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Comparing Hydrology and Hydraulics Surface Routing Approaches in Modeling an Urban Catchment

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Abstract. Urban hydrological environment is difficult to assess with its complex verity of components by using simple hydrological models which are not fully capable enough to represents the exact urban catchment's features. The urban catchments comprising with various infrastructures having low permeability and low roughness coefficients have increased their runoff volume, while decreasing the time of concentration. This has been caused urban flooding threatening the urban environments in many aspects. This study uses two of numerical modeling approaches to represent the urban catchment, and assess the flood risk of an urban catchment; hydrological surface routing approach and hydraulic 2D surface routing approach. Both approaches were combined with 1D hydraulic stormwater drainage network. XPSWMM was used as the modeling tool. Comparison of results of two approaches shows that the both approaches are suitable to represent urban catchment's hydrological behavior, but the results of hydrological surface routing are more close to observation data. When representing the flood inundation areas, it is better to use the hydraulic approach since it calculates the flood depth by using surface runoff and excess water from pipe network at the same time.

Keywords: Stormwater, Flooding, Hydrological modelling, Urban environment

1. Introduction

The urbanization process throughout the world is inevitable with the increasing population and the resource scarcity, which makes the competition to those resources. The modern problems, which are arisen with the dense populations in the urban cities increasingly, affect to the surrounding environments, and one such a major vulnerable element of the environment is the urban hydrology. With the urbanization, the infrastructure, housing facilities and many other necessary man made features will be added to the cities, while reducing the natural environments of the areas. These features of modern cities are included with roads and their features, buildings and car parks and paved landscaping, which reduce the impervious area of the land, and help to increase the surface runoff. Also the rate of runoff is increased by these urban features providing less surface roughness values. Urban drainage systems inclusive of underground drains, manmade channels, manholes and gutters increase the rate of runoff through the drainage (Selvalingam et al., 1987), which demands the comparatively large scaled stormwater management systems, and tends to flood the urban area, where there is no such facilities are provided. Again with the removal of vegetation the evapo-transpiration is reduced, and leads to stormwater to be retained in the surface for more time.

The increased runoff in the urban environment may cause the urban flooding which affects to day-to-day activities, properties and even human lives. The recent flooding in Australia caused to loss of properties worth billions of dollars. Again the inundation of urban areas after flooding may extends to few days by inadequate water management system, and can be caused to economical losses and temporarily breaking down the life style of the people by stopping the day-to-day activities.

The flood prevention by conducting careful analysis of the urban hydrological cycle and supporting adequate stormwater management drainage considering the results of analysis is important to safeguard the

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quality of life within the urban environments. One way of analyzing the urban hydrological cycle is by creating a numerical model, which represents the features of the hydrological cycle in a computer model. Urban catchment modelling is significantly complex to analyses with numerical models than rural catchments, because the modelling demands the consideration of urban features like fences, highly varying land-use, buildings and other structures, narrow flow paths and underground storm water drainage (Syme et al., 2004).

In this study, pipe drainage network is modelled and surface runoff was combined to the drainage system through the manholes. In most of the previous studies, the urban catchments were represented by giving modelling parameters like infiltration, surface roughness based on the impervious and pervious percentages. Then the surface routing was done by usual hydrological methods, which analyse the urban catchment as separate catchments according to given impervious and pervious conditions. The hydrological approach presented here is based on this concept. The catchment used for the study has divided to small sub-catchments, and the flow from each sub-catchment is routed to the pipe network through the adjacent manholes. The obstructions to the runoff and the runoff from and to impervious to pervious are not well represented in this method. For the flood inundation mapping the excess water from manholes is input to the 2D network. Then the inundation water depth is represented relative to the given topography. Meanwhile some of the studies including Mignot et al., 2006, Fewtrell et al., 2010 and Phillips et al., 2005 have presented the urban features in 2D network considering the features like road network and its components, open cannels, detention basins and other water management structures, making the numerical model more similar to the physical urban hydrological cycle as much as possible. Manholes in the 1D network are linked to the 2D network to carry the water through the drainage system. This method has been used in hydraulics approach in this study. Absent of the fine topographical data to generate exact digital terrain model can be caused this approach to be not accurate as anticipated. Also the results can be varied with the time steps and grid sizes used. The flood inundation depth is simulated at the same time at surface flow is routed and the excess water from manholes flows back to 2D network.

2. The study area

The study area, Avenues catchment is in Canning Vale, which is a rapidly urbanizing area in Western Australia, situated about 25 km south to Perth. The Avenues is bounded by Ranford Road to southwest, Campbell Road to southeast, Dumbarton Road to northeast and Washington terrace to northwest, with the total size of 36 hectares. It is basically with flat grades of 1:2000 approximately (Wagner, 2009). The land-use varies from industrial and residential to water logged swales, while about 75% of the catchment is residential and having lots with low permeable paved surface covering about 75% of a lot by building roofs and paved access ways. Some of the roofs were directly connected to the road’s stormwater network while others were not yet being connected. The average annual maximum ground water level in the catchment is within 0.5 – 0.7 m from surface, which is preventing the possibility of infiltration of runoff to the sub soil even in small rainfall event.

The Avenues is having a digitized drainage system with GIS mapping. Underground pipe network connected to the surface level through manholes is directly conveys the storm water to the major basin called Avenue basin. From the basin there is an outlet which carries excess water to the northeast of the catchment. Also there is a computerized data monitoring device fixed at basin's outlet to measure the flow data, basin water depth, rainfall and ground water level which were used to define boundary conditions and to calibrate the model. The aerial photo showing the land-use, with exact coordinates and the 1m contour data is available to the area.

3. Modelling Approach

The Avenues catchment was modelled using two approaches with a major difference of method used for the surface flow routing. The drainage network consisting of pipes and manholes was modelled as consequent 1D links and nodes network in hydraulics layer, which is common to both approaches. As the hydraulic analytical engine, EXTRAN was used for the 1D flow simulation (XP Software, 2009). The major basin was modelled as a reservoir. The outflow boundary condition for the model was given as a fixed back water effect to match the existing tail water conditions. The Initial water depths for the manholes and reservoir were assigned from the observation data. Finally the 2D hydraulics layer was used to generate the flood maps for the critical scenario in both approaches. Manholes were given the boundary condition as connected to the 2D network, so the excess water from manholes can flow in to the 2D network and again fill back to the manholes from the 2D network, when the pipe network have the capacity.

3.1. Hydrological approach

In this approach surface runoff was modelled in the hydrology layer and the sub-catchments were assigned to the appropriate manholes, which are modelled linking with the stormwater pipe network. Then the Laurenson method (Laurenson, 1964), integrated in the software was used for the surface runoff routing. Land-use types were calculated as percentages of the total sub-catchment areas, and given as separate sub-catchments for the appropriate nodes. Infiltration values for the different land-use types were assigned as initial and continuous losses. Manning's roughness values for the surfaces were also assigned according to the land-use categories. Water from the surface runoff, after entering to the manholes is then routed through the pipe network in hydraulic layer. The excess water can flow to the 2D network and represent the flooding areas in the 2D terrain. This water can flow back to the manholes when the pipe network has enough capacity to fill back with excess water. The 2D hydraulic layer uses only to show flooding due to the overflow from manholes. Infiltration values were given as zero for the 2D land-uses to prevent the double counting of the infiltration losses. Only the surface roughness values were given to 2D layer.

3.2. Hydraulic approach

Here the surface runoff was modelled in the hydraulic layer using the XPSWMM 2D option. 6m x 6m grid size was used for the terrain. The digital terrain model was created using the available LIDAR data. The coarseness of the available contour map was reduced to some extend manually by entering the elevation values for the road network, filled areas and ponds. The basin was modelled in the 2D network as a low elevated filling area, rather than a reservoir in the 1D hydraulic layer. The land-use types were defined according to the aerial map and values were assigned with infiltration capacities and roughness coefficients. Rainfall was given in to the 2D network, and the surface water routing was carried out by the 2D engine. The shallow water equation was used by the analytical engine to route the surface water simulation. Same as hydrological approach the water from 2D network link with the 1D network through the manholes. The excess water is represent as flooding as same as hydrological approach. Moreover in this approach the depth of surface-routed water also considered in the flood representation and also in the calculations.

4. Results and Discussions

4.1. Calibration and verification

Calibration of the two approaches was carried out by using the observation data for the water depth of the Avenues basin for a 3 days rainfall event on 14th to 17th June 2010. The outflow backwater condition was one of the major parameter affect to the outflow from the catchment, hence the water depth of the basin. The outfall backwater depth was given from the observation data, and length of the outflow pipe was considered to the length of the main drainage line, while neglecting the inputs to it. This has reduced the effect of change of tail-water conditions to the model calibration parameters. The calibrated models' results are shown in the Figure 1. It shows both approaches are capable in representing the hydrological behaviour of the catchment. Hydrological approach is more accurate than hydraulic method. The comparison was further analysed by Figure 2. It confirms hydrological approach is more accurate, having $R^2 = 0.855$, whereas R^2 for hydraulics approach is 0.5136.

Verification was done for another independent rainfall on 9th to 12th July 2010 and results are shown in Figure 3. The results show the both approaches are appropriate to assess the urban hydrology. The modelled water levels of Avenues basin for both models have similar effect from fixed tail-water conditions, which is varying in the actual case.

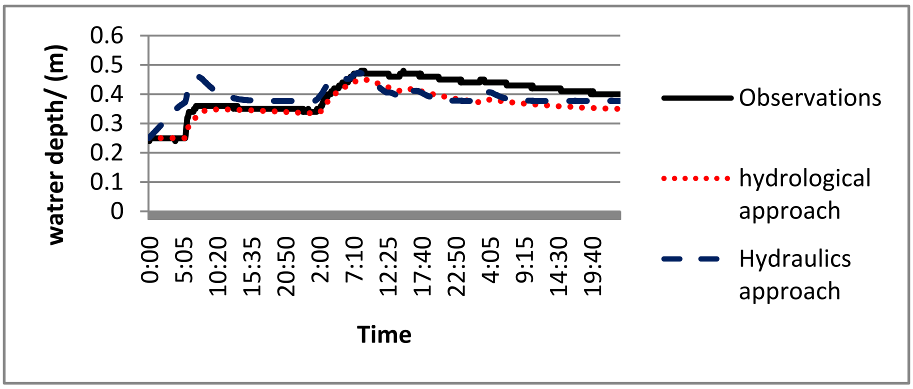

Fig. 1: Calibration of hydrological and Hydraulics models (using the rainfall event 14th to 17th June 2010)

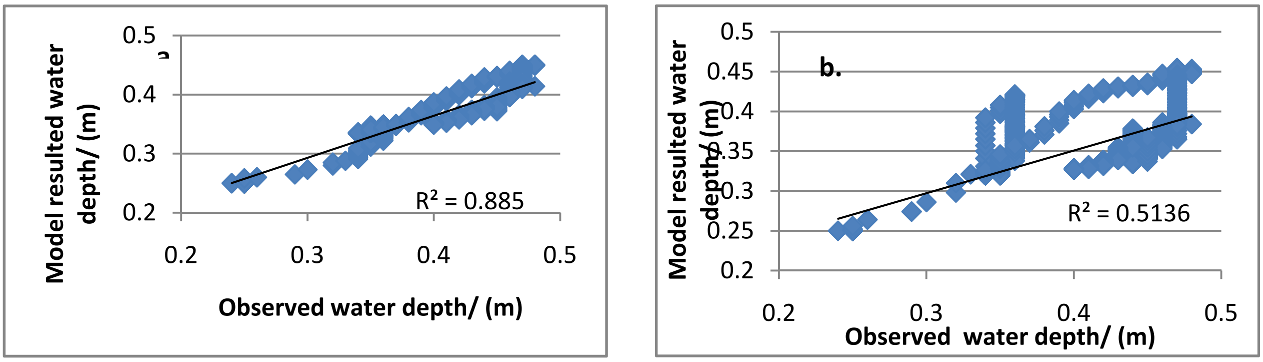

Fig. 2: Model results against observation data: a. Hydrological approach and b. Hydraulics approach

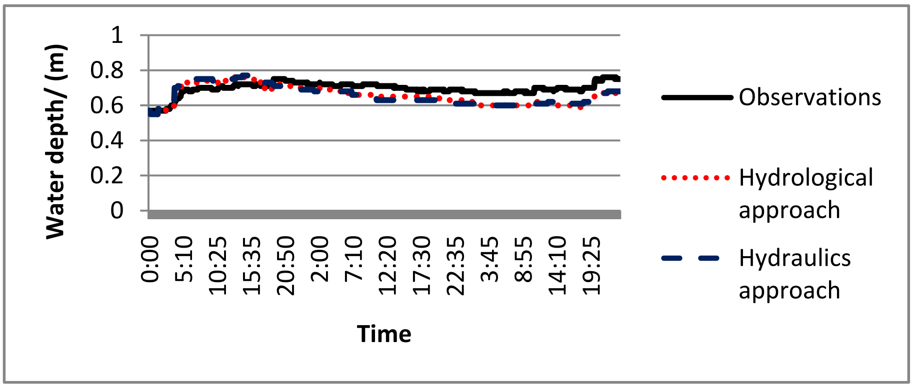

Fig. 3: Verification of hydrological and Hydraulics models. (Using the rainfall event 9th to 12th July 2010)

4.2. Flood Mapping

The 1 in 100 year average recurrent interval flood event was modelled for the two approaches. The historical rainfall data were obtained from the intensity - frequency - duration curves (Pilgrim, 1987). The results are showing in the flood map (Figure 4) shows the vulnerable area for 0.10 m to 0.78 m flood depths. The flood water heights showing above 0.782 m for some clusters, and these are the errors occurred due to the coarseness of the topographical data. The water depth of the basin is showing as 0.283 m due to the initial water levels given. It proves both approaches indicate almost same flood inundation areas and depths. But the hydraulic approach is more suitable since it counts water from surface runoff and excess water from manholes at the same time, when simulating the flood depths. In the method used in the hydrological approach the surface water is routed to the manholes first, and then the excess water from manholes enters to the 2D network. This process has a lag time, and the surface runoff which is routing through the hydrological layer will not simulate to calculate the flood depths until they flow back from manholes. But overall flood depth representation is adequate, and further enhancement can be done by using the topographical contours with the contour gap of about 0.2 m (XP Software, 2009).

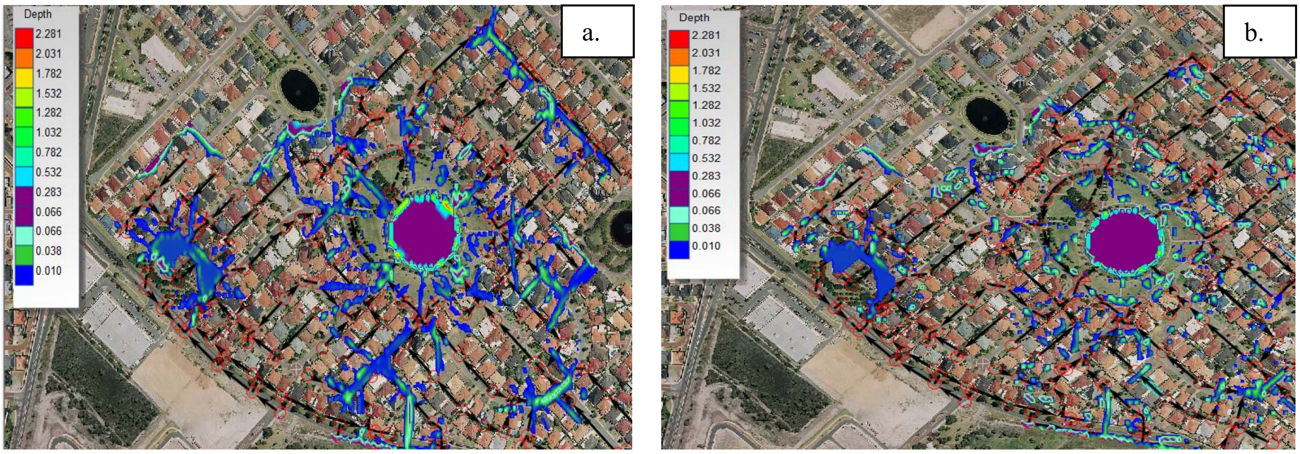

Fig. 4: Flood inundation mapping for 1 in 100 year flood event: a. Hydrologic approach and b. Hydraulics approach.

5. Conclusion

The study used two approaches, hydrological approach and hydraulic approach to simulate the flood inundation of an urban catchment. The comparison was made on both approaches for their capability of represent urban catchment more accurately. It is identified that the both approaches are capable of represent the complex urban hydrological catchment together with 1D drainage network, but the coarseness of the topographical data might reduce the accuracy of the hydraulic approach. The results shows that the hydrological approach is more accurate with the observation data having the $R^2 = 0.855$, whereas the hydraulic approach gives the results of $R^2 = 0.5136$ in the calibration process. Considering the flood inundation representation, the both approaches show similar results for the inundated areas and flood depths. The results of the study are very useful for the local authorities in land development decision making and development of flood management strategies.

6. Acknowledgement

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