Hydrology and Earth System Sciences

Manuscript title: Ratio Limits of Water Storage and Outflow in Rainfall-runoff Process

Response to Anonymous Referees

Dear Editor Roberto Greco

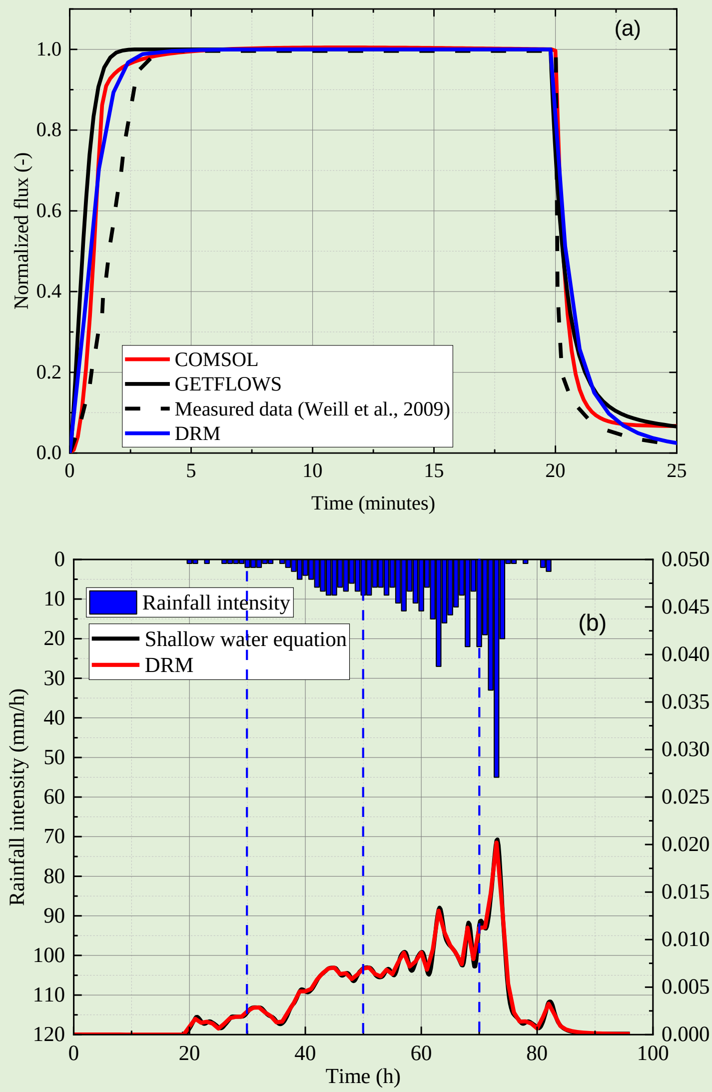
We sincerely thank you and the two referees for their examination of this manuscript. The valuable comments from referees are very helpful for us to revise and improve this manuscript. Based on the referees' comments, we revised the manuscript, and the revised parts are marked in red color in the revised manuscript. Please kindly go through our responses below. Thank you very much.

Kind regards

Zhu

Response to Second Referee

No.	**Comments**	**Response**
General comments:		
	This study establishes the existence of a nonlinear relationship between the average water depth within the watershed and the outlet water depth (i.e., water storage ratio), and investigates the factors influencing the fluctuations of this ratio. The authors also introduce the Distributed Runoff Model as a means to simplify the hydrodynamic model, with the goal of improving the effectiveness and efficiency of flood forecasting. While the idea presented is valuable and the findings are interesting, the quality of the paper requires improvement before publication.	We sincerely thank you for your valuable time to review our manuscript and for providing valuable comments. The valuable comments are very helpful for us to revise and improve this manuscript. Based on the your comments, we revised the manuscript and the revised parts are marked by red colour in the track changes version of the manuscript. Please kindly go through our responses below.
Specific comments:		
	Figure 4 and lines 158 to 170 discussed the effectiveness and efficiency of DRM, yet there is a lack of evidence demonstrating that DRM is computationally more efficient. Should this be addressed by comparing computational time, space requirements, or other relevant aspects?	Thank you very much for your comment. Yes, in our previous work, we have checked the effectiveness and efficiency of DRM compared to the shallow water equations (SWEs), including the comparison of computational time and space requirements. We found that the results of DRM agree well with the results calculated by SWEs or measured data on different spatial scales (Abdul and Gillham system: 0.112×10^{-6} km^2, conceptual slope model: $1\times10^{-3}km^2$, V-catchment system: $1.62km^2$, and Nissho Pass, Japan:0.1356 km^2) as shown in Fig. A below. The calculation time of DRM is greatly shortened compared with SWEs, as shown in Table A below.

		Table A shows the calculation efficiency improvement of DRM compared to SWEs. The calculation efficiency has increased by 70% ~ 90%. The related works have been published in Journal of Hydrology in 2022. 

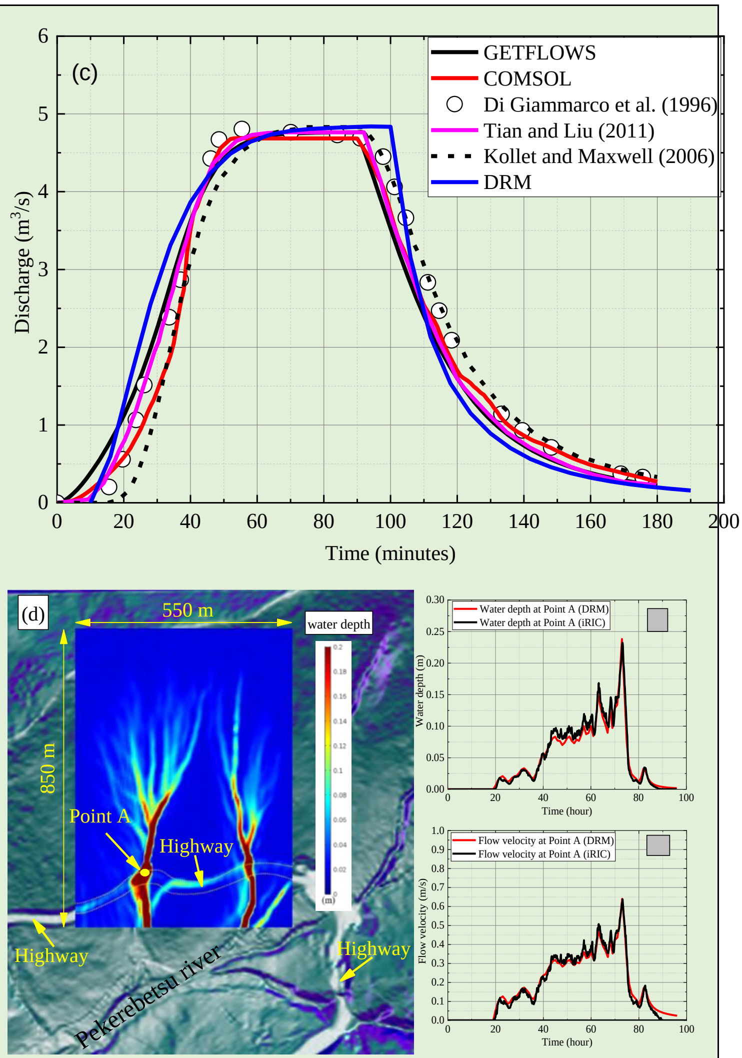


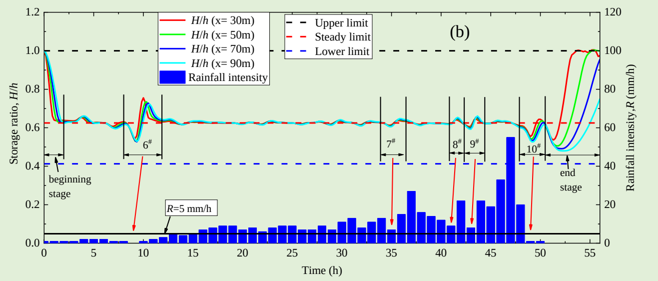
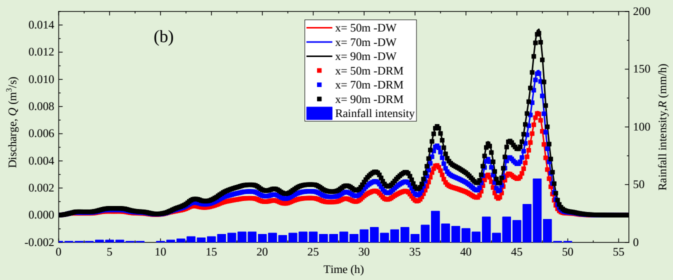
Figure A: comparison of the calculation results of DRM with SWEs and measured data (a) Abdul and Gillham system: 0.112×10^{-6} km^2,(b) conceptual slope model: 1×10^{-3}km^2, (c) V-catchment system: 1.62km^2, (d) Nissho Pass, Japan: 0.1356 km^2.

Table A Calculation efficiency improvement of DRM compared to SWEs.

Table A: Calculation efficiency improvement of DRM compared to shallow water equations.

Model	Catchment area	Simulation time	Calculation time of shallow water equations	Calculation time of DRM	The improvement of calculation efficiency
Impermeable conceptual slope model	1×10^{-3} km^2	1 h	14 s	3 s	78.6%
		1 d	93 s	12 s	87.1%
		3 d	517 s	57 s	89.0%

However, when we performed the above validation works, we did not find the nonlinear relationship between the average water depth within the watershed and the outlet water depth (i.e., water storage ratio) at that time. We assumed it is a

		constant, although the use of this constant has also been able to achieve good calculation accuracy. In this paper, we find that the assumption of constant is insufficient. An exact nonlinear curve should be given. For more validation details, please refer to our previous work: Zhu, Y.L., Zhang, Y.F., Yang, J., Nguyen, B. T., & Wang, Y. (2022.9). A novel method for calculating distributed water depth and flow velocity of stormwater runoff during the heavy rainfall events. Journal of Hydrology, 612, 128064. https://doi.org/10.1016/j.jhydrol.2022.128064
	Figure 7 indicates that the simulation results of DRM closely match those of DW. However, can we confidently draw this conclusion (that DRM reproduces the calculation results of the time-consuming hydrodynamic model well) based solely on one rainfall event at one location? Suggesting applying more rainfall events at different site and using metrics to evaluation the performance of DRM compared with DW.	Thank you very much for your comment. We added the analysis of another rainfall event as plotted in Fig. 5(b) and Fig. 7(b). Combined with our explanation of your previous comment, we have the confidence to draw this conclusion (that DRM reproduces the calculation results of the time-consuming hydrodynamic model well). Fig. 5(b) and Fig. 7(b) are:  
	Section 6 only included the results. Discussion could include the comparison between your results and previous studies.	Thank you very much for your comment. We added more discussion of the results. In particular, the limitations of numerical analysis are discussed, such as the neglect of groundwater and the parts that need to be discussed in depth in the future. The revision is as follows: **6. Discussions and Conclusions** Based on an impermeable conceptual slope model, numerical simulations of the rainfall-runoff process are performed by using the diffusion wave (DW) approximation of SWEs. A “plume” shaped nonlinear relationship between water storage and outflow, defined as the water storage ratio, are found between the inside average water depth and the outlet water depth in a catchment. The water storage ratio is controlled by three limits, namely upper limit, steady limit, and lower limit with the value of approximately 1.0, 0.625, and 0.4125, respectively. Under the control of the three limits, meteorological, vegetation, and terrain conditions only affect the size of the “plume” without changing its shape. The regular

		curve shape of the water storage ratio provides the possibility to construct a correlation between the water storage in the catchment area and the outlet discharge. Based on the water storage ratio, a hydrological-hydrodynamic integrated model-DRM, is established, which shows high calculation accuracy and computational efficiency. It is because the governing equations of DRM are ordinary differential equations (ODEs), which are much easier to solve than nonlinear partial differential equations (PDEs). However, the calculations of DRM and DW only involve the confluence part of surface water and do not consider the interbasin groundwater flow as inputs to the watershed. This is inconsistent with the real rainfall-runoff process in the watershed and may lead to deviations in the calculation results. Therefore, the process of runoff generation in the early stage of rainfall needs to be further discussed. Besides, the flow exchange between surface water and groundwater during the existence and extinction of runoff also needs to be further realized by establishing a dynamic coupling model of surface water and groundwater. In addition, the water storage and discharge are limited to envelope lines and the discharge/water depth process lines during water rising and falling showed a grid-shaped distribution, which might be the cause of the looped rating curve, i.e., higher discharges for the rising limb than for the recession limb at the same stage. Rainfall, especially weak rainfall (i.e. rainfall intensity is less than 5.0 mm h^{-1}) significantly affects the fluctuations of water storage ratio. The fluctuations of water storage ratio during a real rainfall event can be divided into three modes, that is Mode I identified as inverse S-shape type during rainfall beginning stage, Mode II identified as Wave type during weak rainfall duration stage, and Mode III identified as check mark type during rainfall end stage. It is wroth noting that a qualitative determination of the three fluctuation modes of water storage ratio during rainfall events are obtained, but quantitative analysis still needs to be further carried out in the future. The findings in this study provide a key to establish a simpler prediction model for flash floods. The water storage ratio has been proved to be effective in improving the effectiveness and efficiency of flood forecasting. Therefore, the determination of the nonlinear relationship of the water storage ratio curve under different geographical scenarios will provide new ideas for simulation and early warning of flash floods.
	The last paragraph of the Introduction Section lacks clarity in introducing/summarizing your study and needs to be revised.	Thank you very much for your comment. We revised the last paragraph of the Introduction Section to increase clarity in introducing/summarizing. The revised paragraph is: "Efficient and stable solution of the hydrodynamic model has long been an important issue in flood forecasting. Since the SWEs are nonlinear hyperbolic PDEs, the increase in the calculation domain and the increase in the degree of discreteness will greatly increase the difficulty of solving SWEs. In addition, when using high-resolution terrain to improve model calculation accuracy, non-physical phenomena

		such as false high flow velocity in steep terrain will also occur, resulting in calculation distortion and a sharp increase in calculation time. Hence, we try to ignore the complex exchange/transfer process of mass and momentum (hydrodynamic models), and also abandon the empirical relationships (hydrological models) between the input (precipitation), the transmission (flow rate) and the output (discharge) in the catchment area. A catchment is regarded as a semi-open water storage system, and the complex problem is simplified into three megascopic variables, i.e., inflow, water storage and outflow. For any watershed, the complex internal flow processes could be ignored if the physical mechanism between inflow, water storage, and outflow can be found under different meteorological, geographical and geological conditions. In other words, if we can give a physical-based relationship between the three megascopic variables, flood forecasting will become much simpler. For this goal, a "plume" shaped nonlinear relationship between the inside average water depth and the outlet water depth, namely the water storage ratio curve, was found by using the calculation results of the hydrodynamic model."
	Does this study assume that the interbasin groundwater flow is not considered as inputs to the watershed? Please clarify and provide a clear statement regarding this assumption in the Methods Section.	Thank you very much for your comment. Yes, this study assume that the interbasin groundwater flow is not considered as inputs to the watershed. We added a clear statement regarding this assumption in the Methods Section as follows: The calculation of DRM only involves the confluence part of surface water. The interbasin groundwater flow is not considered as inputs to the watershed.
	Minor revision: Lines 134 to 136 should be one sentence, not two.	Thank you very much for your comment. We revise the grammar errors, and turn two sentences into one sentence. The revised sentence is: To obtain further insights into the causes for the formation of the water-rising limb and the water-falling limb of the water storage ratio curve, the ratio of discharge (i.e., the ratio of the total outflows (Q_{out}) to the total inflows (Q_{in})), and the water depth (h) along the slope are discussed in Fig. 3a and Fig. 3b, respectively.