FLOOD MODELING AND MITIGATION MEASURES IN AN URBAN ENVIRONMENT – A CASE STUDY, VICTORIA, AUSTRALIA

Dr Ashis Dey[1] and Sudesh Mudaliar[1]

[1]*XP Software, 8-10 Purdue Street, Belconnen, ACT 2616 <ashis.dey@xpsoftware.com>*

ABSTRACT

Accurate prediction of flood extents in urban catchments is extremely difficult without having a 1d/2d integrated modeling approach. The integrated flood modeling is becoming popular and a new benchmark for urban flood risk management studies.

City of Glen Eira in Victoria, Australia is a developed metropolitan municipality. The council is responsible for the management of 535km of drains servicing roads, properties and parks. Most of the drains were built before 1960, at a time when there were less development densities, less runoff, and less stringent drainage capacity standards. Since 1990 council has recorded a large number of drainage and flooding complaints. Despite its vulnerability to frequent flooding, only some limited flood studies and mapping have been undertaken for the whole of the municipality since 1996.

Recently the council has undertaken an extensive flood study project to delineate the flood extents for minor (10yr) and major (100yr) events. Traditional modeling approach is unable to interpret the complicities in flow behaviour, especially in urban areas. 1d/2d integrated modeling of whole catchments has been done to get an accurate prediction of complex behaviour of overland flow pattern and flood extent in developed urban catchments. The 2d model was set up using LiDAR data with accuracy of +/- 0.1m on hard surfaces. This project area consisted of a network of underground pipes, drainage pits, and road culverts. Capacity deficiencies of the existing drains system and extent of flood risk areas have been identified from modeling results. Both structural and non-structural measures have been suggested as feasible flood mitigation activities.

Keywords: *1d/2d Modeling, Flood simulation, Urban drainage, Storm water management*

INTRODUCTION

Flooding on urban basins is intensifying due to rapid urbanization. Flooding primarily occurs because of drainage congestion of inland flow and/or over bank flow of river during severe rainfall event. Rapid urbanization is causing a major change in rainfall-runoff phenomenon and the drainage system as well. The overland flow pattern is becoming complex due to huge structural development, and therefore, the correct prediction of surface runoff is becoming a challenging issue. Traditional storm water modeling approach, mainly for 1d pipe-network, is able to simulate the drainage system correctly until there is no overflow from the network inlet. When such overflows exist due to insufficient drainage capacity, then it is difficult to produce the actual flooding condition using this traditional one-phase simulation technique [1, 2]. Alternatively, by giving some extra efforts the two-phase modeling (duel drainage) technique can be employed where the street-network is simulated as open channel to drain the water overflowed from the storm water pipe-network, and a better representation of flooding scenario can be obtained, if the flood extents do not expand beyond the streets. However, unfortunately for the larger events (100yr and PMF) in most cases the flood extents expand to private properties, where the duel drainage approach is unable to produce correct flooding scenario. Therefore, the 1d/2d integrated flood simulation model, which is capable to incorporate all the drainage elements (flow paths) and their interactions properly, is necessary for an accurate prediction of urban flooding. This paper demonstrates the 1d/2d integrated modeling approach in urban catchment. XP-SWMM2D mathematical modeling software [3], which is one of the most widely used models designed to simulate urban storm water runoff, has been used to perform a simultaneous and integrated simulation of all drainage element along with the 2d overland flood modeling in order to get a correct delineation of the flood extents for minor (10yr) and major (100yr) events.

BACKGROUND & OBJECTIVE

City of Glen Eira is about 15km South East of Melbourne CBD in Victoria, Australia. The study area was composed of nine drainage catchment areas which are shown in Figure 1. The total drainage area covers approximately 3870ha and is served by a complicated looped drainage network that includes open channels and closed conduits. Glen Eira city council is responsible for the management of 535km of drains servicing roads, properties and parks while Melbourne Water is responsible for managing 54km of the larger main drains servicing the local council drains.

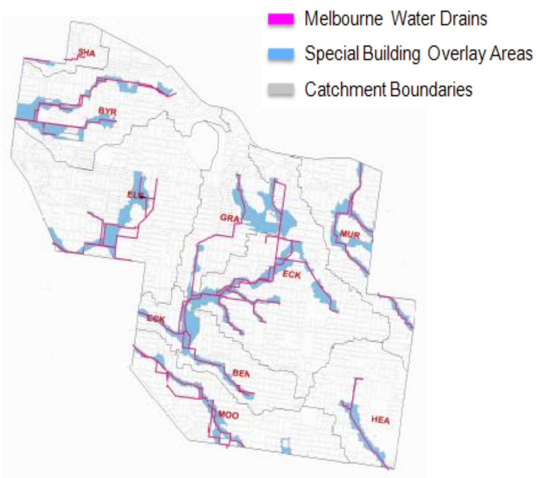

Figure 1 Study area

In last 20 years the basin experienced several severe flooding with a maximum flood depth more than 1m when heavy rainfall occurred over the catchments (Figure 2). Resident experienced knee-deep water on the streets. The most common flooding type in Glen Eira is “flash flooding”. This occurs when runoff from a storm is greater than the capacity of the existing storm water drainage system. Other types of flooding like riverine and/or tidal flooding are not issues for this catchment. There is no river in Glen Eira and the nearest port Phillip does not have any impact on our drainage network. The dominant soil type in the study area is silt/sand, which usually have high infiltration capacity (Figure 3).

Figure 2 Flooding of a suburban street

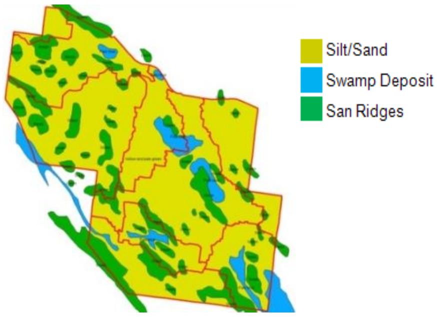

Figure 3 Soil types in study area

A consequence of flash flooding is that it is very difficult for a council to develop or implement an advance warning system to its residents or community. Flash flooding in Glen Eira usually only lasts for a short period of time. Because flash flooding occurs so quickly, it is important that each and every property owner is aware of the likely risk to their property and what they can do to reduce its impact [4]. Community awareness and education are seen as key elements of any solution. Glen Eira is a developed municipality. Nearly all of the development occurred before the mid 1960’s, and hence flooding controls and overland flow paths were not given as much attention as is the case in modern subdivisions. Melbourne Water analyzed its drainage network within Glen Eira in the late 1990s. They identified the areas of land that would be flooded by a large (100yr) storm event and created Special Building Overlay (SBO) maps (Figure 1). Approximately one in seven properties in Glen Eira is within the SBO. The total number of properties that will experience flooding in a major storm is likely to be larger than this. Councils should be able to provide more information to community than the drainage authorities is able to give. The community also needs to know (i) information about the likely depth of flooding, (ii) which properties are affected by smaller and more frequent storms, and (iii) which properties are at risk of flooding from council’s drainage network. The distinction between Melbourne Water’s responsibilities, as a regional drainage and floodplain authority, and those of council is also not as clear as it could be. The objective of this study was to do an accurate flood modeling for the whole of council’s drainage basin in order to:

- Quantify the extent of potential flood risk within the nine drainage catchment areas of Glen Eira; enabling the council to assess possible land use and development overlay controls, and to provide guidelines on controls on development in these areas.

- Identify deficiencies in the council drainage system, based on the councils' existing design guidelines and drainage system objectives for the performance of the drainage system.
- Estimate the drainage upgrade works, and rate works as high, low or medium priority, based on risk, option cost, and effectiveness in mitigating flooding risks; enabling the council to develop a detailed improvement plan and commit resources to its implementation.
- Investigate the possibility of introducing retarding basins as an alternative to upgrading pipe network.
- Assisting the council to develop performance indicators that measure the effectiveness of flood risk management treatments in lowering flooding exposure.

MODEL SETUP & SIMULATION

Detailed integrated hydrodynamic model for the existing topographic and drainage configuration of the basin has been set up in XPSWMM2D based on the relevant structural, topographical, hydrological and demographic information. The data was either available in a directly usable format, or it has been digitized from the maps and subsequently processed into appropriate format. The 2d surface model (5x5m) was set up using LiDAR data with accuracy of +/- 0.1m on hard surfaces. The storm water network of the study area is quite complicated. The looped- and branched-network includes a wide range of closed pipes, some culverts and open channels. There are so many detailed elements (pipe & nodes) at most upstream of the storm water network. The pipes less than 225mm diameter are generally ignored to make the model less complicated and to avoid the numerical instability.

Time-Area hydrological routing approach (inbuilt in XP-SWMM2D) has been adapted. The time of concentration (5 to 25min) was one of the key input parameters needed to be estimated for all subcatchments. Horton infiltration parameters have been set up to build up the loss model for whole catchment, which applied only on pervious subareas. The percentage impervious varies for each subcatchment depending on land use patterns such as: (i) car parks & paved area – 100%, (ii) road reserve – 75-90%, (iii) fully developed area – 75%, (iv) partial developed area – 50-60%, (v) park & grass land – 1-5%. Other losses such as depression storage storages have also considered as appropriate. The models have been set up for 10yr and 100yr AR&R. All storm durations from 10min to 1hr have been analyzed to find the critical storm which creates worst flooding situation. Hydrological model generates hydrographs for selected subcatchment outlet (pit). These hydrographs then route through pipe and/or open channel networks (sub-surface system). All open channels and pipes have been simulated through 1D link-node concept in Hydraulic layer. Dynamic wave flow routing approach (default in XP-SWMM2D) has been adapted to ensure the correct routing through the complicated drainage network.

To ensure the accurate flood prediction and to get simultaneous realistic interaction between subsurface- and surface-system it has been decided that the overland (flood) flow should be simulated through 2d mesh-system. The inflow from surface- to subsurface-system has been controlled by a system of virtual structures (weir or orifice) set at the ground level. The overflow from subsurface- to surface-system happens when the node water level exceeds ground elevation and the downstream pipe or open channel capacity is not enough to drain all upstream flows.

Application of the present integrated simulation technique to produce the flood situation of Glen Eira drainage basin has been under the load of AR&R 10yr and 100yr design rainfall. All outlets of entire drainage system drained water into main drains of Melbourne water – the downstream boundary condition has been set accordingly. Melbourne Water's SBO gives the flood extent only along the main drain, whereas present models able to produce a detailed flood maps for entire basin including local flooding. To match the simulated result with Melbourne water's SBO, the model has been properly calibrated for the surface roughness of different land use patterns and for the parameters of virtual structures (weir or orifice) used in 1d/2d interface. The buildings in 2d domain are modelled with higher roughness to get effect of obstruction in overland flow path.

RESULT AND DISCUSSION

The overall water balance of simulation was quite satisfactory (< 1%). The 10yr and 100yr design rainfall events over 3870ha catchment cause ground flooding due to drainage congestion. Figure 4 shows the maximum flood extent obtained from the simulation of the integrated model, where the flooding along the main drains as well as local flooding is clearly visible. The simulated time series flooding levels also have been traced for several selected location to get an idea on nature of flooding. Table 1 gives a list of under capacity drainage element and properties subject to major (100yr) and minor (10yr) flooding.

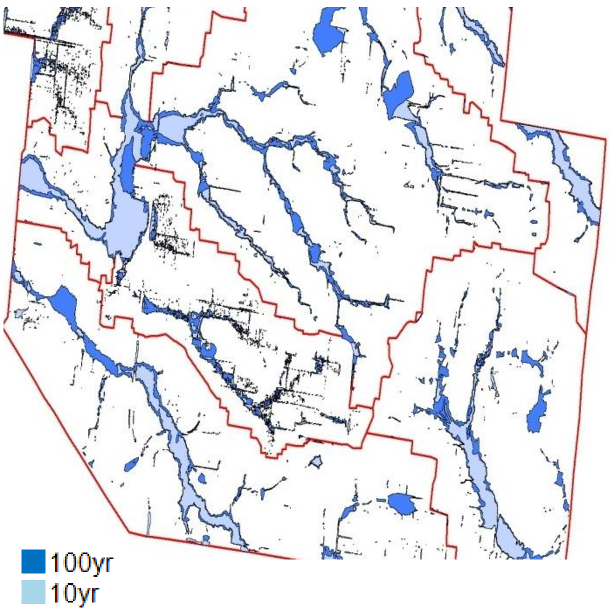

Figure 4 Flood extents (100yr flood extent has been superimposed on 10yr extent)

Catchment	Total area (ha)	Total pipe length (km)	Pipes under capacity (km)		Flooded area (depth >0.1m) (ha)		Properties flooded (depth >0.1m) (nos)		Major flooding (depth>0.3m) (ha)		Properties flooded (depth>0.3m) (nos)	
			10yr	100yr	10yr	100yr	10yr	100yr	10yr	100yr	10yr	100yr
BEN	225	38.2	4.7	5.9	17.1	36.3	876	1459	10.5	18.1	249	384
BYR	528	76.7	14.2	17.3	20.6	53.4	1027	1725	2.7	8.8	110	267
ECK	832	130.0	14.5	17.8	39.5	97.6	1188	2419	18.5	31.1	178	449
ELS	776	118.2	26.9	31.2	38.3	97.6	3238	6176	5.7	21.6	445	988
GRA	340	49.4	3.1	7.3	18.1	35.3	448	762	3.4	7.2	139	234
HEA	332	45.3	10.5	12.3	19.7	40.1	342	751	5.0	15.3	75	172
MOO	416	64.9	5.9	7.7	19.4	41.9	573	1156	1.6	13.6	75	353
MUR	345	54.0	14.1	17.6	35.9	55.3	850	1305	19.8	37.5	469	774
SHA	76	11.2	2.5	3.0	2.4	7.2	265	512	0.3	0.8	15	55
Totals	3870	587.8	96.4	120.1	209.6	463.4	8807	16265	55.1	140.7	1542	3676

Table 1 Under capacity pipes and flooded areas for 10yr & 100yr flood events (existing conditions)

CONCLUSION

An integrated 1d/2d modeling approach has been applied on Glen Eira basin to produce flood maps of 10yr and 100yr AR&R design rainfall events. Virtual structures (weir or orifice) which substitute the inlet gratings of pipe-system have been used as interface module to exchange the flow between 1d and 2d models. Both 10yr and 100yr design rainfall events over 3870ha catchment cause ground flooding due to drainage congestion. The present study ensures that the integrated modeling approach is the best option for a realistic and authentic reproduction of urban flood extents and therefore, the integrated modeling approach is highly recommended for any urban flood simulation. Finally, based on outcomes of the integrated modeling both structural and non-structural measures have been suggested as feasible flood mitigation activities.

ACKNOWLEDGEMENT

Authors gratefully acknowledge the help of Glen Eira City Council during data preparation and model setup. Authors thank Melbourne Water for providing few relevant documents during this study.

REFERENCE

[1] Dey, Ashis K.: An Integrated Flood Simulation Model (PCKK-SWMM)". *In-house research Report, Pacific Consultants Co. Ltd.*, Tokyo, Japan (2004).

[2] Dey, Ashis K., Kamioka, S.: An Integrated Modeling Approach to Predict Flooding on Urban Basin, *Water Science and Technology*, IWA, Vol. 55, No 4, pp. 19-29 (2007).

[3] XP Software Inc.: *XP-SWMM users' manual* (2009).

[4] Melbourne Water: *Flood Management and Drainage Strategy* (2009).