



HOLROYD CITY LGA OVERLAND FLOOD STUDY

VOLUME 1 – REPORT

FINAL REPORT

APRIL 2017

FOREWORD

The State Government's Flood Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through the following four sequential stages:

- | | |
|-------------------------------------|---|
| 1. Flood Study | Determines the nature and extent of flooding. |
| 2. Floodplain Risk Management Study | Evaluates management options for the floodplain in respect of both existing and proposed development. |
| 3. Floodplain Risk Management Plan | Involves formal adoption by Council of a plan of management for the floodplain. |
| 4. Implementation of the Plan | Construction of flood mitigation works to protect existing development. Use of Local Environmental Plans to ensure new development is compatible with the flood hazard. |

The Holroyd City Council (**HCC**) Local Government Area (**LGA**) Overland Flood Study constitutes the first step in the Floodplain Risk Management process (refer over) in relation to overland flow and has been prepared for Holroyd City Council to define flood behaviour under current conditions. The scope of the Overland Flood Study covers nine of the ten catchments within the LGA, noting that a previous study investigated overland flood behaviour within the Pendle Creek catchment.

ACKNOWLEDGEMENT

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FLOODPLAIN RISK MANAGEMENT PROCESS

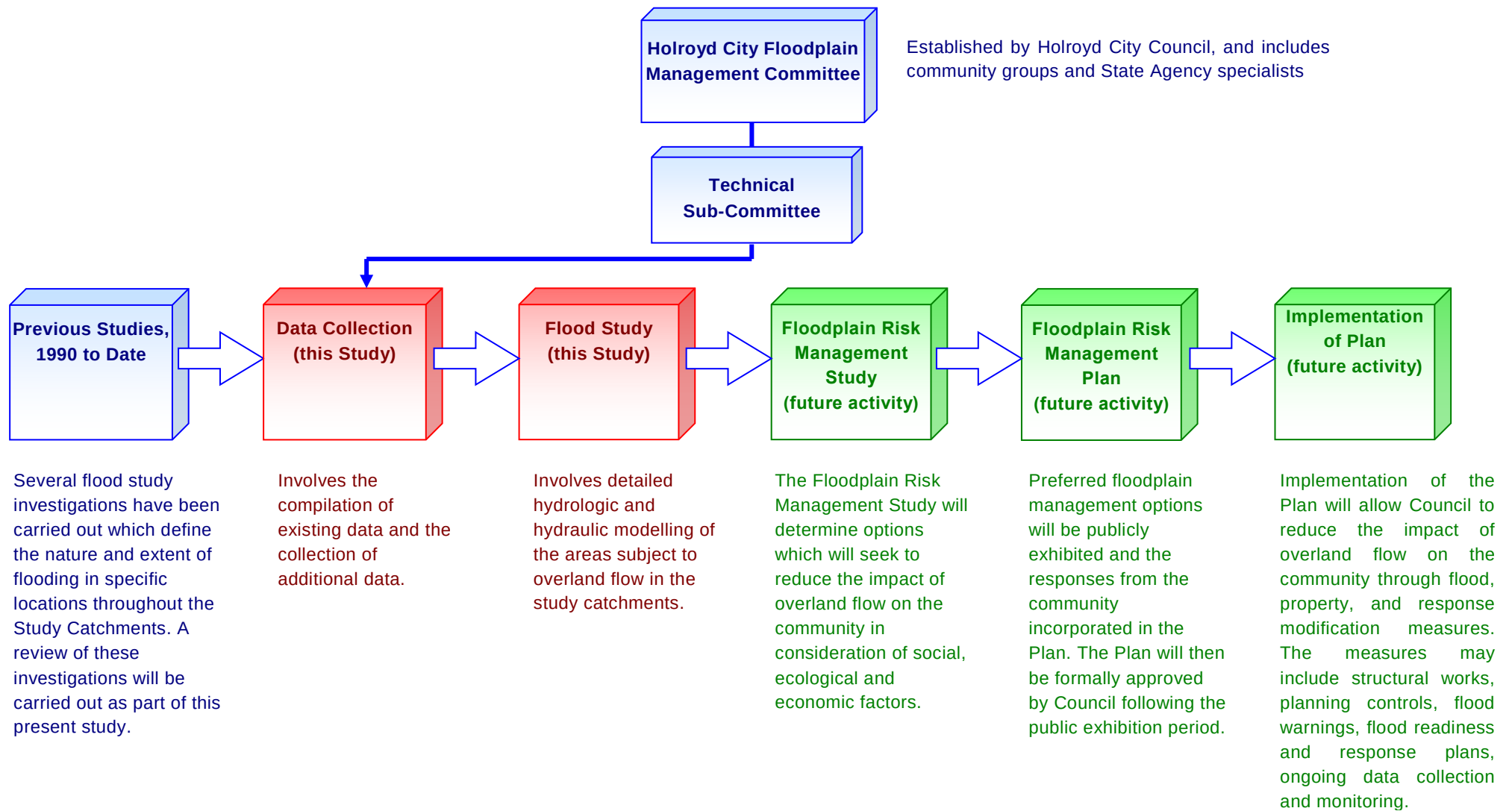


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NOTE ON FLOOD FREQUENCY

The frequency of floods may be referred to in terms of their Average Recurrence Interval (**ARI**) or Annual Exceedance Probability (**AEP**). For example, for a flood having a 100 year ARI there will be a flood of equal or greater magnitude once in 100 years on the average. As another example, for a flood magnitude having 1% AEP, there is a 1% probability that there will be floods of equal or greater magnitude each year. The approximate correspondence between these two systems is:

ANNUAL EXCEEDANCE PROBABILITY (AEP) %	AVERAGE RECURRENCE INTERVAL (ARI) YEARS
0.2	500
0.5	200
1	100
2	50
5	20
20	5

In this report floods are referred to in terms of their ARI. Reference is also made in this report to the Probable Maximum Flood (**PMF**). This flood occurs as a result of the Probable Maximum Precipitation (**PMP**). The PMP is the result of the optimum combination of the available moisture in the atmosphere and the efficiency of the storm mechanism as regards rainfall production. The PMP is used to estimate PMF discharges using a model which simulates the conversion of rainfall to runoff. The PMF is defined as the limiting value of floods that could reasonably be expected to occur. It is an extremely rare flood, generally considered to have a return period greater than 1 in 10^5 years.

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ABBREVIATIONS

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
ALS	Airborne Laser Scanning
AMC	Antecedent Moisture Condition
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval (years)
ARR	Australian Rainfall and Runoff (IEAust, 1998)
BoM	Bureau of Meteorology
CBD	Central Business District
DTM	Digital Terrain Model
FCC	Fairfield City Council
FDM	Floodplain Development Manual (NSW Government, 2005)
FRMS&P	Floodplain Risk Management Study and Plan
GIS	Geographic Information System
HCC	Holroyd City Council
IFPA	Interim Flood Planning Area
IFPL	Interim Flood Planning Level
IFD	Intensity-Frequency-Duration
IFPL	Interim Flood Planning Level
L&A	Lyall & Associates
LHS	Left Hand Side
LGA	Local Government Area
LPT	Liverpool to Parramatta Transitway
OEH	Office of Environment and Heritage, Department of Premier and Cabinet (formerly Department of Environment, Climate Change and Water [DECCW], (formerly Department of Environment and Climate Change [DECC]))
PCC	Parramatta City Council
PFL	Peak Flow Location
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCBC	Reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe
RHS	Right Hand Side
RM	Rational Method
SWC	Sydney Water Corporation
UPRCT	Upper Parramatta River Catchment Trust
WAE	Work-As-Executed

Chapter 8 of the report contains definitions of flood-related terms used in the study.

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SUMMARY

S.1 Background and Study Objective

This report presents the findings of an investigation into the behaviour of overland flow within nine of the ten catchments (excluding the Pendle Creek catchment¹) across the Holroyd City Local Government Area (LGA). **Figure 1.1** shows the extent of the nine study catchments which comprised:

- A'Becketts Creek
- Clay Cliff Creek
- Coopers Creek
- Domain Creek
- Duck Creek
- Finlaysons Creek
- Greystanes Creek
- Prospect Creek
- Westmead Creek

The study objective was to define the nature of overland flow in terms of its depth, extent and velocity for design storms ranging between 5 and 100 year Average Recurrence Interval (**ARI**), as well as for the Probable Maximum Flood (**PMF**). The scope of the study included investigation of overland flow only, since a number of previous studies have investigated main stream flood behaviour along the major creeks within the LGA.

The definition of main stream flood behaviour along the major watercourses of Greystanes Creek, Coopers Creek, Finlaysons Creek were excluded from the Study Brief as HCC presently rely on results of flood modelling which was undertaken by the Upper Parramatta River Catchment Trust (**UPRCT**) using the RAFTS and MIKE 11 software. The definition of main stream flood behaviour along the main arms of A'Becketts Creek downstream of the Merrylands Central Business District (**CBD**), Duck Creek and Prospect Creek were also excluded from the Study Brief due to Holroyd City Council's (**HCC's**) reliance on the findings of previous studies that have been undertaken by others. Details of these investigations are provided in **Appendix A**.

S.2 Study Methodology

Overland flow behaviour for each study catchment was defined using a computer based hydrologic model to generate discharge hydrographs for input to a hydraulic model of the stream channels and floodplains to convert flows into depths and extents of inundation, including flow velocities. The hydrologic models were runoff-routing models based on the DRAINS software, whilst the hydraulic models were based on the TUFLOW software. A DRAINS model and corresponding TUFLOW model were developed for each study catchment.

The outcomes of the data collection phase of the study are presented in **Appendix A** of the report, whilst a photographic record of historic flooding in the Holroyd City LGA is contained in **Appendix B**.

As there were no stream flow data available on the study catchments, model parameters were estimated based on the outcomes of a model tuning process. While an analysis was carried out on rainfall which was recorded during several historic storms (refer **Appendix C** for details), only the data recorded for storms that occurred on 5 August 1986 and 10 February 1990 were considered fit for model tuning purposes. Reliable historic flood data related to overland flow behaviour for these two storm events was further limited to the study catchments of A'Becketts Creek and Duck Creek.

¹ Note that investigation of overland flow behaviour within the Pendle Creek catchment is reported in SMEC, 2010.

Appendix D contains details of historic flood marks and model testing results for the above-mentioned storm events and study catchments. **Appendix F** contains an assessment of the economic impacts flooding has on existing urban development located in the study catchments.

A single set of design model parameters were applied to all study catchments, and were selected after consideration of the results of the tuning process as well as a comparison of design flood flows generated by the various TUFLOW hydraulic models to peak flows extracted from the UPRCT's MIKE 11 hydraulic model result files. Design storm rainfalls were then applied to the DRAINS hydrologic models to generate discharge hydrographs within each of the study catchments. The discharge hydrographs constituted the upstream boundary and sub-catchment inputs to the various TUFLOW hydraulic models.

S.3 Presentation of Results

Figures 6.1 is a key plan showing the layout of the 11 sheets which cover the nine study catchments, while **Figures 6.2 to 6.6** (11 sheets each) show the TUFLOW model results for the 5, 20, 50 and 100 year ARI floods and the PMF. Note that areas affected by depths of overland flow less than 100 mm have not been shown, nor have those areas that are affected by main stream flooding.²

Table E1 in **Appendix E** presents peak flows at selected locations within the study catchments for the modelled design storm events, while **Table E2** summarises the hydraulic behaviour of the regional type flood retarding basins that have been constructed to control local catchment runoff in the upper reaches of the drainage system (i.e. not those located along the major watercourses of the study creeks, the assessment of which has been undertaken by others (refer **Appendix A**).

Figure 6.7 shows the division of the floodplain into high and low hazard areas, while **Figure 6.8** shows the division of the floodplain into floodway, flood fringe and flood storage areas.

Several runs of the TUFLOW hydraulic models were carried out to test the sensitivity of overland flow behaviour to changes in hydraulic roughness within allotments, as well as partial blockage of the piped stormwater drainage system for the 100 year ARI event. The impact on overland flood behaviour of increases in rainfall intensities due to future climate change was also assessed. The results of these sensitivity analyses are shown on **Figures 6.9 to 6.14**. **Figure 6.15** shows the Interim Flood Planning Area (IFPA) based on HCC's nominated freeboard allowance of 500 mm.

S.4 Key Findings

The key findings of the present investigation are broadly as follows:

- The hydrologic and hydraulic models developed as part of the present investigation (i.e. DRAINS and TUFLOW) generate peak flows on the main arms of Coopers Creek and Westmead Creek which are similar to those derived by UPRCT's models (i.e. RAFTS and MIKE 11), while the peak flows generated by the present investigation for the Finlaysons Creek catchment are higher for the more frequent storm events.³

² Note that areas affected by depths of overland flow greater than 100 mm may also be subject to main stream flooding of a greater depth. Consideration of this possibility needs to be given during the assessment of flooding behaviour at the individual allotment level (for example, during the assessment of development applications).

³ While the comparison of peak flows is referenced to the main arm of the study creeks (the TUFLOW model results for which are not presented in this report), they do provide a valuable check on the catchment hydrology and unsteady flow hydraulic modelling undertaken as part of the present investigation.

However, peak flows on the Domain Creek catchment were found to be more than half those generated by UPRCT's RAFTS model. A review of UPRCT's RAFTS model shows that a single lumped catchment was used to generate a single discharge hydrograph that was used for input to the MIKE 11 model, the upstream boundary of which is located downstream of the Western Rail Line culverts in the Parramatta City Council (**PCC**) LGA. It was also found that the RAFTS model does not incorporate details of an existing flood detention basin which is located in Sydney Smith Park (denoted herein as basin BA018). The combination of the lumped catchment approach and the omission of the attenuating effects of the basin are believed to be the reason for the large difference in peak flows between the two sets of models.

- Continuous overland flow paths are shown to occur in all nine study catchments at the 5 year ARI level.
- While depths of overland flow are generally less than 300 mm at the 5 year ARI level, there are a number of locations where existing development is subject to depths of overland flow in the range 300-500 mm.
- There are a limited number of locations where the depth of overland flow at the 5 year ARI level is greater than 500 mm.
- While there are a large number of properties which will be impacted by depths of overland flow greater than 300 mm in a 100 year ARI storm event, there is only a small number that are subject to high hazardous conditions, and only then over a relatively small percentage of the allotment.
- The areas which are worst affected by overland flow at the 100 year ARI level (refer **Figure 6.5**, 11 sheets for details) are as follows:
 - **Greystanes Creek Catchment** – along the continuous overland flow path which runs in a northerly direction from the sag in Mandoon Road, Girraween to its confluence with the main arm of Greystanes Creek in the vicinity of Porta Road and Girraween Park, Girraween (refer overland flow path on **Sheets 1** and **2** along which Peak Flow Locations (**PFL's**) GRE_03, GRE_04, GRE_05, GRE_06 and GRE_08 are located).
 - **Greystanes Creek Catchment** - at the eastern end of Toongabbie Road opposite the Western Rail Line where several commercial properties including the Parkview Medical Centre, are affected by overland flow which ponds at this location (refer ponding area on **Sheet 1** which is controlled by two transverse drainage structures which cross the Western Rail Line corridor at PFL GRE_09 and GRE_10).
 - **Coopers Creek Catchment** – south (upstream) of the M4 Western Motorway corridor along the continuous overland flow path that runs in a northerly direction from the sag in Hanbury Road through to Carolyn Street Park (refer overland flow path on **Sheets 3** and **6** along which PFL COO_02 is located).
 - **Finlaysons Creek Catchment** - along the continuous overland flow path that runs in a easterly direction from the sag in Maxine Road west of Alder Road through to the main arm of Finlaysons Creek (refer overland flow path on **Sheet 6** along which PFL FIN_04 is located). It is noted that overland flow ponds to depths greater than 1 m on the upstream side of the noise wall which is located on the eastern side of the Cumberland Highway.

- **Finlaysons Creek Catchment** - along the continuous overland flow path that runs in a south-easterly direction from the sag in Merrylands Road through to Beechwood Street (refer overland flow path on **Sheet 6** along which PFL FIN_01 is located)
 - **Westmead Creek Catchment** – along the continuous overland flow path that follows the valley of the catchment between Austral Avenue and the Western Rail Line (refer overland flow path on **Sheet 4** along which PFL WES_01 and WES_02 are located).
 - **Domain Creek Catchment** – along the continuous overland flow path that runs from the sag in Amos Street through to the Parramatta Golf Club (refer overland flow path on **Sheet 4** along which PFL DOM_03 and DOM_04 are located).
 - **Clay Cliff Creek Catchment** - along the continuous overland flow path that runs in an easterly direction from sag in Webb Street through to the sag in Pitt Street opposite Ollie Webb Reserve (refer overland flow path on **Sheet 7** along which PFL CLA_01 and CLA_03 are located).
 - **A'Becketts Creek Catchment** – along the continuous overland flow path that runs in an easterly direction from Merrylands Park to Treves Street immediately west of the Merrylands CBD (refer overland flow path on **Sheet 7** along which PFL ABE_03, ABE_04 and ABE_05 are located).
 - **A'Becketts Creek Catchment** – along the continuous overland flow path that runs in a northerly direction from Fowler Road to Merrylands Road immediately south of the Merrylands CBD (refer overland flow path on **Sheet 7, 9 and 10** along which PFL ABE_07, ABE_08 and ABE_10 are located).
 - **Duck Creek Catchment** – along the continuous overland flow path that runs in an easterly direction between the sags in Harris Street and Vulcan Street (refer overland flow path on **Sheet 9** along which PFL DUC_01 and DUC_02 are located).
 - **Prospect Creek Catchment** - along the continuous overland flow paths that extend south from Loftus Road and west from Military Road (refer flow paths on **Sheet 11** in the vicinity of PFL PRO_38 and PFL PRO_39).
- Changes of up to 25 per cent in the assumed hydraulic roughness of individual allotments only results in an increase in the depth of overland flow in the study area generally in the range 0-50 mm.
 - While a partial blockage of the piped stormwater drainage system will increase depths of overland flow generally in the range 0-200 mm, there are several locations where they are increased in the range 200-500 mm.
 - In general terms, depths of overland flow would be increased in the range 0-100 mm for the case where 100 year ARI rainfall intensities are increased by 10 per cent, with greater increases shown to occur in the same areas where a partial blockage of the stormwater drainage system would lead to increases in the range 200-500 mm (refer **Section 6.4.2** for locations).
 - Depths of overland flow are slightly greater for the case where 100 year ARI rainfall intensities are increased by 30 per cent, where a larger number of areas are affected by depths of overland flow in the range 100-200 mm.
 - New overland flow paths are shown to develop within the study area for the case where 100 year ARI rainfall intensities are increased by 30 per cent, namely in the Greystanes Creek, Coopers Creek, A'Becketts Creek (Merrylands CBD) and Prospect Creek catchments.

S.5 Interim Flood Planning Area

The *Interim Flood Planning Area (IFPA)* and associated *Interim Flood Planning Levels (IFPL's)* for each study catchment has been shown at a level equal to the peak 100 year ARI flood level plus an allowance of 500 mm for freeboard (refer **Figure 6.15**).

Note that the IFPA and associated IFPL's only incorporate the results of the present investigation and do not incorporate the results of previous studies which deal with the definition of main stream flooding behaviour along the major watercourses in the following six study catchments:

- Greystanes Creek
- A'Becketts Creek
- Coopers Creek
- Duck Creek
- Finlaysons Creek
- Prospect Creek

The results of these previous studies (refer **Appendix A** for details) will need to be used in combination with those of this present investigation to derive a final set of FPL's when preparing the *Floodplain Risk Management Studies and Plans (FRMS&P)* for each individual catchment.

S.6 Economic Impacts of Flooding

The economic consequences of floods are discussed in **Appendix F**, which assesses flood damages to residential, commercial and industrial property and public buildings in the floodplain. The number of properties predicted to experience "above-floor" inundation, together with estimated flood damages in the study area are listed on **Table S1**, while **Table FS1** in **Appendix F** gives a breakdown of these values on an individual catchment basis.

TABLE S1
TOTAL FLOOD DAMAGES IN THE STUDY AREA

ARI (years)	Number of Properties						Total Damage (\$ Million)
	Residential		Commercial/ Industrial		Public		
	Flooded Above Floor Level	Flood Damages (\$ Million)	Flooded Above Floor Level	Flood Damages (\$ Million)	Flooded Above Floor Level	Flood Damages (\$ Million)	
5	18	5.80	26	3.01	0	0.02	8.82
20	68	13.18	55	7.60	0	0.02	20.79
50	99	17.51	85	10.29	0	0.02	27.82
100	140	21.69	107	12.94	0	0.03	34.66
200	221	26.28	132	17.47	2	0.11	43.85
500	338	33.98	167	29.76	2	0.14	63.89
PMF	3374	243.58	526	140.18	23	4.17	387.93

Figure 6.1 to 6.6 (11 sheets each) show the location and indicative depth of above-floor inundation of affected properties for each design flood event, while **Figure FS1** (11 sheets) in **Appendix F** shows the frequency at which individual properties will be first flood affected and then flood damaged.

The “*present worth value*” of damages in the study catchments resulting from all floods up to the 100 year ARI level of flooding at a seven per cent discount rate in each study catchment is as follows (listed in order of increasing value):

- Clay Cliff Creek - \$1.06 Million
- Domain Creek - \$1.16 Million
- Duck Creek - \$1.16 Million
- Westmead Creek - \$1.27 Million
- Greystanes Creek - \$3.60 Million
- Coopers Creek - \$3.81 Million
- Finlaysons Creek - \$7.20 Million
- A’Becketts Creek - \$10.27 Million
- Prospect Creek - \$19.17 Million.

The above values represent the amount of capital spending that could be justified if a particular set of flood mitigation measures prevented flooding for all properties up to the 100 year ARI event in each catchment.

It is noted that the relatively large flood damages that would be experienced in the Finlaysons Creek and A’Becketts Creek catchments are principally due to damage to residential property, while those in the Prospect Creek catchment are principally due to damage to commercial / industrial property.

S.7 Further Considerations by the Floodplain Risk Management Committee

The findings of the present study will form the basis for preparing future FRMS&P’s to address the impacts of overland flow on both existing and future development within the study catchments. In addition to finalising the IFPA’s (and associated IFPL’s) and setting appropriate controls over future development in areas subject to major overland flow, the FRMS&P’s will include an assessment of available management options including:

- *Property modification measures* such as: flood related controls over future development, voluntary purchase of residential property in high hazard areas and raising of floor levels of residences located in low hazard areas.
- *Response modification measures* including: improvements to flood warning and emergency management procedures, improvements to the community’s awareness of flooding.
- *Flood modification measures* such as: levees, detention basins and improvements to hydraulic capacity of channels and floodways.

In order to comprehensively manage the flood risk that arises in the study catchments, it will be necessary for HCC to also take into consideration the impact of main stream flooding when preparing the future FRMS&P's for the various study catchments. While the flood models developed as part of previous studies could be used for this purpose, it is recommended that the hydrologic and hydraulic models that have been developed as part of the present investigation be expanded to incorporate the major watercourses of the six aforementioned catchments. This would provide a consistent approach to the definition of both overland flow and main stream flood behaviour across the whole of the LGA and allow the impacts of various flood modifications measures to be assessed using a single two-dimensional (in plan) unsteady flow hydraulic model for each catchment.

The current approach to only showing areas affected by overland flow (since the extent and nature of main stream flooding has yet to be accurately mapped by HCC) also has the potential to cause confusion within the community, especially those attempting to interpret the findings of the various flood studies when preparing a development application. A uniform approach to defining both overland flow and main stream flooding behaviour would assist in reducing the likelihood of people misinterpreting the available flood data.

Lastly, extension of the flood models developed as part of the present investigation would be undertaken prior to commencing the preparation of the FRMS&P for each individual catchment, as prior acceptance by the community of the study findings and adoption of the updated flood study report(s) by HCC would be required.

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1 INTRODUCTION

1.1 Study Background and Approach

The study forms the first step in the floodplain risk management process for managing the impact of overland flow within the study catchments (refer process diagram presented in the Foreword), and is a precursor of future FRMS&P's which will consider the impacts of flooding and potential flood mitigation and management measures.

Flood behaviour was defined using computer based hydrologic models of the catchments and hydraulic models of the various creeks and their respective floodplains. The hydrologic models were runoff-routing models based on the DRAINS software, which has been developed primarily for use in modelling the passage of a flood wave through urban catchments and converts historic and design storm rainfalls to discharge hydrographs.

A dynamic hydraulic modelling approach was adopted for the analysis to account for the time varying effects of flow in the stormwater drainage system, the routing effects of the floodplain storage and the two-dimensional effects of flow in the urban parts of the study area. A depth-averaged, one- and two-dimensional free surface flow modelling approach was chosen as it allows for the interaction of flow between the channels and the floodplains, through culverts and over control structures such as flood detention basins and road embankments. The TUFLOW hydraulic modelling program was adopted for this purpose.

The models were tested and tuned using rainfall and flood data which were collected for historic storms which occurred on 5 August 1986 and 10 February 1990. Several other storms of some significance were also identified during the data collection phase of the study. However, the lack of relevant historic flood related data for these events meant that these storms were of limited use in the model tuning process.

Design storm rainfalls were applied to the hydrologic models to generate discharge hydrographs within the study catchments. These hydrographs constituted the upstream boundaries and internal inflow inputs to the hydraulic models. The models were used to prepare plans showing the indicative extent and depth of overland flow throughout the study catchments.

The definition of main stream flood behaviour along the major watercourses of Greystanes Creek, Coopers Creek and Finlaysons Creek were excluded from the Study Brief as HCC presently rely on the results of flood modelling which was undertaken by the UPRCT using the RAFTS and MIKE 11 software. The definition of main stream flood behaviour along the main arms of A'Becketts Creek downstream of the Merrylands CBD, Duck Creek and Prospect Creek were also excluded from the Study Brief due to HCC's reliance on the findings of previous studies that have been undertaken by others. Details of these investigations are provided in **Appendix A**.

1.2 Study Tasks

The flood study had three components:

- **Review of available hydrologic and hydraulic data and previous investigations.**
HCC provided historic flood data, including a number of flood level and depth measurements, and photographic records for several large storm events that have occurred over parts of the Holroyd City LGA since the mid 1980's. Rainfall data for these events were sourced from the Bureau of Meteorology (**BoM**), Sydney Water Corporation (**SWC**) and HCC.

Both the rainfall and flood data were initially assessed for their adequacy in the model testing process. The hydrologic and hydraulic models developed as part of the present investigation were tested and tuned using flood data that were available for historic storms which occurred on 5 August 1986 and 10 February 1990.

The following data were also provided by HCC:

- Airborne Laser Scanning (**ALS**) survey which was captured in April 2013. Approximate building footprints also formed part of the ALS dataset.
- Aerial photography which was flown in September 2011.
- A database which contained pit and pipe details in Geographic Information System (**GIS**) format, as well as a range of other GIS data including cadastral boundaries and land zonings.
- Design drawings in PDF format showing details of several major drainage structures and flood detention basins which have been constructed in the various study catchments.
- Previous TUFLOW model and result files for a previous overland flow investigation undertaken in the upper A'Becketts Creek catchment by Bewsher (2006).
- A large collection of previous reports dealing with flooding and drainage investigations in the study catchments.

UPRCT provided details of MIKE 11 hydraulic modelling previously undertaken as part of flooding investigations for the upper Parramatta River catchment, which included analysis of flooding along the main arms of Greystanes, Coopers, Finlaysons and Westmead Creeks where they run within the Holroyd City LGA. Details obtained from UPRCT comprised MIKE 11 model data and peak flow and flood level results for a range of design storm events ranging between 5 year ARI and the PMF.

The MIKE 11 model data included cross sections along the above-mentioned creeks that were used to define the in-bank topography in the hydraulic models developed as part of the present investigation. Details of major culvert structures along these creeks were also used to assist in the development of the hydraulic models.

PCC provided details of its piped stormwater drainage system in adjacent areas of the Parramatta City LGA.

Further details of the data collection phase of the study are presented in **Appendix A** of the report.

- **A hydrologic component** which included preparation of hydrologic models of the study catchments, tuning of the models to historic storm events and adoption of model parameters for design flood estimation, derivation of design storm rainfalls and their application to the models to define design discharge hydrographs.
- **A hydraulic component** which comprised the preparation and testing of hydraulic models of the study catchments and the application of discharge hydrographs to the models to define extents and depths of inundation, flows and velocities for the design floods.

1.3 Overview of Report

Chapter 2 of the report contains relevant background information including a discussion on the history of flooding in the study catchments, a review of the data base available for the study, and a brief description of the study catchments.

Chapter 3 deals with the development of the computer based catchment models which were used to generate discharge hydrographs for input to the hydraulic model.

Chapter 4 deals with the development of the hydraulic models which were used to analyse flood behaviour in the study catchments.

Chapter 5 deals with the derivation of design flood hydrographs from the study catchments using the DRAINS software. This step involved the determination of design storm rainfall depths over the study catchments for a range of storm durations, and conversion of the rainfall hyetographs to discharge hydrographs.

Chapter 6 details the results of the hydraulic modelling of the design floods using the TUFLOW hydraulic model. Also contained in this section of the report are the findings of several sensitivity studies. The impact of climate change on flooding patterns in terms of a potential increase in rainfall intensity is also discussed.

Chapter 7 contains a list of References.

Chapter 8 contains a list of flood-related terminology that is used within the report.

Appendix A contains a summary of the data collection phase of the study, as well as a review of several previous flood study investigations which cover parts of the study catchments. **Appendix B** contains a photographic record of several historic floods that have occurred in the study catchments dating back to August 1986. The results of analyses which were carried out on rainfall data recorded for thirteen historic storms are presented in **Appendix C**. **Appendix D** contains details of historic flood marks and model testing results for the storms of 5 August 1986 and 10 February 1990. **Appendix E** contains tables of peak flows and information relating to the hydraulic behaviour of existing flood detention basins. **Appendix F** contains an assessment of the economic impact flooding has on existing urban development located in the study catchments.

Figures referred to herein are bound in a separate volume of the report (refer **Volume 2**).

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2 BACKGROUND

2.1 Historic Flooding in the Study Catchments

Reported instances of flooding within the Holroyd City LGA date back to the mid 1970's, with resident reports identifying localised flooding within the lower reaches of the A'Becketts Creek catchment during a storm that occurred in April 1974. This was around the time when the potential for serious flooding throughout the upper Parramatta River catchment was recognised, following the start of significant urban development in western Sydney.

Severe flooding most recently affected Holroyd in the mid to late 1980's and early 1990's when a number of large storms occurred in the Sydney region, particularly over parts of western Sydney including the upper Parramatta River catchment. Several photographs showing flooding which was experienced in the study catchments over this period are contained in **Appendix B**.

Major flooding occurred throughout much of Holroyd and surrounding LGA's as a result of a large storm that occurred on 5 August 1986. This storm was associated with an 'east coast low', a particularly intense low-pressure weather system that can occur off the eastern coast of Australia most commonly during Autumn and Winter, that resulted in 24 hour rainfall totals of more than 300 mm across much of Sydney (BoM, 2007). A database of historic flood marks held by HCC shows that observations of property flooding for this event were recorded across much of the Holroyd City LGA.

Another major storm that occurred in April 1988 was considered at the time to be slightly larger in magnitude than the August 1986 event. However, analyses undertaken as part of this present investigation suggest that rainfall intensities experienced within the Holroyd City LGA were greater for the earlier event. Recorded observations of property flooding were generally located in the northern and western parts of the LGA within the Greystanes Creek, Coopers Creek and Finlaysons Creek catchments.

The following year of 1989 saw the UPRCT established by the State Government to coordinate flood mitigation efforts across the upper Parramatta River catchment and the respective LGA's, including Holroyd City. Whilst the UPRCT's charter includes a range of aspects related to catchment management, including water quality and native vegetation management, flood risk management is a principal focus.

In 1990, two large storm events that occurred in February and August resulted in widespread flooding throughout the Holroyd City LGA. The February 1990 storm was the larger of the two events, with more than 400 mm of rain falling over the first ten days of the month. A particularly heavy burst of rain that occurred on 10 February represented the most intense period of rainfall, with recorded observations of property flooding generally concentrated in the eastern part of the LGA within the A'Becketts Creek and Duck Creek catchments.

The period of major flooding between 1986 and 1990 led to the construction of several regional type flood detention basins throughout the LGA in the late 1980's and 1990's. These basins were aimed at alleviating flooding problems that had been exacerbated by urban development (refer **Table 2.1** on pages 9 and 10 for further details of existing flood detention basins in the study catchments). A number of piped drainage augmentation or improvement works were also undertaken in various locations in response to these major storm events.

It is understood that significant flooding in the Holroyd City LGA did not occur again until the early 2000's, when a series of intense storms were experienced across the LGA, including events in March 2000, January – February 2001 and February 2002. Whilst the rainfall associated with these events was not as intense or prolonged as that experienced during the storms that occurred over the period 1986 – 1990, photographic records held by HCC (refer **Appendix B**) show that several properties across the LGA experienced flooding, including some with above-floor inundation, during these events.

The most recent instance of heavy rainfall over the Holroyd City LGA occurred in December 2011. However, it is understood that HCC did not receive any reports of flooding or flood-related damage and is unaware of any other drainage-related issues resulting from this event.

The findings of a detailed analysis of rainfall which was recorded during the above mentioned storms are contained in **Appendix C** of this report.

It is relevant to note that, as far as could be ascertained during the data collection phase of the study, no specific instances of blockage of either the trunk drainage system (e.g. lined channels, creeks and major culvert structures) or minor piped drainage system are known to have occurred during historic storm events. However, given the experiences in many similar urbanised catchments, in which partial blockage of grated pit inlets and culvert entrances is often a contributor to localised flooding effects, it would appear likely that similar issues in this case have either gone unnoticed or unreported.

2.2 Responses to Overland Flow in the Study Catchments

2.2.1. Previous Studies

A number of investigations have been carried out over the past three decades which deal with flood behaviour (both main stream and overland) in the study catchments. A brief description of several of these studies and their findings are contained in **Appendix A**.

Note that reference is also made in this report to a companion study that was undertaken by Lyall & Associates (**L&A**) on behalf of HCC and SWC which used the same hydrologic and hydraulic models which were developed as part of the present investigation (L&A, 2014). The study involved a detailed investigation into flood risk management options that could be implemented as part of the future redevelopment of the Merrylands CBD, which is located in the A'Becketts Creek catchment.

2.2.2. Flood Mitigation Works

The construction of regional type flood detention basins within the study catchments, in addition to a number of upgrades to piped stormwater drainage systems, has formed the primary response to previous instances of inundation of property by overland flow. These works generally attempt to minimise hazardous flooding conditions that present a high risk to occupants of the floodplain, and reduce the extent and severity of flood-related property damages.

As far as could be ascertained during the course of this present investigation, no other 'structural' flood mitigation measures (e.g. levees, floodways, channel augmentations etc.) specifically targeting mitigation of overland flow were identified.

It is noted that a small number of recommendations in relation to mitigation of main stream flooding along the main arms of several creeks have also been implemented, mainly along Prospect Creek including various stream clearing and bank stabilisation works and construction of a high level floodway in the vicinity of Justin Street, Fairfield.

2.2.3. Development Controls

HCC currently applies flood-related development controls in flood prone areas of the LGA on the basis of a number of classifications, depending on the dominant flood producing mechanism, including:

- main stream flooding;
- overland flow; and
- dam failure.

It is understood that the results of the present study will be used by HCC to review and revise (as appropriate) the classifications of properties affected by overland flow within all nine study catchments.

As previously noted in **Section 1.1**, the present investigation does not include an assessment of main stream flood behaviour along the major watercourses that run through the six study catchments of A'Becketts, Coopers Creek, Duck Creek, Finlaysons Creek, Greystanes Creek and Prospect Creek. Therefore it is not appropriate to use the results of the present study to revise main stream flooding classifications within these study catchments.

2.3 Data Collection

Data collected for the purpose of this present investigation included the following:

- Rainfall recorded at several pluviographic and daily-read stations located either within or in close proximity to the study catchments.
- Historic flood data comprising flood level and depth measurements, as well as photographic records, for several large storm events which have occurred over parts of the Holroyd City LGA since the mid 1980's.
- ALS survey data and aerial photography captured in April 2013. A range of other relevant GIS data provided by HCC was also compiled.
- Details of the local stormwater drainage system, including pit and pipe data.
- Design drawings showing details of several major drainage structures and flood detention basins (refer **Table 2.1** on pages 9 and 10) within the study catchments.
- Details of previous hydraulic modelling undertaken in the study catchments, including:
 - MIKE 11 hydraulic modelling undertaken on behalf of the UPRCT, including model and peak flood level data; and
 - TUFLOW modelling undertaken as part of the Upper A'Becketts Creek Flood Study (Bewsher, 2006).

A large collection of previous reports dealing with flooding and drainage investigations in the study catchments was also provided by HCC. Further details relating to all the above data are contained in **Appendix A**.

2.4 Catchment Descriptions

2.4.1. General

As mentioned, the study area comprises nine of the ten catchments across the Holroyd City LGA (refer **Figure 1.1**). **Figure 2.1** (4 sheets in total) shows the extent of the nine study catchments, as well as details of the existing stormwater drainage system in each catchment, and should be referred to when reading the following sections of the report.

With the exception of the Prospect Creek catchment, the study catchments drain generally to the north or east and form part of the larger Parramatta River catchment. The portion of the Prospect Creek catchment that lies within the Holroyd City LGA drains generally to the south and forms part of the larger Georges River catchment.

The study catchments are urbanised and their natural drainage characteristics have been almost completely altered by development. Natural drainage paths have in the main been either concrete-lined or piped where they run through the urbanised areas of the LGA.

More than 30 regional type flood detention basins have been constructed by HCC in the Holroyd LGA dating back to the mid 1980's. Details of these basins (including one that has recently been constructed at Greystanes Sports Ground within the Prospect Creek catchment) are given in **Table 2.1** over page. *[Note also that numerous privately owned and maintained on-site stormwater detention systems have been constructed throughout the LGA to control stormwater at the allotment level, the location and details of which are not known.]*

The following sections of the report provide a brief description of each catchment and its drainage network. For the purpose of the following discussion, catchments are dealt with in clockwise direction around the LGA, commencing with the Greystanes Creek catchment.

2.4.2. Greystanes Creek

The Greystanes Creek catchment has a total area of 507 ha within the Holroyd City LGA, located within the suburbs of Pemulwuy, Prospect, Greystanes, Girraween and Toongabbie (refer **Figure 2.1, Sheets 1 and 3**).

The catchment drains generally from south to north, extending from its headwaters around the Southern Employment Lands and Watkin Trench Parade, to the LGA boundary along the Western Rail Line, Toongabbie. The Pendle Creek catchment adjoins to the east. Much of the western portion of the catchment (i.e. along the western side of Greystanes Creek) lies within the adjacent Blacktown City LGA. *[Note that the total catchment area contributing runoff to Greystanes Creek at the Western Rail Line is approximately 950 ha. Therefore around 433 ha of the total catchment area is located outside Holroyd City, within the Blacktown City LGA.]*

The catchment contains a broad mix of land uses. In the upper reaches of the catchment south of the M4 Motorway, land use adjacent to the main arm of Greystanes Creek is predominantly residential, whilst industrial land dominates the catchment contributing runoff to a tributary arm of Greystanes Creek further to the west. In the lower reaches of the catchment, industrial areas make up most of the land between the Great Western Highway and Gilba Road in Girraween, whilst residential areas lie closer to the Western Rail Line in Toongabbie. A small number of parks and reserves are located throughout the catchment.

TABLE 2.1
DETAILS OF REGIONAL TYPE FLOOD DETENTION BASINS

Study Catchment	Basin ID	Basin Name	Year of Construction	Outlet Structure ⁽¹⁾		Spillway Elevation (m AHD)
				Dimensions (mm)	Invert Level (m AHD)	
Greystanes Creek	BA014	CSIRO Retarding Basin	1990/2005	1 off 1200 RCP	45.72	51.60
	BA015	DEP Retarding Basin	1990	1 off 1050 RCP	47.50	56.50
	BA016	Fox Hill GC Detention Basin	1990	3 off 1800 RCP's	36.30	41.40
	BA031	Nicholls Way	2008	2 off 600 RCP's	46.10	47.80
	BA032	Cnr Driftway Drive & Grazer Circuit	2008	2 off 675 RCP's	46.75	48.30
	BA035	Driftway Drive Upper Basin	2011	2 off 375 RCP's	48.23	50.00
	BA036	Driftway Drive Middle Basin	2011	2 off 375 RCP's	46.97	48.30
	BA037	Driftway Drive Lower Basin	2011	1 off 375 RCP	45.68	48.00
Finlaysons Creek	BA004	Tucknotts Basin	1993	1 off 1500 RCP	31.40	33.75
	BA013	Darmenia Avenue Park	1989	1 off 375 RCP	46.85	48.50
	BA029	Hampden Road – Basin 2	2003	1 off 375 RCP	34.36	36.30
	BA030	Hampden Road – Basin 1	2003	1 off 375 RCP	36.80	38.30
Domain Creek	BA018	Sydney Smith Park Basin	1998	2 off 600 RCP's	23.57	26.45
A'Becketts Creek	BA001	Fowler Road – Basin 1	1992	1 off 300 RCP	36.70	38.00
	BA002	Fowler Road – Basin 2	1992	1 off 375 RCP	34.37	35.40
	BA003	Cusack Street Basin	1990	1 off 750 RCP	37.52	39.40
	BA021	Merrylands Park – Main Oval	2002	3 off 450 mm diameter orifice plates ⁽²⁾	22.98	25.80
	BA022	Merrylands Park – SW Oval	2002	1 off 375 RCP	24.00	26.00
	BA023	Merrylands Park – SE Oval	2002	1 off 375 RCP	24.80	26.30
	BA028	Todd Street Reserve	2003	1 off 375 RCP	36.90	37.90

(1) RCP = reinforced concrete pipe, RCBC = reinforced concrete box culvert.

(2) Orifice plates installed on 3 off 600 RCP's.

TABLE 2.2 (CONT'D)
DETAILS OF REGIONAL TYPE FLOOD DETENTION BASINS

Study Catchment	Basin ID	Basin Name	Year of Construction	Outlet Structure ⁽¹⁾		Spillway Elevation (m AHD)
				Dimensions (mm)	Invert Level (m AHD)	
Prospect Creek	BA012	Macquarie Road – Basin 3	1993	2 off 450 RCP's	48.95	52.30
	BA019	Sandra Street Basin	1991	n/a ⁽²⁾		
	BA020	Fairfield Road Street Basin	1991	1 off 900 RCP + 2 off 1050 RCP's + 1 off 600 RCP	32.00	34.40
	BA024	Hassall Street Detention Basin	1984	4 off 2400 x 1800 RCBC's + 1 off 1050 RCP + 1 off 375 RCP	24.50	30.80
	BA025	Rosford Street Detention Basin	1984	2 off 2400 x 2250 RCBC's + 2 off 2400 x 2100 RCBC's + 1 off 1200 RCP	19.30	24.30
	BA026	Macquarie Road – Basin 2	1993	1 off 750 RCP	49.97	55.00
	BA027	Macquarie Road – Basin 1	1993	1 off 600 RCP	49.83	55.00
	BA033	Silverthorne Drive – Basin 1	2007	1 off 750 RCP	56.35	58.90
	BA034	Silverthorne Drive – Basin 2	2007	1 off 600 RCP	57.08	60.00
	BA038	Greystanes Sportsground	2013	2 off 1350 RCP's	42.19	46.00

(1) RCP = reinforced concrete pipe, RCBC = reinforced concrete box culvert.

(2) Drainage augmentation works in Sandra Street Park comprise surcharge structure and grassed floodway only.

The main arm of Greystanes Creek commences immediately downstream (north) of Watkin Trench Parade, Pemulwuy and runs north through residential estates and Driftway Reserve. The creek is piped across the M4 Motorway and Great Western Highway before continuing to the north where it runs along the western boundary of the LGA through Fox Hills Golf Club. The original creek line has been formed into a constructed floodway for much of its length downstream (north) to the Western Rail Line. Greystanes Creek joins Toongabbie Creek on its right bank approximately 700 m downstream of the rail line.

Within the Holroyd City LGA, there is one major tributary arm of Greystanes Creek which commences upstream (south-west) of Reconciliation Road, Prospect. A short distance downstream of Reconciliation Road the tributary arm flows out of the LGA (into Blacktown City LGA), crosses under the M4 Motorway via a twin cell box culvert system, before re-entering Holroyd City and joining the main arm of Greystanes Creek on its left (western) bank.

The catchment within the Holroyd City LGA is drained by a number of lateral piped drainage systems, typically following the alignment and grade of the local road network, that generally outlet into the main arm of Greystanes Creek or into its major tributary arm where it runs upstream of the Great Western Highway. The largest of these lateral drainage lines is the piped

branch commencing near Harold Read Park, which drains generally to the north and discharges into Greystanes Creek on its right (eastern) bank immediately south of Girraween Park via twin 1350 RCP's. This drainage line also contains a short section of concrete-lined channel which runs along the eastern side of CV Kelly Park.

Sections of the existing piped drainage system in the lower reaches of the Greystanes Creek catchment adjacent to the Western Rail Line discharge east under the rail line at three locations:

- opposite the eastern end of Oramzi Road via a single 600 RCP;
- opposite the eastern end of Toongabbie Road via a single 1050 RCP; and
- approximately 40 m north of the eastern end of Toongabbie Road via a single 1200 RCP.

Flows conveyed under the rail line in the above three locations discharge into PCC's piped drainage system.

Several flood detention basins were constructed in the Greystanes Creek catchment between 1990 and 2011 (refer **Table 2.1** on pages 9 and 10 for details), the largest of which are the basins on the former CSIRO and DEP sites, and a basin constructed within the Fox Hills Golf Club (identified as basins BA014, BA015 and BA016, respectively, on **Figure 2.1, Sheet 1**).

2.4.3. Coopers Creek

The Coopers Creek catchment has a total area of 286 ha within the Holroyd City LGA, located within the suburbs of Greystanes, Pendle Hill, Wentworthville and South Wentworthville (refer **Figure 2.1, Sheets 1 to 3**).

The catchment drains generally from south to north, extending from its headwaters to the south of Daniel Street Park, Greystanes to the LGA boundary along the Western Rail Line, Wentworthville. The Finlaysons Creek catchment adjoins to the east and south, whilst the Pendle Creek catchment adjoins to the west. The Coopers Creek catchment also forms part of SWC's Stormwater Drainage Area No. 52, which extends north of the rail line into the Parramatta City LGA.

The catchment is predominantly low density residential in nature and almost fully developed with the exception of a number of parks, the largest of which are Daniel Street Park, Carolyn Street Park and Ringrose Park. Pockets of commercial and industrial development exist in the northern part of the catchment between the M4 Motorway and the rail line. A number of schools and churches are also located within the catchment.

In addition to the M4 Motorway, the Great Western Highway also traverses the Coopers Creek catchment in an east-west direction. The Cumberland Highway / Jersey Road forms the third major road corridor within the catchment and runs generally in a north-south direction.

The main arm of Coopers Creek commences immediately upstream (south) of the M4 Motorway. The creek is piped across the Motorway via 3 off 3000 x 2400 RCBC's before continuing to the north. A section of vegetated creek channel between the Motorway and Great Western Highway gives way to concrete-lined channel downstream of the Highway. Downstream of Ringrose Park, the channel approaches the Cumberland Highway and then follows along the western side of the road alignment through to the LGA boundary at the Western Rail Line.

The main arm of Coopers Creek is piped under the rail line via a three cell box culvert measuring 7.3 m wide by 1.8 m high before continuing to the north through the Parramatta City LGA. Flows

surcharging the creek upstream of the rail line are able to discharge across the LGA boundary and rail corridor via the northbound carriageway of the Cumberland Highway, or via a pedestrian underpass located immediately to the west of the creek. Coopers Creek joins Toongabbie Creek on its right bank approximately 1.4 km downstream of the rail line.

Various lateral piped drainage lines connect into the main arm of Coopers Creek along its length between the M4 Motorway and the rail line, the size of which ranges between diameters of 375 mm and 1500 mm. A short section of concrete-lined channel joins the main arm on its left (western) bank in the vicinity of Emert Street, Wentworthville. The short section of concrete-lined channel controls a relatively large catchment which extends west to the Coopers Creek catchment boundary near the Bonds Distribution Centre.

Upstream (south) of the M4 Motorway the trunk drainage system within the catchment is piped, with the exception of two channels running along the southern side of the Motorway. The main branch of the trunk drainage system follows the valley of the catchment from south-west to north-east, and varies in size from 750 mm diameter immediately downstream of Daniel Street Park to 1800 mm diameter at its outlet upstream of the Motorway within Carolyn Street Park. Various lateral piped drainage lines connect into the main branch.

Stormwater drainage augmentation works have been undertaken in the Coopers Creek catchment, for example in the vicinity of Lance Crescent, Greystanes in the early 1990's. However, there are no regional type flood detention basins located within the catchment.

2.4.4. Finlaysons Creek

The Finlaysons Creek catchment has a total area of 556 ha within the Holroyd City LGA, located within the suburbs of Wentworthville, Westmead, South Wentworthville, Merrylands, Merrylands West and Greystanes (refer **Figure 2.1, Sheets 2 and 3**).

The catchment drains generally from south to north, extending from its headwaters south of Central Gardens, South Wentworthville to the LGA boundary along the Western Rail Line at Wentworthville. Adjoining catchment areas within the LGA comprise those of Coopers and Pendle Creeks (to the west), Westmead, Domain, Clay Cliff and A'Becketts Creeks (to the east), and Prospect Creek (to the south). The catchment also forms part of SWC's Stormwater Drainage Area No. 42, which extends north of the rail line into the Parramatta City LGA.

The Finlaysons Creek catchment is predominantly low density residential in nature and almost fully developed with the exception of a number of parks, the largest of which are Central Gardens and Lytton Street Park. Pockets of commercial and industrial development exist throughout the catchment, but are particularly concentrated in the northern part of the catchment between the M4 Motorway and the Western Rail Line. A number of schools and churches are also located within the catchment.

In addition to the M4 Motorway, the Great Western Highway and Merrylands Road also traverse the Finlaysons Creek catchment in an east-west direction. The Cumberland Highway / Jersey Road and Centenary Road / Station Street form the other major road corridors within the catchment and run generally in a north-south direction.

The main arm of Finlaysons Creek commences upstream (west) of the Cumberland Highway, where the trunk drainage system is comprised of a grassed floodway and underlying 1800 mm diameter pipe. Sections of vegetated creek line commence downstream (north) of Central Gardens and Merrylands Road, which transitions to concrete-lined channel downstream of Irrigation Road in the vicinity of Ted Burge Sportsground.

At the M4 Motorway, the concrete-lined channel is bridged by the Motorway and the adjacent Allen Street before being piped under Old Prospect Road and the Great Western Highway via a four cell box culvert. Finlaysons Creek continues north as a concrete-lined channel through to the LGA boundary at the Western Rail Line. The creek is bridged by the rail line and then piped under Wentworth Avenue via a three cell box culvert before continuing to the north through the Parramatta City LGA. Finlaysons Creek joins Toongabbie Creek on its right bank approximately 1 km downstream of the rail line.

Various lateral piped drainage lines connect into the main arm of Finlaysons Creek along its length between the Cumberland Highway and the rail line, the size of which ranges between diameters of 375 mm and 1350 mm. Short reaches of concrete-lined channel, which control catchments extending along the M4 Motorway corridor as well as residential areas immediately to its south, join the main arm on its right (eastern) bank on either side of the Motorway.

Four flood detention basins were constructed in the upper Finlaysons Creek catchment between 1989 and 2003 (refer **Table 2.1** on pages 9 and 10 for details), the largest of which is known as “Tucknotts Basin” (BA004) located immediately south of Merrylands Road in Merrylands West. Whilst a preliminary detailed design has been prepared for a proposed regional type flood detention basin within Central Gardens, it is understood that this basin is yet to be constructed.

2.4.5. Westmead Creek

The catchment drained by Westmead Creek (also known as Milsons Creek) has a total area of 52 ha within the Holroyd City LGA and is located wholly within the suburb of Westmead (refer **Figure 2.1, Sheet 2**).

The catchment drains from south to north, extending from its headwaters near the Great Western Highway to the LGA boundary along the Western Rail Line. The catchment is bounded on its eastern and western sides by Hawkesbury Road and Bridge Road, respectively. The catchments of Domain Creek and Finlaysons Creek adjoin to the east and west, respectively.

The Westmead Creek catchment is predominantly low density residential in nature and almost fully developed with the exception of a number of parks, the largest of which are MJ Bennett Reserve and Austral Avenue Reserve. A short strip of commercial development and Westmead Public School lie along the eastern boundary of the catchment at Hawkesbury Road.

The piped drainage system typically follows the prevailing grade in the local road network toward a central trunk line, which runs along the valley of the catchment from south to north. The size of this central trunk line varies from a single 600 RCP upstream (south) of MJ Bennett Reserve to twin 1200 RCP's under Alexandra Avenue. Lateral pipe branches up to 675 mm diameter in size join the central trunk line at each local road crossing.

Overland flows generally follow the direction of the piped drainage system through the catchment. Downstream (north) of Austral Avenue, the major overland flow path along the valley of the catchment runs through a series of narrow reserves that lie adjacent to existing residential development.

Immediately downstream of Alexandra Avenue the piped drainage system discharges into a short reach of concrete-lined channel before twin brick-lined arch culverts convey flows beneath the rail line. A survey plan dating back to March 2000 shows these brick-lined arch culverts transition to 2 off 1650 RCP's (of similar total waterway area) beneath the rail embankment, before discharging back into Westmead Creek and continuing to the north through the Parramatta City LGA. Westmead Creek joins Finlaysons Creek on its right bank approximately 750 m downstream of the rail line.

There are no regional type flood detention basins located in the Westmead Creek catchment.

2.4.6. Domain Creek

The catchment drained by Domain Creek has a total area of 83 ha within the Holroyd City LGA and is located primarily within the suburb of Westmead, with a small area along the southern boundary of the catchment within Mays Hill (refer **Figure 2.1, Sheet 2**).

The catchment drains generally from south to north, extending from its headwaters along the northern side of the M4 Motorway to the LGA boundary that borders the western and southern sides of the Parramatta Golf Club. The catchment is bounded on its western and southern sides by Hawkesbury Road and the Great Western Highway, respectively. The catchments of Westmead Creek and Clay Cliff Creek adjoin to the west and south, respectively.

The upper part of the catchment located south of Pye Street and Good Street is low density residential in nature and almost fully developed with the exception of several parks. The largest park is Sydney Smith Park, which incorporates the only regional type flood detention basin that has been constructed in the Domain Creek catchment (refer **Table 2.1** on pages 9 and 10 for details).

The lower part of the catchment, to the north of Pye and Good streets, is zoned for high density residential development and is also fully built out. This area is bordered by the LGA boundary and lies adjacent to the Parramatta Golf Club, which is located within the Parramatta City LGA.

The catchment is drained by a number of piped drainage systems that typically follow the alignment and grade of the local road network. The main branch of the piped drainage system follows the major depression through the catchment from south-west to north-east, with the flood detention basin in Sydney Smith Park (BA018) controlling much of the upper catchment. Flows discharging from the basin (both piped flows and flows discharging over the basin's spillway) continue to the north-east towards Good Street, and ultimately flow into Parramatta Golf Club. The outlet of the piped drainage system at this location comprises twin 1500 RCP's. To the north of Pye Street, three smaller piped drainage systems (up to 600 mm diameter in size) also discharge across the LGA boundary and into the golf club from the west.

The main arm of Domain Creek commences within Parramatta Golf Club. To the north of the golf club the creek is piped under the Western Rail Line via twin 1500 RCP's, before continuing to the north through the Parramatta City LGA. An underpass constructed beneath the rail line provides a higher-level relief route for floodwaters to cross the rail corridor at this location. Domain Creek joins the Parramatta River on its right bank approximately 1 km downstream of the rail line.

2.4.7. Clay Cliff Creek

The Clay Cliff Creek catchment has a total area of 111 ha within the Holroyd City LGA and is located within the suburbs of Mays Hill, Parramatta and Merrylands (refer **Figure 2.1, Sheet 2**).

The catchment drains generally from west to east, extending from its headwaters to the south-west of the M4 Motorway to the LGA boundary along Pitt Street, Parramatta. The catchment is bounded on its northern side by the Great Western Highway and the Domain Creek catchment. The catchments of Finlaysons Creek and A'Becketts Creek adjoin to the west and south, respectively. The catchment also forms part of SWC's Stormwater Drainage Area No. 27, which extends east of Pitt Street into the Parramatta City LGA.

The catchment is predominantly low density residential in nature, with a school, church and cemetery also located within the catchment. A number of large parks are situated along the valley of the catchment, the largest of which are Freame Park and Jones Park. The catchment is also traversed by two major road corridors, comprising the M4 Motorway and Burnett Street.

The main branch of the piped drainage system crosses under the M4 Motorway to the north-west of Burnett Street via a single 1350 RCP, before following the valley of the catchment to the east along the northern side of Freame Park. The piped drainage system continues under Jones Park as a single cell box culvert of varying dimensions, crossing under Pitt Street as a single cell 2100 x 1700 RCBC. Downstream (east) of the LGA boundary at Pitt Street, the piped drainage line continues under Ollie Webb Reserve before discharging into a concrete-lined channel on the eastern side of the reserve. PCC constructed a flood detention basin in Ollie Webb Reserve in 2007-08 to assist in flood mitigation further downstream along the main arm of Clay Cliff Creek.

Various lateral piped drainage lines connect into the main branch along its length, the largest of which comprises the second piped crossing of the M4 Motorway corridor to the south-east of Burnett Street. This piped drainage line joins the main branch at Jones Park.

There are no regional type flood detention basins located in the Clay Cliff Creek catchment within the Holroyd City LGA.

2.4.8. A'Becketts Creek

The A'Becketts Creek catchment has a total area of 515 ha within the Holroyd City LGA (refer **Figure 2.1, Sheets 2 and 4**). The catchment is located primarily within the suburb of Merrylands, but has small areas within Guildford, Guildford West, Merrylands West, Parramatta, Granville and Holroyd.

The catchment drains generally from south-west to north-east, with the main arm of A'Becketts Creek discharging across the LGA boundary at its most eastern point adjacent to the M4 Motorway / Western Rail Line crossing. The catchment headwaters lie along a minor ridge line in the vicinity of Tennyson Road and Sherwood Road, Merrylands West.

The A'Becketts Creek catchment is bounded on its northern side by the Clay Cliff Creek catchment. The catchments of Finlaysons Creek and Prospect Creek adjoin to the west, whilst the Duck Creek catchment adjoins to the south. The catchment also forms part of SWC's Stormwater Drainage Area No. 46, which extends east of the Western Rail Line into the Parramatta City LGA.

To the east of the Cumberland and Western Rail Lines, approximately 94 ha of additional urbanised catchment located within the Parramatta City LGA drains into Holroyd via several piped crossings of the rail line (note that the extent of these catchment areas external to the Holroyd City LGA is shown on **Figure 2.1, Sheet 2**). The total catchment area contributing runoff to the main arm of A'Becketts Creek where it leaves the LGA adjacent to the M4 Motorway / Western Rail Line crossing is therefore around 609 ha.

The catchment is predominantly low density residential in nature but includes large areas of high density residential development, in particular around the Merrylands CBD. The CBD area includes a large zone of commercial development, and the lower reaches of the catchment below the CBD contain a number of pockets of industrial development bordering the main arm of A'Becketts Creek. A number of parks are located throughout the catchment, the largest of which are Merrylands Park, Holroyd Sportsground, King Park and open space surrounding the Holroyd Gardens site.

A number of schools and churches are also located within the catchment. The M4 Motorway and Cumberland Rail Line form the major transport corridors either within or bordering the catchment.

The trunk stormwater drainage system forms two primary branches upstream (i.e. to the west and south) of the Merrylands CBD – denoted herein as the Western Branch and Southern Branch (refer **Figure 2.1, Sheet 2**). Along the Western Branch, regional type flood detention basins constructed in Merrylands Park control much of the upper catchment. The piped drainage system continues downstream of these basins to the CBD as twin 1800 RCP's. Along the Southern Branch, a number of small flood detention basins have been constructed in the upper reaches of the catchment. At King Park the piped drainage system along the Southern Branch comprises twin 1800 RCP's, and the system continues north towards the CBD in alternating sections of piped drainage and concrete and brick lined channel. In total there are seven regional type flood detention basins located in the upper A'Becketts Creek catchment (refer **Table 2.1** on pages 9 and 10 for details).

The two branches join under the Stockland Mall site and continue to the east towards Pitt Street as the Main Arm of A'Becketts Creek, comprising a covered concrete-lined channel approximately 7.8 m wide by 1.5 m high. Between Pitt and Neil Streets, the Main Arm transitions into a twin cell box culvert system that runs north across a large at-grade carpark and then under Neil Street.

Downstream (north) of Neil Street, the enclosed section of drainage system discharges into an open channel forming the main arm of A'Becketts Creek. The channel continues as a floodway through the Holroyd Gardens site, with a large twin cell box culvert running beneath the floodway. Downstream (north) of Walpole Street, the system again emerges into open channel and remains in this form through to the LGA boundary at the Western Rail Line. A'Becketts Creek joins Duck Creek on its left bank approximately 1.5 km downstream (east) of the rail line.

Various lateral piped drainage lines connect into the trunk piped branches and main arm of A'Becketts Creek along its length. These lateral lines range in size from 375 mm diameter through to 1650 mm diameter, and also include a number of larger box culverts downstream of Neil Street.

In the lower reaches of the catchment along the northern side of the M4 Motorway, a relatively small catchment within the suburb of Granville is drained south under the motorway and into A'Becketts Creek. A single 1650 RCP controls flows discharging south across the motorway corridor.

2.4.9. Duck Creek

The Duck Creek catchment has a total area of 137 ha within the Holroyd City LGA (refer **Figure 2.1, Sheet 4**). The catchment is located primarily within the suburbs of Guildford and Merrylands, with a small area along the western boundary of catchment within Guildford West.

The Duck Creek catchment drains generally from west to east, extending from its headwaters near SWC's Guildford (Pipehead) facility to the LGA boundary along the Cumberland Rail Line. The catchment is bounded to the north and south by the A'Becketts Creek and Prospect Creek catchments, respectively. The catchment also forms part of SWC's Stormwater Drainage Area No. 35, which extends east of the rail line into the Parramatta City LGA.

The catchment is predominantly low density residential in nature and almost fully developed with the exception of a number of small parks and reserves. A small commercial area lies immediately to the west of Guildford railway station, with some surrounding higher density residential development. A number of schools and churches are also located within the catchment.

The catchment is drained by a number of piped drainage systems, typically following the alignment and grade of the local road network, that generally outlet into Duck Creek. The creek flows from west to east along the valley of the catchment between Vulcan Street and the Cumberland Rail Line, and is concrete-lined along its full length within the LGA. A single cell 2700 x 2900 RCBC conveys flows beneath the rail line, opposite the eastern end of Elizabeth Street, and into the neighbouring Parramatta City LGA. The size of the various lateral piped drainage lines that join into the main arm of the creek between Vulcan Street and the rail line range between 300 mm and 1050 mm in diameter.

Sections of the existing piped drainage system in the Duck Creek catchment discharge east under the rail line at three other locations:

- opposite the eastern end of Guildford Road via a single cell 1200 x 1200 RCBC;
- opposite the eastern end of Campbell Place via a single cell 450 x 450 RCBC; and
- opposite the eastern end of Myee Street via a single 750 RCP.

Flows conveyed under the rail line in the above three locations discharge into PCC's piped drainage system.

There are no regional type flood detention basins located in the Duck Creek catchment.

2.4.10. Prospect Creek

The Prospect Creek catchment has a total area of 1,389 ha within the Holroyd City LGA, located within the suburbs of Pemulwuy, Greystanes, Smithfield, Woodpark, Guildford West, Guildford and Yennora (refer **Figure 2.1, Sheets 3 and 4**).

The local catchments within the LGA drain generally from north to south, discharging to the creek along its left (northern) bank. The creek itself flows generally to the south-east along the length of the LGA's southern boundary. The catchment is bounded to the north by the five catchments of Greystanes Creek, Pendle Creek, Finlaysons Creek, A'Becketts Creek and Duck Creek.

To the east of the Cumberland Rail Line, approximately 91 ha of additional urbanised catchment located within the Fairfield City and Parramatta City LGA's drains into Holroyd via a piped crossing of the rail line (note that the extent of the catchment area and piped drainage system external to the Holroyd City LGA is shown on **Figure 2.1, Sheet 4**). To the west of the Reconciliation Road, approximately 24 ha of additional urbanised catchment located within the Blacktown City LGA's contributes to flow in the overland flow path along the western boundary of the Holroyd City LGA (refer **Figure 2.1, Sheet 3**).

The total catchment area contributing runoff to the portion of the Prospect Creek catchment located within the Holroyd City LGA is therefore around 1,421 ha. *[Note that the total catchment area contributing runoff to Prospect Creek at the Cumberland Rail Line is approximately 3,730 ha. Therefore around 2,400 ha of the total catchment area is located outside Holroyd City, primarily within the Fairfield City LGA.]*

The majority of the catchment located within Holroyd City comprises industrial development, in particular along the southern boundary of the LGA adjacent to Prospect Creek. Areas of low density residential development are located in the upper, northern parts of the catchment. Open space in the form of parks and reserves are interspersed throughout the developed areas of the catchment. A feature of the catchment is a continuous string of reserves formed by the Canal Reserve, Hyland Road Arboretum and Park, Gipps Road Sportsground and various open spaces along the northern floodplain of Prospect Creek.

The Liverpool to Parramatta Transitway (**LPT**) is the major transport corridor running east-west across the catchment between Fairfield Road, Guildford West and the LGA boundary west of Reconciliation Road, Pemulwuy. Gipps Road, the Cumberland Highway and Fairfield Road form the other major road corridors within the catchment and run generally in a north-south direction. The Cumberland Rail Line runs along the south-east boundary of the catchment and LGA.

Major drainage lines running generally south through the study catchment include those originating in the vicinity of (from west to east):

- the Southern Employment Lands, Pemulwuy;
- Silverthorne Drive, Pemulwuy;
- Roberta Street Park, Greystanes;
- Holroyd High School, Greystanes;
- SWC's Guildford Pipehead facility, Guildford West; and
- Springfield Park, Old Guildford (east of the Cumberland Rail Line in Fairfield City LGA).

The stormwater drainage system is predominantly piped within the developed part of the catchment, with reaches of creek line or constructed open channel generally limited to the following areas:

- areas west of Gipps Road, within the Southern Employment Lands and Hyland Road Arboretum and Park;
- sections of drainage line crossing the Canal Reserve along its length;
- below (south) Dennistoun Avenue, Yennora; and
- short lengths of channel at the lower end of various drainage lines where these cross the Prospect Creek floodplain.

Nine regional type flood detention basins were constructed in the Prospect Creek catchment between 1984 and 2007 (refer **Table 2.1** on pages 9 and 10 for details), the largest of which are the Hassall Street and Rosford Street basins located on the main arm of Prospect Creek (identified as basins BA024 and BA025, respectively, on **Figure 2.1, Sheet 3**). Construction of a tenth basin in the catchment, located within Greystanes Sportsground north of Bolaro Avenue, Greystanes (refer basin BA038 on **Figure 2.1, Sheet 3**), was completed in 2013.

3 HYDROLOGIC MODEL DEVELOPMENT AND TESTING

3.1 Selection of Hydrologic Modelling Approach

The present investigation required the use of a hydrologic model which is capable of representing the rainfall-runoff processes that occur within the various study catchments. The practical choice is between the models known as RAFTS, RORB, WBNM and DRAINS, and any of these would have been suitable. However, the DRAINS software has been developed primarily for use in modelling the rainfall-runoff process in urbanised catchments, and was therefore considered to be best suited to the present investigation.

3.2 Brief Review of DRAINS Modelling Approach

The main hydrologic model in DRAINS is based on the ILSAX program (O'Loughlin, 1993), which in turn is based on the American ILLUDAS program. The ILSAX hydrological model uses time-area calculations and Horton infiltration procedures to calculate sub-area discharge hydrographs that are assumed to enter the drainage system, subject to constraints imposed by the entrance and conveyance capacity of the system. DRAINS is also able to calculate hydraulic grade lines throughout a drainage network, enabling users to analyse the magnitude of overflows and stored water for established drainage systems. *[Note that this capability was not utilised as part of this present investigation, as the TUFLOW software was used for this purpose].*

The time-area method utilised in the ILSAX hydrological model is a form of catchment routing model in which a hyetograph of rainfall is combined with a time-area diagram to produce a flow hydrograph. The procedure effectively divides a catchment into a number of equal sub-areas, and superimposes the individual flows from these sub-areas, allowing for time lags depending on their distance from the outlet. In the ILSAX hydrological model, the time-area diagram is considered to be a triangular shape, with the increase in area per time step being constant.

The ILSAX hydrological model uses the depression storage (or initial loss) model for rainfall applied to impervious surfaces and the Horton infiltration model for rainfall applied to pervious surfaces. Horton's equation is the most common relationship for describing infiltration capacity in a soil. It describes the decrease in capacity as more water is absorbed by the soil, and has the form:

$$f = f_c + (f_0 - f_c) \cdot e^{-kt}$$

where:

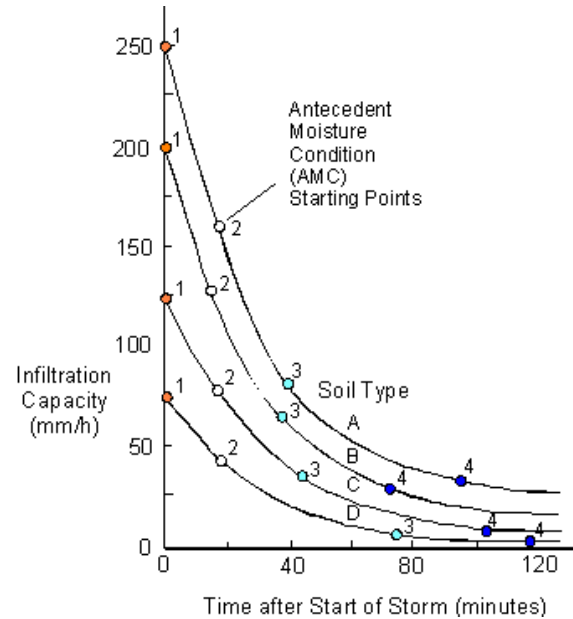
- f is the infiltration capacity (mm/h) at time t ;
- f_0 and f_c are the initial and final constant rates of infiltration (mm/h);
- k is a shape factor (fixed at a value of 2 /h in ILSAX); and
- t is the time from the start of rainfall (h).

The soil type specified in ILSAX determines values for f_0 and f_c . Soil types used in the ILSAX hydrological model follow the U.S. Soil Conservation Service system adopted in the ILLUDAS model from which ILSAX was developed. There are four soil types involving different infiltration characteristics:

- Type 1 (or A) low runoff potential, high infiltration rates (sand and gravels).
- Type 2 (or B) moderate infiltration rates and moderately well-drained.
- Type 3 (or C) slow infiltration rates (may have layers that impede downward movement of water).
- Type 4 (or D) soils with high runoff potential, very slow infiltration rates (consisting of clays with a permanent high water table and a high swelling potential).

Users can specify a number between 1 and 4. ILSAX will interpolate between the standard infiltration factors applying to integer values of 1, 2, 3 or 4. The infiltration curves for these standard soil types are presented in the adjacent illustration (refer right).

Antecedent rainfall is the rainfall that occurs prior to the start of a storm event. It increases soil moisture levels and affects rates of infiltration into the soil. The Antecedent Moisture Condition (AMC) is a parameter used in the loss calculations of the ILSAX hydrological model to specify the wetness or dryness of a catchment at the start of a storm. It is used to set the starting levels for infiltration relationships, and can have a significant effect on the flow rates generated by ILSAX.



An AMC number corresponds to a starting point on an infiltration curve, as shown in the above illustration. The curve defines the rate at which rainwater can penetrate into the soil. During a storm event, this will decrease, due to the soil becoming wetter, soil swelling and other effects. In research on ILSAX and related models, it has proved to be reasonably accurate to relate the AMC value of 1 to 4 to the rainfall in the previous 5 days, as follows:

Number	Description	Total rainfall in 5 days preceding the storm (mm)
1	Completely dry	0
2	Rather dry	0 to 12.5
3	Rather wet	12.5 to 25
4	Saturated	Over 25

Details on model parameters that were found to give a good fit to historic flood data are given in **Section 3.4.2**.

3.3 Hydrologic Model Setup

Figure 2.1 (4 sheets) shows the layout of the various sub-catchments which comprise the hydrologic models for the study catchments.

As the primary function of the hydrologic models was to generate discharge hydrographs for input to the TUFLOW hydraulic models, individual piped reaches and overland flow paths linking the various sub-catchments were not incorporated in the DRAINS models.

Careful consideration was given to the definition of the sub-catchments which comprise the hydrologic models to ensure peak flows throughout the drainage system, in particular at the location of various flow control structures (e.g. regional type flood detention basins) would be properly assessed in the TUFLOW models. In addition to using the ALS-based contour data, the location of surface inlet pits was also taken into consideration when deriving the boundaries of the various sub-catchments.

The extent of the various DRAINS hydrologic models incorporate the entire catchment area contributing runoff to the stormwater drainage system within each of the study catchments, with the exception of the Prospect Creek catchment. In this case the extent of the hydrologic model was limited to those areas upstream of and within the Holroyd City LGA, and excludes the portion of the Prospect Creek catchment located within the Fairfield City LGA that drains directly to the main arm of the creek.

Percentages of impervious area for sub-catchments were assessed using the latest available aerial photography dated April 2013. Sub-catchment slopes used for input to the DRAINS model were derived from average slope values computed by terrain analysis of the ALS survey data.

3.4 Hydrologic Model Testing

3.4.1. General

Historic flood level data related to overland flow for use in the model calibration process is limited to approximately 60 flood marks contained in HCC's database for the storms that occurred on 5 August 1986 and 10 February 1990. Flood mark availability for these two events was further limited to the study catchments of A'Becketts Creek and Duck Creek. **Figure A2.2** in **Appendix A** shows the location of these flood marks.

As there were no historic data on storm flows anywhere in the study catchments, the procedure adopted for the calibration of the hydrologic models involved an iterative process sometimes referred to as "tuning". This process involved the generation of discharge hydrographs for the historic storm events using a starting set of hydrologic model parameters. The discharge hydrographs were then input to the TUFLOW hydraulic model, which was then run with an initial set of hydraulic roughness parameters and the resulting flood levels compared with the recorded flood marks.

Several iterations of this process were required, whereby changes were made to the hydrologic model parameters, after which the resulting adjusted discharge hydrographs were input to the hydraulic model until a good fit with recorded data was achieved.

3.4.2. Hydrologic Model Parameters

As described in **Section 3.2**, the DRAINS hydrologic model requires information on the soil type and losses to be applied to storm rainfall to determine the depth of excess rainfall. Infiltration losses are of two types: initial loss arising from water which is held in depressions which must be filled before runoff commences, and a continuing loss rate which depends on the type of soil and the duration of the storm event. DRAINS also requires information on flow path characteristics in order to compute the time of travel of the flood wave through the sub-catchments.

The following DRAINS model parameters were found to give a good fit to historic flood data:

Soil and Rainfall Loss Parameters

- Soil Type = 3.0
- AMC = 3.0
- Paved area depression storage = 1.0 mm
- Grassed area depression storage = 5.0 mm

Travel Time Parameters

- Paved flow path roughness = 0.02
- Grassed flow path roughness = 0.04

Information contained in ARR suggests that for detached residential dwellings, which are typical of most developed areas within the study catchments, the response time of allotments to rainfall would be in the order of 5 minutes. Slightly longer response times in the range 5 to 15 minutes would be typical for larger commercial and industrial buildings with more extensive internal drainage systems.

For design purposes, DRAINS modelling adopted a minimum response time of 5 minutes for all developed areas within the study area.

3.4.3. Application of Historic Rainfall to the Hydrologic Model

The hydrologic and hydraulic models for A'Becketts Creek and Duck Creek were tested for the storms of 5 August 1986 and 10 February 1990. Continuous rainfall data recorded during these storms at SWC's Guildford (Pipehead) rain gauge were used as input to the hydrologic models. This gauge is located just outside both catchments (refer **Figure A2.1** in **Appendix A** for gauge location).

Review of the earliest available aerial photography dating back to 1995 indicates that the degree of urbanisation throughout the A'Becketts Creek and Duck Creek catchment at that time was broadly consistent with present day conditions. Accordingly, no adjustment to sub-catchment boundaries or characteristics (including imperviousness) was made for model testing purposes.

Note that several regional type flood detention basins located in the upper reaches of the A'Becketts Creek catchment had not been constructed at the time of these historic storms. Further discussion on the adjustments which were made to the hydraulic models to reflect contemporaneous catchment conditions is contained in **Section 4.5.2**.

3.4.4. Results of Model Testing – 5 August 1986 Storm

The discharge hydrographs generated by the DRAINS models for the A'Becketts Creek catchment, when used as input to the TUFLOW hydraulic model, gave reasonable correspondence with observed flood behaviour. Further discussion on the results of modelling the 5 August 1986 storm is contained in **Section 4.5.3**, where the results of the TUFLOW modelling are also presented.

3.4.5. Results of Model Testing – 10 February 1990 Storm

The discharge hydrographs generated by the DRAINS models for the A'Becketts Creek and Duck Creek catchments, when used as input to the TUFLOW hydraulic models, gave reasonable correspondence with observed flood behaviour. Further discussion on the results of modelling the 10 February 1990 storm is contained in **Section 4.5.4**, where the results of the TUFLOW modelling are also presented.

4 HYDRAULIC MODEL DEVELOPMENT AND TESTING

4.1 Selection of Hydraulic Model

The present investigation required the use of a hydraulic model which is capable of analysing the time varying effects of flow in the stormwater drainage system and the two-dimensional nature of overland flow throughout the study area. The model also needed to be capable of defining the pattern of flow which is heavily influenced by features on the floodplain such as buildings or other obstructions and where flow paths cannot readily be identified from site inspection.

The TUFLOW modelling software is one of only a few commercially available hydraulic models which contain all the features described above, and was therefore adopted for use in this present investigation.

4.2 TUFLOW Modelling Approach

TUFLOW is a true two-dimensional hydraulic model which does not rely on a prior knowledge of the pattern of flood flows in order to set up the various fluvial and weir type linkages which describe the passage of a flood wave through the system.

The basic equations of TUFLOW involve all of the terms of the equations of unsteady flow. Consequently the model is "fully dynamic" and once tuned will provide an accurate representation of the passage of the floodwave through the drainage system (both surface and piped) in terms of extent, depth, velocity and distribution of flow.

TUFLOW solves the equations of flow at each point of a rectangular grid system which represent overland flow on the floodplain and along streets. The choice of grid point spacing depends on the need to accurately represent features on the floodplain which influence hydraulic behaviour and flow patterns (e.g. buildings, streets, changes in channel and floodplain dimensions, hydraulic structures which influence flow patterns, etc.).

Pipe drainage and channel systems can be modelled as one-dimensional elements embedded in the larger two-dimensional domain, which typically represents the wider floodplain. Flows are able to move between the one and two-dimensional elements of the model depending on the capacity characteristics of the drainage system being modelled.

The TUFLOW models developed for the study catchments allow for the future assessment of potential flood management measures, such as detention storage, increased channel and floodway dimensions, augmentation of culverts and bridge crossing dimensions, diversion banks and levee systems.

4.3 TUFLOW Model Setup

4.3.1. TUFLOW Model Structure – Current Conditions

A separate TUFLOW model was set up to represent each of the nine study catchments. **Figure 4.1** (4 sheets) shows the layout of the various components which comprise the TUFLOW models.

Key aspects of each model included the existing piped drainage network, modelled as one-dimensional elements, and the extent of the two-dimensional domain in which overland flows are represented. A number of minor open channel reaches that influence overland flow behaviour within the study catchments were also included in each TUFLOW model as one-dimensional elements, and are represented by cross sections normal to the direction of flow.

Note that to assist in developing the TUFLOW models, primarily for generating appropriate downstream boundary conditions for investigation of overland flow behaviour, selected reaches of channel along the main arm of major watercourses in the catchments of Coopers Creek, Duck Creek, Finlaysons Creek and Greystanes Creek were incorporated as one-dimensional elements. However, only a limited number of cross sections along these open channel reaches were used, sufficient for model connectivity purposes. In the case of Prospect Creek, the main arm of the creek was modelled in a simplified form purely in the two-dimensional domain, again for connectivity purposes. **The modelled conveyance along the main arms of these creeks is therefore approximate only and further model refinement would be required in order to accurately define main stream flood behaviour along these watercourses.**

The following sections provide further model development details.

Two-dimensional Model Domains

An important consideration of two-dimensional modelling is how best to represent the roads, fences, buildings and other features which influence the passage of flow over the natural surface. Two-dimensional modelling is very computationally intensive and it is not practicable to use a mesh of very fine elements without incurring very long times to complete the simulation, particularly for long duration flood events. The requirement for a reasonable simulation time influences the way in which these features are represented in the model.

A grid spacing of 2 m was selected for initial model testing. This grid spacing was found to provide an appropriate balance between the need to define features on the floodplain versus model run times, and was therefore adopted for all nine TUFLOW models. Ground surface elevations for model grid points were assigned using a digital terrain model (DTM) derived from ALS survey data.

Ridge and/or gully lines and other topographic modifiers were also applied to the various TUFLOW models where the grid spacing was considered too coarse to accurately represent important topographic features which influence the passage of overland flow, or where ALS survey was found to inaccurately represent overland flow paths. For example, ground levels were lowered in the vicinity of a number of pedestrian and road underpasses where ALS survey data represents the overlying bridge deck or embankment crest level. A gully line was also used to represent the main arm of Prospect Creek where it runs along the full length of the southern boundary of the LGA.

The footprints of a large number of individual buildings located in the two-dimensional model domains were assigned a high hydraulic roughness value relative to the more hydraulically efficient roads and flow paths through allotments. This accounted for their blocking effect on flow while maintaining a correct estimate of floodplain storage in the models. Building polygon data provided by HCC were used as the basis for digitising building footprints throughout the study catchments. However, substantial refinement of the original dataset was undertaken throughout the floodplain of each catchment to provide a more realistic definition of these structures in terms of their shape, total area and spacing between adjacent structures.

In certain areas (e.g. the Merrylands CBD within the A'Becketts Creek catchment) it was considered more appropriate to represent selected buildings as solid obstructions rather than areas of high roughness, due to their blocking effect on the passage of flow and also where their presence had resulted in anomalies in the underlying ALS survey data. In such cases, the region of floodplain within the building footprint was raised to an elevation above the upper limit of flooding.

It was not practicable to model the individual fences surrounding the many allotments in the study catchments. They comprised many varieties (brick, paling, colorbond, etc.) of various degrees of permeability and resistance to flow. It was assumed that there would be sufficient openings in the fences to allow water to enter the properties, whether as flow under or through fences and via openings at driveways. Individual allotments where development is present were therefore digitised and assigned a high hydraulic roughness value (although not as high as for individual buildings) to account for the reduction in conveyance capacity which will result from fences and also other obstructions stored on these properties.

One-dimensional Model Elements

HCC's pit and pipe database was used to obtain details of the drainage conduits which were incorporated into the TUFLOW models. **Table 4.1** over page provides a summary of the pit and pipe network incorporated into each of the nine models.

Limited information was available on pipe invert levels, therefore an assumed cover of 700 mm was adopted for those drainage elements where invert levels or depth measurements were not available. Further adjustments were made to the assumed invert levels where this approach resulted in a negatively graded reach of pipe or culvert.

A substantial amount of checking and refinement of pit and pipe data contained in HCC's asset database was also required to address the following issues:

- Connectivity – checks were undertaken to locate and join a large number of disconnected drainage elements.
- Duplicate pipes – duplicates were removed where the presence of a single barrel/cell could be reasonably determined.
- Multiple barrels/cells – discrepancies in the number of barrels/cells between duplicate database records were resolved by inspection of the surrounding drainage network.

Several types of pits are identified on **Figure 4.1** and in **Table 4.1**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. HCC's asset database contained only limited information in regard to inlet pit types and dimensions. For this reason, inlet capacity relationships were generally not incorporated into the TUFLOW models, and the modelled hydraulic capacity of the pipes therefore controls the assessed capacity of the piped drainage system. The one exception to this occurs for the A'Becketts Creek catchment TUFLOW model, with pit inlet capacity relationships incorporated within the Merrylands CBD (refer **Section 4.6.2** for further details).

Pit losses throughout the various piped drainage networks were modelled using the Engelund approach in TUFLOW. This approach provides an automatic method for determining time-varying energy loss coefficients at pipe junctions that are recalculated each timestep, based on a range of variables including the inlet/outlet flow distribution, the depth of water within the pit, expansion and contraction of flow through the pit, and the horizontal deflection and vertical drop across the pit.

TABLE 4.1
SUMMARY OF MODELLED PIT AND PIPE NETWORK

Study Catchment	Pipes		Box Culverts		Other Conduits		Inlet Pits / Headwalls	Junction Pits
	No.	Length (m)	No.	Length (m)	No.	Length (m)	No.	No.
Greystanes Creek	1,737	43,556	16	398	6	120	1,536	242
Coopers Creek	1,051	28,275	17	332	-	-	826	230
Finlaysons Creek	1,992	54,778	15	348	2	28	1,569	429
Westmead Creek	131	3,978	2	23	-	-	103	26
Domain Creek	315	8,393	2	39	-	-	243	76
Clay Cliff Creek	364	9,710	16	912	-	-	317	71
A'Becketts Creek	1,805	45,958	46	1,997	2	44	1,450	400
Duck Creek	490	12,202	19	416	-	-	428	73
Prospect Creek	3,735	104,005	68	2,649	2	16	3,038	867
Totals	11,620	310,855	201	7,114	12	208	9,510	2,414

Design drawings provided by HCC for the 30 regional type flood detention basins which have been constructed in the study catchments were used as the source of data for input to the TUFLOW model (refer **Table 2.1** on pages 9 and 10 for details).

Design drawings showing details of the existing piped drainage system in a number of specific locations were also provided by HCC where further clarification of its asset database was sought. These included drawings for the area around Lance Crescent, Greystanes (upper Coopers Creek catchment) and Holroyd Gardens Park, Holroyd (lower A'Becketts Creek catchment). Design drawings showing details of major drainage structures that convey runoff across the LPT corridor (located within the Prospect Creek catchment) were also available and used to supplement HCC's asset database in this area.

Approximately 394 cross sections were used to define the in-bank waterway area of open channel reaches throughout the study catchments. Cross sectional data were sourced from the following:

- MIKE 11 model data provided by UPRCT for the main arms of the creeks which lie within the Upper Parramatta River catchment (i.e. Greystanes Creek, Coopers Creek and Finlaysons Creek). Cross sections extracted from the MIKE 11 model were typically trimmed to the top of bank level, with overbank areas represented in the two-dimensional model domains.
- ALS survey data.
- Design drawings provided by HCC showing relevant details in a limited number of areas.

Cross sections along short reaches of SWC's two concrete-lined stormwater channels located upstream (south) of the Merrylands CBD were sourced from the TUFLOW model previously set up as part of the Upper A'Becketts Creek Flood Study (Bewsher, 2006).

While field measurements of concrete lined sections of channel were also undertaken using a tape where possible, detailed field survey of vegetated sections of channel through the catchment was not undertaken. As a result, the TUFLOW models developed as part of the present investigation may underestimate the capacity of these sections of channel given the ALS survey data was relied upon for defining their waterway area. A series of gully lines were incorporated the model based on the invert levels of adjacent culvert reaches to lower the DTM in several locations where the channel system was modelled in the 2D domain.

4.3.2. Model Parameters

The main physical parameter for TUFLOW is the hydraulic roughness. Hydraulic roughness is required for each of the various types of surfaces comprising the overland flow paths, as well as for the cross sections representing the geometric characteristics of the channels. In addition to the energy lost by bed friction, obstructions to flow also dissipate energy by forcing water to change direction and velocity and by forming eddies. Hydraulic modelling traditionally represents all of these effects via the surface roughness parameter known as "Manning's n". Flow in the piped system also requires an estimate of hydraulic roughness.

There are limited historic flood level data available to assist with the tuning of the model for roughness. Assessment of Manning's n values for open sections of creek or lined channel is relatively straightforward, as cross sections taken normal to the direction of flow have traditionally been used when modelling one-dimensional waterways. Channel roughness can be estimated from site inspection, past experience and values contained in the engineering literature.

The process of ascribing roughness to the various types of surfaces encountered on the two-dimensional floodplain, where flow is generally shallow and of low velocity, is more difficult. Past experience shows that peak flows in typical urban catchments are generally quite sensitive to the adopted value of Manning's n. Increasing n results in the retarding and storage of water on the upper reaches of the floodplain, with a subsequent reduction in downstream flood peaks. These effects emphasise the need for undertaking sensitivity studies prior to final selection of values for design.

Table 4.2 over page presents the "best estimate" of hydraulic roughness values adopted for design purposes. These values were found to give reasonable correspondence with observed overland flow behaviour. The adoption of a value of 0.02 for the surfaces of roads, along with an adequate description of their widths and centreline and kerb elevations, allowed an accurate assessment of their conveyance capacity to be made. Similarly, the high value of roughness adopted for buildings recognises that these structures will completely block the flow but are capable of storing water when flooded.

Figure 4.2 is a typical example of flow patterns derived from those values. This example applies for the 100 year ARI 60 minute design flood and shows overland flows to the north of Irrigation Road, South Wentworthville within the Finlaysons Creek catchment. The left hand side of the figure shows the roads and inter-allotment areas that have been digitised in the model. The outlines of buildings are also shown, based on refined building footprint polygons. The right hand side of the figure shows the resulting flow paths in the form of scaled velocity vectors and indicative depths of inundation.

The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwater when inundated and therefore correctly accounts for flood storage. The flow is conveyed primarily through the open parts of the allotments.

Similar information to that shown on **Figure 4.2** may be presented at any location within the various two-dimensional model domains (which are shown on **Figure 4.1**) and will be of assistance to HCC in assessing individual flooding problems on the floodplains of the study catchments.

TABLE 4.2
“BEST ESTIMATE” OF HYDRAULIC ROUGHNESS VALUES
ADOPTED FOR INITIAL TUFLOW MODEL TESTING

Surface Treatment	Manning's n Value
Concrete surfaces (including piped elements)	0.015
Asphalt or concrete road surface	0.02
Well-maintained grass cover (e.g. sports field)	0.03
Water bodies / wetlands	0.035
Grass / lawns	0.045
Lightly vegetated areas	0.05
Rock riprap/ Macrophytes	0.06
Medium vegetated areas	0.07
Trees	0.08
Allotments (between buildings)	0.08
Mildly dense vegetation	0.12
Dense vegetation	0.135
Buildings	10

4.4 Model Boundary Conditions

4.4.1. Inflow Hydrographs

The locations where sub-catchment inflow hydrographs as estimated by DRAINS were applied to the TUFLOW model are shown on **Figure 4.1**. These comprise both point-source inflows at selected locations along the existing piped drainage systems, and distributed inflows via “Rain Boundaries”.

The location of point source inflows coincide with the location of inlet pits and headwalls where runoff can presently enter the piped drainage system, and generally correspond with the downstream limit of each sub-catchment modelled in DRAINS.

The Rain Boundaries act to “inject” flow into the one and two-dimensional domains of the TUFLOW model, firstly at a point which has the lowest elevation, and then progressively over the extent of the Rain Boundary as the grid in the two-dimensional model domain becomes wet as a result of overland flow. The extent of each Rain Boundary corresponds with the sub-catchment area defined in the DRAINS model.

4.4.2. Downstream Boundary Conditions

The locations where downstream boundary conditions were established for the various TUFLOW models are shown on **Figure 4.1**.

The downstream boundaries for each of the TUFLOW models generally comprised one or more free draining culvert and/or broad-crested weir arrangements (as appropriate), each with sufficient capacity to convey flows discharging to the various downstream piped drainage lines and watercourses from the study catchment.

Stage-discharge relationships were also utilised as a downstream boundary condition in selected locations to simulate overland flows leaving the study catchments where applicable. TUFLOW automatically generates the stage-discharge relationship based on a representative ground surface slope entered by the user at the location of the model boundary.

For the purpose of this present investigation, elevated tailwater conditions were not considered for the modelling of historic storm events, with free draining conditions adopted for all downstream boundaries. Similarly, free drainage outlet conditions were adopted for the modelling of design storm events.

4.5 Hydraulic Model Testing

4.5.1. General

As previously mentioned, the hydrologic and hydraulic models for the A'Becketts Creek and Duck Creek catchments were tested for the storms of 5 August 1986 and 10 February 1990, for which several historic flood marks were available.

4.5.2. Adjustments to TUFLOW Model Structure

The TUFLOW hydraulic model parameters were tuned to flood data which were recorded in the late 1980's and early 1990's. In order to tune the hydraulic model to the recorded flood data, it was necessary to make the following adjustments to the structure of the TUFLOW models which had been set up to reflect present day (2014) conditions:

➤ **A'Becketts Creek Catchment TUFLOW Model**

- All seven regional type flood detention basins that currently exist in the catchment were removed, as the construction of these basins occurred post-February 1990.
- A number of piped drainage system improvements that occurred in conjunction with the various basin works were also removed. Details of existing drainage infrastructure which was present prior to 1990 was estimated from available records and details of the surrounding drainage system.
- Ground surface levels and the building layout on the site currently occupied by Stockland Mall within the Merrylands CBD were altered to reflect conditions in place around the period 1986 – 1990. Available aerial photography from 1995 was used for this purpose, as it is understood that significant changes did not occur in this area between 1990 and 1995.

➤ **Duck Creek Catchment TUFLOW Model**

- A minor piped drainage line extending upstream (north) from Phyllis Crescent to Autumn Place was reduced in size from 600 mm diameter to 300 mm diameter. *[This adjustment was made to improve the model's ability to reproduce observed overland flow through No. 10 Phyllis Crescent, Guildford during the storm of 10 February 1990 – refer **Section 4.5.4** for further discussion.]*

4.5.3. Results of Model Testing – 5 August 1986 Storm

Discharge hydrographs generated by the hydrologic model described in **Section 3.4.4** were applied to the adjusted A'Becketts Creek TUFLOW model, which was then run with an initial set of hydraulic roughness values and the resulting flood levels compared with the observed flood marks.

After several iterations of this process, whereby changes to hydraulic roughness values within developed allotments was varied between 0.05 and 0.15, it was determined that a Manning's n value of 0.08 resulted in the best overall fit with observed data.

Indicative flood extents, depths of inundation and water surface elevations as computed by the TUFLOW model for $n=0.08$ for developed allotments are shown on **Figure 4.3**. Also shown on this figure is the location of historic flood marks.

Table D1 in **Appendix D** contains details of available flood marks within the A'Becketts Creek catchment for the 5 August 1986 storm, and provides a comparison and brief assessment of the TUFLOW model results at the location of each flood mark.

In general, the TUFLOW model was found to provide a good match to observed flood levels given the uncertainty associated with the precise location of the flood marks (refer **Section A2.2** for further discussion of this issue). The difference between observed and simulated flood levels is within 160 mm for eight of the nine flood marks, and within 100 mm for five flood marks.

After several runs of the TUFLOW model, it was found that it was not possible to improve the fit to historic flood data in several locations. Apart from potential imprecision in the location of the flood marks, differences are considered most likely due to the localised flow patterns that occur within allotments and which can vary significantly from storm to storm as a result of changes to buildings, fences, gardens beds, the presence of parked cars and other minor obstructions.

Whilst the TUFLOW model typically overestimates flood levels at all flood mark locations, it was found that reducing the hydraulic roughness value for developed allotments to $n=0.05$ resulted in the model generally under-estimating peak flood levels. This highlights the importance of undertaking appropriate sensitivity analyses during modelling of design flood events.

4.5.4. Results of Model Testing – 10 February 1990 Storm

Discharge hydrographs generated by the hydrologic model described in **Section 3.4.5** were applied to the adjusted TUFLOW models for the A'Becketts Creek and Duck Creek catchments, which were then run with an initial set of hydraulic roughness values utilising $n=0.08$ for developed allotments derived from tuning the model to the storm of August 1986.

Indicative flood extents, depths of inundation and water surface elevations as computed by the A'Becketts Creek and Duck Creek catchment TUFLOW models are shown on **Figures 4.4** and **4.5**, respectively. Also shown on these figures is the location of historic flood marks.

Tables D2 and **D3** in **Appendix D** contains details of available flood marks within the A'Becketts Creek and Duck Creek catchments, respectively, for the 10 February 1990 storm, and provide a comparison and brief assessment of the TUFLOW model results at the location of each flood mark.

In the A'Becketts Creek catchment, the TUFLOW model was generally found to provide a reasonable match to observed flood levels given the uncertainty associated with the precise location of the flood marks (refer **Section A2.2** for further discussion of this issue). After several runs of the TUFLOW model, it was found that it was not possible to improve the fit to historic flood data in several locations. As for the August 1986 event, differences are considered most likely due to potential imprecision in the location of the flood marks, as well as the localised flow patterns that occur within allotments and which can vary significantly from storm to storm.

As for the August 1986 event, it was found that reducing the hydraulic roughness value for developed allotments to $n=0.05$ resulted in the model generally under-estimating peak flood levels.

In the Duck Creek catchment, TUFLOW model results show that depths of flooding within each affected allotment generally correspond with the observed data (refer **Table D3** in **Appendix D**).

After several runs of the TUFLOW model, it was found that it was not possible to reproduce the inundation observed in No. 10 Phyllis Crescent, Guildford, even by assuming complete blockage of the piped drainage line extending upstream (north) of Phyllis Crescent. It is therefore considered that unidentifiable changes in topographic features within the catchment upstream of the property and along Phyllis Crescent since 1990 have most likely resulted in a redirection of overland flow away from the property and to the east along the roadway.

4.5.5. Summary

Based on the findings of the model testing process, the hydrologic and hydraulic models for the A'Becketts Creek and Duck Creek catchments were considered to give satisfactory correspondence with available flood data.

As such, the hydraulic model parameters set out in **Section 4.3**, and in particular the hydraulic roughness values set out in **Table 4.2**, were considered appropriate for use in defining flood behaviour in all nine study catchments over the full range of design flood events. Note that due to the relative sensitivity of modelled peak water surface levels to the adopted hydraulic roughness value for developed allotments (as described in **Sections 4.5.3** and **4.5.4**), sensitivity analyses to assess the impact of this parameter on overland flood behaviour were also undertaken, the results of which are presented in **Section 6.4.1**.

Further discussion and presentation of hydrologic model parameters that were adopted for design flood estimation purposes is provided in **Section 5.3**.

4.6 Adjustments to TUFLOW Models Following Model Testing

4.6.1. General

Several adjustments were made to the TUFLOW models for the A'Becketts Creek and Duck Creek catchments following the above-mentioned model testing process as a result of:

- Refinement of the A'Becketts Creek catchment TUFLOW model that was undertaken as part of a concurrent investigation of flooding conditions and potential flood management options for the Merrylands CBD (L&A, 2014).
- Ground-truthing exercises that were undertaken in both catchments for the purpose of validating preliminary hydraulic model results.

The following sections describe the adjustments that were made to the respective TUFLOW models.

4.6.2. A'Becketts Creek Catchment

Incorporation of Work-As-Executed Plans Provided by SWC

Following completion of the model testing process, SWC provided details of its trunk stormwater drainage system in the vicinity of the Merrylands CBD in the A'Becketts Creek catchment. This comprised a series of Work-as-Executed (**WAE**) plans covering trunk drainage elements within the area bounded by Treves Street (to the west), Merrylands Road (to the south) and Neil Street (to the north).

Comparison of the SWC plans to HCC's asset database showed a number of inconsistencies in terms of dimensioning of the various open and covered channels and associated invert levels. Accordingly, the relevant one-dimensional model elements in the A'Becketts Creek catchment TUFLOW model were updated to reflect the SWC asset data.

Incorporation of Pit Inlet Capacity Relationships within the Merrylands CBD

As previously mentioned, inlet capacity relationships were incorporated into the TUFLOW model for all pits within the Merrylands CBD. This model refinement was undertaken to enable the performance of additional inlet capacity to be assessed as part of L&A, 2014. Nominal pit types and kerb inlet sizes were assigned on the basis of visual inspection, supported by available information contained in HCC's asset database. Corresponding depth-discharge relationships were then derived for each pit type for application to the TUFLOW model.

A sensitivity analysis undertaken during the preparation of L&A, 2014 showed that peak depths of overland flow throughout the catchment for a 100 year ARI event were generally not sensitive to variations in pit inlet capacity.

Other Minor Adjustments

Minor adjustments were also made to the structure of the A'Becketts Creek catchment TUFLOW model following ground-truthing of the preliminary hydraulic model results.

4.6.3. Duck Creek Catchment

Only minor adjustments were made to the structure of the Duck Creek catchment TUFLOW model following ground-truthing of the preliminary hydraulic model results.

4.6.4. Impact on Model Testing Process

On review, it was concluded that the adjustments made to the two TUFLOW models would not influence the outcomes of the model testing process for the A'Becketts and Duck Creek catchments. The adjusted TUFLOW models, in combination with the model parameters set out in **Section 4.3.2**, were then used to define flood behaviour over the full range of design flood events.

5 DESIGN FLOOD ESTIMATION

5.1 Design Storms

5.1.1. Rainfall Intensity

The procedures used to obtain temporally and spatially accurate and consistent Intensity-Frequency-Duration (**IFD**) design rainfall curves for the study catchments are presented in Book II of IEAust, 1998. Design storm rainfalls for frequencies of 5, 20, 50, 100, 200 and 500 year ARI were derived for storm durations ranging between 25 minutes and 6 hours. The procedure adopted was to generate IFD data for the study area by using the relevant charts in Volume 2 of IEAust, 1998. These charts included design rainfall isopleths, regional skewness and geographical factors.

5.1.2. Areal Reduction Factors

The rainfalls derived using the processes outlined in IEAust, 1998 are applicable strictly to a point. In the case of a large catchment of over tens of square kilometres, it would not be realistic to assume that the same rainfall intensity can be maintained over a large area, an areal reduction factor (**ARF**) is typically applied to obtain an intensity that is applicable over the entire area.

However, as the areas of the individual study catchments are relatively small (ranging between about 0.5 and 13.3 km²) the reduction in rainfall intensities would be quite small. Furthermore, the purpose of this present investigation is to define overland flood behaviour not only in the lower reaches of each catchment, but also in the middle and upper reaches where the contributing catchment areas are much smaller in size.

Accordingly, no reduction in design point rainfalls was made for this present investigation (i.e. an ARF of 1.0 was adopted).

5.1.3. Temporal Patterns

Temporal patterns for various zones in Australia are presented in IEAust, 1998. These patterns are used in the conversion of a design rainfall depth with a specific ARI into a design flood of the same frequency. Patterns of average variability are assumed to provide the desired conversion. The patterns may be used for ARI's up to 500 years where the design rainfall data is extrapolated to this ARI.

The derivation of temporal patterns for design storms is discussed in Book II of IEAust, 1998 and separate patterns are presented in Volume 2 for ARI's ≤ 30 years and ARI's > 30 years. The second pattern is intended for use for rainfalls with ARIs up to 100 years, and to 500 years in those cases where the design rainfall data in Book II of IEAust, 1998 are extrapolated to this ARI.

5.2 Probable Maximum Precipitation

Estimates of PMP were made using the Generalised Short Duration Method as described in the BoM's update of Bulletin 53 (BoM, 2003). This method is appropriate for estimating extreme rainfall depths for catchments up to 1,000 km² in area and storm durations up to 6 hours.

The steps involved in assessing PMP for each study catchment are briefly as follows:

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.
- Adjust the PMP estimate according to the percentages of the catchment which are meteorologically rough and smooth, and also according to elevation adjustment and moisture adjustment factors.
- Assess the design spatial distribution of rainfall using the distribution for convective storms based on US and world data, but modified in the light of Australian experience.
- Derive storm hyetographs using the temporal distribution contained in Bulletin 53, which is based on pluviographic traces recorded in major Australian storms.

Figure 5.1 shows the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for each of the study catchments. Note that ellipses are not shown on **Figure 5.1** for those study catchments where the catchment lies wholly within Ellipse A.

5.3 Derivation of Design Discharges

The DRAINS hydrologic model was initially run with the parameters set out in **Section 3.4.2** to obtain design hydrographs for input to the TUFLOW hydraulic model. However, on comparison of design flood flows generated by the TUFLOW model to peak flow estimates derived using Rational Method (RM) procedures and also those extracted from UPRCT's MIKE 11 model (refer **Section 6.2.1** for comparison of adopted design peak flows), it was found that modelled peak flows were consistently lower than RM estimates. Accordingly, further sensitivity testing was undertaken by adjusting several DRAINS model parameters and then re-running the DRAINS and TUFLOW models to obtain closer agreement between modelled peak flows and RM estimates. The following DRAINS model parameters were found to generate design hydrographs that, when applied to the TUFLOW model, produced peak 100 year ARI flow rates that were comparable to RM estimates, and were ultimately adopted for deriving design flood hydrographs for ARI's ranging between 5 and 500 years:

Soil and Rainfall Loss Parameters

- Soil Type = 3.0
- AMC = 3.0
- Paved area depression storage = 1 mm
- Grassed area depression storage = 5 mm

Travel Time Parameters

- Paved flow path roughness = 0.02
- Grassed flow path roughness = 0.04

For PMF events, the adopted AMC value was increased from 3 to 4 to reflect an assumed reduction in rainfall losses that is typically associated with extreme rainfall events.

For ARI's up to 500 years, a design storm duration of 25 minutes was generally found to be critical for maximising peak flows for individual sub-catchments in the urbanised areas of the study catchments. Longer storm durations, up to around 90 minutes, were generally found to be critical in less intensely developed and/or bushland areas.

For the PMF, the 15 minute PMP storm duration was typically found to be critical for maximising peak flows for individual sub-catchments in urbanised areas, increasing to 30 to 45 minutes in less intensely developed and/or bushland areas. Peak PMF flow rates for individual sub-catchments computed by DRAINS were typically between about 4.5 and 6 times the magnitude of peak 100 year ARI flow rates. These values lie within the range of expected multiples for urbanised catchments.

Further details of design flood flows generated by the hydrologic and hydraulic models developed as part of this present study, and their comparison to results reported in previous flooding investigations, are provided in **Chapter 6**.

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6 HYDRAULIC MODELLING OF DESIGN FLOODS

6.1 Presentation of Results

6.1.1. Extents and Depths of Inundation

Figures 6.1 is a key plan showing the layout of the 11 sheets which cover the nine study catchments, while **Figures 6.2 to 6.6** (11 sheets each) show the TUFLOW model results for the 5, 20, 50 and 100 year ARI storm events and the PMF. Note that flooding patterns have not been shown along the major watercourses that have been investigated as part of previous studies (i.e. Greystanes Creek, Coopers Creek, Finlaysons Creek, A'Becketts Creek, Duck Creek and Prospect Creek).

In order to create realistic results which remove most anomalies caused by inaccuracies in the ALS survey (which has a design accuracy such that 95 per cent of the points have an accuracy in level of +/- 150 mm), a filter was applied to remove depths of inundation over the natural surface of less than 100 mm. This has the effect of removing the very shallow depths which are more prone to be artifacts of the model, but at the same time giving a reasonable representation of the various overland flow paths.

Note that areas affected by depths of overland flow greater than 100 mm may also be subject to main stream flooding of a greater depth. Consideration of this possibility needs to be given during the assessment of flooding behaviour at the individual allotment level (for example, during the assessment of development proposals).

The depth grids shown on the figures have also been trimmed to the building polygons, as experience has shown that property owners incorrectly associate depths of above-ground inundation at the location of buildings with depths of above-floor inundation.

6.1.2. Accuracy of Hydraulic Modelling

The accuracy of results depends on the precision of the numerical finite difference procedure used to solve the partial differential equations of flow, which is also influenced by the time step used for routing the floodwave through the system and the grid spacing adopted for describing the natural surface levels in the floodplain. Channels are described by cross-sections normal to the direction of flow, so their spacing also has a bearing on the accuracy of the results. The results are also heavily dependent on the size of the two-dimensional grid, as well as the accuracy of the ALS survey data, which as noted above has a design accuracy based on +/- 150 mm.

There are a number of locations where the ALS survey data does not necessarily reflect prototype conditions. These locations include:

- In the industrial areas of the Prospect Creek catchment, where removal of the shots which pick up the rooflines of buildings has left large voids in the dataset.
- In Southern Employment Lands around Reconciliation Road where more recent large scale changes in the topography has rendered the ALS survey data obsolete.

There are also a number of isolated "hot spots" where anomalies in the modelled depth of inundation are apparent. Examples occur in steeper streets where allotments are set below

street level and build-ups of water occur against buildings and garages at the end of driveways. In the prototype, there are usually narrow spaces between buildings which would have the effect of releasing water from these low points. There are also several situations where the grid level of the ALS appears to be based on the tops of structures or vegetation canopies, resulting in unrealistically high model natural surface levels which may affect results. It is not practicable to include all of these local features in the various TUFLOW models or remove all of the anomalies in the ALS survey data. Site specific studies would be required with the benefit of field survey to confirm local flow paths, natural surface levels and depths of flood affectation in individual allotments.

Given the uncertainties in the ALS survey data and the definition of features affecting the passage of flow, maintenance of a depth of flow of at least 200 mm is required for the definition of a “continuous” flow path in the areas subject to shallow overland flow approaching the main arms of the study catchments. Lesser modelled depths of inundation may be influenced by the above factors and therefore may be spurious, especially where that inundation occurs at isolated locations and is not part of a continuous flow path. In areas where the depth of inundation is greater than the 200 mm threshold and the flow path is continuous, the likely accuracy of the hydraulic modelling in deriving peak flood levels is considered to be between 100 and 150 mm.

In addition to the above, the TUFLOW models developed as part of the present investigation may underestimate the capacity of the vegetated sections of channel given the ALS survey data was relied upon for defining their waterway area (refer **Section 4.3.1** for details). While it was not practicable to obtain detailed ground survey of all the vegetated sections of channel in the study area as part of the present investigation, future site specific studies will need to consider the implications of the adopted approach to defining the waterway area of these drainage lines on overland flow behaviour.

Use of the flood study results when applying flood related controls to development proposals should be undertaken with the above limitations in mind. Proposals should be assessed with the benefit of a site survey to be supplied by applicants, in order to allow any inconsistencies in results to be identified and given consideration. This comment is especially appropriate in the areas subject to shallow overland flow, where the errors in the ALS survey data or obstructions to flow would have a proportionally greater influence on the computed water surface levels than in the deeper flooded main stream areas.

Minimum floor levels for residential, commercial and industrial developments should be based on the 100 year ARI flood level plus appropriate freeboard (this planning level is defined as the “*Flood Planning Level*” (**FPL**)), to cater for uncertainties such as wave action, effects of flood debris conveyed in the overland flow stream and precision of modelling. Note that a freeboard of 500 mm has been adopted for defining the IFPL’s pending the completion of future FRMS&P’s for each individual catchment. Derivation of an IFPA based on the interim set of IFPL’s is presented in **Section 6.6**.

The sensitivity studies and discussion presented in **Section 6.4** provide guidance on the suitability of the recommended allowance for freeboard under present day climatic conditions.

In accordance with Office of Environment and Heritage (**OEH**) recommendations (DECC, 2007b), sensitivity studies have also been carried out to assess the impacts of future climate change on overland flow behaviour (refer **Section 6.5**). Increases in depths of overland flow due to future increases in rainfall intensities may influence the selection of FPL’s. However, selection of a final set of FPL’s is a matter for more detailed consideration in the future FRMS’s.

6.2 Discussion of Results

6.2.1. Overview

Sections 6.2.2 to 6.2.10 provide a description of overland flow behaviour within the study catchments. **Table E1** in **Appendix E** presents peak flows at a number of key locations within the study catchments, while **Table E2** summarises the hydraulic behaviour of the regional type flood retarding basins that have been constructed to control local catchment runoff in the upper reaches of the drainage system (i.e. not those located along the major watercourses of the study creeks, the assessment of which has been undertaken by others (refer **Appendix A**).

Table 6.1 over page provides a comparison of peak flow rates which were extracted from UPRCT's MIKE 11 model result files with those derived as part of the present investigation.⁴

By comparison of the peak flow values given in **Table 6.1**, the hydrologic and hydraulic models developed as part of the present investigation (i.e. DRAINS and TUFLOW) generate peak flows on the main arms of Coopers Creek and Westmead Creek which are similar to those derived by UPRCT's models (i.e. RAFTS and MIKE 11), while the peak flows generated by the present investigation for the Finlaysons and Domain Creek catchments are higher for the more frequent storm events.

The notable difference in peak flows occurs at the outlet of the Domain Creek catchment, where the peak rates at the outlet of the TULFOW model are more than half those generated by UPRCT's RAFTS model. A review of the UPRCT's RAFTS model shows that a single lumped catchment was used to generate a single discharge hydrograph that was used for input to the MIKE 11 model, the upstream boundary of which is located downstream of the Western Railway culverts in the PCC LGA. It was also found that the RAFTS model does not incorporate details of the flood detention basin BA018 which is located in Sydney Smith Park. The combination of the lumped catchment approach and the omission of the attenuating effects of the basin are believed to be the reason for the large difference in peak flows between the two sets of models.

6.2.2. Greystanes Creek

The TUFLOW model results for Greystanes Creek are shown on **Sheets 1, 2 and 5** in the 11 sheet series.

A continuous overland flow path is present at the 5 year ARI level along the line of the local piped drainage system which runs in a northerly direction from the sag in Magowar Road west of Girraween High School to its confluence with the main arm of Greystanes Creek (**Sheet 1**). While depths of overland flow in excess of 300 mm are shown to occur in several industrial properties that are located between Magowar Road and Gilba Road at the 5 year ARI level, similar depths of flow are generally confined to the local road reserves in residential properties located further to the north.

Depths of overland flow of greater than 400 mm in residential properties located along the aforementioned overland flow path occur at the 20 years ARI level, and exceed 500 mm at the 50 year ARI level.

⁴ While the comparison of peak flows is referenced to the main arm of the study creeks (the TUFLOW model results for which are not presented in this report), they do provide a valuable check on the catchment hydrology and unsteady flow hydraulic modelling undertaken as part of the present investigation.

TABLE 6.1
COMPARISON OF PEAK FLOWS⁽¹⁾
(m³/s)

Study Catchment	Location	MIKE 11 Cross Section (Branch / Chainage)	L&A TUFLOW Model				UPRCT MIKE 11 Model			
			5 year ARI	20 year ARI	50 year ARI	100 year ARI	5 year ARI	20 year ARI	50 year ARI	100 year ARI
Coopers Creek	M4 Western Motorway	Coopers_Ck / 1575	18	23	26	28	16	20	26	29
	Western Rail Line	Coopers_Ck / 2992	30	36	37	38	27	32	38	40
Finlaysons Creek	M4 Western Motorway	Fnlayson_Ck / 4031.45	44	45	48	53	31	38	46	50
	Western Rail Line	Fnlayson_Ck / 5168.85	54	61	66	71	46	56	62	67
Westmead Creek	Western Rail Line	Milsons_Ck / 1047.15	6.7	9.1	11	12	6.9	8.3	9.2	10
Domain Creek	Immediately Downstream of Western Rail Line	Domain_Ck / 1377.5	10	12	13	14	15	20	24	27

1. Only peak flows less than 10 m³/s quoted to one decimal place, all others have been rounded off to the nearest integer.

Depths of ponding of up to 300 mm occur at the 5 year ARI level at the eastern end of Toongabbie Road opposite the Western Rail Line due to capacity constraints in the local piped drainage system (refer Peak Flow Location's (**PFL's**) GRE_09 and GRE_10 on **Sheet 1**), increasing to about 1 m at the 100 year ARI level. Several commercial properties including the Parkview Medical Centre, are affected by overland flow which ponds at this location.

A continuous overland flow path is also shown to occur in a residential property which is located on the eastern side of Targo Road north of Oramzi Road at the 5 year ARI level. Overland flow which does not enter the local piped drainage system which crosses the rail corridor east of the property (refer PFL GRE_11 on **Sheet 1**) discharges in a northerly direction along the western side of the rail corridor where it combines with flow ponding at the eastern end of Toongabbie Road.

Further to the south, depths of ponding in excess of 300 mm occur at the 5 year ARI level at the location of sags in Mandoon Road west of Girraween Road, the Great Western Highway east of Greystanes Road and Kiama Street south of the Great Western Highway (refer **Sheet 2**). Stormwater ponding in the vicinity of the sag in Mandoon Road (refer overland flow path along which PFL GRE_03 is located) also forms a continuous flow path which extends toward the north at the 20 year ARI level, linking up with the aforementioned continuous flow path which commences at the 5 year ARI level north of the sag in Magowar Road. Several residential properties located between the sags in Kiama Street and the Great Western Highway are affected by overland flow which forms a continuous flow path at the 50 year ARI level.

Further to the west, ponding at the location of the sag in Reconciliation Road adjacent to the transverse drainage culverts on the tributary arm of Greystanes Creek (refer **Sheet 2**) is shown to occur at the 5 year ARI level.

Depths of overland flow of greater than 100 mm in the upper reaches of the catchment (refer **Sheet 5**) are generally confined to the local road reserves and parkland areas for storms up to 100 year ARI.

Table E2 in **Appendix E** summarises the hydraulic behaviour of regional type flood detention basins BA031, BA032, BA035, BA036 and BA037, all of which control local catchment runoff from parts of the Greystanes Creek catchment.

6.2.3. Coopers Creek

The TUFLOW model results for Coopers Creek are shown on **Sheets 3** and **6** in the 11 sheet series.

North (downstream) of the M4 Western Motorway transverse drainage culverts, depths of overland flow in the residentially development portion of the catchment are generally less than 300 mm at the 5 year ARI level (refer **Sheet 3**). However, depths of overland flow along the following overland flow paths are shown to exceed 300 mm at the 20 year ARI level:

- between Arnett Street and Frederick Street west of Jones Street;
- between Frederick Street and the Great Western Highway west of Jones Street;
- between Sturdee Street and Oatlands Street west of Mashman Avenue; and
- on the eastern side of Emert Street south of Pritchard Street west

While depths of overland flow along the abovementioned overland flow paths exceed 300 mm at the 20 year ARI level, they generally do not exceed 500 mm at the 100 year ARI level.

South (upstream) of the M4 Western Motorway transverse drainage culverts, depths of overland flow of up to about 500 mm are shown to occur along the trunk drainage line which follows the valley of the catchment at the 5 year ARI level. While the majority of the overland flow is confined to Carolyn Street Park (refer **Sheet 3**), depths of flow greater than 100 mm are shown to extend into several residential properties which are located on the northern (downstream) side of the sag in Old Prospect Road.

A continuous flow paths is shown to occur at the 20 year ARI level along the line of a local piped drainage systems which run from Willow Street to Old Prospect Road on the western side of the valley (refer overland flow path along which PFL COO_03 is located) and from Jersey Road to Old Prospect Road on the eastern side of the valley (refer overland flow path along which PFL COO_04 is located). While depths of overland flow along these two flow paths are generally less than 300 mm at the 20 year ARI level, it does increase to about 500 mm in several residential properties at the 100 year ARI level.

In the upper reaches of the catchment (refer **Sheet 6**) depths of overland flow are generally less than 300 mm at the 100 year ARI level, with the following exceptions:

- along the overland flow path that follows the line of the local piped drainage system that drains the sag in Braeside Road south of Hector Street (refer overland flow path along which PFL COO_01 is located); and
- along the overland flow path that runs from the sag in Gerald Street, west to Hanbury Street (refer overland flow path along which PFL COO_02 is located) and then north to Carolyn Street Park.

Major ponding is also shown to occur at the location of sags in Virgil Street on the western side of Daniel Street Park and Graham Street to the west of St Pauls Catholic College (refer **Sheet 6**).

There are no regional type flood detention basins located in the Coopers Creek catchment that control local catchment runoff.

6.2.4. Finlaysons Creek

The TUFLOW model results for Finlaysons Creek are shown on **Sheets 3, 4, 6, 7 and 9** in the 11 sheet series.

Depths of overland land flow north (downstream) of the M4 Western Motorway transverse drainage culverts are generally less than 100 mm up to the 100 year ARI level. The exception is in several residential properties that are located on the northern side of Veron Street and between Essington Street and Fulgar Road, where depths of overland flow do reach up to 500 mm at the 100 year ARI level (refer **Sheets 3 and 4**).

Depths of overland flow in existing development south (upstream) of the M4 Western Motorway transverse drainage culverts of greater than 100 mm is more widespread, with a number of properties affected by depths of flow in excess of 300 mm at the 5 year ARI level (refer **Sheet 6**). Locations where overland flow will have an impact on existing development include:

- along the overland flow path that runs in a westerly direction from the sag in Frances Street near its intersection with Benson Street through to the northern end of Alto Street (refer overland flow path along which PFL FIN_09 is located);
- along the overland flow path that runs in a westerly direction from the sag in Frances Street near Alderson Park through to Hamilton Street (refer overland flow path along which PFL FIN_08 is located);
- along the overland flow path that runs in a northerly direction from the sag in Norman Street west of Frances Street through to Monterey Street (refer overland flow path along which PFL FIN_07 is located);
- along the overland flow path that runs in a easterly direction from the sag in Hampden Road north of Currong Street through to Centenary Road (refer overland flow path along which PFL FIN_05 is located);
- along the overland flow path that runs in a easterly direction from the sag in Maxine Road west of Alder Road through to the main arm of Finlaysons Creek (refer overland flow path along which PFL FIN_04 is located);⁵
- along the overland flow path that runs in a northern direction from the sag in Cameron Court (refer **Sheet 9**) through to the upstream boundary of UPRCT's MIKE 11 model adjacent to Tathira Crescent (i.e. through to Basin BA004) (refer overland flow path along which PFL FIN_03 is located);
- along the overland flow path that runs in a easterly direction from the sag in Montague Street north of Terry Street through to the upstream boundary of UPRCT's MIKE 11 model in Beechwood Street (refer overland flow path along which PFL FIN_01 is located); and
- along the overland flow path that runs from the eastern end of Roland Street through to Canal Road.

Table E2 in **Appendix E** also summarises the hydraulic behaviour of flood detention basins BAS029, BA030 and BA013, immediately downstream of which existing development is not impacted by overland flow.

6.2.5. Westmead Creek

The TUFLOW model results for Westmead Creek are shown on **Sheet 4** in the 11 sheet series.

Depths of overland flow greater than 100 mm are confined to the valley of the catchment upstream of the Western Rail Line. Depths of overland flow in existing residential development exceed 300 mm downstream of Austral Avenue at the 5 year ARI level, increasing to almost 800 mm at the 100 year ARI level. Depths of inundation in several residential properties located along the southern (upstream) side of Alexandra Avenue are exacerbated by overland flow which temporarily ponds along the southern (upstream) side of the railway embankment.

There are no regional type flood detention basins located in the Westmead Creek catchment that control local catchment runoff.

⁵ It is noted that overland flow ponds to depths greater than 1 m on the upstream side of the noise wall which is located on the eastern side of the Cumberland Highway.

6.2.6. Domain Creek

The TUFLOW model results for Domain Creek are shown on **Sheet 4** in the 11 sheet series.

An almost continuous flow path is shown to occur extending from the sag in Good Street through to Drew Street at the 5 year ARI level (refer overland flow path along which PFL DOM_03 is located). While depths of overland flow along this flow path are generally less than 300 mm at the 5 year ARI level, they do increase to over 600 mm at the 100 year ARI level in several residential properties which are located on the northern (downstream) side of Drew Street.

Further north, depths of overland flow are less, reaching up to about 500 mm at the 100 year ARI level in several properties.

Depths of overland flow along the overland flow path which discharges directly into regional type flood detention basin BA018 which is located in Sydney Smith Park reach a maximum of between 500-600 mm in several residential properties that are located to the west (upstream) of Whitworth Street at the 100 year ARI level (refer overland flow path along which PFL DOM_01 is located).

Regional type flood detention basin BA018 is not surcharged at the 100 year ARI level, resulting in reduced depths of overland flow immediately to its east (refer overland flow path along which PFL DOM_02 is located). **Table E2** in **Appendix E** summarises the hydraulic performance of the basin over the full range of modelled storm events.

6.2.7. Clay Cliff Creek

The TUFLOW model results for Clay Cliff Creek are shown on **Sheets 4** and **7** in the 11 sheet series.

Depths of overland flow greater than 100 mm are generally confined to the central valley of the catchment (refer overland flow path along which PFL CLA_01 is located), with the exception of an overland flow path that commences near the intersection of Heath Street and Murray Street south (upstream) of the M4 Western Motorway (refer overland flow path along which PFL CLA_02 is located).

Depths of overland flow in existing residential development are greatest along the valley of the catchment (i.e. along overland flow path along which PFL CLA_01 is located) on the western (upstream) sides of Chester Street and Burnett Street, and on the tributary arm (i.e. along overland flow path along which PFL CLA_02 is located) immediately south (upstream) of the M4 Western Motorway.

Depths of ponding in Jones Park reach a maximum of about 800 mm opposite Franklin Avenue at the 5 year ARI level, increasing to over 1 m at the 100 year ARI level.

There are no regional type flood detention basins located in the Clay Cliff Creek catchment within the Holroyd City LGA that control local catchment runoff.⁶

⁶ A flood detention basin is located in the Clay Cliff Creek catchment immediately downstream (east) of the Holroyd City LGA boundary in Ollie Webb Reserve.

6.2.8. A'Becketts Creek

The TUFLOW model results for A'Becketts Creek are shown on **Sheets 6, 7, 9, and 10** in the 11 sheet series.

There are several major overland flow paths that converge on the Merrylands CBD from its west and south (refer overland flow paths along which PFL ABE_03, ABE_04, ABE_05 and ABE_07 are located). While depths of overland flow along these flow paths are generally less than 300 mm, they do exceed 500 mm in several residential properties at the 5 year ARI level. At the 100 year ARI level, depths of overland flow reach up to 500 mm at regular intervals along each flow path and exceed 1 m in residential development located on the southern (upstream) side of Barcom Street (refer overland flow path on **Sheet 6** along which PFL ABE_01 is located). Depths of flow also reach close to 1 m in residential development located on the eastern (downstream) side of Harris Street (refer overland flow path on **Sheet 10** along which PFL ABE_08 are located) at the 100 year ARI level.

While the flood detention basins in Merrylands Park (i.e. Basin BA21, BA22 and BA23) are shown not to be surcharged at the 100 year ARI level, depths of overland flow along the flow path which runs between the park and Treves Street immediately west of the Merrylands CBD are noticeably deeper over the full range of storm events. For example, depths of overland flow of up to 500 mm are shown to occur in a number of residential properties at the 5 year ARI level and reach a maximum of about 800 mm in four residential properties that are located between Lockwood Street and Warwick Road. The reason for the increased depths of flow is attributed to a lack of capacity in the trunk stormwater drainage system in this location which comprises 2 off 1800 mm diameter pipes.

L&A, 2014 identified that the trunk drainage system generally flows part-full for storms up to 100 year ARI where it runs through the Merrylands CBD. Hydraulic modelling undertaken using the HEC-RAS hydraulic modelling software as part of L&A, 2014 showed that flow conditions within the trunk drainage system are principally supercritical in nature. The modelling also identified the location of several hydraulic jumps which form in the covered sections of concrete and brick lined channel due to downstream controls. Capacity constraints on the northern and southern sides of Merrylands Road were also identified where several sections of box culvert have a reduced waterway area when compared to the adjacent sections of covered concrete and brick lined channel. Several flood modification measures were recommended as part of L&A, 2014 which were aimed at reducing the frequency and magnitude of overland flow discharging through the Merrylands CBD. These measures principally comprised improvements to the inlet capacity of the trunk drainage system and also the removal of the aforementioned capacity constraint.

Table E2 in **Appendix E** summarises the hydraulic behaviour of regional type flood detention basins BA001, BA002, BA003, BA021, BA022, BA023 and BA028, all of which control local catchment runoff upstream of the Merrylands CBD.

6.2.9. Duck Creek

The TUFLOW model results for Duck Creek are shown on **Sheets 9, 10 and 11** in the 11 sheet series.

Depths of overland flow greater than 100 mm are generally confined to the upper reaches of the catchment along the Sydney Water Pipeline Corridor (2 off locations) and in several residential properties that are located between Harris Street and Vulcan Street. Depths of overland flow in the affected residential properties are generally less than 300 mm at the 5 year ARI level, increasing to a maximum of 500 mm at the 100 year ARI level.

Depths of ponding along the eastern side of Military Road adjacent to Guildford Railway Station increase from between 100-200 mm at the 5 year ARI level up to about 400 mm at the 100 year ARI level. The entrance to the pedestrian underpass at the railway station is located at the level of the footpath, indicating it would probably be subject to flooding about every 5 years on the average.

There are no regional type flood detention basins located in the Duck Creek catchment that control local catchment runoff.

6.2.10. Prospect Creek

The TUFLOW model results for Prospect Creek are shown on **Sheets 2, 5, 6, 8, 9, 10** and **11** in the 11 sheet series.

Continuous overland flow paths are shown to be present in the catchment at the 5 year ARI level at the following locations:

- between two industrial properties located on the northern (upslope) side of Tarlington Place (refer overland flow path on **Sheet 5** along which PFL PRO_03 is located);
- through an industrial development that is located at the northern end of Hume Road (refer overland flow path on **Sheet 5** along which PFL PRO_04 is located);
- along Kippax Street and through firstly Greystanes Sports Oval and then two residential properties that are located on the southern (downstream) side of Bolaro Avenue (refer overland flow path on **Sheet 5** along which PFL PRO_06 is located);
- through two industrial properties that are located at the southern end of Hume Road (refer overland flow path on **Sheet 8** north (upstream) of where PFL PRO_05 is located);
- through several industrial properties that are located between Woodpark Road and the Water Supply Pipeline Corridor east of Cooper Street (refer overland flow path on **Sheet 8** north (upstream) of where PFL PRO_09 and PRO_10 are located);
- through several industrial properties that are located along the overland flow path that extends from the sag in Woodpark Road west of Percival Road to a location south (downstream) of the sag in Britton Street (refer overland flow path on **Sheets 8** and **9** along which PFL PRO_16a and PRO_16b are located);
- through several residential and industrial properties that are located along the overland flow path that extends from a location east (upstream) of Fairfield Road to a location south (downstream) of the sag in the Cumberland Highway (refer overland flow path on **Sheet 9** along which PFL PRO_19 and PRO_20 are located);
- through several industrial properties that are located along the overland flow path that extends west from Military Road to a location west of Norrie Street (refer overland flow path on **Sheet 11** along which PFL PRO_38 is located); and

- along a predefined overland flow path that runs through an industrial development that is located on the southern side of Loftus Road (refer overland flow path north of the channel along on which PFL PRO_39 is located).

Several other continuous overland flow paths develop throughout parts of the catchment with increasing storm intensity. However, depths of overland flow along these new continuous flow paths are generally less than 300 mm for storms up to 100 year ARI.

Table E2 in **Appendix E** summarises the hydraulic behaviour of regional type flood detention basins BA012, BA020, BA026, BA027, BA033, BA034 and BA038, all of which control local catchment runoff to the north of Prospect Creek.

6.3 Flood Hazard Zones and Floodways

6.3.1. Provisional Flood Hazard

Flood hazard categories may be assigned to flood affected areas in accordance with the procedures outlined in the Floodplain Development Manual (**FDM**) (NSWG, 2005). Flood prone areas may be provisionally categorised into *Low Hazard* and *High Hazard* areas depending on the depth of inundation and flow velocity. Flood depths as high as 1 m, in the absence of any significant flow velocity, could be considered to represent low hazard conditions. Similarly, areas of flow velocities up to 2 m/s, but with small flood depths could also represent low hazard conditions.

A Provisional Hazard diagram for the 100 year ARI event based on Diagram L2 of the FDM is presented on **Figure 6.7**.

For the 100 year ARI, high hazard flooding in the study catchments is generally confined to the incised reaches of channel and areas where the depth of ponding exceeds 1 m. High hazard flooding is also present in the road network where relatively shallow but fast moving floodwater is present.

There are a small number of residential, commercial and industrial properties that are subject to high hazardous conditions, and only then over a relatively small percentage of the allotment.

The Flood Hazard assessment presented herein is based on considerations of depth and velocity of flow and is *provisional* only. As noted in the FDM, other considerations such as rate of rise of floodwaters and access to high ground for evacuation from the floodplain should also be taken into consideration before a final determination of Flood Hazard can be made. These factors would be taken into account in the future FRMS's for the study catchments.

6.3.2. Floodways

According to the FDM, the floodplain may be subdivided into the following three hydraulic categories:

- Floodways;
- Flood storage; and
- Flood fringe.

Floodways are those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with obvious naturally defined channels. Floodways are the areas that, even if only partially blocked, would cause a significant redistribution of flow, or a significant increase in flood level which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow of areas where higher velocities occur.

Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.

Flood fringe is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

Floodplain Risk Management Guideline No. 2 Floodway Definition, offers guidance in relation to two alternative procedures for identifying floodways. They are:

- **Approach A.** Using a *qualitative approach* which is based on the judgement of an experienced hydraulic engineer. In assessing whether or not the area under consideration was a floodway, the qualitative approach would need to consider; whether obstruction would divert water to other existing flow paths; or would have a significant impact on upstream flood levels during major flood events; or would adversely re-direct flows towards existing development.
- **Approach B.** Using the hydraulic model, in this case TUFLOW, to define the floodway based on *quantitative experiments* where flows are restricted or the conveyance capacity of the flow path reduced, until there was a significant effect on upstream flood levels and/or a diversion of flows to existing or new flow paths.

One quantitative experimental procedure commonly used is to progressively encroach across either floodplain towards the channel until the designated flood level has increased by a significant amount (for example 0.1 m) above the existing (un-encroached) flood levels. This indicates the limits of the hydraulic floodway since any further encroachment will intrude into that part of the floodplain necessary for the free flow of flood waters – that is, into the floodway.

The *quantitative assessment* associated with **Approach B** is technically difficult to implement. Restricting the flow to achieve the 0.1 m increase in flood levels can result in contradictory results, especially in unsteady flow modelling, with the restriction actually causing reductions in computed levels in some areas due to changes in the distribution of flows along the main drainage line.

Accordingly the *qualitative approach* associated with **Approach A** was adopted, together with consideration of the findings of Howells et al, 2004 who defined the floodway based on flow velocity and depth. Howells et al suggested the following criteria for defining those areas which operate as a floodway in a 100 year ARI event:

- Velocity x Depth greater than 0.25 m²/s and Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

Based on an iterative procedure which examined the nature of the resulting floodway extents (i.e. the connectivity of areas identified as floodway and also their relativity to the 20 year ARI flood extent which was used as a guide to the area of land which would be impacted by a flow 80 per cent that of the 100 year ARI flow rate), the following criteria were adopted for the purpose of this present investigation:

- Velocity x Depth greater than 0.05 m²/s and Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

The portions of the various overland flow paths which did not reach the above threshold values were denoted as flood fringe, while flood storage areas were identified as those areas which do not operate as floodways in a 100 year ARI event but where the depth of inundation exceeded 1 m.

The results of applying the above criteria to the 100 year ARI flood envelope were reviewed and minor adjustments made to remove small pockets of floodway and flood storage areas. Areas within flood detention basins which have characteristics that suggest they act as floodways during a major flood were also amended to reflect their flood storage characteristic.

Figure 6.8 shows the resulting hydraulic categorisation for the 100 year ARI event.

6.4 Sensitivity Studies

The sensitivity of the nine hydraulic models was tested to variations in model parameters such as hydraulic roughness and potential blockage of pipes. The main purpose of these studies was to give some guidance on the freeboard to be adopted when setting floor levels of development in areas affected by overland flow, pending the completion of the future FRMS for each catchment. The results are summarised in the following sections.

6.4.1. Sensitivity to Hydraulic Roughness

As described in **Section 4.5.5**, the model testing process showed that modelled peak water surface levels were relatively sensitive to the adopted hydraulic roughness value for developed allotments. On the floodplain, hydraulic roughness within developed allotments is likely to vary substantially from property to property due to the inherent variability of local topographic features and obstructions to flow that are present. However, in the model environment it is not practical to consider variability to this degree, so that global parameters are applied to all such developed allotments. On this basis, it is important to understand the impact of this parameter on design overland flow behaviour.

Figure 6.9 shows the difference in peak flood levels (i.e. the “afflux”) for the 100 year ARI 25 minute duration storm resulting from an assumed Manning’s n roughness of 0.10 in allotments, compared with the best estimate value of 0.08 (i.e. an increase of 25 per cent). This figure also identifies areas where land is rendered flood free, or where additional areas of land are flooded.

Figure 6.10 shows the afflux for the 100 year ARI 25 minute duration storm resulting from an assumed Manning’s n roughness of 0.06 in allotments, compared with the best estimate value of 0.08 (i.e. a reduction of 25 per cent). This figure also identifies areas where land is rendered flood free, or where additional areas of land are flooded.

In general terms, a 25 per cent increase in allotment roughness leads to an increase in the attenuation of flood wave resulting in a reduction in peak flows and depths of inundation in the lower reaches of the drainage system. Increases in the depth of inundation in the upper reaches due to the increased attenuation are relatively small, generally in the range 0-50 mm.

Conversely, a 25 per cent decrease in allotment roughness leads to a speeding up of the flood wave which results in an increase in peak flows and depths of inundation in the lower reaches of the drainage systems. Increases in the depth of inundation in the lower reaches of the drainage systems due to the speeding up of the flood wave are also relatively small, generally in the range 0-50 mm.

It is noted that a 500 mm freeboard allowance would typically be sufficient to cater for uncertainties in the estimate of roughness in the floodplain throughout most of the study catchments.

6.4.2. Sensitivity to Blockage of Hydraulic Structures

The mechanism and geometrical characteristics of blockages in the piped drainage system are difficult to quantify and would no doubt be different for each flood event. Whilst a realistic scenario would be that a limited number of pipes become partially blocked during a flood event (although it is noted that no specific instances of blockage were reported to have occurred during historic flooding in the study catchments), for the purposes of this study, analyses were carried out with the cross sectional areas of all hydraulic structures (i.e. pipes and conduits) reduced by 50 per cent of their unobstructed areas. This represents a case which is well beyond a blockage scenario which could reasonably be expected to occur and is presented for illustrative purposes.

Figure 6.11 shows the afflux for the 100 year ARI 25 minute duration storm resulting from a 50 per cent blockage scenario.

While depths of overland flow are generally increased in the range 0-200 mm, there are several locations where they are increased in the range 200-500 mm. For example, at the western end of Toongabbie Road in the Greystanes Creek catchment (refer **Sheet 1**), on the southern (upstream) side of the railway embankment in the Westmead Creek catchment (refer **Sheet 4**), in the Greystanes Sports Oval in the Prospect Creek catchment (refer **Sheet 5**), along the overland flow path that runs in an easterly direction from the intersection of Lance Crescent and Hector Street in the Coopers Creek catchment (refer **Sheet 6**), in the sag in the Cumberland Highway north of Merrylands Road in the Finlaysons Creek Catchment (refer **Sheet 6**), on the southern (upstream) side of the M4 Western Motorway corridor between Murray Street and Rickard Street in the Clay Cliff Creek catchment (refer **Sheet 7**) and in parts of the Merrylands CBD (refer **Sheet 7**). A partial blockage of the stormwater drainage system also has the potential to significantly increase the extent of industrial land affected by overland flow in the Prospect Creek catchment due to the relatively flat nature of the area.

It is noted that a 500 mm freeboard allowance would typically be sufficient to cater for the effects of pipe blockage throughout most of the study catchments.

6.5 Climate Change Sensitivity Analysis

6.5.1. General

The weight of scientific evidence shows that climate change will lead to sea level rise and potentially increase flood producing rainfall intensities. The significance of these effects on flood behaviour will vary depending on geographic location and local topographic conditions. Climate change impacts on flood producing rainfall events show a trend for larger scale storms and resulting depths of rainfall to increase. Future impacts on sea levels are likely to result in a continuation of the rise which has been observed over the last 20 years.

OEH recommends that its guideline *Practical Considerations of Climate Change* (DECC, 2007b) be used as the basis for examining climate change induced increases in rainfall intensities in projects undertaken under the State Floodplain Management Program and the FDM. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent. On current projections the increase in rainfalls within the service life of developments or flood management measures is likely to be around 10 per cent, with the higher value of 30 per cent representing an upper limit. Under present day climatic conditions, increasing the 100 year ARI design rainfall intensities by 10 per cent would produce a 200 year ARI flood; and increasing those rainfalls by 30 per cent would produce a 500 year ARI event.

Assessment of future sea level rise is not relevant to this present investigation as overland flow within the study catchments is well above the zone of tidal influence.

The impacts of climate change and associated effects on the viability of floodplain risk management options and development decisions may be significant and will need to be taken into account in the FRMS's for the study catchments, using site specific data.

At the present flood study stage, the principal issue regarding climate change is the potential increase in flood levels throughout the study area. In addition, it is necessary to assess whether the patterns of flow will be altered by new floodways being developed for key design events, or whether the provisional flood hazard will be increased.

In the future FRMS it will be necessary to consider the impact of climate change on flood damages to existing development. Consideration will also need to be given both to setting floor levels for future development and in the formulation of works and measures aimed at mitigating adverse effects expected within the service life of development.

Mitigating measures which could be considered in the future FRMS's include the implementation of structural works such as flood detention basins, levees and pipe/channel improvements, improved flood warning and emergency management procedures and education of the population as to the nature of the flood risk.

6.5.2. Sensitivity to Increased Rainfall Intensities

As mentioned, the investigations undertaken at the flood study stage are mainly seen as sensitivity studies pending more detailed consideration in the future FRMS's. For the purposes of this present investigation, the design flood envelopes which have been developed for the 200 and

500 year ARI events were adopted as being analogous to flooding which could be expected should present day 100 year ARI rainfall intensities increase by 10 and 30 per cent, respectively.

Figures 6.12 and **6.13** show the afflux resulting from an increase in 100 year ARI rainfall intensities by 10 and 30 per cent, respectively, while **Figure 6.14** shows the increase in the extent of land affected by overland flow should 100 year ARI rainfall intensities increase by either 10 and 30 per cent.

In general terms, depths of overland flow are increased in the range 0-100 mm for the case where 100 year ARI rainfall intensities are increased by 10 per cent, with greater increases shown to occur in the same areas where a partial blockage of the stormwater drainage system would lead to increases in the range 200-500 mm (refer **Section 6.4.2** for locations). Depths of overland flow are slightly greater for the case where 100 year ARI rainfall intensities are increased by 30 per cent, where a larger number of areas are affected by depths of overland flow in the range 100-200 mm. New overland flow paths are also shown to develop within the study area, namely in the Greystanes Creek, Coopers Creek, A'Becketts Creek (namely in the Merrylands CBD) and Prospect Creek catchments.

It is noted that there may also be a reduction in the time of rise of the floodwaters. The study catchments exhibit “flash flood” behaviour with little warning time available to residents (there is typically between 30 and 60 minutes in the time of rise of floodwaters to peak levels after the commencement of heavy rainfall). Given this constraint, effective flood warning may not be achievable even with the benefit of future technical improvements in such systems. Therefore on-going community education via HCC and the NSW State Emergency Service is required to limit risks to people and property. Further consideration of flood warning arrangements and strategies will need to be undertaken in the future FRMS for each catchment.

6.6 Determination of Interim Flood Planning Areas and Levels

After consideration of the TUFLOW results and the findings of sensitivity studies outlined in **Sections 6.4** and **6.5**, HCC's nominated freeboard allowance of 500 mm was adopted for determination of the Interim FPA (and associated FPL's) for each of the study catchments.

The Interim FPA's for overland flow determined on this basis are shown on **Figure 6.15**.

Note that the Interim FPA and associated Interim FPL's only incorporate the results of the present investigation and do not incorporate the results of previous studies which deal with the definition of main stream flooding behaviour along the major watercourses in the following six study catchments:

- | | |
|--------------------|--------------------|
| ➤ Greystanes Creek | ➤ A'Becketts Creek |
| ➤ Coopers Creek | ➤ Duck Creek |
| ➤ Finlaysons Creek | ➤ Prospect Creek |

The results of these previous studies (refer **Appendix A** for details) will need to be used in combination with those of this present investigation to derive a final set of FPL's when preparing the FRMS&P for each individual catchment.

6.7 Economic Impacts of Flooding

The economic consequences of floods are discussed in **Appendix F**, which assesses flood damages to residential, commercial and industrial property and public buildings in the floodplain. There are no data available on historic flood damages to the urban sectors in the study area. Accordingly it was necessary to use data on damages experienced as a result of historic flooding in other urban centres. The residential flood damages were based on the publication *Floodplain Risk Management Guideline No. 4, 2007 (Guideline No. 4)* published by the Department of Environment and Climate Change (**DECCW**) (now OEH). Damages to industrial and commercial development, as well as public buildings were evaluated using data from previous floodplain management investigations in NSW.

It is to be noted that the principal objectives of the damages assessment were to gauge the severity of urban flooding likely to be experienced in the none study catchments and also to provide data to allow the comparative economic benefits of various flood modification measures which will be assessed as part of the future *FRMS* for each catchment. As explained in **Appendix F**, it is not the intention to determine the depths of inundation or the damages accruing to *individual properties*, but rather to obtain a reasonable estimate of damages experienced over the extent of the urban area in each catchment for the various design flood events. The estimation of damages using *Guideline No. 4* (in lieu of site specific data determined by a loss adjustor) also allows a uniform approach to be adopted by Government when assessing the relative merits of measures competing for financial assistance in flood prone centres in NSW.

Damages were estimated for the design flood levels determined from the hydraulic models that were developed as part of the present investigation. While peak flood levels along the main arms of Greystanes Creek, Coopers Creek, Finlaysons Creek, A'Becketts Creek and Duck Creek have been assessed as part of previous studies, the results of the present investigation were used to estimate flood damages in properties that are located adjacent to these watercourses. In the case of Prospect Creek, the TUFLOW model developed as part of the present investigation does not include flows generated by the catchment which lies upstream of the study area. As a result, the flood damage estimates for the Prospect Creek catchment do not take into account the impact main stream flooding would have on existing development.

Elevations of the floors of affected properties were estimated by a combination of a flood level survey as well as a “drive-by” survey which assessed the height of the floor above local natural surface elevations. These natural surface elevations were derived from the LiDAR survey data that were used to construct the hydraulic models. The number of properties predicted to experience “above-floor” inundation, together with estimated flood damages in the study area are listed on **Table S1 in the Summary**, while **Table FS1 in Appendix F** gives a breakdown of these values on an individual catchment basis.

Figure 6.1 to 6.6 (11 sheets each) show the location and indicative depth of above-floor inundation of affected properties for each design flood event, while **Figure FS1** (11 sheets) in **Appendix F** shows the frequency at which individual properties will be first flood affected and then flood damaged. **Figure F8.1 in Appendix F** shows the damage-frequency curves and cumulative distribution of above-floor depths of inundation at the 100 year ARI level of flooding for residential, commercial and industrial and public buildings in each catchment.

At the 100 year ARI level of flooding, 140 residential properties would experience above-floor inundation up to a maximum depth of 440 mm, resulting in flood damages of \$21.69 Million. While about 75 per cent of the properties inundated above-floor level in a 100 year ARI storm event are located in the Coopers Creek, Finlaysons Creek, A'Becketts Creek and Prospect Creek catchments, there are no obvious damage centres. Rather, the flood damaged properties are scattered along the various overland flow paths throughout the study area.

At the 100 year ARI level of flooding, 107 commercial / industrial properties would experience above-floor inundation up to a depth of 600 mm, resulting in flood damages of \$12.94 Million. The majority of the total commercial / industrial buildings that are flooded above-floor level in a 100 year ARI storm event are located in the Prospect Creek, A'Becketts Creek and Greystanes Creek catchments.

As the floor levels of a large number of the large lot commercial / industrial properties located in the Greystanes Creek and Prospect Creek catchments could not be ascertained by visual inspection (and hence were assumed to have floor levels which are only 50 mm above natural surface levels), the commercial / industrial flood damage estimates which were derived as part of the present investigation may be an overestimate of the actual damages that would be experienced in these two catchments.

The majority of the flood damaged commercial properties in the A'Becketts Creek catchment are located in the Merrylands Central Business District (**CBD**), particularly along Merrylands Road which operates as a floodway in storm events that surcharge the piped drainage system.

The total public damages in the study area are relatively minor, as the majority of public buildings in the study area are located on higher ground remote from the major overland flow paths.

A summary of the "*present worth value*" of damages in the study catchments resulting from all floods up to the 100 year ARI level of flooding at a seven per cent discount rate in each study catchment is set out in **Section S6** of the **Summary**, while additional information on the damages is presented in the tables attached to **Section F8** in **Appendix F** and in the figures associated with this appendix (bound in **Volume 2** of this report).

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8 FLOOD-RELATED TERMINOLOGY

Note: For an expanded list of flood-related terminology, refer to glossary contained in the Floodplain Development Manual (NSW Government, 2005).

TERM	DEFINITION
Afflux	Increase in water level resulting from a change in conditions. The change may relate to the watercourse, floodplain, flow rate, tailwater level etc.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m ³ /s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m ³ /s or larger events occurring in any one year (see average recurrence interval).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average period in years between the occurrence of a flood of a particular magnitude or greater. In a long period of say 1,000 years, a flood equivalent to or greater than a 100 year ARI event would occur 10 times. The 100 year ARI flood has a 1% chance (i.e. a one-in-100 chance) of occurrence in any one year (see annual exceedance probability).
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example, the 100 year ARI or 1% AEP flood).
Digital Terrain Model (DTM)	A three-dimensional representation of the ground surface.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m ³ /s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving (e.g. metres per second [m/s]).
Flood fringe area	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood Planning Area (FPA)	The area of land inundated at the Flood Planning Level.
Flood Planning Level (FPL)	A combination of flood level and freeboard selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans.
Flood prone land	Land susceptible to flooding by the Probable Maximum Flood. Note that the flood prone land is synonymous with flood liable land.
Flood storage area	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

TERM	DEFINITION
Floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event (i.e. flood prone land).
Floodplain Risk Management Plan	A management plan developed in accordance with the principles and guidelines in the <i>Floodplain Development Manual, 2005</i> . Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Floodway area	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted Flood Planning Level and the peak height of the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as “greenhouse” and climate change. Freeboard is included in the flood planning level.
High hazard	Where land in the event of a 100 year ARI flood is subject to a combination of flood water velocities and depths greater than the following combinations: 2 metres per second with shallow depth of flood water depths greater than 0.8 metres in depth with low velocity. Damage to structures is possible and wading would be unsafe for able bodied adults.
Low hazard	Where land may be affected by floodway or flood storage subject to a combination of floodwater velocities less than 2 metres per second with shallow depth or flood water depths less than 0.8 metres with low velocity. Nuisance damage to structures is possible and able bodied adults would have little difficulty wading.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State’s rivers and floodplains.

TERM	DEFINITION
Overland flow	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
Peak discharge	The maximum discharge occurring during a flood event.
Peak flood level	The maximum water level occurring during a flood event.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land (i.e. the floodplain). The extent, nature and potential consequences of flooding associated with events up to and including the PMF should be addressed in a floodplain risk management study.
Probability	A statistical measure of the expected chance of flooding (see annual exceedance probability).
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall which actually ends up as stream flow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum).

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APPENDIX A

DATA COLLECTION

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A1. SYNOPSIS

This Appendix deals with the data collection phase of the study, to:

- summarise the findings of a review of historic flood information available for the various study catchments;
- provide details of the collection of relevant stormwater drainage data; and
- provide a brief overview of several flooding investigations which have previously been carried out in various parts of the study catchments.

The main sources of historic flood information were:

- rainfall depths which were recorded at several pluviographic and daily-read gauges located either within or in close proximity to the study catchments;
- a series of photographs showing overland flows in various parts of the study catchments, captured by residents during several historic flood events;
- a database of flood marks maintained by HCC, based on resident reports of previous flooding; and
- a number of previous reports dealing with flooding in various parts of the study catchments.

Review of HCC's flood mark database and photographic record identified several historic storms when instances of flooding occurred within the study catchments, dating back to April 1974. Of these, only the following two historic storms resulted in reported flood marks on overland flow paths located upslope of areas subject to main stream flooding:

- 5 August 1986; and
- 10 February 1990.

Availability of historic flood marks for these events was further limited to the study catchments of A'Becketts Creek and Duck Creek.

Chapter A2 of this Appendix deals with the collection of historic flood data comprising rainfall data as well as flood marks and photography held by HCC.

Chapter A3 provides details of a range of miscellaneous data that were collected during the initial phase of the study. These data were used to develop the computer-based hydrologic and hydraulic models of the study catchments.

Chapter A4 contains a brief summary of several reports which deal with flooding in various parts of the study catchments. The reports reviewed as part of this study deal with both main stream and overland flow behaviour.

Chapter A5 contains a list of references.

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A2. COLLECTION OF HISTORIC FLOOD DATA

A2.1 Historic Rainfall Data

A data search was undertaken which identified a total of 17 rain gauges operated by SWC which have recorded rainfall intensity data both within and in close proximity to the Holroyd City LGA since the mid-1980's. **Figure A2.1** shows the location of the pluviometers relative to the study catchments.

Of the 17 SWC pluviometers only one is located within the study catchments [**Guildford (Pipehead), Gauge Ref. 567079**], whilst a second pluviometer is located within the LGA in the Pendle Creek catchment [**Greystanes (Cumberland Golf Club), Gauge Ref. 567146**]. Two other pluviometers are located just outside the LGA, immediately to its west [**Prospect Reservoir, Gauge Ref. 567083** and **South Prospect, Gauge Ref. 567092**]. A number of other pluviometers are located a short distance outside the LGA.

In addition to the SWC pluviometers, several daily-read rain gauges operated by BoM were also identified within and in close proximity to the Holroyd City LGA (refer **Figure A2.1** for their location). Three of these daily-read gauges are located within the LGA [**Greystanes, Gauge Ref. 67017**, **Westmead (Austral Avenue), Gauge Ref. 67032** and **Merrylands (Welsford Street), Gauge Ref. 67070**].

Rainfall data at 5 minute intervals were obtained from SWC for their 17 pluviometers, whilst daily rainfall depths for the BoM gauges were obtained via the BoM website.

An initial review of the available rainfall data, combined with a review of previous flood and drainage-related investigations within the LGA, including information contained in HCC's Study Brief, identified several periods of interest corresponding to either heavy rainfalls or reported instances of flooding in the study catchments.

Details of data availability for the identified periods of interest are given in **Table A2.1** over.

The findings of an analysis carried out on rainfall recorded at several of the gauges are contained in **Appendix C** of this report.

A2.2 Historic Flood Marks and Photographic Record

A database of historic flood marks maintained by HCC was provided at the commencement of the present study. This database, in GIS format, included the location and surveyed elevation of reported peak flood levels and/or depths of overland flow throughout the Holroyd City LGA for a number of historic flood events, based largely on resident reports of historic flooding.

On review, it was found that the geo-referenced locations of all flood marks contained in the database did not match the corresponding street address attached to each mark. HCC then reviewed the database and ultimately applied a global shift of about 230 m to the location of all flood marks in an attempt to relocate them as closely as possible to their true position. However, as HCC was not able to locate the original flood mark survey from which the GIS database was created, a small spatial error remains that is not possible to quantify.

TABLE A2.1
HISTORIC RAINFALL DATABASE⁽¹⁾

Gauge Owner	Gauge Ref.	Gauge Name	Historic Storm Event								
			Aug 1986	Apr 1988	Feb 1990	Aug 1990	Apr 2000	Jan 2001	Feb 2001	Feb 2002	Dec 2011
BoM	66070	Strathfield Golf Club									
	66085	Granville RSL Bowling Club									
	66124	Parramatta North (Masons Drive)									
	66134	Granville Shell Refinery									
	66185	Carlingford (Barellan Avenue)									
	67017	Greystanes									
	67019	Prospect Reservoir									
	67032	Westmead (Austral Avenue)									
	67070	Merrylands (Welsford Street)									
	67080	Winston Hills (Lanhams Road)									
	67110	Seven Hills (Radio FM 103.2)									
	67114	Abbotsbury (Fairfield City Farm)									
	67119	Horsley Park Equestrian Centre									
SWC	566036	Potts Hill Reservoir									
	566081	Carlingford Bowling Club									
	566082	Auburn RSL Bowling Club									
	566086	Parramatta (Masonic Club)									
	566133	SP0101 Parramatta									
	566140	SP0098 Auburn									
	566169	Chester Hill Bowling Club									
	567077	Fairfield STP									
	567079	Guildford (Pipehead)									
	567083	Prospect Reservoir									
	567092	South Prospect									
	567104	Northmead Bowling Club									
	567111	Westmead Hospital									
	567112	North Parramatta (Burnside Homes)									
	567146	Greystanes (Cumberland Golf Club)									
	567150	Blacktown (Dog Pound)									
	567151	Toongabbie Bowling Club									

1. Refer **Figure A2.1** for location of rainfall gauging stations.

LEGEND

5 Minute Data

Daily Data

No Data



Review of the spatially corrected flood mark database showed that only the following two historic storms resulted in reported flood marks on overland flow paths located upslope of areas subject to main stream flooding:

- 5 August 1986; and
- 10 February 1990.

Availability of historic flood marks for these events was further limited to the study catchments of A'Becketts Creek and Duck Creek.

Figure A2.2 shows the location of the above flood marks that were considered suitable for use in the model tuning process, further details of which are contained in **Chapters 3** and **4** of this report.

HCC also provided historical flood photography relating to both overland and main stream flooding in various parts of the study catchments, captured by residents during past flood events. A number of photographs which were taken during the August 1986 and February 1990 events, as well as several other historic storm events that have affected the study catchments, are contained in **Appendix B**. Note that the location of these photographs is shown on **Figure A2.2**.

In some cases it was possible to estimate depths of overland flow from these photographs, however it is not known whether the photographs were taken at, or near, the peak of the various overland flow events. Whilst this information can be used to verify the extent of inundation predicted by the hydraulic model, and specific residences that were impacted by overland flows, it does not allow the model to be tuned to a recorded flood level.

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A3. COLLECTION OF MISCELLANEOUS DATA

A3.1 Airborne Laser Scanning Survey and Aerial Photography

The Holroyd City LGA was flown by LPI in April 2013 for the purpose of preparing a DTM for HCC based on ALS survey. The LGA was flown at an altitude of 1530 m for a target horizontal accuracy of 95% per cent of points within +/- 400 mm and a target vertical accuracy of 95% per cent of points within +/- 150 mm.

Historic aerial photography captured in 1995, 2001, 2003, 2005, 2009 and 2011 was also provided by HCC.

A3.2 Stormwater Pit and Pipe Network for Holroyd City LGA

At the commencement of the study, HCC provided a copy of its then current stormwater pit and pipe asset database. **Figure 2.1** in **Volume 2** of the report shows the extent of the stormwater pit and pipe network throughout the study catchments.

Review of HCC's asset database showed that reliable information was generally limited to pipe/culvert dimensions, with only a small number of pit or pipe invert levels available, and pit types (e.g. junction, inlet or headwall). Whilst more detailed information relating to inlet pit types was contained in the database, on further review this information proved to be unreliable.

Further discussion on the use of the information contained in HCC's asset database as input data to the hydraulic models is contained in **Section 4.3** of this report.

Design drawings showing details of the existing piped drainage system in a number of specific locations were also provided by HCC where further clarification of their asset database was sought. These included drawings for the area around Lance Crescent, Greystanes (upper Coopers Creek catchment) and Holroyd Gardens Park, Holroyd (lower A'Becketts Creek catchment).

Culvert dimensions and invert levels were also available for major hydraulic structures along the main arms of a number of the creeks within the study catchments based on data contained in separate database sourced from UPRCT. This database relates to the MIKE 11 hydraulic model that is maintained by UPRCT for the Upper Parramatta River catchment. However, based on advice from UPRCT this culvert information was used only for cross-checking against HCC's asset database and identifying discrepancies for later field confirmation, was not relied upon for the purpose of this present investigation. Further details of data provided by UPRCT is provided in **Section A3.4**.

A3.3 Stormwater Pit and Pipe Data for Parramatta City LGA

PCC provided several plans in PDF format showing the location and nominal dimensions of the piped drainage system within adjacent areas of the Parramatta City LGA. These data were used to supplement HCC's asset database where data was otherwise missing along the LGA boundary (e.g. at various piped crossings under the Western and Cumberland Rail Lines).

A3.4 UPRCT MIKE 11 Model Data

UPRCT provided details of MIKE 11 hydraulic modelling previously undertaken as part of flooding investigations for the Upper Parramatta River catchment, which included analysis of flooding along the main arms of Greystanes, Coopers, Finlaysons and Westmead Creeks where they run within the Holroyd City LGA. Details obtained from UPRCT comprised MIKE 11 model data and peak flood level results for a range of design storm events ranging between 5 year ARI and the PMF.

The MIKE 11 model data included cross sections along the above-mentioned creeks that were used to define the in-bank topography in the hydraulic models developed for the study catchments of Greystanes Creek, Coopers Creek and Finlaysons Creek.

Whilst details of major culvert structures along the above-mentioned creeks were also contained within the MIKE 11 models, these data were used for cross-checking purposes only (refer **Section A3.2**).

The extent of MIKE 11 cross section and culvert data provided by UPRCT is shown on **Figure A3.1**.

A3.5 Flood Retarding Basins

Limited survey data were available for the various flood detention basins which have been constructed throughout the study area. HCC provided copies of design drawings for the basins in PDF format and advised that this information was to be used as the basis for configuring the hydraulic models. These drawings included a basin in Greystanes Sportsground off Bolaro Avenue, Greystanes (upper Prospect Creek catchment) that was under construction at the commencement of the present investigation.

The locations of the flood detention basins are shown on **Figure 2.1** in **Volume 2**, whilst data for each basin are given in **Table 2.1** of this report.

It is noted that various survey plans and other related drainage information was also contained in the basin drawing sets provided by HCC, and these data were used to supplement their asset database (refer **Section A3.2**) where applicable.

A3.6 Liverpool to Parramatta Transitway Project

Design drawings showing details of major drainage structures that convey runoff across the LPT corridor were also available and used to supplement HCC's asset database in this area. The LPT is located within the Prospect Creek catchment and runs generally east-west across the catchment between Fairfield Road, Guildford West and Reconciliation Road, Pemulwuy.

A3.7 Upper A'Becketts Creek Flood Study TUFLOW Model Data

As part of the Upper A'Becketts Creek Flood Study (Bewsher, 2006), a two-dimensional hydraulic model using the TUFLOW software was prepared to analyse overland flow behaviour in the upper reaches of the catchment, above (i.e. to the west and south of) the Merrylands CBD (refer **Section A4.1** for further details).

HCC provided TUFLOW model data and result files from the 2006 investigation, the study area for which is incorporated within the extent of the present investigation. The TUFLOW model data included cross sections that were used to define the in-bank topography for short sections of SWC's concrete and brick-lined channel located between King Park and the Merrylands CBD.

Other TUFLOW model data that were used to assist in development of the hydraulic model for this present investigation included details of the piped stormwater drainage system to resolve discrepancies in HCC's asset database.

A3.8 Previous Studies

A large collection of previous reports dealing with flooding and drainage investigations in the study catchments were provided by HCC. **Table A3.1** (located at the end of this Appendix) provides a complete listing of these reports.

The majority of the available reports were privately commissioned and relate to proposed developments throughout the study catchments. As a result they lacked any useful information relating to historic overland flow behaviour and were generally found to be of limited relevance to the broader nature of this present investigation. A number of reports did however contain some useful information and/or drawings relating to details of the (then) existing piped drainage system, which enabled their use for reference where further clarification of pit and pipe data contained in HCC's asset database were required.

Chapter A4 contains a brief summary of a number of previous reports, typically commissioned by HCC or other Authority, that deal with either overland flow or main stream flood behaviour within the study catchments. **Section A4.1** deals with previous investigations related to overland flow, whilst **Section A4.2** deals with investigations related to main stream flood behaviour.

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A4. PREVIOUS STUDIES

A4.1 Investigations Dealing with Overland Flow

A brief summary of key investigations that have previously examined overland flow behaviour within the study catchments is provided below.

Various investigations dealing with UPRCT flood problem areas in the Greystanes Creek, Coopers Creek, Finlaysons Creek and Westmead Creeks catchments

HCC provided copies of several studies that were undertaken over the period 2004 – 2010 dealing with the investigation of known flood problem areas in the Upper Parramatta River catchment. **Table A4.1** provides a summary of these studies (note that only the most recent study for each problem area is shown), including their key findings and recommendations in relation to the need for either further investigation or for flood/drainage mitigation works.

TABLE A4.1
SUMMARY OF STUDIES DEALING WITH INVESTIGATION
OF UPRCT FLOOD PROBLEM AREAS

Investigation	Study Area	Key Findings and Recommendations	Works Completed
Greystanes Creek Catchment			
Toongabbie Road Girraween - HP3GE and HP4GE Flood Investigations (SKM, 2008)	Lower Greystanes Creek catchment in the vicinity of Toongabbie Road, Girraween	➤ Key finding was that minor works within a number of private properties along Toongabbie Road would best address the flooding issues in this area, including driveway re-profiling, landscaping works and fencing modifications.	Unknown
Problem Areas HP6PH and PM3PH1 – Stage 1 Investigation (URS, 2006)	HP6PH – Toongabbie Road at Portico Parade, Toongabbie PM3PH1 – Barangaroo Road to Fitzwilliam Road / Ancona Avenue, Toongabbie	➤ Key finding in relation to HP6PH was that proposed drainage improvement works did not warrant further investigation. ➤ Key findings in relation to PM3PH1 was that further investigation of drainage improvements works, including additional piped drainage and establishment of floodways, should be undertaken.	Unknown
Coopers Creek Catchment			
Problem Area HP3C – Stage 1 Investigation (URS, 2006)	Coopers Creek catchment in the vicinity of Emert Street, Wentworthville	➤ Key finding was that proposed flood/drainage mitigation works, including channel and culvert augmentation works along Coopers Creek, did not warrant further investigation. ➤ Report also noted significant flood affectation along the Cumberland Highway as a result of overland flooding from the east.	n/a

TABLE A4.1 (CONT'D)
SUMMARY OF STUDIES DEALING WITH INVESTIGATION
OF UPRCT FLOOD PROBLEM AREAS

Investigation	Study Area	Key Findings and Recommendations	Works Completed
Finlaysons Creek Catchment			
HP1F Canal Road, Greystanes – Flooding investigation – Stage 1 (Brown Consulting, 2006)	Upper Finlaysons Creek catchment, Greystanes within the area bounded by Merrylands Road to the north, the Cumberland Highway to the east, Canal Road to the south, and Cumberland Road to the west.	➤ Key finding was that proposed flood/drainage mitigation works, including a detention basin within Holroyd High School, did not warrant further investigation.	n/a
Outstanding Flood Problem Area HP2F – Centenary Road, South Wentworthville (SKM, 2007)	Centenary Road, South Wentworthville and adjacent properties between Finlayson Street to the north and Wirrallee Street to the south.	➤ Key finding was that a range of works should be undertaken to reduce the impact of overland flooding on a number of properties in this area, including footpath raising, piped drainage improvements, swale construction and flood proofing works. The report recommended that the above works proceed to the detailed design stage.	Unknown
Flood Investigation of Area HP4F – Supplementary Report (Webb McKeown & Associates, 2004)	Upper Finlaysons Creek catchment, Greystanes, extending from Central Gardens site south of Merrylands Road to main arm of Finlaysons Creek north of Irrigation Road.	➤ Key findings in relation to the proposed Central Gardens detention basin were that the basin would have only a localised influence on flood behaviour, and limited value in terms of reducing the number of flood liable properties. ➤ Report recommended further investigation of alternative basin configurations to optimise its potential flood mitigation performance.	Detailed design of Central Gardens Detention Basin prepared in 2009/10.
Flood Investigation HP5F – Finlaysons Creek – Veron Street to Great Western Railway (UPRCT, 2010)	Lower Finlaysons Creek catchment, Wentworthville, from Veron Street to Western Rail Line.	➤ Key finding was that proposed flood mitigation works in this area did not warrant further investigation. ➤ An alternative option involving creation of flood storage between Veron Street and Fullagar Road was identified for possible future investigation.	n/a

TABLE A4.1 (CONT'D)
SUMMARY OF STUDIES DEALING WITH INVESTIGATION
OF UPRCT FLOOD PROBLEM AREAS

Investigation	Study Area	Key Findings and Recommendations	Works Completed
Finlaysons Creek (Cont'd)			
Investigation of Outstanding Flooding Problem Areas HP2F, HP6F and HP7F – Stage 1 (DHI, 2006)	HP2F – Centenary Road, South Wentworthville HP6F – Great Western Highway / Old Prospect Road, South Wentworthville HP7F – Fullagar Road, Wentworthville	➤ Key finding in relation to HP6F was that proposed drainage improvement works did not warrant further investigation. ➤ Key findings in relation to HP2F and HP7F was that further investigation of proposed flood mitigation works should be undertaken.	Stage 2 investigation for HP2F undertaken by SKM, 2007 (see above).
Westmead Creek (Milson's Creek) Catchment			
Investigation Of Outstanding Flood Problem Areas – Area HP1T – Milson's Creek, Westmead (SMEC, 2007)	Westmead Creek catchment, between Austral Avenue and Alexandra Avenue, Westmead	➤ Key finding was that proposed flood/drainage mitigation works, comprising a range of pipe augmentations, overland flow path improvements and detention basins, did not warrant further investigation.	n/a

In general the investigations found that proposed flood and/or drainage-related improvement works were not warranted, due to the limited benefits of such works at relatively high cost. Most investigations also noted the need for improved development controls on flood-affected properties and continuing flood awareness programs for residents living in these areas. It is also noted that several of the investigations listed in **Table A4.1** either followed or built on earlier drainage studies from the 1980's and 1990's, the details of which are not presented in this report.

Upper A'Becketts Creek Flood Study (Bewsher, 2006)

The objective of this study, which was commissioned by HCC, was to examine flooding in the upper reaches of the A'Becketts Creek catchment above the Merrylands CBD. The study involved a detailed investigation of overland flow behaviour based on application of a two-dimensional hydraulic model.

The study involved updating a previous RAFTS hydrologic model of the upper catchment, followed by the development of a TUFLOW hydraulic model of the floodplain. The piped drainage system was also incorporated into the TUFLOW model. *[Note that HCC provided TUFLOW model data and results for the purpose of this present investigation, further details of which are provided in Section A3.7.]*

Following verification against available historic flood data for the 5 August 1986 and 10 February 1990 storm events, the flood models were used to assess design flood events ranging between 5 and 100 year ARI, as well as for the PMF. Outputs were presented in the form of maps depicting extents and depths of inundation and peak water surface elevations. A flood risk map defining precincts of low, medium and high risk was also prepared.

Bolaro Avenue, Greystanes Flood Study (HCC, 2005)

The objective of this in-house study undertaken by HCC was to examine overland flow behaviour in a known problem area located downstream (south) of Greystanes Sportsground off Bolaro Avenue, Greystanes in the upper Prospect Creek catchment.

The study included development of an ILSAX hydrologic model of the local catchment upstream (north) of Bolaro Avenue. Hydraulic modelling was then undertaken using a one-dimensional HEC-RAS hydraulic model to define flood levels and flow velocities along the overland flow path. The study then assessed measures that could be implemented to reduce the frequency and severity of property flooding in residential development south of Bolaro Avenue.

The study recommended further investigation of the feasibility of constructing a flood detention basin within Greystanes Sportsground, which was found to potentially protect up to 15 houses from above-floor flooding in a 100 year ARI flood event, and reduce the number of properties subject to yard flooding from 39 to 14. Subsequently, HCC proceeded to develop a design for this basin which was constructed in 2013.

A4.2 Investigations Dealing with Main Stream Flooding

A brief summary of previous investigations that have examined main stream flood behaviour within the study catchments is provided below.

Upper Parramatta River Catchment Floodplain Risk Management Study and Plan (Bewsher, 2003)

This study represents the culmination of various flooding investigations undertaken since the 1980's throughout the Upper Parramatta River catchment. Within the Holroyd City LGA, this incorporates the catchments of Greystanes Creek, Coopers Creek, Finlaysons Creek and Westmead Creek. Note that the study did not examine drainage and flood-related issues along the various overland flow paths approaching the main arms of these creeks, which is the focus of the present investigation.

Flood behaviour along the main arms of the various watercourses throughout the catchment, including those within the Holroyd City LGA mentioned above, was defined using a RAFTS hydrologic model and MIKE 11 hydraulic model. Both models are now maintained by the UPRCT, and have been developed and refined since the late 1980's. Whilst the most recent flood study report was prepared in 2000 (UPRCT, 2000), it is understood that UPRCT continues to use, enhance and update the models to reflect ongoing changes within the catchment. *[Note that UPRCT made available MIKE 11 model data and results for the purpose of this present investigation, further details of which are provided in **Section A3.4.**]*

The study investigated a range of potential floodplain management measures aimed at reducing the risk of flooding, and identified a plan of works and further detailed investigations for future implementation. A range of non-structural floodplain management measures, such as planning controls and policies and improved flood awareness, flood warning and emergency management, were also recommended.

Within the Holroyd City LGA, a series of investigations were recommended for future implementation. At least the first stage of these investigations at all recommended locations have now been completed (refer **Section A4.1** for further discussion), however it is understood that no structural works have yet been undertaken in the study catchments as a result of these investigations.

Prospect Creek Floodplain Management Plan Review (Bewsher, 2006)

This study documents a review and update of the floodplain management plan for Prospect Creek, including the full length of creek where it forms the southern boundary of the Holroyd City LGA between Widemere Road, Wetherill Park and the Cumberland Rail Line. Note that the study did not examine drainage and flood-related issues along the various overland flow paths approaching the main arm of Prospect Creek, which is the focus of the present investigation.

Review of the previous plan was instigated by updated two-dimensional TUFLOW flood modelling undertaken to assess main stream flood behaviour along Prospect Creek in the mid 2000's, and the time that had elapsed since earlier floodplain management studies undertaken for the lower and upper reaches of the catchment in the early 1990's. The review was overseen by Fairfield City Council's (**FCC's**) Five Creeks Committee, which included HCC representation as a key stakeholder in the upper Prospect Creek catchment. *[Note that FCC declined to provide TUFLOW model data and results for the purpose of this present investigation.]*

Key aspects of the study comprised:

- community consultation;
- definition of (then) present day main stream flooding conditions and assessment of the overall scale and nature of the flood problem throughout the catchment;
- catchment-wide flood damages assessment;
- review of completed floodplain management measures; and
- identification of the preferred future floodplain management measures to be implemented.

Previous floodplain management measures undertaken either within or adjacent to the Holroyd City LGA include augmentation of existing flood detention basins at Hassall Street and Rosford Street, construction of a high level floodway on the left (northern) overbank of Prospect Creek opposite Justin Street in Fairfield, various stream clearing and bank stabilisation works, and house raising for two properties in Bell Crescent, Fairfield.

Future structural measures recommended for implementation include further stream clearing and bank stabilisation works, channel works upstream of Widemere Road, Wetherill Park and amplification of the Cumberland Highway crossing. A range of flood planning and emergency response measures are also recommended for future implementation.

A'Becketts Creek (SWC No. 46) Catchment Management Study (Bewsher, 1990)

This study was commissioned by the Sydney Water Board (now SWC) who own and maintain parts of the trunk stormwater drainage system in the lower part of the A'Becketts Creek catchment. *[Note that the A'Becketts Creek catchment forms part of SWC's Stormwater Drainage Area No. 46.]*

The study included development of a RAFTS hydrologic model of the overall catchment, and a one-dimensional HEC-2 hydraulic model of the main arm of A'Becketts Creek and its floodplain downstream (east) of the Merrylands CBD to its confluence with Duck Creek in the Parramatta City LGA. Separate hydraulic grade line calculations were also undertaken to analyse the hydraulic behaviour of various sections of SWC's piped drainage system that feeds in to the main arm of the creek.

Community consultation was also undertaken as part of the study, including distribution of a questionnaire seeking feedback on historic flooding in the catchment. A number of historic flood marks, primarily relating to major storm events that occurred in August 1986 and February 1990, were identified as a result of this consultation (further details of HCC's flood mark database is contained in **Section A2.2**).

Following verification against available historic flood data, the flood models were used to determine design flood profiles along the main arm of A'Becketts Creek for events ranging between 5 and 100 year ARI, as well as for the PMF.

The study did not examine drainage and flood-related issues in the upper reaches of the catchment, nor along overland flow paths approaching the main arm of A'Becketts Creek.

Duck Creek Catchment Management Study (SKM, 1991)

This study was commissioned by the Sydney Water Board (now SWC) who own and maintain the concrete-lined stormwater channel that forms the main arm of Duck Creek where it runs between Vulcan Street, Guildford and the Cumberland Rail Line. *[Note that the Duck Creek catchment forms part of SWC's Stormwater Drainage Area No. 35.]*

The study included development of a RORB hydrologic model of the Duck Creek catchment to its confluence with Duck River in the adjoining Parramatta City LGA. Hydraulic modelling was undertaken using a one-dimensional HEC-2 hydraulic model to represent the main arm of Duck Creek and its floodplain. A separate MOUSE hydraulic model was also established to analyse the hydraulic behaviour of various sections of SWC's piped drainage system.

Following verification against available historic flood data, the flood models were used to determine design flood profiles along the various trunk drainage channels and piped drainage systems for events ranging between 5 and 100 year ARI, as well as for the PMF.

The study did not extend to the investigation of overland flow behaviour within the catchment, which is the focus of the present investigation.

Upper Duck Creek Flood Study – Draft Report (HCC, 2007)

The objective of this in-house study undertaken by HCC was to update the previous flooding investigations by SKM (1991) for the section of Duck Creek within the Holroyd City LGA, by making use of available improvements in technology. It is understood that HCC relies on the results of the more recent study for flood-related planning and development assessment in the Duck Creek catchment.

The study involved development of an ILSAX hydrologic model of the Duck Creek catchment extending downstream as far as the LGA boundary along the Cumberland Rail Line. ALS data sourced from UPRCT and based on aerial survey undertaken in 2001 was then used to establish a one-dimensional HEC-RAS hydraulic model of the main arm of Duck Creek as well as a number of lateral overland flow paths that feed runoff into the channel via the surrounding road network.

Following verification against historic flood data for storms in August 1986 and February 1990, the flood models were used to assess flood behaviour for the 100 year ARI design event. Design flood levels along the various channel and overland flow path reaches were presented on cross sections exported from the HEC-RAS model.

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A5. REFERENCES

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Bewsher (2003). "*Upper Parramatta River Catchment Floodplain Risk Management Study and Plan*". report prepared for the Upper Parramatta River Catchment Trust.

Bewsher (1990). "*A'Becketts Creek (SWC No. 46) Catchment Management Study*", report prepared for the Sydney Water Board.

Brown Consulting (2006). "*HP1F Canal Road, Greystanes – Flooding investigation – Stage 1*", report prepared for the Upper Parramatta River Catchment Trust.

Cardno Willing (2008). "*Ollie Webb Reserve Detention Basin – Design Report*", report prepared for Parramatta City Council.

DHI (2006). "*Investigation of Outstanding Flooding Problem Areas HP2F, HP6F and HP7F – Stage 1*", report prepared for the Upper Parramatta River Catchment Trust.

HCC (2007). "*Upper Duck Creek Flood Study – Draft Report*", internal report prepared by Holroyd City Council.

HCC (2005). "*Bolaro Avenue, Greystanes Flood Study*", internal report prepared by Holroyd City Council.

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SKM (2007). "*Outstanding Flood Problem Area HP2F – Centenary Road, South Wentworthville*", report prepared for the Upper Parramatta River Catchment Trust.

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URS (2006). *“Stage 1 Investigation of Outstanding Flooding Problem – Area HP3C”*, report prepared for the Upper Parramatta River Catchment Trust.

Webb McKeown & Associates (2004). *“Flood Investigation of Area HP4F – Supplementary Report”*, report prepared for the Upper Parramatta River Catchment Trust.

TABLE A3.1
LISTING OF PREVIOUS REPORTS DEALING WITH FLOODING AND DRAINAGE INVESTIGATIONS

Title	Date	Created For	Author	Catchment
Review of Environmental Factors: Flood Mitigation Works: Culvert Amplification and Improvements A'Becketts Creek Stormwater Channel No. 46 Memorial Park , Treves Street Merrylands	Jul-92		Water Board	A'Becketts Creek
Cusack Street Basin, Merrylands - Hydraulic Review	Nov-90	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Proposed Diversion of Stormwater Drainage Pipe at 53 Clarence Street Merrylands	4/11/2002		John Romanous & Associates	
Concept Stormwater Drainage and Flood Management Report Stockland Merrylands	6/12/2004	Multiplex	Hyder Consulting	
Stormwater Drainage Report 18 Ruth Street, Merrylands West	Dec-02		United Consulting Engineers	
Flood Study for Proposed Development at 14 Albert Street Guildford	21/04/2004		Ram Baskaran - Rammy Associates Pty Ltd	
Drainage System Investigation Denmark/Meakin Streets Merrylands	Mar-98	Holroyd City Council	Bowdens Australia Pty Ltd	
Cusack Street Basin, Merrylands - Hydraulic Review	Nov-90		Bewsher Consulting - Consulting Engineers	
Design Report for Floodway Through Memorial Park Treves Street, Merrylands	Apr-92	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Merrylands CBD Flood Study - Final Report	May-02	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Merrylands Park Flood Basin Investigation	Dec-94	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Holroyd Gardens Drainage and Development Report	Dec-00	Holroyd City Council	SKM	
Holroyd Gardens Revised Assessment of Channel Flow Profile for Walpole Street Merrylands	20-Aug-04	Holroyd City Council	SKM	
Catchment Management Study	Sep-90	Water Board	Bewsher Consulting - Consulting Engineers	
Overland Flood Study	May-04	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Upper A'Becketts Creek Flood Study	Mar-06	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Drainage Investigation - 76 Burnett Street Merrylands	Dec-04		Glenn Jameson Consulting	
Hydraulic Report - No 6-8 Burford Street, Merrylands	Mar-98	Holroyd City Council	Lucas Consulting Engineers	
Stormwater Drainage Report Proposed Unit Development at 10-14 Burford Street Merrylands	Mar-89	Jay May Constructions Pty Ltd	K.R. Stubbs & Associates Consulting Engineers	
Overland Flood Analysis at 10 Windsor Road Merrylands	Oct-00	Ghassen Nakhoul	RKE Consulting	
Review of Flooding at Lot 362 (No. 10) Morris Street Merrylands	Nov-95		Boubli Lepageier Hastings Pty Ltd Consulting	
Review of Flooding at Lot 362 (No. 10) Morris Street Merrylands	Nov-95		Boubli Lepageier Hastings Pty Ltd Consulting	
Overland Flow Conveyance Report for Proposed Single Dwelling Development at No 8 Otto Street Merrylands	Sep-03	Holroyd City Council	AFCE Environment and Building	
McFarlane Street Merrylands - Preliminary Assessment of Flood Mitigation Works	Jul-04	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Overland Flow Path Investigation for Proposed House at 30 Lockwood Street Merrylands	May-02		SWV Consulting Pty Ltd	
1% AEP Flood Investigation	Feb-03	Allam Homes, Mr and Mrs Dass	Appleyard Forrest Consulting Engineers	
Stormwater Drainage Calculations	7/11/2003		Haddad Khaicy Arraj Partners	
Overland Flood Analysis at 10 Windsor Road Merrylands	Aug-00		RKE Consulting	
Catchment Study Report for the Property at No. 21 Kenyons Road Merrylands	25/11/1999		Hange Design & Construction Pty Ltd	
Proposed Retail & Residential Development Lot 1 Terminal Place, Merrylands, Flood Modelling Report			Bewsher Consulting - Consulting Engineers	
Holroyd Gardens Drainage and Development Report	Aug-00	Delfin Holroyd Pty Ltd	SKM	
Drainage Investigation Bowden Street to Matthew Street Merrylands, NSW	Nov-91	Holroyd City Council	Bewsher Consulting - Consulting Engineers	Coopers Creek
Coopers Creek Upper Catchment Trunk Drainage Assessment (Lance Cres/Adrian Place Greystanes)	Feb-90	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Stormwater Overland Flow Path Assessment at 15 Rogers Street Wentworthville NSW 2145	16/03/2001		John Romanous & Associates	
Stormwater Drainage Design 20 Mashman Avenue, Wentworthville	23/12/2003	Holroyd City Council	SWV Consulting Pty Ltd	
Flood Study For Proposed Residence at 30 Gerald Street Greystanes	14/05/2004		Ram Baskaran - Rammy Associates Pty Ltd	
Overland Flow Path Design for 46 Maple Street, Greystanes	19/02/2002		Cardno Willing Pty Ltd	
Flood Study For Proposed Residence at 53 Ringrose Avenue Greystanes	2/06/2003		Ram Baskaran - Rammy Associates Pty Ltd	

TABLE A3.1 (CONT'D)
LISTING OF PREVIOUS REPORTS DEALING WITH FLOODING AND DRAINAGE INVESTIGATIONS

Title	Date	Created For	Author	Catchment
Proposed Development at No.24 Jones Street Pendle Hill	14/11/2005	Holroyd City Council	D'Amici Colombo Pty Ltd	Coopers Creek (Cont'd)
52-56 Oatlands Street Wentworthville (DA2000-691)			Barry Smith Bateman and Associates Pty Ltd	
Flood Study for Proposed Development at 34 Oatlands Street Wentworthville	22/11/2004		Ram Baskaran - Rammy Associates Pty Ltd	
Stormwater Overland Flow Path Assessment at 15 Rogers Street Wentworthville NSW 2145	16/03/2001		John Romanous & Associates	
Investigation of Potential Flood Retarding Basins Above Braeside Road Greystanes	Jun-88	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Drainage Investigation of Lance Cres/ Adrian Place Greystanes	10/02/1988	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Flood Study Report Premises: 9 Darcic Street, Wentworthville	6/05/2010		G & R Constructions & Designs Pty Ltd	
Preliminary Flood Study Wentworth Leagues Club Draft	19/03/2008	Wentworth Leagues Club	Boydon & Partners (Civil Engineers) Pty Ltd	
51 Berkely Street, South Wentworthville - Hydrology and Hydraulic Report	19/07/2004		G & R Constructions & Designs Pty Ltd	
Investigation of Potential Flood Retarding Basins Above Braeside Road Greystanes	Jun-88	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Proposed Development at No. 10 Montague Street Greystanes	22/09/2005	ACA Design Consultants Pty Ltd	D'Amici Colombo Pty Ltd	Finlaysons Creek
Report on Flood Extents at No. 48 Northcott Street South Wentworthville	Feb-01	Petra Developments P/L	John Molteno	
Lot 1, DP 526622 and Lot 2, DP565315 529 Merrylands Road, Merrylands Hydraulic Assessment	Mar-96	Mr Kirpichnikov	Webb, McKeown & Associates Pty Ltd	
Drainage Study Finlaysons Creek Upstream of Centenary Road Draft	Mar-91	Holroyd City Council	Webb, McKeown & Associates Pty Ltd	
87 Gerald Street, Greystanes - Pre-Development Cross Sections & Calculations	31/08/2006		WEBCON	
Overland Flow Calculations for Proposed Residential Development, 86 Dracic St, Wentworthville, NSW	9/11/1997		H.J.(Toby) Fiander, Toby Fiander & Associates	
Overland Flow Calculations for Proposed Reconstruction of a House at No. 55 Paton Street, Merrylands West, NSW	23/01/2003		H.J.(Toby) Fiander, Toby Fiander & Associates	
Hydraulic Report - Relating to the 1 in 100 Year Average Recurrence Interval Design Storm	5/06/2001	No 110 Boronia Street South Wentworthville	Rafeletos Zanuttini Pty Ltd	
Statement of Environmental Effects	Sep-05	Petra Development (Aust) Pty Ltd & Mr & Mrs Salama	Anthony Krilich	
Flood Study For Proposed Addition at 47 Richmond St. Sth. Wentworthville	8/01/2004		Ram Baskaran - Rammy Associates Pty Ltd	
Estimate of Overland Flowpath at Drainage Reserve to Proposed Development at 17 and 19 Coleman Street Merrylands	8/04/2003		Lomford Engineers	
Holroyd High School Subdivision - Concept Drainage Design	Nov-04	NSW Department of Education and Training	GHD Pty Ltd	
Flood Study For Proposed New Residence 136 Centenary Road, South Wentworthville NSW	27/07/2005	Ange Dore	Healey Castle & Associates	
Stage 3 of Investigation of Outstanding Flood Problem Areas - Area HP4F	2/02/2003	Holroyd City Council	Webb, McKeown & Associates Pty Ltd	
Stormwater & OSD Assessment & Flood Study Report For Proposed New Residence No. 26 Douglas Street, Merrylands	17/08/2004	Idraft Plans Pty Ltd	SW Healey & Associates Pty Ltd	
43 Boronia Road, South Wentworthville - Hydrology/Hydraulic Report	8/05/2002	Mr. L. Chahine	Gabriel Michel Alagha - AMPA Design and Construction	
Flood Investigation for 123 Fullagar Road, Wentworthville	13/06/2007		Rolyn C Sario - Holroyd City Council	
Outstanding Flood Problem Area HP2F - Centenary Road, South Wentworthville	14/11/2007		SKM	
Proposed Development at No. 10 Montague Street Greystanes	22/09/2005		D'Amici Colombo Pty Ltd	
Woolworths, Greystanes Stormwater Concept Plan	Dec-95		Boydon & Partners (Civil Engineers) Pty Ltd	
Flooding Investigation Stage 1 HPIF Canal Road - Greystanes	Apr-06		Brown Consulting	
Flood Study Report Premises: 22 Veron Street, Wentworthville	11/02/2011		MLE Designs Pty Ltd	
Overland Flow Calculations for Proposed Reconstruction of a House at No. 55 Paton Street, Merrylands West, NSW	23/01/2003		H.J.(Toby) Fiander, Toby Fiander & Associates	
Drainage Study Finlaysons Creek Upstream of Centenary Road	Mar-91	Holroyd City Council	Webb, McKeown & Associates Pty Ltd	
Greystanes Creek Trunk Drainage Study	Jun-83	Holroyd City Council	Willing & Partners Consulting Group	Greystanes Creek
Greystanes Creek Retarding Basins Design Report	Oct-87	Holroyd City Council	Willing & Partners Consulting Group	
Greystanes Creek Retarding Basins Drawings	Oct-89	Holroyd City Council	Willing & Partners Consulting Group	
108 - 112 Toongabbie Road, Girraween Drainage Study	Nov-01		Robinson GRC Consulting Pty Ltd	

TABLE A3.1 (CONT'D)
LISTING OF PREVIOUS REPORTS DEALING WITH FLOODING AND DRAINAGE INVESTIGATIONS

Title	Date	Created For	Author	Catchment
Problem Areas HP6PH - Toongabbie Road at Portico Parade, Toongabbie, and PM3PH1 - Barangaroo Road to Fitzwilliam Road/Ancona Avenue, Toongabbie			URS Australia Pty Ltd	Greystanes Creek (Cont'd)
Toongabbie Road Girraween - HP3GE and HP4GE Flood Investigations - Final Report	Aug-08		SKM	
Trunk Drainage Assessment	1/07/2004	Stockland Development Pty Ltd	Brown Consulting Pty Ltd	
Lot 203 Toongabbie Road Girraween Flood Study	Jun-97		Bewsher Consulting - Consulting Engineers	
Trunk Drainage Assessment	Aug-04	Stockland Development Pty Ltd	Brown Consulting Pty Ltd	
Flood Study for Proposed Subdivision at 43 Normac Road Girraween	18/03/1998		Ram Baskaran - Rammy Associates Pty Ltd	
Greystanes Northern Residential Lands Stormwater Management Plan - Final	Oct-01	Boral & CRI	Patterson Britton & Partners	
Supplementary Report - Flood Profile for 69 Girraween Road, Girraween Based on new Survey Provided	May-06			
CSIRO Site - Flood Extents Revision Based on Fill Works Proposed Downstream of the CSIRO Basin			Patterson Britton & Partners	
Industrial Redevelopment of the Former CSIRO Site - Detention Modelling	22/08/2005		Patterson Britton & Partners	
Drainage/Flood Study	9/11/2001	Lot 633D, D.P. 22845, H/No. 41 Normac Road, Girraween	Nasseri Associates	
Hydraulic Investigation for Proposed Filling Area - Greystanes Creek, Stage 4A Lakewood	Mar-08	Stockland Development Pty Ltd	Brown Consulting Pty Ltd	
Drainage Report/Calculations (Estimate Flood Level)	17-May-02	Lot 230, D.P. 8768, H/No. 14 Tungarra Road, Girraween	Nasseri Associates	
Stormwater, OSD Assessment & Flood Study Report	5/09/2005	Gorna Pty Ltd	Healey Castle & Associates	
Greystanes Creek and Pendle Hill Creek Flood Mitigation Study	Dec-85	Water Resources Commission of NSW	Willing & Partners Consulting Group	
Greystanes Creek DEP Retarding Basin - Design Report	Sep-86	Department of Water Resources	Willing & Partners Consulting Group	
Bolaro Avenue, Greystanes Flood Study	17-Feb-05	Holroyd City Council	Mark Evens	
No. 317 Woodpark Road, Smithfield, Flood Study	2006		Bewsher Consulting - Consulting Engineers	
Flood Study Report - 199 Warren Road, Smithfield	Oct-05	G James Australia Pty Ltd	Cardno Pty Ltd	
Liverpool - Parramatta Transitway Section 6 Hyland Road to Fairfield Road, Smithfield Cross Drainage and Dissipater Details	Jun-05	Project Design Technical Services RTA Operations	Lyall and Associates	
Stormwater Impact Report	Aug-01		Richmond and Ross Pty Ltd	
Proposed Development at the Corner of Pine and Loftus Roads, Yennora - Flood Impact Report	30/05/2008	Paclib Pty Ltd	Worley Parsons Services Pty Ltd	
199 Warren Road, Smithfield - Proposed Re-Development Flood Study Report	26/11/2010		Cardno Pty Ltd	
Flood Study Report of the Property at: 111 Percival Road, Smithfield NSW	20/10/2006	Elite Packaging Pty Ltd	KHH Consulting Engineers Pty Ltd	
Berri Juice Processing Plant - New Wastewater Treatment Facility - Flood Study	12/05/2008		SKM	
5 Dursley Road, Yennora Channel Flood Study	1-Nov		GJ Ryan & Associates Pty Ltd	Prospect Creek
63 Britton Street, Smithfield Fullview Plastics - Stormwater Drainage and Overland Flow Study	4/09/2009		Claudia Novati, Northrop	
27-29 Britton Street, Smithfield - 100 Year ARI Flood Study	Jun-05	Mr. Sid Russo	Civic Design	
Assessment of Upper Prospect Creek Flood Mitigation Works	Jan-01		Willing & Partners Consulting Group	
Prospect Creek Floodplain Management Plan	Feb-06	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Upper Prospect Creek Floodplain Management Study	Sep-93		Willing & Partners Consulting Group	
Upper Prospect Creek Floodplain Management Study Executive Summary	Sep-93		Willing & Partners Consulting Group	
Proposed Development at the Corner of Pine and Loftus Roads, Yennora	28/04/2008		Worley Parsons Services Pty Ltd	

TABLE A3.1 (CONT'D)
LISTING OF PREVIOUS REPORTS DEALING WITH FLOODING AND DRAINAGE INVESTIGATIONS

Title	Date	Created For	Author	Catchment
Upper Prospect Creek Floodplain Management Study - Volume 2 - Figures	Sep-93	Fairfield City Council	Willing & Partners Consulting Group	Prospect Creek (Cont'd)
Hydraulic Analysis of 1 in 100 Year Overland Flow Paths	Mar-00		Cardno MBK	
Warren Road, Smithfield - Stage 3 Trunk Drainage	25/07/2001		Development Consulting Pty Ltd	
Palmer Street to Sandra Street, Guildford - Catchment Study Stage 1	Jan-91	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Stormwater Flood Study for Proposed Industrial Development at 144-156 McCredie Road Smithfield	6/06/2002	Pongrass Development Group	Buckton Lysenko Consulting Engineers	
Burns Creek/Barrass Drain Catchment Management Study	Jun-05	Water Board	Kinhill Engineers Pty Ltd	
Stormwater Calculations for 31 Tarlington Place Smithfield (Subdivision Works)	2002		Richmond and Ross Pty Ltd	
Alterations to Existing Industrial Complex at 115 Woodpark Road, Smithfield, NSW - Stormwater Design	Dec-01		Taylor Civil & Structural Consulting Engineers	
CSIRO Site, Prospect - Flood and Dam Break Study	Sep-02	Stocklands	Patterson Britton & Partners	
Southern Employment Lands Impact on Prospect Creek Flood Behaviour	Aug-04	Boral	Patterson Britton & Partners	
Burns Creek/Barrass Drain Catchment Management Study	Jun-05	Water Board	Kinhill Engineers Pty Ltd	
Supplementary Statement of Environmental Effects at 63 Britton Street, Smithfield	Jun-05		Design Collaborative Pty Ltd	
Southern Employment Lands Impact on Prospect Creek Flood Behaviour	Aug-04	Boral	Patterson Britton & Partners	
Prospect Creek Stormwater Management Plan	Jun-05	Bankstown City, Fairfield City, Holroyd City and Liverpool City Councils	Bankstown City, Fairfield City, Holroyd City and Liverpool City Councils	
Upper Prospect Creek Floodplain Management Study - Volume 1 - Report	Sep-93	Fairfield City Council	Willing & Partners Consulting Group	
Macquarie Road Retarding Basins - Macquarie Road Greystanes	9/08/1993	Holroyd City Council	Bewsher Consulting - Consulting Engineers	
Flood Study for Proposed Dual Occupancy at 67 Dennistoun Avenue, Guildford	24/03/2000		Ram Baskaran - Rammy Associates Pty Ltd	
Proposed Development at 56 Parkes Street Guildford	Apr-06		Ibrahim Stormwater Consultants	
Hydraulic Estimation Flood Study Report	11/06/2001	Sam Romanous Architects	TQM Consulting Engineers	
Drainage Investigation 7 Tamarix Street Greystanes	Jan-03	Wayne Earl	Glenn Jameson Consulting	
Hydraulic Investigation Flood Study Issue A	25-Sep-01		Leask & Associates Pty Ltd	
Flood Study for Proposed Development at 26 McCredie Road Guildford	19/08/2005		Ram Baskaran - Rammy Associates Pty Ltd	
Fairfield Flood Mitigation Study - Final Report Volume 1 - Main Report	Apr-85	Fairfield City Council	Snowy Mountains Engineering Corporation, SKM	
Total Catchment and Drainage Study Appendix B - Detailed Hydraulic & Hydrological Calculations and Catchment Information	Aug-01	Yennora Distribution Park	Richmond and Ross Pty Ltd	
Investigations of Outstanding Flood Problem Areas - Area HP1T	Jun-03	Upper Parramatta River Catchment Trust	SMEC	Westmead Creek
Upper Parramatta River Flood Study	Aug-97		Upper Parramatta River Catchment Trust	Upper Parramatta River
Floodplain Risk Management Study, Volume 3 - Floodplain Risk Management Plan	Oct-03	Upper Parramatta River Catchment Trust	Bewsher Consulting - Consulting Engineers	
Floodplain Risk Management Study, Volume 1 - Study Report	Oct-03	Upper Parramatta River Catchment Trust	Bewsher Consulting - Consulting Engineers	
Appendix 1 Design Model Natural Cross Section Plots				
Upper Parramatta River Flood Study Part C Upper Parramatta River	Jun-95	Upper Parramatta River Catchment Trust	Upper Parramatta River Catchment Trust	
Upper Parramatta River Flood Study Part B Lower Toongabbie Creek	Jun-94	Upper Parramatta River Catchment Trust	Upper Parramatta River Catchment Trust	
Upper Parramatta River Flood Study Part C Upper Parramatta River Appendix 1	Jun-95	Upper Parramatta River Catchment Trust	Upper Parramatta River Catchment Trust	

APPENDIX B

PHOTOGRAPHIC RECORD OF HISTORIC FLOODING IN HOLROYD CITY LGA

5 AUGUST 1986 STORM



Floodwaters in Eddy Street, Merrylands West during 5 August 1986 storm, viewed from No. 71 Eddy Street. [Finlaysons Creek Catchment]



View south along Montague Street, Greystanes during 5 August 1986 storm. Floodwaters flowing from right to left (i.e. west to east) across Montague Street and entering No. 15. [Finlaysons Creek Catchment]

30 APRIL 1988 STORM



Floodwaters in the backyard of No. 5 Oleander Street, Greystanes during 30 April 1988 storm. [Prospect Creek Catchment]



Floodwaters approaching Oleander Street, Greystanes from the north through Nos. 5 and 7 during 30 April 1988 storm. [Prospect Creek Catchment]



**No 9 Oleander Street
30 Apr 1988**

Floodwaters approaching Oleander Street, Greystanes from the north through No. 9 during 30 April 1988 storm. [Prospect Creek Catchment]

10 FEBRUARY 1990 STORM



Floodwaters in Eddy Street, Merrylands West during 10 February 1990 storm, viewed from No. 71 Eddy Street. [Finlaysons Creek Catchment]



Floodwaters within No. 3 Gloria Street, Merrylands West during 10 February 1990 storm.
[Finlaysons Creek Catchment]



Floodwaters through properties in Braeside Road, Greystanes (exact location unknown) during 10 February 1990 storm. [Coopers Creek Catchment]



Floodwaters through rear yard of No. 36 Oatlands Street, Wentworthville during 10 February 1990 storm. [Coopers Creek Catchment]



Floodwaters approaching Oatlands Street, Wentworthville from the south through Nos. 28 and 30 during 10 February 1990 storm. [Coopers Creek Catchment]



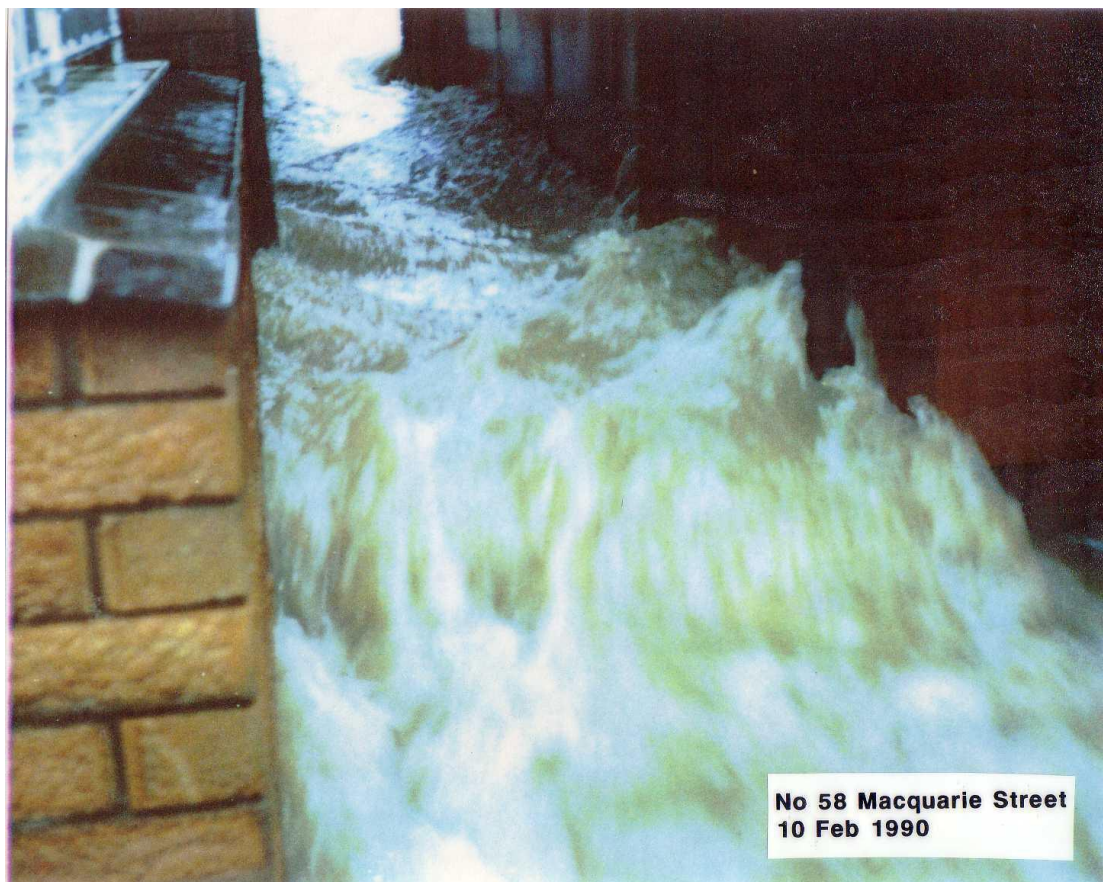
Floodwaters approaching Oatlands Street, Wentworthville from the south through front yard of No. 28 during 10 February 1990 storm. [Coopers Creek Catchment]



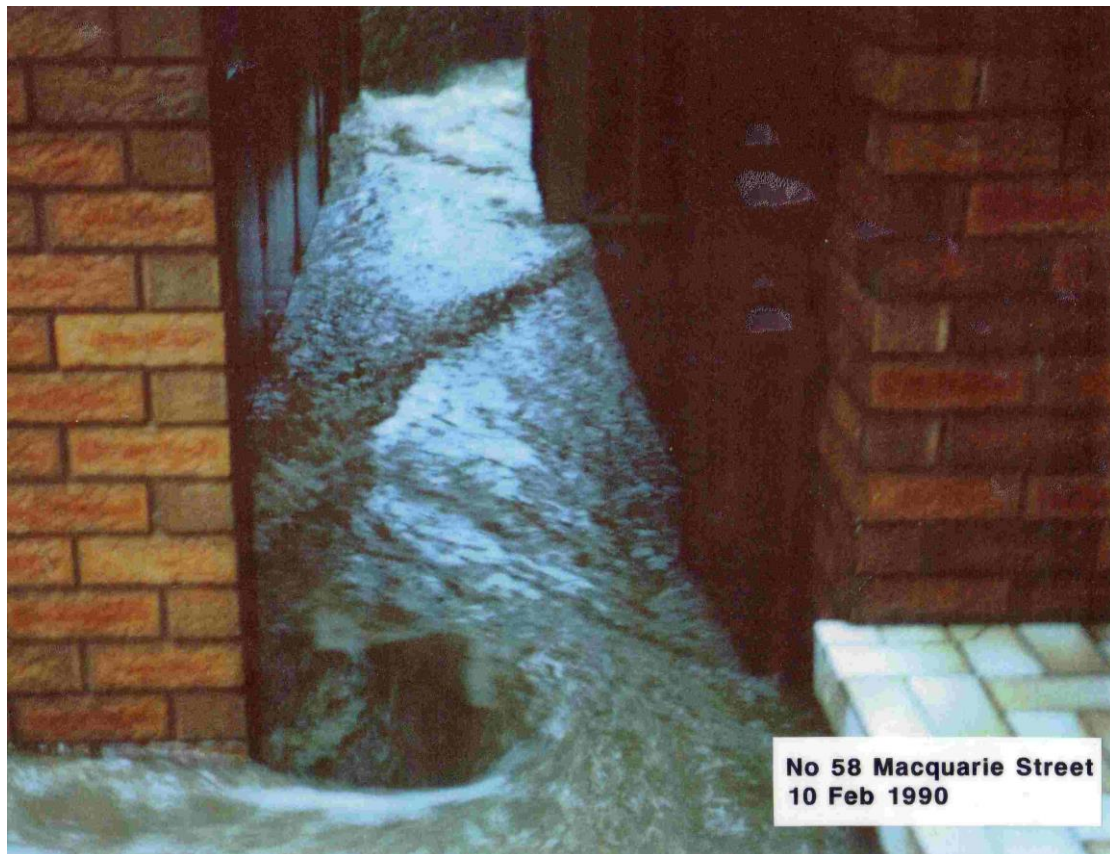
Floodwaters discharging through rear yard of No. 45 Sturdee Street, Wentworthville during 10 February 1990 storm. [Coopers Creek Catchment]



Floodwaters discharging through No. 56 Macquarie Road, Greystanes during 10 February 1990 storm. [Prospect Creek Catchment]



Floodwaters discharging through No. 58 Macquarie Road, Greystanes during 10 February 1990 storm. [Prospect Creek Catchment]



Floodwaters discharging through No. 58 Macquarie Road, Greystanes during 10 February 1990 storm. Photo shows flow path between garage and house. [Prospect Creek Catchment]



Floodwaters in Macquarie Road, Greystanes during 10 February 1990 storm, viewed from No. 58. [Prospect Creek Catchment]

31 JANUARY 2001 STORM



Floodwaters in McCabe Street, Greystanes during 31 January 2001 storm, viewed from No. 8 McCabe Street. [Prospect Creek Catchment]

16 FEBRUARY 2002 STORM



Floodwaters entering No. 7 Palmer Street, Guildford West from the direction of the road reserve during 16 February 2002 storm. [Prospect Creek Catchment]



Floodwaters in the rear yard of No. 72 Richmond Street, South Wentworthville during 16 February 2002 storm. [Finlaysons Creek Catchment]



Aftermath of flooding through No. 62 Boronia Street, South Wentworthville following 16 February 2002 storm. Note tide marks present on internal and external walls indicating depths of inundation in the range 200 – 300 mm. [Finlaysons Creek Catchment]

OTHER STORM EVENTS

**(MINOR STORM EVENTS OR SPECIFIC DATES NOT
KNOWN WITH CERTAINTY)**

6 FEBRUARY 1990 STORM



Floodwaters entering No. 7 Palmer Street, Guildford West from the direction of the road reserve during 6 February 1990 storm. [Prospect Creek Catchment]

**UNIDENTIFIED STORM EVENT(S) IN 1990
(MOST LIKELY 10 FEBRUARY 1990)**



Various photographs showing floodwaters within No. 15 Montague Street, Greystanes during a storm event in 1990 (date unknown). [Finlaysons Creek Catchment]



Aftermath of floodwaters passing through unspecified property located between Lance Crescent and Adrian Place, Greystanes in 1990 (date unknown). [Coopers Creek Catchment]



Floodwaters passing through unspecified property located in Adrian Place, Greystanes in 1990 (date unknown). [Coopers Creek Catchment]



Floodwaters crossing Gregory Street, Greystanes during storm in 1990 (date unknown), viewed from downstream (northern) side of road at No. 15. [Coopers Creek Catchment]



Floodwaters within No. 15 Gregory Street, Greystanes during storm in 1990 (date unknown). [Coopers Creek Catchment]



Floodwaters at rear of No. 15 Gregory Street, Greystanes (within present day M4 Motorway corridor) during storm in 1990 (date unknown). [Coopers Creek Catchment]



Floodwaters in rear yard of No. 22 Whitworth Street, Westmead during storm in 1990 (date unknown). [Domain Creek Catchment]



Floodwaters entering front yard of No. 21 Bernard Street, Westmead during storm in 1990 (date unknown). [Domain Creek Catchment]



Floodwaters entering front yard of No. 23 Bernard Street, Westmead during storm in 1990 (date unknown). [Domain Creek Catchment]

UNIDENTIFIED STORM EVENT IN 1992



Floodwaters approaching Jersey Road (Cumberland Highway), Greystanes from the west during a storm event in 1992 (date unknown), viewed from No. 63 Jersey Road.
[Finlaysons Creek Catchment]

UNIDENTIFIED STORM EVENT IN 1995



Floodwaters in the front yard of No. 46 Grand Avenue, Westmead during a storm event in 1995 (date unknown). [Westmead Creek Catchment]



Floodwaters in the rear yard of No. 46 Grand Avenue, Westmead during a storm event in 1995 (date unknown). [Westmead Creek Catchment]

UNIDENTIFIED STORM EVENT IN 2002



Floodwaters in the front yard of No. 32 Oatlands Street, Wentworthville during a storm event in 2002 (date unknown). [Coopers Creek Catchment]



Floodwaters in the rear yard of No. 32 Oatlands Street, Wentworthville during a storm event in 2002 (date unknown). [Coopers Creek Catchment]

APPENDIX C

ANALYSIS OF HISTORIC STORMS

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C1. SYNOPSIS

Historic flood data are available for a number of storms which have affected the Holroyd City LGA since the mid 1980's. The historic flood data comprises rainfall depths which were recorded at several pluviographic and daily-read gauges located either within or in close proximity to the study catchments, a series of photographs showing overland flows in various parts of the study catchments and a number of flood marks which are contained in a database held by HCC (refer **Appendix B** for further details of both historic photography and flood marks).

An initial appraisal was carried out of the rainfall which was recorded at the pluviographic stations during ten historic storms which date back to 1986, which is presented in this Appendix.

Further inspection of the flood mark database and the available photographic record showed that there is limited historic flood data relating to overland flow behaviour in the nine study catchments for all but two of the historic storms, those being the relatively large events which occurred on 5 August 1986 (refer **Section C2.3**) and 10 February 1990 (refer **Section C2.5**). The availability of historic flood data for these storm events is further limited to the catchments of A'Becketts Creek and Duck Creek.

As a result of the limited availability of flood data, the storms of 5 August 1986 and 10 February 1990 were considered to be the only events which could be used to tune both the hydrologic and hydraulic models. Further details of the model tuning process are contained in **Chapters 3 and 4** of this report.

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C2. HISTORIC FLOODING IN THE STUDY CATCHMENTS

C2.1 General

The following sections provide an overview of historic storm rainfall data recorded within or in close proximity to the Holroyd City LGA. Note that the location of rain gauges referred to in the following sections are shown on **Figure A2.1** in **Appendix A**.

C2.2 Storms Prior to 1986

There is limited available information relating to storms that affected the Holroyd City LGA prior to the mid-1980's. Whilst Bewsher (2003) refers to reports of flooding in the upper Parramatta River catchment dating back to the early 1900's, including events occurring in 1914, 1956 and two in the 1960's, it is not known whether these affected the Holroyd City LGA. These periods also preceded much of the urban development that now exists in western Sydney.

The responses to a resident's questionnaire that was distributed as part of the "*A'Becketts Creek (SWC No. 46) Catchment Management Study*" (Bewsher, 1990) indicated that a storm in April 1974 caused localised flooding within the lower parts of the catchment. However, daily rainfall totals recorded within the Holroyd City LGA suggest this was a minor event, with only 39 mm recorded at BoM's Merrylands (Welsford Street) gauge for the rain day of 26 April 1974.

C2.3 August 1986 Storm

The mid to late 1980's was a period of above average rainfall throughout most of the upper Parramatta River catchment, in which a number of large storm events and subsequent flooding occurred (Bewsher 2003).

Records show that major flooding occurred throughout much of western Sydney as a result of a large storm that occurred on 5 August 1986. Rainfall records within the Holroyd City LGA for this event show that rain commenced to fall in the vicinity of SWC's Guildford (Pipehead) pluviometer at around 06:40 hours on 4 August 1986, continuing through until late on 7 August. The left hand side (**LHS**) of **Figure C2.1** shows approximately 420 mm of rain fell over the rain days of 5 to 7 August, with the most intense rainfall occurring between 12:00 and 15:00 hours on 5 August. Approximately 82 mm of rain was recorded at the Guildford (Pipehead) pluviometer over this 3 hour period.

A comparison of the rainfall intensities recorded at four SWC pluviometers against design IFD data is shown on the right hand side (**RHS**) of **Figure C2.2**. Note that the Guildford (Pipehead) gauge is located within the Holroyd City LGA, whilst the South Prospect gauge is located a short distance west of the LGA. The Fairfield STP and Potts Hill Reservoir gauges are located about 1.2 km south and 6.1 km south-east of the LGA, respectively.

At Guildford (Pipehead) the ARI of the August 1986 storm ranged from approximately 2 years for bursts of rainfall up to 1 hour duration, to more than 20 years for a burst of 3 hours duration. Similar recurrence intervals were assessed for South Prospect. At Fairfield STP and Potts Hill Reservoir recorded rainfall intensities were in the range 10 – 20 year ARI for all durations between 30 minutes and 3 hours.

Figure C2.2 shows 72 hour rainfall isohyets for the rain days of 5 to 7 August 1986, which shows that the distribution of total rainfall depths over this period were relatively uniform across the Holroyd City LGA. The distribution of rainfall depths for shorter duration bursts within the three day period was similarly uniform, based on the minimal spread of the cumulative rainfall traces shown in **Figure C2.1** (refer LHS).

Photographs contained in **Appendix B** show evidence of the flooding that occurred in parts of the upper Finlaysons Creek catchment during the August 1986 storm, including overland flows along Eddy Street, Merrylands West and across Montague Street, Greystanes.

A number of historic flood marks for the August 1986 storm were available to assist in the model tuning process, further details of which are contained in **Chapter 3** of this report.

C2.4 April 1988 Storm

Rainfall records for the April 1988 storm show that rain commenced at 06:00 hours on 28 April and continued until 19:00 hours, before re-commencing at midnight and continuing through until 17:30 hours on 30 April. The LHS of **Figure C2.3** shows that most of the rainfall over this period occurred between 06:00 and 17:00 hours on 30 April when 171 mm of rain was recorded at the Guildford (Pipehead) pluviometer, with a number of short intense bursts of rainfall experienced throughout the day.

The RHS of **Figure C2.3** shows a comparison of recorded rainfall intensities against design IFD data for the April 1988 storm event. At Guildford (Pipehead) the ARI of this event ranged from 1 – 2 years for bursts of rainfall up to 1 hour duration, to more than 5 years for a burst of 3 hours duration. Rainfall experienced at South Prospect was generally more intense than at Guildford across all durations assessed, and exceeded 10 year ARI for a duration of 3 hours.

Figure C2.4 shows 72 hour rainfall isohyets for the rain days of 29 April to 1 May 1988, which shows that the distribution of total rainfall depths over this period were relatively uniform across the Holroyd City LGA. The distribution of rainfall depths for shorter duration bursts within the three day period was similarly uniform, based on the minimal spread of the cumulative rainfall traces shown in **Figure C2.3** (refer LHS).

Photographs contained in **Appendix B** show evidence of the flooding that occurred in the upper Prospect Creek catchment during the April 1988 storm, with overland flows approaching Oleander Street, Greystanes from the north through neighbouring residential properties.

No other historic flood data, such as flood marks, are available within the study catchments for the April 1988 storm, hence it is of limited use in the model tuning process.

C2.5 February 1990 Storms

Records show that there were three main storm events in early February 1990. The LHS of **Figure C2.5, Sheet 1** shows cumulative rainfalls recorded for the period 2 to 10 February.

The first storm event commenced around 06:00 hours on 2 February and continued until mid-morning on 4 February. During this time approximately 300 mm of rain was recorded at all three pluviometers for which data was available. The RHS of **Figure C2.5, Sheet 1** shows that recorded rainfall intensities were generally less than 1 year ARI for this event.

The second storm event commenced at 22:40 hours on 6 February and continued until 03:40 hours on 7 February, over which time 92 mm of rain was recorded within the Holroyd City LGA at Guildford (Pipehead) (refer LHS of **Figure C2.5, Sheet 1**). Slightly lower rainfalls were experienced at Potts Hill Reservoir and South Prospect, with falls lower again at Fairfield STP.

The LHS of **Figure C2.5, Sheet 2** shows a comparison of recorded rainfall intensities against design IFD data for this event. At Guildford (Pipehead) recorded rainfall intensities ranged from 5 year ARI for bursts of rainfall up to 1 hour duration, to greater than 10 year ARI for a burst of 2 hours duration. Rainfall experienced at the adjacent pluviometers were generally less intense than at Guildford across all durations assessed.

The third storm in early February 1990 occurred on 10 February and was the most severe of the three events. Rainfall commenced at 13:30 hours on 10 February and continued until 17:30 hours, over which time 85 mm of rain was recorded at Guildford (Pipehead) (refer LHS of **Figure C2.5, Sheet 1**).

The RHS of **Figure C2.5, Sheet 2** shows a comparison of recorded rainfall intensities against design IFD data for this event. At Guildford (Pipehead) recorded rainfall intensities were approximately 50 year ARI for bursts of rainfall up to 1.5 hours duration, reducing to about 20 year ARI for a burst of 3 hours duration. Rainfall experienced at the adjacent pluviometers were generally much less intense than at Guildford across all durations assessed. For example, at South Prospect rainfall intensities were typically less than 1 year ARI.

Figure C2.6 shows total rainfall isohyets for the nine rain days from 3 to 11 February 1990. The distribution of total rainfall depths over this period was not uniform across the Holroyd City LGA, but was notably higher across the eastern part of the LGA and in particular within the A'Becketts Creek catchment.

Note that a similar rainfall gradient falling from east to west across the LGA is evident when comparing 24 hour rainfall isohyets for the rain day of 11 February 1990, which contained the most intense storm experienced on the afternoon of 10 February (refer **Figure C2.7**).

Photographs contained in **Appendix B** show evidence of the flooding that occurred in parts of the Coopers Creek, Finlaysons Creek and Prospect Creek catchments during the 10 February 1990 storm, including overland flows affecting properties in the suburbs of Greystanes, Wentworthville and Merrylands West.

A number of historic flood marks located in the A'Becketts Creek and Duck Creek catchments for the 10 February 1990 storm were available to assist in the model tuning process, further details of which are contained in **Chapter 3** of this report.

C2.6 August 1990 Storm

Records for the August 1990 storm show that rainfall commenced at 05:00 hours on 31 July and continued until 17:00 hours on 3 August (refer LHS of **Figure C2.8**). The most intense rainfall occurred between 07:20 and 08:00 hours on 2 August, when 30 mm of rain fell in a 40 minute period at Guildford (Pipehead).

The RHS of **Figure C2.8** shows a comparison of recorded rainfall intensities against design IFD data for the August 1990 storm. At Guildford (Pipehead) recorded rainfall intensities were between 2 and 5 year ARI for a burst of 30 minutes durations, reducing to less than 1 year ARI for a burst of 3 hours duration. Rainfall experienced at the adjacent pluviometers were generally less intense than at Guildford across all durations assessed.

No historic flood marks or photographs relating to overland flooding within the study catchments are available for this storm, hence it is of limited use in the model tuning process.

C2.7 March 2000 Storm

Records for the March 2000 storm show that rainfall occurred in three main bursts between 10:00 hours on 20 March and 16:30 hours on 22 March, over which time 79 mm of rain was recorded within the Holroyd City LGA at Guildford (Pipehead) (refer LHS of **Figure C2.9**). The most intense rainfall occurred on 21 March between 04:30 and 09:00 hours, when 26 mm of rain was recorded at Guildford (Pipehead).

The RHS of **Figure C2.9** shows that the March 2000 storm was a relatively minor event, with rainfall intensities much less than 1 year ARI at all pluviometer locations assessed.

The minor nature of this storm, and lack of any historic flood data, means that it is of limited use in the model tuning process.

C2.8 January 2001 Storm

Available rainfall records for the January 2001 storm show that 134 mm was recorded just outside the Holroyd City LGA at South Prospect over the 48 hour period commencing at 12:00 hours on 30 January (refer LHS of **Figure C2.10**). Rainfalls further south were significantly higher, with more than 200 mm recorded over the same period at Fairfield STP.

The most intense rainfall at Prospect Reservoir occurred on the morning of 31 January between 01:30 and 11:00 hours, where about 80 mm was recorded. More than 150 mm was recorded at Fairfield STP over the same period.

The RHS of **Figure C2.10** shows that the January 2001 storm was a relatively minor event in the vicinity of Holroyd City LGA, with rainfall intensities less than 1 year ARI at the Prospect Reservoir pluviometer for all durations assessed.

Photographs contained in **Appendix B** show evidence of the flooding that occurred in the upper Prospect Creek catchment during the January 2001 storm, including overland flows in the vicinity of McCabe Street, Greystanes.

No other historic flood data, such as flood marks, are available within the study catchments for the January 2001 storm, hence it is of limited use in the model tuning process.

C2.9 February 2001 Storm

Records for the February 2001 storm show that rainfall commenced just after 12:00 hours on 5 February and continued until 15:00 hours on 6 February (refer LHS of **Figure C2.11**). A total rainfall depth of around 35 mm was recorded at the Prospect Reservoir pluviometer over this period, which is located just to the west of the Holroyd City LGA.

The RHS of **Figure C2.11** shows that the February 2001 storm was a relatively minor event, with rainfall intensities much less than 1 year ARI at all pluviometer locations assessed.

The minor nature of this storm, and lack of any historic flood data, means that it is of limited use in the model tuning process.

C2.10 February 2002 Storms

Records show that two storm events occurred in February 2002. The first storm occurred over a two day period commencing on 4 February. The LHS of **Figure C2.12** shows that around 120 mm of rain was recorded at Prospect Reservoir over this period, with the most intense rainfall occurring around 18:00 hours on 4 February. Approximately 35 mm of rain was recorded at all six pluviometer locations.

The RHS of **Figure C2.12** shows that the 4 February 2002 storm was a relatively minor event, with rainfall intensities much less than 1 year ARI at all pluviometer locations assessed.

The second storm event occurred on 16 February, with significant rainfalls recorded in two bursts commencing at 17:30 and 22:00 hours (refer LHS of **Figure C2.12**). Substantially higher total rainfall depths were recorded at gauges located east of the Holroyd City LGA (e.g. 55 mm at SP0101 Parramatta) than for those to the west of the LGA (e.g. 20 mm at Prospect Reservoir).

The RHS of **Figure C2.12** shows that rainfall intensities to the west of the LGA (e.g. at Prospect Reservoir) were less than 1 year ARI for all durations assessed. To the east of the LGA, rainfall intensities reached up to 10 year ARI for a 30 minute storm duration, falling to less than 1 year ARI for longer duration events.

Photographs contained in **Appendix B** show evidence of the flooding that occurred in the Prospect Creek and Finlaysons Creek catchment during the 16 February 2002 storm, including overland flows in the vicinity of Palmer Street, Guildford West and Richmond and Boronia streets, South Wentworthville.

No other historic flood data, such as flood marks, are available within the study catchments for the February 2002 storms, hence they are of limited use in the model tuning process.

C2.11 December 2011 Storm

The most recent storm of significance occurred on 19 December 2011 when about 50 mm of rain fell in 60 minutes within the Holroyd LGA at the Greystanes pluviometer (refer LHS of **Figure C2.13**). This burst occurred at around 17:00 hours.

The RHS of **Figure C2.13** shows a comparison of recorded rainfall intensities against design IFD data for the December 2011 storm event. At Greystanes the ARI of this event ranged from 20 – 50 years for a burst of rainfall of 30 minutes duration, to around 2 years for a burst of 3 hours duration. Rainfalls experienced at surrounding pluviometer sites outside the Holroyd City LGA were less intense than at Greystanes for all durations assessed.

Despite the intensity of this event, HCC advised that no reports of flooding were received, hence it is of limited use in the model tuning process.

C3. REFERENCES

Bewsher (2003). *"Upper Parramatta River Catchment Floodplain Risk Management Study"*. report prepared for the Upper Parramatta River Catchment Trust.

Bewsher (1990). *"A'Becketts Creek (SWC No. 46) Catchment Management Study"*, report prepared for the Sydney Water Board.

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APPENDIX D

DETAILS OF HISTORIC FLOOD MARKS AND MODEL TESTING RESULTS

TABLE D1
COMPARISON OF OBSERVED AND MODELLED FLOOD LEVELS
5 AUGUST 1986 STORM – A'BECKETTS CREEK CATCHMENT

Flood Mark Identifier ¹	Flood Mark Location	Observed Flood Level (m AHD) [A]	Ground Level (m AHD) ² [B]	Implied Depth of Inundation at Flood Mark (m) [C] = [B] – [A]	Modelled Flood Level (m AHD) [D]	Modelled Depth of Inundation (m) [E]	Difference Between Observed and Modelled Flood Level (m) ³ [F] = [D] – [A]	Comments
41	12 Clarence St, back step	21.81	21.81	0.38	22.09	0.27	-0.10	Good fit to observed flood level.
38	25 Lockwood St, back steps	20.72	20.71	0.67	21.32	0.61	-0.06	Good fit to observed flood level.
36	21 Warwick Rd, back steps	20.47	20.48	0.38	20.73	0.25	-0.13	Reasonable fit to observed flood level.
34	9A Monitor Rd, garage	19.89	19.89	0.36	20.15	0.26	-0.10	Good fit to observed flood level.
33	21 Monitor Rd, garage	20.28	20.29	0.29	20.42	0.14	-0.16	Reasonable fit to observed flood level.
32	14 Windsor Rd, back steps	19.76	19.76	0.12	19.96	0.20	0.08	Good fit to observed flood level.
30	13 Windsor Rd, floor level	19.69	19.69	0.08	19.71	0.02	-0.06	Good fit to observed flood level.
47	5 Lois Pl, front step	23.29	23.28	0.30	23.33	0.05	-0.25	Observed flooding within properties unable to be reproduced. It is likely that minor changes in ground levels as a result of construction of the flood detention basins in the adjacent Merrylands Park, and which are still reflected in the TUFLOW model for 1986 conditions, has directed runoff away from these properties.
48	23 Major Rd, back fence	23.63	23.66	0.20	23.73	0.08	-0.13	

- (1) Refer **Figure 4.3** for reference to Flood Mark Identifier.
- (2) Ground level determined from TUFLOW model topography, based on 2013 ALS survey data.
- (3) Note that a positive value indicates that the modelled flood level is higher than the observed flood level, and vice versa.
- (4) Rounding may result in minor discrepancies between comparable figures in some instances.

TABLE D2
COMPARISON OF OBSERVED AND MODELLED FLOOD LEVELS
10 FEBRUARY 1990 STORM – A’BECKETTS CREEK CATCHMENT

Flood Mark Identifier ¹	Flood Mark Location	Observed Flood Level (m AHD) [A]	Ground Level (m AHD) ² [B]	Implied Depth of Inundation at Flood Mark (m) [C] = [B] – [A]	Modelled Flood Level (m AHD) [D]	Modelled Depth of Inundation (m) [E]	Difference Between Observed and Modelled Flood Level (m) ⁴ [F] = [D] – [A]	Comments
44	13 Lois Pl, driveway	22.51	22.49	0.11	22.97	0.48	0.37	
46	49 Shannon Ave, garage	22.51	22.52	0.48	22.99	0.46	-0.01	Good fit to observed flood level.
43	57 Shannon Ave, garage	22.25	22.24	0.00	22.42	0.18	0.18	Reasonable fit to observed flood level.
41	12 Clarence St, back step	21.81	21.81	0.38	22.32	0.51	0.13	Reasonable fit to observed flood level.
40	19 Clarence St, front patio	21.80	21.80	0.09	21.91	0.11	0.02	Good fit to observed flood level.
38	25 Lockwood St, back steps	20.72	20.71	0.62	21.48	0.77	0.15	Reasonable fit to observed flood level.
36	21 Warwick Rd, back steps	20.47	20.47	0.22	20.85	0.38	0.16	Reasonable fit to observed flood level.
35	23 Warwick Rd, south fence	20.16	20.20	0.34	20.87	0.67	0.33	
34	9A Monitor Rd, garage	19.89	19.89	0.18	20.29	0.40	0.22	
33	21 Monitor Rd, garage	20.28	20.29	-0.23	20.56	0.27		Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
32	14 Windsor Rd, back steps	19.76	19.76	0.04	20.09	0.33	0.29	
31	24 Windsor Rd, front patio	19.95	19.95	0.29	20.12	0.17	-0.12	Reasonable fit to observed flood level.
30	13 Windsor Rd, floor level	19.69	19.69	0.04	19.88	0.18	0.15	Reasonable fit to observed flood level.
47	5 Lois Pl, front step	23.29	23.29	0.19	23.52	0.24	0.04	Good fit to observed flood level.
45	26 Shannon Ave, front path	23.06	23.07	0.03	dry ³	n/a ³	n/a ³	Observed flooding within property unable to be reproduced.
49	28 Rupert St, driveway	30.42	30.43	-0.16	30.56	0.12		Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
50	21 Kenyons Rd, backyard	31.33	31.31	-1.17	31.46	0.15		Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
51	37 Rubina St, backyard	32.81	32.80	-1.00	33.02	0.22		Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
51	45 Binda St, garage	34.78	34.79	-0.12	dry ³	n/a ³	n/a ³	Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
29	8 Otto St, backyard	46.22	46.24	0.86	46.23	-0.01	-0.87	
28	5A Bowden St, house	38.73	38.74	0.64	38.96	0.21	-0.42	

(1) Refer **Figure 4.4** for reference to Flood Mark Identifier.

(2) Ground level determined from TUFLOW model topography, based on 2013 ALS survey data.

(3) Location of flood mark not inundated in TUFLOW model results.

(4) Note that a positive value indicates that the modelled flood level is higher than the observed flood level, and vice versa.

(5) Rounding may result in minor discrepancies between comparable figures in some instances.

TABLE D2 (CONT'D)
COMPARISON OF OBSERVED AND MODELLED FLOOD LEVELS
10 FEBRUARY 1990 STORM – A'BECKETTS CREEK CATCHMENT

Flood Mark Identifier ¹	Flood Mark Location	Observed Flood Level (m AHD) [A]	Ground Level (m AHD) ² [B]	Implied Depth of Inundation at Flood Mark (m) [C] = [B] – [A]	Modelled Flood Level (m AHD) [D]	Modelled Depth of Inundation (m) [E]	Difference Between Observed and Modelled Flood Level (m) ⁴ [F] = [D] – [A]	Comments
27	2 Bowden St, front steps	37.25	37.25	0.51	37.50	0.26	-0.26	
26	40 Bowden St, front steps	42.34	42.34	0.14	42.31	-0.02	-0.17	Reasonable fit to observed flood level.
25	19 Albert St, front steps	39.79	39.79	0.04	39.92	0.14	0.09	Good fit to observed flood level.
24	151 Fowler Rd, backyard, south fence	35.67	35.68	0.66	36.34	0.66	0.00	Good fit to observed flood level.
23	149 Fowler Rd, garage	35.56	35.56	0.34	36.27	0.71	0.37	
22	98A Fowler Rd, front door	34.80	34.80	0.61	35.03	0.23	-0.38	
20	38 Leigh St, front patio	33.08	33.10	0.41	33.56	0.46	0.05	Good fit to observed flood level.
19	31 Villiers St, house	32.36	32.35	0.65	32.97	0.62	-0.03	Good fit to observed flood level.
18	32 Villiers St, garage	31.75	31.74	0.37	31.95	0.21	-0.16	Reasonable fit to observed flood level.
16	93 Harris St, house	29.79	29.80	0.68	30.42	0.62	-0.06	Good fit to observed flood level.
15	20 Eric Ave, house	29.41	29.40	0.54	29.78	0.38	-0.16	Reasonable fit to observed flood level.
14	15 Matthew St, front door	28.17	28.11	0.44	28.23	0.12	-0.32	
13	34 Davis St, back fence	27.35	27.36	0.49	27.70	0.34	-0.15	Reasonable fit to observed flood level.
12	26 Davis St, back fence	26.76	26.76	0.22	27.24	0.48	0.26	
11	16 Barbara Cres, back fence	25.30	25.29	0.18	25.37	0.08	-0.10	Good fit to observed flood level.
10	72 St Anne St, back steps	24.05	24.03	0.34	24.55	0.52	0.18	Reasonable fit to observed flood level.
8	72 St Anne St, back steps	19.86	19.87	-0.67	dry ³	n/a ³	n/a ³	Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
7	1 McFarlane St	16.92	17.03	-0.13	dry ³	n/a ³	n/a ³	Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.
6	Cnr McFarlane & Pitt Sts	16.72	16.72	0.38	16.97	0.25	-0.13	Reasonable fit to observed flood level.
5	4 Terminal Pl	16.01	16.03	0.07	16.13	0.10	0.03	Good fit to observed flood level.
4	15-17 Neil St	16.11	16.12	-0.22	dry ³	n/a ³	n/a ³	Flood mark considered unreliable - observed flood level is lower than TUFLOW model ground level.

(1) Refer **Figure 4.4** for reference to Flood Mark Identifier.

(2) Ground level determined from TUFLOW model topography, based on 2013 ALS survey data.

(3) Location of flood mark not inundated in TUFLOW model results.

(4) Note that a positive value indicates that the modelled flood level is higher than the observed flood level, and vice versa.

(5) Rounding may result in minor discrepancies between comparable figures in some instances.

TABLE D3
COMPARISON OF OBSERVED AND MODELLED FLOOD LEVELS
10 FEBRUARY 1990 STORM – DUCK CREEK CATCHMENT

Flood Mark Identifier ¹	Flood Mark Location	Observed Depth of Inundation (m) [A]	Modelled Depth of Inundation (m) [B]	Difference Between Observed and Modelled Depth of Inundation (m) ² [C] = [B] – [A]	Comments
60	22 Cecil Avenue	0.1	0.07	-0.03	Description of flood mark location within property not available. Model results show depths of flooding within the property in the range 0.05 – 0.3 m.
63	5 George Street	1.0	0.30	-0.70	Description of flood mark location within property not available. Model results show depths of flooding within the property up to 0.5 m, which is 0.5 m below the observed depth of inundation.
66	10 Phyllis Crescent	0.3	dry ³	n/a ³	Observed flooding within property unable to be reproduced. It is likely that topographic changes in the catchment upstream of the property and along Phyllis Crescent have resulted in a redirection of flows away from the property to the east along Phyllis Crescent.
67	The Esplanade	0.3	dry ³	n/a ³	Flood mark shown within No. 52 The Esplanade, however it is unclear whether this location is precise. Observed flooding within property unable to be reproduced.
68	10 Vulcan Street	0.5	0.22	-0.28	Description of flood mark location within property not available. Model results show depths of flooding within the property up to 0.4 m, which is within 0.1 m of the observed depth of inundation.

(1) Refer **Figure 4.5** for reference to Flood Mark Identifier.

(2) Note that a negative value indicates that the modelled flood level is lower than the observed flood level, and vice versa.

(3) Location of flood mark not inundated in TUFLOW model results.

APPENDIX E

SUMMARY OF DESIGN PEAK FLOWS AND HYDRAULIC BEHAVIOUR OF REGIONAL TYPE FLOOD DETENTION BASINS LOCATED IN AREAS AFFECTED BY OVERLAND FLOW

TABLE E1
SUMMARY OF PEAK FLOWS⁽¹⁾

ID ⁽²⁾	Catchment	Location	Type	5 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF		
				Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	
GRE_01	Greystanes Creek	Upstream Butu Wargun Drive	Overland	9.2	120	11.9	120	13.1	25	15.0	120	91.5	15	
GRE_02		M4 Motorway	Pipe	0.8	120	1.4	120	1.7	120	2.0	120	3.8	120	
GRE_03		Mandoon Road	Pipe	0.9	25	0.9	25	0.9	25	1.0	25	1.7	15	
			Overland	1.4	25	2.1	25	2.4	25	2.7	25	-	-	
GRE_04		Magowar Road	Pipe	2.4	25	2.6	25	2.6	25	2.7	25	4.8	45	
			Overland	1.2	25	1.8	25	2.0	25	2.3	25	-	-	
GRE_05		Gilba Road	Pipe	3.5	25	3.6	60	3.6	60	3.6	90	4.0	45	
			Overland	0.1	25	1.4	60	1.9	60	2.4	90	-	-	
GRE_06		Oramzi Road	Pipe	4.5	60	4.6	60	4.6	60	4.6	60	5.0	60	
			Overland	1.3	60	2.6	60	3.6	60	4.6	60	48.0	60	
GRE_07		Oramzi Road	Pipe	1.9	25	1.9	25	1.9	25	1.9	25	1.9	15	
			Overland	0.4	25	0.9	25	1.0	25	1.3	25	10.3	15	
GRE_08		C V Kelly Park	Pipe	5.7	270	5.7	270	5.7	270	5.8	270	6.0	60	
			Overland	3.9	270	7.1	270	8.8	270	8.0	270	67.0	60	
GRE_09	Western Rail Line	Pipe	0.7	120	1.2	120	1.6	60	1.9	60	3.1	120		
GRE_10	Western Rail Line	Pipe	2.3	120	2.5	120	2.5	60	2.7	60	4.2	120		
GRE_11	Western Rail Line	Pipe	0.9	25	0.9	25	0.9	25	0.9	90	1.1	15		
COO_01	Coopers Creek	Downstream Lance Crescent	Pipe	2.1	120	2.3	25	2.3	120	2.4	120	2.6	120	
			Overland	0.0	-	0.0	-	0.0	-	0.2	120	-	-	
		Hanbury Street	Pipe	2.1	25	2.1	25	2.1	25	2.1	25	2.1	15	
			Overland	1.3	25	2.8	25	3.2	25	3.8	25	28.0	15	
		Downstream Maple Street	Pipe	1.7	120	1.8	25	1.9	25	1.9	25	2.2	15	
			Overland	0.0	-	0.9	25	1.4	25	1.9	25	20.3	15	
		Old Prospect Road	Pipe	1.7	25	1.9	25	1.9	25	1.9	120	1.8	15	
			Overland	0.3	25	0.7	25	0.9	25	1.4	120	-	-	
		COO_05	Gregory Street	Channel	0.3	25	0.7	25	0.9	120	1.3	25	25.2	15
		COO_06	Great Western Highway	Pipe	2.8	120	2.9	25	3.0	120	3.0	120	3.0	15
				Overland	0.4	120	1.1	25	1.6	120	2.1	120	-	-
		COO_07	Downstream Sturdee Street	Pipe	0.8	120	0.8	25	0.8	25	0.8	25	1.0	15
				Overland	0.6	120	1.3	25	1.5	25	1.8	25	14.7	15

TABLE E1 (Cont'd)
SUMMARY OF PEAK FLOWS⁽¹⁾

ID ⁽²⁾	Catchment	Location	Type	5 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF	
				Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)
COO_08	Coopers Creek	Layton Street	Pipe	1.0	25	1.0	25	1.0	25	1.0	25	1.2	15
			Overland	1.5	25	2.0	25	2.2	25	2.4	25	15.2	15
COO_09		Upstream Emert Street	Pipe	2.8	25	3.0	25	3.0	25	3.0	25	3.1	30
			Overland	1.3	25	2.4	25	2.8	25	3.4	25	33.9	30
FIN_01	Finlaysons Creek	Baden Street	Pipe	6.0	120	6.0	120	6.0	120	6.0	120	5.6	30
			Overland	2.4	120	4.3	120	5.7	120	7.6	120	-	-
FIN_02		Paton Street	Pipe	1.4	120	1.4	120	1.5	120	1.5	120	1.5	30
			Overland	0.0	-	0.2	120	0.6	120	1.4	120	30.8	30
FIN_03		Paton Street	Pipe	3.5	25	4.0	25	4.1	90	4.2	90	4.7	30
FIN_04		Northcott Street	Pipe	3.0	90	3.0	120	3.0	120	3.0	120	3.0	45
			Overland	1.9	90	2.6	120	2.9	120	3.6	120	-	-
FIN_05		Boronia Street (South)	Pipe	2.3	90	2.3	120	2.3	120	2.3	120	2.6	30
			Overland	1.7	90	3.0	120	3.8	120	4.7	120	-	-
FIN_06		Boronia Street (North)	Pipe	1.4	25	1.5	25	1.5	25	1.5	25	1.9	15
			Overland	0.4	25	0.9	25	1.1	25	1.5	25	-	-
FIN_07		Lewis Street	Pipe	0.9	120	0.9	60	0.9	90	0.9	60	1.0	30
			Overland	0.4	120	1.0	60	1.3	90	1.6	60	13.8	30
FIN_08		Berkley Street	Pipe	1.9	25	1.9	120	1.9	120	1.9	120	2.1	30
			Overland	0.4	25	1.5	120	2.0	120	2.5	120	21.1	30
FIN_09		Pearson Street	Pipe	2.6	120	2.7	120	2.8	120	2.8	120	3.0	30
			Overland	0.7	120	1.8	120	2.5	120	3.1	120	26.8	30
FIN_10		Richmond Street	Channel	3.9	90	5.1	90	6.2	120	7.2	120	-	-
FIN_11		Finlayson Street	Overland	0.1	120	0.5	120	0.8	120	1.1	120	-	-
FIN_12		Allen Street	Pipe	1.3	90	1.3	120	1.3	120	1.3	120	-	-
			Overland	1.3	90	1.9	120	2.2	120	2.4	120	30.6	90
WES_01	Westmead Creek	Austral Avenue	Pipe	3.8	25	3.8	25	3.8	25	4.0	25	6.5	15
			Overland	2.5	25	5.4	25	6.5	25	7.9	25	59.8	15
WES_02		Western Rail Line	Pipe	6.7	25	9.1	60	10.8	60	12.3	60	27.9	120
DOM_01	Domain Creek	Amos Street	Pipe	1.1	120	1.1	60	1.1	25	1.1	25	1.5	15
			Overland	0.5	120	1.0	60	1.3	25	1.5	25	15.1	15

TABLE E1 (Cont'd)
SUMMARY OF PEAK FLOWS⁽¹⁾

ID ⁽²⁾	Catchment	Location	Type	5 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF	
				Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)
DOM_02	Domain Creek	Houison Street	Pipe	1.8	25	1.9	25	1.9	25	2.5	120	2.6	30
			Overland	0.2	25	0.6	25	0.8	25	0.8	120	47.2	30
DOM_03		Drew Street	Pipe	1.3	120	1.3	120	1.3	120	1.3	120	1.8	30
			Overland	1.5	120	2.5	120	3.1	120	3.8	120	26.1	30
DOM_04		Parramatta Golf Club	Overland	8.4	25	9.6	25	9.9	25	10.9	90	77.2	90
CLA_01	Clay Cliff Creek	M4 Western Motorway	Pipe	3.6	120	4.3	60	4.5	60	4.6	60	5.6	90
CLA_02		M4 Western Motorway	Pipe	2.5	25	3.2	25	3.4	25	3.7	25	7.1	120
CLA_03		Pitt Street	Pipe	10.2	120	10.5	60	10.4	60	10.4	60	13.5	15
			Overland	0.6	120	3.2	60	5.3	60	7.8	60	100.9	15
ABE_01	A'Becketts Creek	Kenyons Road	Pipe	4.8	120	4.9	120	5.1	120	5.4	120	6.2	30
			Overland	2.1	120	3.2	120	4.4	120	6.1	120	71.8	30
ABE_02		Burnett Street	Pipe	3.1	120	3.1	25	3.1	60	3.1	120	3.1	15
			Overland	1.3	120	2.6	25	3.3	60	4.4	120	43.3	15
ABE_03		Shannon Avenue	Pipe	3.3	120	3.3	90	3.3	120	3.3	120	5.2	30
ABE_04		Major Road	Pipe	8.0	25	8.0	25	8.1	25	8.5	25	8.7	45
ABE_05		Warwick Road	Pipe	10.2	60	10.2	90	10.2	120	10.2	25	10.8	15
			Overland	4.3	60	6.9	90	8.4	120	9.7	120	158.2	90
ABE_06		Downstream Treves Street	Pipe	41.2	120	43.9	120	46.1	120	47.8	90	67.1	60
ABE_07		Fowler Road	Pipe	2.6	90	2.8	25	2.9	60	3.0	90	3.4	15
			Overland	0.5	25	0.7	25	1.4	60	2.9	90	43.2	15
ABE_08		Downstream Matthew Street	Pipe	4.7	120	4.8	120	4.8	120	4.9	120	4.9	45
			Overland	1.9	120	3.9	120	5.2	120	6.5	120	78.3	45
ABE_09		Norma Place	Pipe	2.6	120	2.6	90	2.6	90	2.6	90	2.7	15
			Overland	0.5	120	1.6	90	2.1	90	2.7	90	31.5	15
ABE_10		Cambridge Street	Pipe	11.4	90	11.5	60	11.7	60	11.8	90	12.3	45
			Overland	0.6	90	2.9	60	5.1	60	7.4	90	-	-
ABE_11		Downstream McFarlane Street	Pipe	15.1	120	16.4	120	17.5	120	18.8	90	17.1	90
ABE_12		Upstream Pitt Street	Pipe	28.6	120	30.9	120	32.0	120	33.5	90	43.9	60
ABE_13		Neil Street	Pipe	32.8	120	36.3	60	39.5	120	41.2	60	66.5	90

TABLE E1 (Cont'd)
SUMMARY OF PEAK FLOWS⁽¹⁾

ID ⁽²⁾	Catchment	Location	Type	5 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF	
				Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)
DUC_01	Duck Creek	Harris Street	Pipe	1.2	25	1.2	25	1.2	90	1.2	90	1.5	15
			Overland	2.3	25	3.2	25	3.7	90	4.3	90	27.9	15
DUC_02		Vulcan Street	Channel	2.7	90	3.2	120	3.5	60	4.3	120	33.5	15
PRO_01	Prospect Creek	Hyland Road	Pipe	4.3	120	4.6	120	4.7	120	4.7	120	6.0	15
			Overland	6.1	120	10.2	120	12.2	120	12.6	120	-	-
PRO_02		Liverpool to Parramatta Transitway	Pipe	12.5	120	14.7	120	15.4	120	15.3	120	20.3	15
			Overland	2.8	120	7.7	120	11.0	120	12.1	120	101.6	15
PRO_03		Upstream Tarlington Road	Pipe	1.0	25	1.0	25	1.0	60	1.1	90	1.2	15
			Overland	0.6	25	1.1	25	1.2	60	1.8	90	14.1	15
PRO_04		Hume Road	Pipe	4.6	90	5.0	25	5.1	25	5.2	90	5.8	15
			Overland	1.4	90	2.0	25	2.5	25	3.2	90	-	-
PRO_05		Sammut Street	Pipe	7.5	120	8.0	120	8.0	120	8.0	120	8.0	15
			Overland	0.0	-	1.8	120	3.0	120	4.1	120	47.3	15
PRO_06		Merrylands Road	Pipe	5.8	25	5.7	25	5.6	25	5.7	90	5.1	15
			Overland	4.2	25	7.0	25	8.1	25	9.7	90	68.5	15
PRO_07		Upstream Macquarie Road	Overland	7.8	60	10.3	60	11.4	60	11.9	120	74.2	15
PRO_08		Downstream Gardenia Parade	Pipe	10.6	25	11.8	25	12.3	90	13.2	120	16.5	15
			Overland	0.0	-	0.0	-	0.0	-	0.0	-	-	-
PRO_09		Downstream Liverpool to Parramatta Transitway	Pipe	12.2	60	13.3	60	13.3	60	13.3	25	15.4	15
PRO_10		Downstream Liverpool to Parramatta Transitway	Pipe	3.2	60	3.2	60	3.2	60	3.2	60	3.4	15
PRO_11		Downstream Liverpool to Parramatta Transitway	Pipe	15.2	60	16.3	60	16.3	60	16.7	60	18.1	15
PRO_12		Long Street	Pipe	17.4	90	19.1	90	19.7	90	20.2	90	34.5	15
			Overland	0.0	-	0.0	-	0.0	-	0.0	-	-	-
PRO_13		Downstream Gardenia Parade	Pipe	1.9	25	2.0	25	2.0	25	2.0	25	2.1	15
			Overland	0.0	-	0.5	25	0.7	25	1.0	25	-	-
PRO_14		Downstream Gardenia Parade	Pipe	4.6	120	4.8	25	4.8	25	4.8	25	4.9	15
			Overland	0.2	120	1.4	25	1.9	25	2.4	25	17.5	15
PRO_15		Downstream Liverpool to Parramatta Transitway	Pipe	5.6	60	6.0	60	6.6	60	7.2	60	9.2	15

TABLE E1 (Cont'd)
SUMMARY OF PEAK FLOWS⁽¹⁾

ID ⁽²⁾	Catchment	Location	Type	5 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF	
				Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)
PRO_16a	Prospect Creek	Downstream Britton Street	Pipe	9.3	90	9.4	60	9.4	90	9.4	60	9.9	15
			Overland	1.9	90	3.3	60	4.4	90	5.8	60	37.9	15
PRO_16b		Downstream Britton Street	Pipe	7.3	90	7.3	60	7.4	90	7.5	60	7.9	15
PRO_17		Downstream Long Street	Pipe	12.3	90	12.1	180	12.7	120	10.3	120	15.6	15
PRO_18		Downstream Vale Street	Pipe	1.9	120	1.9	120	1.9	120	1.9	120	2.0	15
			Overland	0.2	120	0.8	120	1.4	120	2.0	120	-	-
PRO_19		Upstream Cumberland Highway	Pipe	5.1	90	5.1	60	5.1	120	5.1	60	5.6	15
			Overland	2.7	90	4.2	60	5.0	120	5.9	60	28.4	15
PRO_20		Sandra Street	Pipe	3.0	120	3.0	120	3.0	120	3.1	120	3.4	15
			Overland	3.3	120	5.3	120	6.7	120	8.4	120	-	-
PRO_21		Sturt Street	Pipe	4.0	90	4.8	60	4.9	60	4.9	60	4.9	15
			Overland	0.1	90	0.8	60	1.8	60	2.9	60	-	-
PRO_22		North of McCredie Road	Channel	7.5	25	7.9	60	8.4	60	8.7	60	13.4	15
PRO_23		Prospect Creek	Pipe	9.2	60	9.5	120	9.9	60	10.4	60	13	15
PRO_24		Prospect Creek	Pipe	2.4	60	2.9	120	3.4	60	3.6	60	4.9	15
PRO_25		Prospect Creek	Pipe	6.3	180	6.5	180	6.5	180	6.6	25	7.0	15
PRO_26		Prospect Creek	Pipe	5.4	90	6.0	90	6.1	90	6.1	120	7.1	15
PRO_27		Princes Street	Pipe	0.9	25	0.9	25	1.0	25	1.0	25	1.0	15
			Overland	0.4	25	0.7	25	1.0	25	1.2	25	11.7	15
PRO_28		McCredie Road	Pipe	1.2	120	1.2	120	1.2	120	1.2	90	1.2	15
			Overland	0.4	120	1.1	120	1.5	120	2.0	90	-	-
PRO_29		Faulds Road	Pipe	1.7	120	1.7	25	1.7	25	1.7	25	1.7	15
			Overland	0.4	120	1.6	25	2.0	25	2.6	25	19.2	15
PRO_30		Dennistoun Avenue	Pipe	1.1	120	1.1	120	1.1	120	1.1	120	1.1	15
			Overland	0.4	120	1.4	120	2.2	120	3.2	120	34.1	15
PRO_31		Dennistoun Avenue	Pipe	3.7	60	3.8	120	3.8	60	3.9	60	4.6	15
			Overland	0.4	60	0.8	120	1.2	60	1.7	60	-	-
PRO_32		Downstream Dennistoun Avenue	Channel	0.3	120	0.8	120	1.1	120	1.5	120	-	-
PRO_33		Upstream Dursley Road	Channel	8.2	60	9.9	90	12.1	120	13.7	90	-	-
PRO_34		Prospect Creek	Channel	9.8	90	11.2	120	11.9	120	12.8	120	23.6	15

TABLE E1 (Cont'd)
SUMMARY OF PEAK FLOWS⁽¹⁾

ID ⁽²⁾	Catchment	Location	Type	5 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF	
				Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)	Discharge (m³/s)	Critical Duration (min)
PRO_35	Prospect Creek	Prospect Creek	Pipe	4.8	60	5.2	60	5.2	60	5.3	60	5.9	15
PRO_36		Downstream Dennistoun Avenue	Overland	3.0	25	4.0	25	4.3	25	4.6	25	23.6	15
PRO_37		Loftus Road	Pipe	4.7	25	5.9	25	6.5	25	7.1	25	12.7	15
PRO_38		Western Rail Line	Pipe	9.4	90	11.1	90	11.8	90	12.6	90	17.9	15
PRO_39		Upstream Nelson Road	Channel	19.5	60	22.4	60	23.6	60	25.1	90	41.6	15
PRO_40		Western Rail Line	Pipe	22.4	60	25.6	90	27.3	90	29.2	90	43.8	15
			Overland	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-

1. Peak flows quoted to one decimal place to show minor differences.
2. Refer relevant sheet on Figures 6.2 to 6.6 for Peak Flow Locations.

TABLE E2
SUMMARY OF HYDRAULIC BEHAVIOUR OF REGIONAL TYPE
FLOOD DETENTION BASINS LOCATED IN AREAS AFFECTED BY OVERLAND FLOW^(1,2)

Basin ID ⁽³⁾	Study Catchment	Basin Name	Basin Characteristic	5 year ARI		20 year ARI		50 year ARI		100 year ARI	
				Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)
BA035	Greystanes Creek	Driftway Drive Upper Basin	Peak inflow [1 off 825 RCP] (m³/s)	0.5	25	0.6	25	0.6	25	0.7	25
			Peak inflow [Overland] (m³/s)	0.0	25	0.1	25	0.1	25	0.1	25
			Peak outflow [1 off 375 RCP Low Flow] (m³/s)	0.2	120	0.2	120	0.2	120	0.3	120
			Peak outflow [1 off 375 RCP High Flow] (m³/s)	0.2	120	0.3	120	0.3	120	0.3	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak flood level in basin (m AHD)	48.69	120	49.01	120	49.18	120	49.35	120
BA036		Driftway Drive Middle Basin	Peak inflow [1 off 375 RCP Low Flow] (m³/s)	0.2	120	0.2	120	0.2	120	0.3	120
			Peak inflow [1 off 375 RCP High Flow] (m³/s)	0.2	120	0.3	120	0.3	120	0.3	120
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak outflow [1 off 375 RCP Low Flow] (m³/s)	0.2	25	0.2	25	0.2	25	0.2	25
			Peak outflow [1 off 375 RCP High Flow] (m³/s)	0.0	-	0.0	-	0.1	120	0.2	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
BA037		Driftway Drive Lower Basin	Peak flood level in basin (m AHD)	47.19	120	47.54	120	47.60	120	47.68	120
			Peak inflow [1 off 375 RCP Low Flow] (m³/s)	0.2	25	0.2	25	0.2	25	0.2	25
			Peak inflow [1 off 375 RCP High Flow] (m³/s)	0.0	-	0.0	-	0.1	120	0.2	120
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak outflow [1 off 375 RCP] (m³/s)	0.2	25	0.2	25	0.2	25	0.2	25
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
BA032		Corner Driftway Drive and Grazer Circuit	Peak flood level in basin (m AHD)	46.31	120	46.37	120	46.82	120	47.23	120
			Peak inflow [1 off 825 RCP] (m³/s)	0.7	25	0.9	25	0.9	25	1.0	25
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.0	-	0.1	25
			Peak outflow [2 off 675 RCP's] (m³/s)	0.3	270	0.5	120	0.6	120	0.7	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
BA031		Nicholls Way	Peak flood level in basin (m AHD)	47.88	270	48.02	120	48.08	120	48.13	120
			Peak inflow [1 off 1050 RCP] (m³/s)	1.6	25	2.0	25	2.1	25	2.2	25
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.2	25	0.5	25
			Peak outflow [2 off 600 RCP's] (m³/s)	1.0	120	1.4	120	1.5	120	1.6	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
				Peak flood level in basin (m AHD)	46.76	120	46.99	120	47.13	120	47.28

TABLE E2 (Cont'd)
SUMMARY OF HYDRAULIC BEHAVIOUR OF REGIONAL TYPE
FLOOD DETENTION BASINS LOCATED IN AREAS AFFECTED BY OVERLAND FLOW^(1,2)

Basin ID ⁽³⁾	Study Catchment	Basin Name	Basin Characteristic	5 year ARI		20 year ARI		50 year ARI		100 year ARI	
				Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)
BA013	Finlaysons Creek	Darmania Avenue Park	Peak inflow [1 off 450 RCP] (m³/s)	0.3	25	0.3	25	0.3	25	0.3	25
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak outflow [1 off 375 RCP] (m³/s)	0.2	60	0.2	60	0.2	60	0.2	60
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak flood level in basin (m AHD)	48.19	60	48.33	60	48.42	90	48.49	90
BA030		Hampden Road – Basin 1	Peak inflow [1 off 600 RCP] (m³/s)	0.6	25	0.8	25	0.8	25	0.9	25
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.0	-	0.1	25
			Peak outflow [1 off 375 RCP] (m³/s)	0.2	60	0.2	120	0.2	120	0.2	90
			Peak outflow [Spillway] (m³/s)	0.0	-	0.2	120	0.4	120	0.6	90
			Peak flood level in basin (m AHD)	38.25	60	38.42	120	38.46	120	38.50	90
BA029		Hampden Road – Basin 2	Peak inflow [Overland] (m³/s)	0.0	-	0.1	120	0.3	120	0.5	90
			Peak outflow [1 off 375 RCP] (m³/s)	0.0	-	0.1	120	0.2	120	0.3	90
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak flood level in basin (m AHD)	35.59	-	35.70	120	35.77	120	35.91	90
BA018	Domain Creek	Sydney Smith Park Basin	Peak inflow [1 off 2300x750 RCBC] (m³/s)	2.6	25	2.7	90	2.8	60	2.8	90
			Peak inflow [Overland] (m³/s)	1.6	25	3.0	90	3.8	90	4.6	90
			Peak outflow [2 off 600 RCP's] (m³/s)	0.5	180	1.2	180	1.6	120	2.0	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak flood level in basin (m AHD)	25.92	180	26.14	180	26.29	120	26.42	120
BA003	A'Becketts Creek	Cusack Street Basin	Peak inflow [1 off 525 RCP] (m³/s)	0.8	25	0.8	25	0.8	25	0.8	25
			Peak inflow [Overland] (m³/s)	0.7	25	1.2	25	1.4	25	1.8	120
			Peak outflow [1 off 750 RCP] (m³/s)	1.0	120	1.1	60	1.1	120	1.1	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.1	60	0.7	120	1.5	120
			Peak flood level in basin (m AHD)	39.02	120	39.45	60	39.56	120	39.61	120
BA001		Fowler Road – Basin 1	Peak inflow [1 off 450 RCP] (m³/s)	0.4	25	0.4	25	0.4	25	0.4	25
			Peak inflow [1 off 1050 RCP] (m³/s)	1.5	25	1.9	25	2.0	25	2.1	25
			Peak inflow [Overland] (m³/s)	0.4	25	0.6	25	0.7	25	0.8	25
			Peak outflow [1 off 300 RCP] (m³/s)	0.2	60	0.2	120	0.2	120	0.2	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.5	120	1.1	120	1.7	120
			Peak flood level in basin (m AHD)	37.76	60	38.02	120	38.06	120	38.09	120

TABLE E2 (Cont'd)
SUMMARY OF HYDRAULIC BEHAVIOUR OF REGIONAL TYPE
FLOOD DETENTION BASINS LOCATED IN AREAS AFFECTED BY OVERLAND FLOW^(1,2)

Basin ID ⁽³⁾	Study Catchment	Basin Name	Basin Characteristic	5 year ARI		20 year ARI		50 year ARI		100 year ARI	
				Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)
BA002	A'Becketts Creek	Fowler Road – Basin 2	Peak inflow [1 off 900 RCP] (m³/s)	1.0	25	1.1	25	1.2	60	1.2	60
			Peak inflow [Overland] (m³/s)	0.2	25	0.6	120	1.4	120	2.0	90
			Peak outflow [1 off 375 RCP] (m³/s)	0.2	90	0.3	120	0.3	60	0.3	90
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	120	0.1	60	1.5	90
			Peak flood level in basin (m AHD)	35.18	90	35.47	120	35.54	60	35.59	90
BA028		Todd Street Reserve	Peak inflow [Piped/Overland] (m³/s)	0.7	25	0.9	25	0.9	25	1.0	25
			Peak outflow [1 off 375 RCP] (m³/s)	0.1	120	0.1	120	0.1	120	0.1	90
			Peak outflow [Spillway] (m³/s)	0.0	120	0.3	120	0.5	120	0.6	90
			Peak flood level in basin (m AHD)	38.10	120	38.21	120	38.23	120	38.25	90
BA022		Merrylands Park – SW Oval	Peak inflow [Overland] (m³/s)	3.9	120	6.7	120	8.1	120	9.7	120
			Peak outflow [1 off 375 RCP] (m³/s)	0.2	120	0.2	120	0.2	60	0.2	60
			Peak outflow [Spillway] (m³/s)	0.0	-	2.1	120	3.8	60	5.6	60
			Peak flood level in basin (m AHD)	26.03	120	26.31	120	26.37	60	26.43	60
BA021		Merrylands Park – Main Oval	Peak inflow [Overland] (m³/s)	1.5	120	3.1	60	6.0	60	9.3	90
			Peak outflow [3 off 450 RCP's] (m³/s)	0.6	120	0.8	120	0.8	120	0.8	120
			Peak outflow [1 off 300 RCP] (m³/s)	0.1	120	0.1	120	0.1	120	0.1	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak flood level in basin (m AHD)	24.27	120	24.79	120	25.16	120	25.53	120
BA023		Merrylands Park – SE Oval	Peak inflow [Overland] (m³/s)	0.5	25	0.6	25	0.7	25	0.8	25
			Peak outflow [1 off 375 RCP] (m³/s)	0.3	25	0.4	25	0.4	25	0.4	25
			Peak outflow [Spillway] (m³/s)	0.1	25	0.2	25	0.2	25	0.2	25
			Peak flood level in basin (m AHD)	26.21	25	26.33	25	26.34	25	26.35	25
BA027	Prospect Creek	Macquarie Road – Basin 1	Peak inflow [1 off 375 RCP] (m³/s)	0.3	25	0.3	25	0.3	25	0.3	25
			Peak inflow [Overland] (m³/s)	1.0	25	1.5	25	1.6	25	1.8	25
			Peak outflow [1 off 600 RCP] (m³/s)	0.5	25	0.5	25	0.5	25	0.5	25
			Peak outflow [Spillway] (m³/s)	0.0	120	0.1	60	0.1	60	0.2	90
			Peak flood level in basin (m AHD)	52.52	120	53.00	60	53.23	60	53.45	90

TABLE E2 (Cont'd)
SUMMARY OF HYDRAULIC BEHAVIOUR OF REGIONAL TYPE
FLOOD DETENTION BASINS LOCATED IN AREAS AFFECTED BY OVERLAND FLOW^(1,2)

Basin ID ⁽³⁾	Study Catchment	Basin Name	Basin Characteristic	5 year ARI		20 year ARI		50 year ARI		100 year ARI	
				Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)
BA026	Prospect Creek	Macquarie Road – Basin 2	Peak inflow [1 off 525 RCP] (m³/s)	0.7	25	0.7	25	0.7	25	0.7	25
			Peak inflow [1 off 600 RCP] (m³/s)	0.9	25	0.9	25	0.9	25	0.9	25
			Peak inflow [Overland] (m³/s)	1.0	25	2.1	25	2.4	25	2.8	25
			Peak outflow [1 off 1050 RCP] (m³/s)	1.8	25	2.1	25	2.1	25	2.2	25
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak flood level in basin (m AHD)	52.34	25	52.81	25	53.05	25	53.31	60
BA012		Macquarie Road – Basin 3	Peak inflow [1 off 450 RCP] (m³/s)	0.5	25	0.5	25	0.5	25	0.5	25
			Peak inflow [1 off 1050 RCP] (m³/s)	1.8	25	2.1	25	2.1	25	2.2	25
			Peak inflow [Overland] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
			Peak outflow [1 off 450 RCP Northern] (m³/s)	0.6	90	0.7	60	0.7	120	0.7	120
			Peak outflow [1 off 450 RCP Southern] (m³/s)	0.5	90	0.6	60	0.6	120	0.7	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
BA020		Fairfield Road Street Basin	Peak flood level in basin (m AHD)	50.98	90	51.38	60	51.63	120	51.81	120
			Peak inflow [1 off 900 RCP] (m³/s)	0.9	25	0.9	25	1.0	25	1.1	25
			Peak inflow [1 off 600 RCP] (m³/s)	0.7	25	0.8	25	0.8	25	0.8	25
			Peak inflow [Overland] (m³/s)	1.3	25	2.0	25	2.4	25	2.6	25
			Peak outflow [1 off 900 RCP] (m³/s)	1.3	25	1.4	25	1.4	25	1.5	25
			Peak outflow [1 off 600 RCP] (m³/s)	0.7	25	0.7	25	0.7	25	0.7	25
			Peak outflow [2 off 1050 RCP's] (m³/s)	1.1	90	1.9	120	2.2	120	1.8	90
			Peak outflow [Spillway] (m³/s)	< 0.1	90	< 0.1	120	< 0.1	120	0.8	90
BA033		Silverthorne Drive – Basin A	Peak flood level in basin (m AHD)	34.03	90	34.20	120	34.28	120	34.51	90
			Peak inflow [Overland] (m³/s)	1.7	25	1.8	25	2.2	25	2.2	120
			Peak outflow [1 off 750 RCP] (m³/s)	1.8	25	1.9	25	1.9	90	1.9	90
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	< 0.1	25	0.2	25
BA034		Silverthorne Drive – Basin B	Peak flood level in basin (m AHD)	58.57	25	58.81	25	58.87	90	58.97	90
			Peak inflow [Overland] (m³/s)	0.7	25	0.9	25	0.9	25	1.0	25
			Peak outflow [1 off 600 RCP] (m³/s)	0.8	120	0.9	120	0.9	120	0.9	120
			Peak outflow [Spillway] (m³/s)	0.0	-	0.0	-	0.0	-	0.0	-
				Peak flood level in basin (m AHD)	58.87	120	59.13	120	59.23	120	59.36

TABLE E2 (Cont'd)
SUMMARY OF HYDRAULIC BEHAVIOUR OF REGIONAL TYPE
FLOOD DETENTION BASINS LOCATED IN AREAS AFFECTED BY OVERLAND FLOW^(1,2)

Basin ID ⁽³⁾	Study Catchment	Basin Name	Basin Characteristic	5 year ARI		20 year ARI		50 year ARI		100 year ARI	
				Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)	Discharge (m³/s) / Elevation (m AHD)	Critical Duration (min)
BA038	Prospect Creek	Greystanes Sportsground	Peak inflow [1 off 450 RCP] (m³/s)	0.2	25	0.2	25	0.2	25	0.2	25
			Peak inflow [Overland West] (m³/s)	0.2	90	0.5	90	0.6	90	0.7	90
			Peak inflow [2 off 1350 RCP] (m³/s)	7.0	25	7.1	25	7.2	25	7.2	25
			Peak inflow [Overland North] (m³/s)	4.6	25	7.2	25	9.1	90	11.2	90
			Peak inflow [1 off 600 RCP] (m³/s)	0.8	25	0.8	25	0.8	25	0.8	25
			Peak inflow [Overland East] (m³/s)	0.4	25	1.0	25	1.2	25	1.5	25
			Peak outflow [2 off 1350 RCP under Bolaro Ave] (m³/s)	6.7	25	7.3	120	7.4	120	7.0	120
			Peak outflow [Spillway] (m³/s)	1.1	120	2.9	60	3.6	60	4.3	90
			Peak flood level in basin (m AHD)	44.27	120	45.00	60	45.38	60	45.71	90

- 1. Peak flows quoted to one decimal place to show minor differences.
- 2. Peak flood levels quoted to two decimal places to show minor differences.
- 3. Refer relevant sheet on Figure 2.1 for location of flood detention basin.

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APPENDIX F

ASSESSMENT OF FLOOD DAMAGES

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FS1 Flood Affected Properties

F8.1 Damage – Frequency Curves and Cumulative Flooded Properties Versus Depth of Above-Floor Inundation Diagrams– 100 year ARI

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FS SYNOPSIS

Estimation of flood damages to urban development was carried out to assess the impact of flooding on the community. Damages were assessed for floods ranging between the 5 year ARI and PMF events. Assessment of urban flood damages was carried out for the two categories of development on the floodplain: "Residential" and "Commercial and Industrial". A third category of development, "Public Buildings", was also included in the damages model.

There were no quantitative data available on historic flood damages. Therefore the analysis was carried out using the residential flood damages model attached to "*Floodplain Risk Management Guideline No. 4 - Residential Flood Damages*" (DECC, 2007) (**Guideline No. 4**). This publication was prepared by DECC (now OEH) to allow a consistent assessment of residential damages across NSW for the economic comparison of flood management projects.

In *Guideline No. 4*, damage assessments undertaken after major flooding in other urban centres were adjusted and used to estimate damages likely to be experienced to typical residential development in NSW. Data for the flood damages models comprised the peak water surface elevations over the extent of the study area as determined from the present investigation, as well as information on the unit values of damages to residential property. The depths of above-floor inundation of properties were determined from the results of the hydraulic modelling described in the Main Report and from estimated floor levels of each residence.

Where available, the floor levels of individual buildings were based on survey data provided by Council. In properties where survey data were not available, floor levels were estimated by adding the estimated height of the floor above a representative natural surface within each allotment. In properties where the floor height was unable to be determined by visual inspection, the height of the floor above the representative natural surface level was assumed to be 150 mm and 50 mm for residential and commercial / industrial buildings, respectively. The type of structure and potential for property damage were also assessed by visual inspection.

While peak flood levels along the main arms of Greystanes Creek, Coopers Creek, Finlaysons Creek, A'Becketts Creek and Duck Creek have been assessed as part of previous studies, the results of the present investigation were used to estimate flood damages in properties that are located adjacent to these watercourses. In the case of Prospect Creek, the TUFLOW model developed as part of the present investigation does not include flows generated by the catchment which lies upstream of the study area. As a result, the flood damage estimates for the Prospect Creek catchment do not take into account the impact main stream flooding would have on existing development.

The procedures in *Guideline No. 4* allow for the estimation of structural damage to the building, damage to internals and contents, external damages and clean-up costs. The level of flood awareness and available warning time are taken into account by factors which are used to reduce "potential" damages to contents to "actual" damages. "Potential" damages represent losses likely to be experienced if no action were taken by residents to mitigate impacts. A reduction in the potential damages to "actual" damages is usually made to allow for property evacuation and raising valuables above floor level, which would reduce the damages actually experienced. The ability of residents to take action to reduce flood losses is mainly limited to reductions in damages to contents, as damages to the structure and clean-up costs are not usually capable of significant mitigation.

No specific information is given in *Guideline No. 4* in relation to commercial and industrial properties. Damages to the non-residential sector depend on the nature of the enterprise, the depth of inundation over the floor area and the time available for owners to take action to mitigate losses to contents. A spreadsheet model was used to assess flood damages which was similar to the residential model in terms of estimation of depths of inundation, but used typical unit damage data which had been adopted in similar floodplain risk management studies in NSW in recent years.

The total number of properties flooded above-floor level and the estimated damages which could occur for various flood recurrence intervals in the study area are summarised in **Table S1** in the **Summary** of the Main Report, while **Table FS1** provides a breakdown of the damage estimates for each individual catchment at the end of this Synopsis.

Figure 6.1 to 6.6 (11 sheets each) of the Main Report show the location and indicative depth of above-floor inundation of affected properties for each design flood event, while **Figure FS1** (11 sheets) in this appendix shows the frequency at which individual properties will be first flood affected and then flood damaged. **Figure F8.1** in this appendix shows the damage-frequency curves and cumulative distribution of above-floor depths of inundation at the 100 year ARI level of flooding for residential, commercial and industrial and public buildings in each catchment.

TABLE FS1
FLOOD DAMAGES IN THE STUDY CATCHMENTS

Catchment	ARI (years)	Number of Properties						Total Damage (\$ Million)
		Residential		Commercial/ Industrial		Public		
		Flood Affected	Flooded Above- Floor Level	Flood Affected	Flooded Above- Floor Level	Flood Affected	Flooded Above- Floor Level	
Greystanes Creek	5	212	1	52	4	0	0	0.72
	20	294	7	61	6	0	0	1.45
	50	339	8	67	12	0	0	2.00
	100	368	10	69	17	0	0	2.76
	200	394	21	75	18	1	1	3.45
	500	432	30	78	20	1	1	4.53
	PMF	1142	451	156	94	4	4	53.90
Coopers Creek	5	286	3	3	1	0	0	0.66
	20	376	8	6	1	0	0	1.63
	50	395	14	7	3	0	0	2.09
	100	428	19	7	4	0	0	2.65
	200	436	37	7	4	1	0	3.28
	500	465	48	7	5	1	0	4.34
	PMF	965	326	15	2	1	2	25.31
Finlayson Creek	5	561	4	17	0	3	0	1.25
	20	856	21	22	0	3	0	3.16
	50	938	26	25	0	3	0	4.45
	100	1044	34	27	3	4	0	5.46
	200	1139	53	32	6	4	0	6.58
	500	1266	79	35	10	4	0	8.53
	PMF	2318	881	63	0	5	5	66.33

Cont'd Over

TABLE FS1 (Cont'd)
FLOOD DAMAGES IN THE STUDY CATCHMENTS

Catchment	ARI (years)	Number of Properties						Total Damage (\$ Million)
		Residential		Commercial/ Industrial		Public		
		Flood Affected	Flooded Above- Floor Level	Flood Affected	Flooded Above- Floor Level	Flood Affected	Flooded Above- Floor Level	
Westmead Creek	5	44	1	0	0	0	0	0.25
	20	57	3	0	0	0	0	0.53
	50	61	8	0	0	0	0	0.65
	100	65	11	0	0	0	0	0.86
	200	70	12	0	0	0	0	1.08
	500	74	16	0	0	0	0	1.28
	PMF	157	80	1		0	0	7.82
Domain Creek	5	131	1	0	0	1	0	0.20
	20	179	1	0	0	1	0	0.49
	50	200	1	0	0	1	0	0.61
	100	206	2	0	0	1	0	0.69
	200	212	2	0	0	1	0	0.81
	500	216	5	0	0	1	0	1.07
	PMF	368	94	1	0	1	1	6.64
Clay Cliff Creek	5	106	1	0	0	0	0	0.17
	20	127	3	0	0	1	0	0.52
	50	138	3	0	0	1	0	0.57
	100	36	4	0	0	1	0	0.63
	200	159	7	0	0	1	0	0.84
	500	169	17	0	0	2	0	1.26
	PMF	332	121	0	0	3	1	8.66

Cont'd Over

TABLE FS1 (Cont'd)
FLOOD DAMAGES IN THE STUDY CATCHMENTS

Catchment	ARI (years)	Number of Properties						Total Damage (\$ Million)
		Residential		Commercial/ Industrial		Public		
		Flood Affected	Flooded Above- Floor Level	Flood Affected	Flooded Above- Floor Level	Flood Affected	Flooded Above- Floor Level	
A'Becketts Creek	5	768	4	40	5	10	0	2.09
	20	948	14	57	12	10	0	3.96
	50	1011	17	69	19	12	0	5.19
	100	1047	24	76	23	13	0	6.44
	200	1076	41	81	31	13	0	7.69
	500	1128	79	93	40	13	0	10.04
	PMF	2115	852	192	0	17	7	91.73
Duck Creek	5	87	2	0	0	0	0	0.20
	20	135	3	0	0	0	0	0.55
	50	153	6	1	1	0	0	0.79
	100	179	12	1	1	0	0	1.15
	200	193	16	1	1	1	1	1.55
	500	210	22	1	1	1	1	2.00
	PMF	571	177	6	0	2	1	12.72
Prospect Creek	5	338	1	129	16	0	0	3.28
	20	524	8	168	36	0	0	8.51
	50	585	16	181	50	0	0	11.47
	100	632	24	196	59	0	0	14.01
	200	672	32	213	72	0	0	18.59
	500	736	42	253	91	0	0	30.85
	PMF	1398	392	476	0	2	2	114.82

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F1. INTRODUCTION AND SCOPE

F1.1 Introduction

Damages from flooding belong to two categories:

- **Tangible Damages**
- **Intangible Damages**

Tangible damages are defined as those to which monetary values may be assigned, and may be subdivided into direct and indirect damages. Direct damages are those caused by physical contact of floodwater with damageable property. They include damages to commercial / industrial and residential building structures and contents, as well as damages to infrastructure services such as electricity and water supply. Indirect damages result from the interruption of community activities, including traffic flows, trade, industrial production, costs to relief agencies, evacuation of people and contents and clean up after the flood.

Generally, tangible damages are estimated in dollar values using survey procedures, interpretation of data from actual floods and research of government files.

The various factors included in the **intangible damage** category may be significant. However, these effects are difficult to quantify due to lack of data and the absence of an accepted method. Such factors may include:

- inconvenience
- isolation
- disruption of family and social activities
- anxiety, pain and suffering, trauma
- physical ill-health
- psychological ill-health.

F1.2 Scope of Investigation

In the following sections, tangible damages to residential, commercial / industrial and public properties resulting from flooding in the study area have been estimated. Intangible damages have not been quantified. The threshold floods at which damages may commence to infrastructure and community assets have also been estimated, mainly from site inspection and interpretation of flood level data. However, there are no data available to allow a quantitative assessment of damages to be made to this category.

F1.3 Terminology

Definitions of the terms used in this Appendix are presented in **Chapter F8** which also summarises the value of Tangible Flood Damages.

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F2. DESCRIPTION OF APPROACH

The damage caused by a flood to a particular property is a function of the depth of inundation above-floor level and the value of the property and its contents. The warning time available for residents to take action to lift property above floor level also influences damages actually experienced. A spreadsheet model that has been developed by OEH for estimating residential damages and an in-house spreadsheet model which has been developed for previous investigations of this nature for estimating commercial / industrial and public building damages were used to estimate damages on a property by property basis according to the type of development, the location of the property and the depth of inundation.

A damages database was developed that incorporates all properties that are affected by major overland flow for storm events up to the PMF. Floor levels in approximately 18 per cent of the properties comprising the damages database were based on survey provided by Council. The floor levels of the remaining properties were estimated by adding the height of floor above a representative natural surface level within each allotment, the elevation of which was based on available LiDAR survey data. The type of structure and potential for property damage were also assessed by visual inspection.

A property was deemed to be "flood affected" if the depth of overland flow in any part of the allotment exceeded 100 mm. In addition to damages resulting from above-floor inundation, an "External Damage" cost of \$14,735 was assigned to a property if the depth of overland flow adjacent to the building was greater than 100 mm and within 500 mm of the floor level. This cost represents potential damage to external components of the building such as cladding, paintwork, rendering, and foundations.

The depth-damage curves for residential damages were determined using procedures described in *Guideline No. 4*. Damage curves for other categories of development (commercial, industrial and public buildings) were derived from previous floodplain management investigations.

Damages to the non-residential sector depend on the nature of the enterprise, the depth of inundation over the floor area and the time available for owners to take action to mitigate losses to contents. A spreadsheet model was used which was similar to the residential model in terms of estimation of depths of inundation, but used typical unit damage data which had been adopted in similar studies in NSW in recent years.

It should be understood that this approach is not intended to identify individual properties liable to flood damages and the value of damages in individual properties, even though it appears to be capable of doing so. The reason for this caveat lies in the various assumptions used in the procedure, the main ones being:

- the assumption that computed water levels and topographic data used to define flood extents are exact and without any error;
- the assumption that the water levels as computed by the hydraulic model are not subject to localised influences;
- the estimation of property floor levels by visual inspection rather than by formal field survey;
- the use of "average" stage-damage relationships, rather than a unique relationship for each property;

- the uncertainties associated with assessing appropriate factors to convert *potential damages* to *actual flood damages* experienced for each property after residents have taken action to mitigate damages to contents.

The consequence of these assumptions is that some individual properties may be inappropriately classified as flood liable, while others may be excluded. Nevertheless, when applied over a broad area these effects would tend to cancel, and the resulting estimates of overall damages, would be expected to be reasonably accurate.

For the above reasons, the information contained in the spreadsheets used to prepare the estimates of flood damages for the study catchments should not be used to provide information on the depths of above-floor inundation of individual properties.

F3. SOURCES OF DATA

F3.1 General

To estimate *Average Annual Flood Damages* for a specific area it is necessary to estimate the damages for several floods of different magnitudes, i.e. of different frequencies, and then to integrate the area beneath the damage – frequency curve computed over the whole range of frequencies up to the PMF. To do this it is necessary to have data on the damages sustained by all types of property over the likely range of inundation. There are several ways of doing this:

- The ideal way would be to conduct specific damage surveys in the aftermath of a range of floods, preferably immediately after each. An example approaching this ideal is the case of Nyngan where surveys were conducted in May 1990 following the disastrous flood of a month earlier (DWR, 1990). This approach would not be practicable for the present investigation, as the most recent occurrence of major flooding in the drainage system occurred over five years ago in December 2011.
- The second best way is for experienced loss adjusters to conduct a survey to estimate likely losses that would arise due to various depths of inundation. This approach is used from time to time, but it can add significantly to the cost of a floodplain management study (LMJ, 1985). It was not used for the present investigation.
- The third way is to use generalised data such as that published by CRES (Centre for Resource & Economic Studies, Canberra) and used in the Floodplain Management Study for Forbes (SKM, 1994). These kinds of data are considered to be suitable for generalised studies, such as broad regional studies. They are not considered to be suitable for use in specific areas, unless none of the other approaches can be satisfactorily applied.
- The fourth way is to adapt or transpose data from other flood liable areas. This was the approach used for the present study. As mentioned, the *Guideline No 4* procedure was adopted for the assessment of residential damages. The approach was based on data collected following major flooding in Katherine in 1998, with adjustments to account for changes in values due to inflation, and after taking into account the nature of development and flooding patterns in the study area. The data collected during site inspection in the flood liable areas assisted in providing the necessary adjustments. Commercial and industrial damages were assessed via reference to recent floodplain management investigations of a similar nature to the present study.

F3.2 Property Data

The properties were divided into three categories: residential, commercial / industrial and public buildings.

For residential properties, the data used in the damages estimation included:

- the location/address of each property
- an assessment of the type of structure
- natural surface level
- floor level

For commercial / industrial and public properties, the required data included:

- the location of each property
- the nature of each enterprise
- an estimation of the floor area
- natural surface level
- floor level

The property descriptions were used to classify the commercial / industrial developments into categories (i.e. high, medium or low value properties) which relate to the magnitude of likely flood damages. A similar approach was adopted for compiling data on public buildings.

Table F3.1 shows the total number of residential properties, commercial, industrial and public buildings included in the database, as well as the number of properties of which surveyed floor levels were provided by Council.

TABLE F3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Study Catchment	Number of Properties				Number of Properties in Council's Surveyed Floor Level Database
	Residential	Commercial /Industrial	Public	Total	
Greystanes Creek	819	118	6	943	399
Coopers Creek	954	19	2	975	158
Finlaysons Creek	2376	68	6	2450	626
Westmead Creek	140	1	0	141	46
Domain Creek	351	1	1	353	42
Clay Cliff Creek	340	0	4	344	5
A'Becketts Creek	1999	199	17	2215	197
Duck Creek	414	9	2	425	60
Prospect Creek	1218	413	2	1633	148
Total	8611	828	40	9479	1681

F3.3 Floor Levels Used in the Analysis

As shown in **Table F3.1**, Council provided surveyed floor levels for about 18 per cent of the properties which comprise the damages database. If floor level survey was not available for a particular property then its floor level was derived by adding the estimated height of the floor above a representative natural surface level within each allotment, the elevation of which was derived from available LiDAR survey data (usually at the front door).¹

¹ The height of the floor above the representative natural surface level was estimated by visual inspection.

Where a residential building was unable to be visually assessed, the height of the floor was assumed to be 150 mm above the representative natural surface level, the elevation of which was also derived from the available LiDAR survey data. Similarly, where a commercial / industrial building was unable to be visually assessed, the height of the floor was assumed to be 50 mm above the representative natural surface level, the elevation of which was also derived from the available LiDAR survey data.

The study area contains a number of apartment complexes, particularly in the vicinity of the Merrylands CBD and Western Rail Line. The following criteria were used to determine whether the individual apartments within each complex were to be included in the damages database:

- i. Only the apartments located on the ground floor of the apartment complex were included in the damages database, the floor levels of which were determined using the above methodology. The number of ground floor apartments was approximated by dividing the total number of apartments by the number of stories.
- ii. The apartment complex was omitted from the damages database if the ground floor of the building was utilised for parking.
- iii. Apartment complexes that were under construction at the time of the present investigation (the majority of which were located in the Greystanes Creek and Finlaysons Creek catchments) were omitted from the damages database.

Aerial photography shows that there are a number of residential properties that have structures located in their rear. As it was not possible to determine the type of structure (i.e. shed, awning, granny flat etc.) from visual inspection, these structures were only included in the damages database if they were identified in Council's database of surveyed floor levels as a granny flat.

F3.3 Flood Levels Used in the Analysis

The damage estimates were carried out for floods between the 5 year ARI and PMF events. The design flood levels assume that the drainage system is operating at optimum capacity. They do not allow for any increase in levels resulting from wave action, debris build-ups in the channels which may cause a partial blockage of culverts and which may result in conversions of flow from the supercritical to the subcritical flow regime, as well as other local hydraulic effects. These factors are usually taken into account by adding a factor of safety (freeboard) to the "nominal" flood level when assessing the "level of protection" against flooding of a particular property. Freeboard could also include an allowance for the future effects of climate change.

As discussed in **Section 4.3.1** of the Main Report, the main arms of Greystanes Creek, Coopers Creek, Finlaysons Creek, A'Becketts Creek and Duck Creek were only modelled as part of the present investigation in order to generate appropriate downstream boundary conditions for the major overland flow paths. As the peak flood levels generated by the TUFLOW models along the main arms of these watercourses are approximate only, they were not included in the report figures.

However, for the purpose of the flood damages assessment, the "untrimmed" results (i.e. the results that include the peak flood levels along the major watercourses) were used to estimate flood damages in individual properties affected by main stream flooding.

In the case of Prospect Creek, the TUFLOW model developed as part of the present investigation does not include flows generated by the catchment which lies upstream of the study area. As a result, the flood damage estimates for the Prospect Creek catchment do not include main stream flooding.

Peak flood levels sampled adjacent to each building were used to determine if the property is “flood damaged” and also the depth of above-floor inundation, while peak flood levels sampled at the lowest point in the property were used to determine if the property is “flood affected”.

F4. RESIDENTIAL DAMAGES

F4.1 Damage Functions

The procedures identified in *Guideline No 4* allow for the preparation of a depth versus damage relationship which incorporates structural damage to the building, damage to internals and contents, external damages and clean-up costs. In addition, there is the facility for including allowance for accommodation costs and loss of rent. Separate curves are computed for three residential categories:

- Single storey slab on ground construction
- Single storey elevated floor
- Two storey residence

The level of flood awareness and available warning time are taken into account by factors which are used to reduce “potential” damages to contents to “actual” damages. “Potential” damages represent losses likely to be experienced if no action were taken by residents to mitigate impacts. A reduction in the potential damages to “actual” damages is usually made to allow for property evacuation and raising valuables above floor level, which would reduce the damages actually experienced. The ability of residents to take action to reduce flood losses is mainly limited to reductions in damages to contents, as damages to the structure and clean-up costs are not usually capable of significant mitigation.

The reduction in damages to contents is site specific, being dependent on a number of factors related to the time of rise of floodwaters, the recent flood history and flood awareness of residents and emergency planning by the various Government Agencies (BoM and NSW SES).

Flooding on the main streams and the overland flow paths is “flash flooding” in nature with a time of rise of floodwaters generally less than an hour in the study area. The duration of peak flooding is similarly quite short. Consequently, there would be very limited time in advance of a flood event in which to warn residents and for them to take action to mitigate flood losses.

Provided adequate warning were available, house contents may be raised above floor level to about 0.9 m, which corresponds with the height of a typical table/bench height. The spreadsheet provides two factors for assessing damages to contents, one for above and one for below the typical bench height. The reduction in damages is also dependent on the likely duration of inundation of contents, which would be limited to no more than an hour for most flooded properties.

Table F4.1 over shows total flood damages estimated for the three classes of residential property using the procedures identified in *Guideline No. 4*, for typical depths of above-floor inundation of 0.1 m and 0.5 m (the maximum depth of above-floor inundation in the study area is about 440 mm at the 100 year ARI level of flooding in the Westmead Creek Catchment). A typical ground floor area of 200 m² was adopted for the assessment. The values in **Table F4.1** allow for damages to buildings and contents, as well as provision for alternative accommodation.

F4.2 Total Residential Damages

Table F4.2 over summarises the total residential damages for the range of floods in the study area.

TABLE F4.1
DAMAGES TO RESIDENTIAL PROPERTIES

Type of Residential Construction	0.1 m Depth of Inundation Above Floor Level	0.5 m Depth of Inundation Above Floor Level
Single Storey Slab on Ground	\$47,185	\$57,990
Single Storey High Set	\$51,600	\$63,645
Two Storey Residence	\$33,029	\$40,593

Note: These values include allowances for structural and contents costs. Clean up and external costs are added separately in the determination of total residential damages.

TABLE F4.2
TOTAL RESIDENTIAL FLOOD DAMAGES IN STUDY AREA

ARI (years)	Number of Properties		Total Damages (\$ Million)
	Flood Affected	Flooded Above-Floor Level	
5	2533	18	5.81
20	3496	68	13.19
50	3820	99	17.52
100	4005	140	21.69
200	4351	221	26.28
500	4696	338	33.98
PMF	9366	3374	243.59

Table F4.3 over provides a breakdown of residential damages in each of the nine study catchments. The locations of the flood damaged and flood affected properties are shown on **Figure FS1**, while **Figures 6.2 to 6.6** of the Main Report show the indicative depth of above-floor inundation in each property.

A large portion of the properties that would be damaged at the 5 year ARI level of flooding are located in the Finlaysons Creek and A'Becketts Creek catchments. While very few dwellings would experience above-floor flooding during a 5 year ARI event, a large number of them (77 in the Finlaysons Creek and 113 in the A'Becketts Creek catchments) would suffer external damage as they are subject to overland flow that exceeds 100 mm in depth and is within 500 mm of the floor level.

Three quarters of the 140 dwellings that are inundated above-floor level at the 100 year ARI level of flooding are located in the Coopers Creek, Finlaysons Creek, A'Becketts Creek and Prospect Creek catchments. There are no obvious damage centres in any of the above catchments where there are multiple flood damaged properties in close proximity to one another. Rather, the flood damaged buildings are scattered along the overland flow paths throughout the study area.

TABLE F4.3
RESIDENTIAL FLOOD DAMAGES IN STUDY CATCHMENTS

Flood Damages	ARI (years)	Study Catchment									Total
		Greystanes Creek	Coopers Creek	Finlaysons Creek	Westmead Creek	Domain Creek	Clay Cliff Creek	A'Becketts Creek	Duck Creek	Prospect Creek	
Number of Flood Affected Properties	5	212	286	561	44	131	106	768	87	338	2533
	20	294	376	856	57	179	127	948	135	524	3496
	50	339	395	938	61	200	138	1011	153	585	3820
	100	368	428	1044	65	206	36	1047	179	632	4005
	200	394	436	1139	70	212	159	1076	193	672	4351
	500	432	465	1266	74	216	169	1128	210	736	4696
	PMF	1142	965	2318	157	368	332	2115	571	1398	9366
Number of Properties Flooded Above-Floor Level	5	1	3	4	1	1	1	4	2	1	18
	20	7	8	21	3	1	3	14	3	8	68
	50	8	14	26	8	1	3	17	6	16	99
	100	10	19	34	11	2	4	24	12	24	140
	200	21	37	53	12	2	7	41	16	32	221
	500	30	48	79	16	5	17	79	22	42	338
	PMF	451	326	881	80	94	121	852	177	392	3374
Damages (\$ Million)	5	0.45	0.64	1.22	0.25	0.20	0.17	1.82	0.20	0.86	5.81
	20	0.97	1.57	3.07	0.53	0.49	0.52	3.46	0.55	2.03	13.19
	50	1.35	1.97	4.36	0.65	0.61	0.57	4.46	0.78	2.77	17.52
	100	1.66	2.47	5.30	0.86	0.69	0.63	5.48	1.13	3.47	21.69
	200	2.15	3.10	6.28	1.08	0.81	0.84	6.42	1.51	4.09	26.28
	500	2.89	4.11	8.12	1.28	1.07	1.26	8.29	1.95	5.01	33.98
	PMF	33.13	22.95	62.09	7.77	6.56	8.64	61.98	12.38	28.09	243.59

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F5. COMMERCIAL / INDUSTRIAL DAMAGES

F5.1 Direct Commercial and Industrial Damages

The method used to calculate damages requires each property to be categorised in terms of the following:

- damage category
- floor area
- floor elevation

The damage category assigned to each enterprise may vary between "low", "medium" or "high", depending on the nature of the enterprise and the likely effects of flooding. Damages also depend on the floor area.

It has recently been recognised following the 1998 flood in Katherine that previous investigations using stage-damage curves contained in proprietary software tends to seriously underestimate true damage costs *Guideline No. 4*. OEH are currently researching appropriate damage functions which could be adopted in the estimation of commercial and industrial categories as they have already done with residential damages. However, these data were not available for the present study.

On the basis of previous investigations the following typical damage rates are considered appropriate for potential external and internal damages and clean-up costs for both commercial and industrial properties. They are indexed to a depth of inundation of 2 metres. At floor level and 1.2 m inundation, zero and 70% of these values respectively were assumed to occur:

Low value enterprise	\$280/m ²	(e.g. Commercial: small shops, cafes, joinery, public halls. Industrial: auto workshop with concrete floor and minimal goods at floor level, Council or Government Depots, storage areas.)
Medium value enterprise	\$420/m ²	(e.g. Commercial: food shops, hardware, banks, professional offices, retail enterprises, with furniture/fixtures at floor level which would suffer damage if inundated. Industrial: warehouses, equipment hire.)
High value enterprise	\$650/m ²	(e.g. Commercial : electrical shops, clothing stores, bookshops, newsagents, restaurants, schools, showrooms and retailers with goods and furniture, or other high value items at ground or lower floor level. Industrial: service stations, vehicle showrooms, smash repairs.)

The factor for converting potential to actual damages depends on a range of variables such as the available warning time, flood awareness and the depth of inundation. Given sufficient warning time, a well prepared business will be able to temporarily lift property above floor level. However, unless property is actually moved to flood free areas, floods which result in a large depth of inundation, will cause considerable damage to stock and contents.

For the present study, the above potential damages were converted to actual damages using a multiplier which ranged between 0.5 and 0.8 depending on the depth of inundation above the floor. As shown on **Figure F8.1**, the maximum depth of above-floor inundation experienced at the 100 year ARI level of flooding for commercial and industrial property is about 600 mm in the Greystanes Creek and Prospect Creek catchments. At these relatively shallow depths it would be expected that owners may be able to take significant action to mitigate damages even allowing for the flash flooding nature of inundation. Consequently, the multiplier of 0.5 was adopted to convert potential to actual damages for depths of inundation up to 1.2 m, increasing to 0.8 for greater depths.

F5.2 Indirect Commercial and Industrial Damages

Indirect commercial and industrial damages comprise costs of removal of goods and storage, loss of trading profit and loss of business confidence.

Disruption to trade takes the following forms:

- The loss through isolation at the time of the flood when water is in the business premises or separating clients and customers. The total loss of trade is influenced by the opportunity for trade to divert to an alternative source. There may be significant local loss but due to the trade transfer this may be considerably reduced at the regional or state level.
- In the case of major flooding, a downturn in business can occur within the flood affected region due to the cancellation of contracts and loss of business confidence. This is in addition to the actual loss of trading caused by closure of the business by flooding.

Loss of trading profit is a difficult value to assess and the magnitude of damages can vary depending on whether the assessment is made at the local, regional or national level. Differences between regional and national economic effects arise because of transfers between the sectors, such as taxes, and subsidies such as flood relief returned to the region.

Some investigations have lumped this loss with indirect damages and have adopted total damage as a percentage of the direct damage. In other cases, loss of profit has been related to the gross margin of the business, i.e. turnover less average wages. The former approach has been adopted in this present study. Indirect damages have been taken as 50% of direct actual damages. A clean-up cost of \$15/m² of floor area of each flooded property was also included.

F5.3 Total Commercial and Industrial Damages

Table F5.1 over summarises the total commercial / industrial damages in the study area, while **Table F5.2** shows the breakdown of commercial / industrial damages in each of the nine study catchments. The locations of the flood damaged and flood affected properties are shown on **Figure FS1**, while **Figures 6.2 to 6.6** of the Main Report show the indicative depth of above-floor inundation in each property.

The majority of the commercial / industrial buildings that are flooded above-floor level in a 100 year ARI flood event are located in the Prospect Creek, A'Becketts Creek and Greystanes Creek catchments. As the floor levels of a large number of the commercial / industrial properties that are located in the Greystanes Creek and Prospect Creek catchments could not be assessed visually (and hence were assumed to have floor levels which are only 50 mm above natural surface levels), the commercial / industrial flood damage estimates which were derived as part of the present investigation may be an overestimate of the actual damages that would be experienced in these two catchments.

The majority of the flood damaged commercial properties in the A'Becketts Creek catchment are located in the Merrylands CBD, particularly along Merrylands Road which operates as a floodway in storm events that surcharge the piped drainage system.

TABLE B5.1
TOTAL COMMERCIAL / INDUSTRIAL FLOOD DAMAGES
IN STUDY AREA

ARI (years)	Number of Properties		Total Damages (\$ Million)
	Flood Affected	Flooded Above-Floor Level	
5	241	26	3.01
20	314	55	7.60
50	350	85	10.30
100	376	107	12.95
200	409	132	17.47
500	467	167	29.77
PMF	910	526	140.20

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TABLE F5.2
COMMERCIAL / INDUSTRIAL FLOOD DAMAGES IN STUDY CATCHMENTS

Flood Damages	ARI (years)	Study Catchment									Total
		Greystanes Creek	Coopers Creek	Finlaysons Creek	Westmead Creek	Domain Creek	Clay Cliff Creek	A'Becketts Creek	Duck Creek	Prospect Creek	
Number of Flood Affected Properties	5	52	3	17	0	0	No Commercial / Industrial Properties included in flood damages database	40	0	129	241
	20	61	6	22	0	0		57	0	168	314
	50	67	7	25	0	0		69	1	181	350
	100	69	7	27	0	0		76	1	196	376
	200	75	7	32	0	0		81	1	213	409
	500	78	7	35	0	0		93	1	253	467
	PMF	156	15	63	1	1		192	6	476	910
Number of Properties Flooded Above-Floor Level	5	4	1	0	0	0		5	0	16	26
	20	6	1	0	0	0		12	0	36	55
	50	12	3	0	0	0		19	1	50	85
	100	17	4	3	0	0		23	1	59	107
	200	18	4	6	0	0		31	1	72	132
	500	20	5	10	0	0		40	1	91	167
	PMF	94	14	39	1	0		165	6	207	526
Damages (\$ Million)	5	0.28	0.03	0.03	0	0		0.25	0	2.42	3.01
	20	0.48	0.06	0.09	0	0		0.49	0	6.48	7.60
	50	0.65	0.12	0.09	0	0		0.72	0.02	8.70	10.30
	100	1.11	0.18	0.16	0	0		0.93	0.02	10.55	12.95
	200	1.24	0.18	0.30	0	0		1.23	0.02	14.50	17.47
	500	1.55	0.23	0.41	0	0		1.72	0.02	25.84	29.77
	PMF	19.91	2.27	2.74	0.06	0		28.48	0.28	86.46	140.20

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F6. DAMAGES TO PUBLIC BUILDINGS

F6.1 Direct Damages – Public Buildings

Included under this heading are government buildings, churches, swimming pools and parks. Damages were estimated individually on an area basis according to the perceived value of the property. Potential internal damages were indexed to a depth of above-floor inundation of 2 m as shown below. At floor level and 1.2 m depth of inundation, zero and 70% of these values respectively were assumed to occur.

Low value	\$280/m ²	
Medium value	\$420/m ²	(e.g. council buildings, SES HQ, fire station)
High value	\$650/m ²	(e.g. schools)

These values were obtained from the Nyngan Study (DWR, 1990) as well as commercial data presented in the Forbes Water Studies report (WS, 1992). External and structural damages were taken as 4 and 10% of internal damages respectively.

F6.2 Indirect Damages – Public Buildings

A value of \$15/m² was adopted for the clean-up of each property. This value is based on results presented in the Nyngan Study and adjusted for inflation. Total "welfare and disaster" relief costs were assessed as 50% of the actual direct costs.

F6.3 Total Damages – Public Buildings

Table F6.1 summarises the total public building damages in the study area, while **Table F6.2** provides a breakdown of public building damages in each of the nine study catchments. The locations of the flood damaged and flood affected buildings are shown on **Figure FS1**, while **Figures 6.2 to 6.6** of the Main Report show the indicative depth of above-floor inundation in each building.

The total damages are relatively minor as the majority of public buildings in the study area are located on higher ground away from the major overland flow paths.

TABLE F6.1
TOTAL PUBLIC FLOOD DAMAGES IN STUDY AREA

ARI (years)	Number of Properties		Total Damages (\$ Million)
	Flood Affected	Flooded Above-Floor Level	
5	14	0	0.02
20	15	0	0.02
50	17	0	0.02
100	19	0	0.03
200	22	2	0.11
500	23	2	0.15
PMF	35	23	4.18

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TABLE F6.2
PUBLIC FLOOD DAMAGES IN STUDY CATCHMENTS

Flood Damages	ARI (years)	Study Catchment									Total
		Greystanes Creek Catchment	Coopers Creek Catchment	Finlaysons Creek Catchment	Westmead Creek Catchment	Domain Creek Catchment	Clay Cliff Creek Catchment	A'Becketts Creek Catchment	Duck Creek Catchment	Prospect Creek Catchment	
Number of Flood Affected Properties	5	0	0	3	No Public Buildings included in flood damages database	1	0	10	0	0	14
	20	0	0	3		1	1	10	0	0	15
	50	0	0	3		1	1	12	0	0	17
	100	0	0	4		1	1	13	0	0	19
	200	1	1	4		1	1	13	1	0	22
	500	1	1	4		1	2	13	1	0	23
	PMF	4	1	5		1	3	17	2	2	35
Number of Properties Flooded Above-Floor Level	5	0	0	0		0	0	0	0	0	0
	20	0	0	0		0	0	0	0	0	0
	50	0	0	0		0	0	0	0	0	0
	100	0	0	0		0	0	0	0	0	0
	200	1	0	0		0	0	0	1	0	2
	500	1	0	0		0	0	0	1	0	2
	PMF	4	2	5		1	1	7	1	2	23
Damages (\$ Million)	5	0	0	0		0	0	0.02	0	0	0.02
	20	0	0	0		0	0	0.02	0	0	0.02
	50	0	0	0		0	0	0.02	0	0	0.02
	100	0	0	0		0	0	0.03	0	0	0.03
	200	0.06	0	0		0	0	0.03	0.02	0	0.11
	500	0.09	0	0		0	0	0.03	0.03	0	0.15
	PMF	0.87	0.09	1.51		0.08	0.02	1.27	0.06	0.28	4.18

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F7. DAMAGES TO INFRASTRUCTURE AND COMMUNITY ASSETS

Infrastructure in the study area, such as electrical and telephone supply, sewerage and water supply systems, and the road network, are potentially prone to damaging flooding. Community assets such as parks and other recreational amenities could also suffer damages. No data are available on damages experienced during historic flood events. However, a qualitative matrix of the effects of flooding on these categories is presented in **Table F7.1**.

TABLE F7.1
QUALITATIVE EFFECTS OF MAJOR OVERLAND FLOW ON INFRASTRUCTURE
AND COMMUNITY ASSETS IN STUDY AREA

Damage Sector	Flood Event (Year ARI)				
	5	10	20	100	PMF
Electricity	0	0	0	X	X
Telephone	0	0	0	X	X
Roads	X	X	X	X	X
Bridges	0	0	0	0	0
Sewerage	0	0	0	0	0
Water Supply	0	0	0	X	X
Parks and Gardens	X	X	X	X	X

Notes: 0 = No significant damages likely to be incurred.
X = Some damages likely to be incurred.

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F8 SUMMARY OF TANGIBLE DAMAGES

F8.1 Tangible Damages

Flood damages under existing conditions have been computed for a range of flood frequencies from 5 year ARI up to the PMF. For the purposes of assessing damages, the 2 year ARI was adopted as the “threshold” flood at which damages commence in the drainage systems of each study catchment.

From **Table F8.1**, relatively large flood damages would be experienced in the Finlaysons Creek, A’Becketts Creek and Prospect Creek catchments, while relatively moderate flood damages would be experienced in Greystanes Creek and Coopers Creek catchments during a 100 year ARI storm event. Flood damages experienced in the Westmead Creek, Domain Creek, Clay Cliff Creek and Duck Creek catchments would only be relatively minor during a storm of this return period.

It is noted that the flood damages that would be experienced in the Finlaysons Creek and A’Becketts Creek catchments are principally due to damage to residential property, while those in the Prospect Creek catchment are principally due to damage to commercial / industrial property.

Figure F8.1 shows the damage-frequency curves and cumulative distribution of above-floor depths of inundation at the 100 year ARI flood level for residential, commercial and industrial and public buildings in each study catchment.

TABLE F8.1
TOTAL FLOOD DAMAGES IN STUDY AREA
\$ MILLION

ARI (years)	Study Catchment									Total
	Greystanes Creek	Coopers Creek	Finlaysons Creek	Westmead Creek	Domain Creek	Clay Cliff Creek	A’Becketts Creek	Duck Creek	Prospect Creek	
5	0.73	0.67	1.25	0.25	0.20	0.17	2.09	0.20	3.28	8.84
20	1.45	1.63	3.16	0.53	0.49	0.52	3.97	0.55	8.51	20.81
50	2.00	2.09	4.45	0.65	0.61	0.57	5.20	0.80	11.47	27.84
100	2.77	2.65	5.46	0.86	0.69	0.63	6.44	1.15	14.02	34.67
200	3.45	3.28	6.58	1.08	0.81	0.84	7.68	1.55	18.59	43.86
500	4.53	4.34	8.53	1.28	1.07	1.26	10.04	2.00	30.85	63.90
PMF	53.91	25.31	66.34	7.83	6.64	8.66	91.73	12.72	114.83	387.97

F8.2 Definition of Terms

Average Annual Damages (also termed “expected damages”) are determined by integrating the area under the damage-frequency curve. They represent the time stream of annual damages, which would be expected to occur on a year by year basis over a long duration.

Using an appropriate discount rate, average annual damages may be expressed as an equivalent “*Present Worth Value*” of damages and used in the economic analysis of potential flood management measures.

A flood management scheme which is designed to provide a 100 year ARI level of protection, by definition, will eliminate damages up to this level of flooding. If the scheme has no mitigating effect on larger floods, then these damages represent the benefits of the scheme expressed on an average annual basis and converted to the *Present Worth Value* via the discount rate.

Under current NSW Treasury guidelines, economic analyses are carried out assuming a 20 year economic life for projects and discount rates of 7% pa. (best estimate) and 10% and 4% pa. (sensitivity analyses).

F8.3 Average Annual Damages

The average annual damages in each study catchment for all flood events up to the PMF are shown below in **Table F8.2**.

TABLE F8.2
AVERAGE ANNUAL DAMAGES IN STUDY AREA
\$ MILLION

ARI (years)	Study Catchment									Total
	Greystanes Creek	Coopers Creek	Finlaysons Creek	Westmead Creek	Domain Creek	Clay Cliff Creek	A'Becketts Creek	Duck Creek	Prospect Creek	
5	0.11	0.10	0.18	0.04	0.03	0.02	0.31	0.03	0.49	1.31
20	0.27	0.27	0.51	0.10	0.08	0.08	0.76	0.09	1.38	3.54
50	0.33	0.32	0.64	0.11	0.10	0.09	0.90	0.11	1.68	4.28
100	0.34	0.36	0.68	0.12	0.11	0.10	0.97	0.11	1.81	4.60
200	0.36	0.37	0.71	0.13	0.11	0.10	1.01	0.12	1.89	4.80
500	0.37	0.38	0.74	0.13	0.11	0.11	1.03	0.13	1.96	4.96
PMF	0.42	0.41	0.80	0.14	0.12	0.11	1.13	0.14	2.09	5.36

F8.4 Present Worth of Damages

The *Present Worth Values* of damages likely to be experienced in each of the study catchments for all flood events up to the 100 year ARI and PMF, a 20 year economic life and discount rates of 4, 7 and 10 per cent are shown in **Table F8.3** and **F8.4**, respectively..

For a discount rate of 7 per cent pa, the *Present Worth Value* of damages for all flood events up to the 100 year ARI flood in the study area is about \$48.7 Million for a 20 year economic life. Therefore schemes costing up to this amount could be economically justified if they eliminated damages in the study area for all flood events up to this level. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility. Flood modification measures would need to be considered during the preparation of the future Floodplain Risk Management Study and Draft Plan for each study catchment.

TABLE F8.3
PRESENT WORTH DAMAGES IN STUDY AREA
ALL FLOODS UP TO 100 YEAR ARI FOR AN ECONOMIC LIFE OF 20 YEARS
\$ MILLION

ARI (years)	Study Catchment									Total
	Greystanes Creek	Coopers Creek	Finlaysons Creek	Westmead Creek	Domain Creek	Clay Cliff Creek	A'Becketts Creek	Duck Creek	Prospect Creek	
4%	4.62	4.89	9.24	1.63	1.49	1.36	13.18	1.49	24.60	62.50
7%	3.60	3.81	7.20	1.27	1.16	1.06	10.27	1.16	19.17	48.70
10%	2.89	3.06	5.79	1.02	0.94	0.85	8.25	0.94	15.40	39.14

TABLE F8.4
PRESENT WORTH DAMAGES IN STUDY AREA
ALL FLOODS UP TO PMF FOR AN ECONOMIC LIFE OF 20 YEARS
\$ MILLION

ARI (years)	Study Catchment									Total
	Greystanes Creek	Coopers Creek	Finlaysons Creek	Westmead Creek	Domain Creek	Clay Cliff Creek	A'Becketts Creek	Duck Creek	Prospect Creek	
4%	5.71	5.57	10.87	1.90	1.63	1.49	15.36	1.90	28.40	72.83
7%	4.45	4.34	8.47	1.48	1.27	1.16	11.97	1.48	22.13	56.75
10%	3.57	3.49	6.81	1.19	1.02	0.94	9.62	1.19	17.79	45.62

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F9. REFERENCES

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