

1D and 2D Modelling of Urban Drainage Systems using XP-SWMM and TUFLOW

B.C. Phillips^{1*}, S.Yu², G.R. Thompson³ and N. de Silva⁴

¹ Director, Cardno Willing (NSW) Pty. Ltd.,

Level 3, 910 Pacific Highway, Gordon NSW 2072, Australia

² Senior Hydro-Environmental Engineer, Cardno Willing (NSW) Pty. Ltd.,

Level 3, 910 Pacific Highway, Gordon NSW 2072, Australia

³ Director, XP Software Pty. Ltd., PO Box 3064, Belconnen ACT 2617, Australia

⁴ Senior Engineer - Catchment Management, Fairfield City Council

PO Box 21, Fairfield NSW 1860

*Corresponding author, e-mail: bphillips@cardno.com.au

ABSTRACT

The release of a revised NSW Floodplain Management Manual in 2001 established a new direction for urban flood management in NSW. This new direction was created by a redefinition of the floodplain as the area bounded by the PMF – this poses a challenge to estimate PMF flooding in highly urban areas and particularly in piped drainage areas; and the removal of the distinction between “mainstream flooding” and “local flooding” – this poses challenges in defining and mapping flood risk areas in residential areas inundated by the PMF. At the same time the increasing collection of aerial laser scanning (ALS) across whole local government areas (LGAs) is providing detailed survey levels capable of supporting 2D terrain and hydrodynamic modelling and detailed floodplain mapping.

This new direction and the increasing availability of ALS have ramifications for urban flood studies. The trend in NSW and elsewhere has been for the growing adoption of 2D models as the new benchmark for urban flood studies.

As part of the on-going development of the XP-SWMM modeling system to enhance its functionality and its capability to model urban drainage systems the TUFLOW 2D hydrodynamic model is being incorporated as a layer into an XP-SWMM2D package.

Two case studies that demonstrate the new 1D/2D modeling capability of TUFLOW and XP-SWMM2D are described. The first case study is of a reach of Prospect Creek in the City of Fairfield. A 2D and a combined 1D/2D models of the floodplain were assembled and run. A comparison of 1D, 1D/2D and 2D results is given. The second case study is of a local drainage subcatchment that demonstrates the interaction between the piped drainage system and 2D surface overland flows.

It is concluded that the 2D hydrodynamic modeling layer in the XP-SWMM package offers users new opportunities to undertake more detailed investigations of urban drainage systems and of urban waterways and floodplains. It also demonstrates the on-going evolution of the XP-SWMM package in response to the changing needs of stormwater managers.

KEYWORDS

1D/2D flood modelling, Drainage, Flood studies, Overland flow, Urban flooding

INTRODUCTION

The release of a revised NSW Floodplain Management Manual in 2001 established a new direction for urban flood management in NSW. This new direction was created by:

- (i) A redefinition of the floodplain as the area bounded by the PMF – this poses a challenge to estimate PMF flooding in highly urban areas and particularly in piped drainage areas;
- (ii) Removal of the distinction between “mainstream flooding” and “local flooding” – this poses challenges in defining and mapping flood risk areas in residential areas inundated by the PMF;

At the same time the increasing collection of aerial laser scanning (ALS) across whole local government areas (LGAs) is providing detailed survey levels capable of supporting 2D terrain and hydrodynamic modelling and detailed floodplain mapping.

This new direction and the increasing availability of ALS have ramifications for modelling systems used to characterize flooding in urban areas. The trend in NSW and elsewhere has been for the growing adoption of 2D models as the new benchmark for flooding investigations.

However a number of challenges exist when attempting to apply 2D modelling systems to local drainage systems. These include being able to:

- interface the hydraulic model with a hydrological model and digitally input hydrographs at many locations from subcatchments that may be each only 1-2 ha in area;
- model the interaction between pipe drainage systems (with their associated inlets, pit losses, etc) with overland flow paths particularly where the two do not coincide; and
- start with dry overland flow paths that wet as the capacity of the piped drainage system is exceeded and then dries as the runoff recedes.

As part of the on-going development of the XP-SWMM modeling system to enhance its capability to model urban drainage systems the TUFLOW 2D “engine” is being incorporated into the XP-SWMM package as a new 2D hydrodynamic layer. It interfaces with the other layers in XP-SWMM to facilitate the modelling of the interaction of storm conveyed by conduits with 2D overland flows. This new capability offers opportunities to model:

- (i) Urban watercourses and floodplains in 2D; and/or
- (ii) Urban watercourses and floodplains using a combination of 1D (watercourse) and 2D (floodplain) elements; and/or
- (iii) Urban drainage systems using a combination of 1D (piped drainage) and 2D (overland flow) elements.

Each of these cases is demonstrated in the following two case studies.

PROSPECT CREEK, GREYSTANES

In mid-2000 Fairfield City Council (Council) commissioned a review of flood levels in Prospect Creek (Cardno Willing, 2004). From mid-2001 to mid-2003 the approach to modelling of the Prospect Creek floodplain was a single XP-SWMM floodplain model that was 1D in upper Prospect Creek and quasi 2D in lower Prospect Creek.

In mid-2003 Council commissioned aerial laser scanning of the Fairfield LGA. An initial comparison of typical cross sections in the XP-SWMM 1D floodplain model with sections extracted from Council's digital aerial survey disclosed differences of up to 1.0 m between the cross sections. Council therefore commissioned the creation of a new 1D/2D model for the Prospect Creek floodplain extending from the confluence of the Georges River upstream to upstream of Widemere Road. The new 1D/2D TUFLOW (WBM Oceanics, 2003) floodplain model was calibrated to observed 2001 flood levels and was then used to estimate the design flood levels and velocities (Phillips et al, 2005).

The first case study is based on the Widemere Road reach of Prospect Creek. It draws on the outcomes of the previous 1D floodplain modelling using XP-SWMM and 1D/2D modelling using TUFLOW (Cardno Willing, 2004). The 1D XP-SWMM floodplain model was based on cross sections obtained from previous 1D models and additional survey supplied by Council. The model was calibrated and verified against major 1986 and 1988 floods and recalibrated against the January 2001 flood. The 1D/2D TUFLOW model was based on a 10 m x 10 m grid spacing with the Prospect Creek watercourse and all crossings modeled using embedded 1D elements. Crossings and basin outlets were modeled as conduits in combination with weirs. It was calibrated against the January 2001 flood.

For the purposes of this assessment two further models of the study area were created. The first was a 1D/2D floodplain model using XP-SWMM2D (XP Software, 2005) while the second model was a 2D model only using TUFLOW. The XP-SWMM2D model was based on a 10 m x 10 m grid spacing with the Prospect Creek watercourse and all crossings modeled using embedded 1D elements. The 2D TUFLOW model was based on a 10 m x 10 m grid.

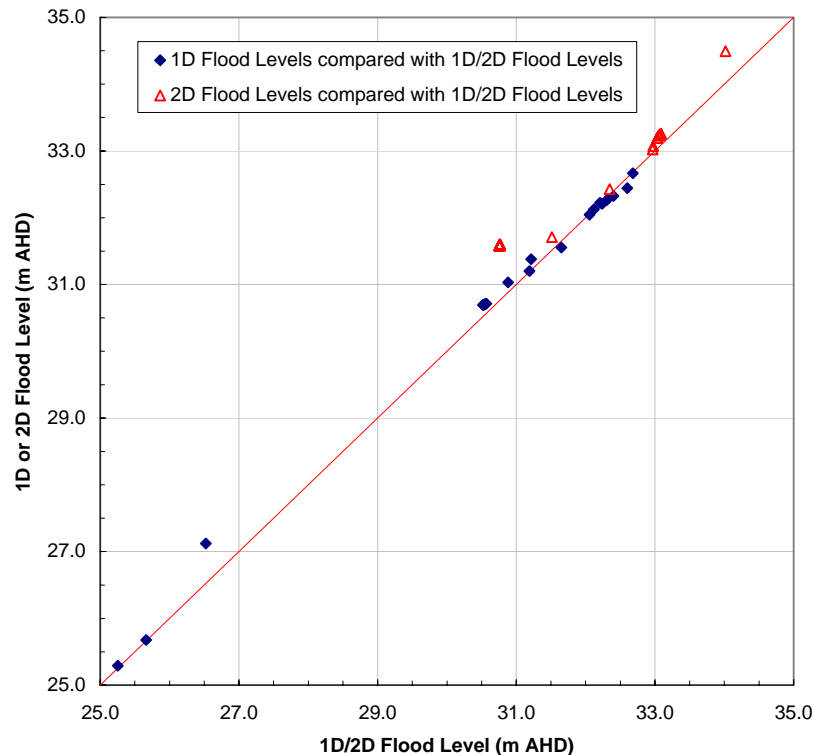


Figure 1 Comparison of Estimated 1D, 1D/2D and 2D Model 100 yr ARI Flood Levels in Widemere Road reach of Prospect Creek

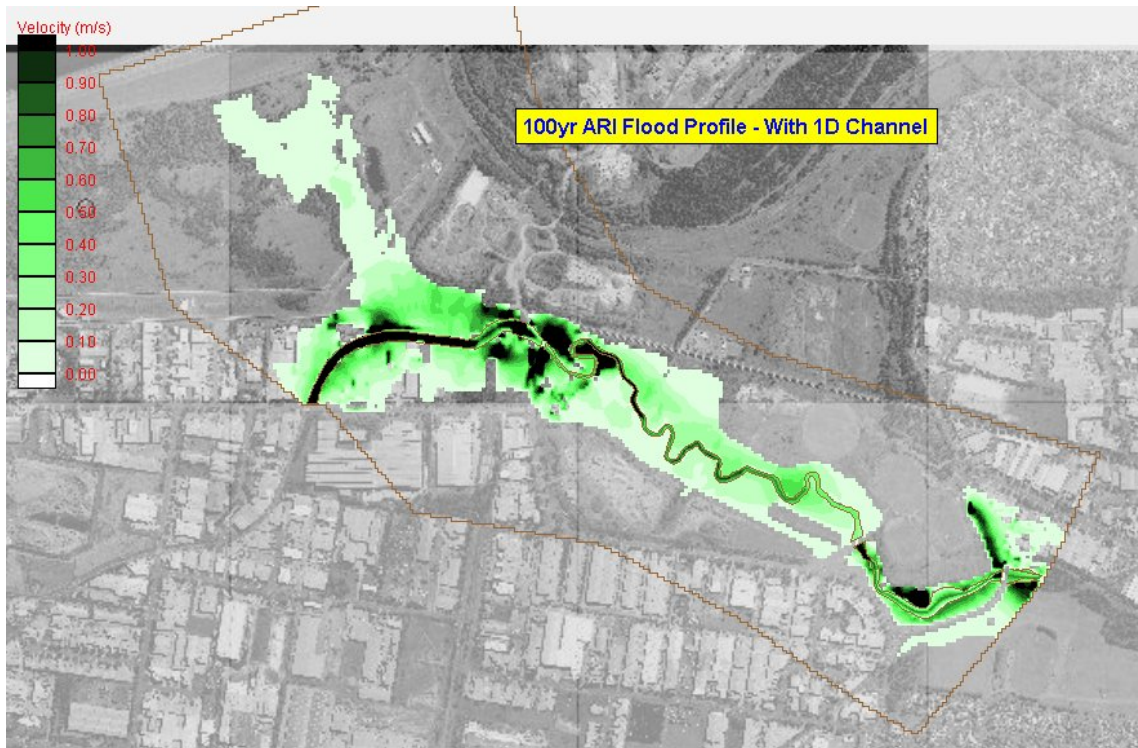


Figure 2 1D/2D Model Velocity Contours

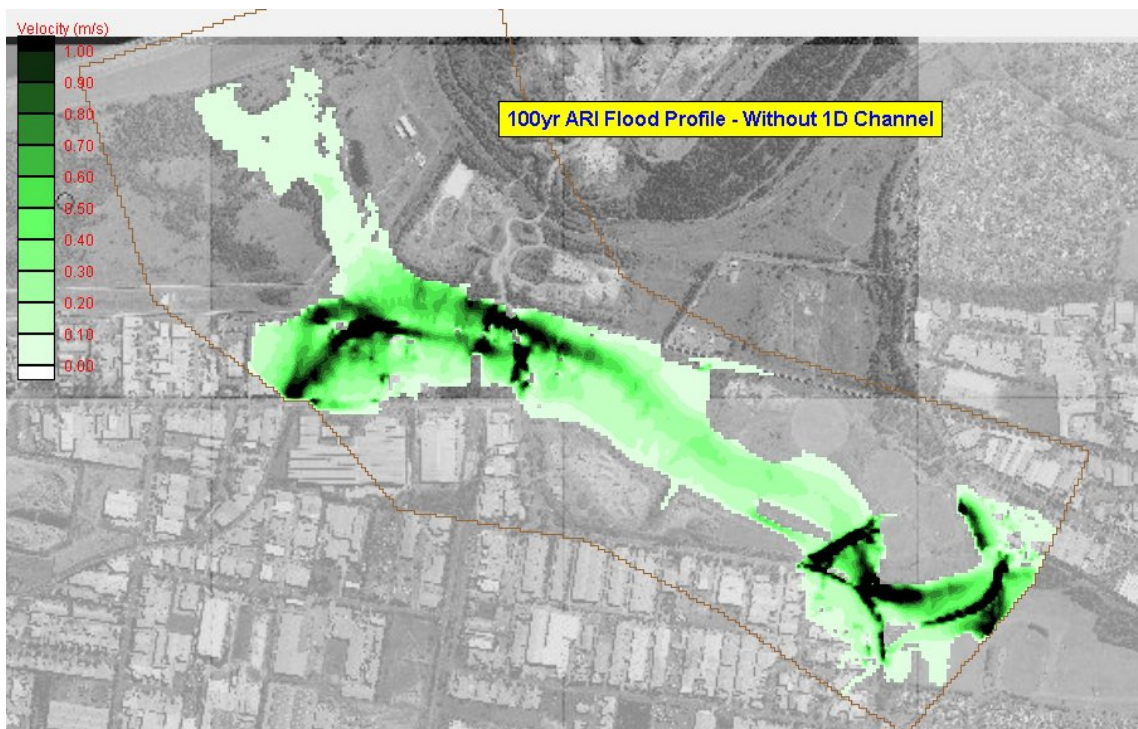


Figure 3 2D Model Velocity Contours

A comparison of the 100 yr ARI flood levels estimated in the Widemere Reach using the 1D XP-SWMM, XP-SWMM2D and 2D TUFLOW models is given in Figure 1.

The calculated velocity contours for the XP-SWMM2D and 2D TUFLOW models are given in Figures 2 and 3.

The results presented in Figure 1 indicate that the 1D and 1D/2D 100 yr ARI flood level estimates are in close agreement while the 2D 100 yr ARI flood level estimates were typically higher than the 1D/2D 100 yr ARI flood levels. This was attributed to loss of definition of channel sections (typically 6-10 m wide) in the 2D floodplain model. While this problem could be overcome by decreasing the grid spacing this approach would lead to an unmanageably large model for the overall Prospect Creek floodplain. It was concluded that these comparisons highlighted the advantages of being able to define narrow watercourses and crossings using 1D elements and to link these to a 2D floodplain.

CUMBERLAND HIGHWAY SUBCATCHMENT, CABRAMATTA

The second case study is of a local drainage subcatchment in the Orphan School Creek catchment that lies within the larger Prospect Creek catchment. The aim of assessment was to investigate the ability of the XP-SWMM2D and TUFLOW modelling systems to model the interaction between a complex local piped drainage system and surface overland flows.

The stormwater subcatchment that was selected covers a section of the Cabramatta to Canley Vale local drainage system. Fairfield City Council had previously assessed the adequacy of this local drainage system. This facilitated the provision of detailed information on the local drainage system. The subcatchment is bounded by Cabramatta Road to the south, Lord Street to the west, Gladstone Street to the east, and Derria Street to the north. The total area of the subcatchment is around 165 ha.

A dendritic stormwater piped drainage system already exists within the catchment (refer Figure 4). The main pipe drainage line is located along the Cumberland Highway before it branches north west crossing John Street, Hughes Street, McBurney Road and St. Johns Road, before discharging into Gladstone Street in the bottom end of the subcatchment. There are over 340 inlet pits in the subcatchment of which 336 pits were modeled. Drainage pipe sizes range from 0.3 m to 1.8m diameter. Details of inlet pit locations, inlet pit capacities, spill levels, pipe sizes, and pipe invert levels were supplied by Fairfield City Council.

In this assessment, each inlet has its own subcatchment. Over 300 subcatchments were defined and input into an XP-RAFTS rainfall runoff model. The catchment model was run to estimate 5 yr ARI design hydrographs. The estimated peak 5 yr ARI subcatchment outflow is around 40 m³/s.

The drainage system model comprised a 2D overland flow TUFLOW model and a 1D XP-SWMM pipe drainage model. They are coupled together to form a complete 2D-1D overland flow model. Local runoff hydrographs generated by XP-RAFTS were input into the TUFLOW layer where the overland flows were captured by inlets to the piped drainage system (as occurs in the field ie. runoff from rooves and other impervious surfaces are discharged into street gutters where these flows are captured by inlets).



Figure 4 Subcatchment Drainage System Layout

The 2D Digital Elevation Model (DEM) was generated using aerial laser scanning supplied by Fairfield City Council. A 4m by 4m grid size was adopted for the 2D DEM, giving over 100,000 elements in the 2D overland flow model.

A Manning roughness value of 0.015 was assigned to all the stormwater pipes, while roads and driveways were assigned a value of 0.02 and houses and lots (including single or double storey dwellings, front and back yards, sheds and fences) were assigned a roughness value of 0.15. Inlet and exit losses of 0.5 were adopted for the conduits in the 1D drainage conduits.

Two cases were modelled. The first was the 5 yr ARI storm with all inlets to the piped drainage system blocked. This equates to the assumption that has been adopted in a number of previous overland flow studies where it was considered that the capacity of the drainage system is modest in comparison with the estimated overland flows. The second was the 5 yr ARI storm with all inlets to the piped drainage system unblocked. It should be noted that the drainage acceptance criterion for local piped drainage systems is a 5 yr ARI capacity.

The inundation and overland flow patterns that resulted from these two cases are presented in Figures 5 and 6.

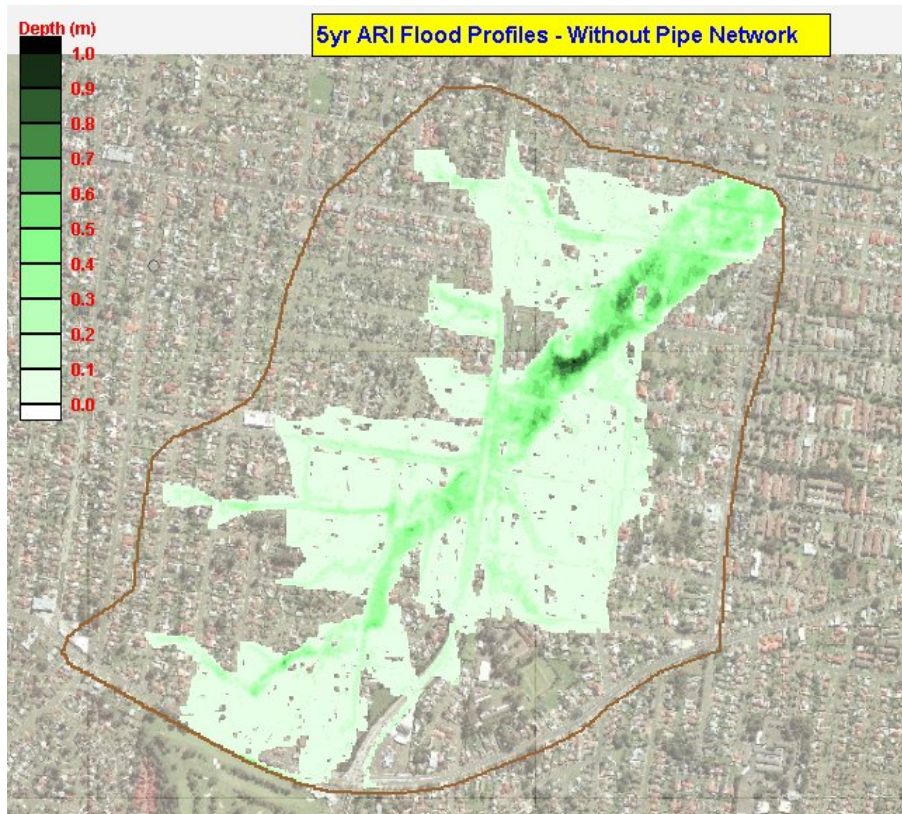


Figure 5 Estimated 5 yr ARI Overland Flows with all Inlets Blocked

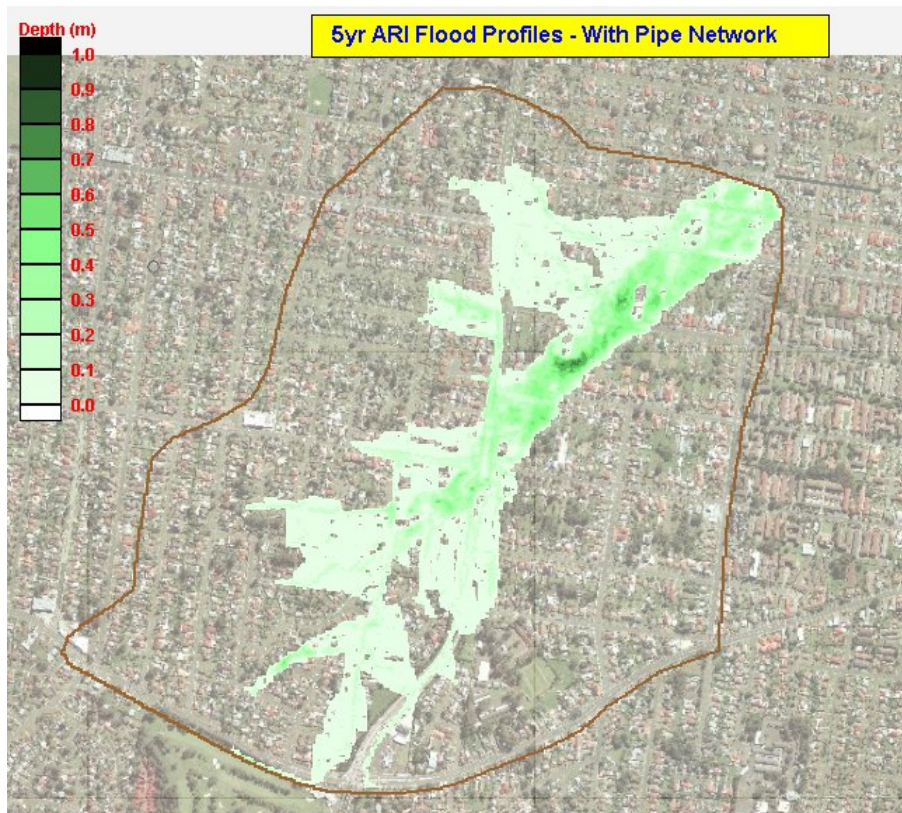


Figure 6 Estimated 5 yr ARI Overland Flows with all Inlets Unblocked

Features of the results presented in Figures 5 and 6 include the:

- presentation of areas of inundation and of overland flows in a form that is readily understood by the community in comparison with results of previous overland flow studies where overland flows are presented diagrammatically as arrows with nominal shaded areas to indicate overland flow paths with little indication of the potential extent of inundation;
- extensive inundation of properties in a 5 yr ARI event albeit with large areas subject to inundation of less than 100 mm;
- additional areas that would be inundated if inlets to the drainage system were substantially or completely blocked (highlighting the need for regular maintenance of drainage pits to ensure their functioning in storm events)
- conclusion that even if the all drainage inlets are fully unblocked that that the piped drainage system does not have a 5 yr ARI capacity and that substantial inundation of sections of the major Cumberland Highway and of residential properties would occur in only a 5 yr ARI storm.

CONCLUSIONS

It is concluded that the increasing consideration of extreme flooding in urban areas and the growing availability of aerial laser scanning of urban catchments is leading to the growing adoption of 2-D models as the new benchmark for urban flood studies in NSW and elsewhere.

It is concluded that the modelling packages like XP-SWMM2D and TUFLOW offer users new opportunities to undertake more detailed investigations of urban drainage systems and of urban waterways and floodplains. It also demonstrates the on-going evolution of the XP-SWMM package in response to the changing needs of stormwater managers.

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