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Interactive comment on "A simple 2-D inundation model for incorporating flood damage in urban drainage planning" *by* A. Pathirana et al.

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We would like to thank the reviewers for their comments. The issues raised by both the reviewers are addressed below:

1 Review #2

1.1 General Comments

The issue related with practical applications of the model (simplicity, simulation speed, and accuracy in an acceptable limit) and the need for comparison with existing models. The authors do not demonstrate clearly what is original or new in their approach.

In urban storm drainage planning, there is a large polarization of models in terms of complexity and precision. On one extreme there are simple 1-D model and on the other there are sophisticated 1-D/2-D models that sacrifice speed/simplicity to precision. The simplicities are based on flow approximation (1D and 2D) and the choice of flood flow equations (kinematic, diffusion or dynamic wave). There is not much middle ground!

Our model development is based on 2D equation with a unique flood flow representation which lays between diffusion and full dynamic wave model and strong simplification of the model is made on the process representation. A new approach is used to represent wetting-drying process by applying a depth factored Manning's coefficient for a sudden drying wet cells. A simple processes representation for topographic barrier using threshold water depth value for elevated cells is also implemented in the model.

Moreover, a simplified numerical solving mechanism, alternating direction implicit (ADI) finite difference method is applied to solve the flood flow equations. This method provides greater superiority due to high computational efficiency which requires less computing time (because it involves only a tridiagonal matrix) compared to implicit methods. Thus, the simplifications and numerical solving mechanism unique and beneficiary features that reduce the time required to simulate flood flows over large urban area.

In the case of fluvial flooding, the computational load of the implicit solutions are justified due to the possible offsetting by longer time steps. However, in case of small scale urban flooding (the subject of this paper), the modeller needs information at relatively finer time-resolution (due to the swift nature of urban floods), therefore explicit approaches could often be more beneficial. Inspite of the postfix 'implicit' the ADI method behaves largely as an explicit method (due to implicit formulation in 1-D in 2-D flood plain) and provide all the said advantages of the explicit approach. Of course this comes with the usual drawback of explicit approach as wel, namely the limitation of time-step size imposed by a CFL condition.

1.2 Specific comments

1. *As explained above, the title and abstract do not correctly reflect the subject of the paper, since relevance for practical application in urban drainage planning is not demonstrated:*

   We differ with the reviewer that the title reflects the subject however the content of the abstract will be modified in the manuscript. In planning of urban drainage a simple and fast prediction of flood within an acceptable level of error is much more useful and can lead to better understanding of the flood damage and we believe that sacrificing some of the precision for accessibility for a wider audience (in terms of simplicity, speed) can indeed improve current situation of under-employing inundation modelling in urban drainage planning among practitioners, particularly in the developing world. The damage calculation block integrated in the model also helps flood control authorities to make a decision on flood damages control measures as a decision support system.

2. *There is no need to elaborate on equations and derivations if they can be found in the literature; it seems that citing of a proper reference would be sufficient, e.g. for the first 10 equations:*

   We accept the need to shorten the number of equations and will be done. However, as stated above, the simplifications made to the shallow water equation here are non-standard (in between the standard dynamic wave and diffusion wave

models) and therefore warrants some explanation. It is not possible to refer to standard literature here.

3. *There seems to be an error in formulas 12 and 13 and following formulas that are derived from these: Sx and Sy should be multiplied by δ_t:*

   We agree with the reviewer that the factor δ_t is missed from Sx and Sy. The following formulae do not need modification as δ_t is included in Sx and Sy.

4. *The way model coupling is implemented is explained only briefly: it seems coupling works only one way, from 1D to 2D model; what about the influence of water levels above manholes on the 1D flow and what about nodes that receive water from both overflowing manhole and upstream node; how does the model handle this?*

   Even though, both direction interactions between sewer flow and 2D inundation models is realistic to simulate the interaction, in our opinion, the implementing the back-flow into sewer system the effect of overland flow over sewer flow is less important than the need for simple flood prediction model for urban areas. Thus a simplified transfer approach, transferring mass from the sewer model to the inundation model, is used to couple the models. Particularly for urban flood damage estimation work, where the prime concern is the maximum flood depth (not the duration as in the case, for example agricultural land). In swift urban floods, the maximum flood height is not heavily influenced by the ability of sewer network to receive return flow.

5. *Mass conservation is only checked globally and mass balance errors are in the order of several percentages; the authors should discuss how these errors influence the model results and if achieved accuracy is sufficient for practical application, under what conditions?*

   The presence of mass-balance errors in flood flow is a well-known problem in non-conservative numerical schemes (as opposed to conservative methods like

Finite Volume approach. The process representations and simplifications that made on the numerical equation to avoid frequent insatiability of the model may cause small inaccuracy in mass balance but often the uncertainties over the specification of topography and boundary roughness are dominant and thus influence the model results to a greater extent than those incurred through simplification of the mathematics. The mass balance error is cheeked at different instants of simulations and the model result shows small inaccuracy in mass balance error (0 to 4 percent) for different conditions. It is a fact that inaccuracies associated with mass balance error are inevitable, but shown to be reduced using small time steps and grid size. However, our objective here was to arrive at a compromise where the model is swift in simulation, while keeping mass balance errors below an acceptable limit. In planning of urban drainage a simple and fast prediction of flood within an acceptable level of error is useful and can lead to better understanding of the flood damage in the flooded area. Therefore, the developed 1D–2D coupled model is particularly suitable for problems where efficient flood prediction is needed (e.g. optimization problems).

6. *In paragraph 5.2 the authors state that the model performs well on an irregular topography; they should motivate this statement by referring to model results and make clear how results are evaluated?*

   The model performance is checked on hypothetical irregular topographies. For problems involving large flow barriers, the flood wave diffusion is visually inspected (shown in Fig.7) and the model works properly The mass balance error is checked for complex topographies (see Fig 6.) and shown to be less than 4 percent. In addition to the global mass balance, close attention is paid for the behavior of flood wave near barriers and other sudden changes of topography (e.g. falls, walls) and hydraulics (e.g. wetting/drying). The result shows that the model performs well on irregular and complex topographies and frequent wetting and drying. The possible frequent numerical instabilities are avoided by the simplified

flood flow representations discussed in section 2.4 and 2.5.

   We agree with the reviewers that this need to be discussed clearly in the paper and will be added to the final version.

7. *A flood damage curve is introduced, but the results are not presented. In paragraph 5.2 the authors refer to some text file that contains monetary values, but the file is not presented in the paper. As such, the value of the developed model for practical application remains unclear.*

   The description about text file was just to inform readers about the outputs that the model produce. A modification of this part will be made on the final draft.

   The monetary value of the damage associated with flooding is one of the fundamental pieces of information upon which expenditure decisions are based. A simple damage-calculation block which is integrated within the 1D-2D coupled model help decision makers to have a good perception about the flood and its damage and identify the effective mitigation measures through flood risk assessment. For case study (part of the city Porto Algere, Brazil), the damage curve which is developed in 2002 was used and the extent of flood and monetary value of the flood damage is presented in section 5.2. (And the practical applicability of the model is discussed in the last paragraph of our response)

1.3 Other comments:

We agree with other comments (figure numbering, captions, language, etc) and will edit the manuscript accordingly.

2 Review #3

2.1 For flood simulation

For simulating urban floods, the major factors are topographic characteristics, the share rate of building, rainfall pattern, and pumping capacity. But the results of rainfall runoff analysis, flood routing analysis in the sewage pipe, and the modified equations included building influence per each cell, etc are not explained in the paper anymore and only the calculated results of inundation in the city is shown. As the authors show the basic equations of shallow water surface in the paper, readers should not understand how boundary condition (Fig. 10) and water interaction between sewer system and overland flow (Fig. 2) has been decided.

In this study, the simulations are done by the developed 1D-2D coupled model. 1D SWIMM is the one which perform hydrologic simulation at catchment level and the hydraulic routing of the drainage network (dynamic wave). The 2D inundation model perform the overland flood routing when the drainage system overflows. The estimation of monetary value of associated food damage is performed by the damage analysis block integrated in the coupled model, using the maximum flood depth records produced by the inundation mode.

In the case of Porto Algere simulation, the overflow occurs at a number of manholes as shown in Fig. 14. The design rainfall for the study area and the flood hydrograph in some of the manholes is also shown in Fig. 13. However, we agree with the reviewer about the importance of detail explanation about the drainage system simulation results and will be added in the final manuscript.

Regarding the coupling, it is more realistic to consider the bi-directional mass flow. See section 4 for justification for one-way coupling (sewer-to-surface) in this model.

The question on share-rate of buildings, lead us to believe that a better explanation

of the process of data preparation for the case study in Brazil is needed. We started with standard SRTM elevation data as the primary DEM source. However, we also digitized google-earth image of the area (which shows buildings and roads clearly) and superimposed the buildings and roads on the DEM (buildings as flow barriers, roads as having a slightly lower elevation than the surrounding topography. Therefore the buildings and roads are explicitly considered in the 2-D flow space. This will be explained in the final manuscript.

Addition of buildings and roads to the elevation model introduced some sharp changes in topography which could lead to instabilities in the model. However, the techniques explained in the section below were adequate to avoid the problems.

2.2 For flood damage

The flood damage curve based on stage-damage curve in inundated area. The curve(Fig. 12) is not common, but local. The damage contents and its possession rate may be different in each region. Finally, the conclusions are general, the readers may fail to find what is new and clear.

We agree with the reviewer comment on the damage curve. Stage-damage functions are essential components of flood damage estimation, which relate flood damage to flood inundation parameters and are different for different classes of objects and areas. In most cities the central agencies have a great deal of data and long experience in making damage estimates but no comprehensive guides are available at the local level. In the cases study we used the damage curve (residential) which is developed for specific area (will be mentioned in the final draft).

Generally, the developed model integrates 1D sewer flow model, 2D inundation model and damage calculation block. The 2D flow equation formulation between diffusion and full dynamic wave, simplifications on flood flow process representations (wetting-drying, flood barriers etc), and simple numerical solving mechanism (as discussed in the response to the general comment by Reviewer #2) are the beneficiary and unique features of the model to represent the realistic flood flows and simulate a large urban area with reduced simulation time.

In planning of urban drainage a simple and fast prediction of flood is useful and can lead to better understanding of the flood damage in the flooded area. In addition planning of urban drainage should couple with an optimization tool to determine optimal mitigation measures and intervention timings. However, Most optimization problems demand large number of simulations and are done based on the volumetric staged flooding (as overflow from sewers), with out considering the inundation effects explicitly. This highlights the possibility of using inundation models in optimization work if they are sufficiently fast. Since this model is fast while the errors are within acceptable limits, it is a good candidate.

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