SAILORS BAY CREEK
FLOOD STUDY

VOLUME 1 – REPORT

FINAL REPORT

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Prepared by:
Lyall & Associates
Consulting Water Engineers
Level 1, 26 Ridge Street
North Sydney NSW 2060

Tel: **(02) 9929 4466**
Fax: (02) 9929 4458
Email: lacewater@bigpond.com

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 Sailors Bay Creek Flood Study constitutes the first stage of the Floodplain Risk Management process (refer over) for this area and has been prepared for Willoughby City Council to define flood behaviour under current conditions.

ACKNOWLEDGEMENT

Willoughby City Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.
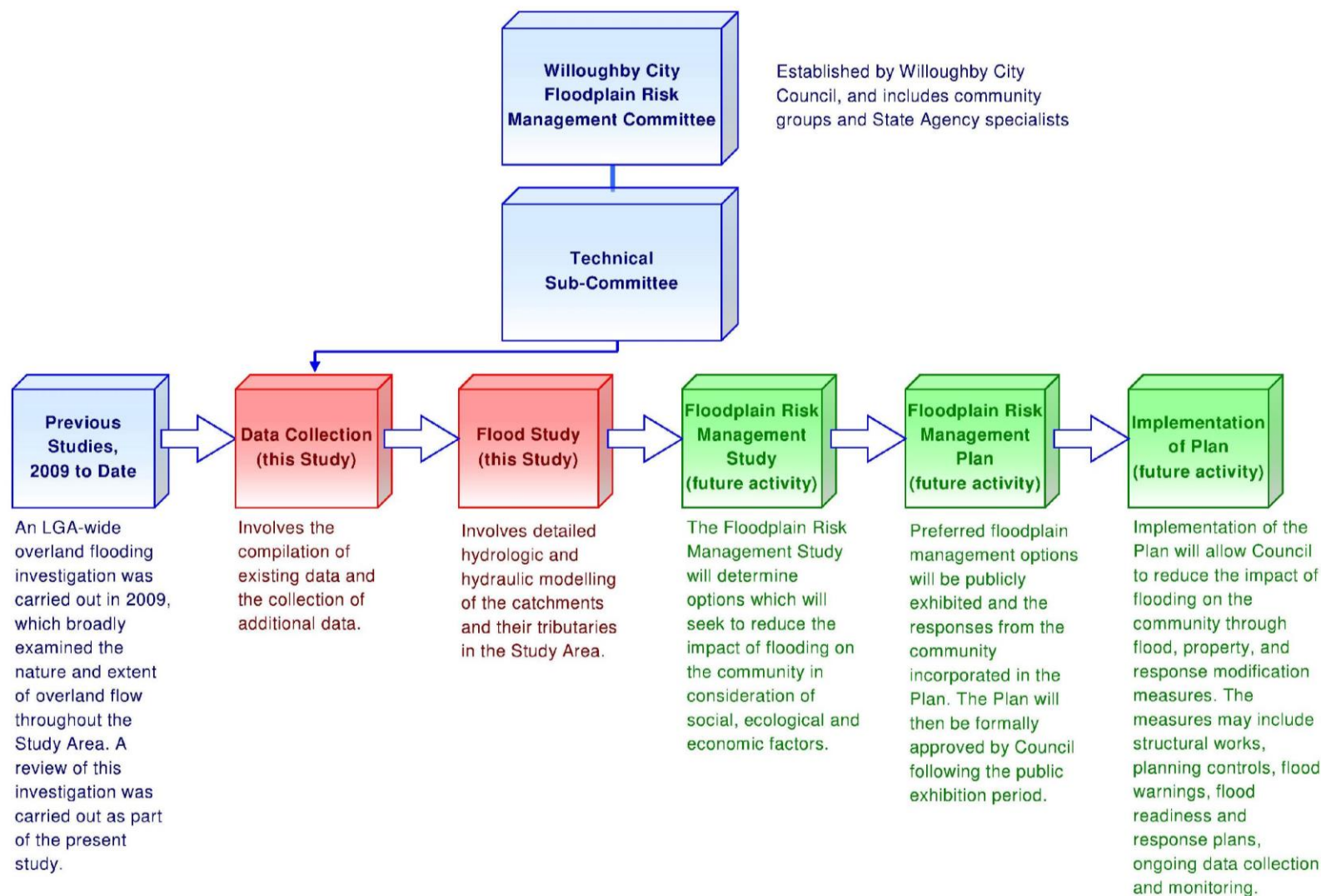
FLOODPLAIN RISK MANAGEMENT PROCESS

Willoughby City Floodplain Risk Management Committee — Established by Willoughby City Council, and includes community groups and State Agency specialists

Technical Sub-Committee

Previous Studies, 2009 to Date

An LGA-wide overland flooding investigation was carried out in 2009, which broadly examined the nature and extent of overland flow throughout the Study Area. A review of this investigation was carried out as part of the present study.

Data Collection (this Study)

Involves the compilation of existing data and the collection of additional data.

Flood Study (this Study)

Involves detailed hydrologic and hydraulic modelling of the catchments and their tributaries in the Study Area.

Floodplain Risk Management Study (future activity)

The Floodplain Risk Management Study will determine options which will seek to reduce the impact of flooding on the community in consideration of social, ecological and economic factors.

Floodplain Risk Management Plan (future activity)

Preferred floodplain management options will be publicly exhibited and the responses from the community incorporated in the Plan. The Plan will then be formally approved by Council following the public exhibition period.

Implementation of Plan (future activity)

Implementation of the Plan will allow Council to reduce the impact of flooding on the community through flood, property, and response modification measures. The measures may include structural works, planning controls, flood warnings, flood readiness and response plans, ongoing data collection and monitoring.

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NOTE ON FLOOD FREQUENCY

The frequency of floods is generally referred to in terms of their Annual Exceedance Probability (AEP) or Average Recurrence Interval (ARI). For example, for a flood magnitude having 5% AEP, there is a 5% probability that there will be floods of equal or greater magnitude each year. As another example, for a flood having a 5 year ARI, there will be floods of equal or greater magnitude once in 5 years on average. 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
10	10
20	5

In this report floods are referred to in terms of their ARI. Reference is also made in the 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.

ABBREVIATIONS

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
ALS	Airborne Laser Scanning
AMC	Antecedent Moisture Condition
ARI	Average Recurrence Interval (years)
ARR	Australian Rainfall and Runoff (The Institution of Engineers Australia, 1998)
BOM	Bureau of Meteorology
DTM	Digital Terrain Model
FDM	Floodplain Development Manual (NSW Government, 2005)
FPA	Flood Planning Area
FPL	Flood Planning Level
FRMS	Floodplain Risk Management Study
HHWSS	Highest High Water Solstice Spring (tidal event)
IFD	Intensity-Frequency-Duration
LGA	Local Government Area
OEH	Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water [DECCW])
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RL	Reduced Level
WCC	Willoughby City Council

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

S1 SUMMARY

The study objective was to define flood behaviour on Sailors Bay Creek in terms of water levels, flows and velocities for design floods ranging between 5 and 100 year average recurrence interval (ARI), as well as for the Probable Maximum Flood (PMF). **Figure 1.1** shows the Sailors Bay Creek catchment and its stormwater system. The flood study investigation involved the following activities:

➢ The collection of flood related data. A Community Newsletter/Questionnaire introducing the study objectives and seeking information on historic flood behaviour was forwarded to residents in the floodplain. Respondents reported flooding problems during a number of storm events in recent years, between 2008 and June 2012. Rainfall data recorded at the pluviometer at Northbridge Bowling Club, Warners Park in Northbridge were collected for those events and used to test the flood model developed for the study by way of comparison to reported flooding patterns. Previous flood studies of the adjacent Sugarloaf Creek catchment (LMCE, 1988 and L&A, 2010) also provided information on historic flooding in the area and identified a number of significant storms which had resulted in flooding problems in that catchment. Rainfall data from two storms (5 August 1986 and 10 April 1998) recorded at the pluviometer at Chatswood Bowling Club were also used to test the flood models developed for the study. (The installation of the Northbridge pluviometer post-dated the occurrence of the two storms.)

➢ The hydrologic modelling of the catchment of Sailors Bay Creek to determine discharge hydrographs.

➢ Application of the discharge hydrographs to a hydraulic model of the main arm of the creek and its overland flow paths. The model extended from the headwaters of the catchment (to the west of Alpha Road) as far as its outfall to Sailors Bay.

➢ Presentation of study results as water surface profiles, as well as diagrams showing indicative extents of inundation, provisional flood hazard and the hydraulic categorisation of the floodplain into floodway and flood fringe areas.

➢ Sensitivity studies to assess the effects on model results resulting from uncertainties in model parameters such as hydraulic roughness of the floodplain, the effects of partial blockage of the piped drainage system, elevated tailwater levels in Middle Harbour, and the effects on flooding patterns resulting from future climate change.

The hydrologic modelling approach was based on the DRAINS rainfall-runoff software. DRAINS derived discharge hydrographs resulting from historic storms for each model sub-catchment area, which were then applied to the hydraulic model.

The TUFLOW two-dimensional modelling system was adopted for the hydraulic analysis to route flows through the piped drainage system and over the land surface and determine peak flood levels and flow velocities, as well as indicative extents and depths of inundation.

After testing the models for the historic floods, design storm rainfalls ranging between 5 and 100 year ARI were derived using procedures set out in *Australian Rainfall and Runoff* (IEAust, 1998) (ARR) and applied to the DRAINS model to determine discharge hydrographs. The PMF was also modelled. Flooding patterns derived by TUFLOW for the design flood events are described in **Chapter 6** of the report, with exhibits presented in **Volume 2**.

Design water surface profiles along the main arm of Sailors Bay Creek are shown on **Figure 6.1**. Discharge and stage hydrographs derived by TUFLOW at key locations are shown on **Figures 6.2a** and **6.2b**, respectively. **Figures 6.3** to **6.8** show the indicative extents of inundation.

Diagrams showing the *provisional flood hazard* and the *hydraulic categorisation* of the floodplain for the 100 year ARI flood and the PMF are shown on **Figures 6.9** to **6.12**.

Several runs of the TUFLOW hydraulic model were carried out to test the sensitivity of flood behaviour to changes in hydraulic roughness of the main stream and floodplain, as well as partial blockage of the piped stormwater system. The impact on flood behaviour of increases in rainfall intensity and sea levels due to future climate change was also assessed. The results of these sensitivity analyses are shown on **Figures 6.13** to **6.18**. The analyses showed that increases in peak 100 year ARI flood levels would lie within the 500 mm freeboard allowance which is usually applied to 100 year ARI peak flood levels for setting minimum floor levels for future development.

The *Interim Flood Planning Area (FPA)* and *Interim Flood Planning Levels (FPL's)* for main stream flooding along the main arm of Sailors Bay Creek are shown on **Figure 6.19**. The FPA represents the area which will be subject to flood related development controls and comprises the area lying within the extent of the 100 year ARI flood plus an allowance of 500 mm for freeboard.

Council placed the Draft Flood Study Report of November 2012 on public exhibition over the period 20 November 2013 to 14 February 2014. Ten written submissions were subsequently received (refer **Section 2.3** for a summary of the main issues that were raised). This report of March 2014 incorporates several minor amendments to the November 2012 document and is the Final Report for the project.

The models developed for this flood study could be used in the future *Floodplain Risk Management Study (FRMS)* for the catchment which would enable Council to comprehensively manage the flood risk. In addition to finalising the Interim FPA and FPL's, and setting appropriate controls over future development in flood prone areas, the FRMS would 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.

1   INTRODUCTION

1.1   Study Background

This report presents the results of an investigation of flooding in the Sailors Bay Creek catchment and has been jointly sponsored by Willoughby City Council (WCC) and the NSW Government, via the Office of Environment and Heritage (OEH). **Figure 1.1** shows the location of the catchment, which drains residential and commercial areas in the suburbs of Willoughby, Northbridge and Castlecrag before discharging to Sailors Bay in Middle Harbour.

The study objective was to define flood behaviour in terms of flows, water levels and flooding patterns for floods ranging between 5 and 100 year ARI, as well as for the PMF.   The investigation involved rainfall-runoff hydrologic modelling of the catchment and drainage system to assess flows in the Sailors Bay Creek drainage system, and application of these flows to a hydraulic model of the main arm of Sailors Bay Creek and its overland flow paths to assess peak water levels and flow patterns. The model results were interpreted to present a detailed picture of flooding under present day conditions.

The scope of the study included investigation of both main stream flood behaviour along the main arm of Sailors Bay Creek as well as overland flooding throughout the study area which occurs either as a result of surcharges of the piped drainage system or upstream of the commencement of the formal drainage system. Flooding in the lower reaches of the study area as a result of storm-driven elevated harbour water levels was also investigated.

The study forms the first step in the floodplain risk management process for the Sailors Bay Creek catchment (refer process diagram presented in the Foreword), and is a precursor of the future FRMS sponsored by WCC which will consider the impacts of flooding on existing and future urban development, as well as potential flood mitigation and management measures.

Note that the results of the present study supersede those presented in the *Overland Flooding Investigation* undertaken for the whole of the Willoughby City Local Government Area (LGA) (L&A, 2009). The work undertaken in that study is summarised in **Chapter 2**.

1.2   Approach to Flood Modelling

1.2.1. Hydrologic and Hydraulic Modelling

Flood behaviour was defined using a two-staged approach to flood modelling involving the running in series of: the hydrologic model of the catchment based on the DRAINS rainfall-runoff software and the hydraulic model of the drainage system based on the TUFLOW software. DRAINS computed discharge hydrographs generated by each model sub-catchment, which were then applied to the TUFLOW hydraulic model at the sub-catchment outlets. TUFLOW used a two-dimensional, grid-based representation of natural surface levels based on an Airborne Laser Scanning (ALS) survey of the catchment as well as piped drainage data supplied by WCC. Field surveys undertaken by WCC and developers provided additional data on ground surface levels and piped drainage details.

TUFLOW routed the discharge hydrographs determined by DRAINS through the drainage system to the catchment outlet. It modelled the main arm of Sailors Bay Creek and its floodplain, as well as the overland flow paths of its tributary streams.

1.2.2. Model Testing

There are no stream flow data available on the Sailors Bay Creek catchment. Consequently it was not possible to "calibrate" either of the models to reproduce recorded discharges. Very little quantitative information on flood levels, limited to a single flood mark at the peak of the August 1986 event, was identified as a result of the distribution of the Community Newsletter and Questionnaire. Therefore it was not possible to calibrate TUFLOW to reproduce historic main stream or overland flooding levels.

The approach adopted was to test the ability of the two models in combination to reproduce observed flood behaviour, using "best estimates" of model parameters and to reduce uncertainty in the results for the design floods by sensitivity analysis.

The DRAINS model was used to generate flows for a number of historic storms occurring between August 1986 and June 2012 which had either been identified by respondents to the Questionnaire or were known to have caused flooding problems in adjacent catchments. Historic rainfall data for each event was obtained from the closest available pluviometer. Flows from the DRAINS model were applied to the TUFLOW model to generate water surface levels and flow patterns for each historic event, which could then be compared to observed flood behaviour.

1.2.3. Design Flood Estimation

Design storms were derived from ARR and then applied to the DRAINS model to generate discharge hydrographs within the study area. These hydrographs constituted sub-catchment inflows to the TUFLOW hydraulic model.

The TUFLOW model was configured to allow assessment of flood behaviour in the study area that is influenced by harbour water levels ranging from normal tidal conditions to elevated storm-driven water levels.

A flood envelope approach was adopted for defining design water surface elevations and flow velocities throughout the study area. The procedure involved running the model for a range of scenarios, for both catchment-driven flooding and inundation of the lower reaches of the study area as a result of elevated harbour water levels, to define the upper limit (envelope) of expected flooding for each design flood frequency.

1.3 Layout of Report

Chapter 2 contains background information including a brief description of the study catchment and its drainage system, details of previous flooding investigations in the catchment, details of community consultation undertaken as part of this present study, and a brief history of past flooding within the catchment.

Chapter 3 deals with the hydrology of the Sailors Bay Creek catchment, and describes the development of a DRAINS hydrologic model which was used to generate discharge hydrographs for input to the hydraulic model.

Chapter 4 deals with the development of the TUFLOW hydraulic model which was used to analyse flood behaviour in the study area.

Chapter 5 deals with the derivation of design runoff hydrographs, including determination of design storm rainfall depths over the catchments for a range of storm durations and conversion of the rainfall hyetographs to discharge hydrographs using the DRAINS model.

Chapter 6 details the results of the hydraulic modelling of the design floods using the TUFLOW hydraulic model. Results are presented as water surface profiles and plans showing indicative extents of inundation for a range of design flood events up to and including the PMF. A provisional assessment of flood hazard and hydraulic categorisation is also presented. (The assessment of flood hazard according to hydraulic criteria such as velocity and depth of floodwaters is necessarily *"provisional"*, pending a more detailed assessment of other flood related criteria which would be undertaken during the future FRMS for the catchment.) The results of various sensitivity studies undertaken using the TUFLOW model, including the effects of changes in hydraulic roughness, partial blockage of the piped stormwater system, and potential increases in rainfall intensities and sea levels due to future climate change, are also presented. This chapter also deals with the selection of interim flood planning levels.

Chapter 7 contains a list of references.

Chapter 8 contains a list of flood-related terminology that is relevant to the scope of the study.

Appendix A summarises responses to the Community Newsletter and describes the testing of the hydrologic and hydraulic models.

Figures referred to in both the main report and the appendices are bound in a separate volume of the report (refer **Volume 2**).

2   BACKGROUND

2.1   Catchment Description

The valley drained by Sailors Bay Creek has a total catchment area of about 1.9 km^2 and extends eastwards through the suburbs of Willoughby, Northbridge and Castlecrag, before discharging to Sailors Bay in Middle Harbour (refer **Figure 2.1**). The catchment has its headwaters to the west of Alpha Road in Willoughby and is bounded on its northern and southern sides by Edinburgh Road and Sailors Bay Road, respectively.

2.1.1.   Main Arm and Tributaries

From the catchment headwaters near Chiltern Road through to Alpha Road, stormwater is conveyed by street gutters and a piped drainage system. In the event of major floods, stormwater would flow through the residential allotments in this area.

Approximately 80 m to the east of Alpha Road, and immediately to the south of Foundation Place, the piped drainage system discharges to a short section of open channel that has been rock-lined as part of recent development of the Willoughby Market Gardens site. East of Foundation Place, the channel continues as a natural creek through to Eastern Valley Way over a distance of approximately 290 m. The creek is piped under Eastern Valley Way via an oval culvert measuring approximately 1.5 m wide by 0.75 m high.

Sailors Bay Creek falls steeply immediately downstream (east) of Eastern Valley Way and continuing through to Warners Park. Twin 1050 mm diameter pipes convey the main arm of the creek beneath the park and Northbridge Bowling Club. These pipes transition to a 1.3 m wide by 1.8 m high box culvert that crosses under The Outpost.

Downstream (east) of The Outpost, the main arm continues as a natural creek for approximately 500 m through to Sailors Bay.

The tributaries of Sailors Bay Creek comprise a number of piped systems that drain the urbanised areas on both northern and southern sides of the creek. Overland flows generally follow the direction of piped drainage systems in these areas, and typically result in flows through residential allotments. The principal tributaries / overland flow paths that drain to Sailors Bay Creek comprise the following:

Draining to the south

- ➢ Along Mowbray Road and Windsor Road.
- ➢ From Warners Avenue across Eastern Valley Way and Morotai Crescent.
- ➢ From The Parapet across The Rampart to join the main arm opposite The Outpost.

Draining to the north

- ➢ From Sailors Bay Road between Eastern Valley Way and Harden Avenue.
- ➢ From Sailors Bay Road between Euroka Street and Bligh Street, across Kameruka Road and Noonbinna Crescent.

2.1.2. Drainage Lines Discharging to Sailors Bay and Middle Harbour

To the east of the main arm of Sailors Bay Creek, the study area comprises relatively steep-sloping areas of Castlecrag and Northbridge that drain directly into either Sailors Bay or Middle Harbour. These areas are predominantly residential in nature interspersed with pockets of bushland. Bushland also dominates on a number of the steeper slopes leading down to the harbour.

The major drainage line on the northern side of the catchment is an un-named watercourse located downstream (east) of The Battlement. The two tributary arms of this watercourse are piped under The Bulwark before they join and continue to the east to discharge into Sailors Bay.

The remaining drainage lines in this part of the catchment are similar in nature to the minor tributaries of Sailors Bay Creek, comprising piped systems and associated overland flow paths that typically pass through or adjacent to existing residential development. These include the following:

North of Sailors Bay

 ➢ From Edinburgh Road (west of Knight Place) south across The Bulwark and The Scarp.

 ➢ From The High Tor east across The Tor Walk.

South of Sailors Bay

 ➢ From Malacoota Road (between Tunks Street and Woonona Road) north across Narooma Road, Kameruka Road and Noonbinna Crescent.

 ➢ From Narani Crescent north across Narooma Road, Kameruka Road, Courallie Road and Coorabin Road.

 ➢ From Neewora Road north across Minnamurra Road and Minibah Road.

 ➢ From Neewora Road east across Dalmeny Road, Sailors Bay Road and Coolawin Road.

2.1.3. Outlet to Sailors Bay

Sailors Bay Creek flows into Sailors Bay, an inlet of Middle Harbour, across a wide tidal flat that is exposed at low tide. Water levels in the bay are controlled by normal or storm tidal hydrographs, which therefore represent the downstream boundary condition of the hydraulic model.

2.2 Previous Investigations

In 2009, WCC commissioned a city-wide "screening" study to broadly define flooding patterns and identify properties potentially at risk of flooding from a 100 year ARI flood in the various catchments which drain the Willoughby City LGA, including the Sailors Bay Creek catchment (L&A, 2009).

That study used two-dimensional hydraulic modelling of the channel and floodplain, based on the TUFLOW software. Flows generated by a rainfall-runoff model of the catchment based on the DRAINS software were applied to a TUFLOW hydraulic model which routed the floodwave through the drainage system and assessed flooding patterns and indicative extents of inundation.

The results of the overland flooding investigation provided WCC with initial information on flooding throughout the LGA pending the completion of a formal flood study undertaken according to the procedure set out in the NSW Government's *Floodplain Development Manual, 2005* (FDM); that is, this present study.

In the L&A, 2009 study, properties in flood prone areas of the various catchments were assessed as being subject to *"Main Stream Flooding"* or *"Local Overland Flooding"* depending on the dominant flood producing mechanism. In broad terms, *Main Stream Flooding* occurs when the trunk drainage systems surcharge and flows extend on to the surrounding floodplain, forming continuous flow paths for the conveyance of floodwaters. *Local Overland Flooding* results from runoff which travels as shallow sheet flow over grassed and paved surfaces in individual allotments or along roads en route to the trunk drainage system (i.e. in areas upstream of the formal drainage system), or which surcharges the minor piped drainage systems in the catchment headwaters and the lateral sub-catchments bordering the trunk drainage system.

Local Overland Flooding was further differentiated into *"Local Drainage"* and *"Major Drainage"* classifications, based on the severity of flooding involved. Areas subject to *Local Drainage* problems typically involved depths of overland flow up to 300 mm, while for *Major Drainage* overland flow depths typically exceeded that value.

These flood classifications are currently being used by WCC to apply flood-related development controls in flood prone areas of the LGA. *(Note that further discussion relating to flood producing mechanisms and characteristic flood behaviour used for property classification purposes is provided in L&A, 2009.)*

The results of the present study supersede flooding patterns of L&A (2009) and may be used to review the classifications of flood affected property undertaken as part of the earlier investigation.

2.3   Community Consultation

To assist with data collection and promotion of the study to the Sailors Bay Creek catchment community, the Consultants prepared a Community Newsletter and Questionnaire which was distributed by WCC in May 2012 inviting residents to provide information on historic flooding.

WCC advised that approximately 2,400 Newsletter/Questionnaires were distributed, with a total of 480 responses received (a response rate of around 20 per cent). Of those that responded, 73 noted that they had observed flooding in or adjacent to their property. **Appendix A** provides further details of the flood-related responses to the Newsletter/Questionnaire.

Reliable flood-related information obtained from Newsletter/Questionnaire responses and follow-up resident interviews were subsequently used to assist in ground-truthing the results of hydraulic modelling. A single historic flood mark was also identified during the consultation process and this was also used to assist in validating the hydraulic model results. Further details are provided in **Appendix A**.

The Draft Flood Study Report of November 2012 was placed on public exhibition over the period 20 November 2013 to 14 February 2014. A community information session was also held at Council Chambers on the evening of Wednesday 27 November 2013, which involved presentation of the study methodology and findings after which representatives of WCC and L&A were available to field questions from the floor. Site inspections were also undertaken at several properties at the request of residents that expressed concern that the flood mapping presented in the Draft Flood Study Report did not correspond with observed local flooding patterns.

Ten written submissions were received by WCC, with the main issues raised noted below (with responses provided in *italics*):

➤ Several respondents were concerned that the exhibited extents and depths of inundation within specific properties were either not consistent with observed patterns of overland flow, were overstated (e.g. in the footprint of individual houses), or did not appear to account for the presence of local drainage or topographic features that may influence localised flow patterns.

The structure of the hydraulic model that has been developed is considered to adequately represent the key features that control overland flow behaviour for the purposes of a catchment-wide investigation, noting that it is not practical to incorporate internal property drainage systems and other local topographic features (e.g. raised gardens beds, retaining walls, boundary fences, etc.) within the scope of the present investigation.

The definition of overland flow patterns at an individual allotment level would require detailed property survey which is outside the scope of the present investigation.

*In several areas it was considered that the approach adopted to represent buildings in the hydraulic model produced artificially high depths of inundation. To reduce the risk of the study findings being misinterpreted, the hydraulic model results were trimmed such that building footprints are shown free of inundation (refer **Section 6.1.1** for further discussion of this issue).*

➤ Several respondents questioned the current flooding classifications applied to their property by WCC, and queried how the current classifications would be impacted by the present investigation.

Current classifications will be reviewed by WCC once the present investigation is finalised and adopted for use.

In addition to the above-mentioned trimming of the hydraulic model results, this report of March 2014 incorporates several minor amendments to the Draft Flood Study Report, and is the Final Report for the project.

2.4 Historic Flooding in the Study Area

The existing piped drainage system within the Sailors Bay Creek catchment is of limited capacity and, based on anecdotal reports, has been surcharged to varying degrees during several storms experienced over the past 25 years. There are, however, very little historic flood data or reported observations of specific flood behaviour over this time to assist in understanding historic flooding in the study area.

Based on experiences in the adjacent Sugarloaf Creek catchment, the most recent severe storm to have affected the Willoughby area occurred on 10 April 1998. This event exceeded 100 year ARI for storm durations ranging between 30 minutes and 1 hour in terms of rainfall intensities recorded at the pluviometer at Chatswood Bowling Club. This gauge is located outside the Sailors Bay Creek catchment, about 1.5 km north-west of the catchment centroid (refer **Figure A2.2** in **Appendix A** for gauge location), however, no rainfall intensity data were available within the catchment for the April 1998 event. Comparison with daily rainfall data at several adjacent rain gauges (refer **Appendix A**) indicates that the Chatswood pluviographic record was representative of rainfalls experienced over much of the Willoughby LGA.

Other instances of intense rainfall in the Willoughby LGA occurred in the late 1980's and are reported in previous flood studies for Sugarloaf Creek. These include storms in August 1986 and April 1988, previously assessed at around 20 year ARI and 2 year ARI, respectively (LMCE, 1988).

The experiences of respondents to the Newsletter/Questionnaire relate primarily to instances of shallow flash flooding resulting from surcharging of internal property drainage systems and some elements of WCC's lateral piped drainage system, resulting in flows along streets and down private driveways and leading to inundation of garages and yard areas. There were no reported instances of property affectation as a result of main stream flooding along the main arm of the creek.

Respondent experiences also relate primarily to a series of relatively minor storm events with a recurrence interval up to around 1 to 2 years that have occurred since October 2009. Only a few of the longer-term residents identified the larger storm events that affected much of the LGA in 1986, 1988 and 1998. The time that has elapsed since the occurrence of these larger storms is likely to be a contributing factor to the lack of feedback.

Analysis of rainfalls for these more recent events was undertaken using data recorded at the pluviometer in Warners Park, Northbridge (refer **Figure A2.2** in **Appendix A** for gauge location). *[Note that the pluviometer was installed at this site in 2001, with earlier data available only as daily rainfall totals.]*

As far as could be ascertained during the data collection and community consultation phases of the study, the trunk drainage system of the Sailors Bay Creek catchment functioned at its potential capacity, with no known instances of blockage. The trunk drainage system is less susceptible to blockage than systems in less urbanised catchments, due to the presence of grates at the inlet pits in the street system and the absence of open channels, apart from the main arm of the creek.

3   HYDROLOGIC MODEL DEVELOPMENT AND TESTING

3.1   Selection of Hydrologic Model

The present investigation required the use of a hydrologic model which is capable of representing the rainfall-runoff processes that occur within the Sailors Bay Creek catchment. The DRAINS software has been developed primarily for use in modelling the passage of a flood wave through urban catchments, and is therefore well suited to the present investigation.

The main hydrologic model in DRAINS is based on the ILSAX model, which uses time-area calculations, surface depression losses and soil infiltration procedures to calculate sub-area rainfall excess.   The rainfall excess is then converted into discharge hydrographs that are assumed to enter the drainage system, subject to constraints imposed by the entrance and conveyance capacity of the system.

Having entered the drainage system, sub-area flows are then added to any existing flow in the system and the combined flow is routed through the system to the outlet. While DRAINS is 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, this capability was not utilised as part of this present investigation. The TUFLOW hydraulic modelling software was used for this purpose (refer **Chapter 4**).

3.2   Hydrologic Model Layout

Figure 2.1 shows the layout of the various sub-catchments which comprise the hydrologic model for the study area.

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

Careful consideration was given to the definition of the sub-catchments which comprise the hydrologic model to ensure peak flows throughout the drainage system would be properly assessed in the TUFLOW model. 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.

Percentages of impervious area were assessed using the aerial photography and cadastral boundary data. 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.

3.3   Hydrologic Model Parameters

DRAINS requires information on the soil type, losses to be applied to storm rainfall to determine the depth of runoff, as well as information on the piped drainage system and the time of travel of the flood wave through the catchment. 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.

As mentioned, there are no stream flow data available on Sailors Bay Creek and therefore it was not possible to "calibrate" the model to historic flood flows. The qualitative approach adopted was to use best estimates of model parameters to simulate flows and levels from historic floods and to compare the models' (i.e. DRAINS and TUFLOW) responses with observed flood behaviour. The results are presented in detail in **Appendix A** and summarised in the following sections.

The best estimate of DRAINS model parameters are as follows:

Rainfall Losses

> ➤ Soil Type [1]   = 3.0
> ➤ Antecedent Moisture Condition (AMC) [2]   = 3.0
> ➤ Paved area depression storage   = 2.0 mm
> ➤ Grassed area depression storage   = 10.0 mm

Travel Times

The following flow path roughness values were adopted for routing of runoff within model sub-catchments:

> ➤ Paved flow path roughness   = 0.02
> ➤ Grassed flow path roughness   = 0.07

Information contained in ARR suggests that for detached residential dwellings, which are typical of most developed areas within the Sailors Bay Creek catchment, 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 Hydrologic Model Testing Procedure

The hydrologic and hydraulic models were tested for the storm of 5 August 1986, for which a flood mark was identified along the main arm of Sailors Bay Creek in the lower part of the catchment adjacent to Noonbinna Crescent, Northbridge. The models were also tested against observed flooding patterns for the large storm which occurred on 10 April 1998, as well as for a number of smaller storms occurring more recently between 2008 and June 2012.

Rainfalls for the two storms recorded at the pluviometers at Chatswood Bowling Club (prior to 2001) and Warners Park (2001 onwards) were applied to the DRAINS model using the "best estimate" parameters set out in the previous section to estimate flows. The resulting flows were applied to the TUFLOW model and the computed flooding patterns compared with reported flood behaviour.

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[1] Soil Type is an assessment of a soil's rate of infiltration. A Soil Type of 3.0 represents a slow infiltration rate with moderate runoff potential.

[2] AMC is an assessment of a catchment's wetness at the start of a storm event. An AMC of 3.0 represents rather wet catchment conditions prior to occurrence of runoff-producing rainfall.

The discharge hydrographs generated by DRAINS, when used as input to the TUFLOW hydraulic model, gave reasonable correspondence with observed flood behaviour. The DRAINS model parameters set out in **Section 3.3** were therefore adopted for the design flood estimation described in **Chapter 5**. Further discussion on the results of model testing is contained in **Section 4.5** and **Appendix A**.

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 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   The 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 floodplain dimensions and hydraulic roughness, 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 model developed for the Sailors Bay Creek catchment allows for the 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. All of these measures will need to be considered in the future FRMS of the catchment.

4.3   TUFLOW Model Setup

4.3.1.   Model Structure

The layout of the Sailors Bay Creek TUFLOW model is shown on **Figure 4.1**. The model comprises the piped system, sections of open channel which are modelled by cross sections normal to the direction of flow, as well as overland flow which is modelled by the rectangular grid.

All of the piped elements contained in WCC's asset database and which influence the passage of flow were included in the TUFLOW model (approximately 630 pipes and 40 box culverts), with the smallest conduit size measuring 100 mm.

A small number of enclosed oviform sections within the piped system were modelled as circular conduits with an equivalent diameter determined from drawings or other relevant information provided by WCC. 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.

Several types of pits are identified on **Figure 4.1**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. WCC's asset database contained only limited information in regard to inlet pit types and dimensions. For this reason inlet capacity relationships were not incorporated into the TUFLOW model. The modelled hydraulic capacity of the pipes therefore controlled the assessed capacity of the piped drainage system.

A total of 47 cross sections derived from both field survey and ALS survey data were used to define the in-bank waterway area of major creeklines which drain parts of the catchment. These comprise open channel reaches along the main arm of Sailors Bay Creek and the un-named tributary downstream (east) of The Bulwark. The location of open channel reaches and cross sections are shown on **Figure 4.1**.

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 the purpose of this present investigation. Grid elevations were based on ALS survey of the catchment. Ridge and gully lines were added to the model where the grid spacing was considered too coarse to accurately represent important topographic features which influence the passage of overland flow.

The footprints of a large number of individual buildings located in the two-dimensional model domain were digitised and 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 model. It was not practicable to model the individual fences surrounding the many allotments in the study area. 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.

Details of a number of ground surveys undertaken within the catchment in recent years were provided by WCC in the form of digital terrain models (DTM's). Limited pipe and culvert details were also available in some locations. **Figure 4.2** shows the location and extent of available survey data, which was incorporated in the TUFLOW model representing present day conditions.

Details of the Willoughby Market Garden site located between Alpha Road and Eastern Valley Way where residential development is currently underway were provided by YSCO Geomatics on behalf of the developer. These data, in the form of a DTM representing finished internal road levels and building pad levels (refer **Figure 4.2** for extent), were also incorporated into the TUFLOW model. TUFLOW piped drainage elements within the Market Gardens site were also adjusted to reflect proposed modifications and major additions to WCC's existing piped drainage system.

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 creek channel. 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 "Mannings n". Flow in the piped system also requires an estimate of hydraulic roughness.

There are very limited historic flood level data available to assist with the tuning of the model for roughness. Assessment of Mannings n values for the open sections of creek was relatively straightforward, as cross sections taken normal to the direction of flow have traditionally been used when modelling one-dimensional waterways. Creek roughness was 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 was generally shallow and of low velocity, was more difficult. Initial experiments showed that peak flows were quite sensitive to the adopted value of Mannings n. Increasing n resulted in the retarding and storage of water on the upper reaches of the floodplain, with a reduction in downstream flood peaks.

Adoption of high values of n had the potential to over-attenuate the downstream flow, resulting in flood levels that were on the low side. These effects emphasised the need for undertaking sensitivity studies prior to final selection of values for design (see **Section 6.3**) and also confirmed the appropriateness of the two-stage (hydrologic-hydraulic) modelling approach adopted for this study.

Table 4.1 over presents the "best estimate" of hydraulic roughness values adopted for model testing. These values gave reasonable correspondence with observed flood 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 recognised that they completely blocked the flow but were capable of storing water when flooded.

TABLE 4.1
"BEST ESTIMATE" OF HYDRAULIC ROUGHNESS VALUES
ADOPTED FOR TUFLOW MODEL TESTING

Surface Treatment	Mannings n Value
Asphalt or concrete road surface	0.02
Well-maintained grass cover (e.g. sports field)	0.03
Grass or Lawns	0.045
Trees / Shrubs	0.08
Creek channel	0.05 – 0.08
Creek bank	0.1
Allotments (between buildings)	0.1
Buildings	10

Figure 4.3 is a typical example of flow patterns derived from those values. This example applies for the 100 year ARI design flood and shows overland flows on the main arm between Marlborough Road and Alpha Road.

The left hand side of the figure shows the roads and inter-allotment areas, as well as the outlines of buildings, which have all been individually digitised in the model. The right hand side shows the resulting flow paths in the form of scaled velocity vectors and the depths of inundation. The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwaters when inundated and therefore correctly accounts for flood storage. The flow is conveyed via the road reserves and through the open parts of the allotments. Similar information to that shown on **Figure 4.3** may be presented at any location within the model domain (which is shown on **Figure 4.1**) and will be of assistance to WCC in assessing individual flooding problems in the floodplain.

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 inlet pits, and distributed inflows via "Rain Boundaries".

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 matches the sub-catchment area defined in the hydrologic model.

4.4.2. Downstream Boundary Conditions

The primary downstream boundary of the TUFLOW model comprised a tailwater representing the tidal conditions in Sailors Bay. Due to the relatively short duration of catchment-driven storm events affecting the study area, harbour water levels were applied to the TUFLOW model as a static tailwater.

 A second downstream boundary comprised a stage-discharge relationship that was used to model overland flows leaving the study area through Northbridge Golf Course, immediately south of Sailors Bay Road.

Tidal Harbour Water Levels

For the purpose of this present investigation, a static harbour water level of RL 1.0 m AHD was adopted for simulation of local catchment flood events in the absence of any storm-driven tailwater influence. This downstream boundary condition was also adopted for simulation of historic flood events. A water level of RL 1.0 m AHD approximately corresponds to the peak water level reached on average once or twice per year during a Highest High Water Solstice Spring (HHWSS) tide.

Storm-Driven Harbour Water Levels

OEH's *"Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments"* (DECCW, 2010) contains an appendix that deals with modelling the interaction of catchment and coastal flooding for different classes of tidal waterway. The appendix may be used to derive scenarios for coincident flooding from those two sources for both present day conditions and conditions associated with future climate change[3].

For a catchment draining directly to the ocean via trained or otherwise stable entrances, such as is the case for Sailors Bay Creek, DECCW, 2010 offers the following alternative approaches for selecting storm tidal conditions under present day conditions. In order of increasing sophistication they are:

➢ A default tidal hydrograph which has a peak of RL 2.6 m AHD for the 100 year ARI event; or 2.3 m AHD for the 20 year ARI event. This default option is acknowledged (in DECCW, 2010) as providing a conservatively high estimate of tides for these types of entrances.

➢ A site-specific analysis of elevated water levels at the downstream boundary location. The analysis should include contributions to the water levels such as tides, storm surge, wind and wave set up. The analysis should also examine the duration of high tidal levels, as well as their potential coincidence with catchment flooding. This approach requires a more detailed consideration of historic tides and the entrance characteristics, but provides information which is more directly relevant to a particular catchment.

The latter approach has been adopted for the purpose of this present investigation. Design still [4] water levels applicable to the lower reaches of Sydney Harbour were obtained from Watson & Lord (2008), and are shown in **Table 4.2** over.

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[3] Note that further discussion of the potential impact that future climate change induced sea level rise may have on storm-driven harbour water levels, and the resultant effects on flood behaviour within the study area, is provided in **Section 6.4**.

[4] Still water levels include astronomical tide and storm surge components, but exclude influences from local storm effects such as wind setup and local wave conditions.

An allowance of 0.3 m to account for local storm effects such as wind setup and wave conditions was added to the design still water levels to yield the design peak 'storm tide' levels (also shown in **Table 4.2**) that were adopted for assessment of harbour-driven flooding in the study area.

TABLE 4.2
DESIGN HARBOUR WATER LEVELS

Event	Design Still Water Level [1] (m AHD)	Design Peak Storm Tide Level (m AHD)
5 year ARI	1.32	1.62
10 year ARI	1.35	1.65
20 year ARI	1.38	1.68
50 year ARI	1.42	1.72
100 year ARI	1.44	1.74

(1)   Source: Watson & Lord (2008)

A flood envelope approach was adopted for defining design water surface elevations and flow velocities throughout the study area. The procedure involved running the model for a range of scenarios, for both catchment-driven flooding and inundation of the lower reaches of the study area as a result of elevated harbour water levels, to define the upper limit of expected flooding for each design flood frequency.

Derivation of design flood envelopes to define the upper limit of expected flooding for each flood frequency (i.e. as a result of both flood-producing rainfall falling on the catchment, and storm-driven harbour water levels) is presented in **Section 4.6**.

4.5   Hydraulic Model Testing

As previously mentioned, the hydrologic and hydraulic models were tested for the storm of 5 August 1986, for which a flood mark was identified along the main arm of Sailors Bay Creek in the lower part of the catchment adjacent to Noonbinna Crescent.

The hydrologic and hydraulic models were also tested against observed flooding patterns for the significant storm which occurred in April 1998, as well as a number of smaller storms which occurred more recently between October 2009 and June 2012.

Apart from piped drainage and channel upgrade works undertaken as part of the Willoughby Market Gardens development within the last 5 years, there have been no significant drainage works undertaken along the main arm of Sailors Bay Creek in recent years. As a result, it was not necessary to adjust to the structure of the TUFLOW model (i.e. from that developed to represent present day conditions) in order to simulate flood behaviour in the lower catchment for these historic storms.

Based on the findings of the model testing process the hydrologic and hydraulic models were considered to give satisfactory correspondence with available observed flood behaviour. In particular, the TUFLOW model was found to provide a reasonable match to the observed extent of flooding at the location of the identified flood mark. Further details and results of the model testing process are provided in **Appendix A**, including TUFLOW model results for the storms of 5 August 1986 and 10 April 1998.

As such, the hydrologic model parameters set out in **Section 3.3** and the hydraulic roughness values set out in **Table 4.1** are considered appropriate for use in defining flood behaviour in the study area over the full range of design flood events.

4.6   Derivation of Design Flood Envelopes

The process undertaken for deriving the design flood envelopes for the study area was as follows:

> ➢ **Step 1** – Run the hydraulic model for local catchment storms of various return periods and durations in combination with the HHWSS tide level. [Note that a static water level of RL 1.0 m AHD was adopted as the downstream boundary of the hydraulic model for these runs].

> ➢ **Step 2** – Combine the results of **Step 1** to create an envelope of maximum local catchment flood levels for each return period (i.e. the results of running storms of the same return period but different duration were combined to create a single envelope).

> ➢ **Step 3** – Run the hydraulic model for local catchment storms in combination with peak design storm tide levels of various return period. [Note that the static water levels shown in **Table 4.2** were adopted as the downstream boundary of the hydraulic model for these runs].

> ➢ **Step 4** – Prepare a final set of flood envelopes for each return period using a combination of the envelopes derived from **Step 2**, and a corresponding storm tide condition from **Step 3**. **Table 4.3** over sets out the combination of local catchment and storm tide conditions which were used to compile the design flood envelopes for the study area.

TABLE 4.3
DERIVATION OF DESIGN FLOOD LEVEL ENVELOPES

Design Flood Envelope	Local Catchment Flood	Harbour Boundary Condition
5 year ARI	5 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	5 year ARI [2]	5 year ARI peak storm tide level (i.e. RL 1.62 m AHD)
10 year ARI	10 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	5 year ARI [2]	10 year ARI peak storm tide level (i.e. RL 1.65 m AHD)
20 year ARI	20 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	5 year ARI [2]	20 year ARI peak storm tide level (i.e. RL 1.68 m AHD)
50 year ARI	50 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	10 year ARI [2]	50 year ARI peak storm tide level (i.e. RL 1.72 m AHD)
100 year ARI	100 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	20 year ARI [2]	100 year ARI peak storm tide level (i.e. RL 1.74 m AHD)
200 year ARI	200 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	20 year ARI [2]	100 year ARI peak storm tide level (i.e. RL 1.74 m AHD)
500 year ARI	500 year ARI [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	20 year ARI [2]	100 year ARI peak storm tide level (i.e. RL 1.74 m AHD)
PMF	PMF [1]	HHWSS peak tide level (i.e. RL 1.0 m AHD)
	20 year ARI [2]	100 year ARI peak storm tide level (i.e. RL 1.74 m AHD)

(1)   Indicates use of local catchment floods for durations ranging between 25 and 180 minutes (for 5 to 500 year ARI), or 15 to 60 minutes (for PMF).

(2)   Indicates use of local catchment flood for duration of 60 minutes only.

5   DERIVATION OF DESIGN FLOOD HYDROGRAPHS

5.1   Rainfall Intensity

The procedures used to obtain temporally and spatially accurate and consistent intensity-frequency-duration (IFD) design rainfall curves for the Sailors Bay Creek catchment are presented in Book II of ARR. Design storms for frequencies of 5, 10, 20, 50, 100, 200 and 500 year ARI were derived for storm durations ranging between 25 minutes and 3 hours. The procedure adopted was to generate IFD data for the catchment by using the relevant charts in Volume 2 of ARR. These charts included design rainfall isopleths, regional skewness and geographical factors.

5.1.1.   Areal Reduction Factors

The rainfalls derived using the processes outlined in ARR 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 is typically applied to obtain an intensity that is applicable over the entire area.

However, as the area of the Sailors Bay Creek catchment (at less than 3 km^2) is relatively small, the reduction in rainfall intensities would be quite small. Accordingly, the assumption of no reduction in point rainfalls was made for this study.

5.1.2.   Temporal Patterns

Temporal patterns for various zones in Australia are presented in ARR. 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 ARIs 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 ARR and separate patterns are presented in Volume 2 for ARI < 30 years and ARI > 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 ARR 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 Bureau of Meteorology's update of Bulletin 53 (BOM, 2003). This method is appropriate for estimating extreme rainfall depths for catchments up to 1,000 km^2 in area and storm durations up to 6 hours.

The steps involved in assessing PMP for the Sailors Bay Creek 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.

Peak PMF flow rates for individual sub-catchments computed by DRAINS for the critical 15 minute PMP storm duration are between 3.4 and 4.2 times the magnitude of peak 100 year ARI flow rates. These values lie at the lower end of the range of expected multiples for an urban catchment.

5.3   Derivation of Design Discharges

The DRAINS model was run with the parameters set out in **Section 3.3** to obtain design hydrographs for input to the TUFLOW hydraulic model. Discharge hydrographs extracted from the hydraulic model at key road crossings along the main arm of Sailors Bay Creek are presented in **Chapter 6**.

6   HYDRAULIC MODELLING OF DESIGN FLOODS

6.1   Presentation and Discussion of Results

6.1.1.   Water Surface Profiles and Extents of Inundation

Water surface profiles along the main arm of Sailors Bay Creek are shown on **Figure 6.1** for the 20 and 100 year ARI design floods and the PMF. The natural surface profile shown on this figure follows the lowest level above the piped drainage system and is derived from WCC's ALS data.

Figures 6.2a and **6.2b** show discharge and stage hydrographs, respectively, for the two major road crossings within the study area where Alpha Road and Eastern Valley Way cross the main arm of Sailors Bay Creek. Discharge and stage hydrographs are also shown for The Outpost crossing downstream (east) of Warners Park.

The results confirm the "flash flood" nature of the catchment, with flood levels generally peaking between 30 and 60 minutes after the commencement of rainfall. Depths of flooding over Alpha Road and Eastern Valley Way reach up to 300 mm and 850 mm, respectively, for the 100 year ARI event.

Nuisance flooding of around 30 minutes duration would occur at the 5 year ARI for Eastern Valley Way. Alpha Road has a higher hydrologic standard and would remain trafficable up to around 20 year ARI level of flooding.

Figures 6.3 to **6.8** show the TUFLOW model results for the 5, 10, 20, 50 and 100 year ARI floods and the PMF. These diagrams show the indicative extents of inundation along the main arm of the creek, as well as the overland flow paths and depths of inundation.

In order to create realistic results which remove most anomalies caused by inaccuracies in the ALS (which has a design accuracy such that 68 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 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.

The relatively high hydraulic roughness that has been applied to building footprints to represent their blocking effect on overland flows, combined with inaccuracies in the ALS which occur across the footprint of buildings, was found to produce artificially high depths of inundation in several properties.   This issue was also raised in submissions received by WCC following public exhibition of the Draft Flood Study Report (refer **Section 2.3**), with a number of residents expressing concern that the extent and/or depth of property inundation was overstated. In order to address these concerns, and to reduce the risk of the study findings being misinterpreted, the hydraulic model results were trimmed such that building footprints are shown free of inundation.

There are isolated "hot spot" areas where the modelled depth of inundation increased to 400 mm and beyond, which may be influenced by local features and are on the high side. 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 bushes or structures, resulting in un-realistically high model natural surface levels which may affect results.   It is not practicable to include all of these local features in the model or remove all of the anomalies in the ALS. Site specific studies would be required, possibly with the benefit of field survey to confirm local flow paths and natural surface levels.

As far as flooding in the main arm of the creek is concerned, the filtering process does not have a significant effect on representation of the areal extent of flooding because of the steep sided nature of the channel and floodplain. It is to be noted that while the flood level and velocity data derived from the analyses are consistent throughout the model, the flood extent diagrams should not be used to give a precise determination of depth of flood affectation in individual allotments bordering the main arm.

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.   Open 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 data, which as noted above has a design accuracy based on +/- 150 mm.

Given the uncertainties in the ALS 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 arm of the creek or Sailors Bay. 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 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.

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 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 and commercial developments should be based on the 100 year ARI flood level plus appropriate freeboard (i.e. the FPL) to cater for uncertainties such as wave action, effects of flood debris conveyed in the overland flow stream and precision of modelling.   Selection of interim FPL's along the main arm of Sailors Bay Creek, pending completion of the future FRMS for the catchment, is presented in **Section 6.5**.

The sensitivity studies and discussion presented in **Section 6.3** provide guidance on the suitability of the recommended allowance for freeboard under present day climatic conditions. In accordance with OEH recommendations (DECCW, 2007), sensitivity studies have also been carried out to assess the impacts of future climate change (refer **Section 6.4**). Increases in flood levels due to future increases in rainfall intensities may influence the selection of FPL's. However, final selection of FPL's is a matter for more detailed consideration in the future FRMS.

6.2   Flood Hazard Zones and Floodways

6.2.1. Provisional Flood Hazard

Flood hazard categories may be assigned to flood affected areas in accordance with the procedures outlined in the FDM. 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 a metre, in the absence of any significant flow velocity, could be considered to represent Low Hazard conditions. Similarly, areas of flow velocities up to 2.0 m/s, but with small flood depths could also represent Low Hazard conditions.

Provisional flood hazard diagrams for the 100 year ARI and PMF events, based on Diagram L2 of the FDM, are presented on **Figures 6.9** and **6.10**. Note that the results shown on these figures have been filtered to remove hazard definitions resulting from a depth of inundation less than 100 mm (refer **Section 6.1.1** for further discussion of this issue).

For the 100 year ARI, high hazard flooding in the study area is generally confined to the main arm of Sailors Bay Creek and near shore areas of Sailors Bay and Middle Harbour. Other areas of high hazard, which typically relate to relatively shallow but fast-moving floodwater, relate to flows along and across roadways and down relatively steep sloping areas which fall towards the harbour.

For the PMF event, the width of the high hazard zone along the main arm of Sailors Bay Creek increases substantially. The extent of high hazard floodwaters in the various overland flow areas throughout the catchment also increases, both in terms of flow width and connectivity.

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 for the catchment.

6.2.2. 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.

Flood storage effects are not significant on Sailors Bay Creek as there is very little storage in the overbank areas. Peak flood levels are primarily determined by the conveyance capacity of the waterway and by definition, most of the conveyance is located within the floodway. For this reason the floodplain was sub-divided into floodway and flood fringe areas only.

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.

The extent of the floodway was assessed by taking into account factors such as the distribution and magnitude of flow velocity vectors and the depths of inundation over the flooded area. On this basis the extent of the floodway closely corresponds with the provisional high hazard zone, with some adjustments in areas where the flooding is of a ponding nature and the high hazard categorisation is primarily based on depth.

The assessed hydraulic categories for the 100 year ARI and PMF events are shown on **Figures 6.11** and **6.12**. Note that the results shown on these figures have been filtered to remove hydraulic definitions resulting from a depth of inundation less than 100 mm (refer **Section 6.1.1** for further discussion of this issue). These figures also show the approximate extent of a *Tidal Inundation Zone*, which has been determined as land which lies below RL 1.0 m AHD (based on WCC ALS data) and would therefore be subject to inundation during a HHWSS tide.

Mapped floodways generally follow the line of the main arm of the creek and other defined watercourses. Areas subject to shallow overland flow traversing the northern and southern slopes of the valley have generally been defined as flood fringe areas for the purposes of hydraulic categorisation. As noted previously, floods greater than 100 year ARI or increases in peak flows due to climate change will not result in the development of new flow paths.

6.3 Sensitivity Studies

The sensitivity of the hydraulic model was tested to variations in model parameters such as hydraulic roughness, blockage of pipes and the effects of elevated harbour water levels. The main purpose of these studies was to give some guidance on the freeboard to be adopted when setting floor levels of development in flood prone areas, pending the completion of the future FRMS for the catchment. The results are summarised in the following sections.

6.3.1. Sensitivity to Hydraulic Roughness

Figure 6.13a shows the difference in peak flood levels (i.e. the "afflux") for the 100 year ARI 60 minute duration storm resulting from an assumed Mannings n roughness of 0.2 in allotments, compared with the best estimate value of 0.1. This figure also identifies areas where land is rendered flood free, or where additional areas of land are flooded.

Along the main arm upstream (west) of Alpha Road and along a number of overland flow paths that follow lateral drainage lines, the higher roughness provides additional resistance to the passage of flow causing the flow to lose momentum. Water is detained in allotments, resulting in an increase in peak flood levels which averages about 100 to 150 mm, but reaches up to 500 mm in isolated locations. Increases in peak flood level are typically accompanied by minor increases to flood extents.

Depths and flows may reduce slightly in downstream watercourses due to the reduction in flows resulting from increased roughness upstream. Examples of this behaviour occur along the main arm of Sailors Bay Creek downstream (east) of both Alpha Road and Warners Park, as well as the unnamed watercourse located downstream (east) of The Bulwark.

Figure 6.13b shows the afflux for the 100 year ARI 60 minute duration storm resulting from an assumed 20 per cent increase in roughness (compared with best estimate values) along existing open creek sections and other heavily vegetated areas throughout the study area. This figure also identifies areas where land is rendered flood free, or where additional areas of land are flooded.

The typical increase in peak flood level along the main arm of Sailors Bay Creek upstream of Warners Park would be less than 100 mm, increasing to between 100 and 180 mm downstream of the The Outpost. The afflux would reach up to 200 mm in isolated areas away from the main arm of the creek.

In general, there are only very localised areas where the increase in roughness as a result of either scenario described above would result in afflux greater than about 300 mm. Generally an allowance of 200 to 250 mm would cater for increases in flood levels resulting from uncertainties in hydraulic roughness.

6.3.2. Sensitivity to Blockage of Pipes

The mechanism and geometrical characteristics of blockages in the piped system are difficult to quantify and would no doubt be different for each flood event.   Realistic scenarios would be limited to one or two pipes becoming partially blocked during a flood event (although it is noted that no instances of blockage were reported to have occurred during historic flooding in the catchment).

However, for the purposes of this study, analyses were carried out with the cross sectional areas of all 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 6.14 shows the afflux for the 100 year ARI 60 minute duration storm resulting from a 50 per cent blockage. The average increase in peak flood level from this global blockage would be around 50 to 100 mm. Increases of up to 300 mm could result in isolated areas along the main arm of the creek and along a number of lateral drainage lines throughout the study area because of the resulting increases in overland flow. Increases in the extent of inundation are generally minor in nature along the main arm of Sailors Bay Creek, but are more substantial in a number of overland flow areas throughout the study area.

A 500 mm freeboard allowance would be sufficient to cater for the effects of pipe blockage plus uncertainties in the estimate of roughness in the floodplain.

6.4 Climate Change Sensitivity Analysis

6.4.1. 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, 2007* 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.

The NSW Government had previously adopted a Sea Level Rise Policy Statement (NSW Government, 2009) to support adaptation to projected sea level rise impacts. The policy statement included sea level rise planning benchmarks for use in assessing potential impacts of projected sea level rise in coastal areas, including flood risk and coastal hazard assessment. These benchmarks were a projected rise in sea level (relative to 1990 mean sea level) of 0.4 m by 2050 and 0.9 m by 2100, based on work carried out by the Intergovernmental Panel on Climate Change and CSIRO. OEH recommends in its guideline *Flood Risk Management Guide: Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010)* that these benchmark rises should be used to assess the sensitivity of flood behaviour to future sea level rise.

The NSW Government announced its Stage 1 Coastal Management Reforms in September 2012. As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks, with local councils now having the flexibility to consider local conditions when determining local future hazards. However, WCC considers that the guidance in DECCW, 2010, and in particular the use of the above-mentioned sea level rise benchmarks, remains an appropriate basis for the assessment of potential impacts of sea level rise throughout the LGA.

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 future FRMS for the Sailors Bay Creek catchment, using site specific data.

At the present flood study stage, the principal issue regarding climate change is the potential increase in flood levels throughout 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 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. When setting floor levels for future developments in planning policies for a developed catchment like Sailors Bay Creek, it will also be necessary to consider the impact of decisions on the existing streetscape.

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

6.4.2. 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. For the purposes of the 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.

Figure 6.15 shows the afflux resulting from an increase of 10 per cent in 100 year ARI rainfall intensities. The average increase in peak flood levels across the catchment is around 50 to 100 mm.

Figure 6.16 shows the afflux for a 30 per cent increase in 100 year ARI rainfall intensities. The increase in peak flood levels along the main arm of Sailors Bay Creek the creek is typically between 100 and 200 mm, with some isolated areas experiencing afflux of around 300 mm. Typical increases along overland flow paths are in the 50 to 100 mm range.

The impact of increased rainfall intensities on flooding patterns may be summarised as follows:

➢ The extent of inundation along the length of the main arm of Sailors Bay Creek does not widen significantly, owing to the relatively steep nature of the surrounding overbank areas.

➢ While flow would continue to follow its existing course along the valley of Sailors Bay Creek, there will be some widening of existing overland flow paths throughout the study area.

➢ There may be a reduction in the time of rise of the floodwaters. Sailors Bay Creek is flash flooding 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). Therefore effective flood warning may not be achievable even with the benefit of future technical improvements in such systems. Therefore on-going community education via WCC and the NSW State Emergency Service is required to limit risks to people and property. Further consideration of flood warning arrangements and strategies will be undertaken in the future FRMS.

6.4.3. Sensitivity to Rises in Sea Level

For the purposes of the investigation, sensitivity analyses were carried out to assess the impact a future 0.4 m (2050 conditions) and 0.9 m (2100 conditions) rise in sea level will have on the design 100 year ARI flood envelope for the study area. Adoption of the benchmark rises would result in the following design peak 100 year ARI storm tide levels:

➢ 2050 conditions = <u>2.14 m AHD</u> (i.e. 1.74 m AHD + 0.4 m)

➢ 2100 conditions = <u>2.64 m AHD</u> (i.e. 1.74 m AHD + 0.9 m)

Figures 6.17 and **6.18** show the afflux for the design 100 year ARI flood envelope resulting from the above increases in harbour water level.

These figures show that increases in peak flood level are confined to the lower reaches of the study area immediately adjacent to Sailors Bay and Middle Harbour. Under 2050 conditions increases in peak flood level along the main arm of the creek are limited to below (east) of Tunks Street, while under 2100 conditions increases in peak flood level extend slightly upstream (west) of this location. Impacts generally do not propagate upstream along the various lateral drainage lines that flow into Sailors Bay Creek or directly into the harbour due to the steepness of both the catchment terrain and piped drainage systems.

6.5 Selection of Interim Flood Planning Levels

After consideration of the TUFLOW results and the findings of sensitivity studies outlined in **Section 6.3**, a freeboard allowance of 500 mm was adopted for determination of Interim FPL's for main stream flooding along the main arm of Sailors Bay Creek.

Interim FPL contours developed on that basis and the associated Interim FPA are shown on **Figure 6.19**.

7   REFERENCES

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8 FLOOD-RELATED TERMINOLOGY

Note: For an expanded list of flood-related terminology, refer to glossary contained within 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.
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.
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).

TERM	DEFINITION
Floodplain Risk Management Plan	A management plan developed in accordance with the principles and guidelines in the *Floodplain Development Manual, 2005*. 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 and 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.
Overland flooding	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.

TERM	DEFINITION
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).

APPENDIX A

HISTORIC FLOODS AND MODEL TESTING

TABLE OF CONTENTS

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ATTACHMENTS

LIST OF FIGURES (BOUND IN VOLUME 2)

A1.   INTRODUCTION

This Appendix deals with the following matters:

➢   The results of the community consultation process aimed at collecting data on flooding on the Sailors Bay Creek catchment.

➢   The results of testing the hydrologic and hydraulic models for historic storm events.

A number of historic storms were identified when instances of flooding occurred within the catchment, dating back as far as the mid-1970's.   The two specific events identified most frequently by residents were that of 5 August 1986 and 10 April 1998. A number of more recent wet periods were also identified, including March-April 2012 and June 2012. However, there is very limited available historical flood data, or recollection of historic flooding by residents, probably because of the extended flood free period since the last major storm on the catchment.

Pluviographic data for the historic storms of August 1986 and April 1998 were available from records at the Chatswood Bowling Club, whilst data for storms occurring since 2001 were available from records at the Northbridge Bowling Club. Recorded rainfalls were analysed and applied to the DRAINS catchment model to estimate discharge hydrographs, which were then applied to the TUFLOW model of the floodplain and overland flow paths.

Section A2 deals with the collection of historic flood data, identification of significant past storm events and analysis of historic storm rainfall data for these events.

Section A3 describes the results of testing the models for the historic storms and compares the results with observed behaviour.

A2.   COLLECTION OF HISTORIC FLOOD DATA

A2.1   Previous Investigations

There have been no previous investigations which have examined or reported on flood behaviour for past storm events occurring in the Sailors Bay Creek catchment.

A2.2   Community Newsletter

A Community Newsletter and Questionnaire was prepared and distributed to residents in the catchment to gain knowledge of historic flood behaviour in the study area (refer **Attachment A**). WCC advised that approximately 2,400 Newsletter/Questionnaires were distributed. A total of 480 responses were received, which represents a response rate of around 20 per cent.

Of those that responded, 84 noted that they had observed flooding in or adjacent to their property. Some respondents were able to identify dates of flooding. However, there was limited information relating to specific flooding patterns or flood levels. On further review, it was determined that 34 respondents had noted identifiable flood behaviour that could be related to dates of historic flooding. **Figure A2.1** shows the location of these respondents, whilst a summary of their comments in relation to historic flood behaviour is provided in **Table B1** in **Attachment B**.

A further 91 respondents noted observations of drain blockages throughout the catchment, but were either not specific about observed flooding at the time or did not provide sufficient information that would enable the flood-affected area to be identified.

The remaining 305 respondents noted that they had not experienced flooding in or adjacent to their property.

For flood information to be of direct use in the testing of the hydrologic/hydraulic models, it is necessary to have evidence of the date the flood occurred and the peak flood level that occurred. The resident of 12A Noonbinna Crescent, Northbridge was able to identify a flood mark corresponding to the peak flood level reached along the main arm of Sailors Bay Creek during the 5 August 1986 event (refer **Figure A3.1 – Sheet 1 of 2** for location). However, this was the only reliable flood mark identified by the consultation process.

Various other separate instances of flooding were identified by respondents, dating back as far as the mid-1970's. However, many reports related only to a year or decade during which flooding occurred, rather than specific events. Where specific events (or at least wet periods) were identified, the following three were identified most frequently by respondents as having caused flooding in or adjacent to their property:

> ➢ April 1998 (observed by 4 respondents);

> ➢ March-April 2012 (observed by 7 respondents); and

> ➢ June 2012 (observed by 5 respondents).

Based on experiences in the adjacent Sugarloaf Creek catchment (L&A, 2010), a storm which occurred on 10 April 1998 was a particularly severe event in terms of short duration rainfall intensities. This event was therefore considered for further analysis and model testing.

Based on review of available rainfall records (refer next section for further details) for those wet periods identified by questionnaire respondents, a number of more recent storm events affecting the Sailors Bay Creek catchment which occurred between October 2009 and June 2012 were also identified, including:

> 25 – 27 October 2009
> 12 February 2010
> 4 – 5 June 2010
> 19 – 22 March 2011
> 19 – 24 July 2011
> 7 January 2012
> 17 – 20 April 2012
> 11 June 2012

These events were also considered for further analysis and model testing. It is noted that available historic flooding information for these events, as well as that of 10 April 1998, was limited to isolated observations of flooding patterns.

A2.3   Historic Storm Rainfall Data

A2.3.1 5 August 1986 and 10 April 1998 Storms

For storms occurring prior to 2001, the closest available rainfall intensity data for the study area was recorded at a pluviometer at Chatswood Bowling Club, which is located just east of the Pacific Highway about 1.5 km to the north-west of the Sailors Bay Creek catchment centroid (refer **Figure A2.2**).

Previous investigations (refer LMCE, 1988 and L&A, 2010) assessed the areal distributions and temporal patterns of rainfall associated with the storms of August 1986 and April 1998 and found that the Chatswood Bowling Club record was reasonably representative of recorded depths across other parts of the LGA. This included analysis of daily rainfalls for gauges located at Northbridge Bowling Club, Castlecove (Rosebridge Avenue) and Gordon Golf Club (refer **Figure A2.2** for gauge locations).

A2.3.2 Storms Between October 2009 and June 2012

In 2001, the station at Northbridge Bowling Club was taken over by Manly Hydraulics Laboratory and the daily read gauge replaced with a pluviometer. Therefore for those storm events identified between October 2009 and June 2012, rainfall intensity data recorded within the study catchment was available.

A2.3.2 Analysis of Historic Storm Rainfall Data

Figure A2.3 shows cumulative depths of rainfall for the various historic storm events.

Figure A2.4 relates the historic storm rainfalls to design rainfall intensity-frequency-duration curves. This provides a measure of the relative magnitude of the various events, based on peak bursts ranging in duration between 5 minutes and 6 hours.

Figure A2.4 shows that the storm of 10 April 1998 exceeded 100 year ARI for storm durations ranging between 30 minutes and 1 hour that are generally critical for maximising flows throughout the Sailors Bay Creek catchment. The storm of 5 August 1986 yielded rainfall intensities generally between 10 and 20 year ARI.

Of the more recent storms occurring over the past few years, the event of 7 January 2012 was between 1 and 2 year ARI with most of the remaining events shown to be less than 1 year ARI.

A3. TESTING HYDROLOGIC AND HYDRAULIC MODELS

A3.1 Procedure Adopted for Testing the Models

The procedure adopted for testing the flood models of Sailors Bay Creek, in situations where historic flood data are available, would involve the collection and analysis of rainfall data to ascertain the temporal and areal distribution of rainfall over the catchment. These rainfalls would then be applied to the model to generate flows within the catchment.

In situations where there was a stream gauging station located on the catchment, the modelled discharge hydrograph would then be compared with historic hydrographs and model parameters varied until a fit was achieved. Similarly, when sufficient data are available on historic flood levels along the channel it is possible to use the known discharges and adjust the parameters of the hydraulic model to achieve a fit between recorded and modelled levels. Thus it would be possible to achieve independent calibration of each of the models (hydrologic and hydraulic) in turn. However, in most situations the streams are not gauged and data is usually limited to some isolated flood marks along the stream plus some recorded rainfall data.

Under those circumstances, independent "calibration" of the models cannot be achieved. The usual procedure adopted is to use realistic values of the hydrologic model parameters, adopted from experience and the engineering literature, in conjunction with recorded rainfall data to estimate flows and to vary the parameters of the hydraulic model to achieve a reasonable agreement with recorded flood levels. Sometimes the recorded flood marks or levels recorded at structures are used in conjunction with uniform flow or culvert formulae to estimate historic flood flows to assist with the selection of model parameters. However, in the absence of recorded stream flow data, the overall process as outlined above can at best be termed "model tuning" or "model testing" rather than calibration.

In the case of Sailors Bay Creek, the only quantitative data were the rainfall depths recorded at the pluviometers at Chatswood and Northbridge Bowling Clubs, as well as a single flood mark identified for the 5 August 1986 event (refer **Section A2.2**). Therefore in the present study, the experience of the investigators dictated the choice of parameters for both the hydrologic and hydraulic modelling phases of the analysis.

A3.2 DRAINS Model

Pluviographic data for the historic storms identified in **Section A2.3** were applied to the DRAINS model to generate discharge hydrographs, which were then applied to the TUFLOW model.

A3.3 DRAINS Model Parameters

Model testing was undertaken with the following parameters:

- ➢ Soil Type = 3.0 (assessment of a soil's rate of infiltration.)
- ➢ AMC = 3.0 (Antecedent Moisture Condition – assessment of a catchment's wetness at the start of storm event).
- ➢ Paved area depression storage = 2.0 mm.
- ➢ Grassed area depression storage = 10.0 mm.

A minimum sub-catchment response time of 5 minutes was adopted for urbanised areas of the catchment.

A3.4   TUFLOW Model Results for Historic Storms

A3.4.1 Presentation of Results

Indicative flood extents and depths of inundation as computed by the TUFLOW model are shown on **Figures A3.1** and **A3.2** for the 5 August 1986 and 10 April 1998 storms, respectively.

A3.4.2 Comparison of TUFLOW Results with Observed Flood Behaviour

The hydrologic and hydraulic models were considered to provide satisfactory correspondence with available historic flood data, given the limited quality and quantity of such data.

For the 5 August 1986 storm, the TUFLOW model was found to provide a reasonable match to the observed extent of flooding at the location of the identified flood mark at the rear of 12A Noonbinna Crescent, Northbridge (refer **Figure A3.1 – Sheet 1 of 2** for location).

For the various smaller storms occurring between October 2009 and June 2012, the TUFLOW model was generally found to reproduce observed flooding patterns. **Table B1** in **Attachment B** provides a brief assessment of the modelled results against reported observations for each of the 34 respondents to the questionnaire that had noted identifiable flood behaviour.

A4.   REFERENCES

L&A (Lyall & Associates Consulting Water Engineers), 2010. *"Sugarloaf Creek Flood Study".*

LMCE (Lyall & Macoun Consulting Engineers), 1988. *"Sugarloaf Creek Flood Study".*

ATTACHMENT A

COMMUNITY NEWSLETTER / QUESTIONNAIRE

SAILORS BAY CREEK
FLOOD STUDY

To Residents:

Willoughby City Council has engaged consultants to prepare a *Flood Study* for Sailors Bay Creek and those residentially developed areas which drain directly to Sailors Bay. The approximate extent of the study area is shown on the back of this Newsletter. The *Flood Study* is an important first step in the Floodplain Management Process for this area, which will be managed by Council according to the NSW Government's Flood Prone Lands Policy. The *Flood Study* will define flooding patterns and flood levels in the study area under present day conditions.

The various stages of the *Flood Study* will be as follows:

- Survey along the creek and collection of data on historic flooding.

- Preparation of computer models of the catchments to determine flows for both historic storms and design floods up to the Probable Maximum Flood.

- Preparation of computer based hydraulic models of the creek and floodplain to determine flooding patterns, flood levels and velocities of flow. Flooding in the study area from both the creek and overland flow paths will be evaluated.

The results of the *Flood Study* will provide Council with information on the nature and extent of flooding to assist with planning of development, pending the completion of *Floodplain Risk Management Study*, which will be the next stage of the Floodplain Management Process.

From our initial review of historic rainfall and streamflow data, we have identified the occurrences of several significant flood events in the study area over the past 30 years. These floods are identified below In descending magnitude of severity:

Rank	Date of Flood
1	April 1998
2	August 1986
3	November 1984
4	April 1988

We would like information on any of the above events, or other floods which you may have experienced. Several questions relating to flooding in the study area are set out on the attached Flood Questionnaire. Please take a minute or two to read these questions and provide responses where you can.

Willoughby City Council has also instigated an initiative whereby local residents can forward electronic photographs and/or videos of hisoric flooding in the local government area. Details on where to send any available information are provided on the poster attached to this Newsletter.

Any information you provide will remain confidential and will only be used as statistical data for the flood study.

Community Newsletter

STUDY AREA

1.   Where are you located in the study area? (Please provide your street address)

_____

2.   Do you recall any significant flooding in your area. If so, please **provide dates** (even if only the year of the flood), from the most severe to the least severe (i.e. rank the floods for us.)

1. _____   2. _____   3. _____   4. _____

3.   For the floods you have listed, do you have any records of the height floodwaters reached; for example, a flood mark on a building, shed, fence or light post?   Yes

No

4.   If you responded **"yes"** to the above question, please provide a short description of the location of the flood mark or marks, so our surveyors can measure their elevations and relate them to the banks of the channel.

For example, floodwaters may have entered your property. If so, please provide information on the locality and flood characteristics (i.e. duration of flooding, source of water or flow directions).

_____

_____

_____

You may care to draw a location sketch in the space below.

5. Do you have any information on any blocking of the local access roads due to floodwaters surcharging the local drains?

Yes
No

6. If you responded *"yes"* to the above question, which roads were flooded (duration and depth).

As part of the flood study, the Consultant may wish to clarify the information you have provided, or estimate flood levels. If you can be of assistance in this regard, please fill in your contact details below. Please note that even if you do not wish to give your contact details, we encourage you to complete and return this Newsletter.

Contact Name: _____

Contact Phone No: _____

When would it be convenient for us to call? _____

For any further enquiries regarding the Flood Study, you are invited to contact Council's Manager – Floodplain Management, Ms Parissa Ghanem.

Willoughby City Council
Parissa Ghanem
Manager - Floodplain Management
Tel: (02) 9777 7736
Fax: (02) 9411 8309
E-mail: Parissa.Ghanem@willoughby.nsw.gov.au

ATTACHMENT B

**SUMMARY OF QUESTIONNAIRE RESPONSES
RELATED TO OBSERVED FLOOD BEHAVIOUR**

TABLE B1
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR

Response Identifier [1]	Address	Storm Event(s) when Inundation Occurred	Observed Flood Behaviour / Other Comments	Model Verification Comments
2	10B The Bulwark, Castlecrag	1978, 1988, 1990, 2012	• Flooding of garage and front yard occurred during each storm event. • Garage of neighbours 10C and 12 are susceptible to flooding during (minor) storm events. • Private access road for residences (1,2,2a,6,8B,8C,10,10B,10C,10A,12,14,16,18 The Bulwark) affected by culvert blockage.	• TUFLOW model shows shallow overland flow at rear of property and across common access driveway for 2012 storm events.
7	36 Alpha Road, Willoughby	March 2012, 2010, 2008	• Cellar was flooded to a depth of 500mm. • Backyard and driveway was flooded to a depth of 150mm. • Water flowed from direction of Mowbray Road through backyards of adjoining houses.	• TUFLOW model does not predict flooding in this area from the direction of Mowbray Road. Potential explanations for lack of correlation include inter-allotment drainage issue or sewerage system surcharge.
8	12A Noonbinna Crescent, Northbridge	1986,1998	• Can show flood peak in creek for 1986 event.	• Good match to observed extent of flooding at location of identified flood mark.
12	4 The Scarp, Castlecrag	2011	• Driveway at street level received 10mm water coverage. • Garage at street level received 25mm coverage over floor.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
13	2 Dorset Road, Northbridge	March/April 2012	• Backyard experienced run-off water ponding from adjacent property (3 Weemala Road).	• TUFLOW model does not predict flooding from the direction of 3 Weemala Road. Observed inundation is believed to be a local drainage issue, potentially exacerbated by construction activity at the time.
15	14 The Barbette, Castlecrag	January to March 2012	• Garage inundation.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
18	65 The Bulwark, Castlecrag	April 2012	• Flow down pathway into backyard from Oriel Reserve. • Flow directly off road into a number of properties due to lack of kerb and gutter.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.

(1)   Refer **Figure A2.1** for cross reference to Response Identifier.

TABLE B1 (CONT'D)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR

Response Identifier [1]	Address	Storm Event(s) when Inundation Occurred	Observed Flood Behaviour / Other Comments	Model Verification Comments
22	17 The Tor Walk, Castlecrag	Various	• Flooding of the ground floor occurs during heavy rain. Depth about 10mm.	• TUFLOW model shows shallow overland flow from The Tor Walk through a number of properties in this area (including No. 17) for all historic events analysed.
24	22 The Bastion, Castlecrag	February 2012	• Driveway and garage inundated.	• TUFLOW model shows shallow flows along kerbline and across driveway for January 2012 event, however garage inundation not predicted.
29	51 High Street, Willoughby	Various	• Grass verge outside 51, 49 High Street pools with water. • Sailors Bay Road and Eastern Valley Way intersection.	• 49 and 51 High Street located near sag in High Street. TUFLOW model predicts ponding of runoff in road reserve and overland flow through a number of properties in this area for all historic events analysed.
32	15 Noonbinna Crescent, Northbridge	Various	• Lower end of Harden Avenue 6-10cm deep along kerb.	• TUFLOW model shows overland flows typically 100 – 200 mm deep at lower end of Harden Avenue flowing north into Kameruka Road for all historic events analysed.
33	45A Euroka Street, Northbridge	Various	• Driveway inundation during heavy rain. • Sailors Bay Road and Eastern Valley Way intersection.	• TUFLOW model shows shallow overland flows affecting property driveway for some of the larger historic events analysed (e.g. January 2012, August 1986).
38	1 The Battlement, Castlecrag	2011, 2012	• Flood level on wall of easement approximately 200mm above floor level.	• TUFLOW model shows overland flows up to approximately 200mm deep along northern boundary of property for 2011-2012 storm events.
44	5 Knight Place, Castlecrag	Early May 2012	• Backyard flooding occurred during sustained rain period.	• TUFLOW model shows overland flows up to approximately 300mm deep through backyard of property for April and June 2012 storm events.
45	28 Weemala Road, Northbridge	Various	• Garage and below floor building inundation occurs during periods of high rainfall.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
47	28 Alpha Road, Willoughby	March 2012	• Property inundated with water (side lane).	• TUFLOW model does not predict flooding in this area from the direction of Mowbray Road. Potential explanations for lack of correlation include inter-allotment drainage issue or sewerage system surcharge.

(1) Refer **Figure A2.1** for cross reference to Response Identifier.

TABLE B1 (CONT'D)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR

Response Identifier [1]	Address	Storm Event(s) when Inundation Occurred	Observed Flood Behaviour / Other Comments	Model Verification Comments
53	290 Edinburgh Road, Castlecrag	Various	• Runoff enters property from direction of Edinburgh Road.	• TUFLOW model shows shallow overland flow from Edinburgh Road through a number of properties in this area (including No. 290) for all historic events analysed.
55	95 Kameruka Road, Northbridge	March/April 2012 (Easter)	• Driveway and garage inundated with overland flow off footpath.	• TUFLOW model does not predict overland flow through property for April 2012 storm event. However, overland flows are predicted to affect property in larger events (e.g. April 1998, August 1986). Site inspection shows that driveway arrangement will direct local runoff from footpath and northern kerbline into property.
56	13 Minnamurra Road, Northbridge	1998	• Front pathway, garage and basement experiences inundation during heavy rain.	• TUFLOW model does not predict overland flow through property for April 1998 event. Site inspection suggests that runoff may enter property as a result of shallow flow along northern kerbline.
57	32 Edinburgh Road, Willoughby	Various	• 11,11A and 13 Remuera Street experienced flooding of backyards and ground level living areas.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
59	29 The Battlement, Castlecrag	Various	• Driveway, garage and below floor level inundation occurred.	• TUFLOW model shows shallow overland flow from The Battlement through a number of properties in this area (including No. 29) for all historic events analysed.
64	10A The Scarp, Castlecrag	1998 plus various other events	• No specific observations for 1998 event. • Flooding over driveway and garage.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
65	28 Courallie Road, Northbridge	2009, 2010, 2011, 2012	• Surface runoff leaks through building walls and runs across concrete floor of garage inundating with up to 25mm of water.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
147	55 Coolawin Road, Northbridge	8 June 2012 (2pm)	• Public walkway next to house inundated with water.	• TUFLOW model shows overland flows along easement and through property during June 2012 event.

(1)   Refer **Figure A2.1** for cross reference to Response Identifier.

TABLE B1 (CONT'D)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR

Response Identifier [1]	Address	Storm Event(s) when Inundation Occurred	Observed Flood Behaviour / Other Comments	Model Verification Comments
148	9 Minnamurra Road, Northbridge	2009, 2010, 2011, June 2012	• Below floor level inundation. Water surcharging Minnamurra Road reached "waterfall proportions" during June 2012 event.	• TUFLOW model shows shallow overland flows through property, as a result of surcharging of the northern kerbline, for all historic events analysed.
149	254 Edinburgh Road Castlecrag	11 June 2012	• Runoff entered property and residence from direction of Edinburgh Road during June 2012 event. Damage to bedroom and adjoining rumpus room. Water was approximately 1m deep against wall underneath house. • Seepage issue also noted from direction of Edinburgh Road.	• TUFLOW model does not predict overland flow through property for June 2012 storm event. However, site inspection shows that driveway arrangement may allow runoff along southern kerbline to enter property.
150	6 The Outpost, Northbridge	1984, 1985, 1986	• Aware of flooding from road into 39 Coolawin Street.	• TUFLOW model shows overland flows through No. 39 Coolawin Road during August 1986 event.
151	43 Coolawin Road, Northbridge	1998, 11 June 2012	• Driveway and garage inundated with overland flow off roadway. • Aware of flooding from road into 39 Coolawin Road.	• TUFLOW model shows overland flows through Nos. 39 and 43 Coolawin Road during 1998 and June 2012 events.
153	226 Edinburgh Road, Castlecrag	Various	• Excessive seepage into cellar, has since installed pump.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
161	87 Kameruka Road, Northbridge	June 2012	• Driveway, building (above and below FL), garage, backyard and shed all experienced stormwater inundation during the June 2012 flood. • Gutter opposite 87 Kameruka Road inadequate.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue exacerbated by steepness of driveway opposite property.
162	8 Courallie Road, Northbridge	Various	• Substantial storm water flow enters our allotment from rear (allotments on Kameruka Road). Stormwater appears to flow down Kameruka near Bonds Corner, has no easement, prior to entering driveways on above lots and flowing into backyard of Nos. 6 and 8 Courallie Road.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.

(1)   Refer **Figure A2.1** for cross reference to Response Identifier.

TABLE B1 (CONT'D)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR

Response Identifier [1]	Address	Storm Event(s) when Inundation Occurred	Observed Flood Behaviour / Other Comments	Model Verification Comments
163	63 Baringa Road, Northbridge	Various	• Water enters property from direction of adjacent St Philip Neri school - potential issue with drainage in south-west corner of school. Footpath outside school floods when it rains. Very wet under-house area with ongoing seepage.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.
164	44 The Rampart, Castlecrag	Various	• Water flows across Eastern Valley Way from west to east, approximately opposite Moratai Crescent. • Water flows down The Postern from Edinburgh Road, and instead of heading down the lane to the creek via the Community Centre, this water follows the camber of road and residences get the water not taken by the storm drains.	• TUFLOW model shows runoff flowing across Eastern Valley Way slightly north of Moratai Crescent, which is consistent with this observation. • TUFLOW model does not show overland flow from Edinburgh Road into The Postern due to the small size of the contributing catchment area. However, overland flows along The Rampart and through properties along its southern side (i.e. to the east of the Community Centre) are predicted by the model.
165	38 The Bulwark, Castlecrag	1970s, June 2012	• Water entered garage and adjoining room. Runoff enters property along driveway from the street.	• TUFLOW model does not show overland flow in this area due to small size of contributing catchment area – observed inundation is believed to be a local drainage issue.

(1)   Refer **Figure A2.1** for cross reference to Response Identifier.