Modelling Overland Flows and Drainage Augmentations in Dubbo

by

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ABSTRACT

Dubbo has experienced a number of overland flooding problems at several locations within the city. Council had formulated possible augmentation works to address the problems and was keen to confirm that the proposed works would address the local flooding problems. The drainage system in Dubbo faces a number of challenges due to the relatively flat grades on stormwater drainage lines and the possibility that overland flows from a local drainage catchment may flow into an adjacent catchment via the road system. It has also been found that minor works like a roundabout can also initiate flooding of local properties.

Council had previously commenced the assembly of XP-SWMM model(s) of some of its drainage systems. Council also had available Aerial Laser Scanning (ALS) of the city.

In view of the sensitivity of overland flows to modest changes in intersection geometries and the problematic issue of the magnitude and direction of overland flows at many intersections in the city an XP-SWMM2D model of subcatchments 102, 103, 104, 105 and Boltje Street was assembled comprising the existing drainage piped system and 2D description of the roads based on available ALS data. The advantages of this modelling approach including the possibility of including roundabouts and other modifications of kerb-lines in the model and to assess the impacts on overland flows are discussed.

The modelling of the interaction of Council's piped drainage system and overland (road) flows is overviewed and the assessment of Council's proposed augmentation works is discussed.

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 was also concluded that:

- the combined 1-D/2-D modelling capabilities in the XP-SWMM2D package offers Dubbo City Council and others new opportunities to undertake more detailed investigations of urban drainage systems and of overland flows;
- the modelling completed to date has highlighted the interconnection of local drainage subcatchments and confirms observed overland flow problems in several areas in Dubbo;
- the assessments have highlighted the value of ALS data.

Keywords: Drainage, Overland Flow, 1-D/2-D modelling, Urban flooding

1. INTRODUCTION

Dubbo is a city of 38,000 people located 400 km north-west of Sydney. The City Council administers both the urban centre of Dubbo and a surrounding rural area in excess of 3,300 square kilometres. The city is bisected by the Macquarie River, one of the major tributaries of the Murray/Darling Drainage Basin.

The City of Dubbo lies within a transition zone between the ranges and tablelands of the Great Dividing Range to the east and the Darling Basin plains to the west. The topographical characteristics of the Dubbo include (Willing & Partners, 2000):

- Broad (up to 4 km wide) alluvial flood plains of the Macquarie and Talbragar Rivers;
- Extremely gentle grades across valley floors (around 1(v):100(H)), into which the rivers themselves are incised between steep (1(v):5(H)) banks up to 10 - 15m high; and
- Valley sides generally of 1(V):20(H) to 1(V):50(H) slope, with localised steepening associated with resident geology;

Dubbo also lies in the transition between the southern winter rainfall area and the northern summer rainfall area. It is also the transition area between the tablelands and the plains. The effect of this is that rainfall is distributed fairly evenly throughout the year. Dubbo has an average annual rainfall of 587 mm (based on records from 1870 to 1996). Pan evaporation averages 1,560 mm per year and whilst this varies slightly year to year because of differing wind and cloud cover conditions, average evaporation constantly exceeds average annual rainfall by almost 3:1.

1.1 Mainstream Flooding

Dubbo City Council (DCC) prepared a floodplain management plan (FPMP) which was adopted by Council in 1993. This FPMP (and its supporting Floodplain Management Study prepared by PPK, 1991a, b, 1992) was largely based on a Flood Study (DWR, 1988) that only considered flooding from the Macquarie River and did not explicitly consider the interaction between the Macquarie and Talbragar Rivers. Since the adoption of the FPMP, DCC has undertaken a number of other studies to investigate flooding in the vicinity of Dubbo (Rust PPK, 1995, PPK Environment & Infrastructure, 1996, 1999).

1.2 Local Drainage and Flooding

The Dubbo stormwater drainage network presently discharges at over 40 different locations. Twenty of these are into the Macquarie River itself and the remainder into three creeks which are tributaries of the Macquarie River. The connected stormwater drainage network includes 156 kilometres of conduits, 4,100 structures and 71 retarding basins, with a total replacement value of $118 million.

The oldest schemes located in Central Dubbo date back to 1873 and include brick arched structures to convey the stormwater flows draining to the Macquarie River.

Dubbo has experienced a number of overland flooding problems at several locations within the city. Council had formulated possible augmentation works to address the problems and was keen to confirm that the proposed works would address the local flooding problems.

The drainage system in Dubbo faces a number of challenges due to the relatively flat grades on stormwater drainage lines and the possibility that overland flows from one local drainage subcatchment may flow into an adjacent subcatchment via the road system. It has also been found that minor works like a roundabout can also exacerbate flooding of local properties.

Council had previously commenced the assembly of 1-D XP-SWMM model(s) of some of its drainage systems. Council also had available Aerial Laser Scanning (ALS) of the city.

2. MODELLING OF LOCAL FLOODING AND OVERLAND FLOWS

2.1 1-D and 2-D Modelling Approaches

As discussed by Goyen and Phillips, 2003, the approach that has routinely been adopted for Council drainage and overland flow investigations has comprised:

- Creation of a model of all pits and pipes and overland flows (typically 200 – 3,000 pits at a time);
- Overland flows only are calculated and are hydrologically routed (ie. overland flows are lagged to the destination downstream node); and
- Hazard assessment is based on the consideration of flows in comparison with the safe carrying capacity of roads and/or overland flowpaths.

Models that are typically used include DRAINS, PCDRAINS, and XP-RATHGL.

In the past Council flooding investigations in NSW have been typically based on the assembly of hydraulic models of all major watercourses and open channels but not routinely for overland flow paths. The challenge posed by the 2005 NSW Floodplain Development Manual (NSW Government, 2005) is to hydraulically model overland flow paths as well.

Models that have been used for flooding investigations include:

- 1-D flood profile: HEC-RAS,
- 1-D flood routing: MIKE-11, XP-UDD/XP-SWMM, RUBICON (SOBEK)
- 2-D flood routing: TUFLOW, SOBEK, MIKE-21, SMS, RMA-2)

At the same time the increasing collection of aerial laser scanning (ALS) across whole local government areas (LGAs) including the City of Dubbo is providing detailed survey levels capable of supporting 2-D terrain and hydrodynamic modelling and detailed floodplain mapping. The increasing availability of ALS has ramifications for modelling systems used to characterize flooding in urban areas. The trend in NSW and elsewhere has been for the growing adoption of 2-D models as the new benchmark for flooding investigations.

However a number of challenges exist when attempting to apply 2-D 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 0.1-2 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 modelling system to enhance its capability to model urban drainage systems, the TUFLOW 2D “engine” has been incorporated into the XP-SWMM package as a new 2-D hydrodynamic layer. It interfaces with the other layers in XP-SWMM to facilitate the modelling of the interaction of storms conveyed by conduits with 2-D overland flows. This new capability offers opportunities to model:

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

Two recent case studies that demonstrate the new 1-D/2-D modelling capability of XP-SWMM2D (incorporating TUFLOW) are described by Phillips et al, 2005. The first case study was of a reach of Prospect Creek in the City of Fairfield. A 2-D model and a combined 1-D/2-D model of the floodplain were assembled and run. A comparison of 1-D, 1-D/2-D and 2-D results was given. The second case study was of a local drainage subcatchment that demonstrates the interaction between the piped drainage system and 2-D surface overland flows.

2.2 Modelling Overland Flows in Dubbo

There are a number of trade-offs when adopting a 1-D or a 2-D approach to the modelling of overland flows at subcatchment scales in urban areas including Dubbo. A characteristic of many streets in Dubbo is that there is significant cross falls from road centre-lines such that the road centre-lines can be higher than the ground level at property boundaries. This can give rise to a "quilted" terrain where the centre-lines of a rectilinear road network controls the spill of overland flows from one side of a road and/or an intersection to the other. If footpaths and properties are lower than the road centre-lines then they can be subject to inundation by overland flows that are ponded until they can either: enter the piped drainage system, flow around a corner or eventually overtop the road centre-line.

A 2-D model can account for the "quilted" terrain but may not fully represent all kerbs and gutters due to limitations on the smallest grid spacing that can be achieved for a large study area. Alternatively a 1-D model representation of the overland flowpaths would require 1-D links to be created for each side of the road centre-line with overflows across a road centre-line represented by a weir. At each intersection there would need to be four weirs to represent the possible overflows from one side of a road to the other side. This would give rise to a very complex 1-D model with each section of road being represented by two parallel links and a weir cross connection. A further challenge is representing a sloping road centre-line as a horizontal weir and deciding the appropriate length of the weir.

In view of the sensitivity of overland flows to modest changes in intersection geometries and the problematic issue of the magnitude and direction of overland flows at many intersections in the Dubbo, an XP-SWMM2D model of subcatchments 102, 104 and 105 comprising the existing drainage piped system (as partially described in Council’s existing model(s)) and 2-D description of the roads based on available ALS data. In December 2005, Dubbo City Council requested the assessment include two additional stormwater subcatchments, namely subcatchment 103 and the Bultje Street subcatchment (refer **Figure 1**).

Council has identified three hot spots where it proposes to implement drainage augmentation works to reduce overland flows preferably up to the 100 year ARI event. These hot spots include the intersections of:

(i) Fitzroy Street and Wingewarra Street,
(ii) Brisbane Street and Church Street, and
(iii) Talbragar Street and Carrington Avenue.

Council supplied concept drainage augmentation works at each location that were tested using the XP-SWMM2D model.

3. THE MODELLING APPROACH

The existing topographies of subcatchments 102, 103, 104, 105, and Bultje Street consist of roads, streets, lanes, pedestrian walkways, kerbs and gutters, roundabouts, carparks and residential, commercial and industrial developments. Each of the subcatchments is serviced by a piped drainage system. The sizes of stormwater pipe diameters vary from 200 mm to 1350 mm. A series of junction pits and inlet pits are also present in each drainage system.

The area of the local catchment draining to each inlet pit and its associated local catchment imperviousness was estimated by Council and input into XP-STORM models of subcatchments 102, 103, 104, 105 and Bultje Street created by Council. The overall area of the five modelled subcatchments is approximately 289 ha.

In accordance with previous assessments undertaken in Dubbo a “split subcatchment” modelling approach was adopted to separately estimate runoff from directly connected impervious areas and pervious subareas within each local catchment. This also allowed different rainfall losses to be applied to impervious and pervious areas respectively.

Based on a review of hydraulic conductivities for soils in Dubbo (including the Troy Gully catchment just north of the subcatchment 102) reported in the “Estimation of Soil properties using the Atlas of Australian Soils” prepared by CSIRO in 2000, the initial and continuous rainfall loss rates adopted for pervious surface were 35 mm and 10 mm/hr respectively. For impervious surfaces, the adopted initial and continuous runoff loss rates were respectively 1 mm and 0.05 mm/hr. The runoff routing method in the XP-SWMM2D model that was selected was the Laurenson (RAFTS) routing method.

The supplied XP-STORM models were converted into XP-SWMM2D models for the purposes of this study.

Existing inlet pits are typically grated pits with or without a lintel. There is a total of 909 pits in the five stormwater subcatchments of which 305 pits are inlet pits. The inlet level at inlet pits were estimated from a digital terrain model (DTM) that was generated from supplied aerial laser scanning (ALS) data for each subcatchment.

Council photographed each inlet pit in subcatchments 102, 104, 105 and Boltje Street. Based on the photographs, inlet pit types (lintel plus grate, lintel only, grate only, etc) were identified, and an inlet capacity rating curve was assigned to each inlet pit. Photographs of the inlet pits for subcatchment 103 were not available. For assessment purposes al inlet pits in these subcatchments were assumed to have no limitations ie. the hydraulic capacity of the piped drainage system could be fully utilised.

The Manning roughness values were defined for overland flow paths as well stormwater conduits. For paved areas such as roads, streets, and lanes, a roughness value of 0.020 was adopted. For pervious areas such as parks, and ovals, a roughness value of 0.060 was adopted. A roughness value of 0.012 was adopted for all existing concrete stormwater conduits including pipes and box culverts.

In the XP-SWMM2D model, the existing underground drainage system was represented in the 1-D layer while overland flows were modelled in the 2-D layer. The 1-D and 2-D layers were connected at inlets to allow overland flows to enter the piped drainage system and for the piped drainage system to surcharge onto roads as appropriate.

The 2D model of overland flowpaths was based on a rectilinear 2.5 m grid (the minimum grid size that could be adopted for the 289 ha study area).

4. EXISTING CONDITIONS

The XP-SWMM2D models for subcatchments 102 to 105 and Bultje Street were run for the 100 year ARI and 20 year ARI events under existing conditions. The hydrological analysis disclosed that critical storm burst duration varies between 30 minutes and 120 minutes depending on location within the catchments and the event ARI. However, a review of the estimated peak flood levels indicated that the critical storm burst duration for flooding in the subcatchments is 60 minutes in both the 100 year ARI and 20 year ARI events.

After each model run, spatial plots of the overland flow depth and velocity were generated at each hot spot intersection. The estimated 100 yr ARI flood depths and extents under existing conditions are given in **Figure 2**. The estimated 100 yr ARI flood depths and extents under existing conditions at one of the intersections of interest (Church Street and Brisbane Street intersection) are given in **Figure 3**.

The 100 yr ARI existing condition assessment disclosed in particular:

(i) Ponding south of Cobra Street on the former RAAF lands and overland flows through residential areas north of Cobra Street;
(ii) Shallow overland flows through Elston Park;
(iii) Flooding of the intersection of Fitzroy Street and Wingewarra Street with only the roundabout remaining dry;
(iv) Overland flows through southern sections of the Showgrounds and Paceway;
(v) Overland flows through the Dubbo High School and Victoria Park and flooding of Talbragar Street opposite Victoria Park; and
(vi) Major overland flows in Brisbane Street between Church Street and Talbragar Street. The flooding also extends back up Talbragar Street to the Carrington Ave intersection;
(vii) Peak overland flow velocities are higher in the upper (eastern) areas of the study area and tend to align with road kerb lines;
(viii) The peak velocity of overland flows in Brisbane Street between Church Street and Talbragar Street are low

The 20 yr ARI existing condition assessment disclosed in particular:

(ix) A similar pattern of overland flows to the 100 yr ARI event but with a reduced extent of inundation eg. Victoria Park;

(x) Reduced overland flows in Talbragar Street between Carrington Ave and Brisbane Street;

(xi) Inundation of the northeast, southeast and southwest corners of the intersection of Fitzroy Street and Wingewarra Street;

(xii) A similar pattern of overland flow velocities to the 100 yr ARI event.

5. IMPACT OF AUGMENTATION WORKS

The XP-SWMM2D model for subcatchments 102 to 105 and Bultje Street were then modified to reflect the proposed drainage augmentation works at the three hot spot intersections and the model was re-run for the 100 year ARI and 20 year ARI events. Details of the proposed augmentation works at the three road intersections namely at the junction of Talbragar Street and Carrington Avenue, Brisbane Street and Church Street, and Wingewarra Street and Fitzroy Street were supplied by Council. The concept upgrade includes the addition of new pipes and inlet pits as well as enlarging existing inlet pipe size(s).

After each model run, spatial plots of the overland flow depth and velocity were generated at each hot spot intersection.

The estimated 100 yr ARI flood depths and extents with the augmentation works are given in **Figure 4**. The estimated 100 yr ARI flood depths and extents with the augmentation works at one of the intersections of interest (Church Street and Brisbane Street intersection) are given in **Figure 5**.

The 100 yr ARI post augmentation works condition assessment disclosed in particular

(i) The overland flows in Brisbane Street between Church Street and Talbragar Street are markedly reduced. Likewise the flooding back up Talbragar Street from Brisbane Street to the Carrington Ave intersection is noticeably reduced;

(ii) The depth of overland flows in Brisbane Street are reduced by more than 0.01 m north of Church Street. The reduction in depth of overland flooding in Brisbane Street south of Church Street and in Church Street west of Brisbane Street is around 0.01 to 0.05 m;

(iii) There is only a minor reduction in the overland flow depth in Carrington Ave south of Talbragar Street. There is a reduction in overland flow depth in Talbragar Street south of Carrington Ave of 0.01 m or more; and

(iv) There is a minimal reduction in overland flood depths at the intersection of Fitzroy Street and Wingewarra Street;

The 20 yr ARI post augmentation works condition assessment disclosed in particular:

(v) The depth of overland flows in Brisbane Street are reduced by more than 0.01 m north of Church Street. The reduction in depth of overland flooding in Brisbane Street south of Church Street and in Church Street west of Brisbane Street is around 0.02 to 0.05 m;

(vi) There is a reduction in the overland flow depth in at the western corner of Carrington Ave and Talbragar Street. Of around 0.05 m There is a reduction in overland flow depth in Talbragar Street south of Carrington Ave of 0.01 m or more; and

(vii) There is a minimal reduction in overland flood depths at the intersection of Fitzroy Street and Wingewarra Street.

Further options that might improve the flooding at the Fitzroy Street and Wingewarra Street intersection include:

(i) Collecting overland flows south of Cobra Street and east of Fitzroy Street and discharging them into Cobra Street west of Fitzroy Street ie. a catchment transfer of overland flows. The potential transfer of a problem from one subcatchment to another subcatchment may not be viewed favourably by the community, and/or

(ii) the construction of a shallow basin in Elston Park to retard overland flows from Cobra Street and Fitzroy Street thereby reducing overland flooding at the intersections of Fitzroy and Wingewarra Streets and Gipps and Wingewarra Streets, possibly in combination with

(iii) a retarding basin south of Cobra Street in the RAAF land.

It was concluded that the modelling completed to date has highlighted the interconnection of local drainage subcatchments and confirms observations of overland flow problems in several areas in Dubbo. The analyses completed to date have assessed the reductions in overland flows and flood extents at intersections of interest to Council. It also provides an opportunity for Council to further refine the possible augmentation options to overcome the residual flooding problems.

6. 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 was also concluded that:

- the combined 1-D/2-D modelling capabilities in the XP-SWMM2D package offers Dubbo City Council and others new opportunities to undertake more detailed investigations of urban drainage systems and of overland flows;
- the modelling completed to date has highlighted the interconnection of local drainage subcatchments and confirms observations of overland flow problems in several areas in Dubbo; and
- the assessments have highlighted the value of ALS data.

7. ACKNOWLEDGEMENT

The support of Dubbo City Council for the assessments described herein through its provision of extensive ALS data and detailed drainage system data is gratefully acknowledged. The views expressed in this paper are those of the authors and are not necessarily the views of Dubbo City Council.

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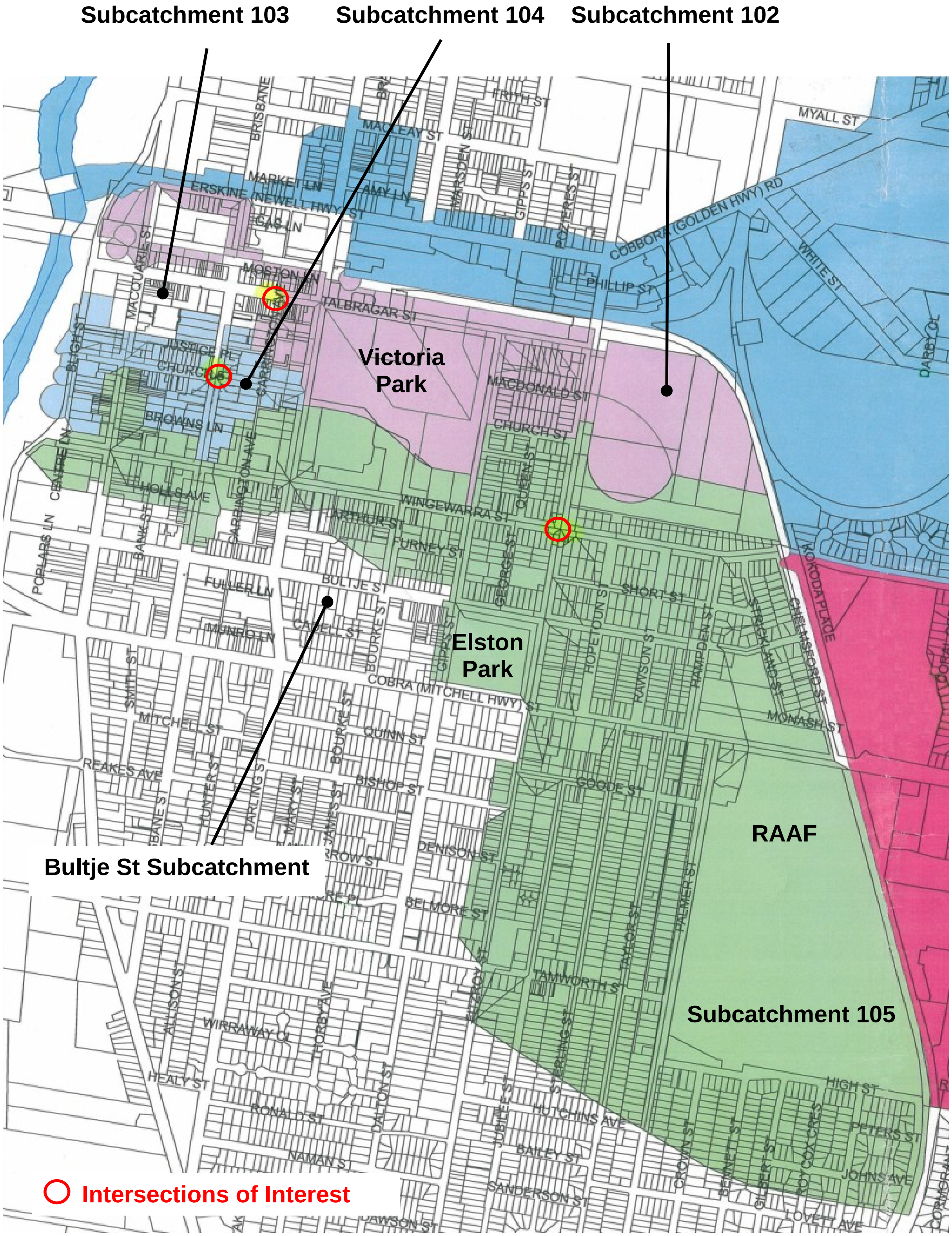

Figure 1 Dubbo Local Drainage Subcatchments

Figure 2 Estimated 100 yr ARI Flood Depths and Extents – Existing Conditions

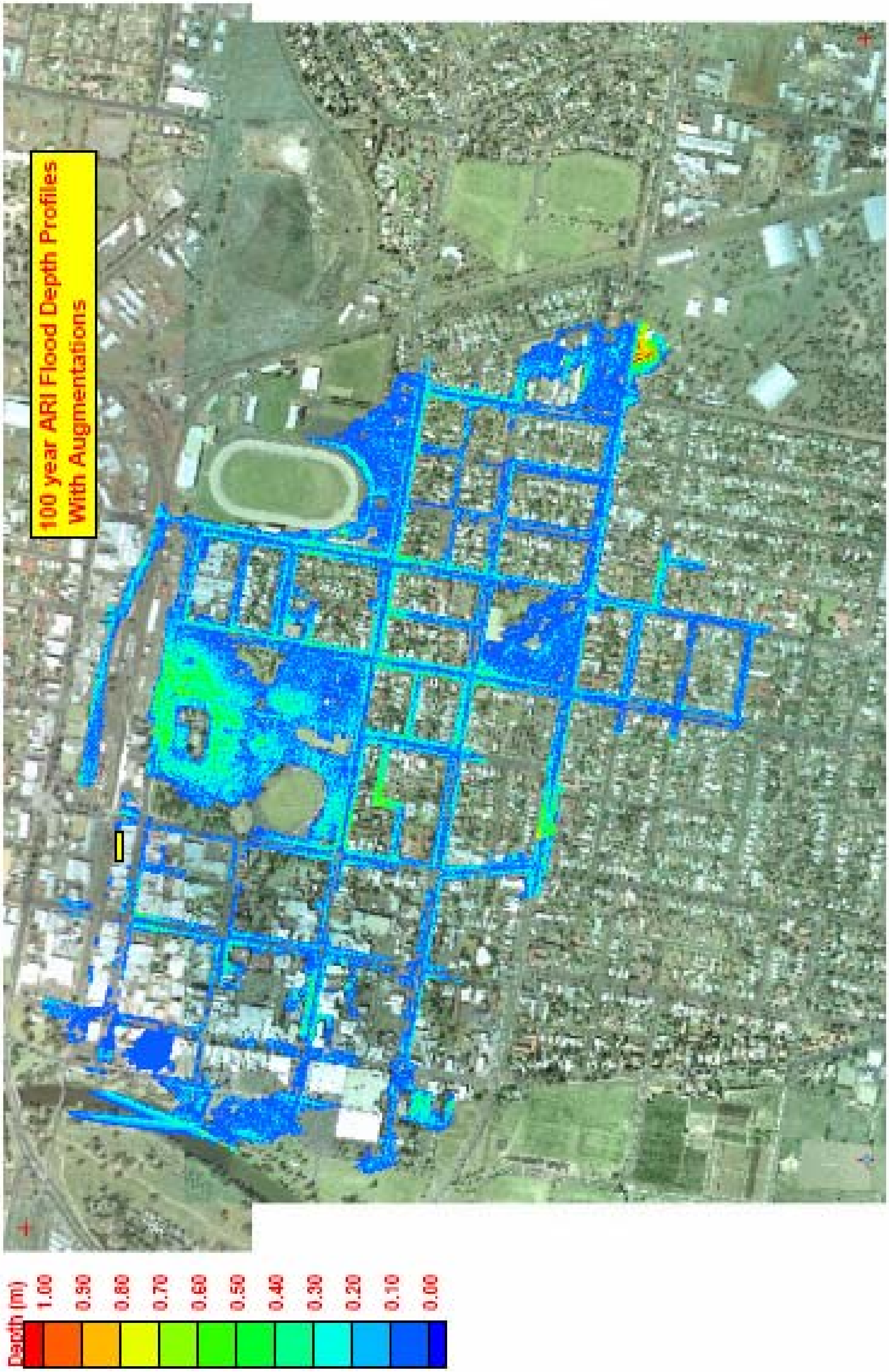

Figure 3 Estimated 100 yr ARI Flood Depths and Extents – With Concept Augmentation Works

Figure 4 Estimated 100 yr ARI Flood Depths and Extents at Brisbane Street & Church Street Intersection – Existing Conditions

Figure 5 Estimated 100 yr ARI Flood Depths and Extents at Brisbane Street & Church Street Intersection – With Concept Augmentation Works

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Dr Brett C. Phillips is a Director of Cardno Willing who has more than 20 years of experience in managing and undertaking a wide range of catchment management studies, flood studies, floodplain management studies, flood mitigation and stormwater quality investigations for Council clients. He is an author of more than 120 papers published in international and Australian journals and conference proceedings on integrated catchment management, sustainable development, flooding and floodplain management and hydrology. He has been responsible for a wide range of studies on waterways and floodplains including the Prospect Creek (Fairfield), Muttama Creek, Jindalee Creek (Cootamundra), Gloucester & Avon Rivers (Gloucester), Lower Parramatta River, Toongabbie, Greystanes Creek, Pendle Hill Creek (Toongabbie), Wolli Creek (Rockdale), Macquarie River (Bathurst), Broken River (Benalla), Fitzroy River (Rockhampton), Doonan Creek (Coolum), Humphreys and Islet Rivulets and Barossa Creek (Glenorchy).

Mr Stephen Yu is a Senior Engineer with Cardno Willing who has over 10 years experience in stormwater hydraulics, hydrology and modelling of water quality in receiving waters. He was responsible for hydrodynamic and water quality modelling of the Parramatta River, Hawkesbury River, Georges River, Cooks River and Lane Cove River and Minamurra River using both 1D and 2D models. Most recently he has undertaken hydrodynamic modelling of Prospect Creek (1-D, quasi 2-D, 2-D) (Fairfield), Chipping Norton Lake/Georges River (2-D) (Fairfield), Humphreys Rivulet (1D, 2D), Fitzroy River (1-D and 2-D) (Rockhampton) and Muddy Creek (1-D), Spring Street Drain (1-D) and Scarborough Ponds (1-D) (Rockdale).

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