Response to Reviewer 2

Anonymous Referee #2

Received and published: 5 January 2021

This paper shows a review of urban flood models for inundation prediction. The structure was clearly organized and presented. But I expect the detailed model description and comparisons which can derive specific conclusions and provide informative insights for model users. This paper still needs to be largely modified in terms of model comparisons and English language.

Response: We appreciate the reviewer for the suggestions. As shown in Table 3, there are many representative urban flood models in research community, so we believe it is not feasible to describe these models individually one by one. However, we do classify these models into four categories based on the model structures and assumptions. As described in each sub-section of Section 3, the model conceptualization, governing equations and key features have been discussed type by type. Following the reviewer's suggestion, we have done further comparison between the four types of models in Section 4 and summarized the key comparative information and the pros and cons of each type of model in Table 4. Moreover, our manuscript has been proof-read by professional English native editor from Cambridge Editing Service, a proof document is shown below.

Order No. 944-13-26

Editor's Report

Thank you for the opportunity to edit your paper. It was a pleasure to review your work, which was engaging. I have focused on correcting the grammar and improving sentence structure throughout and have applied UK English conventions, as requested.

Please carefully read through my edits and in-text comments—which provide further detail and suggestions for improvements—before accepting or rejecting any changes. In addition, please review the table below for an assessment of your manuscript and an overview of key points that have been addressed.

I wish you the best of luck with your paper, and I look forward to working with you again soon.

Sincerely,

Kimberly S, PE

Summary	
Content	Your review of urban surface water modelling was presented clearly and logically.
Grammar and punctuation	Your grammar and punctuation were very good with the except of a few missed items.
Tone and register	The language was appropriate. I only had to make a few suggestions for more formal terms.
Style	There are quite a few long paragraphs and long sentences than can benefit from being split in two. Additionally, there were overused words, e.g. "widely", "reasonable", and "decades".
Format	There were no major issues with formatting. I ensured each heading stayed with the paragraph it preceded (i.e. "keep with next").

1.The introduction emphasized the importance of urban flooding and explained the reasons to choose this topic. I doubt that there was less emphasis on urban surface water flooding compares to fluvial and coastal flooding. Please specify this. How does urban flooding will increase in severity and frequency due to climate change in the future?

Response: Thanks for pointing this out. What we mean is that **historically** coastal and fluvial flooding has been paid more significant attention compared to pluvial flooding, e.g., we have found from literatures that a lot of flood models have been initially developed for the purpose of fluvial and coastal flood modelling more than 15 years ago, but less on urban surface water flooding. For example, the Pitt Review by Cabinet Office UK (2008) commented that during floods that affected the UK in the summer of 2007, two thirds of the damage in urban areas was caused by surface water flooding, for which *no models, forecasts, warnings or management strategies* existed. Since then, surface water flooding in urban areas due to intense rainfall has increasingly attracted attentions in recent decade.

Regarding the increasing in severity and frequency due to climate change in the future, we believe that a lot of scientific papers and reports (e.g., UNISDR, 2015; IPCC, 2013; Bernet et al., 2017; Barredo, 2009; Zhou et al., 2013; Moncoulon et al., 2016) have indicated that urban surface water flooding is expected to increase in severity and frequency in the future with urbanization, economic development, and more frequent extreme weather. For example, the United Nations (UN) recently reported that the world's urban population is projected to grow both in absolute terms, and as a fraction of a growing global population. As more people move to cities, they inevitably turn green areas into impervious areas, increasing urban surface runoff. And as more people and properties in urban areas, flood severity would be definitely increased. Synthesis Report: Climate Change 2014 by IPCC also reported that "*extreme precipitation events will become more intense and frequent in many regions*" and "*recent detection of increasing trends in extreme precipitation and discharges in some catchments implies greater risks of flooding on a regional scale*". The increasing of frequency arises from the possibility for climate change to lead to more extreme rainfall, which is the main reason leading to the urban surface flooding.

United Nations Department of Economic and Social Affairs/Population Division, 2012. World Urbanization Prospects: The 2011 Revision. New York: United Nations.
IPCC Fifth Assessment Report (AR5)(Cambridge Univ. Press, 2014)

We have specified this in the introduction of the revised manuscript.

2. every figure and table need to be explained in details in the text.

Response: Following the reviewer's suggestion, we have provided detailed description to each figure and table in the revised manuscript text (please see the tracked changes).

3. It is suggested to explain the physics behind the model clearly. In the section 3, please explain the equations clearly.

Response: Following the reviewer's suggestion, we have discussed more on the model equations and the physics behind the model. Please see the tracked changes in page 7&8 of the revised manuscript.

4. it is not suggested to use words like 'some' and 'very' and in the text.

Response: Following the reviewer's suggestion, we have revised the text.

5. please explain horizontal coupling and vertical coupling (in Figure5) in the text. Figure 6 is not clear. What does green area mean in Figure 6?

Response: For figure 5 and 6, the more detailed information is described as below,

The horizontal coupling means components exchanging between the 2D surface cell and the drainage cell in horizontal direction. And vertical coupling means the discharge redistribution in the drainage cell, to calculate surcharge from the urban surface into the drainage or backflow from the pipe.

The green area in the Figure 6 is the boundary area, where bidirectional components exchanging between hydraulic and hydrological areas is allowed to update the calculation.

6. Line310: CA models can produce reliable results..... but the authors commented that CA approaches ..... still need to be further verified in line 315.

Response: Based on the published paper, the analysis of the numerical cases showed that CA models can be valuable tools for flood simulation. However, as an emerging method, there is only limited literature and most of the tests are ideal cases. Besides, it showed less accuracy in reproducing two-dimensional flow dynamics in respect to a model based on the full shallow water equations. CA models, with high computational performance and acceptable compromise in accuracy, are more suitable for large domains or a significantly large number of simulations. When only few simulations are performed, they are not the most suitable choice (Dottori & Todini, 2011; Guidolin et al., 2016). So, in this concern, we stated that CA approach still needs to be further verified in 1D and 2D practical applications.

Reference
Dottori, F., Todini, E., (2011). Developments of a flood inundation model based on the cellular automata approach: testing different methods to improve model performance. Physics and Chemistry of the Earth. Parts A/B/C 36 (7-8), 266-280.
Guidolin, M., Chen, A., Ghimire, B., Keedwell, E., Djordjevic, S., & Savic, D. (2016). A weighted cellular automata 2D inundation model for rapid flood analysis. Environmental Modelling and Software, 84, 378-394.

7. The future challenges of these models needs to be discussed thoroughly.

Response: The future challenges section has been re-organized as below. This has been updated in the revised manuscript.

5.1 Refinement of SWEs-based models

In view of the current advances of urban flood models, there are still deficiencies in improving model reliability and efficiency. Urban areas have many complex underlying surface characteristics, and in reality, when the capacity of drainage networks is insufficient, the pipe flow will over-charge to the ground surface. At present, simulation methods of the exchange of pipe flows and surface waters are only focused on local-scale modelling. Some existing numerical models often directly use empirical formulas or simplified methods that are still lacking in stability and accuracy. Therefore, mechanisms between pipe flow and surface water and their modelling approaches would help simulate drainage flooding in urban areas. This could be accomplished by integrating drainage network models with overland flow routing models as some studies have done, but further refinement is needed. Moreover, the question of which model conceptualisation is more appropriate for urban surface water flooding is still unanswered and in need of further investigation with the support of high-quality data.

The spatial heterogeneity of urban catchments is typically more profound, and surface water depths are generally shallower. Both pose numerical challenges in solving SWEs over frictional and extreme, irregular terrain. Although the application of parallel computing technology to improve the computational efficiency of the model has become a trend, efficient urban flood simulation and even real-time flood prediction with better resolutions are still difficult to achieve. In the light of the high computational costs for large-scale modelling at high-resolution, more accurate and faster model algorithms are urgently needed. This is critical for achieving a city-scale urban flood prediction in real-time.

5.2 Data-driven approaches

With the continuous improvement of remote sensing technology, the data become more readily available. A data-rich environment also encourages model calibration, validation and assimilation. In practical terms, the accuracy of terrain data obtained from modern LiDAR system has met the requirements for surface flow simulation, but it is necessary to fuse such dataset with digital map data of buildings and land use to realize the maximum development and utilization of contained information. Furthermore, these terrain data are readily available, and topographical data with a grid scale of roughly 30 m at best hardly meets accuracy requirements for urban flood models.

Model calibration is an essential way to reduce uncertainty over model parameters, but to this day, such data has been scarce for urban areas. Despite the frequency of urban floods, field observations during urban flooding are rarely available for model calibration and validation. Calibration data will be the key factor constraining the future development of urban flood inundation models. Some effective methods or tools are therefore urgently needed to infer from these limited data sources, extending the quantity and range of typically available calibration-validation data. Development of physical urban flood models is an option to gather benchmark data for urban flood modelling as some researchers have done (e.g., Rubinato et al., 2017). Nowadays, the application of social media for both collection and dissemination of flood information is increasingly recognised and thus provide an important basis for flood inundation estimation (Fohringer et al., 2015; Smith et al., 2017). The flood related information provided by general public through social media such as Twitter or Weibo, is also effective and valuable calibration-validation data source as an addition to the hardly available traditional monitoring data. Besides, studies (e.g., Joanne et al., 2018; Matteo et al., 2019) have verified that the combination of data assimilation and numerical model is used operationally to improve model performance and reduce uncertainties in flood prediction. Matteo et al. (2019) assimilated field data into the flood model and the prediction result was improved up to 90%. Among the relevant literatures, this method is mostly applied to fluvial flood with the support of satellite-based data or field water level measurements but rarely applied to urban pluvial flood. Moreover, as it is recognised that current two-dimensional (2D) hydrodynamic models are still computationally demanding and challenging for real-time applications at large-scale, recent innovative modelling exploration has focused on machine learning approach, e.g., a deep convolutional neural network (CNN) method has been developed by Kabir et al., (2020). Such an approach is presented for rapid prediction of fluvial flood inundation. However, a good model training still requires good quality inundation data and/or robust hydrodynamic model. Application of machine learning approach in urban flood modelling is promising but still very challenging.

5.3 Inter-model and interdisciplinary approaches

Inter-model and interdisciplinary approaches can help to develop the strengths of the various approaches while avoiding shortcomings. Facing the knowledge gap among urban flood risk management, innovative use of computer-based visualization and Virtual Reality (VR) technology has been shown to encourage greater engagement amongst diverse participants. A combined simulation-visualization platform can become an important shared learning tool and there are good prospects for developing an interactive model through the use of computer-based visualisation and virtual reality technology (Wang et al., 2019; Zhi et al., 2020; Yang et al., 2021). The innovation will be helpful for practitioners to communicate and perceive an extreme flood event. With the help of interactive 3D visualization tools, the extent of inundation and other features such as water depth and floodwater velocity can be better viewed and understood. A combined simulation-visualization approach can enhance decision support by incorporating 2D inundation modelling and 3D data visualization. Besides, as mentioned in the previous part, multi-source data such as social media, remote sensing provides an excellent source of model calibration-validation data during and after flood events. Its application may be further enhanced when coupled with accelerated real-time urban flood modelling. In other words, the combination between social media data and efficient simulation model provides a strong support to

build a real-time surface water flood warning system. Astute combination of models is promising and successfully developed and applied in the future.