) a schematic cross section, showing soils thickness with the position of the sensors, the unsaturated perched karst aquifer, and the water table of the monitored well.

**Reply:** Including a conceptual model showing the soil, sensor positions and the groundwater well as proposed by the referee is a good suggestion and would contribute to communicate our system understanding. We will provide a schematic cross section in the revised manuscript.

**Comment 3:** Page 4, Lines 33-37 specify the measurement frequency of the precipitation, air temperature, groundwater levels and water temperature recorded in the monitored well.

**Reply:** Precipitation was measured with tipping buckets, where each 0.2 mm is recorded with a time stamp. Cumulative precipitation sums are then calculated on 5-minute intervals. Meteorological parameters are recorded every 10 minutes and groundwater temperature and groundwater levels every 20 minutes. We will provide this information in the revised manuscript.

C4156

**Comment 4:** Page 5, Line 2 specify the area (slope or plain) where there are the soil moisture plots (SM1-SM-3). Furthermore, with reference to Table 1, specify if the textural characteristics of the soils are theoretical, or referred to other literature data (in this case, provide the quote), or derived from experimental test.

**Reply:** One soil moisture plot is located on a hillslope while the two others are located on rather flat topography. The textural characteristics of the soils are determined in the laboratory by sieving (particle size  $>0.063$  mm) and sedimentation method (particle size  $<0.063$  mm). We will add this information to the revised manuscript.

**Comment 5:** Page 5, Line 19-20 specify the measurement frequency of soil temperatures.

**Reply:** Sensors for soil temperature are attached directly to the probes measuring water content. Soil temperature is recorded every 10 minutes at the same frequency as soil moisture. We will add this information to the revised manuscript.

**Comment 6:** Page 5, Lines 24-25 specify why the water balance equation does not consider the runoff. The tree experimental sites are located in an flat sector or on slope?

**Reply:** Good comment! We will discuss this point and also possible errors in our revised manuscript. One soil moisture plot is located on a hillslope while the two others are located on rather flat topography. In irrigation experiments (Sohrt et al. 2014) we found out that infiltration rates at locations close to the soil moisture plots were considerably higher than the rainfall intensities we measured during our observation period. Only during one event and at one plot we found indications of soil saturation from the bottom up to the surface which might have caused saturation overland flow.

C4157

**Comment 7:** Is there any experimental evidence confirming that also during rainfall events of high intensity and duration there is no runoff?

**Reply:** As part of our hydrometeorological monitoring network we installed runoff gauges in several ephemeral streams in Wadi Auja. During events with high rainfall amounts and periods of high rainfall intensity runoff was observed (below 2% of seasonal rainfall and 5% of single rainfall events). The question on where runoff was generated is still an issue of current investigations. It is more likely that runoff was generated specifically at locations with high fraction of outcropping bedrock, locations, which we avoided to select for our soil moisture plots. See also our reply on reviewer's comment 6.

**Comment 8:** Page 6, Lines 1-2 "Potential evapotranspiration was calculated by the Hargreaves-equation (Hargreaves and Samani, 1985)". Why the authors did not calculate the actual evapotranspiration, provided that the peaks in soil water content are only recorded in rainy season and/or during rainfall events of high intensity?

**Reply:** Actual evapotranspiration was calculated within the Hydrus-1D model. In a first step potential evapotranspiration is calculated according to the Hargreaves equation. After splitting the potential evapotranspiration into potential evaporation from the soil surface and potential transpiration from plants according to Beer's law, Hydrus-1D calculates actual evaporation and transpiration based on a root water uptake model and an energy balance surface evaporation model. This procedure is described in the manuscript on page 8810 line 27 to page 8811 line 8.

**Comment 9:** Page 8, lines 28-29 "The calibrated parameter sets used for further assessment of the plot scale soil water balance, are given in Table 3". The values of ks included in the model (mm/day), given the textural characteristics of the soils (clays with silt, clays with sand), seem too high (ranging between  $4.94 \times 10^4$  to  $4$  cm/s  $\times 10^4$ )

C4158

1.15 Å 10iËYA 2 cm/s) and not in line with those reported in the literature for these soil material. The Authors should have at least run the tests in the field or lab, in order to justify the choice of these high values of hydraulic conductivity for the modeling of the percolation flow.

**Reply:** We took undisturbed soil samples from different locations within our study site and determined soil hydraulic parameters by means of multistep-outflow (MSO) experiments (Puhmann et al., 2009). Soil hydraulic parameters from MSO were in the range of our parameter sets but did not account for scale effects like stoniness or vegetation influences. We will add this data to our revised manuscript. Please see also our replies to the comments of referee 1.

**Comment 10:** Page 9, Lines 7-9 "Water temperatures in a groundwater well near soil moisture plot SM-3". If the variation of temperature is related to flow percolation, it would be interesting to show also the rise of the piezometric levels recorded in the well. To this end, Figure 7 should be modified accordingly.

**Reply:** The water level of the groundwater well at Ein Samia near soil moisture plot SM-3 is strongly influenced by pumping for water supply. Nevertheless the major recharge events are clearly reflected in a sudden rise of piezometric levels in the well, which are occurring simultaneously with drops in water temperature. We will add a graph of the water level in the well to Figure 7.

**Comment 11:** Page 9, Lines 16-19: "Percolation from the bottom of the soil zone only started after cumulative rainfall during winter season exceeded in an certain threshold. This threshold was found to be approximately 240 mm at plot SM-1, SM-plot at 200 mm 2 and 150 mm at plot SM-3". For the site SM-2 this threshold seems to be in contrast with what is reported in table 4, where it is noted that for 2010/2011 there are rainfall (248 mm) higher than the threshold (200 mm) that did not produce bottom flux (see Ta-

C4159

ble 4). Sections 4.3.2, 4.3.3 and 4.34 (Plot scale water balance, Spatial extrapolation of deep percolation and Temporal extrapolation of deep percolation) describe the main results of the water percolation rates provided by model. 1) The groundwater recharge rates calculated certainly deserve some comparison with those already available in the literature, estimated for other karst aquifers of the Mediterranean region. 2) Why are the rates of groundwater percolation determined (up to 66Å°u69% of precipitation) are not visible in Table 4?

**Reply:** We will clarify the threshold behaviour of percolation fluxes in our updated manuscript. In Figure 11 we compare the percolation fluxes of our modelling work with those derived by other studies in the area (Guttman and Zukerman, 1995; Weiss and Gvirtzman, 1999). Table 4 contains plot scale percolation rates only for our three soil moisture plots. In our extrapolation we simulated the water balance components for a range of climatic conditions and soil depths within our study area. Under conditions of higher rainfall, because of higher topographic elevation, and shallow soils, percolation rates reached up to 9

**Comment 12:** Page 12, Lines 33-36 "These findings are in good agreement with measurements at discharge Auja spring, a large karst spring in the Jordan Valley, where 7 and 8 million m<sup>3</sup> were Measured for the winter seasons 2011/2012 and 2012/2013 respectively, but only 0.5 million m<sup>3</sup> for the 2010/2011 season (Schmidt et al., 2014)". The Auja spring is a large basal karst spring located of the Jordan Valley fed by regional karst aquifers, characterized by dynamics and response time different from the perched karst aquifer of the study area. Conversely, for the study area a more appropriate comparison would be with spring discharges and / or piezometric levels of local perched karst aquifers, in the upper part of the western margin of the Jordan Rift Valley (to see, for example, Peleg and Gvirtzman, 2010, in *Journal of Hydrology*, 388, 13–27, 2010; Weiss and Gvirtzman, 2007, in *Ground Water*, Vol. 45, No. 6, 761–773, 2007).

C4160

**Reply:** We share the opinion of the referee that a comparison of simulated plot scale percolation events with spring discharge from local perched aquifers in the mountains would be more appropriate than a comparison with Auja spring located in the Jordan Valley. Unfortunately Samia spring, the only spring close to our soil moisture plots, is strongly influenced by local pumping and is discharging only for few days per year after intense rainfall events when the pumping stops because of contamination risk. So we will concentrate our comparison on the well data and refrain from using Auja spring.

**Comment 13:** Page 2, lines 28 to correct the citation Alloca et al., 2014. The correct citation is Allocca et al., 2014.

**Reply:** This typing error will be corrected.

**Comment 14:** Page 10, Lines 12-13 “Percolation at the three plots varied between 0% and 66% of cumulative seasonal rainfall with an average between 16% and 24%”. Insert in Table 4 the full range of values.

**Reply:** This phrase refers to the results of the water balance simulation for the 62-year period (1951-2013) while Table 4 contains the simulated water balance components for the single years for the period 2010/11 to 2012/13 only. The full range of values for the long period is illustrated in Figure 10.

**Comment 15:** Figure 3: Provide details about station elevation (m a.s.l. and b.s.l.).

**Reply:** Will be included.

**Comment 16:** Figure 8: Improve the editing of the graph at present, is not readable.

**Reply:** As also requested by referee 1 we will check all figures especially Figure 8 for

C4161

readability.

**References cited in this reply:**

Guttman, Y. and Zukerman, C. H.: Flow model in the Eastern Basin of the Judea and Samaria hills, unpublished report in Hebrew, TAHAL Consulting Engineers Ltd. 01/95/66, Tel Aviv, Israel, 1995.

Sohrt, J., Ries, F., Sauter, M., and Lange, J.: Significance of preferential flow at the rock soil interface in a semi-arid karst environment, *Catena*, 123, 1–10, 2014.

Weiss, M. and Gvirtzman, H.: Estimating ground water recharge using flow models of perched karstic aquifers, *Ground Water*, 45, 761–773, 2007.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 8803, 2014.

C4162