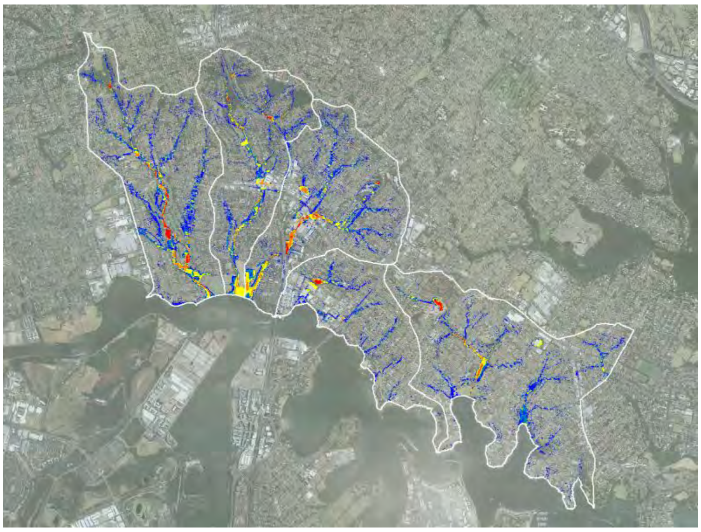
# Parramatta River - Ryde Sub-Catchments Flood Study and Floodplain Risk Management Plan



FLOOD STUDY REPORT

- Revision C
- 29 August 2013

# Parramatta River - Ryde Sub-Catchments Flood Study and Floodplain Risk Management Plan

## FLOOD STUDY

- Revision C
- 29 August 2013

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LIMITATION: The sole purpose of this report and the associated services performed by Sinclair Knight Merz Pty Ltd (SKM) is to document the development and verification of the hydrologic and hydraulic models for the definition of overland flooding behaviour in the City of Ryde Parramatta River Catchments study area, in the undertaking of a flood study for this area. The focus of this flood study is on the broad overland flooding behaviour in the study area, and hence localised drainage issues may not be represented.

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# Contents

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# Executive Summary

A flood study has been undertaken for the five drainage catchments in Ryde Local Government Area (LGA) which drain to the Parramatta River. Development in the study area is at risk to flooding during heavy rainfall events due to the nature of the urban environment and the limited capacities of the natural and built drainage network. Such events have occurred in 1984, 1986, 1988 (twice), 1989 (twice) and 1990, leading to widespread flooding and damage to properties.

A number of major drainage improvement projects have been completed in the study area to alleviate the flooding problems. The storm events in May 1998 and April 2003 caused significant problems but not to the extent as those in the late 1980's due to the drainage upgrades. However, there are numerous locations where existing development is at risk from flooding.

This flood study has been commissioned by the City of Ryde (Council), with the assistance of NSW Office of Environment and Heritage, and defines the existing flood behaviour in the five catchments, being: Archer Creek; Denistone; Charity Creek; River and Gladesville. Flooding occurs primarily as overland flows in the majority of the study area, while mainstream flooding is experienced adjacent to the watercourses. Flood extents, depths and levels and main flow paths have been determined.

The flood modelling indicates that there would be a number of areas within the study area where development would be subject to flood depths exceeding 2m in the 1% AEP event, including parts of Meadowbank TAFE, several locations upstream of the Main Northern Railway and several residential and industrial areas. Up to 44 individual roads would experience maximum depths of flooding exceeding 0.3m in the 20% AEP event along the road centreline, rising to 79 roads in the 1% AEP event. This depth of flooding is indicative of these roads becoming impassable to vehicles, although the safe depth of flooding may be lower depending on the overland flow velocity. Up to 588 properties (including private and public lot parcels) have been categorised as provisional high flood risk, with this to be updated during the Floodplain Risk Management Study to reflect true flood risk with consideration of evacuation, isolation, flood damages and social impacts of flooding.

Hydrologic modelling of rainfall-runoff processes was conducted using the DRAINS modelling software, to determine storm event flows in the catchments. A separate DRAINS model was developed for each of the five catchments, based on the stormwater asset data base provided by Council. The drainage network down to pipes with a 225mm diameter and major flood storages were represented in the DRAINS models. Each catchment was divided into several hundred sub-catchments, and design event flow hydrographs obtained for these sub-catchments for input into the flood hydraulic models developed for this study.

Hydraulic modelling was undertaken using TUFLOW, which defines the surface of the catchments in 2D using a 3m grid of the topography, while allowing features such as the stormwater pit and pipe network, trunk drainage channels, culverts and bridges as 1D objects. The hydraulic roughness of the catchments was varied according to land use. Buildings were defined as solid obstructions to overland flow. Partial blockage of pits, culverts, bridges and mesh-type fencing at waterway crossings was applied for the design case.

Inflow hydrographs from the DRAINS models were input at the sub-catchment outlets in the TUFLOW model, with stormwater pit inlets intercepting the flows up to the system capacity. Excess flows surcharge and form overland flow, which flows over the 2D model domain in patterns according to the topography and modelled obstructions.

A joint-model verification was conducted for the combined DRAINS-TUFLOW models, with the estimated depths of flooding for the November 1984 (approximately 1% AEP (Annual Exceedance Probability)) and February 1990 (approximately 20% AEP) historic storm events compared to observed depths reported by local residents. The flood model results were generally comparable to the observed depths. Peak flows at various locations in the study area were also found to be comparable to estimates from a number of previous flood and drainage studies for the study area. The modelling was therefore considered to be reliable and suitable for defining existing flood behaviour in the study area.

Flood behaviour was defined for the 20%, 10%, 5%, 2% and 1% AEP and Probable Maximum Flood (PMF) events. Flood depths have been mapped for all events, while flood levels have been mapped for the 1% AEP and PMF events. Flood risk precincts have been determined based on the hydraulic hazard rating of areas within the 1% AEP flood extent, in addition to the PMF extent. Flood planning areas have been defined based on the 1% AEP flood surface plus 0.3m freeboard. The flood mapping has had areas with depths less than 100mm filtered out, to avoid these areas, which are affected by shallow sheet flow, being denoted as “flood-affected”.

The sensitivity of the modelled flood behaviour to changes in modelling parameters has been assessed. The varied parameters include changes in rainfall losses, increased hydraulic roughness of the catchment surface and pipes/channels, increased hydraulic energy losses at structures, decreased blockage of pipes and structures and reduced tailwater levels in the Parramatta River. The flood depths are typically not sensitive to the variations in parameter values globally (less than 0.03m) although there are marked localised decreases in flood depths for a number of scenarios upstream of the Main Northern Railway cross-culvert adjacent to Meadowbank TAFE, with up to 0.6m change in flood level. The model appears to be more sensitive to reductions in inflow and obstructions than to increases.

The impact of climate change on flooding in the study area has been investigated by analysing three scenarios of storm event rainfall intensity increase (10%, 20% and 30%) coupled with two sea level rise scenarios (2050 and 2100 scenarios, corresponding with 0.4m and 0.9m sea level rise, respectively, on top of the 5% AEP ocean level at Fort Denison). The analysis indicates that flood levels are not sensitive to sea level rise except at the outlets of the catchments and along the Parramatta River, with a number of low-lying riverside residential properties at risk from increased sea level alone, without river or overland flooding. Where flow depths are typically shallow, results weren’t sensitive to the increased rainfall intensity (less than 0.03m increase), while flood depths in flow paths and storage areas were more sensitive to the increase in rainfall intensity. In the extreme 30% rainfall intensity increase scenario, depths typically increased by up to 0.4m in flow paths and storages, although depths may increase by up to 1.35m in some areas, including the informal storage upstream of the Main Railway Line, downstream of the Meadowbank TAFE.

It is recommended that the findings from this study and the models themselves be used in the subsequent floodplain risk management study and plan to identify and assess potential mitigation options and develop a plan for managing flood risk in the study area.

# 1. Introduction

## 1.1. General

Ryde Local Government Area (LGA) encompasses an area of 40.7km$^2$ in northern Sydney covering a number of catchments draining to the Parramatta River and the Lane Cove River. The area of focus for this study includes five catchments in the southern part of the LGA, draining to the Parramatta River. Patterns of urbanisation and associated construction of drainage infrastructure dating back to as early as the 1930's, have resulted in a number of watercourses being piped and development occurring in sometimes unsuitable locations, putting this development at risk to flooding during heavy rainfall events. Such flooding has occurred in 1984, 1986, 1988 (twice), 1989 (twice) and 1990, leading to widespread flooding and damage to properties.

A number of major drainage improvement projects have been completed in the study area to alleviate the flooding problems. The storm events in May 1998 and April 2003 caused significant problems but not to the extent as those in the late 1980's due to the drainage upgrades. However, there are numerous locations where existing development may be at risk from flooding.

Hydrologic and drainage studies have been undertaken in the study area in the past, though some of these studies are up to 20 years old and most do not define the flood behaviour to the level of detail required in the NSW Government's *Floodplain Development Manual* (2005), which forms the current guidance for management of development and flood risk in NSW. Additionally, some catchments have been assessed in a disjointed manner and not been considered as a whole.

The City of Ryde ("Council") commissioned SKM to undertake a flood study and subsequent floodplain risk management study for five catchments with a total area of 12.7km$^2$. This report documents the flood study portion of the project to determine the existing nature of flooding in the study area.

## 1.2. Purpose of this Flood Study

The purpose of this study is to investigate the existing and future flood risks in the study area and to develop the subsequent floodplain risk management study and plan in accordance with the NSW Government's *Floodplain Development Manual*.

Key objectives of this study are to:

- Develop and calibrate hydrologic and hydraulic models for the estimation of overland flood behaviour in the study area, taking into account the performance of the stormwater drainage network including overflows from the drainage network. The overflows constitute overland flooding in some areas.
- Determine overland flooding behaviour and flood risk in the study area.
- Produce flood model results for the 20%, 10%, 5%, 2% and 1% AEP and PMF storm events
- Prepare flood depth mapping for all storm events assessed.

- Prepare flood level and flood risk precinct mapping for the 1% AEP and PMF events.
- Determine the flood planning areas for the 1% AEP events based on the existing and future (2050 and 2100 scenario) sea levels.
- Assess the sensitivity of flood behaviour to changes in hydrologic and hydraulic characteristics in the catchments.
- Assess the impact of climate change on flood levels in the study area.

The outcomes from this flood study will form the basis for the identification, assessment and prioritisation of management measures during the subsequent floodplain risk management study and plan.

# 2. Background on Study Area

## 2.1. Catchment Description

The study area has a total area of 12.7km$^2$ and has been defined by Council as five separate catchments. A description of each catchment is provided below, and is illustrated on **Figure 2-1**. The stormwater drainage infrastructure in the catchments, which are listed west-to-east, is summarised in **Table 2-1**.

**Table 2-1 Stormwater Infrastructure per Catchment**

| Catchment | Area (ha) | Length of Stormwater Pipes (km) | Number of Stormwater Pits |
|---|---|---|---|
| Archer Creek | 286 | 15.8 | 736 |
| Denistone | 215 | 16.5 | 632 |
| Charity Creek | 247 | 20.2 | 810 |
| River | 158 | 10.6 | 470 |
| Gladesville | 366 | 22.7 | 987 |
| Total | 1,272 | 85.8 | 3,635 |

### 2.1.1. Archer Creek Catchment

Archer Creek Catchment has an area of 286ha within Ryde LGA and has an additional portion of the catchment of 50ha located to the west of Wharf Road, in the Parramatta Local Government Area (LGA). The catchment is typically 1km wide and about 3km long. It originates south of Eastwood and runs through the residential areas of Denistone East and Melrose Park.

A large portion of the catchment includes Brush Farm Park and the Ryde – Parramatta Golf Course. Land use is mainly residential. Drainage in the catchment mainly consists of a mix of pipes and natural and developed flow paths. Archer Creek flows through the Ryde – Parramatta Golf Course as a series of constructed channels and ponds. Downstream of the Golf Course and Andrew Street, Archer Creek flows in a culvert and then in a concrete-lined channel through Meadowbank Park, before discharging into the Parramatta River.

### 2.1.2. Denistone Catchment

Denistone Catchment has an area of 215ha. The catchment is typically 0.7km wide and about 2.9km long. It originates from Denistone and runs through the residential areas of West Ryde and Meadowbank. Land use is mainly residential with industrial and commercial developments in the West Ryde area. The catchment consist a mix of pipes, trunk drainage tunnels and natural and developed flow paths. A concrete-lined channel forms the main flow path downstream of Constitution Road, where it flows through Meadowbank Park, before discharging into the Parramatta River.

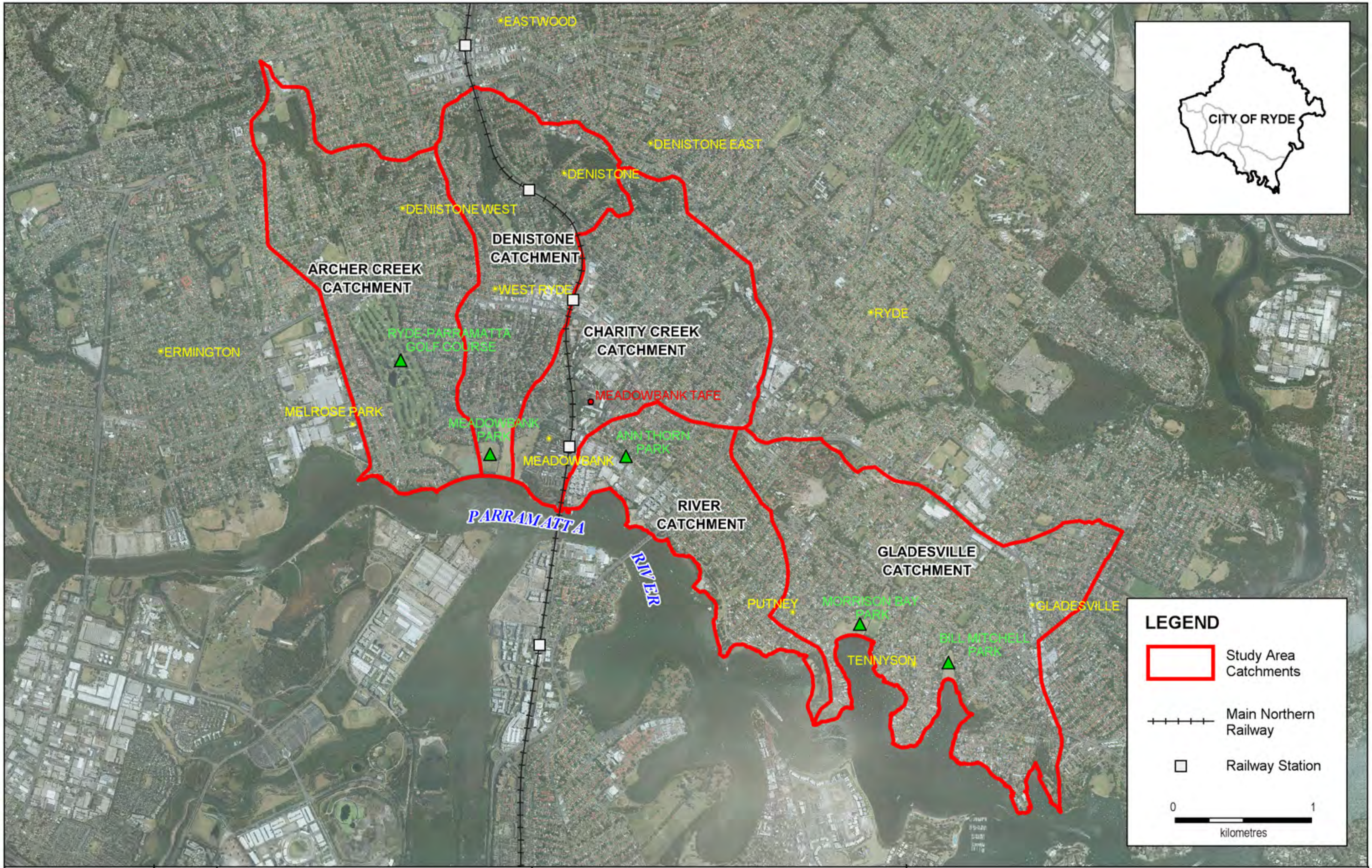


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**Figure 2-1**
**Study Area Catchments and Locations**

February 7, 2013 | EN02970_Figure_2-1.wor

West Ryde Town Centre area experienced heavy flooding during 1984 and 1990 storms. The West Ryde stormwater tunnel was built in 1999 from Miriam Rd, West Ryde to Meadowbank Park to alleviate the flooding in West Ryde Town Centre area. Victoria Road to the south of the Town Centre is raised and is a significant control on overland flooding in West Ryde.

The Northern Railway Line runs through the north-eastern portion of the catchment. The Railway is constructed on a raised fill embankment in several sections and is an obstruction to overland flows. It represents an informal flood storage in the area.

### 2.1.3. Charity Creek Catchment

Charity Creek Catchment has an area of 247ha and is typically 1.7km wide and about 0.9km long. It originates from Denistone and runs through the residential areas of West Ryde and Meadowbank. Land use is mainly residential with industrial and commercial developments in the West Ryde area. The catchment consists mainly of a piped drainage system with developed flow paths through the urban areas.

The Northern Railway Line runs through the south-western portion of the catchment. The Railway is constructed on a raised fill embankment just to the north of Meadowbank Station and is an obstruction to overland flows. also It represents an informal flood storage in this area. Victoria Road between Falconer Street and Linton Avenue is a raised control to overland flow from the north.

### 2.1.4. River Catchment

River Catchment has an area of 158ha is the smallest catchment within the study area. The catchment is typically 1.1km wide and about 2.3km long. It originates from south of Ryde and runs through the residential areas of Putney. Land use is mainly residential with industrial and commercial developments in the Meadowbank area. The catchment is drained by a piped system, with a number of overland flow paths draining surface flows to the Parramatta River. Constitution Road in the vicinity of Ann Thorn Park is constructed on a raised embankment and is an obstruction to overland flow into, and upstream of, Ann Thorn Park.

More high density residential development in the Meadowbank area at the western side of the River Catchment is proposed in the short to medium term. Drainage systems at the western side of River Catchment were upgraded recently to allow increased flows from future development.

### 2.1.5. Gladesville Catchment

Gladesville Catchment has an area of 366ha and is the largest catchment within the study area. The catchment is typically 2.1km wide and about 1.7 km long. It originates from south of Ryde and runs through the residential areas of Putney, Gladesville and Tennyson Point. Land use is mainly residential with industrial and commercial developments in the Gladesville area. The catchment is drained by a pipe network and several main overland flow paths, including a concrete-lined channel flowing through Morrison Bay Park and discharging into the Parramatta River. One overland flow path drains into the adjacent Hunters Hill LGA to the east, in the vicinity of Pittwater Road and Cambridge Street, Gladesville.

A detention basin/stormwater quality pond has recently been constructed at the Royal Rehabilitation Centre Sydney, Ryde, in the north-western portion of the catchment.

## 2.2. History of Flooding

A number of historic flood events have occurred in the study area in the last 30 years, including events during 1984, 1986, 1988, 1990, 2005, 2009, 2010 and 2011 as reported by residents during this study. Particularly notable was the November 1984 event, which caused significant flooding in the West Ryde town centre, with some commercial properties experiencing depths of flooding of two (2) metres, prompting Council to commission the construction of the West Ryde Stormwater Tunnel to improve drainage and alleviate the flood risk to the area. The Tunnel was completed in 1999.

The following photos of historic flooding were provided by local residents.

- **Plate 2-1 Flooding in Cobham Avenue, Melrose Park, 1988 storm event (courtesy G. Parry)**

- **Plate 2-2 Flooding and surcharging stormwater pit in Cobham Avenue, Melrose Park, 1988 storm event (courtesy G. Parry)**

- **Plate 2-3 Overland flood damage to yard, Gladesville, 1989 storm (courtesy R. Tuckwell)**

- **Plate 2-4 High water marks on exterior wall and damaged carpets, Gladesville, 1989 storm (courtesy R. Tuckwell)**

# 3. Review of Available Data

## 3.1. Previous Studies

A number of previous relevant studies that were available for the study included:

- *Ryde Stormwater Drainage Investigation* (Willing & Partners, 1990). This study investigated piped and overland flows in the Charity Creek catchment, among other catchments in Ryde LGA. Hydrologic modelling was undertaken in RAFTS and hydraulic modelling of overland flows in RATHGL. Typical depths of overland flow were estimated but flood extents were not delineated.
- *West Ryde/Denistone Catchment Stormwater Drainage Management Study* (Ryde City Council, 1992). This study investigated flood mitigation options for the West Ryde Town Centre, building on a drainage study previously undertaken for the Denistone Catchment by Willing & Partners in 1991 (not available for this study). The report provides details of flooding and flood damages in the area and evaluates potential mitigation options.
- *Mid Parramatta (North) River Stormwater Management Plan* (Robinson GRC, 1999). This study focuses mainly on stormwater quality and management in areas north and south of the Parramatta River, although it does provide a brief discussion on drainage and flooding issues in the Archer Creek, Denistone and Charity Creek catchments.
- *Drainage Investigation Meadowbank River Catchment* (Rose Consulting Group, 2001). This study was prepared to analyse the stormwater system in parts of the River Catchment, identify problem areas and required system upgrades. The 5% and 1% AEP events were assessed using DRAINS. The flood extents were not delineated.
- *Catchment Management Strategic Review* (City of Ryde, 2005). Summarises the characteristics of the stormwater catchments and management assets in Ryde LGA, outlines historic flood behaviour, summarises the various stormwater, flooding and asset management plans in the LGA, and identifies and defines a strategic action plan for ongoing catchment management.
- *Charity Creek Cascades Overland Flood Study and Detailed Design* (WMAwater, 2009). This study investigated overland flooding in the Charity Creek Catchment between Shepherd Street and Victoria Road, and assessed options for the formation of an overland flow path through vacant properties purchased by Council. Detailed design of the overland flow path was developed for the preferred option. The hydrologic analysis was undertaken in DRAINS, with the flood definition and impact assessment undertaken in TUFLOW.

## 3.2. Stormwater Asset Data Base

Council's stormwater asset data base is the primary source of information on the stormwater network in the study area. The data was provided in the form of GIS layers and associated spreadsheets, with information including the type and dimensions of conduit or node, coordinates and levels. However, approximately 50% of the conduits depicted in the data base did not have invert level data, and there were also numerous locations where there were gaps in the drainage network data set.

A separate CAD data set depicting the drainage network was also provided by Council. This data set differed in some parts of the network and was useful for gaining an understanding of some (but not all) parts of the network which were missing from the GIS layer.

## 3.3. Topographic Survey

### 3.3.1. Airborne Laser Survey

Airborne Laser Survey (ALS) was used to generate a Digital Terrain Model (DTM) for the study area. The data has a vertical accuracy of +/- 0.15m and horizontal accuracy of +/- 1m. The ALS data used had been filtered to remove non-ground points such as buildings and trees.

### 3.3.2. Ground Survey

Ground survey was conducted to obtain levels and dimensions of selected hydraulic structures where these were not available in the stormwater asset data base. These structures included open channel invert levels, culverts and footbridges.

Additional stormwater pit depth measurements were collected at selected pits to estimate pit and pipe invert levels at these locations.

### 3.3.3. Design and Works as Executed Drawings

Design plans and works as executed (WAE) drawings were obtained for the following features for use in this study:

- Royal Rehabilitation Centre Sydney (Gladesville Catchment). Newly constructed detention basin/water quality pond and amended drainage network.
- West Ryde Stormwater Tunnel (Denistone Catchment). Existing trunk drainage tunnel, specialised inlets and connections to street-level stormwater network.

## 3.4. Spatial Data

Various layers of GIS data were made available for this study by Council. These include:

- Cadastre;
- LEP/zoning layer; and
- Building polygon layer, derived from the ALS non-ground points.

## 3.5. Rainfall Intensity-Frequency-Duration Data

Rainfall Intensity-Frequency-Duration (IFD) data parameter values were obtained from existing DRAINS stormwater models for Meadowbank – River Catchment, provided by Council. The data is in the form of log-normal rainfall intensities obtained *from Australian Rainfall and Runoff Volume 2* and is summarised in **Table 3-1**.

- **Table 3-1 IFD Parameters for Study Area**

| Parameter | 2 year ARI | 50 year ARI |
|---|---|---|
| 1hr Event Intensity (mm/h) | 36.3 | 69.8 |
| 12hr Event Intensity (mm/h) | 7.7 | 16.8 |
| 72hr Event Intensity (mm/h) | 2.45 | 5.5 |
| Frequency Factor | 4.29 | 15.7 |
| Skewness | 0 | |

## 3.6. Data on Historic Flood Events

### 3.6.1. Historic Event Rainfall Data

Rainfall data was obtained for the 8 November 1984 storm event and the 7 February 1990 event. Data for the historic storm events were recorded at the West Ryde pumping station (within the Charity Creek Catchment). The daily total rainfall depths and maximum rainfall intensities for a range of durations for these two events are summarised in **Table 3-2**.

- **Table 3-2 Daily maximum rainfall intensities for historic storm events at West Ryde Pumping Station**

| Location | Maximum Rainfall Intensity per Event Duration (mm/hr) | | | | |
|---|---|---|---|---|---|
| | 10min | 20min | 30min | 1hr | 2hr |
| 8 November 1984 | 113.3 | 101.42 | 80.5 | 61.1 | 38.0 |
| 7 February 1990 | 78.0 | 66.0 | 58.0 | 37.5 | 21.5 |

Comparison of the maximum rainfall intensities in the historic events to the IFD data for the study area indicates that the 1984 storm event was equivalent in intensity to the design 5% AEP storm event, and the 1990 storm was equivalent to the design 50% AEP storm event.

### 3.6.2. Observations of Historic Floods

Observed flood depths were reported by local residents in response to a questionnaire distributed to the community as a part of this flood study. Due to the anecdotal nature of the observations, including reduced certainty about exact location of observations and the passage of time, the data is not considered highly accurate to undertake a detailed calibration of the hydrologic and hydraulic modelling. However, the data is useful for conducting a validation of the broad flood behaviour in the study area, including approximate depths of flow.

Additional, though limited, information on other historic storm events, including the February 2007 event and February 2010 event, was available in Council's stormwater Incidents Register. Three reports relating to stormwater drainage and flooding were located within the study area.

There are no stream gauges located in the study area.

# 4. Hydrologic Model Development

## 4.1. Model Selection

The DRAINS modelling software was selected to undertake the catchment hydrologic modelling for this study, as it is well-suited to representing rainfall-runoff in urban areas with sub-catchments at the suburban-block scale. It was also selected for its capability in stormwater drainage network analysis, with one of the objectives of this study being to develop detailed stormwater network models for Council's use for drainage problem assessment. The model version used was DRAINS Version 2012.04.

## 4.2. Model Extent

Separate DRAINS models were developed for each of the five catchments in the study area. The model extents are defined by the catchment boundaries shown in **Figure 4-1**. The modelled stormwater network is also shown.

## 4.3. Stormwater Network Details

The layout, dimensions and levels of the stormwater network were extracted from Council's stormwater asset data base and imported into DRAINS. Stormwater network parameters were then input on the following basis:

- Values for the pressure loss $K_u$ parameters were estimated using the Queensland Urban Drainage Manual (QUDM) automated procedure available in DRAINS.
- An inlet loss coefficient value of 0.5 was adopted for headwall inlets.
- Ponding volumes and depths at sag pits were estimated from the DEM.
- Pits in the study area typically are similar to the following DRAINS pits:
  - Hornsby Council pit database: 0.9, 1.2, 1.8, 2.4, 3.0, 3.6, 4.2m pit inlet sizes (lintel length) were selected for the kerb inlet pits. The inlet capacities for additional pit inlet sizes were estimated at 1.5, 2.1, 2.7, 3.3 and 5.0m based on the DRAINS pit inlet capacity data. The pits in Council's stormwater asset database were allocated to the closest pit inlet size.
  - Department of Housing RM7 inlet pits with 3% cross fall and 4% grade were selected for surface pits with a grated inlet of approximately 0.5m x 0.9m.
  - Additional pit inflow relationships were estimated for non-standard pits and other pits in the study area which were not well described by the Hornsby and RM7 pit inlet types. This includes the high-capacity inlets in Miriam Park and Darvall Park (Denistone Catchment).
- Blocking factors of 20% for on-grade pits and 50% for sag pits were adopted.
- Pipe and culvert dimensions were rounded to the nearest standard conduit size available from manufacturers. "Tonkin" pipes, with an elliptical profile, were represented as a box culvert with equivalent flow area (approximately 1 x height and 0.8 x width).

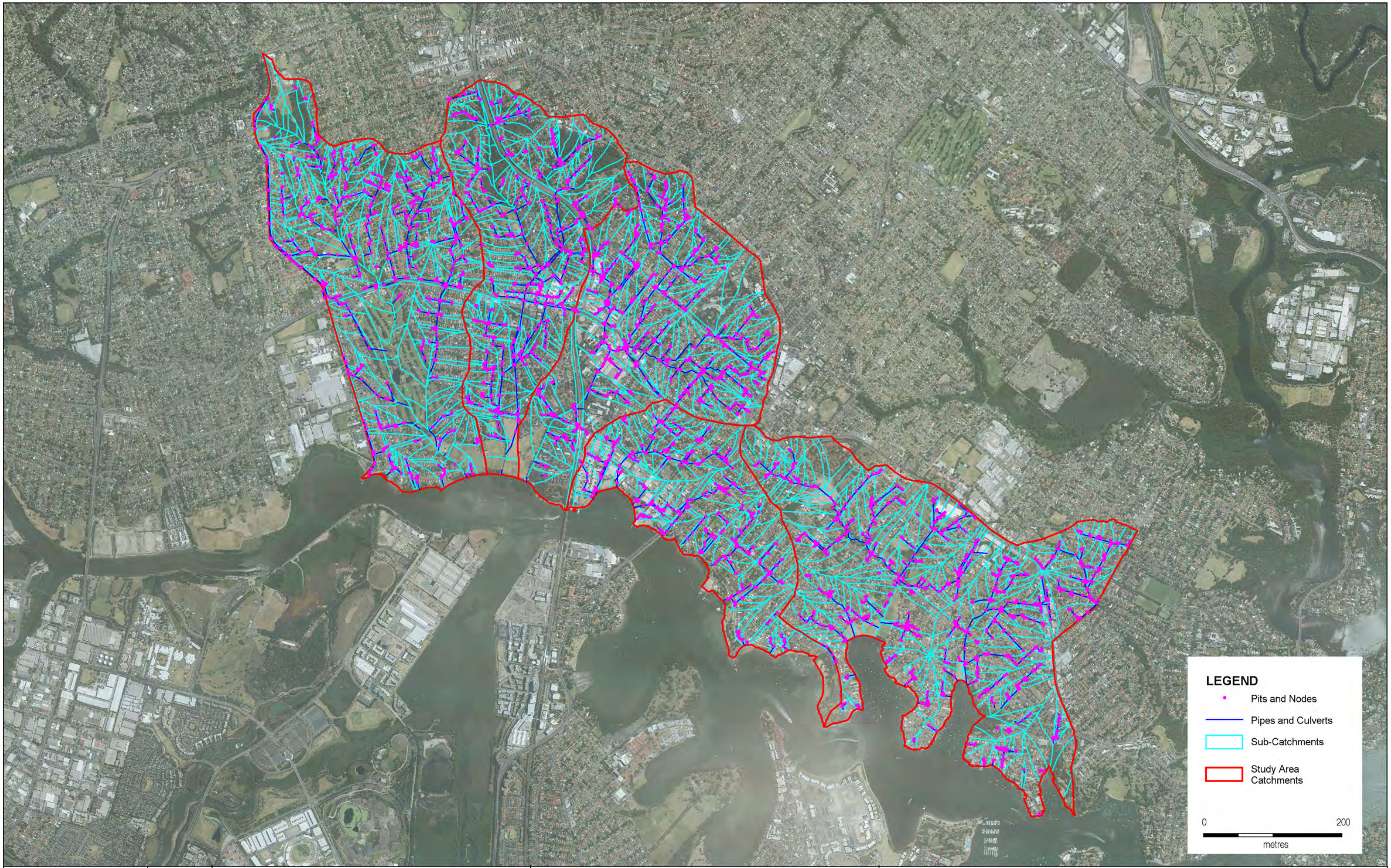


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**Figure 4-1**

**DRAINS Model Layout**

- Approximately 50% of the conduits in Council's stormwater asset data base had either one, or both, of the upstream and downstream invert levels missing as a data entry. Site inspection allowed a small portion of the pipe invert levels to be measured. The remaining missing invert levels were estimated using the "Design" function in DRAINS, which infilled the missing levels according to minimum pipe cover and grade criteria.
- The concrete-lined channels at the downstream end of the catchments were modelled as irregular channels in DRAINS, to ensure that the pipes discharging into the channels were influenced by the elevated tailwater conditions during high channel flows. Hence, the pipe flows would be backwater affected. This would not occur if the channels were represented as overflow routes.
- The West Ryde Stormwater Tunnel (Denistone Catchment) was represented as a 3.65m diameter pipe. This is consistent with previous stormwater modelling of the Denistone Catchment undertaken for Council.

### 4.4. Sub-Catchment Data

Sub-catchments were manually delineated based mainly on the ground level contours, and adjusted where required to suit road or property drainage conditions. A sub-catchment was delineated for approximately every third pit, with the overflows from these pits forming the approach flow to downstream pits with no sub-catchment delineated. Additional sub-catchments were delineated for watercourses and overland flow paths with no pit and pipe network. Areas where runoff would drain directly to the Parramatta River as sheetflow, were excluded as these areas were considered not to contribute to the drainage or overland flooding assessment of this study.

Once the sub-catchment boundaries were finalised in GIS, the following parameters were measured or estimated for each sub-catchment:

- Sub-catchment areas were measured in GIS
- Impervious fractions were estimated using Council's LEP data on land use, plus estimated typical impervious fractions for each land use category.
- Runoff travel times (i.e. time of concentration) were estimated based on the length of each catchment and an estimated flow velocity of 1m/s for paved surfaces, and 0.5m/s for grassed surfaces.

### 4.5. Hydrologic Parameters

The following hydrologic parameter values were adopted in the DRAINS modelling:

- Depression storage: Paved areas – 1mm; Grassed areas – 5mm.
- Soil type: Type 3
- Antecedent Moisture Condition: A value of 3 was adopted for storms up to and including the 1% AEP event. It was assumed that the ground would be completely saturated during extreme storm events, therefore, a value of 4 was adopted for the PMP event.

## 4.6. Design Rainfall

The storm events including the 20%, 10%, 5%, 2% and 1% AEP events were modelled as Australian Rainfall and Runoff 1987 (ARR87) Zone 1 storms in DRAINS.

Design rainfall time series were derived for the Probable Maximum Precipitation (PMP) events, based on the Generalised Short Duration Method (GSDM) in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (BOM, 2003).

## 4.7. Limitations of the Model

The DRAINS models schematise the highly complex piped and overland drainage networks in the catchments. Users of the models are advised of the following limitations:

- The models include the piped network in close to its entirety. In some locations there are very large areas of ponding during large storm events, which inundate a number of pits in the area. As these pits are linked to each other by overflow routes, and because the model doesn't perform a backwater analysis from downstream pit to upstream pit, the downstream pit may have a higher hydraulic grade level. This may cause instabilities in the pipe hydraulics. Simplification of the modelled network would potentially eliminate these instabilities, however, it was the scope of this study to develop detailed DRAINS models with all pits and pipes to permit future detailed drainage analysis.
- A similar situation to the above occurs adjacent to the concrete-lined channels at the downstream end of the catchments, where flood levels in the open channel may be higher than the hydraulic grade level in the adjacent pits.
- Flow paths in the DRAINS model are one-dimensional and dictate that overflows between pits must follow a defined path. In reality, pit overflows may split into several flow directions, for example, at road intersections.

As a result, the outputs from the DRAINS models should be viewed with care, particularly for large and extreme storm events. It is recommended that the DRAINS overland flow results be cross-checked against the TUFLOW hydraulic model outputs, particularly where the overland flow patterns are complex and not confined to a single flow path. The models may also require modification to suit the particular purpose of future drainage investigations.

# 5. Hydraulic Model Development

## 5.1. Model Selection

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model has been developed for this study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex flow patterns on the floodplain, including flows through street networks and around buildings.
- Capability in representing the stormwater drainage network, including pit inlet capacities and interflows between the network and floodplain including system surcharges.
- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

## 5.2. Configuration of Hydraulic Model

### 5.2.1. Extent and Structure

Separate TUFLOW models were initially developed for each of the five catchments to represent the entire catchment areas and drainage network as indicated in the stormwater asset data base. The models are comprised of:

- A 2D domain of the catchment surface reflecting the catchment topography, with varying roughness as dictated by land use.
- A 1D network of pits and pipes representing the stormwater network. The pits have a defined inflow capacity as dictated by their type and size.
- Additional hydraulic structures including culverts (1D), footbridges (1D and 2D) and open channels (1D).
- Obstructions to flow are represented as 2D objects, including existing buildings and selected fences, with partial blockage.

Refer to the following report sections for details on these features.

For the simulation of design floods, The Archer Creek, Denistone and Charity Creek TUFLOW models were joined to form a Combined model as there were a number of locations with inter-catchment flows.

### 5.2.2. Model Topography

The topography of the catchment is represented in the model using a 3m grid. This level of precision in the grid is considered necessary in order to represent detailed flood behaviour in a fully developed catchment. The basis of the topographic grid used in the TUFLOW model is the ALS survey.

The topography of the newly-constructed detention basin in the Royal Rehabilitation Centre Sydney (Gladesville Catchment), which was not captured by the ALS, was derived using contour data from engineering design plans of the basin.

Bed levels of the ponds on the Ryde-Parramatta Golf Course (Archer Creek Catchment) were estimated from the ALS assuming a pond water depth of 1m.

### 5.2.3. Stormwater Pits

The location of the stormwater pits and associated attributes were exported directly from the DRAINS model to GIS format. Surface levels for the pits were obtained from Council's stormwater asset data base.

Pit inflow relationships were defined in terms of flow depths versus pit inflow. The pit types and inflow relationships adopted in the DRAINS model were also used in the TUFLOW model.

Hydraulic loss coefficient values at the pits were taken from the DRAINS model, in which the pit loss coefficients were revised and confirmed using the QUDM method. The QUDM method iteratively adjusts the pit loss coefficient values based on the calculated pipe flow velocities in the DRAINS model.

### 5.2.4. Stormwater Conduits and Open Channels

Each of the stormwater pits and pipes in the DRAINS models are also modelled in the TUFLOW models. Pipes down to a diameter of 225mm are represented. The conduits are represented as circular pipes or rectangular culverts with dimensions matching those adopted in the DRAINS models.

The concrete-lined channels at the downstream end of the catchments are modelled as 1D elements in the TUFLOW models using the channel dimensions provided in the stormwater asset data base. Natural channels, flow paths and swales are represented in the 2D model domain.

### 5.2.5. Building Polygons

This study considers buildings as solid objects in the floodplain. This means that buildings form impermeable boundaries within the model, and while water can flow around buildings, it cannot flow across their footprint. This approach is consistent with the other overland flow studies that have been undertaken in Ryde LGA (Bewsher Consulting, 2010).

The building footprints in the TUFLOW model are based on polygon objects derived from ALS and provided by Council. Some modifications were made to the data set to reflect current development on the aerial photography, remove "false" buildings (e.g. trees picked up in the data set) and smoothing out the objects and creating gaps between buildings where these objects were deemed to incorrectly impede flows during preliminary model runs. The building polygons were superimposed on the model grid to make model computational cells under the footprints inactive.

### 5.2.6. Property Fencelines

Fencelines have not been explicitly represented in the model and floodwaters are allowed to flow across them freely. Although fences may obstruct overland flood flows in some parts of the catchment, experience indicates that representing fences in the hydraulic model requires making unvalidated assumptions about depths at which fences overflow or fail.

Hence, the potential obstruction to flow caused by fences was represented in the model by increasing the cell roughness (Manning's n values) for certain land uses, as described in **Section 5.2.7**. The limitation of this approach is that the flood levels may be slightly overestimated and flow velocities slightly underestimated for flooding within properties depending on the actual locations of obstructions and the interaction of flood flows with these obstructions. However, this approach does preserve the likely typical flooding behaviour, in which floodwaters use the road corridor as the preferential flow path.

### 5.2.7. Surface Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness values according to the LEP zoning and ground cover. These are based on engineering experience and typical values used in previous flood studies undertaken for Council (Bewsher Consulting, 2010). The relatively high Manning's n values for the residential land uses accounts for expected obstructions such as minor structures (sheds, etc.) and fences.

- **Table 5-1 TUFLOW Model Grid Hydraulic Roughness Values**

| Land Use Type | Manning's n Value |
|---|---|
| Road | 0.02 |
| Low density urban – Typical residential development | 0.10 |
| High urban – Units, commercial and industrial development | 0.025 |
| Special Use (e.g. schools, hospitals) | 0.04 |
| Train corridor | 0.04 |
| Grass | 0.03 |
| Vegetated | 0.05 |
| Vegetated Thick | 0.07 |
| Open water | 0.03 |

### 5.2.8. Footbridges and Pipe Crossings

Details of the footbridges in the study area were obtained from survey. Footbridges were modelled as either 1D or 2D structures, depending on whether the watercourse that it crosses was modelled in 1D or 2D. Footbridges crossing over the concrete-lined open channels, which were modelled as 1D objects, were modelled in 1D as a bridge opening and a weir structure as the bridge deck and hand railing. Footbridges crossing watercourses modelled in 2D, specifically the numerous footbridges over the watercourses in the Ryde-Parramatta Golf Course, were modelled as 2D objects. Hand railings on these footbridges typically incorporated wire mesh or metal panels with vertical bars at narrow intervals, and were assumed to be fully blocked.

Pipe crossings over open channels, including those in the Gladesville catchment (downstream of Morrison Road) were represented in a similar manner to the footbridges.

### 5.2.9. Floodways through Existing Buildings

Several floodways through existing buildings were identified in the study area. These were located at:

- West Ryde Town Centre: Two arcades through commercial premises, linking up the sag point in Graf Avenue and Victoria Road (Denistone Catchment); and
- 22-26 Herbert Street West Ryde: Floodway through underground car park of a commercial/residential apartment complex (Charity Creek Catchment).

These floodways function by conveying floodwaters from the upstream sag point, through the building and discharging them to the overland flow path downstream of the building. They were represented as rectangular culverts in the TUFLOW model.

## 5.3. Blockages

Partial blockage was applied to the majority of stormwater pit inlets, culverts, bridges and waterway crossing mesh-type fences aligned perpendicular to the direction of flow. Stormwater pit inlets were assigned a 20% blockage for on-grade pits and a 50% blockage for sag pits, consistent with the DRAINS modelling. A zero blockage was adopted in consultation with Council for the main high capacity inlet to the West Ryde Tunnel located at New Betts Street, West Ryde.

Culverts and bridges were assigned the following blockage factors, consistent with previous flood studies in Ryde LGA (Bewsher Consulting, 2010):

- 25% blockage for waterway openings with a diagonal dimension greater than 6m;
- 35% blockage for waterway openings with a diagonal dimension of 2 to 6m; and
- 50% blockage for waterway openings with a diagonal dimension less than 2m.

Mesh-type fences at waterway crossings and other selected additional mesh fences, such as along the boundary of the Ryde-Parramatta Golf Course, were assigned a blockage factor of 35%.

## 5.4. Boundary Conditions and Initial Conditions

### 5.4.1. Model Inflows

Runoff generated in the pit sub-catchments from the DRAINS model was input to the TUFLOW model, either:

- At the pits located within each sub-catchment. The sub-catchment flow hydrograph was equally split and then assigned to each pit inlet in the sub-catchment. Sealed pits are not assigned a flow. The amount of surface flow entering the pit is dictated by the pit inflow relationship. Flows in excess of the pit inlet capacity remain in the 2D model domain as point inflows, subsequently forming overland flow, or;
- At the outlet to the sub-catchment if there are no pits in that sub-catchment, for example, in forested sub-catchments. Flows are input at the lowest point of the sub-catchment

Pit surcharge flows are caused when flows in the drainage network exceed network capacity and spill out of the pits and into the 2D domain. Pit surcharges would similarly form overland flow in the model. Depending on the hydraulic conditions in the pipe system, overland flows can re-enter the pipe system via the stormwater pits.

### 5.4.2. Tailwater Conditions

A constant tailwater level of 1m AHD was applied at the downstream boundary of each catchment. This is approximately equivalent to a king high tide at Fort Denison tidal gauge.

Flows out of the Gladesville Catchment into Hunters Hill LGA, across Pittwater Road at Cambridge Street, Gladesville, were represented assuming a normal-depth flow condition at the model boundary at this location.

### 5.4.3. Initial Water Levels

An initial water level of 1m AHD was adopted, corresponding to the adopted tailwater levels at the downstream end of the catchments.

Additional initial water level conditions were applied at the ponds in the Ryde-Parramatta Golf Course and in the detention basin/water quality pond in the Royal Rehabilitation Centre Sydney, corresponding to the permanent water levels in these ponds.

## 5.5. Model Verification

Rigorous model calibration of overland flood models cannot generally be carried out because direct measurements of overland flows and accurate measurements of flood levels are usually not available. Hence, overland flood models are often validated using observations of flood depths and flood behaviour as a way of “sanity-checking” the modelling and confirming its reliability.

This study has relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information is considered indicative as only the general location of the observation is usually given, the depths are often rounded up to the nearest 0.1m, and there are often uncertainties about the year that the flood event occurred, for example, in some cases the flooding was reported to have occurred in the "mid 1980's". Additionally, there are likely to have been changes to the topography, buildings and other structures and drainage upgrades which are likely to result in differences between the modelling based on current conditions and observations from decades ago. However, the reported flood depths are still useful information for validating the general behaviour of flooding predicted by the flood models.

The flood model results have also been compared to results from previous flood studies in the study area as a validation against other estimates.

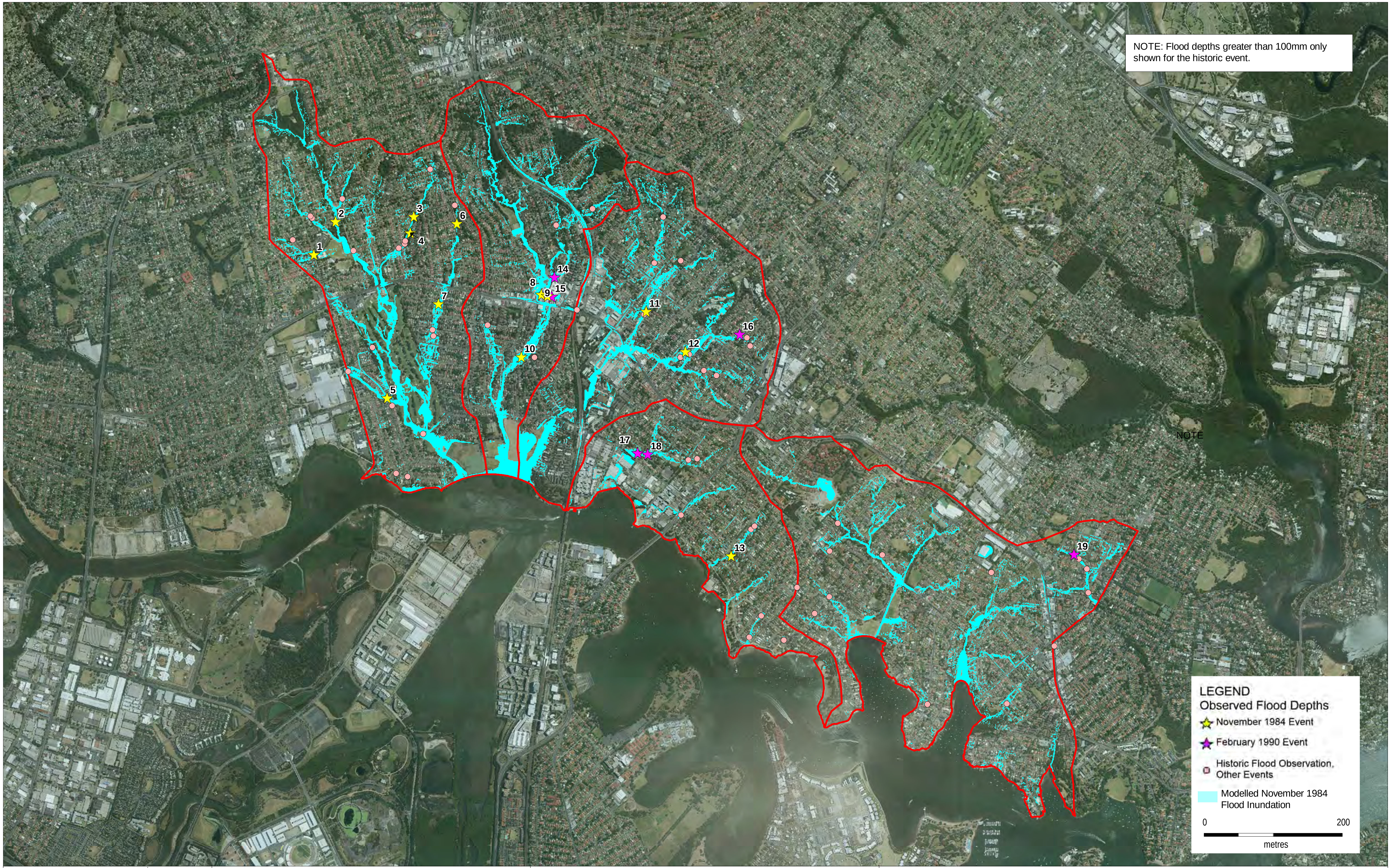
### 5.5.1. Comparison to Observed Flood Depths

The questionnaire responses and additional information from Council's data base were reviewed for observations of historic flood events. Out of 1,726 questionnaires distributed by Council, 319 responses were received, with 75 observations reported in total. Out of the total number of observations, 71 could be located on a map, though there is uncertainty about the date and exact location of some of these observations, and in some instances a depth was not reported.

A count of the number of observations per flood event revealed that the most number of observations were reported for the November 1984 event (13 responses) and the February 1990 event (7 responses). The DRAINS and TUFLOW models were therefore run for the 1984 and 1990 storm events. Note that since these events pre-date the construction of the West Ryde Stormwater Tunnel, the inlets to the Tunnel were blocked off in the TUFLOW model for the simulation of the historic events.

Additional observations were obtained from the previous flooding and drainage studies in the study area. The resulting flood depths from the TUFLOW models are compared to observed flood depths in **Table 5-2** and **Table 5-3** for the November 1984 and February 1990 events, respectively. Locations of the observed flood depths for the verification flood events are shown on **Figure 5-1**.

The TUFLOW model produces an acceptable match to the observed flood depths in the historic events.




SINCLAIR KNIGHT MERZ SKM

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Datum: GDA 1994
Coordinate System: MGA Zone 56

Parramatta River - Ryde Sub-Catchments
Flood Study and Floodplain Risk Management Plan

**Figure 5-1**
**Historic Flood Depth Observations for Model Verification Events**

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**Table 5-2 Comparison of TUFLOW Results to Observed Flood Depths – November 1984 Event**

| ID | Location | Catchment | Observed Depth (m) | Modelled Depth (m) | Difference (m) | Comment |
|---|---|---|---|---|---|---|
| 1 | Winbourne St , West Ryde, | Archer Creek | 0.5 | 0.32 | -0.18 | |
| 2 | 3 Daphne St, West Ryde | Archer Creek | 0.8 | 0.51 | -0.29 | Depths in the order of 0.8m on the adjacent lot |
| 3 | Driver St, Denistone, | Archer Creek | 0.6 | 0.52 | -0.08 | |
| 4 | 30 Mirool St, Denistone | Archer Creek | 0.3 | 0.09 | -0.2 | Modelled 0.4m depth in open space behind property |
| 5 | Cobham Ave, Melrose Park | Archer Creek | 0.4 | 0.35 | -0.05 | Assumed location in low point of Cobham Ave. Exact location unknown. |
| 6 | 43 Shaftsbury St, Denistone | Archer Creek | 0.3 | 0.29 | 0.01 | |
| 7 | 30 Hay St, West Ryde | Archer Creek | 0.5 | 0.52 | 0.02 | |
| 8 | 1 Chatham Rd, West Ryde | Denistone | 1 | 1.12 | 0.12 | |
| 9 | West Ryde Arcade | Denistone | 1.5 | 1.70 | 0.2 | |
| 10 | Station St, West Ryde | Denistone | 0.3 | 0.41 | 0.09 | Exact location could not be determined. |
| 11 | 61a Falconer St, West Ryde | Charity Creek | Not stated | 0.58 | N/A | |
| 12 | 27 Bowden St, Ryde | Charity Creek | 0.5 | 0.24 | -0.26 | |
| 13 | 3 Watson St, Putney | River | 0.15 | 0.23 | 0.08 | |

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**Table 5-3 Comparison of TUFLOW Results to Observed Flood Depths – February 1990 Event**

| ID | Location | Catchment | Observed Depth (m) | Modelled Depth (m) | Difference (m) | Comment |
|---|---|---|---|---|---|---|
| 13 | 3 Watson St, Putney | River | 0.15 | 0.10 | -0.05 | |
| 14 | West Ryde shopping centre | Denistone | 0.6 | 0.65 | 0.05 | |
| 15 | Graf Ave, West Ryde | Denistone | 1.0 | 1.67 | 0.67 | Exact location of observation not known. Assumed to be at low-point in Graf Ave, where maximum depth occurs. |
| 16 | 10 Colston St, Ryde | Charity Creek | 0.6 | 0.33 | -0.27 | Existing house on this property is recent. Greater flood depth may have occurred with pre-development landform |
| 17 | Ann Thorn Park, Ryde | River | 1.5 | 1.14 | -0.36 | |
| 18 | 11 Richard Johnson Cres, Ryde | River | 1.2 | 0.62 | -0.58 | Respondent noted that Council improved the drainage under Constitution Road (downstream of location) soon after 1990 event, which is what is represented in TUFLOW and is likely to account for the reduced flood depth. |
| 19 | Albert St, Gladesville, | Gladesville | <0.5 | 0.32 | < 0.18 | |

### 5.5.2. Comparison to Previous Studies

Peak flows for the 1% AEP event from the TUFLOW model were compared to estimates from previous studies and available catchment and drainage models from Council. These are summarised in **Table 5-4** for various locations across the five study area catchments. For the current study, peak flows are the total flow at the stated location (pipe and overland flow), unless specified.

The peak flows from the current study are typically within +/- 30% of the previous studies and models, which is considered to be a satisfactory result.

### 5.5.3. Conclusions on Model Verification

The TUFLOW model results have been verified against observed flood depths in two historic flood events ranging in AEP from 20% AEP (February 1990 event) to 5% AEP (November 1984 event), with an acceptable match to the observed flood depths. The model peak flows have also been compared to flow estimates in previous studies for the 1% AEP event, with generally good agreement between the current and previous flow estimates. The current TUFLOW models are therefore considered to be suitable for the estimation of design flood behaviour in the study area.

### Table 5-4 Comparison of Peak 1% AEP Flows from Current and Previous Studies

| Location | Peak Flow ($m^3/s$) | | | Source of Previous Estimate | Note |
|---|---|---|---|---|---|
| | Current Study | Previous Study | Current as % of Previous | | |
| **River Catchment** | | | | | |
| Outflow to Parramatta River east of Bowden St | 8.01 | 8.36 | 96 | "1_Ann Thorn_Existing_Drainage_System as at Apr 2010.drn" DRAINS model from Council | |
| Ann Thorn Park | 10.28 | 8.68 | 118 | Table 4.2 Meadowbank river Catchment - Masterplan (Rose Consulting, 2001) | Overland flow only, non-upgraded drainage |
| Well Street | 3.46 | 3.41 | 102 | Table 4.2 Meadowbank river Catchment - Masterplan (Rose Consulting, 2001) | Overland flow only, non-upgraded drainage |
| **Charity Creek Catchment** | | | | | |
| Shepherd Street | 9.30 | 10.28 | 91 | Figure A9 Charity Creek Cascades Overland Flow Study and Detailed Design (WMAwater, 2009) | |
| | | 7.60 | 122 | Ryde Stormwater Drainage Investigation (Willing & Partners, 1990) | |
| Griffiths Avenue | 24.82 | 28.89 | 86 | Figure A9 Charity Creek Cascades Overland Flow Study and Detailed Design (WMA, 2009) | |
| | | 20.90 | 119 | Ryde Stormwater Drainage Investigation (Willing & Partners, 1990) | |
| Linton Avenue | 24.54 | 30.38 | 84 | Figure A9 Charity Creek Cascades Overland Flow Study and Detailed Design (WMAwater, 2009) | |
| Victoria Road | 42.67 | 51.00 | 84 | Table 5 Charity Creek Cascades Overland Flow Study and Detailed Design (WMAwater, 2009) | |
| Rhodes Street | 54.25 | 77.30 | 70 | Table 6.6 Ryde Stormwater Drainage Investigation (Willing & Partners, 1990) | Not clear if the significant amount of floodplain storage is represented in the previous study |

| Location | Peak Flow ($m^3/s$) | | | Source of Previous Estimate | Note |
|---|---|---|---|---|---|
| | Current Study | Previous Study | Current as % of Previous | | |
| Charity Creek Outlet | 66.74 | 88.60 | 75 | Table 6.6 Ryde Stormwater Drainage Investigation (Willing & Partners, 1990) | Not clear if the significant amount of floodplain storage is represented in the previous study |
| **Denistone Catchment** | | | | | |
| Station St at Dunmore Road (south of Victoria Road) | 44.27 | 36.50 | 121 | Table 5.1 West Ryde Denistone Catchment Stormwater Drainage Management Study (Ryde City Council 1992) | |
| **Archer Creek Catchment** | | | | | |
| Archer Creek Outlet | 98.61 | 100.00 | 99 | Mid Parramatta (North) River Stormwater Management Plan | |
| **Gladesville Catchment** | | | | | |
| Morrison Bay Park | 47.45 | 54.00 | 88 | "GLAD_Ex_4.xp" XP-RAFTS model from Council | |

# 6. Estimation of Design Floods

## 6.1. Simulated Design Events

The storm events modelled include the 20%, 10%, 5%, 2% and 1% AEP and PMF events. The storm durations assessed include the 15, 25, 60, 90 and 120 minute duration for the 20% to 1% AEP events, and the 15, 30, 45, 60 and 90 minute durations for the PMF event.

## 6.2. Flood Mapping

The maximum indicative flood depths are presented for each catchment and for all magnitude events assessed in **Appendix A**. The peak flood levels for the 1% AEP and PMF events are presented in **Appendix B**. The maps indicate the areas affected by flood depths greater than 100mm only, to ensure that areas affected by shallower flows are not shown as being “flood affected”.

Note that the floodplain within the study area is depicted as being the area lower than Council’s most upstream stormwater pits in the catchments. Local drainage issues may still occur in the areas above the most upstream pits, which have not been assessed in this study.

## 6.3. Flood Planning Area

The flood planning area, depicting the extent of the area affected by the 1% AEP flood plus an additional 0.3m in flood level, is shown in **Appendix C**. Properties within the flood planning area may be considered as requiring development controls to ensure that there is sufficient freeboard above the 1% AEP flood. The flood planning area is shown for tailwater conditions during:

- Present conditions – assumed high tide level of 1m AHD in the current climate,
- Conditions in 2050 – a 0.4m rise in sea level (relative to 1990 mean sea level), overlying the 5% AEP ocean level at Fort Denison, resulting in a tailwater level of 1.74m AHD; and
- Conditions in 2100 – a 0.9m rise in sea level (relative to 1990 mean sea level), overlying the 5% AEP ocean level at Fort Denison, resulting in a tailwater level of 2.24m AHD.

Refer to **Section 6.7** for further details on the climate change impact modelling. The guidance for applying the predicted sea level rise on top of the 5% AEP ocean level is taken from *Flood Risk Management Guide – Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments* (NSW Government, 2010).

The flood planning area extents were derived in GIS by creating a Triangulated Irregular Network (TIN) from the 1m interval flood level contours of the 1% AEP flood surface plus 0.5m, extended laterally from each flow path and intersected with the ground surface to determine the extent. A visual review was undertaken to check whether the flood planning area extent was effectively a lateral expansion of the flood inundation extent, and manual adjustments to the flood planning area extent were made where required. Given the irregularity of the terrain and complexity of the overland flooding patterns in some areas, there was some level of interpretation required in the delineation of the flood planning area. Locations where interpretation of the extent was needed include:

- Areas on the low side of a road, where the road forms a flow path and is deemed to be flooded. These were generally defined as being inside the flood planning area;
- Areas around the junction of two flow paths; and
- Where the automated procedure delineated small “dry” or “wet” areas, which were typically removed.

The mapping indicates that there is only minor expansion of the flood extents and flood planning area extents from the present conditions to the 2050 and 2100 sea level rise scenarios. This minor expansion of extents occurs at the downstream extremities of the catchments, with virtually no change in other parts of the catchments due to the relatively steep terrain. Note that areas with shallow flooding depths have not been filtered out of the flood planning areas.

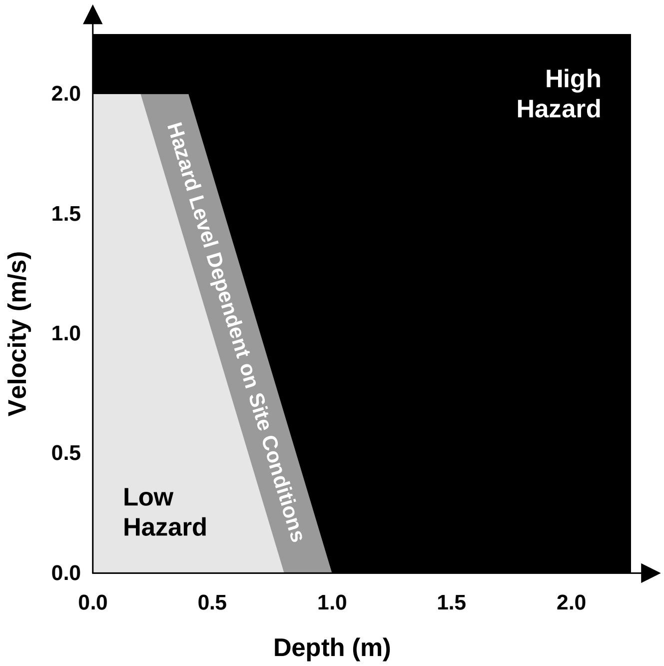
## 6.4. Provisional Flood Risk Precinct Mapping

The TUFLOW modelling results were used to delineate flood risk precinct areas, as agreed with Council, for the study area from interpretation of the 1% AEP and PMF event results, based on the flood risk precinct definitions described in **Table 6-1.** The provisional flood risk precinct definitions were derived, in part, from the hydraulic hazard category diagram presented in the *Floodplain Development Manual* (NSW Government, 2005), shown in **Figure 6-1**, and from discussion with Council. Shallow depths less than 100mm have been filtered out from the Medium and Low risk precinct extents, and small, isolated patches of flooding which were not part of a main flow path have also been filtered out.

- **Table 6-1 Provisional Flood Risk Precinct Definitions**

| Risk Precinct | Description |
|---|---|
| High | The area of land below the 1% AEP flood outline that is subject to high hydraulic hazard as defined by Figure L2 of Appendix L in the *Floodplain Development Manual* as reproduced in **Figure 6-1**. The High Hazard area describes areas where floodwaters present a danger to personal safety, could cause structural damage to buildings and where the resultant social disruption and financial losses could be high. |
| Medium | Land below the 1% AEP flood outline that is not in the High Risk Flood Precinct |
| Low | All other land within the floodplain (i.e. within the extent of the PMF) but not identified within either the High Risk or Medium Risk Precincts. |

- **Figure 6-1 Hydraulic Hazard Category Diagram (reproduced from Figure 6-1 in *NSW Floodplain Development Manual*)**




Hazard categories delineated in this study are based on depths and velocities of floodwaters and do not consider evacuation, isolation, flood damages and social impacts of flooding, hence, these categories are considered provisional.

## 6.5. Discussion on Existing Flood Behaviour

Flooding in the study area occurs in natural watercourses and flow paths in which development has occurred. Roads form the main overland flow path in many locations, while floodwaters also flow through neighbourhood properties in other locations. The concrete-lined channels at the downstream ends of the catchments have a capacity of approximately the 5 - 10% AEP event.

Relatively deep overland flows (up to 0.4m in the 1% AEP event), as opposed to shallow sheet flow, discharge from the Gladesville Catchment into the Hunters Hill LGA across Pittwater Road at Cambridge Street, Gladesville.

Up to 44 individual roads would experience maximum depths of flooding exceeding 0.3m in the 20% AEP event along the road centreline, rising to 79 roads in the 1% AEP event. This depth of flooding is indicative of these roads becoming impassable to vehicles, though the safe depth of flooding may be lower depending on the overland flow velocity. Up to 588 properties (including private and public lot parcels) contain areas of provisionally high flood risk, which will need to be updated to reflect true flood risk with consideration of evacuation, isolation, flood damages and social impacts of flooding.

There are a number of significant obstructions to flow in the study area, and the depth of flooding in these locations are described in **Table 6-2**. Key developed areas experiencing deep flooding are also included in the table.

**Table 6-2 Flood Depths at Major Flow Obstructions and Key Developed Areas**

| Location | Catchment | Maximum Depth (m) | | |
|---|---|---|---|---|
| | | 20% AEP | 1% AEP | PMF |
| Main Northern Railway downstream of Meadowbank TAFE | Charity Creek | 3.0m | 6.0m | 14.1m (up to 10.3m on TAFE grounds) |
| Victoria Road between Falconer Street and Linten Lane, West Ryde | Charity Creek | 2.1m | 2.5m | 7.1m |
| Main Northern Railway at Denistone Station | Denistone | 2.0m | 3.7m | 5.5m |
| Main Northern Railway: Depths on East Parade at Fourth Avenue | Denistone | 0.2m | 1.0m | 4.7m |
| Constitution Road: Depths in Ann Thorn Park | River | 2.3m | 3.5m | 4.3m |
| 22-26 Herbert Street, West Ryde | Charity Creek | 0.8m | 1.6m | 2.7m |
| Industrial area between Victoria Road and Rhodes Street, West Ryde | Charity Creek | 3.3m | 3.6m | 8.3m |
| West Ryde Town Centre (Graf Avenue) | Denistone | 0.6m | 1.0m | 3.9m |
| Industrial complex off Tennyson Road opp. Searle Street, Gladesville | Gladesville | 0.6m | 1.0m | 3.1m |

There are locations within the study area where floodwaters appear to build up to excessive depths against buildings, which were represented as solid obstructions. One location includes a townhouse development at 22 Anzac Avenue, West Ryde. The potential flooding at this location could not be ground truthed as the area where floodwaters are trapped is on private property and could not be accessed or viewed from the street. From the aerial photography, there appear to be no gaps between the townhouses to allow water to flow out of the low point in this area. Floodwaters would need to flow through doorways or windows to pass through the building. The potential for flooding of this property should be further investigated during the Floodplain Risk Management Study.

## 6.6. Sensitivity Analysis

A number of scenarios have been assessed for the 1% AEP 2 hour storm event, which is the critical event at the lower parts of the catchments, to test the sensitivity of the model results to changes in the adopted parameter values. The scenarios are described and the impacts summarised in **Table 6-3**.

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- **Table 6-3 Sensitivity Analysis Description and Results**

| Scenario | Description | Change in Flood Level[1] |
|---|---|---|
| Rainfall losses – increase | Updated DRAINS hydrology - adopt AMC[2] of 2 and double the depression storage (2mm for paved areas; 10mm for grassed areas) | Typically less than 30mm decrease in flood levels globally.<br>Up to 60mm decrease in West Ryde Town Centre (Graf Ave) and 0.6m decrease immediately downstream of Meadowbank TAFE. |
| Rainfall losses – decrease | Updated DRAINS hydrology - adopt AMC of 4 and 0mm in the depression storage | Typically less than 10mm increase in flood levels globally, with up to 0.1m increase in main flow paths.<br>Up to 30mm increase in West Ryde town centre (Graf Ave) and 0.35m increase within the storage area upstream of the Main Northern Railway at Meadowbank. |
| Friction | Increase Manning's n in TUFLOW 1D and 2D domain by 20% | Typically less than +/- 10mm change in flood levels globally. Some localised changes of +/- 0.1m in flood levels. |
| Energy losses | 50% increase in loss coefficient at pits/culvert entrances in TUFLOW | Typically no change in flood level globally. Localised increases of 0.1m immediately upstream of major drainage structures (road and railway cross-drainage culverts). |
| Blockage | Zero blockage at culverts, bridges and pits in TUFLOW | Typically no change in flood level globally. Localised decreases of up to 0.25m upstream of several culverts, with the storage area upstream of the Main Northern Railway at Meadowbank experiencing a decrease in flood level of 0.75m.Some localised increases of up to 0.15m. |
| Reduced tailwater level: 0m AHD | Approximately mid tide | Typically no change in flood level globally. Localised decreases of up to 0.9m in concrete channel in Gladesville Catchment |
| Reduced tailwater level: -0.9m AHD | Lowest Astronomical Tide at Fort Denison | Typically no change in flood level globally. Localised decreases of up to 1.1m in concrete channel in Gladesville Catchment |

1 Comparison of sensitivity case to design case peak flood level in 1% AEP 2 hour event.

2 Antecedent Moisture Condition.

## 6.7. Impact of Climate Change on Flooding

### 6.7.1. Impacts due to Increased Rainfall and Sea Level

The impact of climate change on flooding in the study area has been assessed by adopting the following changed conditions:

- Rainfall intensity: Increase of 10%, 20% and 30% in design rainfall intensity.
- Increase in sea level corresponding to the years 2050 (0.4m increase) and 2100 (0.9m increase). These sea level increases have been superimposed on the 5% AEP ocean level at Fort Denison, resulting in a catchment tailwater level of 1.74m AHD and 2.24m AHD for the 2050 and 2100 scenarios, respectively.

The DRAINS models were rerun with the increased rainfall intensities, and the resulting sub-catchment hydrographs input into the TUFLOW models with the increased tailwater levels. The climate change impacts were assessed for the 1% AEP 2 hour storm event.

The climate change impacts on flood depths are mapped in **Appendix F** at the study area scale, and summarised in **Table 6-4**. On the broad catchment scale, the increase in rainfall intensity results is the most widespread impact, hence the description of the impacts is organised based firstly on the increased rainfall intensity. Due to the steepness of the catchments the impact of sea level rise on flooding is restricted mainly to the catchment outlets and the immediate vicinity of the Parramatta River shoreline, in areas where catchment runoff flows directly to the River instead of the creek outlets.

### 6.7.2. Impacts due to Sea Level Rise only

The design 1% AEP flood event was modelled for all durations with the sea level rise scenarios described in **Section 6.7.1** for derivation of the flood planning areas for these future scenarios (see **Section 6.3**). An analysis of tidal inundation (with no concurrent catchment flooding) during the sea level rise scenarios has also been undertaken, and is described here.

The majority of residential properties in the study area are not directly at risk from tidal inundation due to sea level rise only, as properties along the Parramatta River shoreline are generally located on steep land with residences above 3m AHD. The exceptions are properties along the River shoreline in the Archer Creek Catchment, where residences are located as low as 1.5m AHD.

The ground level contour lines corresponding to the 2050 and 2100 sea level imposed on several tidal and river flooding scenarios are mapped on figures in **Appendix F**. The scenarios include:

- Mean High Water Spring (0.68m AHD) plus sea level rise;
- Highest Astronomical Tide (1.15m AHD) plus sea level rise; and
- 5% AEP ocean level (1.34m AHD) plus sea level rise.

These scenarios cover typical high tides, “king” tides and tidal influences combined with storm surge and other elevated ocean level events.

## Table 6-4 Climate Change Impact Summary

| Increase in Rainfall Intensity[1] | Typical Increase in Flood Depth[2] | | | |
|---|---|---|---|---|
| | On Catchment Surface[3] | Within Flow Paths | In Main Storages | At Catchment Outlets[4] |
| 10% | < 0.01m | Up to 0.1m | 0.1m in West Ryde Town Centre.<br>0.25m upstream of railway, along East Pde (Denistone Catchment).<br>0.45m downstream of Meadowbank TAFE.<br>0.1m in Ann Thorn Park, 0.2m downstream of Ann Thorn Park.<br>0.2m in RRCS basin. | Up to 0.15m in the 2050 scenario and up to 0.3m in the 2100 scenario, in Meadowbank Park (Archer Creek outlet) and Morrison Bay Park (Gladesville Catchment). |
| 20% | Typically < 0.01m, up to 0.03m. | 0.1 – 0.2m, some areas up to 0.35m | 0.3m in West Ryde Town Centre.<br>0.45m upstream of railway, along East Pde (Denistone Catchment).<br>0.9m downstream of Meadowbank TAFE.<br>0.15m in Ann Thorn Park, 0.4m downstream of Ann Thorn Park.<br>0.4m in RRCS basin. | Up to 0.3m in the 2050 scenario and up to 0.35m in the 2100 scenario, in Meadowbank Park (Archer Creek outlet) and Morrison Bay Park (Gladesville Catchment). |
| 30% | Typically < 0.01m, up to 0.03m. | 0.1 – 0.3m, some areas up to 0.4m | 0.6m in West Ryde Town Centre.<br>0.6m upstream of railway, along East Pde (Denistone Catchment).<br>1.35m downstream of Meadowbank TAFE.<br>0.2m in Ann Thorn Park, 0.6m downstream of Ann Thorn Park.<br>0.5m in RRCS basin. | Up to 0.3m in the 2050 scenario and up to 0.4m in the 2100 scenario, in Meadowbank Park (Archer Creek outlet) and Morrison Bay Park (Gladesville Catchment). |

1 Increase from design rainfall intensity.

2 Change from existing conditions.

3 Denotes areas of the floodplain where shallow sheet and overland flows characterise the flooding behaviour.

4 The table does not describe the flood level increases due to the increase in sea level of up to 0.74m for the 2050 scenario directly due to increase in tailwater level, and 1.24m for the 2100 scenario. These impacts are generally restricted to the immediate vicinity of the Parramatta River shoreline, with large increases also within the Gladesville Catchment concrete channel (Morrison Bay Park).

# 7. Identified Flooding Hot-Spots

## 7.1. Overview

Ten locations have been identified in consultation with Council from the TUFLOW model results as flooding "hot-spots", where existing development is at risk from flood damage and capital works may be feasible for flood mitigation. The ten locations and possible mitigation works are briefly discussed in this section. More detailed assessment of mitigation works at these locations will be undertaken using the TUFLOW model in the FRMS following discussion and agreement with Council. Other non-structural measures should also be considered for these and other locations in the study area, and will be evaluated in the FRMS.

## 7.2. Cobham Avenue, Melrose Park (Archer Creek Catchment)

Flooding in this area (refer to **Figure 7-1**) affects the rear of 79 and 81 Cobham Avenue to a depth of 0.6m in the 1% AEP event, in addition to the sag point of the road, where flood depths are up to 0.6m. There is an existing floodway and easement at the rear of the properties on Cobham Avenue which follows the natural creek line, however, localised undulations in the ground surface in the floodway act as minor flow obstructions and also divert flows onto the residential properties. A high road verge on the eastern side of Cobham Avenue prevents surface flows from draining away from the sag freely.

Minor earthworks in the floodway and the road verge may reduce flood depths at this location. There are two existing trees in the floodway which may be a constraint to the extent of earthworks.

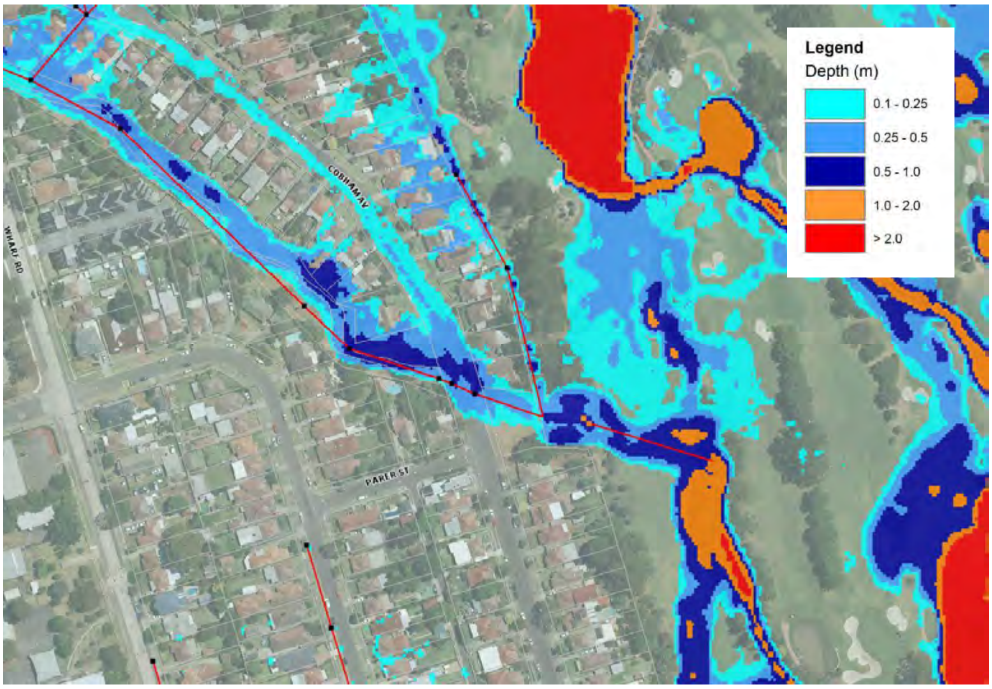
## 7.3. West Ryde Town Centre (Denistone Catchment)

West Ryde town centre has historically been a problem area for flooding, and the West Ryde stormwater tunnel has significantly improved flooding conditions (refer **Figure 7-2**). There are some remaining locations in the existing case where flooding in the 1% AEP event may impact on properties, including the low point in Graf Avenue where flood depths are up to 1m and floodwaters would enter adjacent commercial premises.

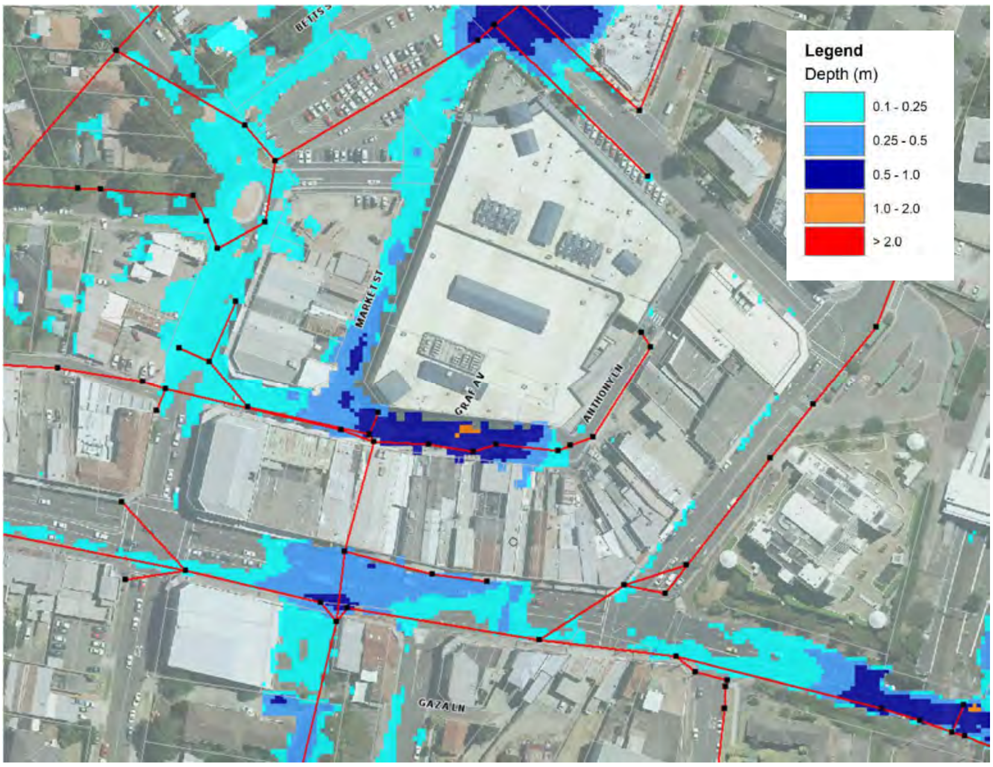
A potential mitigation option in this location involves increasing pit inlet capacity on Graf Avenue, as there appears to be redundant pipe capacity in the pipe branch that drains this location. It is recommended that pit depths and pipe alignments in this area be considered in greater detail in the field, as there were numerous gaps in the Council stormwater GIS layer in this area and inspection by SKM flood modellers could not fill the data gaps with full certainty.

A new pipe branch connection to the stormwater tunnel, which appears to have redundant capacity, is likely to be prohibitively expensive and has not been considered further.

- **Figure 7-1 Cobham Avenue, Melrose Park, with 1% AEP flood Depth**



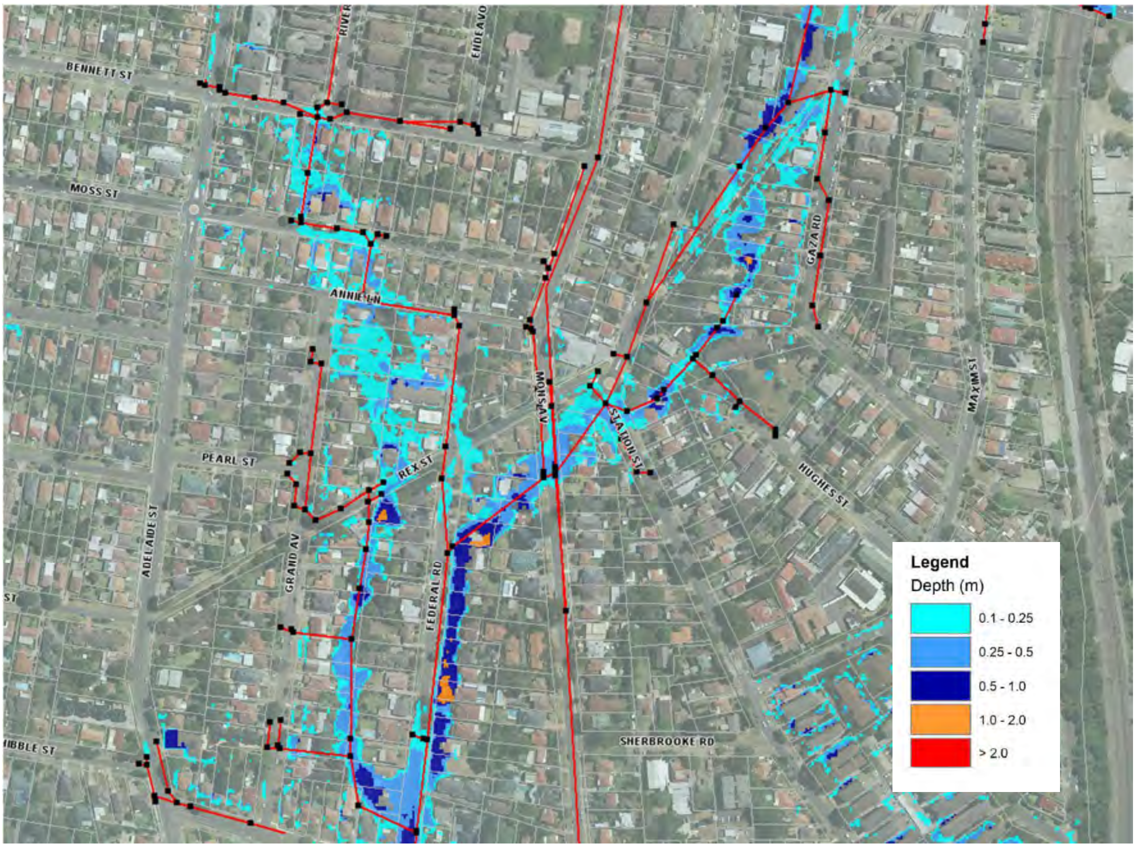

- **Figure 7-2 West Ryde Town Centre with 1% AEP flood Depth**



## 7.4. Gaza Road – Station Street – Federal Road, West Ryde (Denistone Catchment)

Flooding occurs mainly at the rear of on Gaza Road and Station Street, with flooding depths up to 0.75m in the 1% AEP event. The same flow path continues across Mons Avenue and onto the front of properties on Federal Road (refer **Figure 7-3**).

- **Figure 7-3 Gaza Road ,Station Street and Federal Road flow path, with 1% AEP flood Depth**




Most of the Federal Road properties have a defined floodway and their driveways include a dip to accommodate this overland flow. However, this has not been provided at 26 Federal Road, which causes a 1m high obstruction to flows from 24 Federal Road and depths up to 1.3m. There also may not be any provision to drain the ponded water away from 24 Federal Road. The properties downstream of 26 Federal Road do not appear to have a well defined floodway as present upstream. It is observed that the habitable floor levels are above the 1% AEP flood level, though it is likely that floodwaters would enter the garage and lower levels of the houses.

For the properties on Gaza Road and Station Street, pit inlet amplification may assist in reducing flood depths, although there may be pipe constraints further downstream at Mons Avenue. This could potentially be improved by connecting the pipe to the stormwater tunnel, which has some redundant capacity at Mons Avenue. Any upgrades to pit capacity at West Ryde Town Centre would need to be considered in conjunction with Gaza Road pit capacity amplifications.

For the properties on Federal Road, regrading the front yard and driveway of 26 Federal Road would result in a significant improvement to flooding on upstream properties, but may increase flooding on the downstream properties. Reducing the driveway crest at 34 Federal Road, where the floodway spills out to the road, may counter some of this increase.

Lowering Federal Road and the eastern verge to accept flows from the floodway is likely to improve flooding on the properties, however, the road and verge would need to be lowered by 1m or more to significantly reduce flood levels on the properties, and this may also increase the flood hazard to road users in this area. Existing buried utilities are also likely to be constraints. This option is therefore likely to be unfeasible.

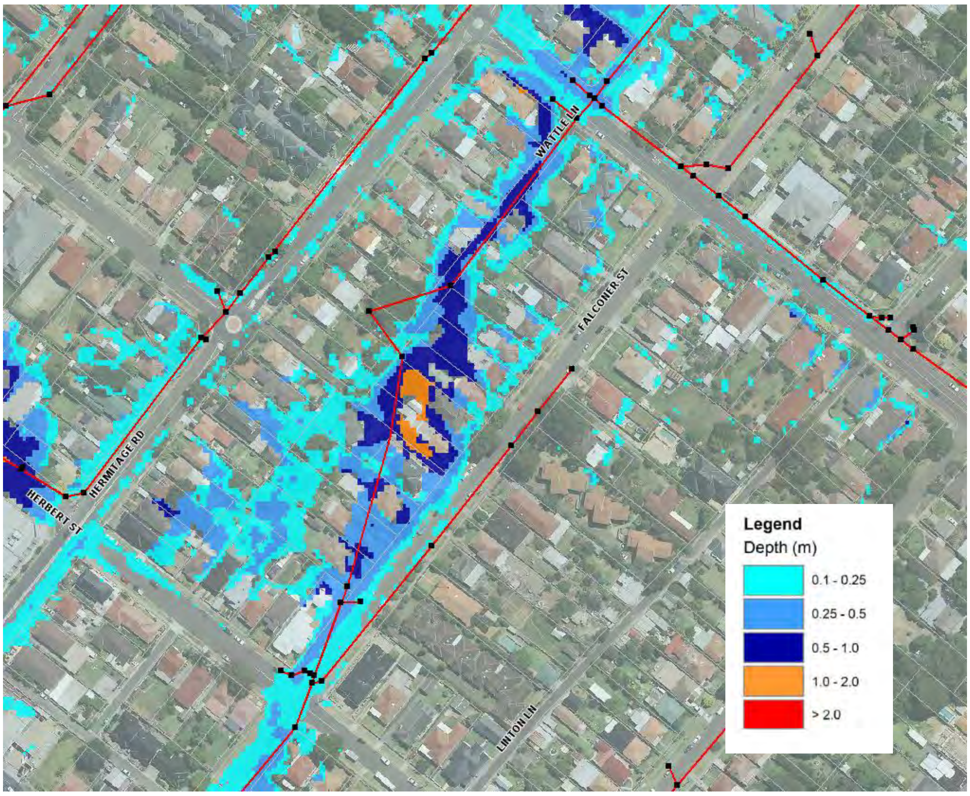
## 7.5. Falconer Street near Wattle Street, West Ryde (Charity Creek Catchment)

Several properties are at risk to flooding in the 1% AEP event, with depths of between 0.8m and 1.2m, due to the overland flow path low point being located at the rear of these properties and Falconer Street raised about 1m above the low point, trapping floodwaters at the rear of the properties. The two properties with the deepest flooding are 57 and 59 Falconer Street. There does not appear to be a sag pit/s draining the low points on these properties (refer **Figure 7-4**).

There is redundant capacity in the pipe branch, which runs through this area, so increasing pit capacity particularly in the low point on the private properties would provide an improvement to flood depths. It is observed that the main Charity Creek trunk drainage branch, which the Falconer Street branch joins upstream of Victoria Road, is at capacity and additional pipe inflows into the system via increase pit capacity on the Falconer Street branch may reduce drainage capacity and have an adverse effect on flooding elsewhere in the catchment.

An alternative option would involve regrading (lowering) the driveways of 57, 59 and/or 61A Falconer Street in addition to the footpath and verge to match the low point level of 20m AHD, to allow the trapped floodwaters to escape from the low point on the private properties. It may require a low retaining wall and fencelines to be reconstructed. The viability of the option is contingent on approval from the residents for construction on their property, location of existing utilities and an assessment of whether acceptable finished surface grades for the driveways and footpath can be achieved. Resultant flood impacts to properties downstream would also need to be considered.

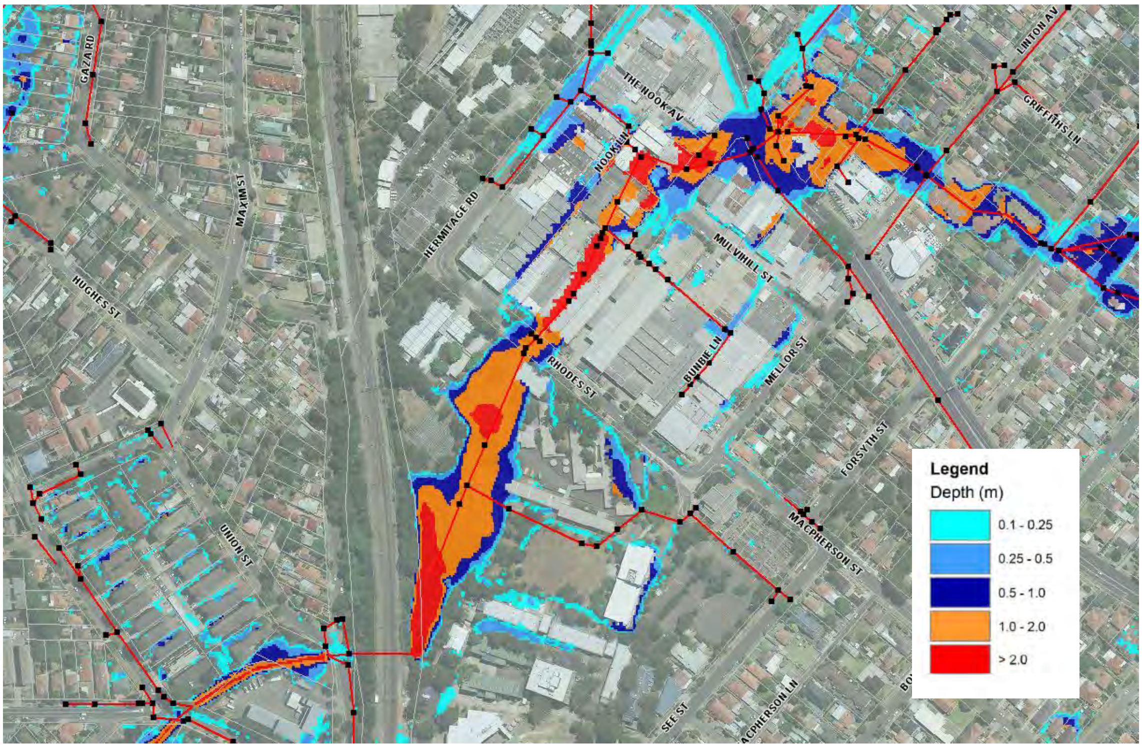
- **Figure 7-4 Falconer Street near Wattle Street flow path, with 1% AEP flood Depth**




## 7.6. Industrial area at Mulvihill Road and Rhodes Street, West Ryde (Charity Creek Catchment)

This area contains the main floodway of the Charity Creek catchment and has been developed with a number of industrial properties being built on fill in the natural watercourse (refer **Figure 7-5**). Some of these properties each have a depression in the ground surface with only relatively small sump pits to drain these low points. Further, there are sheds and possibly concrete boundary walls obstructing flow along the floodway. Downstream of the industrial complex, Rhodes Street and Meadowbank TAFE is built in fill which traps floodwaters on the industrial property at 11 Rhodes Street, particularly in the 20% AEP event. Further downstream, there are irregularities in the ground surface on the TAFE grounds which obstruct flow in the 20% and 5% AEP events, while the Main Northern Railway embankment is a significant obstruction to flow in the 5% and 1% AEP events, with backwater effects up into the industrial area.

- **Figure 7-5 Industrial Area at Mulvihill Street to Rhodes Street and the area downstream, with 1% AEP flood Depth**




The trunk drainage line running through the industrial area is at capacity in the 5% AEP event, hence pit capacity amplification will not have a significant effect on flooding conditions. The most effective options for improving flooding conditions in this area would be:

- Removal of blocking buildings, walls and other obstructions to flow on the industrial properties;
- Lowering Rhodes Street and providing a floodway through the TAFE car park. Alternatively, a new culvert line (approximately 200m) linking the 11 Rhodes Street low point and the low point downstream of the TAFE could be considered; and
- Amplifying culvert capacity through the railway embankment.

Downstream channel and culvert capacity and flood impacts would need to be assessed. Existing utilities and other engineering issues would need to be considered.

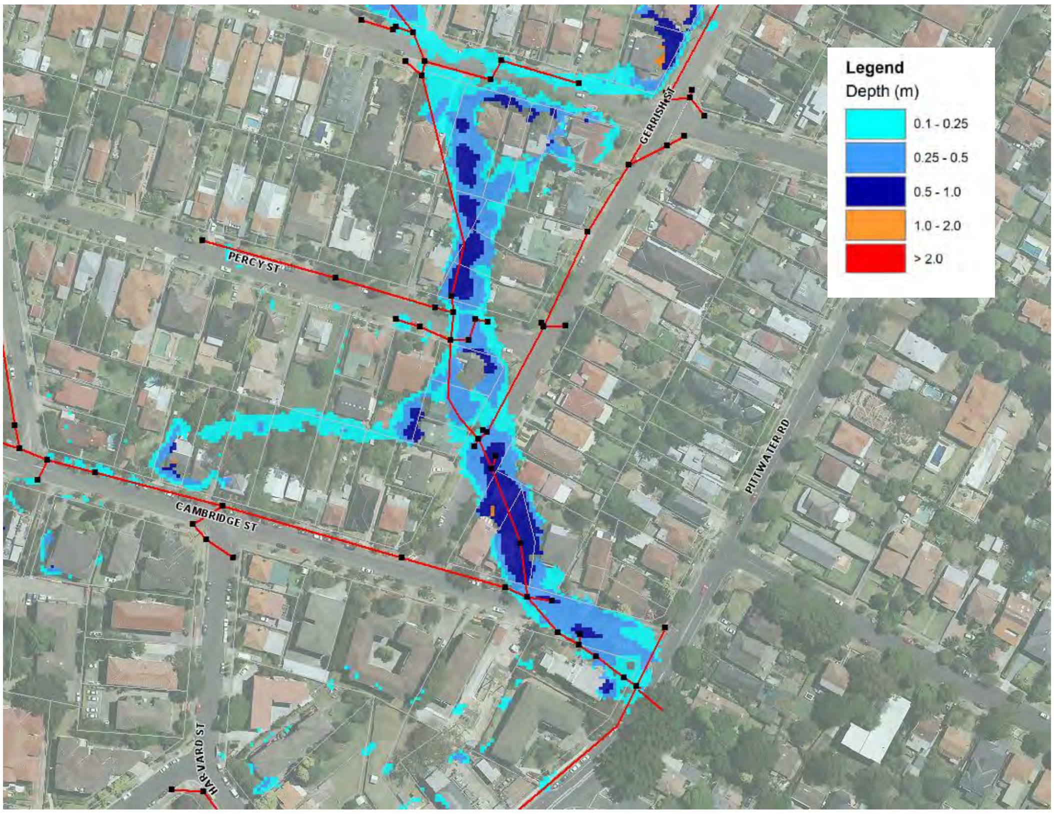
## 7.7. Gerrish Street – Cambridge Street – Pittwater Road, Gladesville (Gladesville Catchment)

Floodwaters flow through residential properties on 22 and 22A Cambridge Street at depths of up to 1m from the low point of Gerrish Street onto Cambridge Street, then tend to cut the corner and flow through 48 Pittwater Road (refer **Figure 7-6**). The apartment block on this property has its basement car park built below the surrounding ground level and there is potential for floodwaters to enter and become trapped in the basement.

The residences on 22 and 22A Cambridge Street are not built in the low point, however, above floor and garage flooding may occur on these properties. It is not possible to divert flows from the Gerrish Street low point to Cambridge Street via the road corridor due to the high surface level at the road junction. There is no redundant capacity in the pipe network to accept additional flows. Additionally, Cambridge Street is not raised and does not obstruct or trap flows from 22A Cambridge Street so re-profiling the footpath or street is not a potential option. Other non-structural measures (e.g. development controls) would need to be considered for these properties.

A diversion structure such as a low block wall would assist in reducing the volume of floodwater entering the basement car park of 48 Pittwater Road. The wall would need to be approximately 0.4m in height and linkage issues would need to be considered with the existing footpath and accessways, including steps up to the apartment entrance and down into the basement. Existing ventilation holes would need to be filled in and relocated above flood level.

- **Figure 7-6 Gerrish Street Area, Gladesville, with 1% AEP flood Depth**



## 7.8. Morrison Road at Gregory Street, Putney (Gladesville Catchment)

The natural flow path is through the back of properties on Morrison Road, with flooding depths of up to 1.3m experienced in the 1% AEP event (refer **Figure 7-7**). The dwellings of most of the properties are located on higher ground out of the flow path, with the exception of a few of the properties near the intersection with Gregory Road. The property at 141 Morrison Road is the worst-affected by flooding in this location.

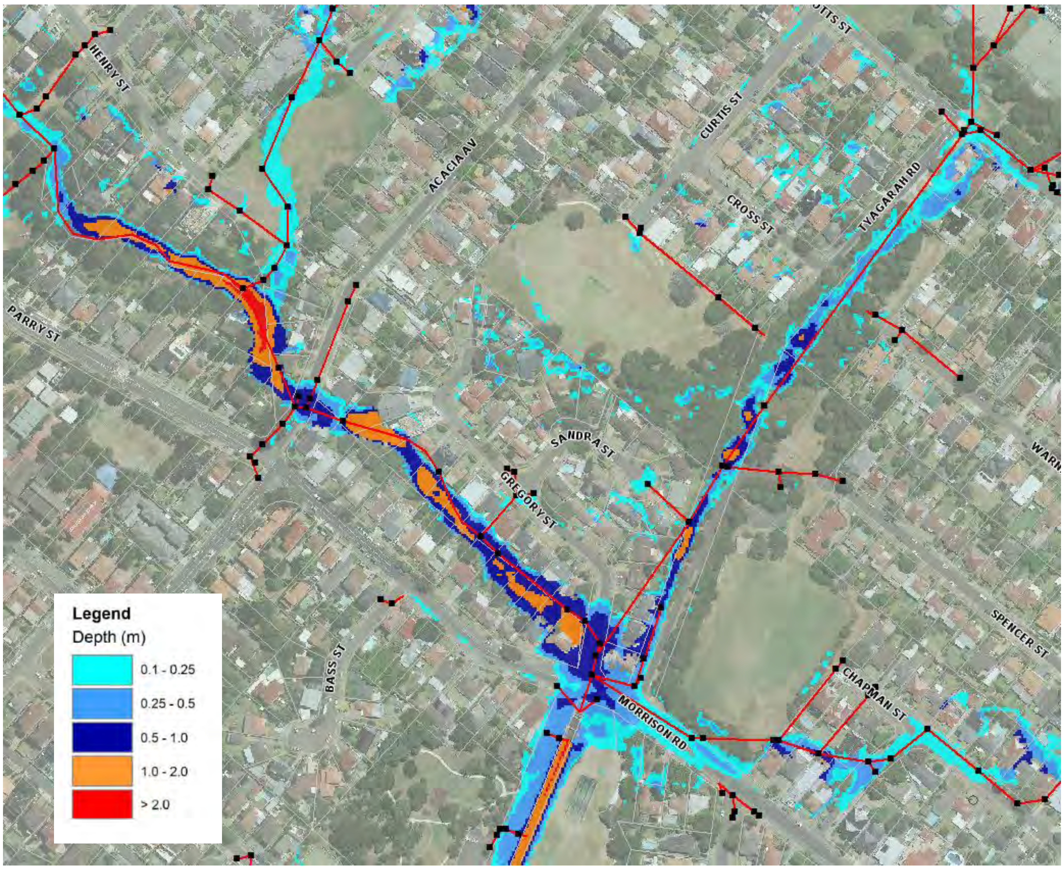
Both Morrison Road and Gregory Street are raised above the natural surface and obstruct floodwaters from freely flowing off 141 Morrison Road. There are some raised areas at the northern end of Morrison Bay Park, which are approximately 0.3m higher than the crown of Morrison Road. These areas could be regraded to a similar level as the road crown to allow floodwaters to drain more freely into the concrete open channel which drains to the Parramatta River, although this may require a large fig tree to be removed from the park.

Lowering of the road profiles of Morrison Road and Gregory Street, including the roundabout, would provide further improvements to flooding. Amplifying the pit inlet capacity along the flow path is not likely to be effective as the pipe branch along the flow path is at capacity.

Detention basins have been considered to mitigate flooding at this location. Possible sites for basins include:

- Mallee Reserve, north of Tyagarah Street: The reserve contains a separate overland flow path which does not drain directly to the low point at 141 Morrison Road, but may interact with floodwaters on this property and hence may have some beneficial effect on flooding in this area. The gully in the reserve is quite deep, and hence, there may be significant storage available. The reserve is densely vegetated and may have significant environmental value.
- Cudal Reserve: The existing ground surface could be readily regraded to form a detention basin, however, only a minor overland flow path runs through the reserve and therefore it may have only a small effect on flooding at Morrison Road. The main overland flow path, which causes flooding at Morrison Road, flows near the reserve but is too low for flows to be diverted into the reserve.

- **Figure 7-7 Morrison Road at Gregory Street and upstream overland flow paths, with 1% AEP flood Depth**

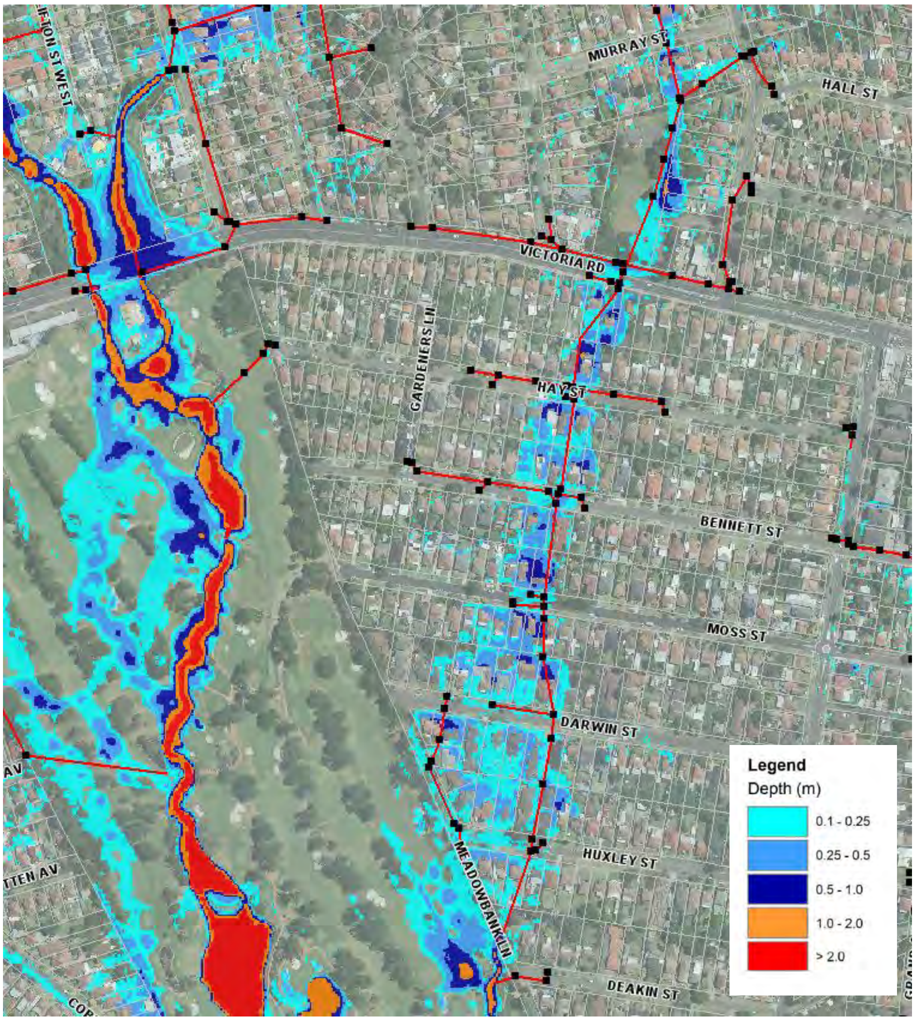



## 7.9. Victoria Road near Gardeners Lane to Deakin Street, West Ryde (Archer Creek Catchment)

The overland flow path in this area flows from north of Victoria Road and through six neighbourhood blocks of residential development before entering Ryde-Parramatta Golf Course and joining the main branch of Archer Creek (refer **Figure 7-8**). The overland flows cut through the neighbourhood blocks as the streets are aligned laterally to the overland flow direction. Depths of flow are typically 0.3 – 0.5m, however, the area of affectation is extensive.

There is scope to construct a detention basin in Lions Park, north of Victoria Avenue. This would reduce, but not eliminate, overland flows through this problem area since there would be a significant volume of local catchment runoff entering the flow path downstream of Victoria Road.

- **Figure 7-8 Victoria Road near Gardeners Lane, to Deakin Street, with 1% AEP flood Depth**




## 7.10. Belmore Street to Shepherd Street, Ryde (Charity Creek Catchment)

This area is at the headwaters of the Charity Creek catchment (refer **Figure 7-9**). Flooding of residential properties occurs in two separate flow paths through the properties, which converge at Shepherd Street. Flow depths are typically 0.3 – 0.4m.

The terrain is gently sloping in this area so it may be possible to reprofile the road verges to reduce the amount of runoff flowing off the road and into the overland flow paths running through the properties, in addition to creating new flow paths on the road carriageway. Works are proposed for Nicoll Avenue, Primrose Avenue, Addington Avenue, Sewell Street and Shepherd Street. Increasing the flow depths in the road is likely to also increase inflows into the pipe system, where there is some redundant capacity. Flows converging at the Shepherd Street sag point would then flow through the corridor of vacant lots previously purchased by Council to form a floodway down towards Victoria Road.

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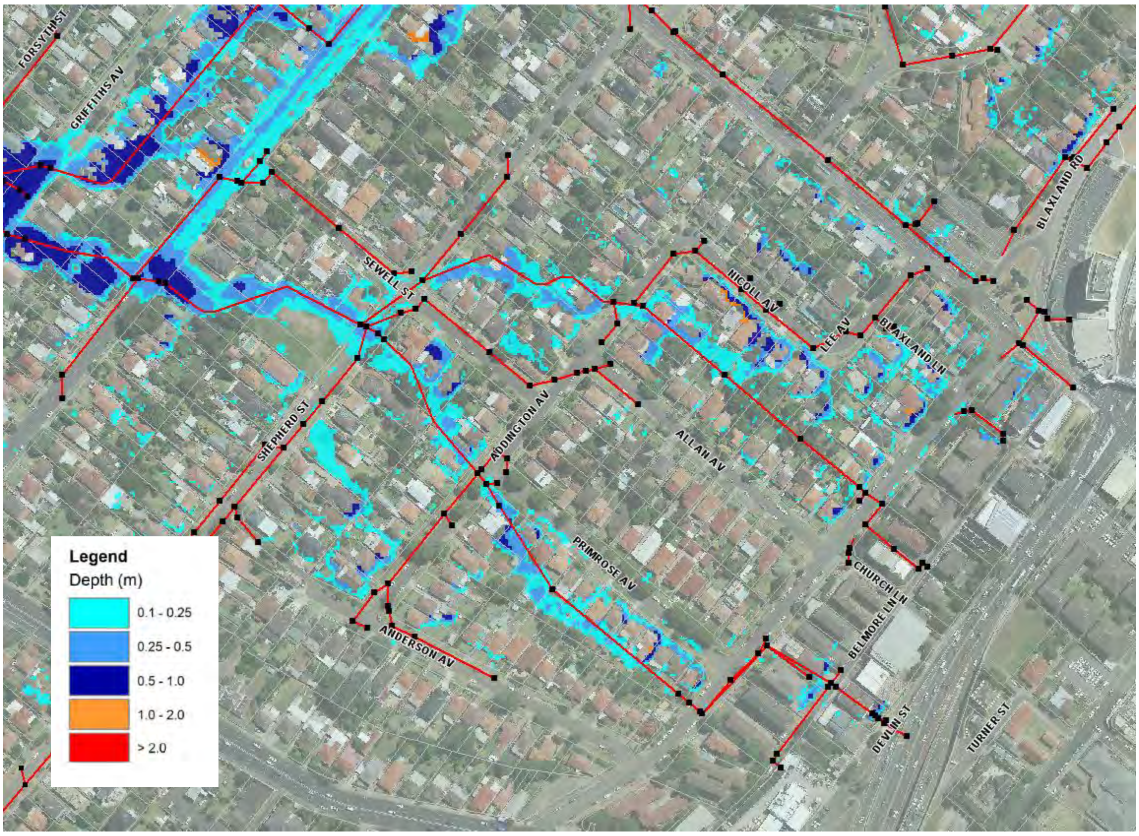
- **Figure 7-9 Belmore Street to Shepherd Street, with 1% AEP flood Depth**




## 7.11. Princes Street, Putney, from Morrison Road to Waterview Street (River Catchment)

Flooding in this area occurs in an overland flow path which flows through properties on Princes Street (refer **Figure 7-10**). Flood depths are typically 0.3 – 0.4m in the 1% AEP event. Runoff to the flow path originates from Regent Street to the west and Boulton Street to the east.

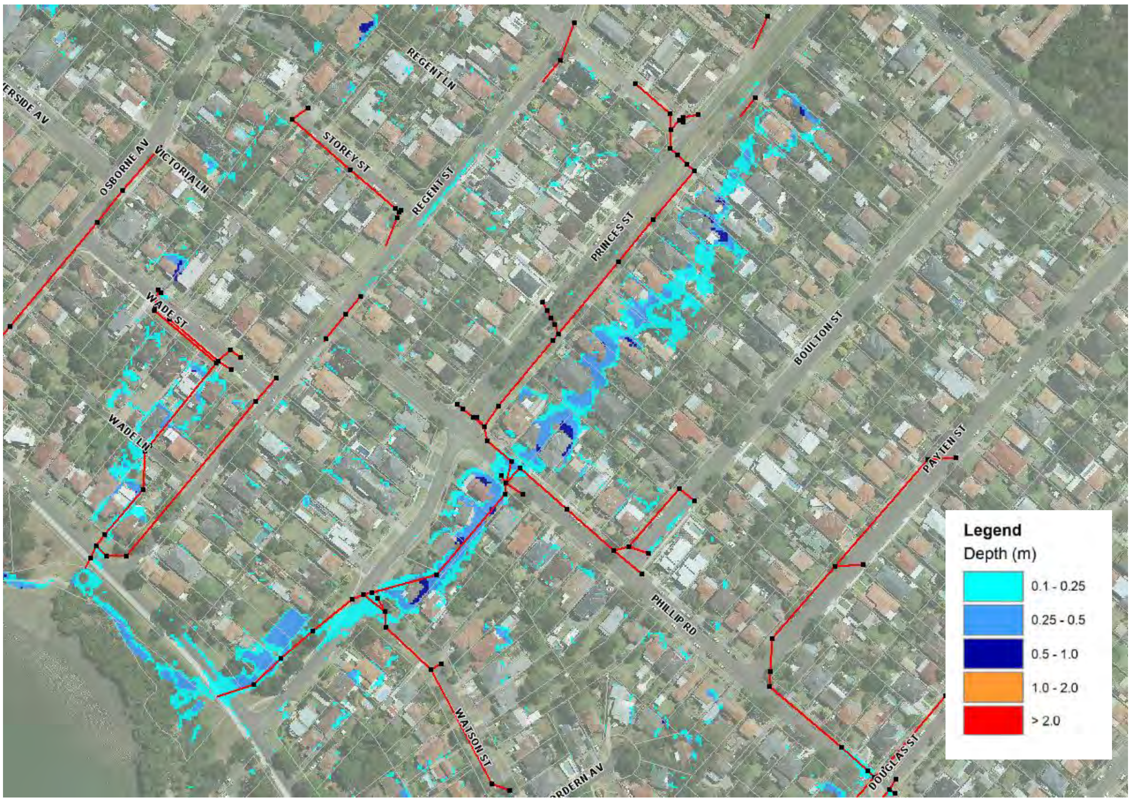
Princes Street is a dual-carriageway road with a 10m wide median grassed and vegetated strip. It may be feasible to construct a swale to intercept the runoff flowing from Regent Street, before it enters the properties on the low side of Princes Street. This may intercept approximately half of the flow which enters the overland flow path. Issues with this option include:

- The steep grade of Princes Street;
- Several breaks in the median strip;
- A possible gas line in the median;
- A large section of the median strip is landscaped with well-established dense vegetation; and

- It would be challenging to convey surface flows contained in the swale across Phillip Street and retaining them within Princes Street, without the flows returning to the overland flow path through residential properties. A large capacity pit and new culvert branch under Prince Street may be required to convey the flows and discharge them into the Parramatta River.

Another possible option is reprofiling the road verge on the low sides of Princes Street and Boulton Street to retain more runoff in the road corridor, although this would depend on whether acceptable driveway cross-over and footpath grades can be achieved, and would only benefit the properties on upstream side of Phillip Street.

- **Figure 7-10 Princes Street, between Morrison Street and Waterview Street, with 1% AEP flood Depth**



# 8. Conclusions

Overland flooding in the five drainage catchments in the Ryde – Parramatta River Catchments study area has been defined for a range of design storm event magnitudes for the existing drainage and development scenarios. This has been achieved with DRAINS hydrologic and TUFLOW 1D/2D hydraulic models of the catchments, which have been verified against two historic events of 20% and 1% AEP magnitudes.

The existing flood behaviour has been defined using flood depth, flood level and provisional flood risk precinct mapping. Peak overland flow rates are also presented at a number of road crossings and other key locations.

The changes to flooding depths have been assessed for a number of sensitivity scenarios relating to varied rainfall losses, hydraulic energy losses at structures, the level of blockage at structures and varied tidal boundary levels. The impacts to flooding resulting by climate change-induced increases in design rainfall intensity and sea level have also been assessed.

Potential structural mitigation options have been identified for ten flooding “hot-spots” in the study area. The nature of the suggested options will be discussed and agreed with Council.The findings from this study and the associated models will be used in the subsequent floodplain risk management study and plan, where the effectiveness and feasibility of these potential mitigation options will be assessed.

# 9. References

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Rose Consulting Group (2001) *Drainage Investigation Meadowbank River Catchment*

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Willing & Partners (1990) *Ryde Stormwater Drainage Investigation*

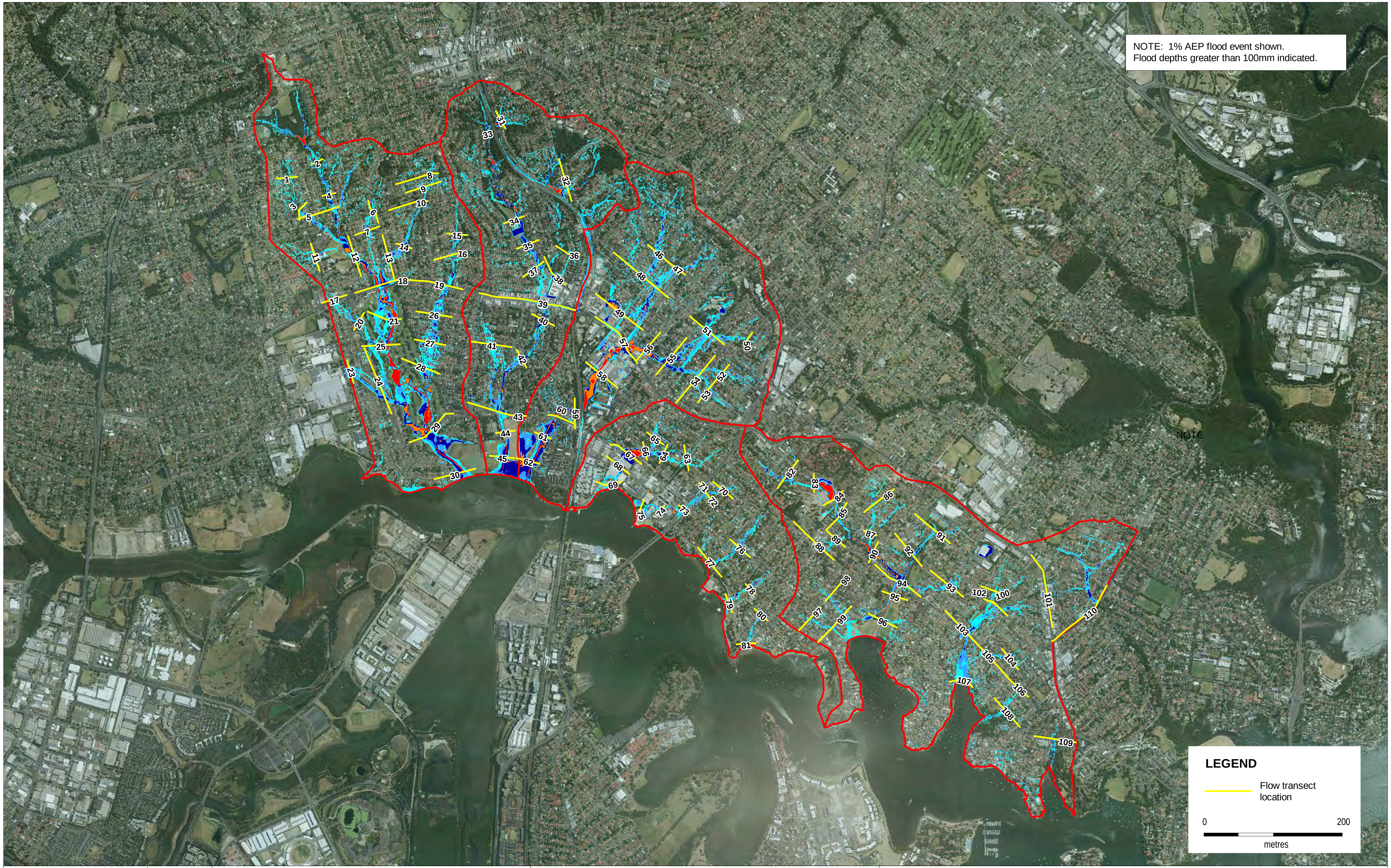
WMAwater (2009) *Charity Creek Cascades Overland Flood Study and Detailed Design*

# Appendix A Flood Depth Mapping

# Appendix B Flood Level Mapping

# Appendix C Flood Planning Area Mapping

# Appendix D Peak Overland Flows

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SKM

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Datum: GDA 1994
Coordinate System: MGA Zone 56

Parramatta River - Ryde Sub-Catchments
Flood Study and Floodplain Risk Management Plan

**Flow Transect Locations for Summary of Peak Flows**

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## Table D-1 Peak Overland Flows at Selected Locations

| ID | Label | Catchment | Total Overland Flow ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | PMF |
| 1 | John St | Archer Creek | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 4.4 |
| 2 | Archer Ck 4 | Archer Creek | 0.2 | 0.4 | 0.5 | 0.6 | 2.0 | 36.3 |
| 3 | Winbourne St 1 | Archer Creek | 2.4 | 2.9 | 3.8 | 4.3 | 4.9 | 25.8 |
| 4 | Archer Ck 5 | Archer Creek | 3.9 | 4.4 | 5.2 | 5.7 | 6.3 | 49.2 |
| 5 | Hermoyne St | Archer Creek | 3.6 | 5.0 | 6.8 | 8.6 | 10.7 | 83.9 |
| 6 | Darvall Rd2 | Archer Creek | 0.6 | 0.8 | 1.2 | 1.5 | 1.9 | 12.9 |
| 7 | Cheers St | Archer Creek | 1.0 | 1.4 | 1.8 | 2.2 | 2.8 | 17.6 |
| 8 | Sluman St | Archer Creek | 0.8 | 1.0 | 1.2 | 1.3 | 1.5 | 9.8 |
| 9 | Perkins St | Archer Creek | 1.1 | 1.4 | 1.9 | 2.3 | 2.8 | 19.0 |
| 10 | Tramway St | Archer Creek | 1.5 | 1.7 | 2.6 | 3.4 | 4.1 | 27.7 |
| 11 | Winbourne St 2 | Archer Creek | 0.4 | 1.0 | 1.7 | 2.1 | 2.6 | 19.9 |
| 12 | Brush Road | Archer Creek | 8.0 | 10.8 | 14.8 | 18.0 | 21.7 | 132.1 |
| 13 | Darvall Rd1 | Archer Creek | 3.0 | 4.1 | 5.3 | 7.0 | 9.0 | 58.7 |
| 14 | Morvan St 2 | Archer Creek | 2.3 | 3.0 | 4.0 | 5.3 | 6.8 | 44.5 |
| 15 | Morvan St 1 | Archer Creek | 0.4 | 0.5 | 0.5 | 0.6 | 0.7 | 5.6 |
| 16 | Murray St | Archer Creek | 1.3 | 1.7 | 2.2 | 2.6 | 3.1 | 18.7 |
| 17 | ARC_Victoria Road 3 | Archer Creek | 1.6 | 1.9 | 2.4 | 2.8 | 3.2 | 16.9 |
| 18 | ARC_Victoria Road 2 | Archer Creek | 2.1 | 3.5 | 5.7 | 26.1 | 26.1 | 196.7 |
| 19 | ARC_Victoria Road 1 | Archer Creek | 2.3 | 3.1 | 4.0 | 4.9 | 5.8 | 36.8 |
| 20 | GC 2 | Archer Creek | 1.2 | 1.7 | 2.4 | 2.9 | 3.7 | 22.8 |

| ID | Label | Catchment | Total Overland Flow ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | PMF |
| 21 | GC 1 | Archer Creek | 17.5 | 22.4 | 28.3 | 45.2 | 50.2 | 234.5 |
| 23 | Taylor Ave | Archer Creek | 3.8 | 4.9 | 6.3 | 7.6 | 9.1 | 48.5 |
| 24 | Cobham Ave 1 | Archer Creek | 3.4 | 4.7 | 6.4 | 7.9 | 9.5 | 54.4 |
| 25 | GC3 | Archer Creek | 21.8 | 26.6 | 33.7 | 49.2 | 56.1 | 272.4 |
| 26 | Bennett St | Archer Creek | 1.9 | 3.1 | 4.6 | 5.7 | 7.1 | 49.1 |
| 27 | Darwin St | Archer Creek | 1.5 | 2.8 | 4.4 | 5.9 | 7.8 | 59.4 |
| 28 | Meadowbank Lane | Archer Creek | 2.2 | 3.1 | 5.0 | 6.9 | 9.2 | 67.3 |
| 29 | Andrew St | Archer Creek | 7.6 | 14.6 | 22.8 | 37.7 | 48.7 | 410.5 |
| 30 | Archer out 1 | Archer Creek | 34.2 | 48.2 | 64.7 | 86.8 | 98.6 | 480.1 |
| 31 | East Pde 1 | Denistone | 1.3 | 1.7 | 2.1 | 2.4 | 2.7 | 10.0 |
| 32 | DEN_Ryedale Rd | Denistone | 1.2 | 2.1 | 3.1 | 3.9 | 4.7 | 35.7 |
| 33 | DEN Ck 1 | Denistone | 5.4 | 6.0 | 6.8 | 7.3 | 8.0 | 24.5 |
| 34 | Den Ck 3 | Denistone | 6.0 | 8.0 | 10.2 | 12.2 | 14.5 | 78.9 |
| 35 | Park Ave | Denistone | 4.4 | 6.7 | 9.4 | 11.9 | 14.5 | 86.3 |
| 36 | Miriam rd | Denistone | 0.0 | 0.2 | 0.4 | 0.5 | 0.5 | 38.8 |
| 37 | Darvall Park | Denistone | 1.1 | 3.3 | 6.1 | 9.5 | 13.2 | 95.7 |
| 38 | Anthony Rd | Denistone | 1.0 | 1.2 | 1.5 | 1.7 | 2.1 | 40.9 |
| 39 | DEN_Victoria Rd | Denistone | 0.2 | 0.2 | 0.5 | 1.3 | 2.1 | 116.3 |
| 40 | Gaza Rd | Denistone | 0.5 | 0.6 | 0.7 | 1.7 | 3.0 | 121.5 |
| 41 | Annie Lane | Denistone | 1.1 | 1.5 | 2.1 | 2.4 | 3.0 | 18.9 |
| 42 | DEN_Station St | Denistone | 1.0 | 0.9 | 1.6 | 2.4 | 2.9 | 128.7 |

| ID | Label | Catchment | Total Overland Flow ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | PMF |
| 43 | DEN_Constitution Rd W | Denistone | 1.1 | 2.0 | 3.9 | 6.5 | 8.9 | 154.5 |
| 44 | Meadowbank Park 3 | Denistone | 15.2 | 16.3 | 17.6 | 18.7 | 21.3 | 175.1 |
| 45 | Meadowbank Park 4 | Denistone | 27.2 | 36.4 | 44.6 | 51.8 | 57.6 | 205.9 |
| 46 | Goodwin St 2 | Charity Creek | 2.5 | 3.2 | 4.2 | 5.1 | 5.8 | 34.6 |
| 47 | Goodwin St 1 | Charity Creek | 3.2 | 3.8 | 4.2 | 5.0 | 5.8 | 31.7 |
| 48 | Parkes_Orchard St | Charity Creek | 4.8 | 6.5 | 9.4 | 11.5 | 14.0 | 92.4 |
| 49 | Herbert St | Charity Creek | 5.6 | 6.8 | 9.1 | 11.2 | 14.5 | 128.2 |
| 50 | Dunbar St | Charity Creek | 0.3 | 0.5 | 0.8 | 1.1 | 1.4 | 9.4 |
| 51 | Parkes St | Charity Creek | 4.9 | 5.9 | 7.2 | 8.8 | 10.6 | 54.2 |
| 52 | Addinton Ave 2 | Charity Creek | 0.8 | 0.9 | 1.3 | 1.8 | 2.1 | 17.0 |
| 53 | Addinton Ave 1 | Charity Creek | 0.7 | 1.0 | 1.4 | 1.7 | 2.1 | 18.6 |
| 54 | Sheperd St | Charity Creek | 1.3 | 2.2 | 3.3 | 4.4 | 5.9 | 47.6 |
| 55 | Griffiths Ave | Charity Creek | 6.7 | 9.0 | 12.5 | 15.9 | 19.9 | 119.0 |
| 56 | Linton Ave | Charity Creek | 7.2 | 9.6 | 13.1 | 16.9 | 20.8 | 126.8 |
| 57 | CHA_Victoria Rd | Charity Creek | 12.4 | 16.3 | 22.2 | 28.0 | 34.6 | 234.6 |
| 58 | Rhode St | Charity Creek | 11.1 | 15.6 | 23.5 | 31.8 | 40.2 | 205.6 |
| 59 | Banks St | Charity Creek | 0.6 | 0.8 | 1.5 | 2.8 | 3.6 | 59.8 |
| 60 | CHA_Constitution Rd W | Charity Creek | 0.3 | 0.4 | 0.5 | 0.5 | 0.5 | 53.5 |
| 61 | Meadowbank Park 1 | Charity Creek | 21.8 | 26.6 | 30.4 | 33.3 | 35.2 | 136.3 |
| 62 | Meadowbank Park 2 | Charity Creek | 24.0 | 27.5 | 32.0 | 35.7 | 38.3 | 135.0 |
| 63 | Q Meadowbank Public | River | 1.3 | 1.8 | 2.3 | 2.8 | 3.2 | 19.9 |

| ID | Label | Catchment | Total Overland Flow ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | PMF |
| 64 | GALE ST | River | 2.7 | 3.2 | 4.3 | 5.2 | 6.2 | 37.5 |
| 65 | THORN ST | River | 1.5 | 1.8 | 2.3 | 2.6 | 3.2 | 16.7 |
| 66 | Q Richard-Johnson | River | 4.2 | 5.2 | 6.9 | 8.4 | 10.2 | 58.4 |
| 67 | Q Constitution Rd | River | 0.1 | 0.2 | 0.4 | 0.5 | 1.4 | 65.9 |
| 68 | NANCARROW AV | River | 2.8 | 2.9 | 3.3 | 3.8 | 4.7 | 72.0 |
| 69 | Q Bowden St out | River | 3.8 | 4.2 | 4.8 | 5.4 | 6.0 | 70.7 |
| 70 | WADE LN | River | 2.0 | 2.4 | 3.0 | 3.2 | 3.7 | 20.8 |
| 71 | Q Church St 2 | River | 0.3 | 0.4 | 0.6 | 0.8 | 0.9 | 2.8 |
| 72 | OSBORNE AV | River | 1.3 | 1.6 | 2.0 | 2.2 | 2.6 | 15.8 |
| 73 | Q Church St 1 | River | 1.9 | 2.5 | 3.1 | 3.7 | 4.3 | 25.5 |
| 74 | WELL ST | River | 1.0 | 1.5 | 2.2 | 2.8 | 3.5 | 22.6 |
| 75 | Q Belmore St out | River | 0.5 | 0.8 | 1.6 | 2.3 | 3.1 | 26.4 |
| 76 | PHILLIP RD | River | 1.6 | 2.1 | 2.7 | 3.3 | 3.9 | 23.5 |
| 77 | Q Regent-Princes St out | River | 2.8 | 3.5 | 4.4 | 5.3 | 6.3 | 41.7 |
| 78 | Q Douglas St | River | 2.0 | 2.3 | 2.8 | 3.0 | 3.5 | 20.6 |
| 79 | Q Douglas St out | River | 2.4 | 2.9 | 3.6 | 4.2 | 4.9 | 30.1 |
| 80 | NANCARROW AV | River | 2.8 | 2.9 | 3.3 | 3.8 | 4.7 | 72.0 |
| 81 | Q Delange Rd out | River | 0.7 | 0.9 | 1.2 | 1.5 | 1.8 | 12.5 |
| 82 | PRINCES ST | Gladesville | 1.3 | 1.6 | 1.8 | 2.2 | 3.1 | 23.1 |
| 83 | Basin in | Gladesville | 2.6 | 3.1 | 3.7 | 4.1 | 4.6 | 33.3 |
| 84 | Basin out | Gladesville | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 48.2 |

| ID | Label | Catchment | Total Overland Flow ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | PMF |
| 85 | CHARLES ST | Gladesville | 0.2 | 0.7 | 1.1 | 1.5 | 1.8 | 61.3 |
| 86 | FREDERICK ST | Gladesville | 0.0 | 0.0 | 0.1 | 0.5 | 0.9 | 9.7 |
| 87 | Flow Path 2 | Gladesville | 1.0 | 1.4 | 2.0 | 3.2 | 3.8 | 28.5 |
| 88 | MORRISON RD 1 | Gladesville | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 |
| 89 | PARRY ST | Gladesville | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90 | ACACIA AV | Gladesville | 3.8 | 5.3 | 8.0 | 10.2 | 12.8 | 117.8 |
| 91 | POTTS ST | Gladesville | 1.6 | 2.1 | 2.8 | 3.2 | 3.8 | 23.6 |
| 92 | SPENCER ST 1 | Gladesville | 3.0 | 3.7 | 4.7 | 5.5 | 6.4 | 36.1 |
| 93 | SPENCER ST 2 | Gladesville | 1.2 | 1.6 | 2.0 | 2.3 | 2.6 | 15.5 |
| 94 | MORRISON RD 2 | Gladesville | 9.1 | 11.8 | 15.6 | 19.5 | 24.9 | 184.2 |
| 95 | Morrison Pk 1 | Gladesville | 19.5 | 22.4 | 27.1 | 50.0 | 37.1 | 199.1 |
| 96 | Morrison Pk 2 | Gladesville | 20.6 | 24.7 | 29.8 | 33.9 | 40.0 | 221.8 |
| 97 | MITCHELL ST 1 | Gladesville | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 3.8 |
| 98 | MITCHELL ST 2 | Gladesville | 0.5 | 0.6 | 0.9 | 1.0 | 1.2 | 7.9 |
| 99 | STANLEY ST | Gladesville | 2.4 | 2.9 | 3.7 | 4.4 | 5.5 | 32.8 |
| 100 | OSGATHORPE RD | Gladesville | 1.3 | 1.7 | 2.3 | 2.9 | 3.5 | 20.5 |
| 101 | VICTORIA RD | Gladesville | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 1.8 |
| 102 | STANBURY ST | Gladesville | 2.7 | 3.8 | 4.9 | 5.7 | 6.8 | 41.5 |
| 103 | MORRISON RD 3 | Gladesville | 4.4 | 5.6 | 7.5 | 9.2 | 11.0 | 71.0 |
| 104 | RAVEN ST | Gladesville | 0.8 | 0.9 | 1.2 | 1.4 | 1.8 | 12.2 |
| 105 | MORRISON RD 4 | Gladesville | 0.7 | 0.9 | 1.2 | 1.6 | 1.8 | 14.2 |

| ID | Label | Catchment | Total Overland Flow ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | PMF |
| 106 | MORRISON RD 5 | Gladesville | 0.6 | 0.8 | 1.0 | 1.3 | 1.2 | 6.4 |
| 107 | Bill Mitchell Pk 2 | Gladesville | 5.2 | 7.3 | 10.2 | 14.3 | 16.0 | 121.6 |
| 108 | YORK ST | Gladesville | 0.9 | 1.2 | 1.9 | 2.2 | 2.8 | 20.9 |
| 109 | ASHBURN PL | Gladesville | 0.5 | 0.7 | 1.0 | 1.1 | 1.3 | 8.6 |
| 110 | PITTWATER RD 1 | Gladesville | 3.5 | 4.0 | 5.1 | 6.6 | 8.2 | 60.5 |

# Appendix E Provisional Flood Risk Precinct Mapping

# Appendix F Climate Change Impact Flood Mapping