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.

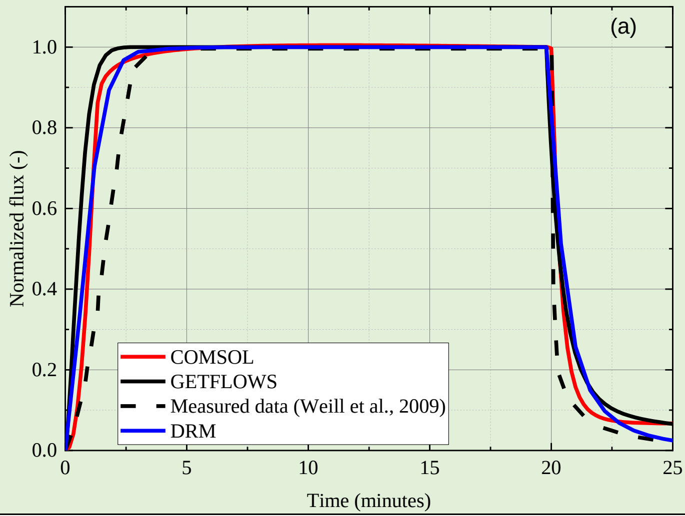
Kind regards

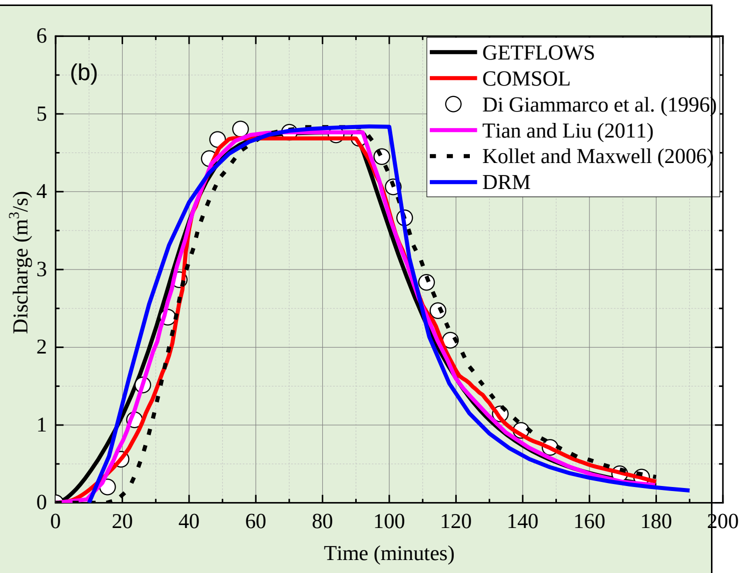
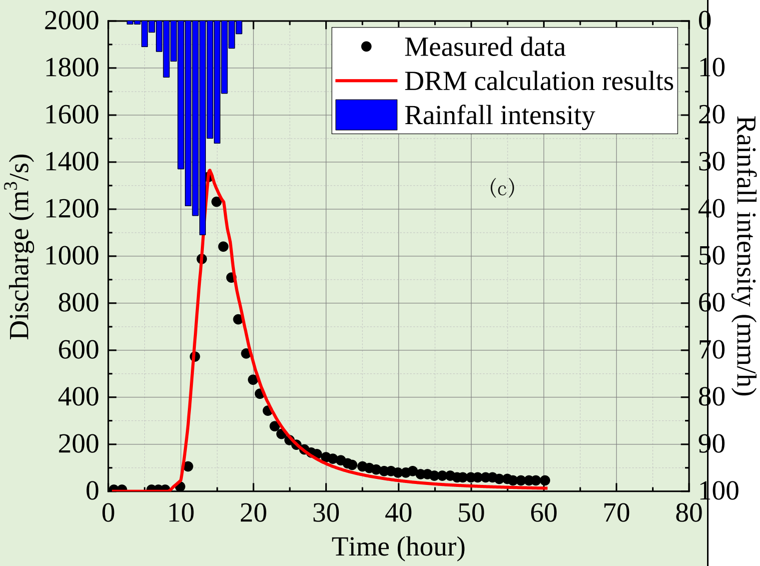
Zhu

Response to First Referee

No.	Comments	Response
General comments:		
G-1	This manuscript investigates the realtionship between the inside average water depth (H) and outlet water depth (h) in an arbitrary catchment which is assumed to be a conceptual water tank. After evaluating the water storage ratio curve (H/h) sensitivity to the catchment area, the Manning's coefficient, the slope gradient and the rainfall intensity, they propose the application of this variable within a simplified yet apparently quite effective rainfall-runoff model named distributed runoff model (DRM), and positively compare the results with an already validated diffusion wave (DW) approximation of the shallow water equations by numerical simulations for simulating ground surface runoff. The paper has some useful elements, but in my opinion it cannot be published in its current format due to the following reasons:	We sincerely thank you for your valuable time to review our manuscript and for providing valuable comments, We are grateful for your guidance and correction in our English grammar, spelling, and sentences. The valuable comments are very helpful for us to revise and improve this manuscript. Based on your comments, we revised the manuscript, and the revised parts are marked in red color in the track changes version of the manuscript. Please kindly go through our responses below. To save you time in checking our revisions, we have listed your comments and our corresponding modifications one by one in the table below, which includes the original text (quotation marks), your comments (bold font), our corrections (red color), and our responses.
G-2	the abstract starts in medias res, without any introduction regarding the aim and the	Thank you very much for your comment. We added the aim and the methodology of the work in the abstract beginning part as follows:

	methodology of the work	Flash floods typically occur suddenly within hours of heavy rainfall. Accurate forecasting of flash floods in advance using the two-dimensional (2D) shallow water equations (SWEs) remains a challenge, due to the governing equations of SWEs being difficult-to-solve partial differential equations (PDEs). Aiming at shortening the computational time and gaining more time for issuing early warnings of flash floods, a new relationship between water storage and outflow in the rainfall-runoff process is attempted to be constructed by assuming the catchment as a water storage system.
G-3	the discussion is basically absent, the authors just sum up the main results with no added comments	Thank you very much for your criticism. We revised the Discussions and Conclusions section. 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: **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, is 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. This 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 the rainfall beginning stage, Mode Ⅱ identified as Wave type during the weak rainfall duration stage, and Mode Ⅲ identified as checkmark type during rainfall end stage. It is worth noting that a qualitative determination of the three fluctuation modes of water storage ratio during rainfall events is obtained, but the quantitative analysis still needs to be further carried out in the future. The findings in this study provide a key to establishing a simpler prediction model for flash floods. The water storage ratio has been proven 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.
G-4	results are presented in terms of comparison between DW and DRM for a real rainfall event, but no real runoff data (not even discharge) is used	Yes, 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 and measured data on different spatial scales (Abdul and Gillham system: 0.112×10-6 km^2, V-catchment system: 1.62km^2, and Kusaki dam, Japan: 254km^2). 

		  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) V-catchment system: 1.62km^2, and (c) Kusaki dam, Japan: 254km^2.
G-5	the overall writing needs some improvement (see the attached file)	Thank you very much for your comments. We revised the text point by point according to your attached comments. Please check our responses below.
Specific comments:		
S-1	Abstract: Comment: At least a couple of introductive sentences (e.g. sentences dealing with the aims and methods of this research) are needed before the current first sentence, which already addresses the results of the work.	Thank you very much for your comment. We added the following sentences dealing with the aims and methods of this research before the first sentence: Flash floods typically occur suddenly within hours of heavy rainfall. Accurate forecasting of flash floods in advance using the two-dimensional (2D) shallow water equations (SWEs) remains a challenge, due to the governing equations of SWEs being difficult-to-solve partial differential equations (PDEs). Aiming at shortening the computational time and gaining more time for issuing early warnings of flash floods, a new relationship between water storage and outflow in the rainfall-runoff process is

		attempted to be constructed by assuming the catchment as a water storage system.
S-2	L22: “the” Comment: Not needed	Thank you very much for pointing out this English grammar error. We have deleted it.
S-3	L31: “rainfall” Comment: (i.e. when rainfall...	Thank you very much for your comment. We have revised the expression.
S-4	L38: “dollars direct economic loss” Comment: dollars in direct economic losses	Thank you very much for your comment. We have revised the expression.
S-5	L39-40: “Weather prediction-based distributed hydrological/hydraulic models are considered to be an effective strategy for flood forecasting (Ming, et al., 2020).” Comment: Move this sentence to line 55	Thank you very much for your comment. We have moved this sentence to line 55 and combined this sentence with other sentences: Flood simulation provides an effective means of flood forecasting to reduce property and life losses in flood-threatened areas around the world. Particularly, weather prediction-based distributed hydrological/hydraulic models are considered to be an effective strategy for flood simulation (Ming, et al., 2020). Hence, a large number of scholars are committed to improving the simulation efficiency or simulation accuracy of distributed hydrological/hydraulic models.
S-6	L42-44: “Based on the daily satellite imagery at 250-metre resolution of the 913 large flood events in the same period, a total inundation area of 2.23 million km2, with 255-290million people were estimated directly affected by floods (Tellman, et al., 2021).” Comment: This sentence does not read very well, consider rephrasing it	Thank you very much for your comment. We have rephrased it. Based on 250-meter resolution daily satellite images of 913 major flood events during the same period, the total area inundated by floods is estimated to be 2.23 million km2 and the directly affected population is estimated to be 255 to 290 million (Tellman, et al., 2021)
S-7	L50-51: “(e.g., Taklimakan Desert (Li and Yao, 2023) and Atacama Desert (Cabré, et al., 2023))” Comment:(e.g. in the Taklimakan Desert and the Atacama Desert, as reported by Li and Yao, 2023 and by Cabré et al., 2023 respectively)	Thank you very much for your comment. We have revised the expression.
S-8	L60: “one-dimension(1D)” Comment: one-dimensional (1D)	Thank you very much for your comment. We have revised the expression.
S-9	L57-63: “Accordingly, they have developed many forms of hydrological models (e.g., Stanford Watershed Model IV (SWM) (Crawford and Linsley, 1966), SHE/MIKESHE model (Abbott, et al., 1986), Tank model (Sugawara, 1995), Soil	Thank you very much for your comment. Indeed, we're not very good at dealing with using brackets within brackets. We revised the sentence and tried our best to avoid using brackets within brackets. The revised sentence is: Accordingly, they have developed many forms of hydrological models and hydrodynamic models. Among

	and Water Assessment Tool (SWAT) (Arnold and Williams, 1987), TOPMODEL (Beven and Kirkby, 1979), etc.), hydrodynamic models (the one-dimension(1D) Saint-Venant equation (Köhne, et al., 2011), the two-dimensions (2D) shallow water equations (SWEs) (Camassa, et al., 1994), and the three-dimensions (3D) integrated equations of runoff and seepage (Mori, et al., 2015)), or coupling models of the two (Kim, et al., 2012; Liu, et al., 2019; Hoch, et al., 2019)" Comment: See if you can avoid using brackets within brackets, for example using dashes to include the lists of models. This will help the readability of the paragraph	them, the hydrological models include Stanford Watershed Model IV—SWM (Crawford and Linsley, 1966), SHE/MIKESHE model (Abbott, et al., 1986), Tank model (Sugawara, 1995), Soil and Water Assessment Tool—SWAT (Arnold and Williams, 1987), and TOPMODEL (Beven and Kirkby, 1979), etc. The hydrodynamic models include the one-dimension (1D) Saint-Venant equation (Köhne, et al., 2011), the two-dimensions (2D) shallow water equations (SWEs) (Camassa, et al., 1994), and the three-dimensions (3D) integrated equations of runoff and seepage (Mori, et al., 2015). In addition, a variety of hydrological-hydrodynamic coupling models have also been proposed by Kim, et al. (2012); Liu, et al. (2019); Hoch, et al. (2019), and other scholars.
S-10	L65: "due to its governing equations are a " Comment:either ...due to the fact that its governing equations are a... or ...due to its governing equations being a...	Thank you very much for your comment. We have revised the expression to "...due to its governing equations being a...
S-11	L67-68: "(GPU parallel computing (Crossley, et al., 2010) or advanced numerical scheme (Sanders, et al., 2010))" Comment:get rid of the outer brackets, introduciind the sentence with "e.g. applying" or something similar	Thank you very much for your comment. We got rid of the outer brackets and revised the sentence as : e.g. applying GPU parallel computing (Crossley, et al., 2010) or advanced numerical scheme (Sanders, et al., 2010)
S-12	L89: "Eq. 2" Comment:Before this sentence, you should list the variables which are present in equation 2. Then after eq. 3 you list only the ones you did not list before	Thank you very much for your comment. We list the variables which are present in Eq.2 and list only ones we did not before after Eq.3.
S-13	L93: "," Comment: not needed	Thank you very much for your comment. We have deleted the comma.
S-14	L93: "q is conceptual outflow (m s-1), q=Q/A (m s-1)" Comment:q=Q/A is conceptual outflow (units);	Thank you very much for your comment. We have revised the expression.
S-15	L98: "designed" Comment:design	Thank you very much for your comment. We have revised the word.
S-	L121: "rainfall intensity rainfall	Thank you very much for your comment. We have deleted

16	intensity" Comment:No	the repeated words.
S-17	L121: "(f)" Comment:Figure not described in the caption	Thank you very much for your comment. We have added the description of Fig. 2f as : (f) collection of the above twenty one water storage ratio curves.
S-18	L124: "resemble a shape of "plume"" Comment:... resemble the shape of a "plume".	Thank you very much for your comment. We have revised the expression.
S-19	L124-125: "Higher water storage ratio (H/h) for the water-rising limb than for the water-falling limb at the same outlet water depth." Comment: This sentence has no verb in it, rephrase it or connect it to the previous one	Thank you very much for your comment. We have added the verb. The sentence is revised as: When the water outlet depth is the same, the water storage ratio (*H*/*h*) of the water-rising limb is higher than that of the water-falling limb.
S-20	L134-135: "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." Comment: no verb in this sentence	Thank you very much for your comment. We have revised the expression. We connected it to the previous sentence: 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.
S-21	L136: "(Qin)" Comment: I think another closed bracket is needed here	Thank you very much for your comment. We have added the closed bracket.
S-22	L139: "by power function (h=kxa)" Comment: by a power function of general form h=...	Thank you very much for your comment. We have revised the expression.
S-23	L161: "the" Comment: a	Thank you very much for your comment. We have revised "the" to "a".
S-24	L166: "due to the governing equations od DRM is ordinary" Comment:either ... due to the governing equations of DRM being an ordinary... or due to the fact that the governing equations of DRM is an ordinary...	Thank you very much for your comment. We have revised the expression.
S-25	L167: "which governed" Comment:which is governed	Thank you very much for your comment. We have added the "is".
S-26	L183: "i.e., 1#, 2#, 3#, 4#, and 5# fluctuation" Comment:identified as ... in Fig.5 there's no need to use "i.e." nor to repeat "fluctuation"	Thank you very much for your comment. We have revised the expression as: identified as $1^{\#}$, $2^{\#}$, $3^{\#}$, $4^{\#}$, and $5^{\#}$ in Fig. 5a and $6^{\#}$, $7^{\#}$, $8^{\#}$, $9^{\#}$, and $10^{\#}$ in Fig. 5b.
S-	L201: "Fig. 7. Time-dependent	We are very sorry, as our laboratory has just been

27	discharge calculated by DRM and DW model." Comment:It would be nice to plot also the measured data	established and currently does not have a rainfall simulator and monitoring instruments, so we compared the calculation results of DRM with different commercial software, experimental results in the literature, and field monitoring results.
S-28	L202: "6.Discussions and Conclusions" Comment:There is actually no discussion here, this is just summing up the results. Also, it is too similar to the abstract.	Thank you very much for your comment. We rewrote the Discussions and Conclusions section. Please refer to our response to Comment No. G-3.