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Interactive comment on "Solver for Hydrologic Unstructured Domain (SHUD): Numerical modeling of watershed hydrology with the finite volume method" *by* Lele Shu et al.

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Thank the reviewer for these valuable comments concerning the manuscript entitled "Solver for Hydrologic Unstructured Domain (SHUD): Numerical modeling of watershed hydrology with the finite volume method". These comments are very helpful for revising and improving my paper, as well as the important guiding significance to my researches. We have studied comments carefully and have made corrections, which we hope to meet with approval.

*Comments by the anonymous reviewer are pasted here in bold font; our answers are given in normal font.

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Comment 1: The authors need to provide information about how they implement the discretization. Will the discretization be implemented through the model or using different software such as PIHMgis?

SHUDtoolBox is the tool for pre- and post-process input/output data for the SHUD model. Within the SHUDtoolbox, we used the triangulation program written by Shewchuk (Shewchuk 1996) to generate the Delaunay triangulation. Nevertheless, the SHUD model does not limit the triangulation to Delaunay. Besides the SHUDtoolbox, any GIS tool or language (Matlab, R, Python) has various methods to build a triangular mesh that is acceptable in the SHUD modeling system.

PIHMgis (with supports of C++, Qt and Qgis) is GIS-tool supporting PIHM v2.x, that helps users to build the PIHM model. SHUDtoolbox developed in R, realized GIS functions and data processing for SHUD model.

I added the explanations into the revision. The details of SHUDtoolbox would be another paper.

Comment 2: The link to the model source code is not really useful for other users since there is not any user manual that explains how to implement the model.

I updated the Readme file of the model source code and three examples that give direct guidelines to run the model.

Comment 3: One clear disadvantage of the SHUD model relative to Flux-PIHM, which is the PIHM model coupled with Noah-LSM, is using a temperature index approach instead of energy balance for snowmelt estimations.

Yes, Flux-PIHM couples the NOAH-LSM into the PIHM model that makes the model more capability on computing snow dynamics. Flux-PIHM is one of the fruitful branches in the PIHM family.

Both PIHM and SHUD, however, are aiming to build a community model that encourages experts from other fields to contribute the model coupling based on their requirements, instead of making a sophisticated but clumsy model for all users. ET and snow are important for water balance in a hydrological model and the simple methods are useful for many and even most hydrological model applications. When users think the simple process algorithm cannot meet their requirements, the open-source and simplified design of the direct coupling in PIHM and SHUD allow users to modify specific processes and import their own code in a relatively short time. The simplicity of adding processes is the strength of the PIHM-SHUD line of models.

Comment 4: In SHUD model deep groundwater cannot be considered in subsurface flow simulations while in Flux-PIHM it is, which is another shortcoming to SHUD model that authors tried to justify by assuming most rocks are impermeable, which is not the case in some cases.

I rephrased the assumption about the impermeable bedrock in the revision. However, the assumption this version of SHUD makes is that there is an effective depth within which flows contribute to local streams. When this assumption is not reasonable the SHUD model is not appropriate. The impermeable bedrock is however a general assumption utilized in many hydrological models, even though they do not explicitly elaborate on the assumption, such as TopModel, VIC, WRF-Hydro, and SWAT when we use the mass balance equation: **Storage change = Rainfall - ET - Discharge**, and in the long-term period, the storage change is considered to be closing to zero, we already assumed a close boundary and impermeable bedrock.

Indeed, the impermeable bedrock does not apply to all regions or modeling purposes. SHUD has one option to solve this issue — define the exchange of shallow and deep groundwater as time-series boundary conditions, then the influence of the porous bottom boundary is considered in the calculation. However, modeler must pay attention that both the permeable bedrock or bottom boundary conditions raise more uncertainties in the model.

Comment 5: Adding irrigation to the simulation is not possible in the PIHM model

and based on what the authors mentioned on page 8, line 198, it is possible in SHUD model simulations. If true, authors need to add this to the list of differences between two models and explain in the model user manual how is that possible.

Both PIHM and SHUD use the same algorithms to consider the irrigation. There are two options to embed the irrigation.

1. To preprocess the time-series irrigation as precipitation. This is simplest way, but the model would calculate the interception based on the vegetation features.

2. To apply the irrigation as surface boundary conditions.

Comment 6: One drawback to the PIHM model was the assumption of homogeneous soil properties within each cell, which is the same in SHUD. Indeed, it is homogeneous within each cell. SHUD and PIHM allow a surface soil layer (user specified) and a deeper hydrologic layer so it is not quite homogeneous in the vertical. It also is heterogenous areally as each prismatic element receives a separate set of soil properties, In the case of SWAT it uses the HRU idea where heterogeneity exists only between HRU's. Namely, only one set of parameters, including the landuse, soil characteristics, slope of the terrain, lag time, and so on, exist within an HRU. The heterogeneity of distributed model is represented within the differences among computing units (HRUs, elements, cells, and volumes) all over the domain.

The soil properties in SHUD also vary along the vertical direction due to the macropore effect, where the macropore depth is set by the user. This also impacts the effective conductivity as groundwater levels vary in time.

Comment 7: Page 9, Line 230: Authors claim that it is realistic to assume that the water exits the watershed only through stream discharge, considering that the groundwater lateral flow is insignificant and minimal in so many cases, which is not true.

I rephrase the words about this assumption in revision. This should not be an assumption, but a default model configuration. Once the default configuration is not acceptable, the user can alter the configuration based on their research areas and requirements. Examples which can be specified in SHUD include applications with internal boundary conditions such as lakes or reservoirs, pumping wells and channel diversions given appropriate geospatial representation in the model set-up.

Comment 8: Authors mention that the mathematical equations are different than what used in PIHM such that they produce different results using the same parameters. The difference and how they are "better" than equations that were used in PIHM should be explained.

The reviewer points out an inconsistency in the explanation of the process equations. What we meant to say was that approximations to process equations such as infiltration can produce very different results (e.g 1-D Richard's equation versus Green and Ampt). What we have tried to do in SHUD is follow four rules: simplicity of the conceptual-mathematical process, approximations that have community acceptance, numerical efficiency of the process equation (particularly in the numerical models), and the ability to simply replace process model code. As all models require calibration, the nudges to the parameters are opting to fit the simulation to the observation.

Still, it is valuable to make a comprehensive comparison of the outcomes from different process equations allowed in SHUD in a future paper.

Comment 9: Flux-PIHM addresses most of the improvements mentioned on page 28 such as checking the range of forcing data, exporting initial condition, supporting human-readable input and output. The authors do not clearly show how the SHUD is better than the current existing versions of PIHM.

Flux-PIHM does make useful technical extensions from PIHM which relate to coupling with sophisticated eco-hydrologic, and geochemical sub-modules. Bt adding states to be solved these extensions are computationally restricted to coarse grids, smaller

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scales and limited time periods even where HPC resources can be used. The goal of SHUD is to improve the core hydrologic modeling of hillslope, catchment and river basin scales and to allow very large and/or high resolution hydrologic processes over these domains. In the future we expect SHUD and Flux-PIHM to converge as efficiency improvements are adopted for adding new process equations as part of PIHM-SHUD ecosystem improvements in the future.

Comment 10: Page 5, Line 95: snowmelt unit could not be m3/s.

Fixed this typo. It is m/s.

Comment 11: Page 5, Line 101 and 102: Two different parameters have the same annotations.

Deleted the Line 101. Thank you.

Comment 12: Page 15, Equation 13: Define Lj.

L_j is defined in Nomenclature. I will move the Nomenclature into the appendix.

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