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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Partitioning snowmelt and rainfall in the critical zone: effects of climate type and soil properties" *by* John C. Hammond et al.

John C. Hammond et al.

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Referee comment: The submitted manuscript is a contribution to new ideas in the hydrologic sciences. Understanding the partitioning of soil water, runoff and deeper percolation below the root zone are important to understanding weathering, plant water use, stream water source and travel time distributions. I really enjoyed this paper. It is generally well written and well cited. I recommend the paper for acceptance with minor revisions. Specifically, I have no recommendation for additional modeling efforts. My main criticism are (1) I feel the key points are not well defined for the reader, and (2) the "Discussion Section" a bit repetitive of the results. Instead, the paper would benefit

from more insight (compare and contrast) of this work with previous literature results and thoughtful hypotheses for how more complex boundary conditions may influence results (i.e. future work). Instead, I feel the reader gets bogged down in detailed results (that are in the Results section) and the key points are sort of lost.

Response: We agree that we need to better emphasize key points that emerge from our work and we will work to remove redundancies from results and discussion section to focus on several key points: -Snowmelt is a more efficient runoff generator than rainfall due to both higher input rates and higher antecedent moisture -Deep drainage also tends to be higher with more snowmelt, but its connection to input type is weaker because soil storage buffers the effects of changing input -When soil storage is lower than mean annual precipitation, surface runoff and deep drainage substantially increase -Soil texture modifies daily wetting and drying patterns but has limited effect on annual runoff and deep drainage -In dry climates snowmelt produces greater concentration of input in time, which also increases runoff and deep drainage

We will also add discussion of how boundary conditions affect results and add more comparison of our results with previous studies.

Referee comment: I very much enjoyed the Introduction. It is well written. I especially enjoyed your section on soil conductance, diverging patterns in growing season length. Consider looking at and adding Knowles et al., 2018 GRL paper (doi.org/10.1002/2017GL0706504) to the Intro. The introduction should provide the reader with some hint at the limiting assumptions of a 1D approach, as I found it took too long to mention complex topography and lateral flow in my initial read through. Only in the Discussion Section "Uncertainties" is this brought to the attention of the reader with a fairly nice review. I recommend bringing some of this literature review to the Introduction. In addition to rooting depth, I suggest some discussion of how above-ground vegetation influences snow accumulation and melt rate.

Response: The other reviewer also suggested the addition of relevant recent literature, and after looking at Knowles et al., 2018, we agree that it would be a good addition to the introduction and discussion:

Knowles, J. F., Molotch, N. P., Trujillo, E., & Litvak, M. E. (2018). SnowmeltâĂŘdriven tradeâĂŘoffs between early and late season productivity negatively impact forest carbon uptake during drought. Geophysical Research Letters, 45(7), 3087-3096.

We will also introduce the limitations of the 1-D modeling approach in the introduction and add discussion on above-ground vegetation influences snow accumulation and melt rate.

Referee comment: Page 5, line 151: Did you explore sensitivity of PET derived from a coarse grid of 4Km, as this is likely not representative of a single SNOTEL site given mountainous terrain.

Response: We did not explore the sensitivity of PET from the 4km product. The gridded products is likely more representative of conditions at some sites than others, but we wanted to apply a uniform approach across all sites. The SNOTEL sites do not have measured values of PET, so we do not have information on realistic PET values. We will comment on this issue in the discussion section.

Referee comment: Page 6, line 190: I am ok with the conceptual model but I think one needs to consider the implications of removing the lower boundary effects on the solution through free drainage in the discussion. Specifically, I am thinking of Brantley et al., 2017 paper where she nicely states in the abstract, "water can also flow laterally in the shallow subsurface as interflow in zones of permeability contrasts. Interflow can also be perched or it can occur during periods of high regional water table".

Response: Text on lines 428 to 452 loosely discusses this issue, but we will refine this text and include the Brantley reference:

Brantley, S. L., Lebedeva, M. I., Balashov, V. N., Singha, K., Sullivan, P. L., & Stinchcomb, G. (2017). Toward a conceptual model relating chemical reaction fronts to water

flow paths in hills. Geomorphology, 277, 100-117.

Further references are provided below in a comment specifically addressing lower boundary conditions.

Referee comment: Page 11, line 392, "once subsurface storage is at capacity, D will plateau and Q will increase with further input due to the saturation excess mechanism". This is a very interesting conclusion, can you provide more evidence through previous research that this result is a physical representation and not a result of the model construct.

Response: Kampf et al. 2015 show that soil moisture plateaus when saturation overland flow occurs. We do not know of other studies showing rates of deep drainage in relation to soil saturation as this is mostly inferred from hydraulic gradients.

Kampf, S., Markus, J., Heath, J. and Moore, C.: Snowmelt runoff and soil moisture dynamics on steep subalpine hillslopes, Hydrol. Process., doi:10.1002/hyp.10179, 2015.

Referee comment: Page 11, line 409, interesting result that soil water storage<mean annual precipitation, and you do provide the Smith et al., 2011 reference. But I would like to see more literature on the soil storage capacity, D and Q relationship; perhaps bring in how this might influence where D is generated (or not generated) across the watershed.

Response: We support the idea proposed by the reviewer to think spatially about the ratio of annual precipitation to soil storage and its linkage to where deep drainage may or may not be generated. We will add further discussion related to the interaction of topography, surface water inputs, vegetation, soil profile depth, etc. on controlling spatial variability of subsurface storage and deep drainage. The following references will be used to update discussion on this topic:

Bales, R. C., Hopmans, J. W., O'Geen, A. T., Meadows, M., Hartsough, P. C., Kirchner, P., ... & Beaudette, D. (2011). Soil moisture response to snowmelt and rainfall in a

Sierra Nevada mixed-conifer forest. Vadose Zone Journal, 10(3), 786-799.

Tetzlaff, D., Birkel, C., Dick, J., Geris, J., & Soulsby, C. (2014). Storage dynamics in hydropedological units control hillslope connectivity, runoff generation, and the evolution of catchment transit time distributions. Water resources research, 50(2), 969-985.

Seyfried, M. S., & Wilcox, B. P. (2006). Soil water storage and rooting depth: key factors controlling recharge on rangelands. Hydrological Processes: An International Journal, 20(15), 3261-3275.

Seyfried, M. S., Grant, L. E., Marks, D., Winstral, A., & McNamara, J. (2009). Simulated soil water storage effects on streamflow generation in a mountainous snowmelt environment, Idaho, USA. Hydrological Processes: An International Journal, 23(6), 858-873.

Grant, L., Seyfried, M., & McNamara, J. (2004). Spatial variation and temporal stability of soil water in a snowâĂŘdominated, mountain catchment. Hydrological Processes, 18(18), 3493-3511.

Wohling, D. L., Leaney, F. W., & Crosbie, R. S. (2012). Deep drainage estimates using multiple linear regression with percent clay content and rainfall. Hydrology and Earth System Sciences, 16(2), 563-572.

Farrick, K. K., & Branfireun, B. A. (2014). Soil water storage, rainfall and runoff relationships in a tropical dry forest catchment. Water Resources Research, 50(12), 9236-9250.

Referee comment: Page 12, line 416. Consider renaming this section from Uncertainties to something like "Limiting Assumptions" as you do not actually address uncertainty mathematically. While this section is fairly complete, consider speculating on how your results may be different by including (a) transient LAI (look at Kim et al., 2018, GRL doi.org/10.1029/2018JG00438) for some discussion ideas on phenological response to warming induced earlier green-up, (b) potential lower boundary condition controls im-

posing on the solution – i.e groundwater, (c) complex topography of slope and aspect and (d) lateral flow.

Response: We agree with the suggested change in title for this subsection.

We also appreciate the suggested added speculation on transient LAI, effects of lower boundary controls, and complex topography, and inclusion of lateral flow.

In addition to references already included in this section and in the introduction, we will add the following references to the discussion to more fully address assumptions of our approach as compared to other works as enumerated below, and speculate on how our results might be different if these changes were incorporated.

Transient LAI:

Kim, J. H., Hwang, T., Yang, Y., Schaaf, C. L., Boose, E., & Munger, J. W. (2018). WarmingâĂŘInduced Earlier Greenup Leads to Reduced Stream Discharge in a Temperate Mixed Forest Catchment. Journal of Geophysical Research: Biogeosciences, 123(6), 1960-1975.

Lower boundary conditions:

Chen X D, Liang X, Xia J, She D X. 2018. Impact of lower boundary condition of Richards' equation on water, energy, and soil carbon based on coupling land surface and biogeochemical models. Pedosphere.28(3): 497–510.

Leterme, B., Mallants, D., & Jacques, D. (2012). Sensitivity of groundwater recharge using climatic analogues and HYDRUS-1D. Hydrology and Earth System Sciences, 16(8), 2485-2497.

Complex topography:

We will add discussion relevant to limitations of our approach given the lack of complex topography because we used a 1-D model. This discussion will be based on references in the introduction lines 78-90, and focus on the references below:

Western, A. W., Zhou, S. L., Grayson, R. B., McMahon, T. A., Blöschl, G., & Wilson, D. J. (2004). Spatial correlation of soil moisture in small catchments and its relationship to dominant spatial hydrological processes. Journal of Hydrology, 286(1-4), 113-134.

Litaor, M. I., Williams, M., & Seastedt, T. R. (2008). Topographic controls on snow distribution, soil moisture, and species diversity of herbaceous alpine vegetation, Niwot Ridge, Colorado. Journal of Geophysical Research: Biogeosciences, 113(G2).

Williams, C. J., McNamara, J. P., & Chandler, D. G. (2009). Controls on the temporal and spatial variability of soil moisture in a mountainous landscape: the signature of snow and complex terrain. Hydrology and Earth System Sciences, 13(7), 1325-1336.

Brooks, P. D., Chorover, J., Fan, Y., Godsey, S. E., Maxwell, R. M., McNamara, J. P., & Tague, C. (2015). Hydrological partitioning in the critical zone: Recent advances and opportunities for developing transferable understanding of water cycle dynamics. Water Resources Research, 51(9), 6973-6987.

Lateral flow:

In addition to discussion on lateral flow influence on lines 433 to 445, we will add the following references and associated text:

Kim, J., and B. P. Mohanty (2016), Influence of lateral subsurface flow and connectivity on soil water storage in land surface modeling, J. Geophys. Res. Atmos., 121, doi:10.1002/2015JD024067.

Weiler, M., and J. J. McDonnell (2007), Conceptualizing lateral preferential flow and flow networks and simulating the effects on gauged and ungauged hillslopes, Water Resour. Res., 43, W03403, doi:10.1029/2006WR004867.

Referee comment: Page 14, line 485. Your last sentence is not very strong, "water managers should develop strategies to mitigate . . ..". It should contain some qualifications based directly on your analysis.

Response: We agree with the reviewers assertion and will update this sentence to read along the lines of what is shown below:

Original:

"Although more work is necessary to translate these finding to streamflow response, water managers should develop strategies to mitigate impacts of reduced streamflow generation in places that are most at risk for shifts from snow to rain."

Potential update (though further wordsmithing is needed for brevity and clarity):

"Although more work is necessary to translate these findings to watershed-scale streamflow response, water managers should develop strategies to mitigate anticipated impacts of reduced streamflow from surface and subsurface pathways in dry climates where snowmelt is currently a substantial contribution of annual input."

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