Authors’ response to Reviewer 1

Summary and Recommendation

Comment from Referee: In this study, a high-resolution surface-unsaturated_zone-aquifer flow model was fit to a km2 scale hilly drainage basin near Los Angeles, to investigate spatial and temporal variability of groundwater recharge. The main result is that, although the long-term spatial average recharge under the catchment is 16 mm/yr, under the small alluvial valley after heavy rain, focused temporal recharge rate may reach 1000 mm/yr.
Although this type of variability in recharge is not totally new for this setting, the work is worthy for its rare and intensive modelling effort and comparison with local estimates (e.g. chloride mass balance). Nevertheless, substantial changes need to be made in the manuscript before it can be published in HESS.

Author’s response: We thank the reviewer 1 for the positive feedback and for recognizing the modeling effort we put in place. We tried to respond exhaustively to all the comments.

Major comments

1) Comment from Referee: Structure: There is no Methods section and no Discussion in the paper. The authors avoiding the classic titles of sections in a scientific paper is deep in the content, many methods are not clear (S. comments 7-10, 13 below), and there is no discussion of the results with the wide literature on recharge. Methods and Discussion sections should be included and taken more seriously (it could be Results and Discussion but a discussion should be done).

Author’s response: The description of the methodology used in the MIKE SHE model section. We expanded this section to make it more clear and complete according to the reviewers’ comments.

A discussion about recharge characteristics and about the occurrence of preferential flow in the ET zone has been added to the “conceptual model of recharge” that now has become “Conceptual model of recharge and discussion” section.

Author's changes in manuscript:

-line 456 – 464: The high recharge values along the valley, at the edge of the slope might recall what has been defined Mountain Front Recharge (MFR) (Wilson and Guan, 2004). However, our catchment is located on the top of a ridge standing 300 m above the surrounding valleys (Manna et al., 2016) and, thus, our case study represents groundwater recharge on the mountain block rather than MFR. Nonetheless, it is interesting that the processes observed in our small catchment are similar to those described in aquifer-scale (Aishlin and McNamara, 2011; Carling et al., 2012) or regional studies (Manning and Solomon, 2003; Bresciani et al., 2018) and defined as MFR.

Line 475: Similar case studies of water that crosses the ET zone preferentially in time and space to become potentially recharge have been also reported in literature (e.g., Kurtzmann et al., 2016). The occurrence of these fluxes has been also analyzed in function of precipitation characteristics and antecedent water content with rainfall intensity being the main factor (Allocca et al., 2015; Crosbie et al., 2012; Nasta et al., 2018; Taylor et al., 2013).

2) Comment from Referee: Concerning the discussion above: I would say that the recharge characteristics described in the manuscript is similar to what many studies term: Mountain Front Recharge (MFR). Aquifers under alluvial valleys in mountainous regions are recharged from the edge of the valley (mountain front) or maybe altogether in subsurface recharge of rain percolating in the mountain block (can explain fresh groundwater above saline unsaturated zone). Discuss your findings in light of MFR literature.

Author's response: We thank you the reviewer for this suggestion that allows us to describe better our conceptual model and the hydrologic processes involved. The spatial distribution of recharge and the proposed conceptual model might recall what has been defined Mountain Front Recharge (Wilson and Guan, 2004). However, the catchment is located on an upland ridge that represents, on a regional scale, the mountain block. Although the processes observed are similar to those described as diffuse and focused MFR (direct water-table recharge at the edge of a slope front), we believe that recharge characteristics are more similar to recharge at the mountain block. A classic MFR and MBR approach would have been possible including the surrounding Simi and San Fernando valleys (about 300 m below the studied catchment). Instead, we only focused on a small watershed (2.16 km^2), with a local relief of 150 m located on the top of the Simi Hills. The maximum thickness of the alluvium overlying the sandstone bedrock in the low areas of the catchment, where the majority of recharge occurs, is only 3.8 m and therefore this setting is different from the alluvial-filled basins described in several Mountain Front recharge papers (Aishlin and McNamara, 2011; Carling et al., 2012; Manning and Solomon, 2003; Bresciani et al., 2018). Given all these considerations, we believe that the system represents a small portion of the Mountain block rather than the MFR (see Figure 1 at the end of the document)

The presence of less saline groundwater below a more saline vadose zone in our case has been attributed by Manna et al. (2017) to preferential flow along the fracture network in the vadose zone. This fast component of the unsaturated flow represents, on average, only 20% of the total recharge with the majority of the flow occurring in the porous matrix blocks.

Author's changes in manuscript: We added some text with reference to MFR in the discussion and conceptual model (see comment 1)

3) Comment from Referee: Figures graphics. Although digital era, some of us do print and read from paper some of their work (manuscripts for review, especially). The manuscript include figures with axis-titles that are extremely small (unreadable). Check figures graphics on a printed version with a reader older than 50.

Author's response: We increased the size of the fonts to improve the readability.

Specific comments

1) Comment from Referee: L25 The Abstract is a standalone entity, it should not contain references.

Author's response: Accepted. We removed references from the abstract

2) Comment from Referee: L49 and throughout the manuscript – put a space after the semicolon.

Author's response: Accepted. We modified throughout the manuscript.

3) Comment from Referee: L62 I would change "transient" to fast changing. The literature is full of examples of changing recharge due to change in land-use that were shown via chloride mass balance and similar methods.

Author's response: We changed to "dynamic, short-term" temporal effects

4) Comment from Referee: L64-L70. In many semiarid regions surface run-off is ~1% of precipitation way within the modeling error, hence sub-surface unsaturated - saturated zone flow models (and in some cases even only unsaturated zone models) are a very reasonable choice for studying recharge and contamination. This type of studies are quite common in the literature of the last decade (e.g. Levi et al., 2017 HESS; Turkeltaub et al., 2015 WRR). Therefore, the elaboration on 2006 review, is outdated and not very convincing, I suggest to discard.

Author's response:
Embracing the reviewer's suggestion, we added more recent references of recharge studies in semi-arid environments using different approaches. The elaboration on Scanlon et al., 2006 was introduced to show that until that date only few modeling studies were carried out in semiarid regions, mainly at the regional scale. We left the reference to the main paper and discarded the citations of the single studies. Anyway, we would like to highlight the lack of papers that feature an integrated surface water and groundwater approach in semiarid environments. Sometime, as the reviewer pointed out, this interaction can be considered negligible but, in several cases (like the presented manuscript), it has a huge impact on the spatial distribution of recharge.

Author's changes in manuscript: Numerical hydrologic models that integrate surface water and groundwater flows have been developed to simulate the spatial and temporal distribution of surface runoff, infiltration, evapotranspiration and groundwater recharge. However, the application of nearly all such simulation tools have been limited to humid regions (Wheater et al., 2007) with minimal application to semiarid regions. Scanlon et al. (2006), in their review on recharge in semiarid areas reported only 7 papers providing a continuous spatial distribution of recharge, out of a total of 98 studies. These studies investigated large areas, from 1,039,647 km^2 (Flint and Flint, 2007) to 60 km^2

(Flint et al., 2001), using a relatively coarse spatial resolution (from 72,900 m^2 - Flint and Flint, 2007 to 900 m^2 - Flint et al., 2001). In the last decade, although modeling techniques have advanced to include combined surface water-groundwater simulations, recharge in semiarid areas has been represented with a GIS approach (Hernández-Marín et al., 2018) often using remote sensing data (Wang et al., 2008; Coelho et al., 2017; Crosbie et al., 2015) or neglecting the surface water component and focusing on unsaturated zone (Levy et al., 2017;Turkeltaub et al., 2015). However, especially where streamflow represents an important part of the hydrological budget, a more complete approach requires the continuous interaction in space and time of surface water and groundwater.

5) Comment from Referee: L88. Potential evaporation – give the numbers.

Author's response: 1400 mm y^{-1}. Added to the text.

6) Comment from Referee: L 93 chemical contamination – say what contamination (in 2-3 words, nitrate, industrial organic compounds).

Author's response: The main contaminant is Trichloroethene (TCE). Added to the text.

7) Comment from Referee: L140 – How is infiltration capacity modeled? is it constant at field capacity or starts significantly higher after a dry period?

Author's response: Infiltration capacity of soil in the model is dynamic and a function of the conductivity of the surficial material and the water content properties (saturation point, field capacity and wilting point). The conductivity of the soils is a function of degree of saturation in the soil and a soil moisture characteristic curves. The soil moisture characteristic curve describes the variation in soil water content and conductivity and matric potential. The van Genuchten model is used to describe the soil moisture characteristic curves in this MIKE SHE model. The conductivity and matric potential of subsurface materials is computed for each layer within the unsaturated zone at each time step. Values used have been added to table 2 for more clarity.

Author's changes in manuscript

8) Comment from Referee: L143-146 – Not clear is the root zone and the deeper unsaturated zone modeled as a continuous domain with Richards Equation with root water uptake sink at the root zone. Or is the root-zone modeled as bimodal: above FC –deep drainage, below no deep drainage?

"…It is mainly vertical" is it a 1D model in this zone, or of higher dimension.

Author's response: The unsaturated zone is a continuous domain that is modelled as a 1D column of finite difference cells which have variable discretization from the top of the column (ground surface) to the base of the column (the unsaturated/saturated zone interface). The Richard's equation governs flow throughout the unsaturated zone. Typically, when we refer to the root zone we are describing that portion of the unsaturated zone in which vegetation has roots and the capillary fringe which may exist below the roots themselves.

Author's changes in manuscript

9) Comment from Referee: L153-154, as far as I understand if there is a constant head as a bottom boundary condition the water table will not change and recharge or discharge will be reflected only by flux out or into the model domain. Was the model fitted to transient head in wells? or only to a steady-state approximation? If so, say it explicitly in Figure 6 captions.

Author's response: There is a fixed head boundary conditions applied to the base of the model based on observed groundwater levels. If heads in the layer above the base layer of the model exceed the fixed heads then water will flow out of the model, conversely if heads in the layer above the base layer of the model fall below those in the fixed head then water will flow into the model. The model was calibrated to long term average groundwater levels over the period of simulation (1995-2014).

Author's changes in manuscript

10) Comment from Referee: L187 – "physical properties" there is only Ks in the table (not enough to model unsaturated zone flow, parameters of hydraulic functions? What type of functions? – not clear

Author's response: The table has been completed with porosity, field capacity, residual water content and the Van Genuchten parameters (α, n) used in the model.

					Van Genuchten parameters		
Hydrogeologic unit	**K_s (m s^{-1})**	**Saturation (θ_s)**	**Field capacity (θ_{fc})**	**Residual Water content (θ_{fc})**	**α**	**n**	**l**
Alluvium	1×10^{-6}	0.4	0.25	0.05	0.021	1.61	0.5
Weathered bedrock	2×10^{-7}	0.2	0.11	0.01	0.033	1.49	0.5
Unweathered bedrock	4.1×10^{-10} to 2.3×10^{-7}	0.13	0.1	0.025	0.01	1.23	0.5
Unweathered bedrock	1×10^{-10} to 1×10^{-5}	0.13	0.09	0.01	0.01	2	0.5
Unweathered bedrock	1×10^{-9} to 1×10^{-6}	0.13	0.1	0.025	0.01	2	0.5

The model uses three separate sets of Van Genuchten parameter to represent the pressure-saturation-hydraulic conductivity relationships; 1) alluvium, 2) weathered bedrock, 3) un-weathered bedrock. The parameters used reflect our understanding that the rock matrix transmits the largest volume of recharge, while recharge through the fractures is faster. The relationships used are biased towards the matrix response. These values were further calibrated using the groundwater level responses and the stream flow. Further rock core samples indicate a high moisture content (~80%) indicating that K is often close to K_s and the hydraulic conductivity-saturation curve reflects this understanding.

Author's changes in manuscript

11) Comment from Referee: L 242, MIKESHE, MIKE SHE or MIKE-SHE choose 1 and be consistent.

Author's response: It is MIKE SHE. We made it consistent throughout the text.

12) Comment from Referee: L 265, I would change "centuries" to decades in this sentence.

Author's response: Changed at line 265.

13) Comment from Referee: L 270-277 when and how these analysis of samples 24 years old were done? Is it new data, if not, reference? If yes a sentence on the analytical methods.

Author's response: Oxygen isotope ($^{18}O/^{16}O$) and hydrogen isotope ($^{2}H/^{1}H$) ratios were measured on an automated gas-source mass spectrometer at the Center for lsotope Geochemistry at the Berkeley Lab. Water samples for O-isotope analysis were inlet directly into an automated, computer driven gas equilibration system attached to the mass spectrometer. Hydrogen gas samples were prepared for D/H ratio analysis using conventional reduction methods over heated zinc beads in closed tubes. The hydrogen gas was inlet to the mass spectrometer through an automated inlet system.

Author's changes in manuscript: We added a line at L276-277.

14) Comment from Referee: L305-307, I assume these are spatially average recharge rates, if right say it explicitly, if not describe.

Author's response: Correct.

Author's changes in manuscript: We added "spatial average" to line 307.

15) Comment from Referee: L 449- 452, typical Mountain Front Recharge (major comment 2).

Author's response: see response to major comment 2

16) Comment from Referee: L 468 see Kurtzman et al., 2016 HESS, for discussion on by-pass preferential flow recharge of fresh water to aquifers under saline unsaturated zone.

Author's response: We added a reference to Kurtzmann et al., 2016 and we also added references regarding the link between precipitation characteristics and preferential flow.

17) Comment from Referee: Table 3 – rainfall at bottom line is cumulative not mean

Author's response: Correct. We modified accordingly.

18) Comment from Referee: Figure 1. Confusing map. In physical (topographic) maps green is for low lands and brown for high land. Switch the color scale to fit to the customary color scale.

Author's response: We switched the colors according to the reviewer's suggestion.

19) Comment from Referee: Figure 3 enlarge text

Author's response: We increased the size of the text.

20) Comment from Referee: Figure 7 enlarge text. m-1 shouldn't be used for per month (its per meter in the SI system).

Author's response: We changed m^{-1} to $month^{-1}$ to avoid misunderstanding

21) Comment from Referee: Figure all graphics and writing are too small. Panel C is missing.

Author's response: We adjusted all the graphics increasing the font size. What do you mean by "Panel C" here?

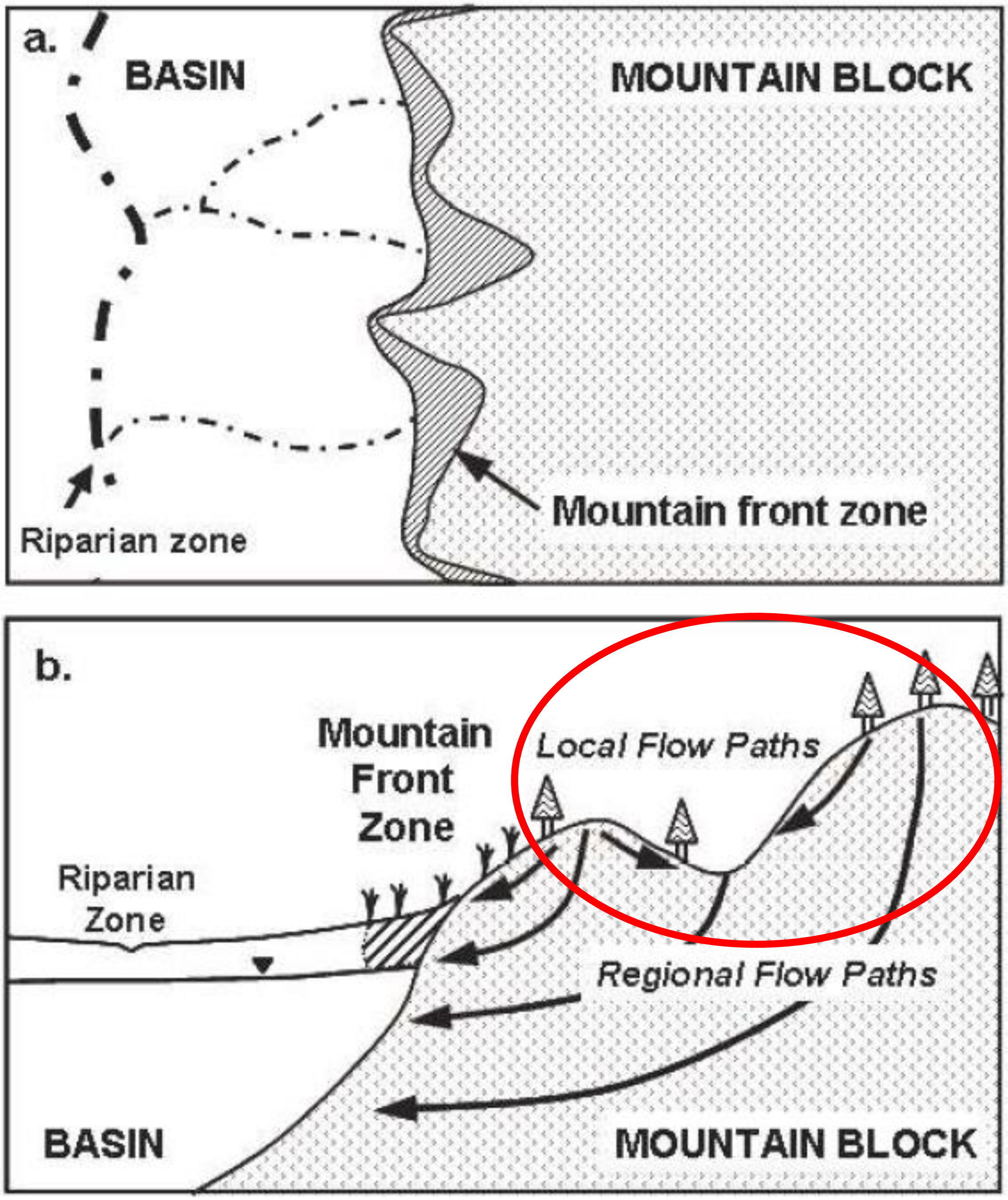

Figure 1. Schematic diagram for Mountain block and Mountain Front Recharge (Figure 2 from Wilson and Guan, 2004). The red circle represents the location of the catchment in this study.