WARRINGAH COUNCIL

ATTACHMENT BOOKLET 6a

ORDINARY COUNCIL MEETING

TUESDAY 27 AUGUST 2013

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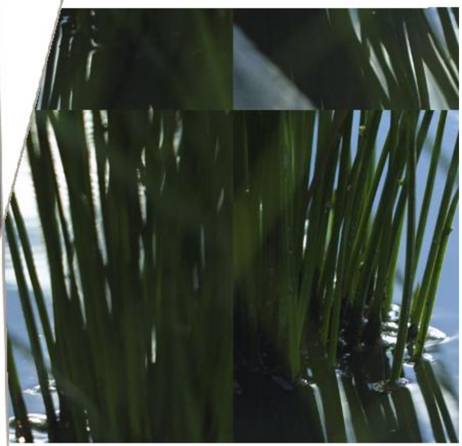
8.13 ADOPTION OF THE DEE WHY SOUTH CATCHMENT FLOOD STUDY

Stage 3: Flood Study Report

Dee Why South Catchment Flood Study

W4961



Prepared for
Warringah Council

27 June 2013

Cardno
Shaping the Future

Document Information

Prepared for	Warringah Council
Project Name	Dee Why South Catchment Flood Study
File Reference	R001 Stage 3 Flood Study Report_FinalDraft.docx
Job Reference	W4961
Date	27 June 2013

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Document Control

Version	Date	Author	Author Initials	Reviewer	Reviewer Initials
Revised Draft	27 March 2013	Andrew Reid	AR	Emma Maratea and Heath Sommerville	EM & HS
Amended Draft	17 April 2013	Andrew Reid	AR	Rhys Thomson	RST
Exhibition Draft	29 April 2013	Andrew Reid	AR	Rhys Thomson	RST
Final Draft	27 June 2013	Andrew Reid	AR	Brett Phillips	BCP

Foreword

The NSW Government Flood Prone Land Policy is directed towards providing solutions to existing flood problems in developed areas as well as 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 prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy identifies the following floodplain management 'process' for the identification and management of flood risks:

1. Formation of a Committee -

   Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists. For the purpose of this study, the Dee Why South Catchment Flood Study Working Group was established.

2. Data Collection -

   The collection of data such as historical flood levels, rainfall records, land use, soil types etc.

3. Flood Study -

   Determines the nature and extent of the flood problem.

4. Floodplain Risk Management Study –

   Evaluates management options for the floodplain in respect of both existing and proposed development.

5. Floodplain Risk Management Plan –

   Involves formal adoption by Council of a management plan for the floodplain.

6. Implementation of the Plan –

   Implementation of actions to manage flood risks for existing and new development.

This Dee Why South Catchment Flood Study is the first stage of the management process for the Catchment. The study, which has been prepared for Warringah Council by Cardno, defines flood behaviour for existing catchment conditions in the Dee Why South Catchment.

Executive Summary

Background and Study Purpose

The Dee Why South catchment comprises parts of Dee Why and Narraweena, including the Dee Why Town Centre, draining to Dee Why Lagoon. Dee Why Town Centre is situated at the confluence of three drainage lines, with a relatively large upstream catchment draining to Dee Why Lagoon. Dee Why has developed from low density residential development in the 1940s to a commercial and retail area, including further high rise residential development in the future.

Numerous flood investigations have been undertaken for the Dee Why Central Business District (CBD) area. However, a formal Flood Study, in accordance with the Floodplain Development Manual (NSW Government, 2005), has never been undertaken for the whole catchment. In order to ensure Warringah Council is fulfilling its responsibility in regards to floodplain risk management it has undertaken a formal Flood Study which allows for a Floodplain Risk Management Study and Plan in the future.

This document comprises the Flood Study. Cardno was commissioned by Warringah Council to undertake a Flood Study for the Dee Why South Catchment. This study aims to define the nature and extent of flooding under historical, existing and future conditions in Dee Why South Catchment as specified in the Floodplain Development Manual (NSW Government, 2005).

The key outcomes of the current study are:

- Maps showing flood extents, flood depths, flood hazard, velocities and the location of floodways (including the potential impacts of climate change);
- Identification of flood risks to inform the selection and assessment of floodplain management measures in the next step of the floodplain risk management process outlined in the Floodplain Development Manual (NSW Government, 2005); and
- A comprehensive document to communicate flood risks to the community and improve flood awareness.

The study has been undertaken in three stages:

1. Community Consultation and Data Compilation;
2. Peer Review of Hydrological and Hydraulic Components of the XP-SWMM 2D Model; and
3. Flood Study Report.

This Flood Study is currently in draft form for review and input from the community and stakeholders.

Community Consultation

Community involvement is important at all stages of the floodplain risk management process. In the development of a Flood Study it allows community experience with flooding to be incorporated into the development of flood prediction models and high flood risk areas to be identified. At later stages during the Floodplain Risk Management Study, it allows community input to the development of options for managing flood risk. Ongoing community involvement throughout the process ensures the acceptance of the final recommendations of the Floodplain Risk Management Plan.

The purpose of the community consultation undertaken in the preparation of the Draft Flood Study was to advise residents and allow input to the study. A questionnaire was mailed to all residents in the catchment (and made available on Council's website) enquiring about a range of flood related issues

The key outcomes of the consultation are summarised below:

- 38 percent of respondents have lived in the area for more than 20 years. This may provide a good historical experience of flooding in the area.

- 40 percent of respondents indicated they are not aware of potential flooding in the catchment which is an important objective of the study of defining flood behaviour to enable the community to be informed about potential risks.
- Responses identified the following experience of flood events:
  - 12 recorded that their daily routine was affected due to flooding;
  - 4 respondents were concerned for their safety;
  - 25 had access to their property affected;
  - 21 respondents had their property damaged; and,
  - 2 experienced difficulties in operating their business.
- 34 percent of respondents indicated their residential/commercial property has been flooded.
- 32 percent of respondents advised that drains or culverts were blocked, generally by leaves and garbage.
- Pittwater Road at the intersection of Lismore Avenue was identified by several respondents as being flood affected.

The draft report was publicly exhibited from 30 May 2013 to 19 June 2013 inviting comments from the community. Three public meetings in Council Chambers were also held during this period. Several submissions were received, including requests for individual property affectation information, comments on application of development controls, and recommendations for the future Floodplain Risk Management Study.

Hydrological and Hydraulic Model Set Up

XP-SWMM was used to model the hydrological and hydraulic behaviour of the catchment. XP-SWMM is a comprehensive software suite that simulates stormwater flows by calculating flows in channels and pipes as one-dimensional (1D) elements coupled to a two-dimensional (2D) surface of the floodplain and overland flow area. Model simulations can be run for a range of storm events including small to large rainfall intensities and recorded historical event rainfall patterns. Data and model outputs are readily integrated in a geographical information system (GIS) for review and presentation of results.

Flood modelling for this study uses the rainfall-on-grid (direct rainfall) methodology in XP-SWMM whereby rainfall is applied directly to every grid cell in the model. Each cell represents a pocket of land surface described by elevation, land use and soil infiltration to develop a virtual ground surface of the catchment. The model then performs hydrological and hydraulic calculations to determine flow quantity and distribution from each cell. Generally, the rainfall-on-grid methodology is better suited to identifying and simulating overland flowpaths.

As the rainfall-on-grid methodology is used for the flood study model, the extent of the model includes the total Dee Why South Catchment. The model was also extended to include portions of the adjoining catchments to model flow interactions between these areas and the study area in order to provide a more accurate overland flow profile for the design storm events modelled.

LiDAR data (in the form of ground surface points) was provided for the entire Dee Why South Catchment by Council. The LiDAR data was collected on the 15th and 16th March 2007 by AAM Hatch. This raw ground LiDAR data was used to derive a high resolution digital elevation model (DEM) of for the Dee Why South Catchment. The DEM was applied as a 2 m by 2 m grid-cell size to represent the 2D model surface in XP-SWMM.

A grid cell size of 2 m by 2 m is used in the rainfall-on-grid model which consists of over 1.5 million cells in the model. The model resolution of 2 m grid cells is selected for the flood study model as it is the best balance between clarity of calculation and results as well as model runtimes.

A series of land use types was identified for the study area based upon aerial photographs and site visitations. A roughness value was applied to each of the identified land uses estimating the resistance to flow between a surface and the water. The rainfall loss is a representation of the proportion of rainfall which is infiltrated into the ground and does not contribute to runoff. Initial and continuing losses were applied to the XP-SWMM model according to the land uses present.

In order to allow for the runoff from roofs to be modelled, buildings which include residential, commercial, and industrial were raised in the model. Similarly, the blockage to flow caused by building footprints has been modelled with their solid grid cells 3 metres higher than the surrounding ground level. This was guided by the use of the aerial photographs supplied by Council.

In the model, all stormwater drainage pipes, box culverts, and open channels in the Dee Why South Catchment were modelled.

A fixed water level is used in the XP-SWMM model to represent the level in Dee Why Lagoon at the downstream boundary of the model. This tailwater level of 2.3m AHD represents a 5% AEP storm event level in the Lagoon.

Verification and Calibration

The XP-SWMM computer model was calibrated and validated to demonstrate that it is a suitable representation of the catchment to simulate flooding. The calibration process included several methodologies.

Rainfall and streamflow measuring gauges were installed in the catchment by Manly Hydraulics Laboratory. A storm event of significant magnitude did not occur during the period between installation in June 2012 and the development of the XP-SWMM model. Two storm events of July 2011 and June 2012 were reviewed for detailed modelling, however these relatively minor events of less than 1 year Average Recurrence Interval (abbreviated as ARI – listed in the glossary) did not provide suitable results for calibration.

The peak flow for a portion of the catchment at The Circle determined using an alternative hydrological computer program (XP-RAFTS) was compared to the flow determined in the XP-SWMM model.

Peak flows modelled at several locations were compared for the XP-SWMM models of the SMEC Study and this Flood Study. Variations between the two models were noted due to different modelled catchment extents, hydrological calculation methodology, and adopted model parameters (such as surface roughness and pit inflows).

Particular flooding trouble spots described by respondents to the community questionnaire were reviewed in comparison to those identified in the modelled results. The model generally showed similar flood inundation at those locations reported. However some locations that were advised of flooding may have resulted from particular factors influencing flood behaviour as they were not shown in the modelled results.

In general, the comparison of results indicated a reasonable agreement and the model was adopted for the Flood Study.

Results

The results show that generally the main overland flowpath starts from several branches at Alfred Street to Beverley Job Park. Flows in the open channel at Victor Road and Redman Road combine with overland flows from Mooramba Road, Fisher Road, and Pittwater Road at the intersection of Redman Road and Pittwater Road. Overland flows are then conveyed along several roads and properties to Dee Why Lagoon as well as in the open channels between Pacific Parade / Oaks Avenue and downstream of Dee Why Parade.

In a 1% AEP event, the results show that ponding of runoff occurs at several locations with restricted outlet capacity. This is potentially through insufficient piped drainage or elevations that result in trapped lowpoints. Examples of these locations include Sturdee Parade (near Pittwater Road) and Alfred Street (near McIntosh Road) as well as on Beverley Job Park. Ponding also occurs at several locations in the catchment due to localised depressions from the LiDAR ground survey or building structures restricting overland flowpaths.

High pedestrian areas in Dee Why CBD also experience overland flow inundation, particularly along Redman Road, Pittwater Road, Oaks Avenue and Howard Avenue. Ponding at lowpoints in these roads is modelled, with some depths in the range of 0.5 to 1.0 m deep. Some roads show scattered inundation up to 0.3 m such as Alfred Street (near McIntosh Road), Redman Road, and Howard Avenue as well as on the Victor Road side of Beverley Job Park.

Significant inundation is shown in a PMF event with some roads having a flood depth greater than 1 m and velocity greater than 2 m/s. Overall, the PMF results show that the catchment comprises a series of trapped lowpoints with insufficient piped drainage capacity or dedicated overland flowpaths.

Sensitivity Analysis

A sensitivity analysis of the results was undertaken to evaluate the range of uncertainty in the modelled flood behaviour to changes in key parameters including:

- Surface roughness;
- Downstream boundary level;
- Conduit roughness;
- Pervious area rainfall losses;
- Inlet blockage;
- Energy losses at structures; and
- Inclusion of Dee Why Town Centre Masterplan.

In most cases the base model results are within +/- 0.05m of the adjusted parameters. Particular locations, such as the trapped lowpoint in Sturdee Parade, shows higher increases but is generally confined to the road.

Hydraulic Categorisation and Provisional Flood Hazard

Hydraulic categories and provisional flood hazard were defined for the PMF, 1% AEP, 5% AEP and 5 year ARI events. In a PMF event, a large portion of the flow paths in the catchment are categorised as floodway and high provisional hazard. In a 1% AEP event, flow conditions along the open channels, on roads, and some properties are categorised as floodway and high provisional hazard. The Dee Why CBD is an area of high pedestrian activity and vehicle movement which is shown to have overland flooding which is categorised as floodway and high provisional hazard.

Stormwater Infrastructure Capacity

The stormwater drainage infrastructure, comprising inlet pits, pipes and culverts, is constructed to convey runoff underground and reduce the surface overland flows along roads and in properties. An assessment of the capacity of the drainage network was completed. Results showed a series of pipelines distributed across the network. For example, the main trunk pipeline from Redman Road to Oaks Avenue has some reaches of restricted capacity as well as from Alfred Street (near McIntosh Road) to Beverley Job Park and on pipe branches draining Howard Avenue. These sections with limited capacity compared to upstream pipes potentially choke inflow and may result in increased surface runoff.

Dee Why Lagoon

Dee Why Lagoon is the downstream receiving waterbody for the Dee Why South Catchment and for modelling this downstream boundary, a fixed water level of 2.3 m AHD was adopted. Water levels in the Lagoon from 1996 to the present day (from Manly Hydraulics Laboratory) indicate that water level in the Lagoon has not exceeded 2.41 m AHD. Generally, Lagoon levels, as adopted for the present study define well the limits of likely tail water levels for Dee Why Creek. Only in a future very severe storm with projected sea levels above that currently advised for 2050 will ocean levels govern tail water levels for catchment flood events.

Climate Change

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. Potential changes to flood behaviour have been modelled for a range of scenarios incorporating a sea level rise of 0.4 m or 0.9 m in the Lagoon, a 10% or 20% increase in rainfall intensity, and the 1% AEP flood event level from Dee Why Creek. Results show that the modelled increases to Lagoon level have an impact to peak flood levels near the Lagoon if it is elevated to close to the existing ground levels of properties and roads. Modelled increases in rainfall intensity showed a rise in peak water levels across the catchment, particularly in trapped low points such as on Sturdee Parade and Alfred Street.

Planning and Development

Council applies land use planning and development controls to manage development within flood prone areas. This includes designation of certain land uses in parts of the catchment and specific requirements for particular developments depending on the potential risk or hazard and overall suitability of an area. The Local Environmental Plan and Development Control Plan are the two primary mechanisms which specify controls based on the flood planning level and flood risk planning precinct.

The Warringah Local Environmental Plan 2011 is applied to manage development within the catchment to minimise flood risks and to avoid significant impacts on flood behaviour. The Flood Planning Level is defined as 'the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard'.

The Warringah Development Control Plan 2011 specifies controls and conditions for developments based on the location of the property within the floodplain. Three planning precincts with different controls are established based on the flood characteristics – High Flood Risk, Medium Flood Risk and Low Flood Risk.

Conclusions

This report has been prepared for Warringah Council to define the nature and extent of flood in the Dee Why South Catchment. Flood modelling was completed to define flood behaviour for a range of storm events from 1 year Average Recurrence Interval (ARI) to Probable Maximum Flood (PMF).

The modelling shows that significant flows are conveyed in the piped drainage network and overland through roads and properties. Generally the main overland flowpath starts from several branches at Alfred Street to Beverley Job Park. Flows in the open channel at Victor Road and Redman Road combine with overland flows from Mooramba Road, Fisher Road, and Pittwater Road at the intersection of Redman Road and Pittwater Road. Overland flows are then conveyed along several roads and properties to Dee Why Lagoon as well as in the open channels between Pacific Parade / Oaks Avenue and downstream of Dee Why Parade. In a 1% AEP event, the results show that ponding of runoff occurs at several locations with restricted outlet capacity.

High pedestrian areas in Dee Why CBD also experience overland flow inundation, particularly along Redman Road, Pittwater Road, Oaks Avenue and Howard Avenue. In a 1% AEP event floodway and high provisional hazard flow conditions along the open channels, on roads, and some properties including in the Dee Why CBD.

A series of climate change scenarios were also modelled to evaluate potential impacts from elevated sea levels and increased rainfall intensity. Results showed that the modelled increases to Lagoon level have an impact to flood inundation of low-lying land near the Lagoon. Most properties within the Dee Why South catchment do not show a significant change in inundation extent for the modelled scenarios. Modelled increases in rainfall intensity showed a rise in peak water levels across the catchment, particularly in trapped low points such as on Sturdee Parade and Alfred Street.

Council applies land use planning and development controls to manage development within flood prone areas. The flood result and mapping provided in the document will assist Council with future land use planning, development controls and floodplain risk management.

The next stage of the floodplain risk management process following the adoption of the Flood Study is the Floodplain Risk Management Study and Plan. This next stage will investigate various floodplain risk management measures and prioritise these measures for implementation.

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Glossary and Abbreviations

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded each year; it would be fairly rare but it would be relatively large. The 1% AEP event is equivalent to the 1 in 100 year Average Recurrence Interval event.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random. That is, an event of a certain magnitude may occur several times within its estimated return period.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. E.g. some roads may be designed to be overtopped in the 1 in 1 year ARI flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.

Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.
Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood planning levels	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. The concept of FPLs supersedes the "Standard flood event" of the first edition of the Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only

	partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical Information Systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.

Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
NPER	National Professional Engineers Register. Maintained by Engineers Australia.
Overland Flow	The term overland flow is used interchangeably in this report with "flooding".
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a more detailed explanation see Annual Exceedance Probability.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

1 Introduction

1.1 Background

Dee Why Town Centre is situated at the confluence of three drainage lines, with a relatively large upstream catchment draining to Dee Why Lagoon. Dee Why has developed from low density residential development in the 1940s to a commercial and retail area, including further high rise residential development in the future. Historically, the drainage lines have been upgraded to cater for developments based on the flows generated from the upstream catchment characteristics at the time of development. A number of these developments incorporate piped or covered channels to convey flood flows underground without designated overland flow paths.

Numerous flood investigations have been undertaken for the Dee Why Central Business District (CBD) area. However, a formal Flood Study, in accordance with the Floodplain Development Manual (NSW Government, 2005), has never been undertaken for the whole catchment. In order to ensure Warringah Council is fulfilling its responsibility in regards to floodplain risk management it has undertaken a formal Flood Study which allows for a Floodplain Risk Management Study and Plan in the future.

This document comprises the Flood Study.

1.2 Floodplain Management Process

The NSW Government Flood Policy is directed towards providing solutions to existing flood problems in developed areas and 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 prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy identifies the following floodplain management process for the identification and management of flood risks:

1. Formation of a Committee - Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists;
2. Data Collection - The collection of data such as historical flood levels, rainfall records, land use, soil types etc;
3. Flood Study - Determines the nature and extent of the floodplain;
4. Floodplain Risk Management Study - Evaluates management options for the floodplain in respect of both existing and proposed development;
5. Floodplain Risk Management Plan - Involves formal adoption by Council of a management plan for the floodplain; and
6. Implementation of the Plan - This may involve the construction of flood mitigation works (eg culvert amplification) to protect existing or future development. It may also involve the use of Environmental Planning Instruments to ensure new development is compatible with the flood hazard.

The Dee Why South Catchment Flood Study is the first stage of the management process and comprises Steps 1, 2, and 3 above. Flood inundation and behaviour is defined in this Study for future application to the next stage of evaluating options for the management of the floodplain.

1.3 Study Outline

Cardno was commissioned by Warringah Council to undertake a Flood Study for the Dee Why South Catchment. This study aims to define the flood behaviour under historical, existing and future conditions in Dee Why South Catchment as specified in the Floodplain Development Manual (NSW Government, 2005).

There are three stages to this Flood Study. Interim papers were prepared at the conclusions of Stages 1 and 2 which have been incorporated into this Stage 3 Flood Study Report.

Stage 1 – Community Consultation and Data Compilation

Consultation is an important component of the project. Council intended to produce a document such that the community can clearly understand potential flood risks within the catchment. Community involvement throughout the floodplain management process (as outlined in the Floodplain Development Manual) is important for acceptance of the final recommendations of the process.

Stage 1 of the Flood Study involved initial community consultation to advise residents of the study and allow input to the study. A questionnaire was mailed to all residents in the catchment enquiring about a range of flood related issues. Council was also seeking to identify residents who would be interested in joining the Dee Why South Catchment Working Group. The questionnaire and other information related to the study were also available on the internet linked to Council's website.

Stage 1 of the Flood Study also involved the collation, compilation and assessment of all information relevant to the undertaking of the Dee Why South Catchment Flood Study. As part of this process, each of the previous flood investigations undertaken for the study area have been reviewed for their relevance to the current flood study.

Stage 2 – Peer Review of Hydrological and Hydraulic Components of the XP-SWMM Model

Stage 2 of the Dee Why South Catchment Flood Study was to review the XP-SWMM 2D model prepared by SMEC Australia. The SMEC model was developed in 2011 to evaluate mitigation options for the CBD and was reviewed for adoption as the flood model for preparing the formalised Flood Study. It was considered a suitable base model and refined for modelling in this Flood Study.

Stage 3 – Flood Study Report

This Flood Study Report has been prepared as Stage 3 of the process. The Flood Study Report incorporates the outcomes of Stages 1 and 2 and the hydrological and hydraulic assessments undertaken in accordance with the Floodplain Development Manual (NSW Government, 2005).

The XP-SWMM modelling software is used to model the flood behaviour for a range of storm frequencies and potential climate change scenarios. Model outputs are reviewed for inundation characteristics such as depths, water levels, velocities, and provisional hazard. This Report includes figures showing key results and all model outputs are provided to Council as files for their geographical information system.

1.4 Study Area

The Dee Why South Catchment is bordered by McIntosh Road to the north, Waratah Parade to the west, May Road to the south and discharges to Dee Why Lagoon. The catchment area is approximately 268 hectares and is characterised by largely residential development with the CBD located in its lower reaches. This catchment includes parts of the suburbs of Dee Why and Narraweena.

The study area is shown on Figure 1-1.

The study area is a sub-catchment of the greater Dee Why Lagoon catchment. This entire catchment consists of the Dee Why Lagoon North sub-catchment, which includes parts of the Cromer, Dee Why and Narraweena suburbs.

1.5 History of Flooding

Council's records indicate that the catchment was subject to flooding in the past. The historic photographs available for the major flood events that occurred in 1947, 1953 and 1954 show both the CBD and outer catchment area affected by significant overland flow.

The rainfall information for these floods was not available to assist in estimating the recurrence interval of the events or to help in calibrating hydrological models. However, the photographs indicate that major storm events have potential to create very hazardous flooding conditions along the major flowpaths within the catchment, characterised by significant depth of flood water and rapid flow.

1.6 Study Outcomes

The key outcomes of the current study are:

- Maps showing flood extents, flood depths, flood hazard, velocities and the location of floodways (including the potential impacts of climate change);
- Identification of flood risks to inform the selection and assessment of floodplain management measures in the next step of the floodplain risk management process outlined in the Floodplain Development Manual (NSW Government, 2005); and
- A comprehensive document to communicate flood risks to the community and improve flood awareness.

2 Data Compilation and Review

2.1 Previous Flood Studies and Reports

Numerous flood assessments have been undertaken in Dee Why since 1975. Most recently, SMEC undertook an options assessment to assist Warringah Council to develop and select an appropriate stormwater upgrade design for the Dee Why Town Centre.

A summary of each of the previous flood investigations has been undertaken and is provided in Table 2-1. A more comprehensive review of the SMEC (2011) Options Assessment is provided in Section 2.2.

Table 2-1 Previous Flood Studies and Reports

Flood Study	Summary and Relevance to Current Study
Physical Model by Sydney University, 1975, Test No T244	A physical model to assess the additional trunk drainage underneath the now Woolworths site was undertaken in 1975 (according to Dee Why Town Square Flood Study Investigation, 2001). No record of this model is currently available. However, it may be obtainable from Sydney University. This data was not required for the current study.
Warringah Council ILSAX model	In 1991 Warringah Council developed an ILSAX model. Details on this model development are not available. A number of ILSAX format files are available in Council's records, however the locations and specific purpose of the analysis is generally unknown. The model was used for a number of years to determine peak flow rates for a number of locations and design storms throughout Dee Why. This model has formed the basis for a number of the flood investigations detailed below but has not been used directly as an input into the current study.
Dee Why Town Square Flood Study Investigation, July 2001, Lyall and Associates	This study formed part of the broader study, Dee Why CBD Flood Study, Oct 2001, Lyall and Associates. It describes flooding conditions relating to the then proposed commercial development at No 29 Howard Ave.
Dee Why Central Business District Flood Study, Oct 2001, Lyall and Associates	The objective of the study was to assess the capacity of the trunk drainage system discharging through the CBD area and determine the magnitude and severity of flooding throughout the road network. Hydrology is drawn from Council's ILSAX model. This report deals with flooding for the full range of design storm events, from 5 year Average Recurrence Interval (ARI) up to 1% AEP (100 year ARI). The Probable Maximum Flood (PMF) was also modelled to provide Council with information relating to the upper limit of flooding resulting from an event of this magnitude. The peak flow estimates in this report were revised downward, when compared to those estimated in the July 2001 study.
Feasibility Study: Proposed Oaks Ave Stormwater Drainage Upgrade, June 2002	This study assessed the source of the overland flows through Oaks Ave, an assessment of pit and pipe network required to convey overland flow up to and including 20yr flood event and the cost estimates to carry out this work. This report resulted in a possible solution to minimise flooding throughout the CBD by suggesting an upgrade to the pipe system in Oaks Avenue, Dee Why. No data or model results were extracted from this study for use in the current Flood Study. This information may be useful when developing floodplain risk management measures as part of the Floodplain Risk Management Study.

Flood Study	Summary and Relevance to Current Study
Dee Why Lagoon and Curl Curl Lagoon Flood Studies, February 2004, Lyall and Associates	A RORB hydrological model was developed for the Dee Why Lagoon. This model covered a number of catchments and did include Dee Why South Catchment. The description of the RORB assumptions and methodology does not allow for the reproduction of calculations. It appears that the RORB model was calibrated to give the same peak flows as the Probabilistic Rational Method (but no detail is given). The RORB hydrology appears to produce much higher peak flows for the Dee Why South Catchment. This report was first published in 2002.
Dee Why Lagoon and Estuary Management Study, March 2004, Lawson and Treloar	This study details management plans and options for Dee Why Lagoon and Estuary. A digital terrain model of Dee Why Lagoon was developed from 2001 photogrammetry, and details were provided of how the Lagoon hydraulic behaviour might be modified by dredging (including a three dimensional hydrodynamic model of the Lagoon in DELFT3D).
Dee Why Triangle Park, August 2004, Lyall and Associates	Review of documentation and hydraulic modelling to assess the proposed redevelopment of the Dee Why Triangle Park. Lyall & Associates (letter dated 21 August 2004) undertook a review of flooding impacts in relation to proposed development works adjoining the Dee Why Triangle Park. This assessment utilised the HEC-RAS model which was set up as part of the July 2001 study (mentioned above).
Dee Why and Curl Curl Floodplain Risk Management Studies and Plan, Nov 2006, Lyall & Associates	Warringah Council subsequently commissioned Lyall & Associates Consulting Water Engineers (LACE) to prepare a Floodplain Risk Management Study and Plan for the Dee Why and Curl Curl Lagoon catchments and surrounding areas. The Brief for the study issued by Council generally follows the scope of work required for a Floodplain Management Study as identified in the Floodplain Development Manual (NSW Government, 2005).
Dee Why Central Business District Flood Study, Jan 2006, Lyall and Associates	Dee Why CBD Flood Study 2001 was updated in January 2006 to respond to changes in the NSW Government's Flood Policy and Manual. No calculations, results or conclusions were changed. This study gave a comprehensive description of the catchment, flood behaviour and local features. This information has been used in the current study.
Dee Why CBD Flood Study Update, 2 November 2007, Cardno Lawson Treloar	This Flood Study was undertaken to update the 1D hydraulic model to a 2D hydraulic model (XP-SWMM2D and SOBEK). The existing ILSAX hydrological model was examined, but no catchment layout plan could be located to identify the sub-catchment boundaries. Consequently it was not possible to decipher the ILSAX model files from Council's model to allow conduit flows and overland flows to be separately identified within the available study timeframe. As a result the hydrology used for this study was taken from the January 2006 Lyall and Associates' Mike-11 models. These inflows represent surface flows only and were originally obtained from Councils ILSAX model. This study investigated the differences between SOBEK and XP-SWMM model results, together with various methods of modelling building footprints within XP-SWMM. The model and its parameters were used to develop the XP-SWMM model of 2009 which is integral to the current model.

Flood Study	Summary and Relevance to Current Study
Dee Why CBD Flood Study - Augmentation Options: Interim Results, 13 December 2007, Cardno Lawson Treloar	This Study ran three scenarios as sensitivity tests to the XP-SWMM 2D model, together with "Rainfall on Grid" flow path analysis. The scenarios were general in nature, and aimed at understanding flood behaviour rather than evaluating civil engineering solutions to flood mitigation. It also compares the XP-SWMM flood levels to the levels provided by the 2001 Lyall and Associates Flood Study. The model and its parameters were used to develop the XP-SWMM model of 2009 which is integral to the current model.
Dee Why CBD Flood Study Update, December 2007, Cardno Lawson Treloar	This study update presents results from both the SOBEK 2D model and the XP-SWMM 2D model and compares them with the 2006 Lyall and Associates Flood Study It identifies areas of high hazard and provides flood depths for the 1% AEP (100yr ARI) and PMF. The model and its parameters were used to develop the XP-SWMM model of 2009 which is integral to the current model.
Dee Why CBD Flood Feasibility Assessment: Proposed Augmentation Options, March 08, Cardno Lawson Treloar	This study converted the 1991 ILSAX hydrology model into the DRAINS software format. This DRAINS model adopted the same model data and parameters as previously adopted in the ILSAX model. This DRAINS model was checked by comparing the predicted overland peak flows with the overland flow hydrographs previously input into the 2001/2006 Lyall Associates MIKE11 model. A good agreement was achieved between the predicted overland peak flows at key locations. The peak 1% AEP (100 year ARI) and PMF values were then extracted from the DRAINS model and copied into the XP-SWMM 2D model. Pit, pipe and open channel data from Council's GIS records was incorporated into the XP-SWMM 2D model. This data was extracted from Council's GIS database on 11 January 2008. Council's database is compiled from a number of different data sources, including work-as-executed data, field survey, design plans submitted prior to construction, historical databases with unknown origin, CCTV footage and others. This model was used to suggest mitigation options to enable the overland flows in Oaks and Howard Avenues to be below the kerb. There was to be no blockage factor associated with these designs. The model and its parameters were used to develop the XP-SWMM model of 2009 which is integral to the current model. The mitigation options assessment may be relevant for a future floodplain risk management study.
Dee Why CBD Feasibility Assessment – Results for Option 4, 31 March 2008, Cardno Lawson Treloar	This study updated the "existing" XP-SWMM 2D model to incorporate the development of the planned stormwater works for the Dee Why Grand on the corner of Pittwater Road, Pacific Parade and Sturdee Parade. The study then developed "Option 4" which was adopted as the preferred hydraulic solution. The model and its parameters were used to develop the XP-SWMM model of 2009 which is integral to the current model. The mitigation options assessment may be relevant for a future floodplain risk management study.
Dee Why CBD Feasibility Assessment: Results for Option 4 + 10% Rainfall increase, 20 May 2008, Cardno Lawson Treloar	This study increased the 1% AEP (100 year ARI) rainfalls in DRAINS by 10%. The resulting hydrographs were then copied into the XP-SWMM 2D model for Option 4. The study concluded that the increased rainfall intensity would increase flood levels by between 20mm and 70mm depending on location and increase in the velocity-depth product was "minimal". The model and its parameters were used to develop the XP-SWMM model of 2009 which is integral to the current model. The mitigation options assessment may be relevant for a future floodplain risk management study.

Flood Study	Summary and Relevance to Current Study
Warringah Council XP-SWMM 2D Model Development, December 2009	Warringah Council undertook in-house development of the XP-SWMM2D model between August and December 2009. In summary the following alterations to the model were implemented: • Incorporation of the "Dee Why Grand" development into the "Existing" model (pit and pipes copied from Cardno "Option 4" model) • Incorporation of the proposed Multiplex development building footprint into the "Existing" model (from the approved Stage 1 DA2007/1249) • Incorporation of the Craig and Rhodes detail ground survey in to the digital terrain model (DTM) • Incorporation of the Cardno DRAINS model pit and pipe network. This extended the network to cover the entire Dee Why South Catchment. Catchment details were imported to enable the hydrology to be calculated using the Laurenson method within XP-SWMM. Catchment areas, slope and % impervious were not checked. • Incorporation of Council's Airborne Laser Survey (ALS) data in the DTM to cover the pit and pipe network from the Cardno DRAINS model. • Removal of the cut-and-pasted Cardno DRAINS "user-inflow" hydrographs. Delineation of catchment areas for all unsealed pits within the "Existing" Cardno (2008) model region. This enabled the complete hydrological calculation to be performed natively within XP-SWMM2D. Note no calibration has been carried out. Hydrograph timing and peak volume vary from the DRAINS results, but not more than would be expected (+/- 20%). • Incorporation of Cardno Options 1, 1A, 2, 3 and 4 into the new "Existing" model, utilising the "scenarios" functionality within XP-SWMM to enable the effective comparison of results between options. The XP-SWMM flood model developed for this 2009 study formed the basis for the SMEC modelling of 2011.

2.2 Options Report for Dee Why Town Centre Drainage Design (SMEC, 2011)

The intention of the Options Report for Dee Why Town Centre Drainage Design (SMEC, 2011) was to provide a stormwater augmentation design to reduce flooding within Dee Why CBD area. This study utilised the XP-SWMM 2D model (developed by Warringah Council in 2009) incorporating pit, pipe, channel and topographical survey. A further adjustment to the hydrological and hydraulic parameters was also undertaken.

This model was not calibrated to historical flood events due to the limited data available. SMEC refined the Council's DRAINS model (Cardno, March 2008) and calibrated the XP SWMM 2D model to these flows. In deriving the final flows for the stormwater augmentation design, climate change parameters of 90 cm for sea level rise and 20% for an increase in rainfall intensity were incorporated.

SMEC developed three options to reduce the flood risks within the CBD area. These options along with previous management options were assessed for their hydraulic feasibility and presented in an Options Report.

2.2.1 Initial Review

The SMEC model is extensive and contains substantial detail of the hydrological and hydraulic components. Figure 2-1 shows the general layout of the model (showing pits, pipes and the extent of the model grid). Comments on the methodology and parameters adopted in the SMEC model are:

- The 2D viscosity parameter shown in 2D job control seems to be very large (constant value of 1) compared to the recommended Smagorinsky method with default values of 0.5 and 0.05.
- The XP-SWMM modelling engine used is a pre-2012 version rather than the most recent version.

- The 1D hydraulic model time step (30 seconds) is very large compared to the 2D time step. It is generally recommended to use a 1D hydraulic time step the same as the 2D time step. Also, the results time step (of 120 seconds) for both 1D and 2D models is large which could result in some inconsistencies in model output.
- Both 2D inflow capture and 1D inlet rating were together used in the model. Therefore, the capture of overland flow into pits depends on which inlet capture curve dominates. For the 1D inlet rating, flow capture would not be a function of the actual 2D flood depth, instead an imaginary flood depth in the 1D domain would be used which was derived from the 2D captured flow. The model would either under-estimate or over-estimate overland flow capture in pits, depending on locations. It was recommended to use just the 2D inlet capture in a 2D modelling environment. For a quasi-2D model setting, the 1D inlet rating should be used instead.
- Pit head losses are not modelled. Pipe entrance and exit losses were set to zero in the model. An over-estimate of pipe flow might occur in this model setting which would then give rise to an under-estimate on overland flow. It was recommended to adopt 0.5 for both entrance and exit losses of all pipes and culverts modelled.
- Results from the SMEC model indicate that only one roughness zone was modelled. An investigation on the model setup has identified that the ordering of the roughness zones specified in the model setup is not correct. Although several roughness zones have been specified in the model setup, the roughness zone entitled ‘Overall’ has dominated over the entire modelled area. Therefore, Manning’s ‘n’ roughness value of 0.06 has only been adopted in the model irrespective of road, residential, driveway, commercial, and other landforms in the model.
- The open section of the existing formalised channel between Victor Road and Redman Road was modelled as a 1D link with a constant roughness value representing concrete surfaces. Some sections of the channel are constructed with coarse stones which would have a higher roughness than concrete. In the model, all driveway crossings, walls, and fences between Victor Road and Redman Road along the length of the open channel are omitted in the current 1D/2D setup in the model. This would over-estimate the capacity of the open channel, hence under-estimate overland flows in close proximity of the channel area.
- The adopted tailwater methodology at the Lagoon for the 1D network indicates a small discrepancy for the initial timestep.

It is considered from the initial review, the XP-SWMM model prepared by SMEC is a suitable basis for establishing a model for the Flood Study. The alternative methodology and parameters for the XP-SWMM model to be adopted for the Flood Study are reviewed in comparison to the SMEC model as described in the following section.

2.2.2 Comparative Model Runs

The hydrology and hydraulics of the SMEC model is compared to the preliminary Flood Study model.

2.2.2.1 Hydrology

The SMEC XP-SWMM model hydrology is the runoff method with lumped impervious and pervious subcatchments. It applies a moisture loss based on the Horton maximum-minimum losses and decay relationships. The rainfall-on-grid (direct rainfall) model methodology will be used for the Flood Study in which an initial and continuing loss of rainfall depth for different landforms will be applied.

The modelled rainfall loss is a representation of the proportion of rainfall lost by infiltration into the ground of the total rainfall depth that precipitates. Thus not all rainfall that lands on the ground becomes surface runoff. The loss rate is consequently lower for impervious surfaces such as roofs and road than for pervious surfaces such as grassed and vegetated areas.

A comparison of the runoff for the two methodologies was carried out. Briefly, the Laurenson runoff-routing hydrology was used with all subcatchments split into separate impervious and pervious areas. The SMEC model used the Horton infiltration method and the rainfall-on-grid model used the rainfall initial and continuing loss method which applied:

- Pervious areas - initial loss of 10 mm and a continuing loss of 2.5 mm/h; and
- Impervious areas - initial loss of 1 mm and a continuing loss of 0 mm/h.

Runoff generated at each of the 478 hydrological nodes in the model had a difference in flows of -27% to +377% for the rainfall-on-grid model compared to the SMEC model in a 1% AEP event. The maximum peak flow calculated in the rainfall-on-grid model at a single node is 3.1 m^3/s and the median flow is 0.14 m3/s. Three nodes, SMEC26, SMEC27, and SMEC28, showed an increase of 377% in the rainfall-on-grid model but this is considered an anomaly as the previous catchment width was adopted as 1 m for an area of 1ha. Excluding these three locations, the differences in flow at individual nodes ranges from -27% to +25%, with a median difference of 0%.

2.2.2.2 *Hydraulics*

As the rainfall-on-grid methodology is used for the Flood Study model, the extent of the SMEC model was extended to include the total Dee Why South Catchment. The model was also extended to include portions of the adjoining catchments to model flow interactions between these areas and the Study Area. Figure 2-2 shows the current rainfall-on-grid model layout (showing pits, pipes and the extent of the model grid). The total number of pipe nodes within the model has been limited to a maximum of 1000 due to Council's XP-SWMM license. An initial model with over 1300 pits and pipes was reduced to 1000 by excluding pits and pipes in upstream reaches of the external subcatchments which would have a relatively minor impact on modelled flood behaviour in the Dee Why South catchment.

Rainfall temporal patterns for each storm event were adopted from those used in the SMEC model.

The hydraulic roughness is an estimate of the resistance to flow due to energy loss as a result of friction between a surface and the water. For example, runoff is able to move more freely across a clear hard surface than across a rough vegetated surface. Roughness in XP-SWMM is modelled as Manning's 'n' roughness co-efficient. Figure 2-3 shows the land use zones applied in the rainfall-on-grid model and Table 2-2 lists the adopted Manning's roughness and initial and continuing loss for each land use.

Table 2-2 Model Land Use Roughness and Losses

Land Use	Manning's Roughness	Initial Loss (mm)	Continuing Loss (mm/h)
Overall	0.06	5	1.5
Open	0.06	10	1.5
Residential	0.035	5	1.5
Road	0.02	0	0
Concrete Channel	0.02	0	0
Stone Channel	0.04	0	0
Building	0.035	0	0
Business	0.035	0	0
Open Water	0.012	0	0
Beach	0.03	20	5
Roof	0.015	0	0

The blockage to flow caused by buildings has been modelled by two alternate methods, but the results of both models exclude flows from these areas. Buildings are adopted as inactive flow areas in the SMEC model and in the rainfall-on-grid model as solid grid cells 3 m higher than the surrounding ground level.

A grid cell size of 2 m by 2 m is used in the preliminary rainfall-on-grid model compared to the 1.1 m by 1.1 m grid cells used in the SMEC model. The model resolution of 2 m grid cells is selected for the Flood Study model as it is the best balance between clarity of calculation and results as well as model runtimes. Generally, halving the grid cell size (say from 2 m to 1 m) will quadruple the model simulation time. Model results from similar studies indicate that the increased grid cell resolution from 2 m to 1 m does not necessarily result in significant differences to results. Also, as noted previously, the model extent has been extended to include adjoining sub-catchment areas.

For this comparison, the rainfall-on-grid model has been run for the 1% AEP durations of 60 minute, 90 minute, and 120 minute storms. Figure 2-4 shows the critical duration being predominantly the 90 and 120 minute events in the catchment. The final Flood Study will be run for both shorter durations and longer durations to determine the peak flood behaviour.

The peak water level difference of the rainfall-on-grid model to the SMEC model is shown in Figure 2-5. Figure 2-6 shows the peak depths for the modelled 1% AEP events of the preliminary rainfall-on-grid model. Increases to peak water level are shown on Figure 2-5 at the edges of the building footprints due to them being raised in the rainfall-on-grid model, however these instances do not show as significant depths on Figure 2-6. Peak water levels are lower in some of the primary flowpaths compared to the SMEC model, whilst some of the contributing reaches show a comparative increase, notably at Beverley Job Park.

2.2.2.3 Calibration and Verification of the Flood Study Model

Calibration of the flood model to gauged data and specific flood extents reported for specific events is preferred. However, such detailed information is not available for the Flood Study of this catchment. In lieu of this information it was proposed to undertake the following to verify the model for Stage 3:

- Comparison to gauged data - for the event of June 2012 which had an ARI of less than 1 year;
- Review of historical flood records – examining model results at locations reported as being flood problem areas;
- Comparison to an alternative calculation methodology – hydrology model for one upstream flowpath; and
- Review of previous studies and flood models – comparison to results from the SMEC model.

2.3 GIS Information

Council has supplied GIS data to cover the extended area of the proposed Flood Study model. This includes cadastre, zoning, building footprints and ALS. Raw LiDAR data (in the form of ground surface points) was provided for the entire Dee Why South Catchment by Council. The LiDAR data was collected on the 15th and 16th March 2007 by AAM Hatch. It was supplied with a stated vertical accuracy +/- 0.15 m at 68% confidence and horizontal accuracy +/- 0.55 m at 68% confidence. The raw ground LiDAR data was used to derive a high resolution (2 m grid) digital elevation model (DEM) for the Dee Why South Catchment.

2.4 Stormwater Infrastructure Survey

Pit and pipe details compiled in the SMEC XP-SWMM model were adopted for the Flood Study model.

Council has compiled closed-circuit television (CCTV) inspections of some pipe sections within the catchment. CCTV footage of the conduits can be applied for maintenance assessments (to identify blockages and structural damage), and assessments of the conduit configuration (external connections and pipe alignments). Debris was noticed in some sections resulting in potential reduced capacity of the pipe, however this is primarily a maintenance issue rather than for the flood modelling. Effects of blockage on the flood model results are assessed by the sensitivity runs which include blockage scenarios.

The pipeline configuration in the flood model was reviewed based on the CCTV footage. Reaches reviewed include:

- Dee Why Grand (Pacific Parade) – an additional pipe connection to the trunkline was evident that has not been included in the model. This branchline is considered to be for internal site drainage (which is not explicitly modelled) rather than Council's street drainage network.
- Pacific Parade – a section of culvert is larger than the upstream and downstream links. In the model, this section is adopted as the size of the downstream culvert which will be the factor limiting flow conveyance.

- Pittwater Road (near Pacific Parade) – the pipelines crossing Pittwater Road may not be constructed in a straight line between the west and east side of the road as setup in the flood model. Instead it may comprise additional bends to allow a more perpendicular crossing of the road. CCTV footage of the west side of the road did not clarify the layout. The straight line layout has been retained in the model as the alternate layout would likely only result in a relatively minor increase in energy losses (due to bends and pipe friction).

An upgraded drainage pipe from the existing 600 mm diameter to 1200 mm diameter at Painters Parade to Mooramba Road is also proposed but is not included in the model as it is currently not active.

2.5 Channel Survey

The Study Area includes three reaches of open channel to be defined in the Flood Study model:

1. Victor Road to Redman Road;
2. Downstream of Pittwater Road between Pacific Parade and Oaks Avenue; and
3. Downstream of Dee Why Parade.

Council supplied detailed survey for Channel Reach 1 by Craig & Rhodes, and for Reach 2 by Land Partners. Survey of Channel Reach 3 and cross-sections of inundated road profiles along Lewis Street, Dela Close, Redman Road, Delmar Parade, Sturdee Parade and Pacific Parade was not conducted for this study.

2.6 Rainfall and Streamflow Data

Manly Hydraulics Laboratory (MHL) installed two rainfall gauges and three flow gauging stations in the catchment for Council. The objective of the data collection was to provide site-specific information to calibrate the flood model for Stage 3.

Flood models are ideally calibrated to actual records to confirm they accurately represent flood behaviour in the catchment. Specialist gauges that record data at frequent timesteps are required as the flood model calculates flow behaviour to time periods of minutes or even seconds. Generally the specific rainfall event records can be input in the flood model and the model outputs compared to the recorded flow behaviour at the gauges. Model parameters and data can then be adjusted to fine-tune and refine the model to specific conditions in the catchment.

Rain gauges were installed at Beverley Job Park and the Civic Centre on 4 May 2012 to record every 0.5 mm of rainfall to Eastern Standard Time. The flow gauges log the level and velocity in 15 minute intervals to Eastern Standard Time at three locations – Redman Road, Oaks Avenue and Dee Why Parade. Approximate locations are shown in Figure 2-7.

2.6.1 Rainfall

Rainfall Intensity-Frequency-Duration (IFD) for the catchment are listed in Table 2-3 and have been determined using the Bureau of Meteorology (BoM) website tool for review of the recorded rainfall events.

Peak rain depths in each month recorded by the gauges and evaluated by MHL as rainfall intensities are summarised in Table 2-4 and Table 2-5 with the ARI estimated for the event. The highest recorded rainfall is 69.5 mm and 71 mm at Beverley Job Park and Civic Centre respectively on 11th June 2012.

Table 2-3 Design Rainfall Intensities (mm/h)

Frequency / Duration	1 Year ARI	2 Year ARI	5 Year ARI	10 Year ARI (10% AEP)	20 Year ARI (5% AEP)	50 Year ARI (2% AEP)	100 Year ARI (1% AEP)
5 min	97.9	126	160	180	206	240	266
15 min	63	81	105	119	137	161	179
30 min	44.6	57.9	76	86.6	101	119	133
1h	30.4	39.6	52.4	60	69.9	83	93
2h	20.3	26.4	34.8	39.9	46.4	55.1	61.8
3h	15.9	20.7	27.2	31.1	36.1	42.7	47.8
6h	10.5	13.6	17.7	20.2	23.3	27.5	30.7
12h	6.9	8.92	11.6	13.1	15.2	17.9	19.9
24h	4.44	5.76	7.55	8.61	10	11.8	13.2
48h	2.76	3.6	4.8	5.53	6.47	7.72	8.68

Table 2-4 Approximate ARI of Rainfall Events for Beverley Job Park

Storm Event	Details	Duration							
		15 mins	30 mins	60 mins	3 hour	6 hour	12 hour	24 hour	48 hour
Jun-12	Intensity (mm/h)	26	19	13	6.7	5.8	5	3.3	1.9
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Jul-12	Intensity (mm/h)	8	5	3	1.2	1	0.7	0.5	0.3
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Aug-12	Intensity (mm/h)	12	6	3	1.8	1.1	0.5	0.3	0.3
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Sep-12	Intensity (mm/h)	12	8	6	2.3	1.4	0.7	0.4	0.2
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Oct-12	Intensity (mm/h)	10	6	3	1.3	0.7	0.5	0.2	0.2
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Nov-12	Intensity (mm/h)	22	18	16.5	6.2	3.1	1.6	0.8	0.5
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Dec-12	Intensity (mm/h)	24	18	9.5	4.2	3.8	2.2	1.2	0.7
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y

Table 2-5 Approximate ARI of Rainfall Events for Civic Centre

Storm Event	Details	Duration							
		15 mins	30 mins	60 mins	3 hour	6 hour	12 hour	24 hour	48 hour
Jun-12	Intensity (mm/h)	22	15	12.5	8	6.3	5.1	3.4	2
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Jul-12	Intensity (mm/h)	10	6	3.5	1.5	1.1	0.7	0.5	0.4
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Aug-12	Intensity (mm/h)	12	7	3.5	2	1.3	0.6	0.2	0.2
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Sep-12	Intensity (mm/h)	10	7	5.5	2.3	1.3	0.7	0.4	0.2
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Oct-12	Intensity (mm/h)	14	7	5	1.8	1.1	0.6	0.3	0.2
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Nov-12	Intensity (mm/h)	18	12	9	3.7	1.9	1	0.6	0.3
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y
Dec-12	Intensity (mm/h)	26	19	10	4.2	3.8	2.2	1.3	0.7
	Approx. ARI	<1y	<1y	<1y	<1y	<1y	<1y	<1y	<1y

The total rainfall depth recorded for each of the five months in Beverley Job Park and Civic Centre is summarised in Table 2-6 and shown in Figure 2-8. Overall the rainfall depths indicate reasonable similarity between the two sites.

Figure 2-8 Recorded Monthly Rainfall Depth

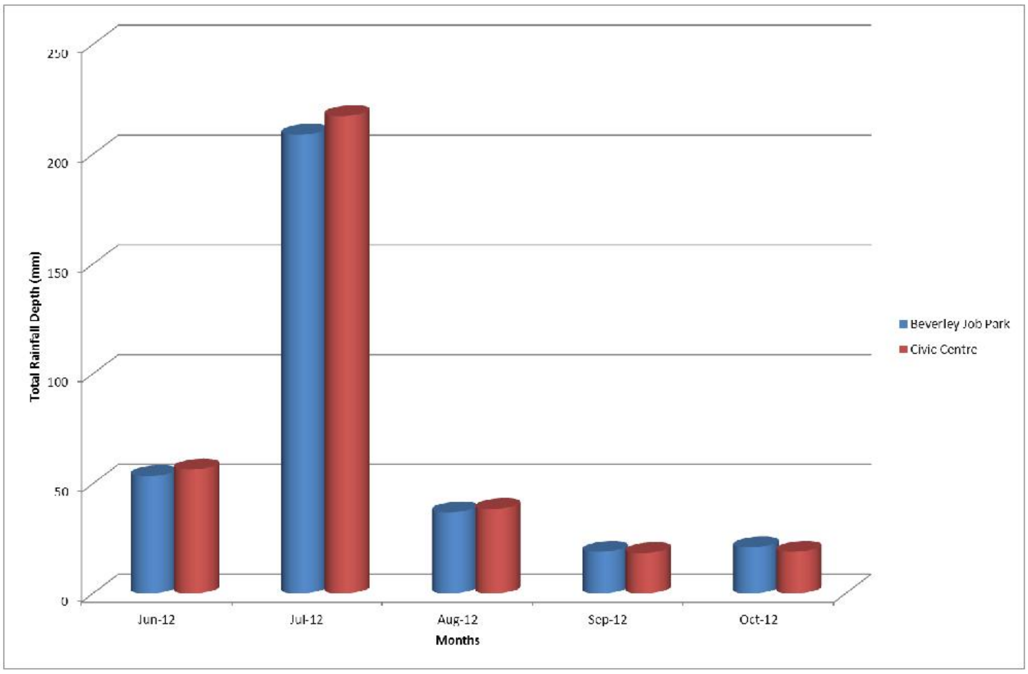


Table 2-6 Recorded Monthly Rainfall Depth

Month	Total Rainfall Depth (mm)	
	Rain Gauge Location	
	Beverley Job Park	Civic Centre
June	53.5	56.5
July	209.0	217.5
August	37.0	38.5
September	19.0	18.5
October	21.0	19.0
November	52.0	45.5
December	46.0	45.0

In the period of gauge operation there has not been a storm event of greater than 1 year ARI. This prevents calibration of the flood model to these recorded events. Calibration of a flood model is generally recommended to cover a range of event frequencies including a large event (e.g. 1% AEP) and a more frequent event (e.g. 5% to 10% AEP). The flood model of Stage 3 will be run to define flood behaviour to a 1 year ARI event however the recorded rainfall events have a peak intensity notably less than the 1 year ARI.

2.6.2 Channel Flow

MHL identified problems with the data recorded at Dee Why Parade and undertook the following:

1. The sensor for flow gauge at Dee Why Parade was relocated (21/6/2012) 2 m upstream to avoid the hydraulic jump during wet weather flows.
2. On 13/7/2012 the sensor and logger were re-configured to improve the quality of the data.

The recorded monthly rainfall depths are shown in Figure 2-8.

The peak flow recorded for each of the five months at the three flow gauges is summarised in Table 2-7 and shown in Figure 2-9. It is considered that the non-ideal operation of the Dee Why Parade gauge for the June and July periods results in the abnormal peak flow which is lower than the upstream gauges.

Table 2-7 Peak Flow Recorded

Month	Peak Discharge (m^3/s)		
	Flow Gauge Location		
	Redman Road	Oaks Avenue	Dee Why Parade
Jun-12	1.88	2.21	0.24
Jul-12	0.22	0.45	0.11
Aug-12	0.16	0.42	0.51
Sep-12	0.22	0.42	0.74
Oct-12	0.16	0.25	0.62
Nov-12	0.40	1.10	4.52
Dec-12	0.47	0.71	1.47

Figure 2-9 Peak Flow Recorded

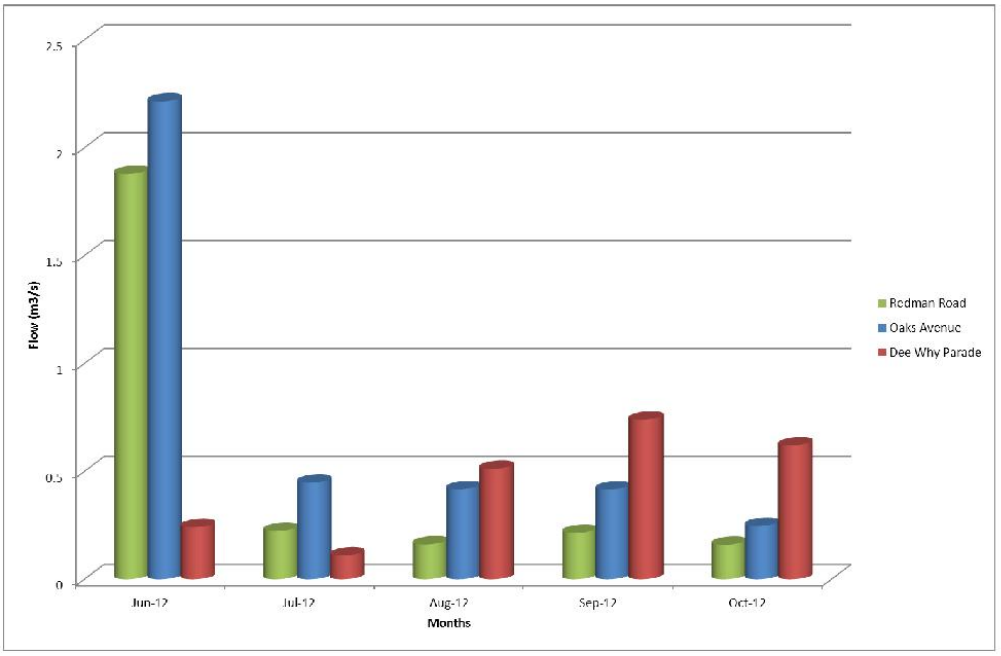


Table 2-8 lists the time of the peak discharge recorded at the gauges. It would be expected that the peak flow at the downstream gauge would occur later than the upstream gauge. This is not evident from the recorded data but may be a result of the small rainfall depths that occurred in the gauging period. Localised rainfall patterns are more likely to influence the timing of the peaks for the recorded periods at each location for the smaller more frequent events.

Table 2-8 Peak Discharge Time

Month	Peak Discharge Time		
	Flow Gauge Location		
	Redman Road	Oaks Avenue	Dee Why Parade
Jun-12	11/06/2012 15:30	11/06/2012 10:30	10/06/2012 14:00
Jul-12	22/07/2012 21:15	5/07/2012 19:15	5/07/2012 22:15
Aug-12	24/08/2012 2:00	24/08/2012 2:00	24/08/2012 2:15
Sep-12	18/09/2012 19:45	18/09/2012 19:45	18/09/2012 19:00
Oct-12	1/10/2012 2:00	9/10/2012 2:00	11/10/2012 2:00
Nov-12	9/11/2012 0:45	9/11/2012 0:45	9/11/2012 0:30
Dec-12	25/12/2012 11:45	25/12/2012 12:00	25/12/2012 15:15

Manly Hydraulics Laboratory supplied photographs from the channel between Beverley Job Park and Redman Road taken on the 11 June 2012 (Figures 2-10 and 2-11). Council supplied photographs in this area for the storm event of 21-22 July 2011 as shown in Figures 2-12 to 2-19.

Figure 2-10 Photograph of 11/6/2012 (from MHL)

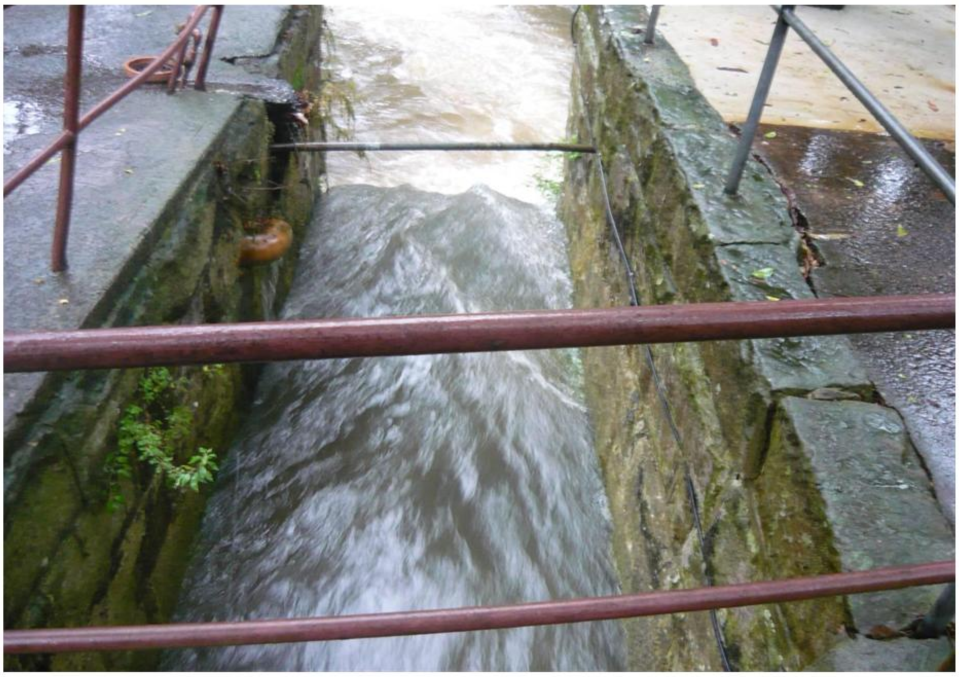


Figure 2-11 Photograph of 11/6/2012 (from MHL)

Figure 2-12 Photograph of 21/7/2011 at Redman Road (from Council)

Figure 2-13 Photograph of 22/7/2011 11:30AM at Beverley Job Park (from Council)

Figure 2-14 Photograph of 22/7/2011 at 3 Lewis St (from Council)

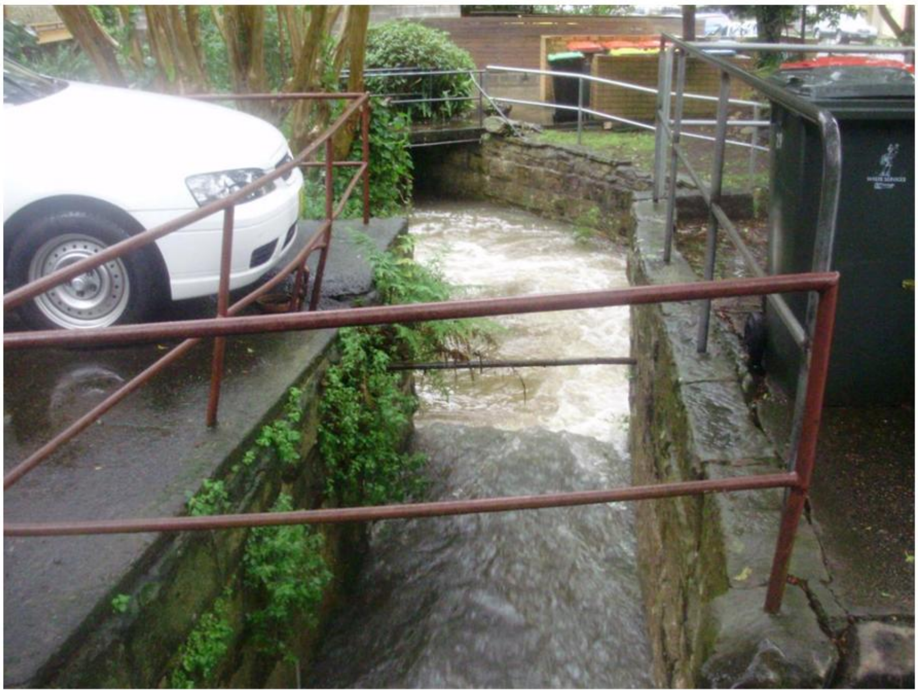
Figure 2-15 Photograph of 22/7/2011 11:44AM at 5 Dela Crescent (face u/s) (from Council)

Figure 2-16 Photograph of 22/7/2011 at 27 Redman Road (from Council)

Figure 2-17 Photograph of 22/7/2011 11:31AM at 21 Redman Road (from Council)

Figure 2-18 Photograph of 22/7/2011 at 21 Redman Road (from Council)

Figure 2-19 Photograph of 22/7/2011 11:33AM at 19 Redman Road (from Council)



3 Community Engagement

Community consultation is an important component of the project, being one of the key objectives of Council to ensure that the community can clearly understand potential flood risks within the catchment. The NSW Government Floodplain Development Manual (2005) details a framework and process for implementing the Flood Prone Land Policy. Following the completion of the Flood Study, a Floodplain Risk Management Study and Plan is to be completed which reviews potential options for flood management and mitigation. The resultant Plan is a strategic framework for Council to implement policies and undertake works. Community involvement throughout the process is important for acceptance of the final recommendations of the process.

The initial community consultation stage is to advise residents and allow input to the study. Initially a questionnaire was mailed to all residents in the catchment enquiring about a range of flood related issues. Council was also seeking residents who would be interested in joining the Dee Why South Catchment Working Group.

The questionnaire and other information related to the study were also available on the internet linked to Council's website. Appendix B has items from the consultation process including a Manly Daily newspaper article (Figure B1), a Council column from the Manly Daily (Figure B2), an extract from Council's website (Figure B3), and the documents issued to residents (cover letter and questionnaire in Figure B4). A summary of questionnaire responses is provided in Section 3.1.

An exhibition period of the draft report comprises a significant component of community consultation which is held following the preparation of the draft report in Stage 3. This allows feedback and input from the community prior to the completion of the report. A summary of the public exhibition is provided in Section 3.2.

3.1 Community Questionnaire

The questionnaire submission period of four weeks closed on October 26, 2012. A total of 203 responses were received – 44 completed online and 159 hardcopies returned.

Eight questions formed the basis for the questionnaire and responses are summarised in the following sections.

3.1.1 Question 1 – Time of Residence

Table 3-1 lists the responses for the years that the respondent has lived / worked in the catchment. Time of residence is an important criteria for evaluation of the responses that follow. Specifically, a resident may have lived in the catchment for a couple of years and thus may not have experienced a flood event in the catchment due to no significant storms occurring within their relatively short time in the area.

A quarter of the responses to this Question indicated they have been in the catchment for less than five years which would have an effect on awareness of local flooding (noting Question 2). Notably 38% have lived in the area for more than 20 years.

Table 3-1 Time of Residence

Period of Residence	Number of Responses	Percentage
0 to 5 years	50	27%
6 to 10 years	29	16%
11 to 15 years	23	12%
16 to 20 years	14	8%
More than 20 years	70	38%
Total	*186*	

3.1.2 Question 2 – Awareness of Flooding

Table 3-2 lists the responses for awareness of flooding in the catchment. Responses to awareness of flooding is a guide for general flood exposure in the catchment, however it can be influenced by a resident's location and time in the catchment as well as the period since the last major storm event. It can be applied to the next stage of the Floodplain Management Process for the implementation of education campaigns to raise the general awareness and specific flooding locations and risks within the catchment.

Forty percent (40%) indicated they are not aware of potential flooding in the catchment which is an important objective of the study of defining flood behaviour to enable the community to be informed about potential risks.

Table 3-2 Flood Awareness of Respondents

Level of Awareness	Number of Responses	Percentage
Very Aware	54	28%
Some Awareness	62	32%
Not Aware	77	40%
Total	*193*	

Awareness of flooding in the catchment does not directly relate to the years residing in the catchment as it is also dependent on the respondent's location in the catchment and floodplain extent.

3.1.3 Question 3 – Flood Experience

This question provides an indication of the impacts of flooding to residents in the catchment. The description of particular events and impacts is relevant for the flood model calibration / verification process.

Responses identified the following experience of flood events:

- 12 recorded that their daily routine was affected due to flooding;
- 4 respondents were concerned for their safety;
- 25 had access to their property affected;
- 21 respondents had their property damaged; and,
- 2 experienced difficulties in operating their business.

3.1.4 Question 4 – Property Inundation

The degree of affectation at particular properties is relevant to the flood model calibration / verification process as it identifies the actual impact advised by the resident to compare to the flood model outcome. Responses also indicate the general exposure within the catchment to flood risk and property damage in particular areas.

Sixty-six (66) respondents indicated their residential/commercial property has been flooded compared to 129 indicating they had not been flooded. Affectation on the property is summarised in Table 3-3.

3.1.5 Question 5 – Drain and Culvert Blockage

Responses to this question serve several purposes. For model calibration / verification, residents may advise of flooding impacts worse than modelled which may be the result of blockage to stormwater inlets and conduits. The responses may identify particular locations requiring maintenance to remove debris or locations that are particularly susceptible to blockages during storm events.

Fifty-two (52) respondents advised that drains or culverts were blocked, generally by leaves and garbage (Table 3-4), compared to 113 responses that drains were not blocked during heavy rainfall. About 20% of the total responses indicated blockage of half to almost entirely blocked drainage systems. Table 3-5 lists locations identified in the questionnaire responses.

Table 3-3 Property Inundation

Flooding Description	Number of Responses	Street Location of Above-Floor Flooding
Front yard or backyard	22	
Garage or shed	15	
Residential – below floor level	15	
Residential – above floor level	1	Redman Road
Commercial – below floor level	1	
Commercial – above floor level	3	Pittwater Road, Dee Why Parade, Mooramba Road
Industrial	0	

Table 3-4 Drain and Culvert blockage

Blocked Drain/Culvert	Number of Responses	Percentage
A Little (<25%)	3	6%
A Quarter (25%)	4	8%
Half (50%)	16	31%
Mostly (75%)	21	40%
Almost Entirely (>75%)	8	15%
Total	*52*	

Table 3-5 Blocked Culverts

Location	Comments
Hawkesbury Ave and Clarence Ave	Culvert Blocked 75% corner of Hawkesbury Ave and Clarence Ave
Howard Ave and Clyde Rd	Culvert Blocked 50%
The Circle	Culvert 50% Blocked, corner of The Circle.
Fisher Rd / Pittwater Rd	Flooding Fisher Rd/ Pittwater Rd
Howard Ave and Avon Ave	Culvert Blocked 75%
Warringah Rd and Pittwater Rd	Culvert Blocked 75%
Howard Ave and Clyde Rd	Culvert Blocked 50%
Front of 22 Clyde Rd Dee Why	Culvert Blocked
Oaks Ave and Avon Ave	Culvert Blocked 75%
17 - 19 Mooramba Rd	Culvert Blocked
Corner of Lismore Ave and Westminster Ave	Sand blocking the entrance of the Dee Why Lagoon
Headland Road, at the lower end of Wingala Reserve	Culvert Blocked 50%
Corner of South Creek Rd and Pittwater Rd	Culvert Blocked 50%
Mundara Place	Culvert along Mundara Place Blocked 50%
Dee Why Lagoon	Dee Why Lagoon filled with silt, rotting vegetation

3.1.6 Question 6 – Flooding Locations

Table 3-6 lists other locations that respondents had seen flooding in the catchment. Pittwater Road at the intersection of Lismore Avenue was the most frequent response. This location however is outside of the Dee Why South Catchment and is therefore not assessed in this Study.

Table 3-6 Flooding Locations

Location
Howard Ave and Clyde Rd
Beverley Job Park
Delmar Parade
Oaks Avenue
Pittwater Road at Lismore Avenue
Hawkesbury Avenue
Howard Avenue and Dee Why Parade
Walter Gors Park (on Howard Avenue)
Alamein Avenue
James Meehan Reserve

Figure 3-1 shows general locations of flooded properties and blocked culverts advised in the questionnaire.

3.1.7 Question 7 – Additional Materials

Photographs or flood marks from previous storm events assist in the model calibration / verification process supplementing the descriptions provided. Photographs may also be relevant for local historians.

No significant additional materials were received.

3.2 Public Exhibition

The draft report of this Flood Study was publicly exhibited inviting comments and feedback from the community and stakeholders from 30 May 2013 to 19 June 2013. A notice was published in the Manly Daily on 1 June and the associated media release is attached as Figure C1 in Appendix C. Figures C2 and C3 in Appendix C are the letter and brochure posted to residents within the extent of the flood planning level and probable maximum flood. Open information sessions were held in Council Chambers at the Civic Centre on 6 June, 13 June, and 15 June.

Three written submissions were received during the exhibition period as summarised in Table 3-7. Eight residents and property owners attended the meetings and comments are summarised in Table 3-8.

Table 3-7 Summary of Written Submissions

Comment	Response
Submission 1 – Query regarding flood affectation on individual property.	Reported flood behaviour at site corresponds with inundation extents shown in Flood Study. Council to follow up enquiry.
Submission 2 – Suggestion that starting immediately hospitals, schools, facilities for the elderly not be established in flood affected areas. Additionally, sensitive facilities, such as telephone exchanges, and underground car parks should be protected against king tides and floods. Developers should be advised of the risk of building in flood affected areas.	The Flood Study will inform Council and property owners of flood behaviour in the catchment. The existing Warringah Development Control Plan (2011) specifies controls on proposed development. The next stage of the Floodplain Management Process is the Risk Management Study and Plan includes examination of the applicable development controls.
Submission 3 - Comment regarding flood affectation on individual property.	Reported flood behaviour at site corresponds with inundation extents shown in Flood Study. Council to follow up request for additional information.
Submission 3 – Future development of public reserves may increase flood affectation of adjacent properties if grass and trees are replaced with concrete. Council should consider the role of parks and reserves, as well as other community properties, in flood mitigation.	The Flood Study will inform Council of flood behaviour at reserves for future planning. The existing Warringah Development Control Plan (2011) specifies controls on proposed development. The next stage of the Floodplain Management Process is the Risk Management Study and Plan includes assessment of landuses within the catchment.
Submission 3 – Concern as noticed significant amounts of rubbish alongside canal/lagoon. Also potential impact on fauna of lagoon. Recommend education program for waste disposal / recycling and its effect on pollution and flooding.	The next stage of the Floodplain Management Process is the Risk Management Study and Plan evaluates management measures in the catchment (including education programs). Council to follow up on issue of rubbish alongside channels.

Table 3-8 Summary of Comments from Meetings

Comment	Response
Comment 1 – How long has Council known about flooding in Narraweena?	Council has undertaken numerous studies in the catchment previously, but this Flood Study is the first to review inundation across the whole catchment.
Comment 2 – What effect will this Study have on insurance costs?	Insurance companies are independent of Council and rely on their own assessment of natural hazard when setting premiums.
Comment 3 – Have not experienced flooding as shown in the Flood Study at a particular location.	The location is a trapped lowpoint potentially susceptible to inundation as shown in the Flood Study. Partial blockage of stormwater inlets are accounted for in the Study. Actual flooding at the location may not have been witnessed due to the circumstances of previous storm events not being of a large magnitude and inlet blockage being minimal.

4 Hydrological and Hydraulic Modelling

The XP-SWMM model established by SMEC is reviewed as described in Section 2 and is considered suitable as a modelling base for the Flood Study.

XP-SWMM is a comprehensive software suite for planning, modelling and managing drainage systems that is widely used both in Australia and overseas. The suite simulates stormwater flows by calculating flows in channels and pipes as one-dimensional (1D) elements coupled to a two-dimensional (2D) surface of the floodplain and overland flow area. The 1D and 2D components incorporate details of surface roughness, elevations, and losses for example. Model simulations can be run for a range of storm events including small to large rainfall intensities and recorded historical event rainfall patterns. Data and model outputs are readily integrated in a geographical information system (GIS) for review and presentation of results.

Flood modelling for this study uses the rainfall-on-grid (direct rainfall) methodology in XP-SWMM whereby rainfall is applied directly to every grid cell in the model. Each cell represents a pocket of land surface described by elevation, land use and soil infiltration to develop a virtual ground surface of the catchment. The model then performs hydrological and hydraulic calculations to determine flow quantity and distribution from each cell. Generally, the rainfall-on-grid methodology is better suited to identifying and simulating overland flowpaths.

Calculations in the flood model generally relate to two categories:

- Hydrological - to determine flowrates at particular times during the rainfall event; and
- Hydraulic - to determine the behaviour (eg depth and velocity) and routing (eg direction of runoff) in conduits or on a ground surface.

4.1 Hydrology

4.1.1 Design Rainfall

Design rainfall intensities for the 1% AEP, 5% AEP, 10% AEP, 5 year ARI, and 1 year ARI were adopted from the SMEC XP-SWMM model. These values were verified by comparing peak rainfall intensities for various events using the rainfall Intensity-Frequency-Duration (IFD) parameters within the catchment from the Bureau of Meteorology website. The IFD parameters are listed in Table 4-1 and the calculated average intensities are listed in Table 4-2.

Table 4-1 Design IFD Parameters for Dee Why South Catchment

Parameter	Value
2 Year ARI 1 hour Intensity	39.66 mm/h
2 Year ARI 12 hour Intensity	8.95 mm/h
2 Year ARI 72 hour Intensity	2.66 mm/h
50 Year ARI (2% AEP) 1 hour Intensity	83.95 mm/h
50 Year ARI (2% AEP) 12 hour Intensity	17.84 mm/h
50 Year ARI (2% AEP) 72 hour Intensity	5.81 mm/h
Skew	0
F2	4.3
F50	15.87
Temporal Pattern Zone	1

Table 4-2 Design Rainfall Intensities (mm/h)

Frequency-Duration	1 Year ARI	2 Year ARI	5 Year ARI	10 Year ARI (10% AEP)	20 Year ARI (5% AEP)	50 Year ARI (2% AEP)	100 Year ARI (1% AEP)
5 min	97.9	126	160	180	206	240	266
15 min	63	81	105	119	137	161	179
30 min	44.6	57.9	76	86.6	101	119	133
1h	30.4	39.6	52.4	60	69.9	83	93
2h	20.3	26.4	34.8	39.9	46.4	55.1	61.8
3h	15.9	20.7	27.2	31.1	36.1	42.7	47.8
6h	10.5	13.6	17.7	20.2	23.3	27.5	30.7
12h	6.9	8.92	11.6	13.1	15.2	17.9	19.9
24h	4.44	5.76	7.55	8.61	10	11.8	13.2
48h	2.76	3.6	4.8	5.53	6.47	7.72	8.68

Probable Maximum Precipitation (PMP) is defined on the Bureau of Meteorology website as "the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends". Australian Rainfall and Runoff describes estimation of the AEP for a PMP based on the catchment area, noting that there is considerable uncertainty in this methodology. For this catchment, the PMP is estimated as a 1×10^{-7} AEP (equivalent to a 1 in 10,000,000 year ARI). PMP rainfall intensities for Dee Why were estimated using the parameters listed in Table 4-1 within XP-RAFTS which uses the procedures documented in Bureau of Meteorology Generalized Short-Duration Method Bulletin 53.

Rainfall intensities for the 0.1% AEP and 0.5% AEP were estimated in XP-RAFTS which uses the calculation methodology described in Australian Rainfall and Runoff.

4.1.2 Rainfall Losses

As described in Section 2.2.2, the rainfall loss is a representation in the XP-SWMM model of the proportion of rainfall which is infiltrated into the ground and does not contribute to runoff. In order to obtain similar runoff volume as predicted using the moisture loss hydrological model as adopted in the original SMEC model for the Dee Why South Catchment, a comparison was undertaken of the runoff for the moisture loss model, and rainfall-on-grid methodology. Based on the comparison, initial and continuing losses were derived for a range of existing land uses in the Dee Why South Catchment. These are listed in Table 4-3.

Table 4-3 Model Land Use Roughness and Losses

Land Use	Manning's Roughness	Initial Loss (mm)	Continuing Loss (mm/h)
Overall	0.06	5	1.5
Open	0.06	10	1.5
Residential	0.035	5	1.5
Road	0.02	0	0
Concrete Channel	0.02	0	0
Stone Channel	0.04	0	0
Building	0.035	0	0
Business	0.035	0	0
Open Water	0.012	0	0
Beach	0.03	20	5
Roof	0.015	0	0

4.2 Hydraulic

4.2.1 Model Terrain

The model terrain developed from aerial laser survey (ALS) data was supplied by Council in a two-dimensional digital terrain model (DTM) format for the extension of the original SMEC model to form the presently adopted rainfall-on-grid model. Raw LiDAR data (in the form of ground surface points) was provided for the entire Dee Why South Catchment by Council (as described in Section 2.3). This raw ground LiDAR data was used to derive a high resolution digital elevation model (DEM) of for the Dee Why South Catchment. The DEM was applied as a 2 m by 2 m grid-cell size to represent the 2D model surface in XP-SWMM.

4.2.2 Buildings

As the rainfall-on-grid approach was adopted in the modelling, runoff from the impervious roof areas of buildings would need to be modelled. If these were not explicitly modelled the total runoff volume from the study area would be grossly under-estimated. In order to allow for the runoff from the impervious roof areas to be modelled, buildings which include residential, commercial, and industrial were raised in the model. Similarly, the blockage to flow caused by building footprints has been modelled with their solid grid cells 3 m higher than the surrounding ground level. This was guided by the use of the aerial photographs supplied by Council.

4.2.3 Roughness

A series of land use types were identified for the study area based upon aerial photographs and site visitations. An appropriate Manning's roughness value was applied to each of the identified land uses. Table 4-1 lists the Manning's roughness values adopted in the rainfall-on-grid model as shown on Figure 2-3.

4.2.4 Model Extent

As the rainfall-on-grid methodology has been used for the flood study model, the extent of the SMEC model was extended to include the total Dee Why South Catchment. The model was also extended to include portions of the adjoining catchments to model flow interactions between these areas and the study area in order to provide a more accurate overland flow profile for the design storm events modelled. Figure 2-2 shows the current rainfall-on-grid model extent as well as pits and pipes. The total number of pipe nodes within the model has been limited to a maximum of 1000 due to Council's XP-SWMM license.

Rainfall temporal patterns for each storm event were adopted from those used in the SMEC model. Figure 2-3 shows the land use zones applied in the rainfall-on-grid model and Table 4-1 lists the adopted Manning's roughness and initial and continuing loss for each land use.

A grid cell size of 2 m by 2 m is used in the rainfall-on-grid model which consists of over 1.5 million cells in the model. The model resolution of 2 m grid cells is selected for the flood study model as it is the best balance between clarity of calculation and results as well as model runtimes. Generally, halving the grid cell size (say from 2 m to 1 m) will quadruple the model simulation time. Model results from similar studies indicate that the increased grid cell resolution from 2 m to 1 m does not necessarily result in significant differences to results. Also, as noted previously, the model extent has been extended to include adjoining sub-catchment areas.

For this comparison, the rainfall-on-grid model has been run for the 1% AEP durations of 30 minute, 60 minute, 90 minute, 120 minute and 180 minute storms. Figure 2-4 shows the critical duration being predominantly the 90 and 120 minute events in the catchment.

The peak water level difference of the rainfall-on-grid model to the SMEC model is shown in Figure 2-5. Figure 2-6 shows the peak depths for the modelled 1% AEP events of the preliminary rainfall-on-grid model. Increases to peak water level are shown on Figure 2-5 at the edges of the building footprints due to them being raised in the rainfall-on-grid model, however these instances do not show as significant depths on Figure 2-6. Peak water levels are lower in some of the primary flowpaths compared to the SMEC model, whilst some of the contributing reaches show a comparative increase, notably at Beverley Job Park.

4.2.5 Pits and Pipes

Additional pit and pipe information supplied by Council to cover additional sub-catchment areas in the rainfall-on-grid model was incorporated into the model. However, due to Council's XP-SWMM license, the model was trimmed from over 1300 pits and pipes to a limit of 1000 pit nodes in the model. Those pits and pipes deleted from the model were located in upper reaches of areas outside the study area catchment.

In the model, all stormwater drainage pipes, box culverts, and open channels in the Dee Why South Catchment were modelled.

4.2.6 Pit Inlet Rating Curve

Pit inlet capacities were determined in the SMEC XP-SWMM model based upon the detailed survey of pit inlet type received. The pit type and size were not explicitly stated in the model. A blockage factor of 50% for sag and 20% for on-grade pits was adopted in the SMEC model for pits within the inner catchment. For the Flood Study model, 2D inlet rating curves were derived based upon SMEC's modelled 1D inlet rating curves identified for kerb inlets.

4.2.7 Pit Losses

Hydraulic head losses at pits are not part of the modelling capabilities in the current version of the software modelling suite. Losses were considered in the model by adopting a higher conduit entrance and exit loss of 0.5.

4.2.8 Boundary Condition

A fixed water level is used in the XP-SWMM model to represent the level in Dee Why Lagoon at the downstream boundary of the model. This tailwater level of 2.3 m AHD represents a 5% AEP storm event level in the Lagoon.

The sensitivity of the model to changes in adopted parameters is assessed in Section 7.

5 Calibration and Validation

The XP-SWMM computer model was calibrated and validated as described in this Section to demonstrate that it is a suitable representation of the catchment to simulate flooding.

5.1 Hydrology Verification

As the direct-rainfall (rainfall-on-grid) methodology is still relatively new to the industry, it was verified against a traditional hydrological model. The verification was undertaken by comparing the results for a 1% AEP event for the direct-rainfall model with the results from a traditional hydrological model (XP-RAFTS). It is not always expected that the two models will exactly match (in fact, two separate traditional hydrological models with similar parameters can produce significantly different results). However, where there are differences some interpretation of the results can be made, and the models can be checked as to why this is the case.

The comparison was undertaken on relatively small sub-catchments, as a larger sub-catchment would be more influenced by hydraulic controls, such as culverts and localised depression storages that would not be accounted in the hydrological model. In addition, the primary aim of this comparison is to ensure that the timing and peak flows from the direct rainfall hydraulic model (XP-SWMM) are reasonable, with the focus on the runoff areas rather than the mainstream flooding areas.

The Dee Why South Catchment has limited reaches suitable to allow verification of the overland flow. However, the flows downstream of The Circle prior to entering Beverley Job Park (shown in Figure 5-1) have been compared. Table 5-1 lists flows estimated by the XP-RAFTS hydrological model and the XP-SWMM model with rainfall-on-grid.

Table 5-1 Results for XP-SWMM2D and XP-RAFTS Models

Location	Catchment Area (ha)	XP-RAFTS Peak Flow (m^3/s)	XP-SWMM Peak Flow (m^3/s)
The Circle	4.508	1.66	0.97

These results indicate a reasonable agreement between the rainfall-on-grid model (XP-SWMM) and the XP-RAFTS models. Flows from the overland component and the piped component of the XP-SWMM model were combined to determine the peak flow discharging from the site (as is the case in the XP-RAFTS model). The overall volume of runoff is higher in the XP-RAFTS model than in the XP-SWMM model due to storage effects in the elevation grid that details localised depression storages, such as at roads, properties, and buildings, which are not represented in the XP-RAFTS model.

Peak flows are also reduced in the XP-SWMM model compared to the XP-RAFTS model due to the storage effects and due to the elevation and roughness grids in XP-SWMM that result in a more detailed assessment of the conveyance and concentration of flows.

The XP-SWMM model using the rainfall-on-grid methodology is therefore considered to suitably model flow behaviour when compared with the traditional separate hydrology model methodology.

5.2 Verification to SMEC Model

A comparison was undertaken between the modelled results of the current study with the previous study Dee Why Town Centre Drainage Design (SMEC, 2011). Peak flows are compared at the same locations used by SMEC 2011 for calibration (shown in Figure 5-2) and results are listed in Table 5-2. Two general points are noted:

- The approach of modelling is rainfall-on-grid in the current model compared to a subcatchment delineated hydrology and hydraulic model; and

- The inflow point source was specified in SMEC (2011) whereas in the current model the flow is generated based on the grid whereby storage and depression effects occur.

Table 5-2 Comparison of Results for XP-SWMM Validation

Location		XP-SWMM Peak Flow (m^3/s)	
ID	**Description**	**Cardno**	**SMEC**
Location1	Downstream of Dee Why Parade	18.5	43.7
Location2	Redman Road	28.3	24.3
Location 3-1	Pacific Parade	5.1	2.8
Location 3-2	Sturdee Parade East	3.3	3.6
Location 3-3	Sturdee Parade West	13.5	6.4

The result shows a significant decrease in flow at Location 1, which is downstream of the study area, in the current result compared to the SMEC (2011) model. This may be partially due to the storage effects and roughness grids in current XP-SWMM 2D that result in more detailed assessment of the conveyance and concentration of flows. Also, the SMEC model is significantly different to the Flood Study model in terms of modelled parameters and calculation methodology (as described in Section 2.2), thus the two may would not be expected to give identical peak flow results.

5.3 2011 and 2012 Event Calibration

Gauged rainfall and channel flows were available for the June 2012 event from the Manly Hydraulics Laboratory data. Rainfall data for the July 2011 event was sourced from a Bureau of Meteorology rainfall pluviometer at Dee Why Bowling Club (Station 566068) which is less than 2 km north of the CBD. Model simulations of the July 2011 and June 2012 events were attempted but the model was unable to run satisfactorily. As noted previously, calibration to events of this magnitude only provide limited use for calibration.

5.4 Questionnaire Responses

Responses from the community questionnaire (detailed in Section 3) identified locations where flooding had been observed. Table 3-6 and Figure 3-1 show general locations advised by respondents. Pittwater Road at Lismore Road was frequently mentioned however it is not located within the Dee Why South Catchment and has not been assessed in this Study. Some of the reported flooding locations are located on the nominal boundary of the catchment, thus the reported flooding may be due to localised conditions rather than mainstream overland flooding which is the focus of this Study. Similarly, some reported locations of flooding within the catchment may be due to localised conditions at the time rather than mainstream overland flows being the cause.

In general, the mainstream flooding locations advised in the questionnaire responses are identified in the flood model results.

5.5 External Catchments

The XP-SWMM model includes catchment areas beyond the boundary of the Dee Why South Catchment. These areas are modelled to allow for any runoff that may contribute to flows across the nominal catchment boundary (both into and out of the catchment).

Figure 5-3 shows peak depths for the 1% AEP event within the model extent before the filtering of results (described in Section 6.2). Peak depths less than 0.15 m are shown which indicates that inter-catchment flows are relatively small. Figure 5-4 shows the peaks depths for the 5 year ARI event.

Peak flows at seven locations, four to the north-west from Narrabeen Catchment, one to the south-west from Greendale Creek Catchment, and two to the south-east from Dee Why Catchment, where the main inter-catchment flows occur are listed in Table 5-3.

Table 5-3 Inter-Catchment Flows

Reference Location (Figure 5-3)	Peak Flow (m^3/s)	
	1% AEP	5y ARI
1	0.88	0.31
2	0.14	0.04
3	0.26	0.07
4	1.27	0.35
5	0.90	0.48
6	0.64	0.07
7	2.43	0.89

Though the flows may be relatively minor, these external catchment areas are retained in the XP-SWMM model extent, thus any inter-catchment flows are included in the modelled results.

5.6 Summary

In the absence of available gauged rainfall and flow data for calibration, model verification was undertaken through the comparison of the hydrological results against a separate hydrological model (XP-RAFTS) and the hydraulic results were compared against the previous SMEC (2011) model for the area. The comparison of results indicated a reasonable agreement and the model was adopted for the Flood Study.

6 Design Events

The adopted XP-SWMM model of the Dee Why Catchment was used to estimate flow behaviour for a series of Annual Exceedance Probability (AEP) storms.

6.1 Events

Flood model simulations were run for the design events listed in Table 6-1.

Table 6-1 Design Events Modelled

Event	Modelled Durations
PMF	30 min, 60 min, 90 min
0.1% AEP	60 min, 120 min
0.5% AEP	60 min, 120 min
1% AEP	30 min, 60 min, 90 min, 120 min, 180 min
5% AEP	90 min, 120 min
10% AEP	90 min, 120 min
5 year ARI	90 min, 120 min
1 year ARI	90 min, 120 min

6.2 Results

The critical durations from the five durations modelled for the 1% AEP event are the 90 minute and 120 minute. The rainfall-on-grid methodology shows runoff occurring on every cell within the model extent which is an advantage as it can identify all flowpaths within the catchments. However the output results can look 'noisy' as all flowpaths and small localised depressions are identified. Therefore model results are filtered to clarify the locations of main overland flowpaths and significant areas of inundation. The results filtering process consists of three components:

- Cropping to Dee Why South Catchment;
- Exclusion of locations with inundation depth less than 0.15m; and
- Deleting 'islands' of area less than 100m^2. That is, to remove isolated ponds where runoff may be retained in localised depressions or retained by raised buildings in the grid which may not be reflective of actual conditions or available flowpaths.

A filter depth of 0.15 m was adopted as this is the depth of flow in roadways as the standard road kerb is 0.15 m high. The Building Code of Australia also recommends that slab-on-ground houses are built 0.15 m above surrounding ground. In some cases, flowpaths with a low depth but high velocity may be excluded from the results but review of modelled results indicated this is not an issue relevant for this catchment.

Table 6-2 lists the results figures included in this report showing peak depths and peak velocities. Model output files are supplied separately as GIS layers for detailed assessments as the report figures may not show sufficient detail.

Table 6-2 Design Events Figures

Event	Peak Depth	Peak Velocity
PMF	Figure 6-1	Figure 6-2
0.1% AEP	Figure 6-3	Figure 6-4
0.5% AEP	Figure 6-5	Figure 6-6
1% AEP	Figure 6-7	Figure 6-8
5% AEP	Figure 6-9	Figure 6-10
10% AEP	Figure 6-11	Figure 6-12
5 year ARI	Figure 6-13	Figure 6-14
1 year ARI	Figure 6-15	Figure 6-16

6.3 Discussion

The results show that generally the main overland flowpath starts from several branches at Alfred Street to Beverley Job Park. Flows in the open channel at Victor Road and Redman Road combine with overland flows from Mooramba Road, Fisher Road, and Pittwater Road at the intersection of Redman Road and Pittwater Road. Overland flows are then conveyed along several roads and properties to Dee Why Lagoon as well as in the open channels between Pacific Parade / Oaks Avenue and downstream of Dee Why Parade.

In a 1% AEP event, the results show that ponding of runoff occurs at several locations with restricted outlet capacity. This is potentially through insufficient piped drainage or elevations that result in trapped lowpoints. Examples of these locations include Sturdee Parade (near Pittwater Road) and Alfred Street (near McIntosh Road) as well as on Beverley Job Park. Ponding also occurs at several locations in the catchment due to localised depressions from the LiDAR ground survey or building structures restricting overland flowpaths.

High pedestrian areas in Dee Why CBD also experience overland flow inundation, particularly along Redman Road, Pittwater Road, Oaks Avenue and Howard Avenue. Ponding at lowpoints in these roads is modelled, with some depths in the range of 0.5 to 1.0 m deep. Some roads show scattered inundation up to 0.3 m such as Alfred Street (near McIntosh Road), Redman Road, and Howard Avenue as well as on the Victor Road side of Beverley Job Park.

Significant inundation is shown in a PMF event with some roads having a flood depth greater than 1 m and velocity greater than 2 m/s. Overall, the PMF results show that the catchment comprises a series of trapped lowpoints with insufficient piped drainage capacity or dedicated overland flowpaths.

6.3.1 Peak Water Level Reference Locations

Peak water levels for selected locations in the catchment (shown on Figure 6-17) are listed in Table 6-3 for a range of modelled storm events.

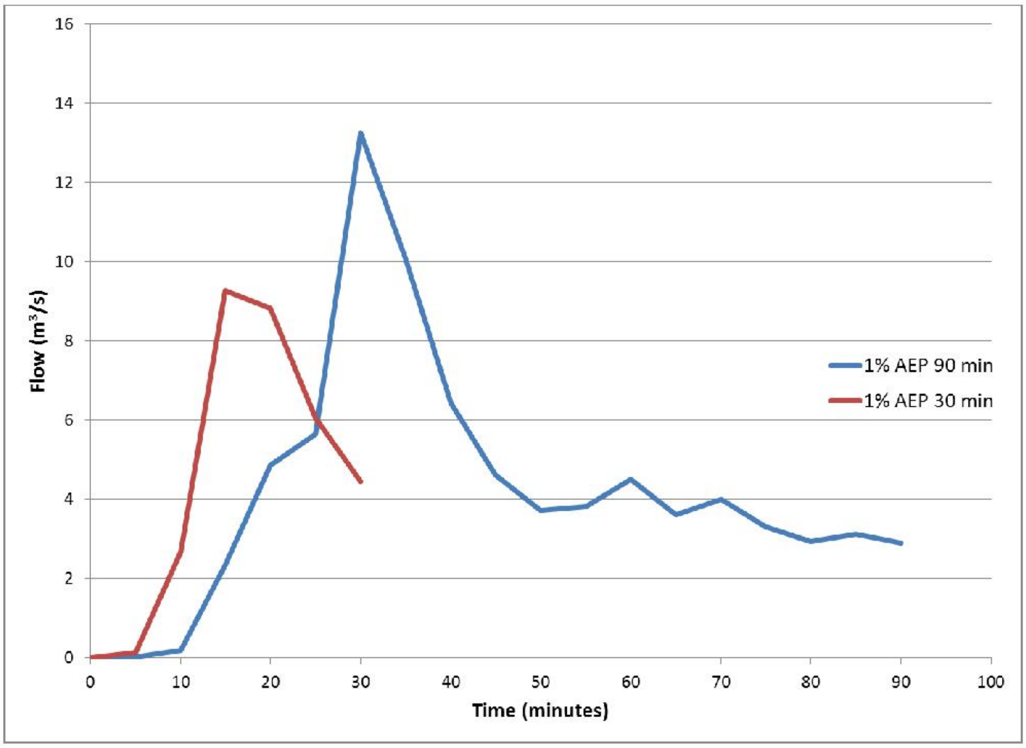
6.3.2 Timing of Overland Flow

A time-series flow hydrograph of overland flow at Redman Road (near Pittwater Road) is shown in Figure 6-18 for two 1% AEP storm durations of 30 minutes and 90 minutes. The graphs show instantaneous flows at 5 minute intervals, noting they do not show the peak overflows of 14.3 m^3/s for the 30 minute storm and 19.0 m^3/s for the 90 minute storm (which occur at times between the graphed intervals). These results show that the 30 minute storm event has a peak overland flow that is less than the 90 minute event but occurs earlier following the start of the rainfall.

Table 6-3 Peak Water Levels (m AHD)

Location (Figure 6-17)	1 year ARI	5 year ARI	10% AEP	5% AEP	1% AEP	0.5% AEP	0.1% AEP	PMF
1	73.70	74.03	74.07	74.15	74.26	74.63	74.66	74.90
2	60.99	61.32	61.39	61.42	61.43	61.44	61.43	61.88
3	58.34	58.47	58.56	58.60	58.67	58.72	58.71	59.55
4	25.45	25.67	25.67	25.68	25.79	25.82	25.78	26.15
5	21.23	21.45	21.54	21.59	21.68	21.71	21.68	22.51
6	27.24	27.43	27.46	27.49	27.59	27.60	27.51	28.06
7	23.99	24.12	24.14	24.28	24.47	24.96	25.19	26.50
8	16.63	16.71	16.76	16.81	16.92	17.02	16.99	17.69
9	13.91	14.04	14.10	14.16	14.28	14.35	14.33	15.14
10	9.87	10.12	10.18	10.22	10.33	10.43	10.42	11.51
11	7.59	7.65	7.71	7.80	7.93	8.09	8.08	8.97
12	2.83	3.12	3.18	3.22	3.26	3.29	3.32	3.64
13	3.04	3.36	3.39	3.43	3.47	3.49	3.50	3.84

Figure 6-18 Overland Flow Hydrograph – Redman Road at Pittwater Road



The time that elapses from the start of rainfall to flood inundation occurring in the catchment is an important consideration for safety and event management. Dee Why South Catchment is a flash-flood type environment meaning that there is limited time between the start of a storm event to elevated flood levels on roads and properties. Specifically, in the 1% AEP 90 minute storm, the time to peak at two locations (from rainfall first occurring) is:

1. Pittwater Road at Redman Road – approximately 30 minutes to a peak depth about 0.5m; and
2. Oaks Avenue near the open channel – approximately 35 minutes to a peak depth of about 0.3m.

6.3.3 Basement Car Parks

Council is assessing the potential flood risk of locating basement car parks in the Dee Why Town Centre area as inundation by floodwaters into basements is a potential safety hazard for people and a risk due to property damage. Runoff that enters a basement area may cause people to be trapped in rising waters if insufficient evacuation routes are available and is an issue for draining water after the flood event.

Figure 6-19 shows the indicative locations of existing properties with basement car parks advised by Council and the modelled peak depths of a 1% AEP flood event. Depths in excess of 0.15 m (nominal kerb height) at numerous locations in the catchment show that potential basements need consideration of potential inflow of floodwater.

Figure 6-20 shows existing basement car parks (indicative only) with the modelled peak depth for the PMF event indicating that numerous properties may therefore be subject to inundation in storm events greater than 1% AEP.

In order to confirm the risk to these basement car parks, further data would be required on entry levels and any openings to the basements. This could be undertaken as part of the Floodplain Risk Management Study and Plan. Proposed basement areas within the catchment would require consideration of potential inundation from floodwater. A freeboard allowance above the modelled flood level may be appropriate to allow for potential wave effects of passing vehicles.

7 Sensitivity Analysis

The sensitivity of the model was tested to evaluate the range of uncertainty in the modelled flood behaviour for changes in key parameters. Table 7.1 lists the parameters and variations modelled for the 1% AEP 90 minute critical duration storm event. Variations in sea level and rainfall intensity induced by climate change are assessed in Section 11.

Table 7-1 Sensitivity Cases Modelled

Parameter	Modelled Variation
Surface roughness	+20% and -20%
Boundary level	+20% and -20%
Conduit roughness	+20% and -20%
Pervious area rainfall losses	+20% and -20%
Inlet blockage	Unlimited inlet capacity (0% blockage) and 100% blockage to all inlets (0% conveyance in pipelines)
Energy losses at structures	+20% and -20%
Dee Why Town Centre Masterplan Development	Masterplan layout

7.1 Modelled Results

7.1.1 Surface Roughness

The 2D roughness grid represents the restriction to runoff flow resulting from the various surfaces of land uses within the catchment. A localised increase to the roughness would likely increase flood levels at locations and would slow runoff which would affect the coincidence of flows from separate branchlines.

Peak water level differences in the catchment for the scenario of +20% and -20% compared to the base case 1% AEP 90 minute event are shown in Figures 7-1 and 7-2 respectively.

The model results do not show a significant difference for the varied surface roughness.

7.1.2 Boundary Level

Dee Why Lagoon is the downstream boundary of the model and is set as a constant level for the model simulation. A higher adopted Lagoon level will result in a reduction of the effectiveness of the downstream pipelines as they are partially filled as well as increased peak depths to downstream areas with an elevation close to the Lagoon level.

The base model has a boundary level of 2.3 m AHD. The sensitivity analysis assessed a 20% increase (2.76 m AHD) and 20% decrease (1.84 m AHD).

Peak water level differences in the catchment for the scenario of +20% and -20% compared to the base case are shown in Figures 7-3 and 7-4 respectively.

The modelled results show that adopting a Lagoon level of 2.76 m AHD does not result in additional flood impact to properties near the Lagoon. Properties in this area, for example Richmond Avenue, have ground elevations higher than this level. Similarly, peak water levels at properties in the Study Area are not affected by adopting a lower water level in the Lagoon.

7.1.3 Conduit Roughness

The roughness parameter in conduits (pipelines and culverts) influences the capacity and velocity of flows conveyed. A lower roughness would likely reduce peak flood levels on the surface resulting from the additional conveyance capacity and flow velocity. The resultant flow in the conduits would be dependent on the inlet capacity and the coincidence with flows from other branchlines.

Peak water level differences in the catchment for the scenario of +20% and -20% compared to the base case are shown in Figures 7-5 and 7-6 respectively.

An increase to conduit roughness shows an increase in peak water levels of up to 0.05 m in most areas across the catchment. This occurs as more flow is conveyed overland as pipe flows have been restricted. An increase in peak water level of more than 0.5 m occurs at Sturdee Parade as drainage of this trapped low point is dependent on pipe flows to convey runoff downstream.

Lower water levels, generally less than 0.05 m, occur at this and other low points with increased pipe capacity for the -20% modelled case. Some areas show an increase of up 0.05 m as the additional pipe flows from upstream are conveyed overland (or at increased levels in open channels).

7.1.4 Pervious Area Rainfall Losses

All rainfall precipitating on the ground does not contribute to surface runoff as a proportion is infiltrated into the ground. Losses are modelled as an initial loss and a continuing loss applied at different rates for the different land uses based on the available pervious area proportions. An increased rainfall loss rate will generally result in reduced runoff volumes and peak water levels.

Peak water level differences in the catchment for the scenario of +20% and -20% compared to the base case are shown in Figures 7-7 and 7-8 respectively.

The model results do not show a significant difference for the varied rainfall loss parameters as the catchment is highly urbanised with land uses that have a low relative initial loss and continuing loss.

7.1.5 Inlet Blockage

The modelled piped drainage network incorporates an inlet-rating curve to determine the proportion of flows that are conveyed into the system from the surface runoff. Two scenarios were modelled:

- Unlimited inlet capacity to evaluate sensitivity for a case where pipes are operating to maximum capacity; and
- Complete blockage to the inlets for a case where the piped drainage conveys no flow.

Peak water level differences in the catchment for the unlimited inlet capacity and complete inlet blockage scenarios compared to the base case are shown in Figures 7-9 and 7-10 respectively.

The unlimited inlet capacity case does not show significant changes in peak water levels as the pipe system is already at capacity in a number of sections in the 1% AEP event. Stormwater infrastructure capacity is further discussed in Section 9.

Complete blockage of the inlets, thus rendering the pipe system ineffective, results in significant increases to peak water levels across the catchment as all runoff has to be conveyed overland. Increases over 0.5 m are particularly evident in the CBD and downstream partially due to the constriction of overland flowpaths due to buildings. Water levels in the open channel near Hawkesbury Avenue are reduced as flow is not conveyed to it by the piped system and the overland flowpath concentrates flows to the east. It is noted that the complete blockage scenario is an extreme case.

7.1.6 Energy Losses At Structures

The modelled piped drainage network incorporates a flow energy loss at pits and junctions to represent the losses resulting from turbulence due to flows combining and changing direction in the stormwater pits as well as contraction and expansion losses from changed conduit dimensions. Increased losses would be expected to reduce the capacity of the piped drainage system to convey flows.

Peak water level differences in the catchment for the scenario of +20% and -20% compared to the base case are shown in Figures 7-11 and 7-12 respectively.

Sturdee Parade and Alfred Street (near McIntosh Road) show increased water levels for the scenario of additional energy losses (Figure 7-11) indicating these trapped low points are dependent on the piped drainage to relieve flooding. Decreases are shown in Beverley Job Park and in the open channel near

Hawkesbury Avenue as less flow is conveyed by the pipe system to these areas. Increases in peak water level up to 0.05 m are shown in some locations where the reduced capacity of the pipe system results in additional flows conveyed overland.

The lower energy loss case results in additional flow being conveyed in the piped system with reductions in some locations up to 0.2 m. Flow levels are notably increased along the open channel between properties (up to 0.05 m) near Hawkesbury Avenue which results in a reduction across the parkland at Richmond Avenue.

7.1.7 Dee Why Town Centre Masterplan Redevelopment

Warringah Council has prepared a draft Masterplan for Dee Why Town Centre to guide its revitalisation. The Masterplan links into consequent plans for the redevelopment of the area as a commercial and residential hub. It incorporates open-space areas and the application of water-sensitive urban design with stormwater drainage systems that are functional and aesthetic features. Figure 7-13 is a copy of the draft Masterplan (received April 2013) prepared by Place Design Group and Warringah Council.

Figure 7-13 Draft Dee Why Town Centre Masterplan Development (Place Design Group and Warringah Council)

Peak water level differences in the catchment for the Dee Why Town Centre Masterplan redevelopment scenario compared to the base case 1% AEP 90 minute duration event are shown in Figure 7-14. The figure also shows the modifications made to the XP-SWMM model representing the changes of the draft Masterplan. Generally the changes are to provide additional open space and flowpaths with some sites being converted to buildings.

Increases of up to 0.1 m to peak water levels are shown in the area around and downstream of the modified layout due to the changes to overland flowpaths and loss of floodplain storage on some properties. However, the open channel downstream of Dee Why Parade (to Hawkesbury Avenue) shows minor reductions. The modelled layout is preliminary at this stage and incorporates open space which in future stages can be investigated as potential sites for flood mitigation options. The Masterplan layout should thus consider potential changes to flow behaviour and flood management opportunities.

7.2 Summary

The scenarios modelled have a different degree of effect on the resultant peak water levels. In most cases the base model results are within +/- 0.05 m of the adjusted parameters. Particular locations, such as the trapped lowpoint in Sturdee Parade, shows higher increases but is generally confined to the road.

In general, the model is not significantly sensitive to different assumptions on parameters in the model.

8 Hydraulic Categorisation and Provisional Hazard Classification

8.1 Hydraulic Categorisation

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to fall into one of the following three hydraulic categories:

- Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1 m and/or would cause the peak discharge to increase by more than 10%.
- Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

8.1.1 Hydraulic Category Identification

Floodways were determined for the PMF, 1% AEP, 5% AEP and 5 year ARI events by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 m^2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross-sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied. To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2 m; and
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent, where the depth is greater than 0.05 m, are represented as Flood Fringe.

Hydraulic categories for the PMF, 1% AEP, 5% AEP, and 5 year ARI events based on the aforementioned peak depth and velocity criteria from local catchment runoff determined in the flood model, are shown in Figures 8-1 to 8-4 respectively.

8.2 Provisional Hazard Classification

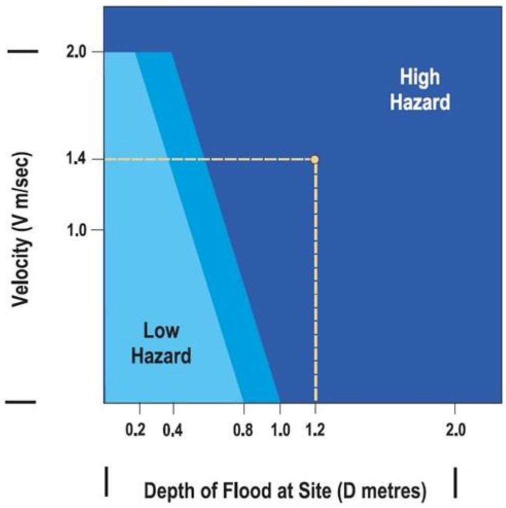
Flood hazard can be defined as the risk to life and property damage caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain. The Floodplain Development Manual (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

- Size of the flood;
- Depth and velocity of floodwaters;
- Effective warning time;
- Flood awareness;
- Rate of rise of floodwaters;
- Duration of flooding;
- Evacuation problems; and
- Access.

Hazard categorisation based on all the above factors is part of establishing a Floodplain Risk Management Plan. The scope of the present study calls for determination of provisional flood hazards only, which when considered in conjunction with the above listed factors provides comprehensive analysis of the flood hazard.

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters as detailed in the Floodplain Development Manual (NSW Government, 2005). The provisional hazard is defined as either High or Low as shown in Figure 8-5. High hazard is considered to occur when flow velocity exceeds 2 m/s, depth is greater than 1.0 m, or a velocity-depth profile between these values. The transition zone between high and low is adopted as medium hazard.

Figure 8-5 Provisional Hazard Classification (NSW Government)



The hazard categories are defined in the Floodplain Development Manual as:

- High hazard – possible danger to personal safety, evacuation by trucks difficult, able-bodied adults would have difficulty in wading to safety, potential for significant structural damage to buildings; and
- Low hazard – should it be necessary, a truck could be used to evacuate people and their possessions, able-bodied adults would have little difficulty in wading to safety.

The provisional flood hazard is determined using equations based on the graph of Figure 8-5 relating the velocity and depth. Provisional hazard due to local catchment runoff determined in the flood model for the PMF, 1% AEP, 5% AEP, and 5 year ARI events are shown in Figures 8-6 to 8-9 respectively.

8.3 Discussion

The modelled PMF event shows a large portion of the catchment is categorised as floodway and high provisional hazard. These areas are primarily along roads. However, properties upstream of Beverley Job Park, along the open channel from Victor Road to Redman Road, and downstream of Pittwater Road are also affected.

Results for the 1% AEP event show floodway areas on some roads near and in the Dee Why CBD as well as downstream. Floodway categorisation is shown along the channel from Victor Road to Redman Road and through some properties from Alfred Street to Beverley Job Park. High provisional hazard is shown to occur at locations including:

- On the road at the intersection of Victor Road and Lewis Street;
- In the CBD on Redman Road, Pittwater Road, Oaks Avenue, Howard Avenue;
- Downstream of the CBD on Dee Why Parade and Clyde Road;
- Along the open channels of Victor Road to Redman Road, between Pacific Parade and Oaks Avenue and downstream of Dee Why Parade to the Lagoon; and
- Some properties near these areas.

Results show high provisional hazard in a 5% AEP event in the open channels and along Redman Road and Pittwater Road.

9 Stormwater Infrastructure Capacity

The stormwater drainage infrastructure, comprising inlet pits, pipes and culverts, is constructed to convey runoff underground and reduce the surface overland flows along roads and in properties. It is not normally designed, nor is it normally feasible to convey all flows within piped systems due to the scale of systems that would be required. An assessment of the capacity of the drainage network has been undertaken.

9.1 Methodology

The XP-SWMM model includes a detailed representation of the piped drainage system to enable flow behaviour to be evaluated both in the piped system and as overland flows. Pipe network data, including size, inverts, and length, and storm event results are extracted to facilitate an evaluation of the stormwater infrastructure efficiency across the catchment.

A theoretical flow capacity was estimated using hydraulic equations based on the pipe data. This capacity is an estimate of the just-full flow (i.e. effectively to top of pipe). A pipe would be able to convey additional flow as a pressurised system in which water levels in the upstream would be elevated but may still not result in surcharging onto the surface.

Peak pipe flows for the modelled storm events up to 1% AEP are compared to the estimated theoretical capacity.

Figure 9-1 shows the calculated storm event which results in a pipe flow that is less than 100% of the theoretical capacity. Pipes showing "No ARI" indicates that the pipe is conveying flows of greater than 100% of the theoretical capacity in a 1 year ARI event, or in other words has a nominal capacity of less than a 1 year ARI.

Figure 9-2 shows the percentage of the flow conveyed in a 5 year ARI event to the theoretical capacity of the pipe.

9.2 Discussion

The results show that the overall network efficiency may be restricted by pipes with low capacity distributed across the network, not specifically in a single reach. Figure 9-3 summarises a review of the stormwater network capacity at particular locations. The capacity of the existing main trunk pipeline from Redman Road across Pittwater Road to Oaks Avenue is potentially a major contributor to flood inundation as it is the drainage link from upstream of Pittwater Road. The trapped lowpoint at Alfred Street near McIntosh Road may benefit from upgrade works as it is dependent on piped drainage to convey floodwaters.

Pipes that are potentially oversized are estimated by comparing sections that are less than 25% full in a 5 year ARI event as shown in Figure 9-2. A significant number of pipes in this condition are at the upstream reaches of branches indicating the downstream pipe has restricted capacity or the surface inlets could be upgraded to allow more inflow. In some upstream areas the pipes may be oversized for the contributing catchment as there is not significant overland flow resulting (for example in Waratah Parade). The main trunkline from Beverley Job Park to the Lagoon does not show significant reaches that are under 25% capacity in a 5 year ARI event. The final pipe sections discharging to Dee Why Lagoon show low utilisation as their capacity may be affected by backwater effects of the modelled Lagoon level.

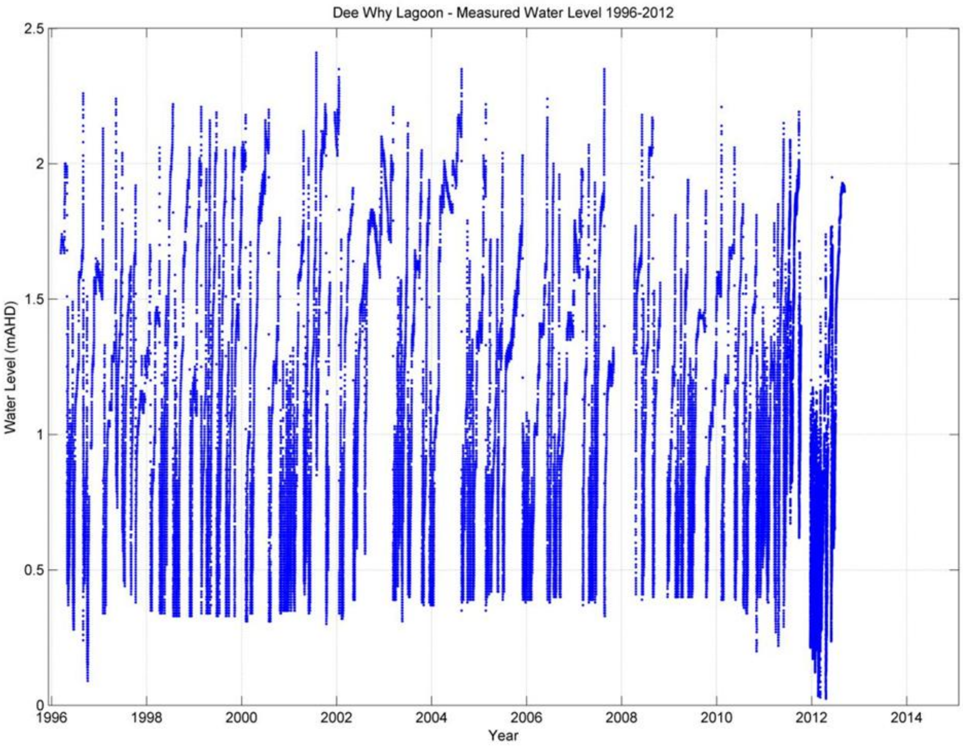
Potential upgrade works would need to be prioritised based on the degree of inundation at particular locations. A holistic view of the catchment needs to be considered for potential upgrade works as improvements in one location may result in worse flood inundation downstream as sufficient pipeline capacity may not be available. This could be considered as part of the future Floodplain Risk Management Study and Plan.

10 Dee Why Lagoon

10.1 Background

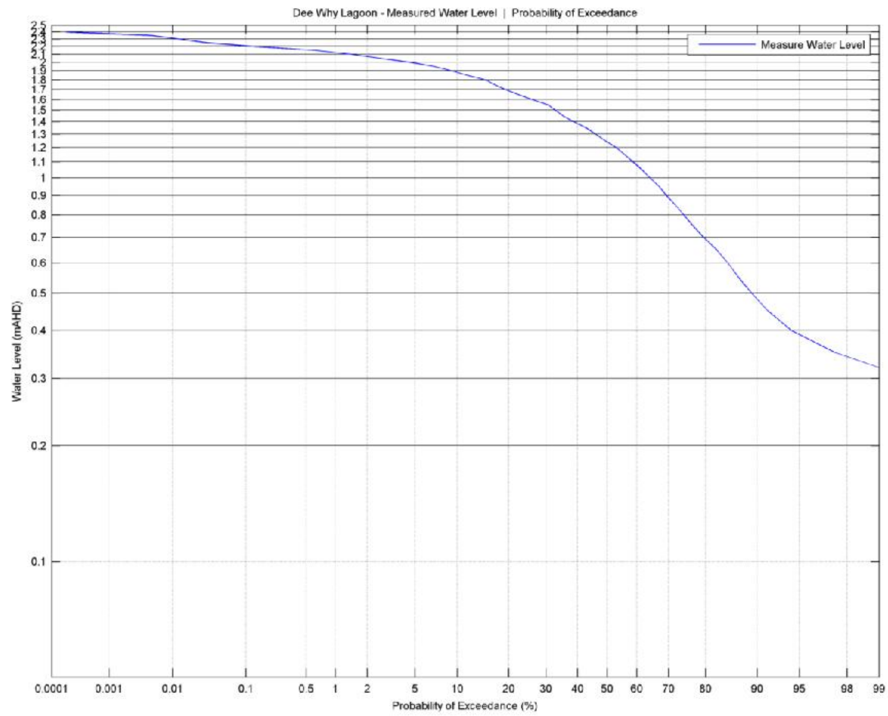
Dee Why Lagoon is the downstream receiving water body for the Dee Why South Catchment. To model this downstream boundary, a fixed water level of 2.3 m AHD was adopted in Dee Why Lagoon. Figure 10-1 shows the recorded water levels in the Lagoon from 1996 to 2012. It was provided by Manly Hydraulics Laboratory and indicates that water level in the Lagoon has not exceeded 2.41 m AHD during this period. Figure 10-2 describes the probability of exceedance of these water levels and that the median water level is 1.25 m AHD. The time-series data shows that the entrance breaks-out about once a month, on average. Generally the Lagoon level then drops to about 0.4 m AHD and then rises again quite rapidly. The adopted downstream water level in the Lagoon of 2.3 m AHD is quite rare (on the basis of this data), and is exceeded for only 0.01% of the time (see Figure 10-2) based on water level data available from 1996 to 2012.

Figure 10-1 Dee Why Lagoon Water Level Time Series (1996-2012)



Because water levels in the Lagoon depend on complex interactions between catchment and ocean events, a 5% AEP water level in the Lagoon cannot be defined as an independent parameter. Based on the available data, it might be approximately 2.4 m AHD. For previous flood studies in small catchments (Newport, Brisbane Water, Newcastle, Smiths Lake, for example), Cardno have advised that adopting a downstream water level with only 1% probability of exceedance would provide 99% certainty that the 1% AEP catchment flood would not encounter a tail water level greater than that level – 2.12 m AHD in Dee Why Lagoon. Hence, adopting a level of 2.3 m AHD, and subsequent sensitivity testing at 2.5 m AHD showed that flood inundation at downstream properties was not affected.

Figure 10-2 Dee Why Lagoon Probability of Exceedance (1996-2012)



10.2 Flood Modelling

In modelling the Lagoon level, there are generally two cases:

- Adopting the ocean as the tailwater location; and
- Adopting a lagoon level as the tailwater location.

In both cases there are difficulties with the selection of the tailwater level and jointly occurring catchment flows, including the questions of phasing and flood duration.

To adopt the ocean as the tailwater location, the jointly occurring ocean storm needs to be considered. For a 1% AEP catchment flood event, a common basis of ocean storm selection might be the 5% AEP storm. The basis for this selection has been flood-ocean event correlation analyses. In terms of peak storm wave height, the 5% AEP event offshore waves are most likely to come from the south-eastern sector. However, some lagoon entrance locations are more exposed to the east-north-east sector and 5 year ARI wave heights from that sector may produce larger waves at the lagoon entrance and hence greater wave set-up. Other issues include the effects of entrance scour and underlying rock (some locations) on lagoon water levels, and ocean storm duration (being direction dependent). In principle, ocean storm influence on lagoon levels is introduced best into the flood model as maps of near-shore ocean level and radiation stresses (being a coupled-model system).

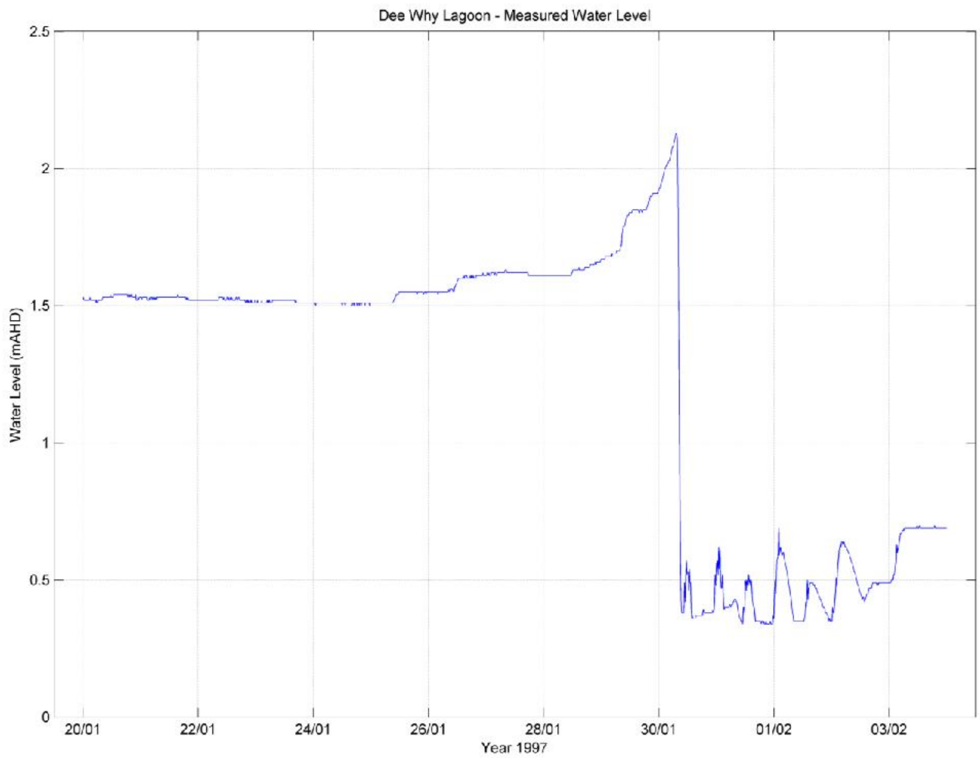
To adopt a lagoon level as the tailwater location, the following points need to be considered:

- Lagoon level depends not only on the ocean processes, but the catchment flood itself, as well as jointly occurring floods in other streams, such as Dee Why Creek, that discharge to the Lagoon. Hence the catchment flood and lagoon level are not independent and the tailwater level should vary with time.

- Dee Why Lagoon is closed to the ocean frequently. When closed the Lagoon has a surface area of about 30 hectares and a maximum depth of about 1.5 m. The entrance berm level is not managed by Council, but Council opens the berm (irrespective of berm height) when the Lagoon water level reaches 2.3 m AHD. The Lagoon has been described as a saline coastal lake with a seaward boundary of coastal dune fields that intermittently opens to the ocean. This process occurs either as a result of heavy rain or by artificial means (authorised or unauthorised).

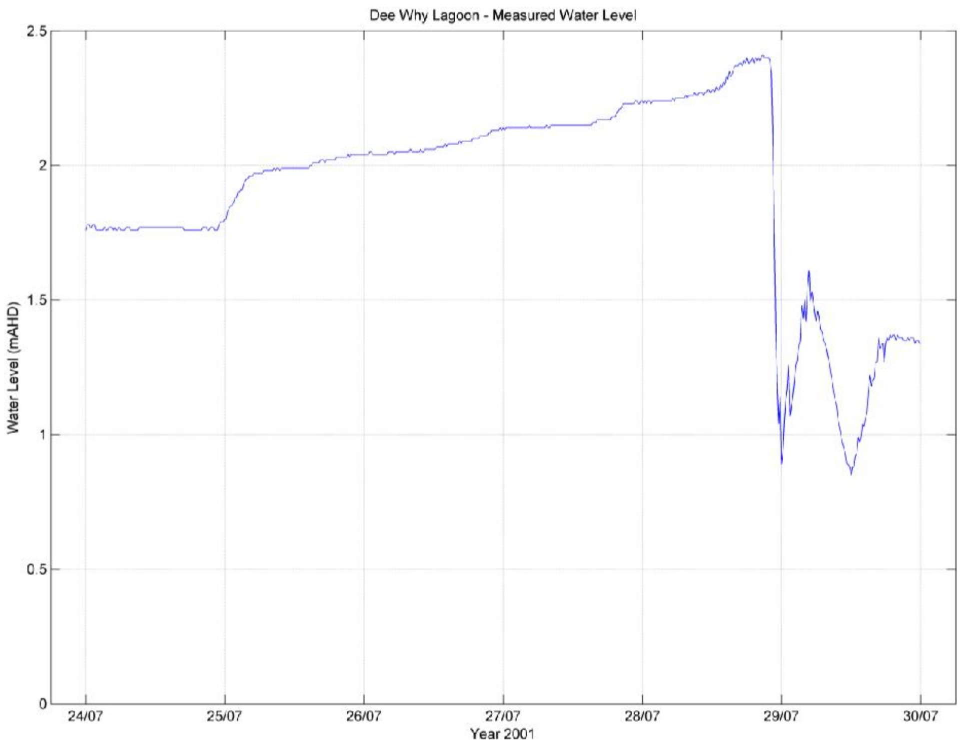
When the Lagoon is 'closed' at the start of a flood event, the level may be 'low' or 'high', depending upon the berm level and antecedent weather conditions. However, the peak tail water level is unlikely to exceed 2.4 m AHD (see Figure 10-1) because at, or prior to, this level overtopping of the entrance berm commences and berm scour is initiated and develops rapidly (depending upon the ocean level at the time). Figures 10-3 and 10-4 show a rapid rise of the Lagoon water level during catchment events in 1997 and 2001, followed by the rapid decrease in water level during breakout and subsequent scouring. Entrance opening may be preceded by some wave overtopping and seawater ingress to the Lagoon. Wave run-up above typical berm levels is common at high tide, but Lagoon entrance berms are generally set back from the dune line and wave run-up is somewhat dissipated by bed friction and percolation into the beach face. After the breakout, water levels inside the Lagoon are dictated by the tides whilst the lagoon entrance remains open, typically for several days (noting Figures 10-3 and 10-4).

Figure 10-3 Dee Why Lagoon Water Level Time Series (Jan-Feb 1997)



When the Lagoon is 'open', there will be a range of possible tidal and storm tide/wave set-up responses. An examination of available data from the Dee Why Lagoon water level recorder shows that it may be as high as 1 m AHD in dry periods – for example, late March 2013. Numerical hydrodynamic modelling of the Lagoon using 2001 bathymetric data and a narrow entrance set at about 0.5 m AHD shows that the Lagoon gradually pumps up during times of spring tide and stays at about 0.65 m AHD during neap tides when tidal influx ceases (with slow drainage back to the sea). Intermittent catchment rainfall and continual development of the berm level by wave and flood tide ingress occur. Flood tides carry water with suspended sediments into the entrance. Within the entrance, lower wave agitation leads to sediment deposition, with the consequence of berm development and thus potential for the Lagoon level to slowly increase.

Figure 10-4 Dee Why Lagoon Water Level Time Series (July 2001)



A typical tidal range in the ocean at Dee Why might be 1 m. The tidal range in the Lagoon is generally zero, but following a break-out event, there may be a tide range in the Lagoon in the order of 0.1 m or less, but is obscured by the tidal pumping which 'jacks-up' the level on consecutive spring tides, with a slow efflux on neap tides – until tide and wave processes close the entrance.

Based on the available, reliable recorded water level data in the Lagoon, flood modelling at 2.3 m and 2.5 m AHD Lagoon levels is a relevant and appropriate position to adopt for present day conditions.

In cases when it is 'open' and the berm is low, for a 5% AEP jointly occurring ocean storm, the ocean tailwater levels are likely to be 1.38 m AHD, 1.72 m AHD and 2.22 m AHD for 2010, 2050 & 2100 projected sea level rise cases (Watson and Lord, 2008; Coastal Risk Management Guide, 2010). Consequently the ocean levels are likely to be 2.2 m AHD, 2.5 m AHD and 3.0 m AHD, respectively, with the inclusion of 0.8 m wave set-up. Higher wave set-up may occur on the back-beach areas nearby, but lower set-up occurs within the entrance itself where full wave breaking does not occur. For projected sea-level-rise based cases, future flooding in the Lagoon may be affected significantly. Flood modelling with a Lagoon level of 2.76 m AHD describes conditions between 2050 and 2100 when the 5% AEP (20 year ARI) ocean level is projected to be between 2.5 and 3.0 m AHD. Whilst these SLR scenarios may potentially result in higher berm levels, it is not likely the berm will be higher as Council will still need to prevent shoreline flooding. A major storm that causes a future ocean level of 3.0 m AHD at the Lagoon entrance is likely to persist for some days and elevate the Lagoon to 3.0 m AHD. Note that during the May 1974 storm (with very little catchment rainfall) water levels in Tuggerah Lake were elevated to 1.2 m AHD – which potentially equates to about 1 m of wave set-up in the lake. Hence, Dee Why Lagoon would likely rise to 3.0 m in 2100 for the design 5% AEP ocean storm.

It is noted that if potential sea level rises occur to the projected extents, then the entrance berm will tend to increase in crest level and maintenance may be required to prevent catchment flooding.

10.3 Summary

This lagoon and ocean water levels assessment has shown that water levels recorded in Dee Why Lagoon have not exceeded 2.4 m AHD since 1996. Council does not maintain the berm at 2.2 m AHD but opens the Lagoon when the water level reaches 2.3m AHD. Generally, Lagoon levels, as adopted for the present study define well the limits of likely tail water levels for Dee Why Creek. Only in a future very severe storm with projected sea levels above that currently advised for 2050 will ocean levels govern tail water levels for catchment flood events.

11 Climate Change

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. The NSW Department of Environment and Climate Change (DECC, now Office of Environment and Heritage (OEH)) guideline, Practical Consideration of Climate Change (2007), provides advice for consideration of climate change in flood investigations. The guideline recommended sensitivity analysis is conducted for:

- Sea level rise – for low (0.18 m), medium (0.55 m), and high level impacts up to 0.91 m; and
- Rainfall intensities – for 10%, 20%, and 30% increase in peak rainfall and storm volume

The NSW Sea Level Rise Policy Statement (October 2009) prepared by the Department of Environment, Climate Change and Water (DECCW, now OEH) listed that the best projections of sea level rise along the NSW coast are for a rise relative to the 1990 mean sea levels of 0.4 m by 2050 and 0.9 m by 2100. It was acknowledged that potentially higher rates are possible. The supporting Technical Note by DECCW identified the components of the sea level rise estimates were sea level rise, accelerated ice melt and regional sea level rise variation. The Policy Statement recommends these sea level rise benchmarks for use in coastal hazard and flood risk assessments.

Recently, the NSW Government announced its Stage One Coastal Management Reforms (September, 2012). As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils, but instead provides councils with the flexibility to consider local conditions when determining future hazards within their LGA.

Accordingly, it is recommended by the NSW Government that councils should consider information on historical and projected future sea level rise that is widely accepted by scientific opinion. This may include information in the NSW Chief Scientist and Engineer's Report entitled "Assessment of the Science Behind the NSW Government's Sea Level Rise Planning Benchmarks" (2012).

The NSW Chief Scientist and Engineer's Report (2012) acknowledges the evolving nature of climate science, which is expected to provide a clearer picture of the changing sea levels into the future. The report identified that:

- The science behind sea level rise benchmarks from the 2009 NSW Sea Level Rise Policy Statement was adequate;
- Historically, sea levels have been rising since the early 1880's;
- There is considerable variability in the projections for future sea level rise; and
- The science behind the future sea level rise projections is continually evolving and improving.

As this Flood Study had commenced prior to the announcement of the NSW Government's Coastal Management Reforms in September 2012, the potential impacts of sea level rise have been based on sea level rise projections from the 2009 NSW Sea Level Rise Policy Statement. Given that the Chief Scientist and Engineer's Report finds the science behind these sea level rise projections adequate, it was agreed between Council and Cardno that the potential impacts of sea level rise for the Dee Why South Catchment were based on the best available information at hand during preparation of this report.

11.1 Scenarios

Climate change scenarios as listed in Table 11.1 have been modelled to estimate potential changes to flood behaviour in the catchment. The base case for the scenarios is the 1% AEP 90 minute critical duration storm event with a Lagoon level of 2.3 m AHD. Lagoon levels are modelled as increasing by the equivalent sea level rise estimate, i.e. by 0.4 m to 2.7 m AHD and by 0.9 m to 3.2 m AHD.

Table 11-1 Climate Change Scenarios Modelled

Scenario	Sea Level Rise (m)	Rainfall Intensity Increase	Additional Parameters
1	0.4	-	-
2	0.9	-	-
3	-	10%	-
4	-	20%	-
5	0.4	10%	-
6	0.4	20%	-
7	0.9	10%	-
8	0.9	20%	-
9	0.4	20%	1% AEP Dee Why Creek
10	0.9	20%	1% AEP Dee Why Creek

11.2 Results

11.2.1 Sea Level Rise 0.4 m

Peak water level differences in the catchment for the scenario compared to the base case 1% AEP 90 minute duration event are shown in Figure 11-1.

Results show that adopting an elevated Lagoon level of 2.7 m AHD does not result in increases to peak water levels on private property in the Dee Why South catchment. That is, peak water levels have increased in the Lagoon and surrounding bushland areas.

11.2.2 Sea Level Rise 0.9 m

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-2.

An elevated Lagoon level of 3.2 m AHD does not result in increases to peak water levels on private property in the Dee Why South Catchment as ground elevations are generally higher and the stormwater drainage system continues to function.

11.2.3 Rainfall Intensity Increase 10%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-3.

A 10% increase in rainfall intensity results in up to a 0.05 m increase to peak water levels across the catchment. Higher increases occur at the trapped lowpoint in Sturdee Parade (up to 0.5 m though increased water levels are confined to the road) and to some properties downstream of Howard Avenue.

11.2.4 Rainfall Intensity Increase 20%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-4.

A 20% increase in rainfall intensity shows additional increases to peak water levels to those of Figure 11-3. The largest increases occur at the trapped lowpoints of Sturdee Parade and Alfred Street (near McIntosh Road). The peak water levels for 1% AEP 90 minute event have increased by up to 0.05m for this scenario of increased rainfall intensity.

11.2.5 Sea Level Rise 0.4 m and Rainfall Intensity Increase 10%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-5. Peak flood depths and provisional hazard are shown in Figures 11-6 and 11-7 respectively.

This Scenario potentially represents a mid-level climate change case with the predicted 0.4m sea level rise by 2050 and a 10% increase in rainfall intensity. Results show an increase to the extent of high provisional hazard areas compared to the base case.

11.2.6 Sea Level Rise 0.4 m and Rainfall Intensity Increase 20%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-8. Modelling for Scenario 1 showed the sea level rise increases water levels for the extent of the Lagoon and adjoining bushland only, thus changes to peak water levels across the rest of the catchment is due to the increase in rainfall intensity.

11.2.7 Sea Level Rise 0.9 m and Rainfall Intensity Increase 10%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-9. Modelling for Scenario 2 showed the sea level rise increases water levels for the extent of the Lagoon and adjoining bushland only, thus changes to peak water levels across the rest of the catchment is due to the increase in rainfall intensity.

11.2.8 Sea Level Rise 0.9 m and Rainfall Intensity Increase 20%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-10. Peak flood depths and provisional hazard are shown in Figures 11-11 and 11-12 respectively.

This Scenario potentially represents a high-level climate change case with the predicted 0.9m sea level rise by 2100 and a 20% increase in rainfall intensity. Results show that in addition to the noted Scenario 5 changes, new high provisional hazard areas are evident, including Alfred Street near McIntosh Road and Dee Why Parade near Clyde Road.

11.2.9 1% AEP from Dee Why Creek, Sea Level Rise 0.4 m and Rainfall Intensity Increase 20%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-13.

Council has advised that the 1% AEP catchment flood in the Dee Why Creek catchment results in a Lagoon level of 2.55 m AHD. This level has been adopted as the Lagoon boundary level in the model.

The elevated level in the Lagoon results in additional increases to peak 1% AEP 90 minute flood levels compared to Scenario 4 (of 20% increase in rainfall intensity only) at properties that are close to the Lagoon.

11.2.10 1% AEP from Dee Why Creek, Sea Level Rise 0.9 m and Rainfall Intensity Increase 20%

Peak water level differences in the catchment for the scenario compared to the base case are shown in Figure 11-14.

Results show an increase to inundation at the downstream properties near the Lagoon due to the increased Lagoon level.

The elevated level in the Lagoon results in increases to peak 1% AEP 90 minute flood levels to properties near to the Lagoon compared to Scenario 9 (discussed in Section 11.2.9). This affects properties and roads near Hawkesbury Avenue (eastern end), Richmond Avenue, Clyde Road and Dee Why Parade (eastern end).

11.3 Summary

Peak water levels for selected locations in the catchment (shown on Figure 6-17) are listed in Table 11-2 and Table 11-3 for modelled storm events greater than 1% AEP and for all the climate change scenarios. The 90 minute duration results for the 1% AEP event are presented for comparison to the climate change scenarios. Slight differences between some scenarios may be attributed to the model calculation processes in each separate run.

Table 11-2 Peak Water Levels – Climate Change Scenarios (m AHD) – Part A

Location (Figure 6-17)	1% AEP	0.5% AEP	0.1% AEP	PMF	Climate Change – 1% AEP + 0.4 m SLR	Climate Change – 1% AEP + 0.9 m SLR	Climate Change – 1% AEP + 10% Rainfall	Climate Change – 1% AEP + 20% Rainfall
1	74.26	74.63	74.66	74.90	74.26	74.26	74.30	74.57
2	61.43	61.44	61.43	61.88	61.43	61.43	61.43	61.44
3	58.67	58.72	58.71	59.55	58.67	58.67	58.70	58.72
4	25.67	25.82	25.78	26.15	25.68	25.69	25.69	25.69
5	21.68	21.71	21.68	22.51	21.67	21.68	21.71	21.72
6	27.59	27.60	27.51	28.06	27.59	27.59	27.60	27.60
7	24.38	24.96	25.19	26.50	24.39	24.43	24.62	24.66
8	16.92	17.02	16.99	17.69	16.92	16.91	16.97	17.05
9	14.27	14.35	14.33	15.14	14.27	14.27	14.32	14.37
10	10.31	10.43	10.42	11.51	10.31	10.31	10.37	10.43
11	7.92	8.09	8.08	8.97	7.92	7.92	7.97	8.08
12	3.25	3.29	3.32	3.64	3.26	3.27	3.27	3.29
13	3.46	3.49	3.50	3.84	3.46	3.52	3.48	3.49

Table 11-3 Peak Water Levels – Climate Change Scenarios (m AHD) – Part B

Location (Figure 6-17)	Climate Change – 1% AEP +0.4m + 10% Rainfall	Climate Change – 1% AEP +0.4m + 20% Rainfall	Climate Change – 1% AEP +0.9 m + 10% Rainfall	Climate Change – 1% AEP +0.9 m + 20% Rainfall	Climate Change – 1% AEP Dee Why Creek +0.4 m SLR + 20% Rainfall	Climate Change – 1% AEP Dee Why Creek +0.9 m SLR + 20% Rainfall
1	74.31	74.34	74.30	74.62	74.36	74.35
2	61.43	61.44	61.43	61.44	61.43	61.44
3	58.70	58.72	58.69	58.72	58.72	58.72
4	25.68	25.69	25.70	25.72	25.73	25.70
5	21.69	21.72	21.71	21.73	21.72	21.72
6	27.60	27.60	27.60	27.60	27.60	27.60
7	24.64	25.10	24.51	25.11	24.63	24.96
8	16.98	17.04	16.97	17.04	17.05	17.03
9	14.32	14.37	14.32	14.37	14.37	14.37
10	10.37	10.44	10.37	10.44	10.43	10.44
11	7.97	8.07	7.98	8.09	8.09	8.08
12	3.27	3.29	3.28	3.30	3.30	3.51
13	3.48	3.49	3.53	3.54	3.50	3.63

The peak water level difference figures for the sea level rise scenarios (without rainfall intensity increase) show no increase to water levels except near the bushland boundaries of the Lagoon itself. This is shown in Table 11-2 whereby only Reference Location 13 indicates an increase. However, the increase in rainfall intensity affects the entire catchment with an increase to peak water levels and overland flowpath extents. The increase in peak water level is particularly significant at the trapped lowpoints of Locations 1 and 7 for the scenario with 20% increased rainfall intensity.

An approximation of the relative AEP of the climate change scenarios compared to the base case are:

1. Sea Level Rise 0.4 m – 1% AEP
2. Sea Level Rise 0.9 m – 1% AEP except for adjacent to Lagoon of 0.1% AEP
3. Rainfall Intensity Increase 10% - 1% AEP
4. Rainfall Intensity Increase 20% - 0.5% AEP
5. Sea Level Rise 0.4 m and Rainfall Intensity Increase 10% – 1% AEP except for adjacent to Lagoon of 0.5% AEP
6. Sea Level Rise 0.4 m and Rainfall Intensity Increase 20% – 0.5% AEP except for adjacent to Lagoon of 0.5% AEP
7. Sea Level Rise 0.9 m and Rainfall Intensity Increase 10% – 1% AEP except for adjacent to Lagoon of 0.1% AEP
8. Sea Level Rise 0.9 m and Rainfall Intensity Increase 20% - 0.5% AEP except for adjacent to Lagoon of 0.1% AEP
9. 1% AEP from Dee Why Creek, Sea Level Rise 0.4 m and Rainfall Intensity Increase 20% - 0.5% AEP except for adjacent to Lagoon of 0.1% AEP
10. 1% AEP from Dee Why Creek, Sea Level Rise 0.9 m and Rainfall Intensity Increase 20% - 0.5% AEP except for adjacent to Lagoon of 0.1% AEP

12 Planning and Development

Council applies land use planning and development controls to manage development within flood prone areas. This includes designation of certain land uses in parts of the catchment and specific requirements for particular developments depending on the potential risk or hazard and overall suitability of an area. The Local Environmental Plan and Development Control Plan are the two primary mechanisms which specify controls based on the flood planning level and flood risk planning precinct.

12.1 Flood Planning Level

The Warringah Local Environmental Plan 2011 (LEP) is applied to manage development within the catchment to minimise flood risks and to avoid significant impacts on flood behaviour. The Flood Planning Level (FPL) is defined in the LEP as 'the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard'.

Figure 12-1 shows the extent of the modelled flood planning level area. It was determined by extrapolating the 1% AEP modelled peak flood levels to locations with elevations that are up to 0.5 m higher (in locations where flows are more than 0.15m deep). A significant proportion of the catchment at the CBD and downstream is shown within the extent as well as some properties near Beverley Job Park.

12.2 Flood Risk Planning Precinct

The Warringah Development Control Plan 2011 (DCP) specifies controls and conditions for developments based on the location of the property within the floodplain. Three planning precincts with different controls are established based on the flood characteristics – High Flood Risk, Medium Flood Risk and Low Flood Risk. Development within a High Flood Risk Planning Precinct is more restricted and has additional controls due to the potential hazard and risk in these areas.

The extents of the Precincts are shown in Figure 12-2 based on the flood model results for the classifications of the DCP:

- High Flood Risk Planning Precinct – located within a defined floodway or high hazard area in the 1% AEP event;
- Medium Flood Risk Planning Precinct – defined as land below the FPL but not within the High Flood Risk Planning Precinct; and
- Low Flood Risk Planning Precinct – defined as all other land within the floodplain (up to the PMF).

High Flood Risk Planning Precinct is predominantly shown within road areas however some properties are identified, noting sites upstream of Beverley Job Park, adjacent to open channels, and near the CBD and downstream to the Lagoon.

13 Conclusion

This report has been prepared for Warringah Council to define the nature and extent of flooding in the Dee Why South Catchment.

The Study was completed in three stages:

- Stage 1 – Community Consultation and Data Compilation
- Stage 2 – Peer Review of Hydrological and Hydraulic Components of the XP-SWMM Model
- Stage 3 – Flood Study Report

Community consultation is an important component of the project, being one of the key objectives of Council to ensure that the community can clearly understand potential flood risks within the catchment. The initial community consultation was a questionnaire mailed to all residents in the catchment advising of the Study and enquiring about a range of flood related issues. The responses were reviewed for application to the next stages of the Study.

Numerous flood assessments have been undertaken in Dee Why since 1975. Most recently, SMEC undertook an options assessment to assist Warringah Council to develop and select an appropriate stormwater upgrade design for the Dee Why Town Centre. A summary of each of the previous flood investigations has been undertaken and a more comprehensive review of the SMEC (2011) Options Assessment.

The Stage 2 review identified that the SMEC XP-SWMM model was a suitable basis for adaptation to this Study by the adoption of revised hydrological and hydraulic parameters over an expanded catchment area. The revised XP-SWMM model was applied to the Stage 3 flood modelling.

Flood modelling was completed to define flood behaviour, such as peak water depths and potential hazard, for a range of storm events from 1 in 1 year ARI to PMF and climate change scenarios. Model results, described below, are summarised in this Report and detailed results will be supplied to Council for their geographical information system.

The results show that generally the main overland flowpath starts from several branches at Alfred Street to Beverley Job Park. Flows in the open channel at Victor Road and Redman Road combine with other flows at the intersection of Redman Road and Pittwater Road. Overland flows are then conveyed along several roads and properties to Dee Why Lagoon as well as in the open channels between Pacific Parade / Oaks Avenue and downstream of Dee Why Parade.

This is through insufficient piped drainage or elevations that result in trapped lowpoints. Examples of these locations include Sturdee Parade (near Pittwater Road) and Alfred Street (near McIntosh Road) as well as on Beverley Job Park. Ponding also occurs at several locations in the catchment due to localised depressions from the LiDAR ground survey or building structures restricting overland flowpaths.

Ponding at lowpoints in these roads is modelled, with some depths in the range of 0.5 to 1.0 m deep. Some roads show scattered inundation up to 0.3 m such as Alfred Street (near McIntosh Road), Redman Road, and Howard Avenue as well as on the Victor Road side of Beverley Job Park.

Significant inundation is shown in a PMF event with some roads having a flood depth greater than 1 m and velocity greater than 2 m/s. Overall, the PMF results show that the catchment comprises a series of trapped lowpoints with insufficient piped drainage capacity or dedicated overland flowpaths.

A sensitivity analysis of the results was undertaken to evaluate the range of uncertainty in the modelled flood behaviour to changes in key parameters (e.g. surface roughness, downstream boundary level and inlet blockage). In most cases the base model results are within +/- 0.05m of the adjusted parameters. Particular locations, such as the trapped lowpoint in Sturdee Parade, shows higher increases but is generally confined to the road.

Hydraulic categories and provisional flood hazard was defined for the PMF, 1% AEP, 5% AEP and 5 year ARI events. The modelled PMF event shows a large portion of the catchment is categorised as floodway and high provisional hazard. In a 1% AEP event these floodway and high provisional hazard flow conditions along the open channels, on roads, and some properties. The Dee Why CBD is an area of high pedestrian activity and vehicle movement which is shown to have overland flooding which is categorised as floodway and high provisional hazard.

The stormwater drainage infrastructure, comprising inlet pits, pipes and culverts, is constructed to convey runoff underground and reduce the surface overland flows along roads and in properties. An assessment of the capacity of the drainage network was completed. Results showed a series of pipelines distributed across the network that have limited capacity compared to upstream pipes which may result in increased surface runoff.

Dee Why Lagoon is the downstream receiving waterbody for the Dee Why South Catchment and for modelling this downstream boundary, a fixed water level of 2.3 m AHD was adopted. Water levels in the Lagoon from 1996 to the present day (from Manly Hydraulics Laboratory) indicate that water level in the lagoon has not exceeded 2.41 m AHD. Generally, lagoon levels, as adopted for the present study define well the limits of likely tail water levels for Dee Why Creek. Only in a future very severe storm with projected sea levels above that currently advised for 2050 will ocean levels govern tail water levels for catchment flood events.

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. Potential changes to flood behaviour have been modelled for a range of scenarios incorporating a sea level rise of 0.4 m or 0.9m in the Lagoon, a 10% or 20% increase in rainfall intensity, and the 1% AEP flood event level from Dee Why Creek. Results showed that the modelled increases to Lagoon level have an impact to flood inundation of low-lying land near the Lagoon. Most properties within the Dee Why South catchment do not show a significant change in inundation extent for the modelled scenarios. Modelled increases in rainfall intensity showed a rise in peak water levels across the catchment, particularly in trapped low points such as on Sturdee Parade and Alfred Street.

Council applies land use planning and development controls to manage development within flood prone areas. This includes designation of certain land uses in parts of the catchment and specific requirements for particular developments depending on the potential risk or hazard and overall suitability of an area. The Local Environmental Plan and Development Control Plan are the two primary mechanisms which specify controls based on the flood planning level and flood risk planning precinct. The flood planning level extent and flood risk precinct mapping has been provided in this study to assist Council with future planning and development controls.

The next stage of the floodplain risk management process following the adoption of the Flood Study is the Floodplain Risk Management Study and Plan. This next stage will investigate various floodplain risk management measures and prioritise these measures for implementation.

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