ATTACHMENT BOOKLET 3

ORDINARY COUNCIL MEETING

TUESDAY 23 APRIL 2013

Warringah Council

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A part of BMT in Energy and Environment

Manly Lagoon Flood Study

Draft Report:
R.N2069.005.01
March 2013

Warringah Council

Manly Lagoon Flood Study

Draft Report

Prepared For:	Warringah Council
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Title :	Manly Lagoon Flood Study – Draft Report
Author :	Darren Lyons and Joshua Eggleton
Synopsis :	Report for the Manly Lagoon Flood Study covering the development and calibration of computer models, establishment of design flood behaviour and flood mapping.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE OF ISSUE	CHECKED BY		ISSUED BY	
0	12/03/2013	DJL		DJL	
1	21/03/2013	DJL		DJL	
2					

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EXECUTIVE SUMMARY

Introduction

The Manly Lagoon Flood Study has been prepared for Manly and Warringah Councils (The Councils) to define the existing flood behaviour in the Manly Lagoon catchment and establish the basis for subsequent floodplain management activities.

This study updates previous studies on the Lagoon including the Manly Lagoon Flood Study (MHL, 1992) and studies of the individual tributary streams, providing a holistic assessment of flooding within the catchment. The current Flood Study considers land use changes subsequent to previous modelling investigations, the influence of the Manly Lagoon entrance on flood behaviour and the influence of potential climate change.

The primary objective of this Flood Study is to define the flood behaviour under historical, existing and future conditions (incorporating potential impacts of climate change) in the Manly Lagoon catchment for a full range of design flood events. The study provides information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. The Flood Study has also identified the impact on flood behaviour as a result of future climate change and potential changes in the catchment and lagoon entrance. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking of a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Probable Maximum Flood (PMF), 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment derived flooding and the 0.5%, 1%, 2%, 5%, 10% and 20% AEP events for ocean derived flooding; and
- Assessment of potential impact of climate change using the latest guidelines.

Catchment Description

The Manly Lagoon catchment is situated on the southern boundary of the Warringah LGA bordering on the Manly LGA on Sydney's northern beaches. The Manly Lagoon catchment occupies a total area of approximately 18km^2, extending from Frenchs Forest and flowing generally south-east to the entrance to the Tasman Sea via Manly Lagoon.

The topography of the catchment is shown in Figure 2-1. From an elevation of around 160m AHD at the top of the catchment, the topography grades relatively steeply from the upper slopes (including the suburbs of Frenchs Forest, Allambie Heights, North Balgowlah and Beacon Hill) to the floodplain areas west of Manly Lagoon. From an elevation of around 50m AHD to the north and south of Manly

Lagoon (including the suburbs of Balgowlah, Fairlight, and Queenscliff) the topography also grades relatively steeply to the floodplain areas surrounding the Lagoon. The elevation of the floodplain grades gradually to the sea level at the Lagoon entrance at Queenscliff Beach.

The catchment of Manly Lagoon is predominantly urbanised, with industrial, commercial and residential development. There are three major commercial centres located within the catchment, namely Warringah Mall, Balgowlah Industrial Estate and Stockland Balgowlah. The Manly Lagoon floodplain is primarily open space, with a combination of four golf courses, parks and reserves dominating the lower catchment. Manly Dam is located in the catchment with a catchment area of approximately 500 hectares. The dam catchment is predominantly bushland and accounts for approximately one quarter of the total Manly Lagoon catchment area (DLWC, 1996).

Manly Lagoon is fed primarily by Burnt Bridge Creek, Brookvale Creek and Manly Creek. These three waterways each form a distinct sub-catchment, with the Manly Creek sub catchment incorporating inflows from Manly Dam and Curl Curl Creek in the upper catchment. The main basin of Manly Lagoon is long, narrow and relatively deep (up to 2 metres at Queenscliff).

Community Consultation

Community consultation is an important component of the Flood Study. The consultation has aimed to inform the community about the development of the Flood Study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience, their concerns on flooding issues and to collect feedback and ideas on potential floodplain management measures and other related issues.

Model Development

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of the Flood Study, a hydrological model and a hydraulic model are developed.

The **hydrological model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the overland flow paths, creeks and lagoon producing flood levels, flow discharges and flow velocities.

Information on the topography and characteristics of the catchments and floodplains are built into the hydraulic model. Recorded historical flood data, including rainfall and flood levels, are used to simulate and validate (calibrate and verify) the model. The model produces as output, flood levels, flows (discharges) and flow velocities.

With consideration to the available survey information and local topographical and hydraulic controls, a linked 1D/2D model was developed extending from the Lagoon entrance in Queenscliff at the downstream limit, to the head of the catchment. The floodplain area modelled within the 2D domain comprises a total area of approximately 18km^2 which includes the Manly Lagoon catchment in its entirety.

Model Calibration and Validation

The selection of suitable historical events for calibration and validation of flood models is largely dependent on the availability of relevant historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design events to be considered.

Review of the available rainfall and water level data for the Manly Lagoon catchment highlighted two relatively recent flood events with sufficient data to support a calibration process – the April 1998, and March 2011 event. The April 1998 event resulted in the highest recorded Lagoon water levels since the installation of the MHL water level gauges.

The models were found to provide a reasonable representation of the observed flood behaviour in the catchment.

Design Event Modelling and Output

The developed models have been applied to derive design flood conditions within the Manly Lagoon catchment. Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). A range of storm durations using standard AR&R (2001) temporal patterns, were modelled in order to identify the critical storm duration for design event flooding in the catchment.

A suite of design event scenarios was defined that is most suitable for future floodplain management planning in Manly Lagoon. Consideration was given to flood events driven by both catchment and ocean processes. The catchment derived events were found to be the critical events in terms of determining maximum flood levels.

The design events simulated include the PMF event, 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment derived flooding and the 0.5%, 1%, 2%, 5%. 10% and 20% AEP events for ocean derived flooding.

The model results for the design events considered have been presented in a detailed flood mapping series for the catchment (see Appendix A). The flood data presented includes design flood inundation, peak flood water levels and depths and peak flood velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected areas.

Sensitivity Testing

A number of sensitivity tests have been undertaken to identify the impacts of the adopted model conditions on the design flood levels. Sensitivity tests included:

- The modelled lagoon entrance berm conditions;
- The coincident catchment and ocean flooding conditions;
- Structure and stormwater pipe blockages; and
- Changes in the adopted roughness parameters.

Climate Change

The impacts of future climate change are likely to lead to a wide range of environmental responses in coastal lagoons such as Manly Lagoon. These are likely to manifest throughout the physical, chemical and ecological processes that drive local estuarine ecosystems.

Key elements of future climate change (sea level rise, rainfall intensity) have been incorporated into the assessment of future flooding conditions in the Manly Lagoon catchment for consideration in the ongoing floodplain risk management. The key potential influences on flood behaviour incorporated in the assessment include:

- Increases in rainfall intensity for flood producing events;
- Higher ocean water levels (tide and storm surge) under sea level rise;
- Higher entrance berm heights under sea level rise; and
- Higher initial Lagoon water levels under sea level rise.

Conclusions

Provided below is a summary of the key findings of the Flood Study, in particular some of the important considerations for future floodplain risk management in the catchment:

- The design flood conditions documented in the report typically provide for a small increase in previously adopted design flood conditions for Manly Lagoon. The main contributing factor to this change is the way the entrance condition has been modelled. In addition to advances in the software to simulate entrance breakout response, the initial conditions in respect to berm elevations and initial water levels in the Lagoon have been represented in the model according to current Council entrance management practices.
- Longer duration events (9-18 hours) typically provide for the worst case flooding conditions in Manly Lagoon. With the Lagoon waterbody providing flood storage, events of longer duration are required to generate sufficient flood runoff volumes from the catchment to elevate Lagoon water levels. In the lower reaches of all the tributary catchments, flood levels are dominated by the Lagoon flooding conditions. The peak flood water level in the Lagoon extends a significant distance up the tributary channels. In the upper reaches of the tributary catchments, shorter duration events of the order of 2-hours provide the critical flood condition in terms of peak flood water level.
- The rise in flood water levels can be relatively fast from the catchment's response to rainfall. Even for the longer duration events providing for the highest peak flood water levels in the Lagoon, the main period of rise in Lagoon water level can occur over a few hours. The April 1998 flood event (used for model calibration in the current study) is an example of such a response in the catchment. Flood levels in the tributary catchments may also rise significantly faster owing to the shorter critical durations in these catchments. This potentially rapid inundation has implications for flood warning and emergency response, particularly in flood situations where property and access roads may be quickly inundated.
- Catchment derived flooding events represent the dominant flooding mechanism in Manly Lagoon. Whilst some ocean flooding scenarios will provide for inundation of some foreshore areas, the extent and severity of flooding is significantly less than the corresponding catchment derived

event magnitude. The entrance condition has some influence on catchment flood behaviour with higher entrance berm levels providing for higher peak flood levels. The existing entrance management policy provides for manual breakout of the Lagoon entrance at defined trigger levels in preparation for imminent flooding. Irrespective of the successful implementation of a manual entrance breakout, significant flood inundation may be expected during major catchment flood events.

- There are a number of areas within the Manly Lagoon catchment which represent the most significant flood risk exposure to existing property. The worst affected areas are typically in the lower parts of the catchment and most severely impacted on by major flooding in Manly Lagoon. These areas include the foreshore areas of the Lagoon around Riverview Parade. Much of the lower floodplain area is however occupied by park lands / golf courses such that flood risk exposure of existing property is limited. Elsewhere, the Warringah Mall and Balgowlah Industrial Estate are located on the alignments of Brookvale Creek and Burnt Bridge Creek respectively. When drainage system capacities in these areas are exceeded, there is potential for overland flow through these areas.
- Peak design flood water levels are expected to progressively increase as the impacts of climate change manifest. For the Manly Lagoon catchment, potential sea level rise will provide for a worsening of existing flood conditions through higher ocean water levels (tide and storm surge), higher entrance berm and higher initial water levels in the Lagoon. Robust land use planning and development policies will be required to ensure future flood risks are not unduly exacerbated in light of predicted flood behaviour under potential climate change scenarios.
- Council's existing entrance management policy is to open the entrance at a defined trigger water level (currently 1.4m AHD). With potential sea level rise, normal tide levels in the Lagoon will approach and eventually exceed the current trigger levels. Future openings would need to be at significantly higher trigger levels to be effective. Low-lying land currently impacted by flooding may also be subject to regular (or permanent) tidal inundation at sometime in the future.

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GLOSSARY

afflux	The change in water level from existing conditions resulting from a change in the watercourse or floodplain – e.g. construction of a new bridge.
annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (see also average recurrence interval)
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Astronomical Tide	Astronomical Tide is the cyclic rising and falling of the Earth's oceans water levels resulting from gravitational forces of the Moon and the Sun acting on the Earth.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
Australian Rainfall and Runoff (AR&R)	Engineers Australia publication pertaining to rainfall and flooding investigations in Australia
calibration	The adjustment of model confuguration and key parameters to best fit an observed data set
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood event	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in tems of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.

flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage. These areas are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
flood liable land	see flood prone land
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Development Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPL)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk 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 landuse and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood source	The source of the floodwaters. In this study, Manly Lagoon and its tributaries are the primary sources of floodwaters.
flood storage	Floodplain areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.

floodway	Areas and flowpaths where a significant proportion of floodwaters are conveyed during a flood (including all bank-to-bank creek sections).
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
geomorphology	The study of the origin, characteristics and development of land forms.
gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrographic survey	Survey of the bed levels of a waterway.
hydrologic	Pertaining to rainfall-runoff processes in catchments
hydrology	The term given to the study of the rainfall-runoff process in catchments.
hyetograph	A graph showing the depth of rainfall over time.
Intensity Frequency Duration (IFD) Curve	A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.
intermittently closed and open Lake/Lagoon (ICOLL)	A Lake/Lagoon that is seperated from the ocean by a sand beach barrier or berm and is subject to forces that act to close the entrance (waves, tides and wind) and those that act to maintain an open entrance (flood flows and dredging), which results in the Lake/Lagoon being intermittently closed and open to the ocean.
isohyet	Equal rainfall contour
morphological	Pertaining to geomorphology
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continously measuring rainfall intensity
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.

riparian	The interface between land and waterway. Literally means "along the river margins"
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep
topography	The shape of the surface features of land
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
validation	A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.
water level	See flood level.

1 INTRODUCTION

The Manly Lagoon Flood Study has been prepared for Warringah Council and Manly Council (The Councils) to define the existing flood behaviour in the Manly Lagoon catchment and establish the basis for subsequent floodplain management activities.

This study will update the previous studies on the Lagoon including the Manly Lagoon Flood Study (MHL, 1992) and smaller localised flood studies, providing a holistic assessment of flooding within the catchment. The current flood study considers land use changes subsequent to previous modelling investigations, the influence of the Manly Lagoon entrance on flood behaviour and the influence of potential climate change.

The study has been prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy. This project has been conducted under the State Assisted Floodplain Management Program and received State financial support.

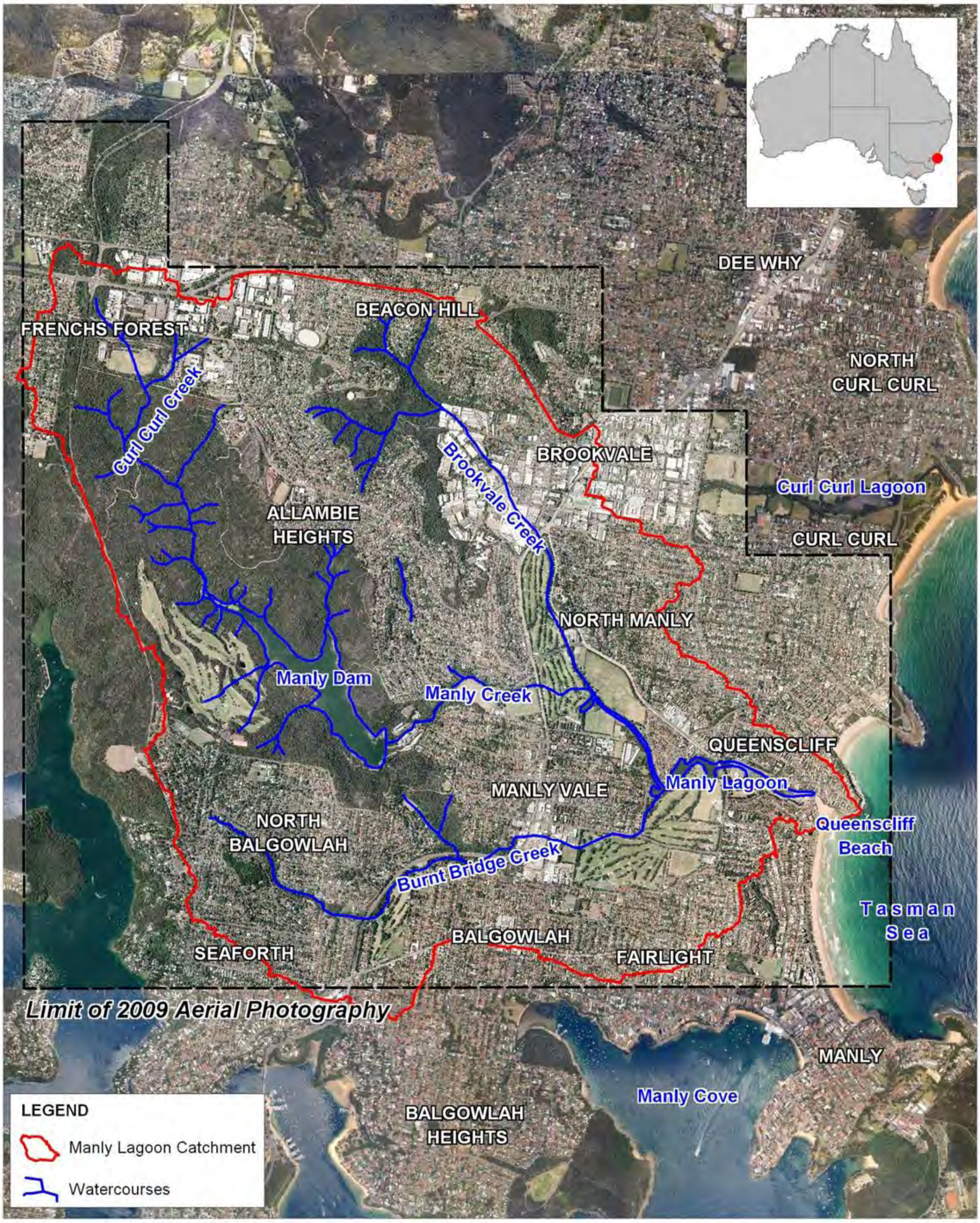
The study has been undertaken in a staged approach as outlined below:

- Stage 1 - Collection, Compilation and Review of Available Information;
- Stage 2 - Hydrological Analysis;
- Stage 3 - Hydraulic Modelling;
- Stage 4 - Climate Change Analysis; and
- Stage 5 - Final Reporting.
- An interim report outlining the methodologies, analysis and key outcomes has been provided at the completion of each stage. This report is the Stage 5 Draft Report documenting the Study's overall objectives, results and recommendations.

1.1 Study Location

The Manly Lagoon catchment encompasses an area of approximately 18km^2 located on the border of the Warringah LGA and Manly LGA on Sydney's northern beaches as shown in Figure 1-1. Manly Lagoon is a relatively small waterbody (surface area of approximately 0.1km^2) located in the east of the catchment with an entrance to the Tasman Sea located at Queenscliff Beach.

Manly Lagoon is fed primarily by Burnt Bridge Creek, Brookvale Creek and Manly Creek. These three waterways each form a distinct sub-catchment, with the Manly Creek sub catchment incorporating inflows from Manly Dam and Curl Curl Creek in the upper catchment. Manly Lagoon also receives inflow from a large number of stormwater drains distributed throughout the catchment.



Title:
Study Locality

Figure: 1-1

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There are upstream and downstream modifications to the watercourse entering and leaving Manly Lagoon that can potentially influence flooding in the catchment. Manly Dam lies upstream of the Lagoon, and as a consequence the levels in the dam are tied closely to the potential for downstream flooding and the opening of the Lagoon. At the downstream end of the Lagoon there are low flow pipes which permanently connect the Lagoon to the ocean, allowing outflow of Lagoon waters as well as constant tidal exchange. A rock bar is present across the channel under the Queenscliff Bridge[1] at approximately 0.2m AHD and this effectively controls the Lagoon's minimum water level (MHL, 1992). Opening the entrance of the Lagoon at Queenscliff Beach ultimately provides the most immediate relief from floods. Manly Council currently initiates a mechanical opening of the Lagoon entrance using a bulldozer to breach the beach berm when Lagoon water levels reaches 1.4m AHD with a head difference between the Lagoon and ocean water levels of ~0.6m.

The catchment of Manly Lagoon is predominantly urbanised, with industrial, commercial and residential development. The Manly Lagoon floodplain is primarily open space, with a combination of golf courses, parks and reserves dominating the lower catchment.

1.2 Study Background

A series of floodplain management studies, including a Flood Study (MHL, 1992), a Floodplain Management Study (DLWC, 1996) and a Floodplain Management Plan (DLWC, 1997), have previously been completed to define and manage the flood behaviour of the Manly Lagoon catchment (mainly focusing on the lower floodplain).

Due to changes within the catchment over the past 21 years, as well as the need to take into consideration the impacts of climate change on the flooding of coastal environments, up-to date information is required to accurately predict the flood behaviour and impacts of climate change and sea level rise on the catchment. This current Flood Study aims to provide the up to date information in the form of up to date flood modelling. This up to date flood modelling will provide details on existing and future flood risk including the potential impacts of climate change and overland flows.

The flood study update will also utilise significant advances in the methodologies used to predict flood behaviour, including updates in modelling techniques and the capture of high quality ground level data (LiDAR).

1.3 The Need for Floodplain Management at Manly Lagoon

Previous investigation of the flooding characteristics of the Manly Lagoon catchment (MHL, 1992; MHL, 2003) have found that the majority of the Manly Lagoon floodway and flood storage/fringe area is occupied by open space, including Manly and Warringah golf courses, David Thomas Reserve, Graham Reserve, Keirle Park, Lagoon Park, Miller Reserve, Nolan Reserve, and Passmore Reserve. Some parts of the flood storage area have been developed, however, and Lagoon flooding can potentially affect properties in North Manly and Manly Flat and the eastern fringes of Manly Vale, particularly Cambell Parade and Addiscombe Rd (MHL, 2003).

[1] Queenscliff Bridge has been renamed Stuart Somerville Bridge. Draft Flood Study document refers to Queenscliff Bridge which will subsequently be amended in future document revisions

Flood inundation maps (created using geo-referenced two metre contour data) produced as part of the Manly Lagoon Flood Intelligence Report (MHL, 2003) indicate that in the event of The Council's designated design flood (1% AEP flood event) 361 properties are likely to be affected by over-ground flooding (based on a peak flood level at the Riverview Parade gauge of 2.69m for the 1% AEP event as reported in the Manly Lagoon Flood Study (MHL, 1992)). Of these 361 properties approximately 142 properties are affected by over-floor flooding (based on floor level survey undertaken in 1993-1994). It should be noted that these figures could be outdated due to changes to the catchment including new development within the floodplain since the production of the Flood Intelligence Report (MHL, 2003).

The flood risk of the Manly Lagoon catchment has previously been assessed based on hydraulic criteria of velocity and depth of flow. Most of the flood liable properties were previously categorised as low hazard (DLWC, 1996) with one area at the eastern end of Campbell Parade (including the Manly Vale Bowling Club and Manly Small Bore Rifle Club properties) characterised as high hazard. It has since been shown that this high hazard area could be reduced to low hazard if an effective evacuation plan was implemented for this area (MHL, 2003).

Flood mitigation in Manly Lagoon is presently achieved through the management of the Manly Lagoon Entrance. The Manly Lagoon Floodplain Risk Management Plan (DLWC, 1997) outlines the following important aspects of the entrance management procedure:

- Control of sand accumulation in the vicinity of Queenscliff Bridge, and maintenance of a channel across the beach during dry weather periods;
- Artificial opening of the emergency channel to the sea when the Lagoon flood level reaches 1.4m AHD. This practice has since been updated to use the Lagoonwatch model, which uses the predicted Lagoon and ocean levels to determine the most suitable window of opportunity for an entrance opening attempt (see Section 2.1.2); and
- Low flow pipes to minimise the possibility of pipe blockage by sand and seaweed.

Current practice in floodplain management generally requires consideration of the impact of potential climate change scenarios on design flood conditions. For the Manly Lagoon catchment this includes both increases in design rainfall intensities and sea level rise scenarios impacting on ocean boundary conditions. Accordingly, these potential changes will translate into increased design flood inundation in the Manly Lagoon catchment. Future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

Floodplain risk management considers the consequences of flooding on the community and aims to develop appropriate floodplain management measures to minimise and mitigate the impact of flooding. This incorporates the existing flood risk associated with current development, and future flood risk associated with future changes in land use (urbanisation) and the impact of potential future climate change.

Accordingly, The Councils desires to approach local floodplain management in a considered and systematic manner. This Flood Study comprises the initial stages of that systematic approach, as outlined in the Floodplain Development Manual (DIPNR, 2005). The approach will allow for more informed planning decisions within the floodplain of Manly Lagoon.

1.4 The Floodplain Management Process

The NSW State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding 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. Policy and practice are defined in the NSW State Government's Floodplain Development Manual (2005).

Under the Policy the management of flood liable land remains the responsibility of Local Government. The NSW State Government subsidises floodplain management studies and flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the NSW State Government through the six sequential stages shown in Table 1-1.

Table 1-1 Stages of Floodplain Management

	Stage	Description
1	Formation of a Committee	Established by Council and includes community group representatives and State agency specialists.
2	Data Collection	Past data such as 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 developments.
5	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
6	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of local environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stages 2 and 3 of the above process and aims to provide an understanding of existing and future flood behaviour within the Manly Lagoon catchment.

1.4.1 Climate Change

The primary impacts of climate change in coastal areas are likely to result from sea level rise, which, coupled with a potential increase in the frequency and severity of storm events, may lead to increased coastal erosion, tidal inundation and flooding.

In 2009 the NSW State Government announced the NSW Sea Level Rise Policy Statement (DECCW, 2009) that adopted sea level rise planning benchmarks to ensure consistent consideration of sea level rise in coastal areas of NSW. These planning benchmarks adopt increases (above 1990 mean sea level) of 40 cm by 2050 and 90 cm by 2100. However, on 8 September 2012 the NSW Government announced its Stage One Coastal Management Reforms which no longer recommends state-wide sea level rise benchmarks for use by local councils. Instead councils have the flexibility to consider local conditions when determining future hazards of potential sea level rise.

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 the majority of analysis and modelling tasks associated with this current Flood Study were completed 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 The Council's and BMT WBM that the potential impacts of sea level rise for the Manly Lagoon catchment were based on the best available information at hand during preparation of this report.

For Manly Lagoon, rising sea level is expected to increase the frequency, severity and duration of flooding. This is particularly the case when the entrance is open, with potentially more ocean water flowing through the entrance and into the main body of the Lagoon.

Projected sea level rise will also result in higher sand levels at the entrance when it is closed than existing baseline conditions. This means that the Lagoon water levels will need to be even higher in the future in order to initiate effective break-out channels, resulting in increased flood risk to foreshore properties.

In 2007, the NSW State Government released a guideline for practical consideration of climate change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. Accordingly, this increase in design rainfall will translate into increased flood inundation in the Manly Lagoon catchment. Future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

In consultation with The Councils and the Office of Environment and Heritage (OEH), a range of climate change sensitivity tests incorporating combinations of sea level rise and increased design rainfall intensity were formulated. The results of these sensitivity tests (refer Section 8) were then compared to the base case (i.e. models with existing sea level and climate) model results in order to assess the potential increase in flood risk due to climate change.

1.5 Study Objectives

The primary objective of this Flood Study is to define the flood behaviour under historical, existing and future conditions in the Manly Lagoon catchment for a full range of design flood events. The study will provide information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. The flood study is to be used to identify the impact on flood behaviour as a result of future climate change and potential changes in the catchment and Lagoon entrance. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertake a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Probable Maximum Flood (PMF), 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment derived flooding and the 0.5%, 1%, 2%, 5%, 10% and 20% AEP events for ocean derived flooding; and
- Examine potential impact of climate change using the latest guidelines for the 20%, 5%, 1% AEP and PMF design events.

The models and results produced in this study are intended to:

- Outline the flood behaviour within the catchment to aid in strategic land use management planning; and
- Form the basis for a subsequent floodplain risk management study where detailed assessment of flood mitigation options and floodplain risk management measures will be undertaken.

1.6 About This Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the study and summary of background information.

Section 3 outlines the community consultation program undertaken.

Section 4 details the development of the computer models.

Section 5 details the hydraulic model calibration and validation process.

Section 6 details the design flood conditions.

Section 7 details the design flood results and associated flood mapping.

Section 8 details the climate change analysis.

2 STUDY APPROACH

2.1 The Study Area

2.1.1 Catchment Description

The Manly Lagoon catchment is situated on the southern boundary of the Warringah LGA bordering on the Manly LGA on Sydney's northern beaches. The Manly Lagoon catchment occupies a total area of approximately 18km^2, extending from Frenchs Forest and flowing generally south-east to the entrance to the Tasman Sea via Manly Lagoon.

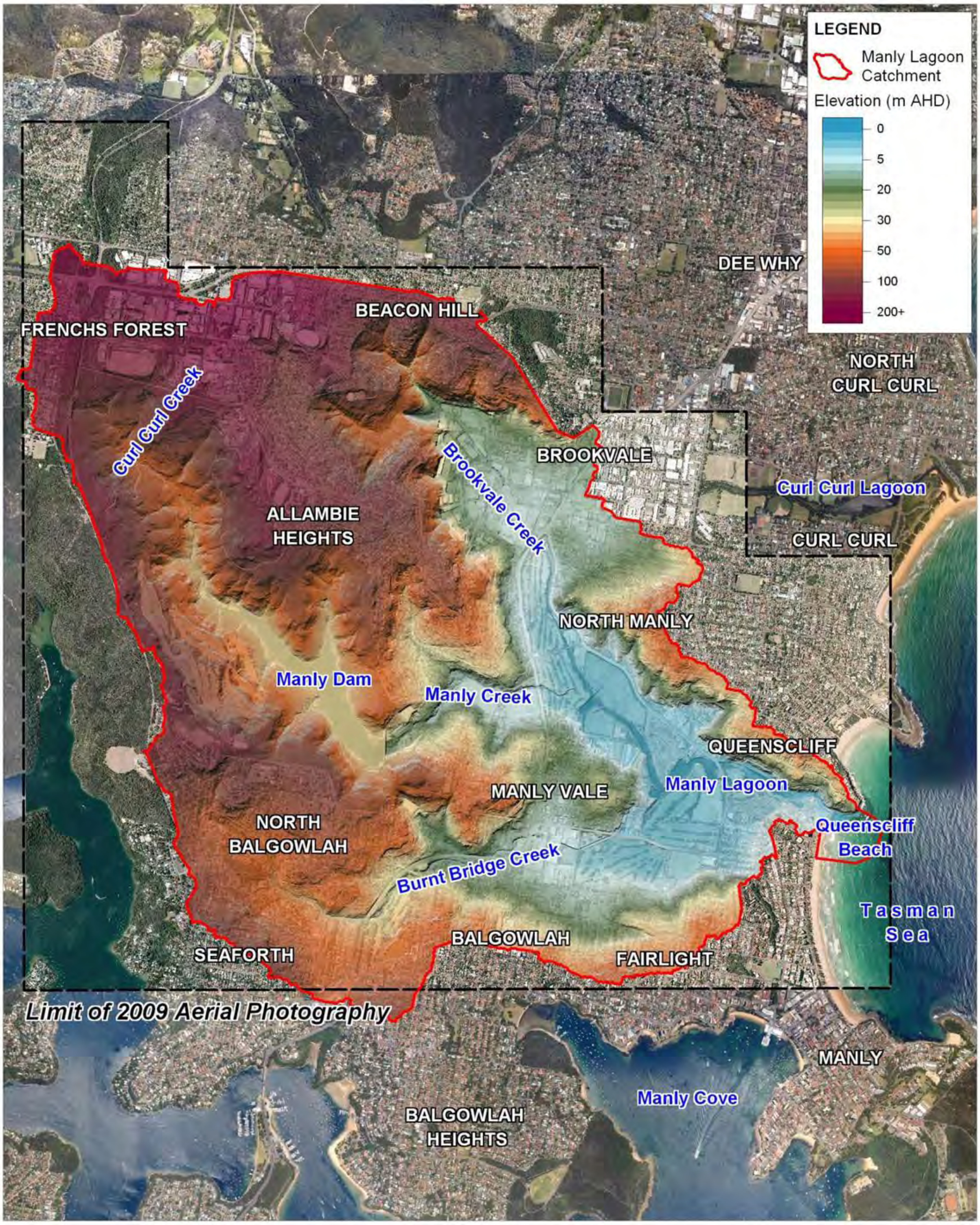
The topography of the catchment is shown in Figure 2-1. From an elevation of around 160m AHD at the top of the catchment, the topography grades relatively steeply from the upper slopes (including the suburbs of Frenchs Forest, Allambie Heights, North Balgowlah and Beacon Hill) to the floodplain areas west of Manly Lagoon. From an elevation of around 50m AHD to the north and south of Manly Lagoon (including the suburbs of Balgowlah, Fairlight, and Queenscliff) the topography also grades relatively steeply to the floodplain areas surrounding the Lagoon. The elevation of the floodplain grades gradually to the sea level at the Lagoon entrance at Queenscliff Beach.

The catchment of Manly Lagoon is predominantly urbanised, with industrial, commercial and residential development. There are three major commercial centres located within the catchment, namely Warringah Mall, Balgowlah Industrial Estate and Stockland Balgowlah. The Manly Lagoon floodplain is primarily open space, with a combination of golf courses, parks and reserves dominating the lower catchment. Manly Dam is located in the catchment with a catchment area of approximately 500 hectares. The dam catchment is predominantly bushland and accounts for approximately one quarter of the total Manly Lagoon catchment area (DLWC, 1996).

Manly Lagoon is fed primarily by Burnt Bridge Creek, Brookvale Creek and Manly Creek. These three waterways each form a distinct sub-catchment, with the Manly Creek sub catchment incorporating inflows from Manly Dam and Curl Curl Creek in the upper catchment. The main basin of Manly Lagoon is long, narrow and relatively deep (up to 2 metres at Queenscliff).

2.1.2 Manly Lagoon Entrance

The entrance to Manly Lagoon lies at the northern end of an easterly facing beach and is bounded by a rocky headland to the north and urban development to the south. The entrance has been modified with the presence of two low flow pipes (1.8m diameter) and a concrete channel, which are situated at the ocean end of the Lagoon. The flow pipes have an invert level of -0.71m AHD which allows freshwater to flow into the ocean and also some limited tidal exchange between the Lagoon and the ocean. The permanent channel is under the control of Manly Council (MHL, 1992). Prior to 1999, timber gates were used to close the permanent channel during periods when sand was deposited at the northern end of Queenscliff Beach in order to prevent sand build up in the pipes. During periods when the gates were closed there was no permanent connection between Manly Lagoon and the ocean. The timber gates were removed in 1999 when the low flow pipes were extended to the eastern end of the pool.



Title:

Topography of the Manly Lagoon Catchment

Figure: **2-1**

Rev: **A**

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The Queenscliff Bridge traverses Manly Lagoon at Queenscliff immediately adjacent to Queenscliff Beach. The Manly Lagoon Flood Study (MHL, 1992) found that the bridge plays an important role in the Lagoon entrance behaviour. A rock bar is present across the channel under the Queenscliff Bridge at approximately 0.2m AHD. This limits the amount of channel scour in the Lagoon entrance and together with the walls of the bridge, controls the rate of discharge into the ocean. The rock bar also effectively controls the Lagoon's minimum water level.

In the event that the permanent channel is unable to discharge sufficient flows during flood events, a relief channel is cut through the sand berm at Queenscliff Beach allowing water to discharge directly from the Lagoon into the ocean. The relief channel is excavated across the beach using a bulldozer which is permanently on standby for such flood events. During dry weather periods the relief channel is maintained parallel and approximately 20m to the south of the low flow pipes (MHL, 2003). The subsequent discharge of water out of the Lagoon results in a scouring effect that progressively widens and deepens the channel as the flow increases until an equilibrium point is reached. Following the flood event, the relief channel is to remain open until the beach berm is naturally reinstated resulting in the entrance being closed off (Manly and Warringah Councils, 2000).

Historically, Manly Council policy has been to breach the berm using the bulldozer when the water in the Lagoon at Queenscliff Bridge has reached a level of 1.4m AHD. However, the criterion for mechanically opening the relief channel has been updated to use the LagoonWatch system. The Manly LagoonWatch system is a real time rainfall and water level monitoring system for Manly Lagoon that provides early flood warning and predictions. The system was developed by Manly Hydraulics Laboratory for Manly Council. The LagoonWatch system uses the predicted Lagoon and ocean levels to determine the most suitable window of opportunity for an entrance opening attempt. The Council's decision to open the relief channel is currently dependent upon the Lagoonwatch entrance breakout recommendation, monitoring of current and predicted Lagoon water levels on the Lagoonwatch system, and observed hydraulic, weather and ocean conditions (MHL, 2003). The Manly Lagoon Emergency Flood Channel Protocol (2000) states that the cutting of the emergency channel should commence immediately upon rainfall causing the Lagoon water level to rise above 1.0-1.4m AHD and subject to a head difference (between the Lagoon and ocean water levels) of 0.6m.

The beach berm at the entrance to Manly Lagoon is naturally built up over time by the interaction of ocean tides and wave processes. The process of natural Lagoon breakouts results from overtopping of the berm due to high Lagoon levels during heavy rainfall events and/or wave processes at the entrance.

2.1.3 Manly Dam

Manly Dam has a storage capacity of approximately 2,000 ML, with the crest of the dam at 35.84m AHD. The water level in the dam is maintained at 34.16m AHD (1.7m below the crest) in accordance with the Manly Lagoon Floodplain Management Plan (DLWC, 1997). The dam has a fixed crest continuous spillway approximately 250m long. The water levels in the dam are controlled and monitored by Sydney Water and Warringah Council, with Sydney Water primarily releasing water from the dam for dam safety control and Warringah Council primarily releasing water for flood mitigation.

Prior to 2001, the dam had two scour valves that were originally constructed to allow silt deposits that built up in the dam to be discharged into Manly Creek. The scour valves were also subsequently used to regulate the water level in the dam, however, the combined discharge capacity of the two scour valves was only 1.16m^3/s. At this discharge rate it took approximately five days to lower the water level in the dam from the spillway crest to the normal operating level (34.1m AHD). In 2001, a new scour valve was installed, increasing the combined discharge capacity of the valves to 2.6m^3/s, decreasing the time required to reduce the dam water level from the spillway crest to the normal operating height to 2.2 days. The scour valves are presently used in a limited capacity to regulate the water level in the dam and maintain a flood mitigation component. Warringah Council is responsible for operating the scour valves (MHL, 2003). Water in the dam is also extracted by the two hydraulics laboratories located in Manly Vale for testing of physical models. This water is later released into Manly Creek thus providing a flow in the creek during normal periods (MHL, 1992).

The Manly Lagoon Flood Study (MHL, 1992) investigated the impact that the actual water level in Manly Dam can have on the flood behaviour of the Manly Lagoon catchment. The study found that the initial water levels in the dam can affect the peak flood levels in the catchment by 0.1m to 0.2m.

The current operating procedure for the opening and closing of the scour valves (as outlined in the Procedures for Manly Dam (Sydney Water & Warringah Council, 2010)) are as follows:

- Water level in the dam is to be maintained at 34.16m AHD (1.7m below the Spillway Crest Level of the dam);
- At 1.0m below the Spillway Crest Level Warringah Council is to be notified through SMS text message from MHL to open the scour valves owned and operated by Warringah Council;
- At 0.5m below the Spillway Crest Level an alarm will trigger at Sydney Water System Operation Centre to open the scour valves owned and operated by Sydney Water; and
- At 1.6m below the Spillway Crest Level Warringah Council is notified through SMS text message from MHL to close the scour valve owned and operated by Warringah Council. Sydney Water is also notified to close the scour valves owned and operated by Sydney Water if they have been opened.

2.2 Compilation and Review of Available Data

2.2.1 Previous Investigations

A Flood Study of Manly Lagoon has previously been undertaken by Manly Hydraulics Laboratory (MHL) in 1992. This flood study was subsequently followed by a Floodplain Management Study for the Manly Lagoon (completed by the Department of Land and Water Conservation (DLWC) in 1996) and the preparation of a Floodplain Management Plan (completed by DLWC in 1997). In addition to these floodplain management studies, numerous studies have been undertaken investigating the management of the Manly Lagoon entrance at Queenscliff Beach.

Details of these previous investigations and their relevance in the context of the current flood study are presented in the following sections.

2.2.1.1 Manly Lagoon Flood Study (MHL, 1992)

As discussed in Section 2.2.1, MHL have previously completed a flood study of Manly Lagoon in 1992. The objective of the study was to estimate the design flood levels for the 1% AEP, 5% AEP and 20% AEP flood events. Flood level estimates were also undertaken for the extreme flood event.

The relevant components of the study include:

- Flood Study – historical background, rainfall data, cross section survey, model build and calibration, compilation of historical flood levels;
- Review of historical flooding in the catchment – based predominantly on flood levels collected by Mr Ross Stephens, former resident of 25 Lakeside Crescent, North Manly;
- Analysis of Lagoon entrance conditions;
- Analysis of ocean condition at the entrance to the Manly Lagoon – taking into consideration still ocean water levels and wave setup;
- Development of a database of surveyed cross sections to define the topography of the floodplain and Manly Lagoon for developing the one-dimensional hydraulic (MIKE11) model;
- Development and preliminary calibration of hydrologic (RORB and WBNM) and one-dimensional hydraulic (MIKE11) models using available data; and
- Presentation of design flood information (the 1% AEP, 5% AEP and 20% AEP and PMF flood events) in the form peak flood levels and flood contours at specific locations/chainages within the modelled area.

It should be noted that the hydraulic study was not a catchment wide model but rather was limited to the following study area:

- Manly Lagoon and surrounding parks and golf courses;
- Brookvale Creek down from Warringah Mall;
- Manly Creek down from Manly Dam; and
- Burnt Bridge Creek down from Condamine Street.

The one-dimensional hydraulic (MIKE11) model network was defined by a series of cross sections at approximately 200m intervals throughout the modelled area, with ten boundaries defining water flowing into the model and the ocean connection as the downstream boundary.

The MIKE-11 model was calibrated using the June 1991 rainfall event. The model was then tested using the April 1988, March 1975 and May 1974 rainfall events. The calibrated hydraulic model was then used to estimate the PMF, 1% AEP, 5% AEP and 20% AEP flood levels in Manly Lagoon.

It should be noted that the flood levels estimated in the 1992 Flood Study were based on the assumption that the entrance would always be mechanically opened when the water level reaches 1.4m AHD. If the Lagoon was not mechanically opened the flood levels estimated would have significantly increased. This study did not take into consideration the urban trunk drainage schemes that feed into Manly Lagoon and its tributaries. This additional flow could further exacerbate the estimated flood levels.

2.2.1.2 Bangaroo Street Flood Investigation (Cardno Lawson Treloar, 2006)

In 2006 Cardno Lawson and Treloar were engaged by Warringah Council to undertake a flood investigation of the North Balgowlah subcatchment surrounding the upper reaches of Burnt Bridge Creek. The area investigated comprised a section of Burnt Bridge Creek, extending from just upstream of the Eileen Street Pedestrian Bridge to approximately 50m downstream of the Bangaroo Street culverts.

Runoff hydrographs for the study area (used as inputs into the hydraulic model) were estimated using the XP-RAFTS hydrological model. The one-dimensional hydraulic modelling package MIKE-11 was used to model the flooding behaviour of the catchment. The model network was defined by a land survey and a series of 18 cross sections surveyed along the modelled length of Burnt Bridge Creek.

The MIKE-11 model was calibrated using the January 1989 (~1% AEP – 2 hour duration), April 1998 (~50%-20% AEP – 2 hour duration) and February 2005 (~50%-20% AEP – 0.5 hour duration) rainfall events. The calibrated hydraulic model was then used to estimate design overland flow depths for the existing catchment and floodplain conditions.

A number of preliminary flood mitigation options were also identified with the aim of improving flood conditions in the area between the Eileen Street footbridge and the Bangaroo Street culverts. These preliminary options included a detention basin upstream of the Eileen Street footbridge; upgrade of the culverts under Bangaroo Street and channel widening/stabilisation within Burnt Bridge Creek.

2.2.1.3 Ryan Place Overland Flood Study (Webb, McKeown and Associates, 2007)

Webb McKeown and Associates were engaged by Warringah Council to undertake an Overland Flood Study of Ryan Place and its surrounds. Ryan Place has a catchment of approximately 12 hectares which drains into Brookvale Creek. There is also an extensive piped drainage system within the catchment.

Hydrological modelling was undertaken using a runoff routing formulation based on the methodology contained in the ILSAX/DRAINS model while the hydraulic modelling was undertaken using the MIKE-Storm hydraulic model. The MIKE-Storm model established for Ryan Place made use of existing drainage information as well as additional topographic data collected as part of the study. Due to insufficient historical data at Ryan Place no model calibration was undertaken.

2.2.1.4 Brookvale Bus Depot Flood Study (Arup, 2007)

ARUP were engaged by the State Transit Authority of NSW to undertake a Flood Study of Brookvale bus depot site and its surrounds, and assess the implications of a proposed upgrade of the site. A DRAINS model was developed to estimate follows at the boundary of the Brookvale bus depot site. The DRAINS model included the upstream pipe networks and the wider overland flow catchment. The DRAINS model was used to determine peak flows for the 1% AEP event. Due to insufficient historical data no model calibration was undertaken.

2.2.1.5 Summary Table of Manly Lagoon Flood Studies

Table 2-1 summarises the hydrologic and hydraulic models and calibration/ validation events used in relevant Manly Lagoon (and associated catchments) flood studies/investigations.

Table 2-1 Summary of Previous Flood Studies

Study Area	Report	Model (Hydrologic / Hydraulic)	Calibration & (Validation) Events
Manly Lagoon	MHL (1992)	RORB & WBNM MIKE-11 1D	June 1991 (April 1988, March 1975, May 1974)
Bangaroo Street	CLT (2006)	XP_RAFTS MIKE-11 1D	Jan 1989, April 1998, Feb 2005
Ryan Place	WMA (2007)	ILSAX/DRAINS MIKE_Storm 1D	No Calibration Undertaken
Brookvale Bus Depot	(Arup, 2007)	DRAINS	No Calibration Undertaken

Figure 2-2 presents the previously mapped 1% AEP and PMF flood extents each of the flood studies previously completed within the Manly Lagoon catchment (the flood extents for the Brookvale Bus Depot not provided). Figure 2-3 provides indicative extents of the existing models model extents (i.e. upstream and downstream bounds) of each of the previously completed flood studies (does not represent flood inundation extents). This Flood Study will provide an up to date catchment wide flood model that will effectively update and fill in the gaps of the previous investigations.

2.2.2 Water Level Data

MHL operates three continuous water level recorders within the Manly Lagoon catchment: two recorders are located within the Lagoon (Queenscliff Bridge and Riverview Parade) and a third at Manly Dam. The location and period of record for each recorder is presented in Table 2-2. The distribution of the three continuous water level recorders is shown in Figure 2-4.

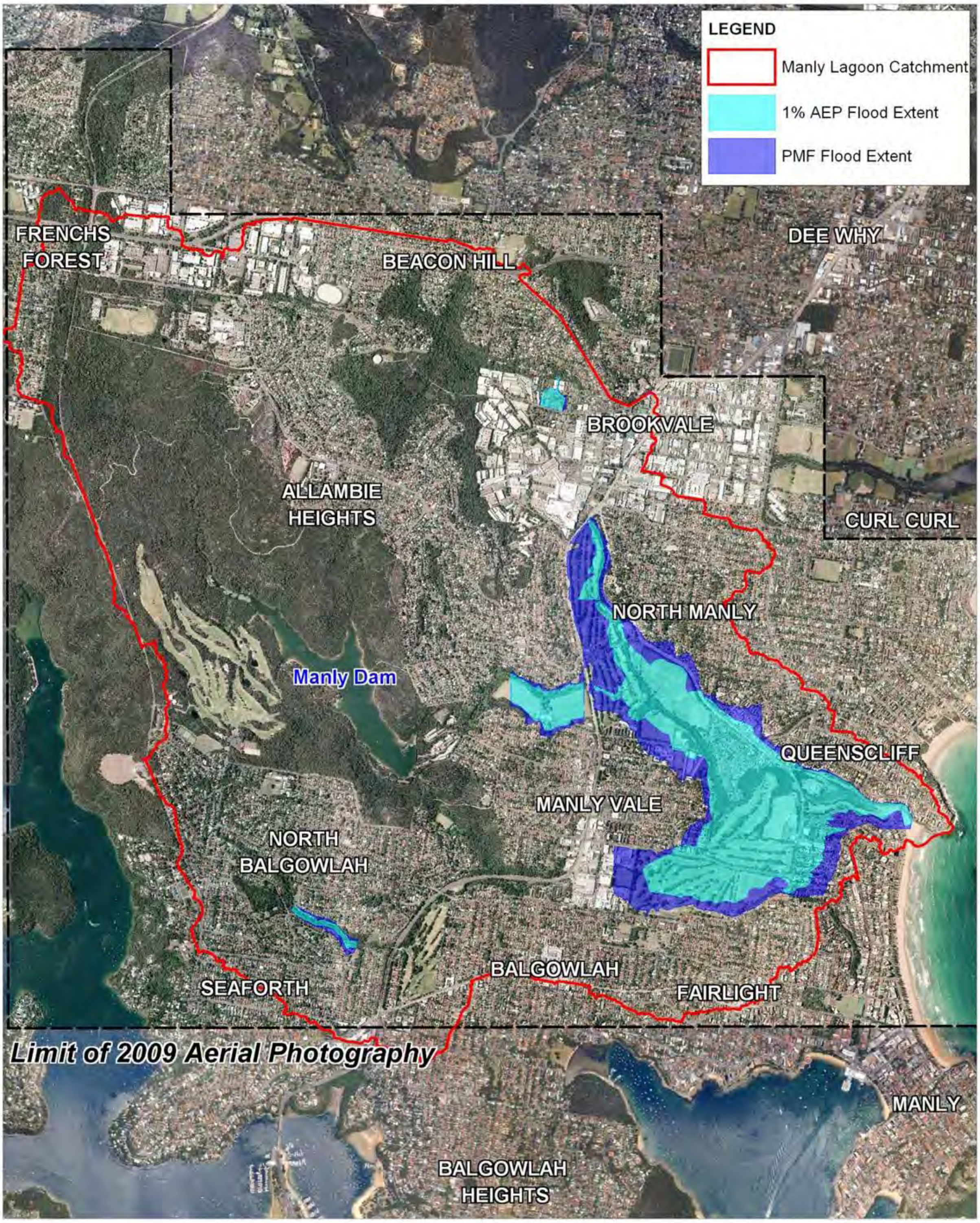
Table 2-2 Location of Continuous Water Level Recorders

Waterway	Location	Period of Data
Manly Lagoon	Queenscliff Bridge	September 1990 - Present
Manly Lagoon	Riverview Parade	March 1990 – Present
Manly Dam	Manly Dam	June 1990 - Present

2.2.3 Historical Flood Levels

There is limited historical flood data available for the Manly Lagoon. Water levels in the Lagoon have been continuously recorded since 1990 at the two MHL water level gauges within the Lagoon, one located a short distance upstream of the Queenscliff Bridge, and the other adjacent to Riverview Parade. A third water level gauge is located in Manly Dam.

There is no comprehensive record of water levels in Manly Lagoon prior to operation of the continuous water level recorders in 1990, with historical flood levels predominantly recorded by local residents. Mr Ross Stephens, formerly of 25 Riverview Parade, North Manly, kept a continuous record of flood levels at his property between March 1942 and April 1988 (peak levels used for model calibration in Manly Lagoon Flood Study (MHL, 1992)). Peak water levels within the Manly Lagoon have been identified from these records for a number of significant flood events as summarised in Table 2-3.



Title:
Previously Modelled Flood Extents

Figure: **2-2**

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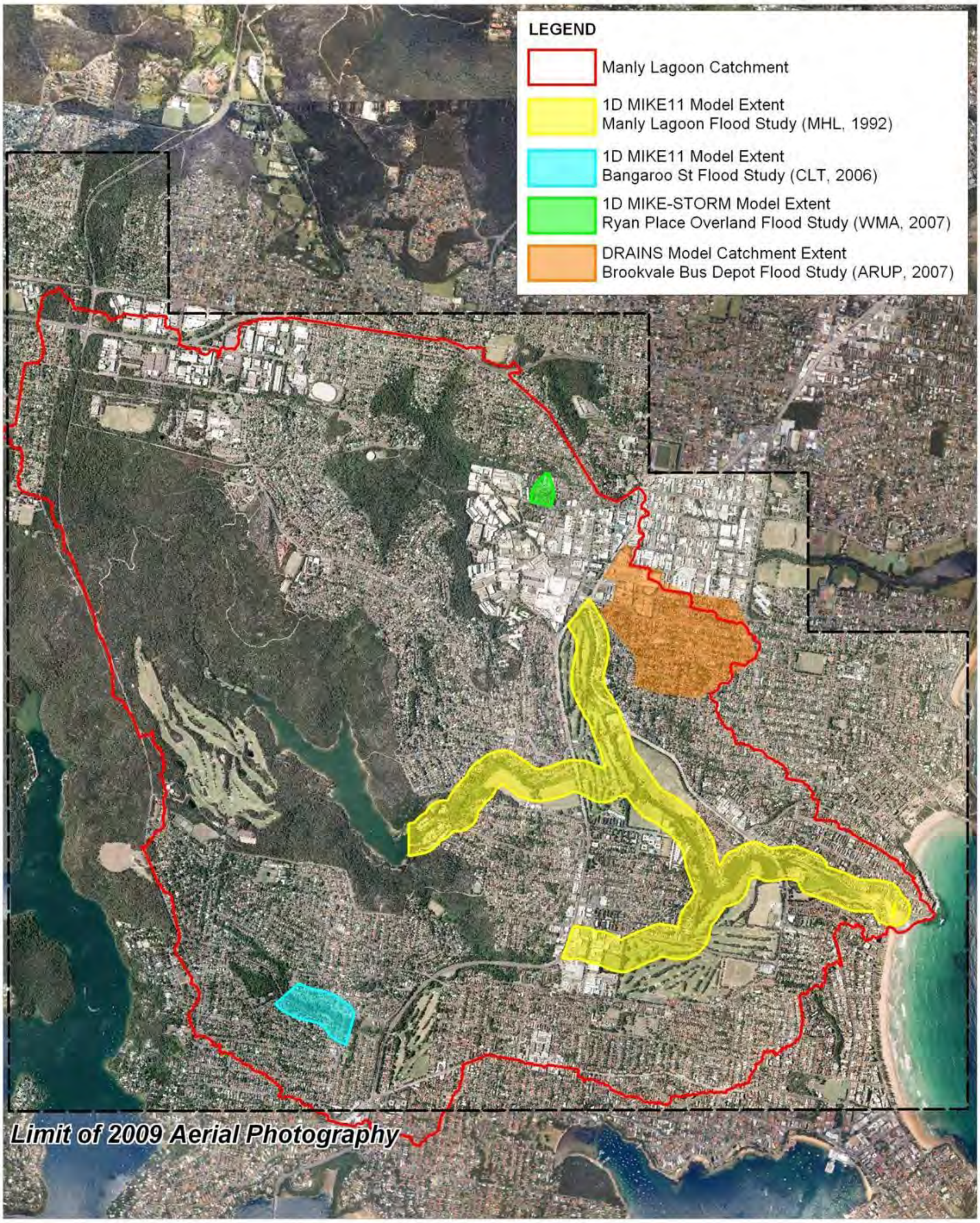

Title:
Manly Lagoon Previous Hydraulic Model Extents

Figure: 2-3

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Title:
Water Level Recorders in the Manly Lagoon Catchment

Figure: 2-4

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Table 2-3 **Historical Peak Flood Levels (m AHD)** Source: (MHL, 2003)

Date	Manly Lagoon Flood Level (m AHD)
30 April 1988	2.57
28 March 1942	2.49
4 March 1977	2.41
17 January 1988	2.41
19 November 1961	2.36
8 May 1953	2.18
25 May 1974	2.15
20 November 1961	2.15
20 April 1945	2.13
10 January 1948	2.13

Additional historical flood level data has been targeted as part of the community consultation process (refer Section 3 for further details). In addition to water level records other historical data sets such as photographs of flood events can provide important information on historical flood events. The Councils have provided photographs of several historical flood events that have occurred in the Manly Lagoon catchment.

2.2.4 Rainfall Data

The MHL operates six continuous read rainfall gauges within or in close proximity to the Manly Lagoon catchment. The location and period of record for each continuous read gauge is presented in Table 2-4.

Table 2-4 Summary of MHL Rainfall Gauges in the Manly Lagoon Locality

Location	Type	Start Year	End Year
Balgowlah	Continuous	1999	2007
North Manly	Continuous	1995	Present
Manly Dam	Continuous	1995	Present
Allambie	Continuous	1999	Present
Belrose	Continuous	1994	Present
Cromer	Continuous	1994	Present

In addition to the six MHL continuous read gauges, there are a further six active and thirteen inactive/closed daily read rainfall gauges operated by the Bureau of Meteorology (BoM) located within or in close proximity to the Manly Lagoon catchment. The daily read gauges, including closed gauges, within or in close proximity to the Manly Lagoon catchment are shown in Table 2-5 with their respective period of record. The distribution of these rainfall gauges (including the continuous read rainfall gauges) is shown in Figure 2-5.

Table 2-5 Summary of BoM Rainfall Gauges in the Manly Lagoon Locality

Gauge No.	Name	Type	Start Year	End Year
66089	Manly North Bowling Club	Daily	1962	1987
66099	Manly (Fairlight)	Daily	1926	1936
66035	Manly Town Hall	Daily	1914	1963
66088	Manly North	Daily	1959	1975
66002	Balgowlah (Ethel St)	Daily	1940	1989
66153	Manly Vale (Manly Dam)	Daily	1906	Current
66145	Seaforth Castle Circuit	Daily	1968	1993
66127	Beacon Hill RAAF	Daily	1968	1973
66118	Frenchs Forest (Fitspatrick Av)	Daily	1964	1982
66182	Frenchs Forest (Frenchs Forest Rd)	Daily	1957	Current
66126	Collaroy (Long Reef Golf Club)	Daily	1965	Current
66044	Cromer Golf Club	Daily	1898	Current
66188	Belrose	Daily	1991	Current
66080	Caste Cove (Rosebridge Ave)	Daily	1958	Current
66094	Willoughby	Daily	1908	1927
66167	Northbridge Bowling Club	Daily	1980	2006
66151	Primrose Park (Folly Point)	Daily	1912	1918
66138	Manly (North Head)	Daily	1968	1997
66042	Mosman (Bapaume Rd)	Daily	1895	2006

Further discussion on recorded rainfall data for historical events is presented with the calibration and validation of the models developed for the study in Section 5.

Title:
Rainfall Gauges in the Vicinity of the Manly Lagoon Catchment

Figure: 2-5

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2.2.5 Ocean Tide Data

Ocean tide (water level) data will be used for the downstream water level boundary (with allowance for wave and wind setup) to drive the hydraulic model of the Lagoon. MHL has been collecting ocean tide data for Sydney at Middle Head with 15 minute interval data available since 1987.

2.2.6 Topographic Data

Raw LiDAR data (in the form of ground surface points) was provided for the entire Manly Lagoon catchment by The Councils. The LiDAR data were collected on the 15th and 16th March 2007 by AAM Hatch. The LiDAR data was supplied with a stated vertical accuracy +/- 0.15m @ 68% confidence and horizontal accuracy +/- 0.55m @ 68% confidence. The raw ground LiDAR data was used to derive a high resolution (2m grid) digital elevation model (DEM) for the Manly Lagoon catchment.

Bathymetric survey data of Manly Lagoon extending from Kentwell Rd to Queenscliff Beach was provided by The Councils in January 2012. The data was provided in the form of bed surface elevation points. The bathymetric survey data was used to derive a high resolution (2m grid) digital elevation model (DEM) for the Manly Lagoon water body.

In addition, a number of datasets containing topographic information were provided by The Councils and are summarised as follows:

- Combination of photogrammetry and land survey undertaken by PWD Coast and Rivers Branch and MHL to obtain cross sections of the floodplain (completed as part of the 1992 Flood Study); and
- Hydrosurvey of Manly Lagoon undertaken by MHL to obtain cross sections of the Lagoon (completed as part of the 1992 Flood Study).

2.2.7 Council Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, vegetation communities and soil landscapes were provided by The Councils in the form of GIS datasets.

2.3 Community Consultation

The success of a floodplain management plan hinges on its acceptance by the community, residents within the study area, and other stake-holders. This can be achieved by involving the local community at all stages of the decision-making process. This includes the collection of their ideas and knowledge on flood behaviour in the study area, together with discussing the issues and outcomes of the study with them.

The key elements of the consultation program undertaken for the study are discussed in Section 3.

2.4 Development of Computer Models

2.4.1 Hydrological Model

For the purpose of the Flood Study, a hydrological model (discussed in Section 4.1) was developed to simulate the rate of storm runoff from the catchment. The model predicts the amount of runoff from rainfall and the attenuation of the flood wave as it travels down the catchment. This process is dependent on:

- Catchment area, slope and surface coverage;
- Variation in distribution, intensity and amount of rainfall; and
- Antecedent conditions of the catchment.

The output from the hydrological model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by a hydraulic model to simulate the passage of a flood through the Manly Lagoon catchment to the downstream study limits at the Lagoon entrance into the Tasman Sea.

2.4.2 Hydraulic Model

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historical and design events.

The TUFLOW hydraulic model (discussed in Section 4) developed for this study includes:

- two-dimensional (2D) representation of the Manly Lagoon catchment covering an area of approximately 18 km^2 (complete coverage of the total catchment area); and
- one-dimensional (1D) representation of the stormwater pipe network.

2.5 Calibration and Sensitivity Testing of Models

The hydrological and hydraulic models were calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of adequately simulating real flood events.

The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level event data;
- The amount of reliable data collected during the historical flood information survey; and
- The variability of events – preferably events would cover a range of flood sizes.

Review of the available rainfall and water level data for the Manly Lagoon catchment highlighted two flood events with sufficient data to support a calibration process – the April 1998 and March 2011 event. Due to data availability, the March 2011 event has been selected as the primary calibration event, with April 1998 to be used for model validation.

The calibration and validation of the model is presented in Section 5.

2.6 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For example, the 1% Annual Exceedance Probability (AEP) event is the best estimate of a flood with a peak discharge that has a 1% (i.e. 1 in 100) chance of occurring in any one year. For the Manly Lagoon catchment, design floods were based on design rainfall estimates according to Australian Rainfall and Runoff (IEAust, 2001).

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The predicted design flood conditions are presented in Section 6.

2.7 Mapping of Flood Behaviour

Design flood mapping is undertaken using output from the hydraulic model. Maps are produced showing water level, water depth and velocity. The maps present the peak value of each parameter. Provisional flood hazard categories and hydraulic categories are derived from the hydraulic model results and are also mapped. The mapping outputs are described in Section 7 and presented in Appendix A.

3 COMMUNITY CONSULTATION

3.1 The Community Consultation Process

Community consultation has been an important component of the current study. The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience, their concern on flooding issues and to collect feedback and ideas on potential floodplain management measures and other related issues.

The key elements of the consultation process have been as follows:

- Media release and notices in the Manly Daily to inform the wider community of the study;
- Development and maintenance of a project web-page providing general information on the study background and objectives, reporting progress of the flood study against key milestones, and providing preliminary study output;
- Distribution of a questionnaire, letter and newsletter to all landowners, residents and businesses located within the existing extreme flood extents for Manly Lagoon;
- An information session for the community to present information on the progress and objectives of the flood study and obtain feedback on historical events in the catchment and other flooding issues *(to be undertaken)*; and
- Public exhibition of the draft Flood Study *(to be undertaken)*.

These elements are discussed in detail below. Copies of relevant consultation material are included in Appendix B.

3.2 Media Release

A media release informed the wider community of the study, canvassed any existing flooding issues and informed the community of the community consultation process to be carried out as part of the study.

3.3 Information Website

A website has been established to keep the community informed on the study progress. The website has further information on flooding in Manly Lagoon and will be updated throughout the study as new information becomes available. Community members are also able to complete the community questionnaire and send photographs through the website.

Website address: http://gis.wbmpl.com.au/manlyLagoon/About.html

3.4 Community Questionnaire

A questionnaire, letter and newsletter were distributed to all landowners, residents and businesses located within the approximate PMF flood extent. The purpose of the questionnaire was to collect information on their previous flood experience and flooding issues. The focus of the questionnaire was historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

The focus of the questionnaire was to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the catchment. Council received back 125 responses to the questionnaire with some 22 photos of various flooding locations.

As part of this Flood Study comments relating to flood behaviour contained within the responses were extracted where useful for model calibration purposes. The responses have been compiled into a GIS layer by BMT WBM.

3.5 Public Exhibition of Draft Report

To be completed for Final Report following public exhibition period, incorporating collation of submissions received and responses.

4 MODEL DEVELOPMENT

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of the Flood Study, a hydrological model and a hydraulic model are developed.

The **hydrological model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the drainage network, overland flow paths, creeks and Lagoon producing flood levels, flow discharges and flow velocities.

Information on the topography and characteristics of the catchments, drainage network and floodplains are built into the model. Recorded historical flood data, including rainfall and flood levels, are used to simulate and validate (calibrate and verify) the model. The model produces as output, flood levels, flows (discharges) and flow velocities.

Development of a hydraulic model follows a relatively standard procedure:

1. Discretisation of the catchment, drainage network, floodplain, etc.
2. Incorporation of physical characteristics (stormwater pipe details, floodplain levels, structures etc).
3. Establishment of hydrographic databases (rainfall, flood flows, flood levels) for historic events.
4. Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
5. Validation to one or more other historic floods (validation is a check on the model's performance without further adjustment of parameters).
6. Sensitivity analysis of parameters to measure dependence of the results upon model assumptions.

Once model development is complete it may then be used for:

- establishing design flood conditions (as part of the current flood study);
- determining levels for planning control ; and
- modelling development or management options to assess the hydraulic impacts (as part of the floodplain risk management study).

4.1 Hydrological Model

The hydrological model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependent on:

- the catchment slope, area, vegetation, urbanisation and other characteristics;
- variations in the distribution, intensity and amount of rainfall; and
- the antecedent moisture conditions (dryness/wetness) of the catchment.

These factors are represented in the model by:

- Sub-dividing (discretising) the catchment into a network of sub-catchments inter-connected by channel reaches representing the creeks and rivers. The sub-catchments are delineated, where practical, so that they each have a general uniformity in their slope, landuse, vegetation density, etc;
- The amount and intensity of rainfall is varied across the catchment based on available information. For historical events, this can be very subjective if little or no rainfall recordings exist.
- The antedecent moisture conditions are modelled by varying the amount of rainfall which is "lost" into the ground and "absorbed" by storages. For very dry antedecent moisture conditions, there is typically a higher initial rainfall loss.

The output from the hydrological model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by the hydraulic model to simulate the passage of the flood through the Manly Lagoon catchment.

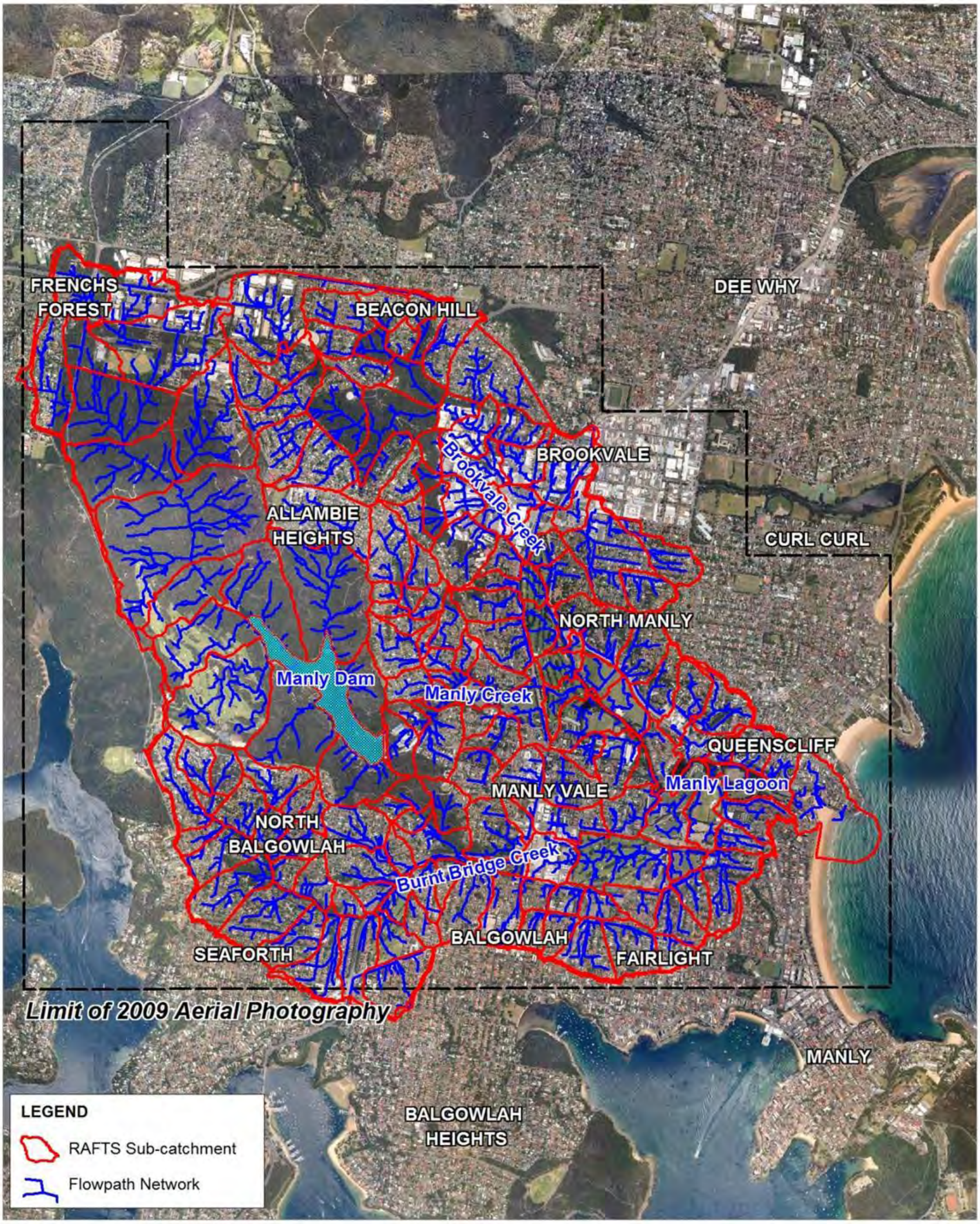
The XP-RAFTS software was used to develop the hydrological model using the physical characteristics of the catchment including catchment areas, ground slopes and vegetation cover as detailed in the following sections.

4.1.1 Catchment Delineation

The Manly Lagoon catchment drains an area of approximately 18km^2 to the lagoon entrance at Queenscliff Beach. For the hydrological model this area has been delineated into 175 sub-catchments as shown in Figure 4-1. The sub-catchment delineation provides for generation of flow hydrographs at key confluences or inflow points to the hydraulic model.

Key catchment parameters for the XP-RAFTS model, include catchment area, vectored slope and PERN (roughness) value estimated from the available topographic information and aerial photography. The adopted PERN values considered the proportion of forested catchment to developed area.

Impervious areas and land use/surface roughness areas were classified using a combination of aerial photography and cadastral information. A significant proportion of the catchment comprises urban development, typically providing for quicker rainfall response and higher runoff volumes associated with higher proportion of impervious area.



Title:
Manly Lagoon RAFTS Model Sub-catchment Layout

Figure: 4-1

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4.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model which simulates the catchment's response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 270mm in 36hours or average intensity 7.5mm/hr); and
- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment during any given event and between different events.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern (refer Section 2.2.4 for rainfall gauge locations). Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (2001). Similarly AR&R (2001) defines standard temporal patterns for use in design flood estimation.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 5.

4.1.3 Rainfall Losses

The antecedent catchment condition reflecting the degree of wetness of the catchment prior to a major rainfall event directly influences the magnitude and rate of runoff. The initial loss-continuing loss model has been adopted during the hydrological modelling process. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

The rainfall loss parameters for the historical calibration/validation events and design events are discussed in further detail in Section 5 and Section 6 respectively.

4.2 Hydraulic Model

The overland flow regime in urban environments is characterised by large and shallow inundation of urban development with interconnecting and varying flowpaths. Road networks often convey a considerable proportion of floodwaters due to the hydraulic efficiency of the road surface compared to developed areas (eg. blocked by fences and buildings), in addition to the underground pipe network draining mainly to open channels. Given this complex flooding environment, a 2D modelling approach is warranted for the overland flooding areas.

BMT WBM has applied the fully 2D software modelling package TUFLOW. TUFLOW was developed in-house at BMT WBM and has been used extensively for over fifteen years on a commercial basis by BMT WBM. TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems, and overland flows through complex overland flowpaths using a linked 2D / 1D flood modelling approach.

4.2.1 Model Configuration

Consideration needs to be given to the following elements in constructing the model:

- topographical data coverage and resolution (e.g. LiDAR data);
- location of recorded data (eg. levels/flows for calibration);
- location of controlling features (eg. dams, levees, bridges);
- catchment specific factors (e.g. Lagoon entrance);
- computational limitations (e.g. model run time).

With consideration to the available survey information and local topographical and hydraulic controls, a linked 1D/2D model was developed extending from the Lagoon entrance in Queenscliff Beach at the downstream limit, to the head of the catchment. The stormwater drainage network has been modelled as 1D branches underlying the 2D (floodplain) domain. This approach enables the hydraulic capacity of the pipe drainage to be accurately defined by true pipe dimensions, whilst enabling the overland flow to be represented in 2D.

The floodplain area modelled within the 2D domain comprises a total area of approximately 18km^2 (up to approximately 160m AHD) which includes the Manly Lagoon catchment in its entirety and the Queenscliff Beach area.

A TUFLOW 2D domain model resolution of 5m was adopted for the study area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 5m cell size results in DEM elevations being sampled every 2.5m. This resolution was selected to give the necessary detail required for accurate representation of floodplain, channel and lagoon entrance topography.

4.2.2 Topography

The ability of the model to provide an accurate representation of the flood behaviour of the catchment ultimately depends upon the quality of the underlying topographic data. For the Manly Lagoon catchment, a high resolution DEM (2m grid) has been derived from a combination of the following data sets (refer to Section 2.2.6 for further details):

- LiDAR survey data; and
- Manly Lagoon bathymetry survey data.

The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM. It is a representation of the ground surface and does not include features such as buildings or vegetation.

In the context of the overland flow path study, a high resolution DEM is important to suitably represent available flow paths, such as roadway/gutter flows that are expected to provide significant flood conveyance within the study area. Experience has proved this to be a successful approach and enables detailed simulation of flooding from overland flow paths.

4.2.3 Lagoon Entrance

The ability to model morphological changes in the Lagoon entrance during a flood event is critical for this study, as it incorporates changes to the effectiveness of the Lagoon entrance in conveying water out of the Lagoon during the flood event. The changing entrance shape as the entrance scour develops affects peak water levels in the Lagoon during a flood.

The Van Rijn formulation of sand transport is generally accepted as being currently the most feasible and accurate method for estimating sand transport. However, it must be noted that sand transport is a complex interaction of processes that is still not fully understood. In order to account for these uncertainties, it is necessary to make approximations related to a number of the process interactions. Although these approximations are unavoidable, the Van Rijn method is still considered appropriate and has been combined with the TUFLOW hydraulic model to achieve realistic time-varying entrance shoal and beach berm levels and the accompanying simulated flood discharges.

The model allows the integration of scouring processes at the Lagoon entrance in terms of cross-sectional conveyance capacity. The scouring rate is based on inter-related parameters: flood flows, initial water levels, downstream ocean water levels and, of greatest importance, the original lagoon entrance/berm geometry.

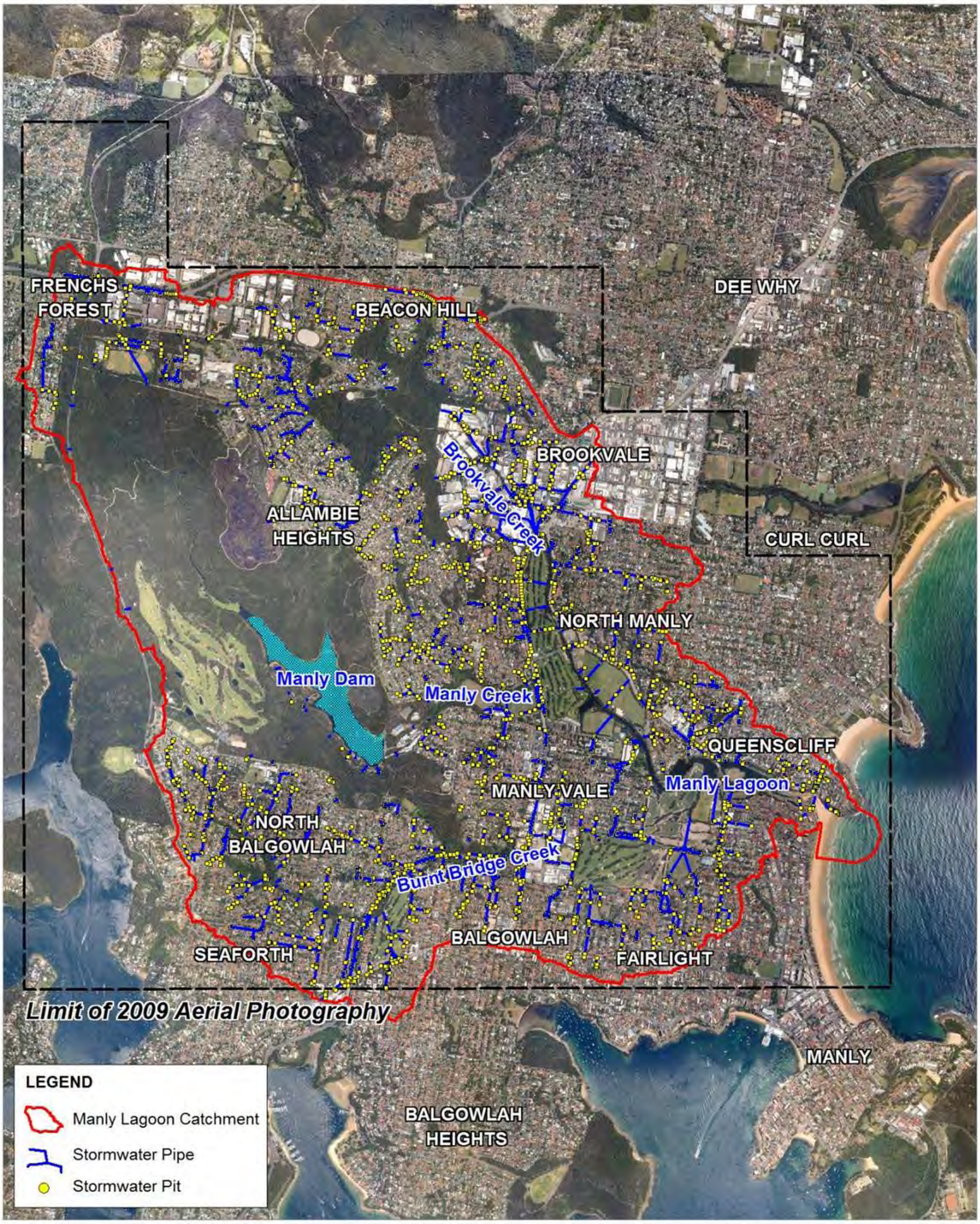
4.2.4 Stormwater Drainage Network

The study requires the modelling of the drainage system across the catchment. The Councils provided recent survey on the existing drainage system. This data comprised a GIS layer of pit/pipe locations, together with survey details including pipe sizes, invert levels and pit inlet structures.

For this study the entire trunk drainage network indicated by the council GIS data was modelled. The study area contains a number of locations that would drain poorly without the inclusion of the pipe network. Modelling all pipes ensures that the drainage of these areas is well represented.

The pipe network, represented as a 1D layer in the model, is dynamically linked to the 2D domains at specified pit locations for inflow and surcharging. Pit inlet capacities have been modelled using dimensions contained within the GIS database. Pit inlet curves have been developed for sag pit configurations. The modelled pipe network, which consists of around 4,100 pipes with a combined run length of approximately 90km, is shown in Figure 4-2.

For the magnitude of events under consideration in the study, the pipe drainage system capacity is expected to be well exceeded with the major proportion of flow conveyed in overland flow paths. Therefore any limitations in the available data or model representation of the drainage system may not have a significant effect on flooded area for the major flood events considered.



Title:
Manly Lagoon Stormwater Drainage Network

Figure: 4-2

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4.2.5 Structures

There are two major bridge structures that traverse Manly Lagoon, namely Queenscliff Bridge and Pittwater Bridge. Incorporation of these major hydraulic structures in the hydraulic model provides for simulation of the hydraulic losses associated with these structures and their influence on peak water levels within the catchment. The general configuration of the bridges can be seen in the photographs in.

Figure 4-3 General Arrangement of Pittwater Bridge and Queenscliff Bridge

In addition to the two bridge structures traversing Manly Lagoon there are also numerous culvert and pipe drainage structures located along the main tributary alignments of Burnt Bridge Creek, Manly Creek and Brookvale Creek. These structures vary in terms of construction type and configuration, with varying degrees of influence on local hydraulic behaviour. These structures are incorporated into the 1D drainage network described in Section 4.2.4 above.

4.2.6 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness (Manning's 'n') zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (eg. forest, cleared land, roads, urban areas, etc) for modelling the variation in flow resistance. The 2009 aerial photography and 2011 cadastral data supplied by The Councils were used to generate the hydraulic roughness zones for the Manly Lagoon catchment. The base land use map used to assign the different hydraulic roughness zones for the design flood events is shown in Figure 4-4.

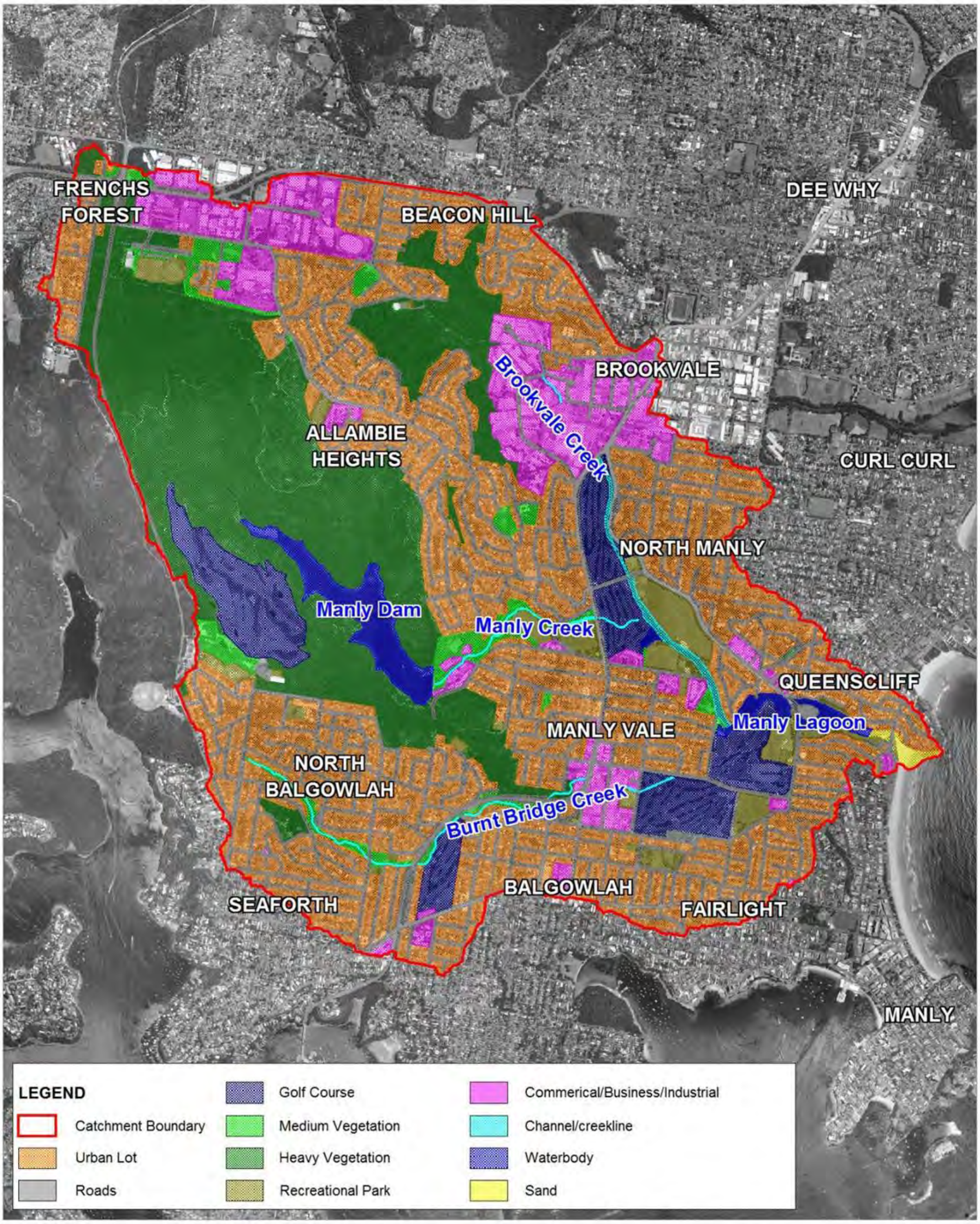
The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a major influence on flow routing and flood levels. During the model calibration process the Manning's 'n' surface roughness values are adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. The degree of variability largely reflects the degree of channel vegetation, channel size and sinuosity.

4.2.7 Boundary Conditions

The hydraulic model boundary conditions are derived as follows:

- Inflow – catchment runoff is determined through the hydrological component of the model and is applied directly to the TUFLOW model 2D domain, where it is routed as sheet flow until the runoff contribution is substantial enough to generate an overland flow path. Flow is automatically transferred to the 1D domain where sufficient pipe and inlet capacity is available. Surcharging will then occur from the 1D to the 2D domain once the pipe capacity becomes exceeded.
- Downstream Water Level – the downstream model limit corresponds to the tidal water level of the Tasman Sea. A water level time series has been applied at this location for the duration of the modelled events.
- Entrance condition – entrance bathymetry defined by existing bathymetric survey has been adopted.
- Manly Dam – initial storage levels for the Dam were defined based on available water level records for calibration events, with full storage levels conservatively adopted for design events.

The adopted water levels for the downstream boundary condition for the calibration and design events are discussed in Section 5 and Section 6 respectively.



Title: **Land Use Map**

Figure: **4-4**

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5 MODEL CALIBRATION AND VALIDATION

5.1 Selection of Calibration Events

The selection of suitable historical events for calibration and validation of flood models is largely dependent on the availability of relevant historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design events to be considered.

Review of the available rainfall and water level data for the Manly Lagoon catchment highlighted two flood events with sufficient data to support a calibration process – the April 1998 and March 2011 event. Due to data availability, the March 2011 event has been selected as the primary calibration event, with April 1998 to be used for model validation.

5.2 March 2011 Model Calibration

5.2.1 Calibration Data

5.2.1.1 Rainfall Data

There were ten active rainfall gauges within or in close proximity to the Manly Lagoon catchment for the March 2011 event. Five of these gauges were continuous read gauges operated by MHL with the remaining five gauges being daily read gauges operated by BoM. The recorded daily totals (for the 24 hours to 9am) for March 19th – 21st 2011 for the ten active rainfall gauges are summarised in Table 5-1.

Table 5-1 Recorded Rainfall March 2011 Event

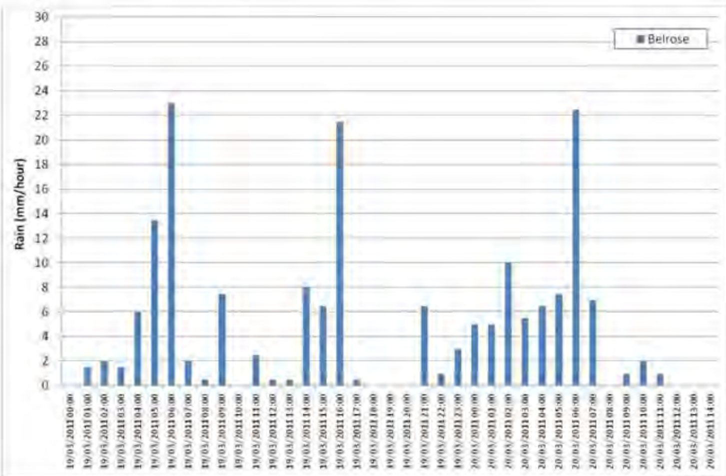
Gauge Location	Operator	24 hr Total (to 9am 19/03/11) (mm)	24 hr Total (to 9am 20/03/11) (mm)	24 hr Total (to 9am 21/03/11) (mm)	72 hr Total (to 9am 21/03/11) (mm)
North Manly	MHL	41	122	37	200
Manly Dam	MHL	48	111	40	199
Belrose	MHL	60	121	35	216
Cromer	MHL	62	121	40	223
Allambie	MHL	45	100	37	182
Collaroy (Long Reef Golf Club)	BoM	79	115	42	236
Cromer Golf Club	BoM	61	122	65	248
Castle Cove (Rosebridge Ave)	BoM	52	104	24	180
Frenchs Forest Rd	BoM	56	119	40	215
Belrose (Evelyn Place)	BoM	57	137	30	224

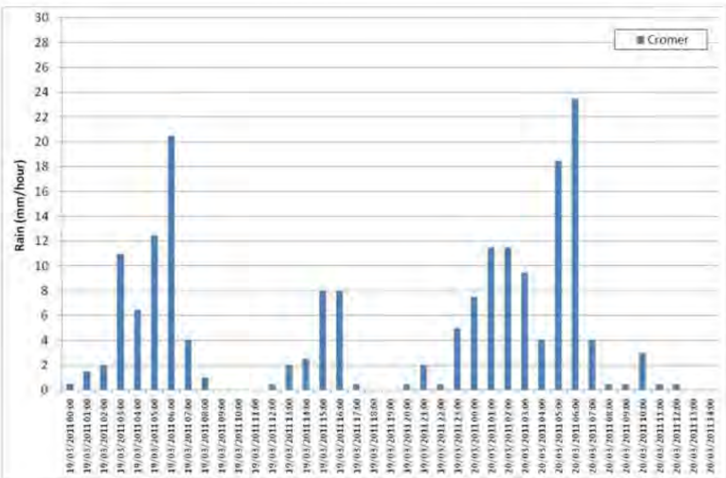
As shown in Table 5-1, there was extensive rainfall across the local area over a 3-day recording period. The majority of the rain fell in the 24 hours to 9:00am on the 20th March, however, this was preceded by substantial falls recorded in the 24 hours to 9:00am 19th March, and followed by further substantial falls recorded in the 24 hours to 9:00am 21st March. The combined 72 hour totals across the catchment were typically in excess of 200mm, with the Cromer Golf Club gauge recording the highest 3-day total of some 248mm.

The recorded hyetographs at the continuous rainfall gauges within the Manly Lagoon catchment or in the near vicinity are shown in Figure 5-1. The hyetograph period shown is from 12:00am 19th March to 2:00pm 20th March 2011, corresponding to the period of the main rainfall resulting in the peak flood levels attained in Manly Lagoon.

As evidenced in the recorded hyetographs, there is some variability across the gauges in terms of the relative intensities and rainfall depths across the period. Typically however, all of the recorded hyetographs show that the rainfall generally fell within three distinct bursts.

The recorded daily totals for both the continuous and daily read rainfall gauges were used to derive a spatial distribution of rainfall across the Manly Lagoon catchment. The rainfall distribution for the March 2011 event is shown in Figure 5-2.





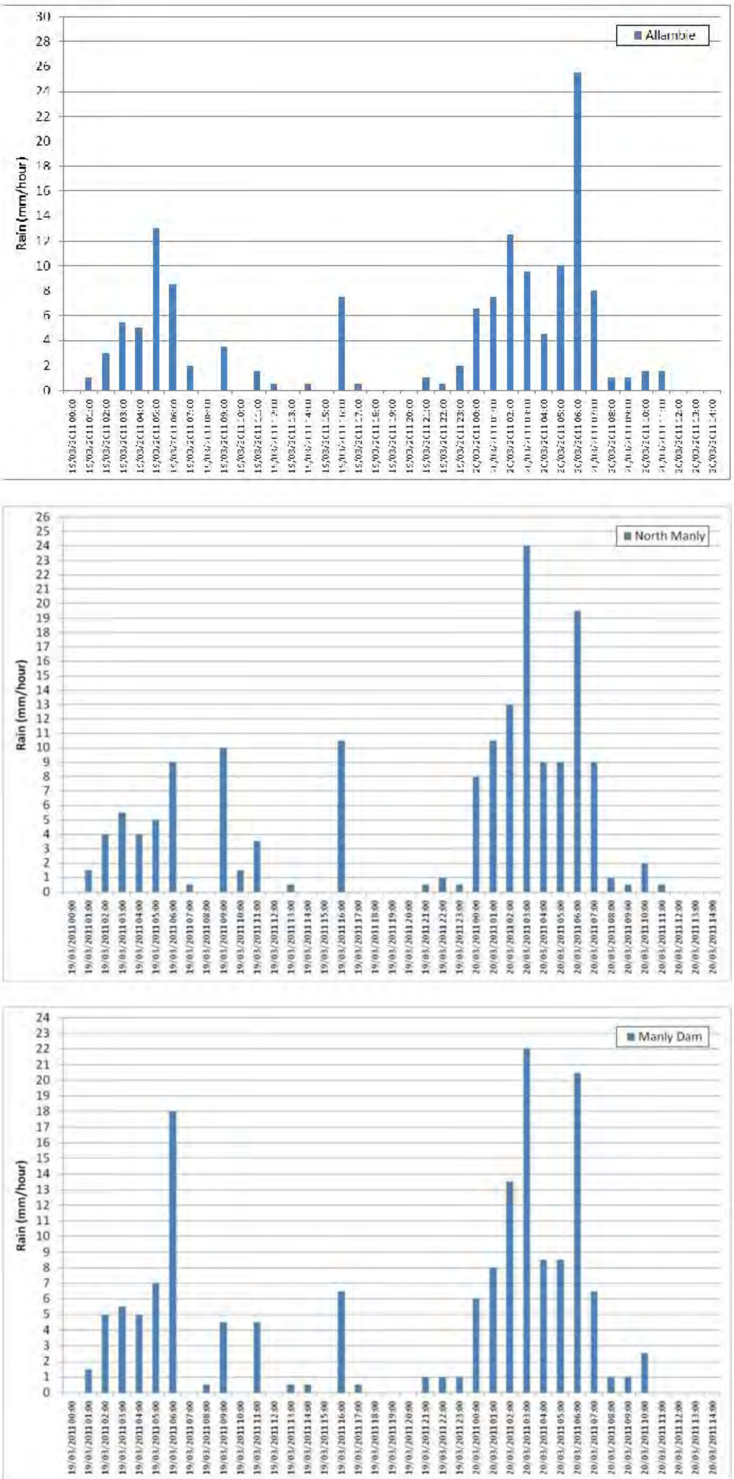
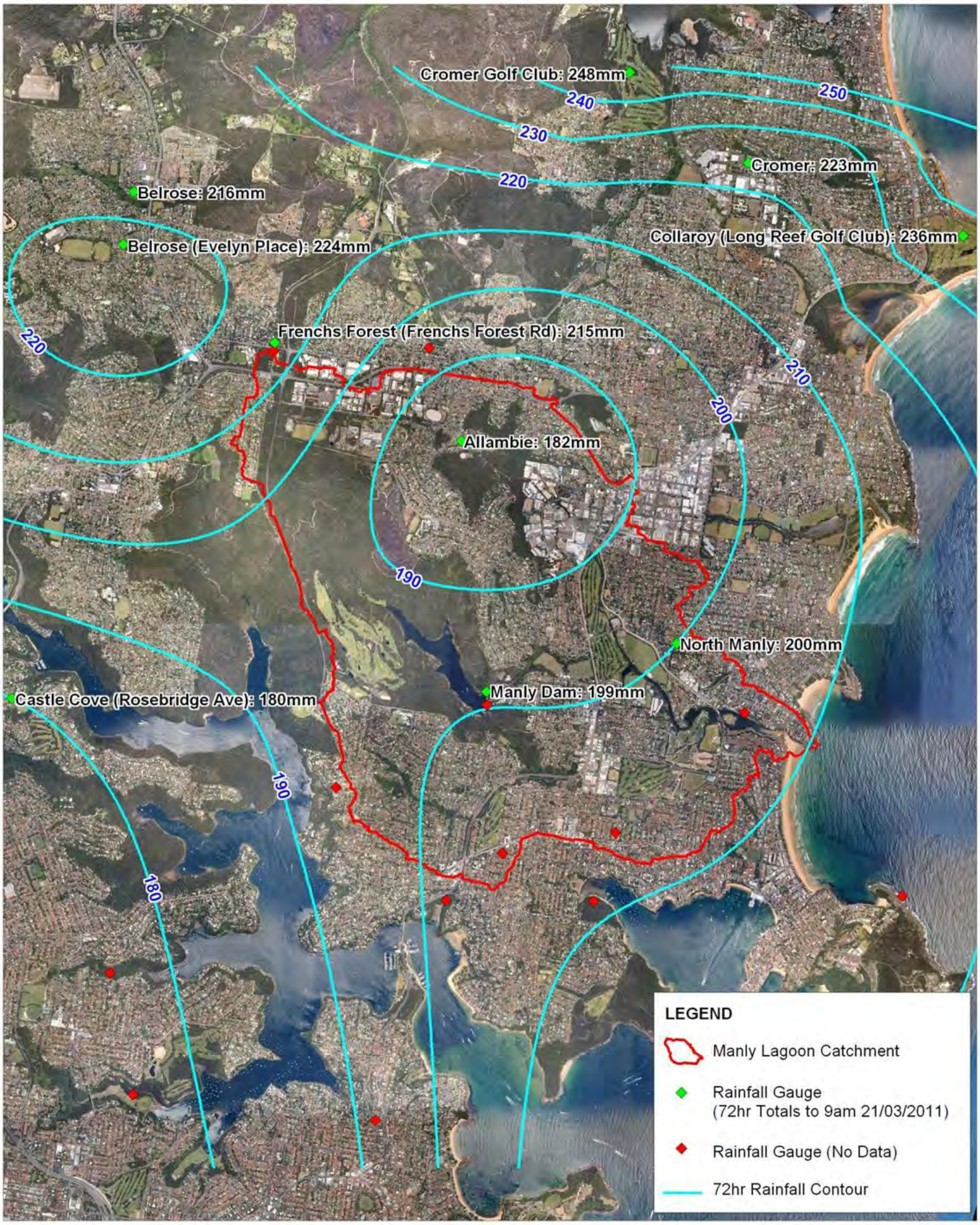


Figure 5-1 March 2011 Recorded Rainfall



Title:
March 2011 Rainfall Distribution

Figure: **5-2**

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To gain an appreciation of the relative intensity of the March 2011 event, the recorded rainfall depths at the North Manly MHL continuous read rainfall gauge for various storm durations were compared with the design IFD data for the Manly Lagoon catchment as shown in Figure 5-3. The March 2011 event generally tracks the design 50% AEP (2-year ARI) rainfall depth for the duration of the event. For the North Manly continuous rainfall gauge the following comparisons to design rainfall depths can be made for the March 2011 event:

- 12-hour duration – 106mm recorded compared with 105mm design 50% AEP;
- 24-hour duration – 131mm recorded compared with 136mm design 50% AEP; and
- 48-hour duration – 164mm recorded compared with 172mm design 50% AEP.

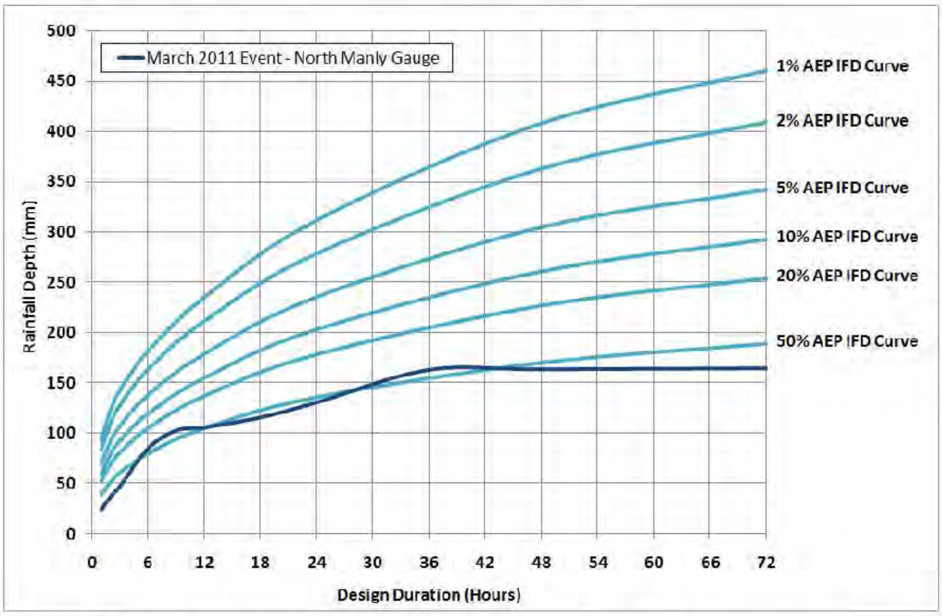
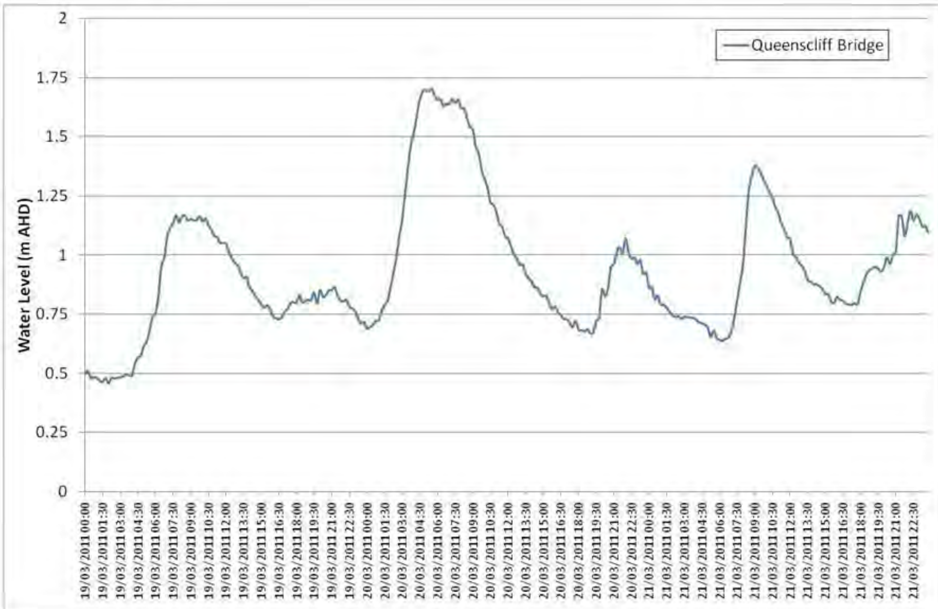


Figure 5-3 Comparison of March 2011 Rainfall with IFD Relationships

5.2.1.2 Water Level Data

There were three active water level recorders operating within the Manly Lagoon catchment during the March 2011 event – Manly Dam (located on Manly Dam), Queenscliff Bridge (Manly Lagoon) and Riverview Parade (Manly Lagoon).

The recorded water level time series at the two gauges located on Manly Lagoon for the March 2011 event is shown in Figure 5-4 and the recorded water level at Manly Dam shown in Figure 5-5. The time series shown covers a period of some 3-days. As noted in the rainfall analysis, three separate significant rainfall periods occurred during the event. In addition to the increase in water level associated with catchment rainfall, the water levels in the Lagoon are influenced by the tidal water level boundary at the entrance to the Lagoon.



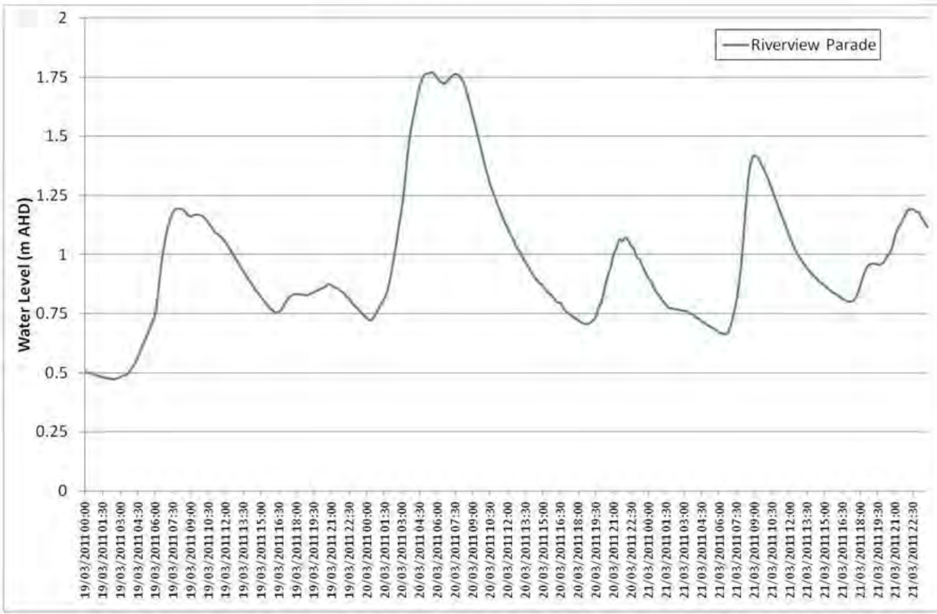


Figure 5-4 March 2011 Recorded Water Levels at Manly Lagoon

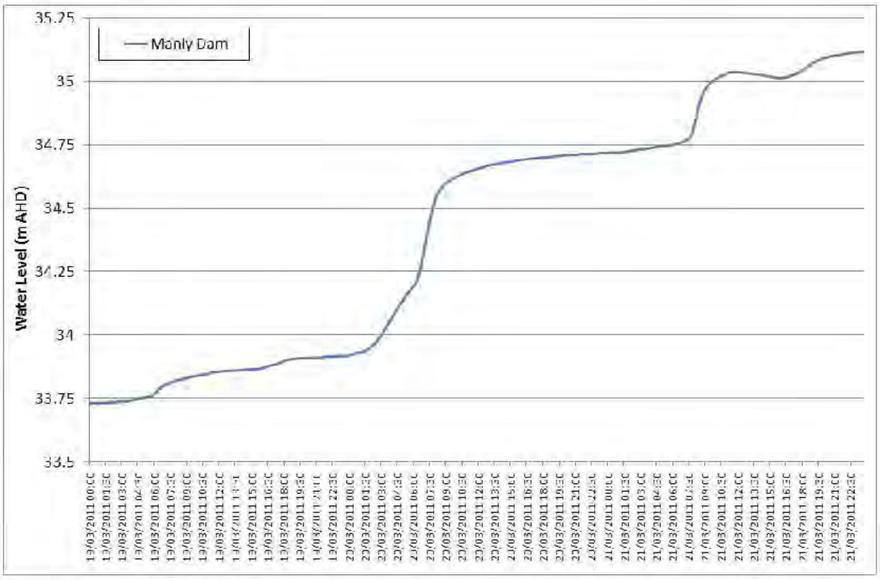


Figure 5-5 March 2011 Recorded Water Levels at Manly Dam

5.2.2 Rainfall Losses

Typical design loss rates applicable for NSW catchments east of the western slopes are initial loss of 10 to 35 mm and continuing loss of 2.5mm/hr (AR&R, 2001). For historical events however, the initial loss is indicative of the catchment wetness and any rainfall that fell prior to the modelled storm burst.

For pervious surfaces, an initial loss of 20mm and continuing loss of 2.5mm/hr; and for impervious surfaces an initial loss of 2mm and continuing loss of 0mm/hr, were found to provide a reasonable fit to the observed hydrological behaviour in the Manly Lagoon catchment for the March 2011 event.

5.2.3 Downstream Boundary Conditions

Ocean tide (water level) data was available for the March 2011 event from a continuous tide gauge maintained by MHL at Middle Head. This water level data is considered to be representative of the ocean water levels at the Manly Lagoon entrance and as such was used as the downstream boundary for the March 2011 event. The relationship between recorded ocean water levels and recorded rainfall for the March 2011 event is shown in Figure 5-6.

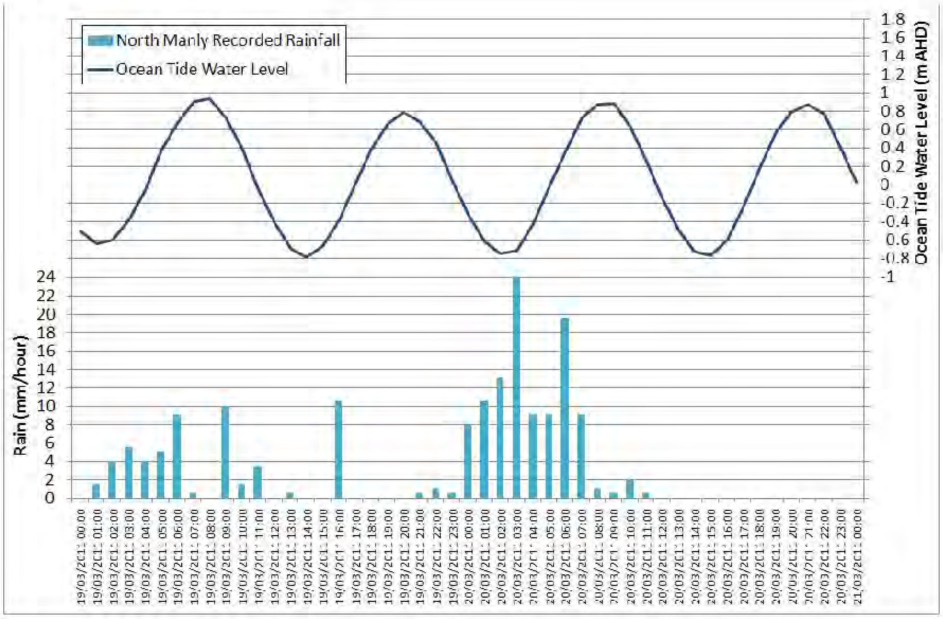


Figure 5-6 March 2011 Recorded Tidal Water Level

5.2.4 Lagoon Entrance Bathymetry

The modelled bathymetry of the Lagoon entrance can impact on the response of modelled Lagoon levels to catchment inflows and tides. Ideally, for full calibration of the entrance dynamics, bathymetric survey data of the entrance before and after the event would be available. However, this data was not available for the March 2011 calibration event (nor was it available for the April 1998 validation event).

Inspection of the available aerial photography of the Manly Lagoon entrance (shown in Figure 5-7, shows that the entrance is typically heavily shoaled, with a channel running along the northern rock wall discharging into the low flow pipes to the ocean. Under flood conditions, the entrance shoal is overtopped with subsequent natural scouring of the entrance to convey floodwater. In the 2007 aerial photograph shown in Figure 5-7, the relief channel periodically maintained by Manly Council for flood management purposes is evident.

In the absence of event specific survey data, a shoaled Lagoon entrance condition was adopted for the calibration and validation events. The shoaled entrance condition was considered representative of the average long term entrance condition for the Manly Lagoon, whilst it is acknowledged that configuration of entrance channel shoals is highly dynamic in response to coastal processes.

Title:
Manly Lagoon Entrance Aerial Photography

Figure: 5-7

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5.2.5 Adopted Model Parameters

The model calibration centred around the adjustment of the sub-catchment PERN values, Bx storage coefficient factor and rainfall loss values (hydrological model parameters) and the Manning's 'n' values for the floodplain and channel (hydraulic model parameters).

The final parameter values adopted, as shown in Table 5-2, were found to give a good result in representing the hydrological and hydraulic behaviour in the Manly Lagoon catchment for the March 2011 event.

Table 5-2 March 2011 Model Parameters

Parameter	Value	Comment
Initial Water Level in Manly Lagoon (m AHD)	0.5m AHD	The recorded water level at the Riverview Parade water level gauge at the start of the March 2011 simulation period.
Initial Loss (mm): pervious area impervious area	 20 5	The 20mm initial loss provided the best fit for initial catchment response and total storm volumes with respect to available data for the 2011 event.
Continuing Loss (mm/hr): pervious area impervious area	 2.5 0	As recommended in AR&R (2001).
Storage Factor (Bx)	1.0	Default value found appropriate
PERN	0.015 – 0.10	Variable adjusted dependent on surface coverage – e.g. 0.015 for hardstand/impervious areas to 0.1 for forested catchment
Manning's 'n' (Lagoon and tributaries)	0.02 -0.06	Variable adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. Variability largely reflects degree of channel vegetation, channel size and sinuosity.
Manning's 'n' (floodplain)	0.02 – 0.20	Variable adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. Variability largely reflects land use on the floodplain (cleared, forested, roads, urban lots)

5.2.6 Observed and Simulated Flood Conditions March 2011

Calibration data for the Manly Lagoon catchment is limited to the available water level time series at the Manly Dam, Riverview Parade and Queenscliff gauges. None of these gauges however are flow gauging stations, such that a direct flow calibration is not possible. However, given the large storage associated with the body of the Lagoon and the Dam, the water level time series provides for a simplified flow calibration on the basis of rates of rise and total flood volumes generated.

A comparison of recorded and simulated water level profiles in Manly Lagoon for the March 2011 event are shown in Figure 5-8 and Figure 5-9 for the Riverview Parade and Queenscliff Bridge gauges respectively.

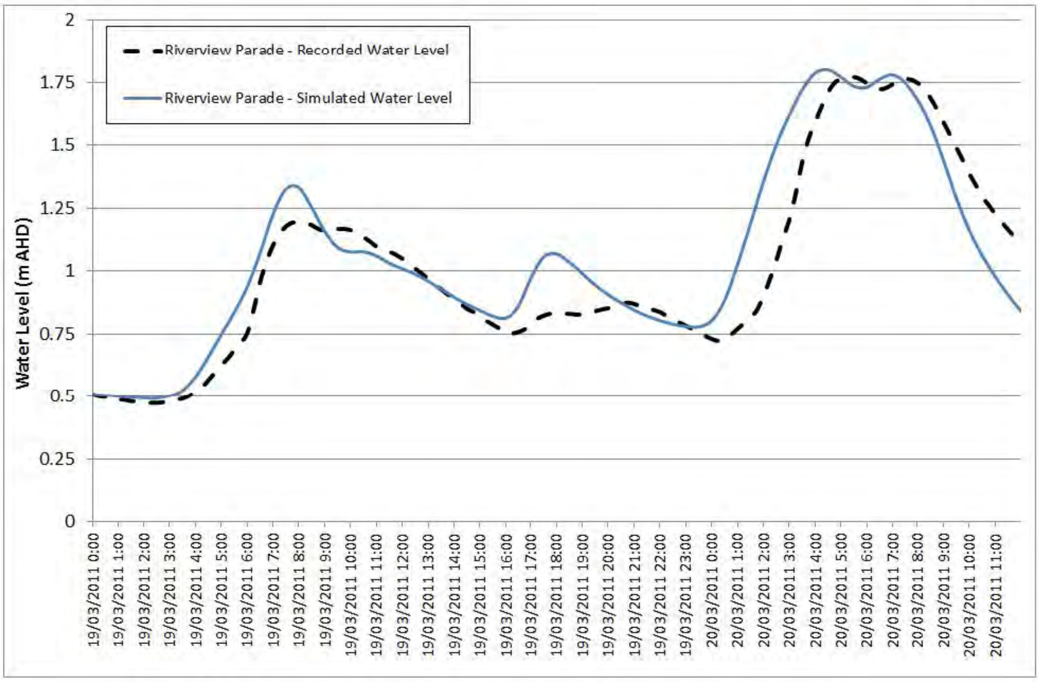


Figure 5-8 Riverview Parade Water Level Calibration – March 2011

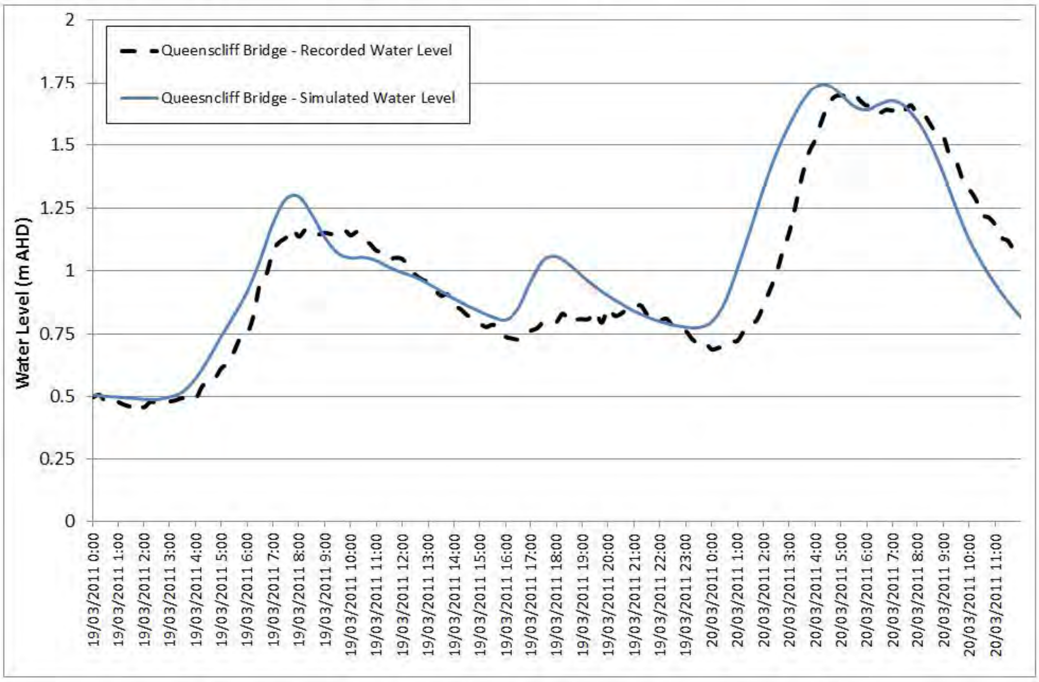


Figure 5-9 Queenscliff Bridge Water Level Calibration – March 2011

The simulated results show that a good model calibration has been achieved for a number of aspects of the simulated catchment flood behaviour:

- Catchment runoff response – the relative timing of the observed and simulated water level hydrographs show a good agreement throughout the simulated event. This shows the catchment runoff processes are being well simulated including the initial catchment response from the wetting-up period (incorporating rainfall losses) and the general rise of water levels in the Lagoon indicating a good simulation of the relative timing of the main tributary inflows. The catchment response is highly sensitive to the rainfall inputs, such that localised rainfall not represented by the catchment rainfall gauges can contribute to differences in observed and simulated response.

- Peak flood levels – the peak flood levels show a reasonable agreement, particularly considering the changing entrance shape during the event with multiple peaks in the inflow hydrograph. The first peak occurring around 8:00am on the 19th March is well simulated following the relatively shoaled condition at the onset of the event. Following this first peak, the entrance channel opens up further under scouring from the higher flow condition. The main peak of the event is well simulated with the entrance in a more open condition following the channel scour. The simulated results also show a slight water level gradient between Riverview Parade and Queenscliff Bridge at the peak of the event which is also evident in the recorded levels.

- Total flood volumes – the area under the water level time series graph is indicative of the total flood volume for the event. As evident in the observed vs. simulated comparisons, both water level profiles generally track the same for the duration of the event, and accordingly the total volumes would appear to be in good agreement (considering the variable entrance state). The adopted rainfall depth distribution and the modelled initial and continuing loss parameters provide for a good representation of total runoff volume generated from the catchment.

The entrance condition in terms of its degree of shoaling and conveyance capacity is dynamic and likely to be different at the onset of the flood event for both of the calibration events considered. The entrance condition will have some impact on the simulated flood behaviour. The model simulations incorporate scouring processes to simulate the impact of the changing shape of the entrance channel on conveying flow out of Manly Lagoon.

5.3 April 1998 Model Validation

The April 1998 flood has been used as a model validation event, given the availability of rainfall and water level data.

5.3.1 Validation Data

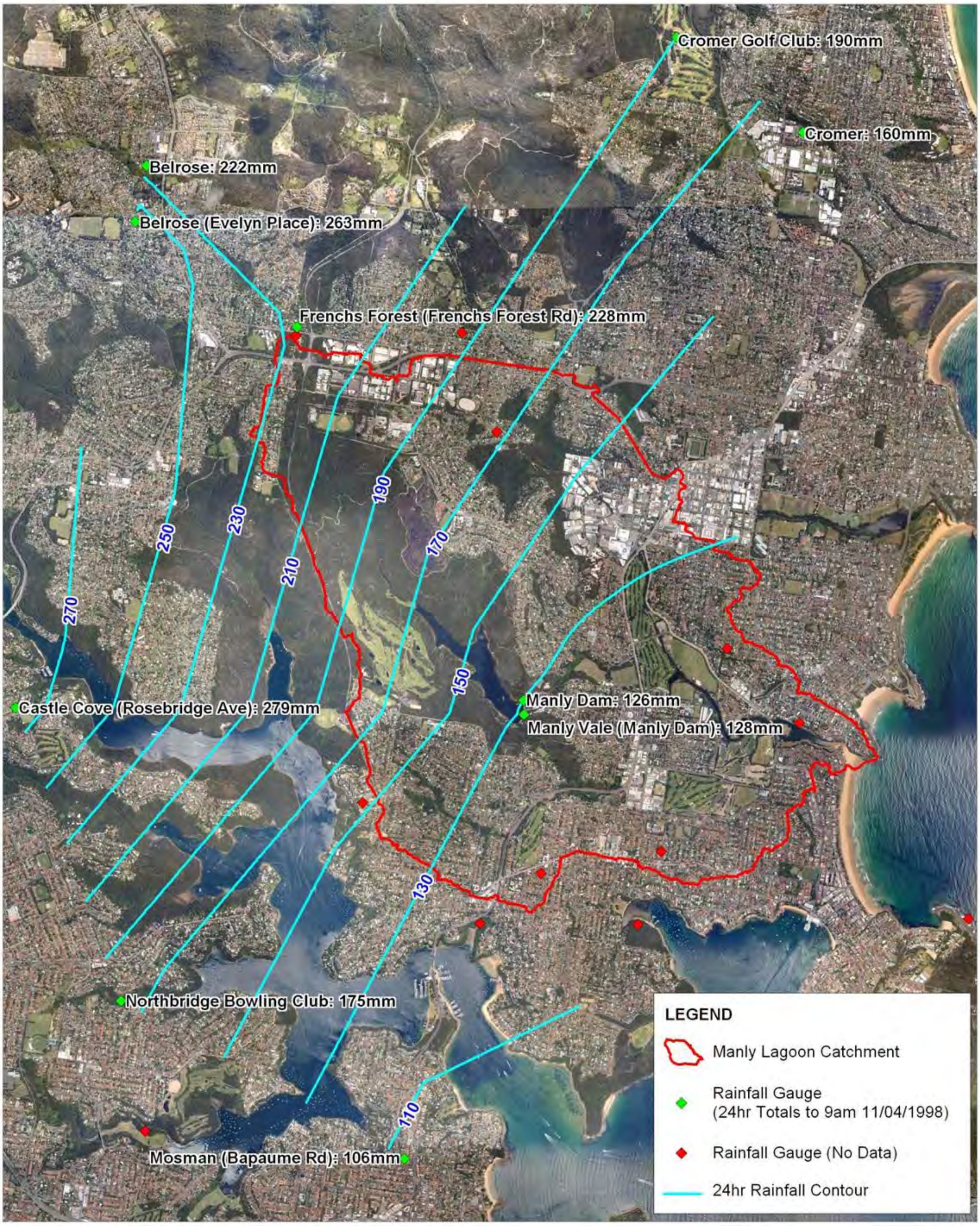
5.3.1.1 Rainfall Data

There were eleven active rainfall gauges within or in close proximity to the Manly Lagoon catchment for the April 1998 event. Three of these gauges were continuous read gauges operated by MHL with the remaining eight gauges being daily read gauges operated by BoM. The recorded daily totals (for the 24 hours to 9am) for the 10th and 11th April 1998 are summarised in Table 5-3. The rainfall distribution for the April 1998 event is shown in Figure 5-10.

Table 5-3 Recorded Rainfall April 1998 Event

Gauge Location	Operator	24 hr Total (to 9am 10/04/98) (mm)	24 hr Total (to 9am 11/04/98) (mm)
Manly Dam	MHL	41	126
Cromer	MHL	31	160
Belrose	MHL	30	222
Collaroy (Long Reef Golf Club)	BoM	200 (2-day total)	
Cromer Golf Club	BoM	35	190
Manly Vale (Manly Dam)	BoM	38	128
Frenchs Forest Rd	BoM	32	228
Belrose (Evelyn Place)	BoM	30	263
Caste Cove (Rosebridge Ave)	BoM	38	279
Northbridge Bowling Club	BoM	31	175
Mosman	BoM	76	106

The recorded hyetographs at the continuous read rainfall gauges within the Manly Lagoon catchment or in the near vicinity are shown in Figure 5-11. The hyetograph period shown is from 9:00am 10th April to 9:00am 11th April 1998. As evidenced in the recorded hyetographs, there is some variability across the gauges in terms of the relative intensities and rainfall depths across the period. Typically however, the recorded hyetographs show that the majority of the rainfall fell within a 7-hour period from 12:00pm to 7:00pm on the 10th April 1998.



Title:
April 1998 Rainfall Distribution

Figure: 5-10

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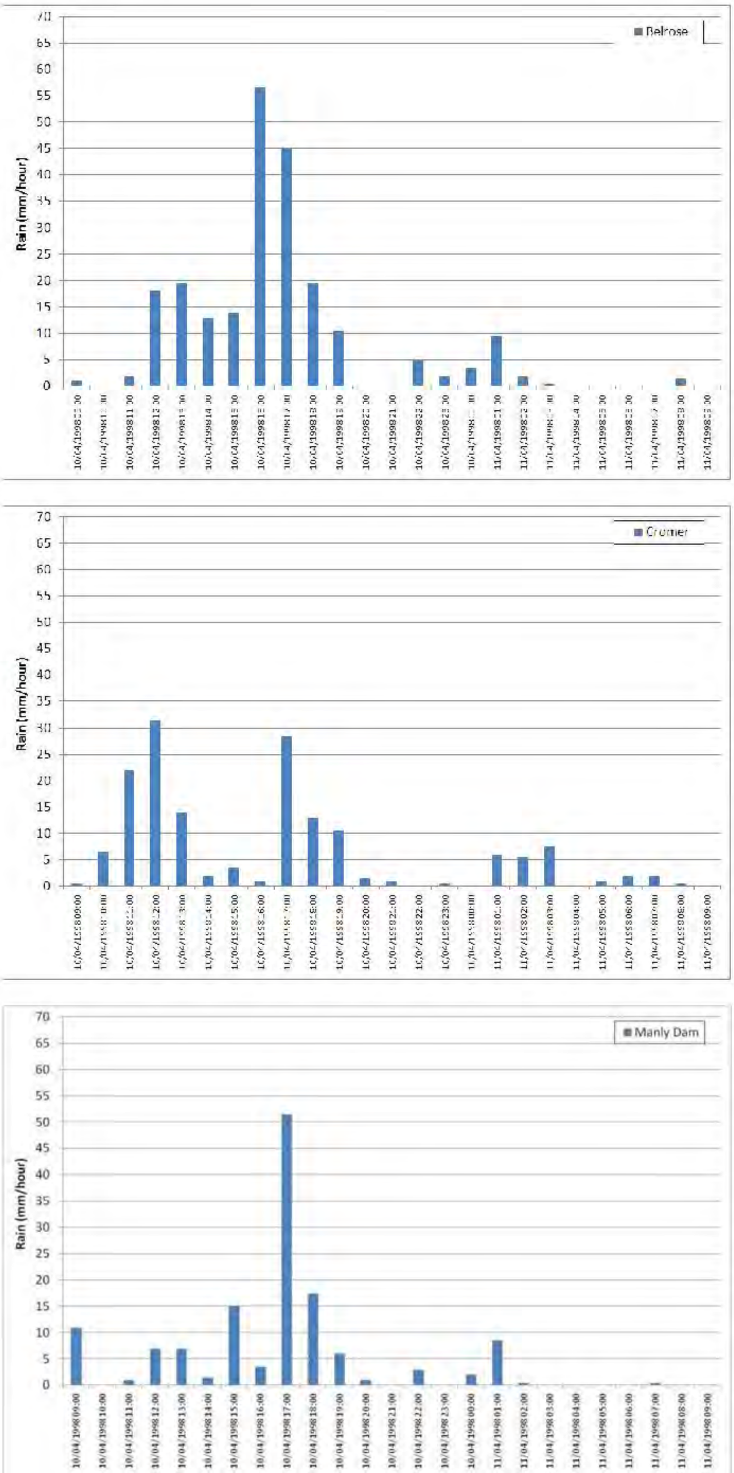


Figure 5-11 April 1998 Recorded Rainfall

As previously stated, there is some variability across the gauges in terms of the relative intensities and rainfall depths across the event, therefore in order to gain an appreciation of the relative intensity of the April 1998 event, the recorded rainfall depths at both the Manly Dam and Belrose MHL continuous read gauges for various storm durations were compared with the design IFD data for the Manly Lagoon catchment as shown in Figure 5-12.

At the Belrose gauge location the April 1998 event generally tracks above the design 2% AEP (50-year ARI) rainfall depth for the duration of the 12 hour rainfall event before falling to below the 5% AEP event for a 24 hour duration. For the Belrose continuous rainfall gauge the following comparisons to design rainfall depths can be made for the April 1998 event:

- 3-hour duration – 121mm recorded compared with 128mm design 2% AEP;
- 6-hour duration – 168mm recorded compared with 163mm design 2% AEP;
- 12-hour duration – 203mm recorded compared with 211mm design 2% AEP; and
- 24-hour duration – 223mm recorded compared with 235mm design 5% AEP.

In contrast, at the Manly Dam gauge location the April 1998 event generally tracks between the design 20% AEP (5-year ARI) and 50% AEP (2-year ARI) rainfall depth for the full 24 hour duration. For the Manly Dam continuous read rainfall gauge the following comparisons to design rainfall depths can be made for the April 1998 event:

- 3-hour duration – 75mm recorded compared with 81mm design 20% AEP;
- 6-hour duration – 96mm recorded compared with 105mm design 20% AEP;
- 12-hour duration – 122mm recorded compared with 137mm design 20% AEP; and
- 24-hour duration – 143mm recorded compared with 178mm design 20% AEP.

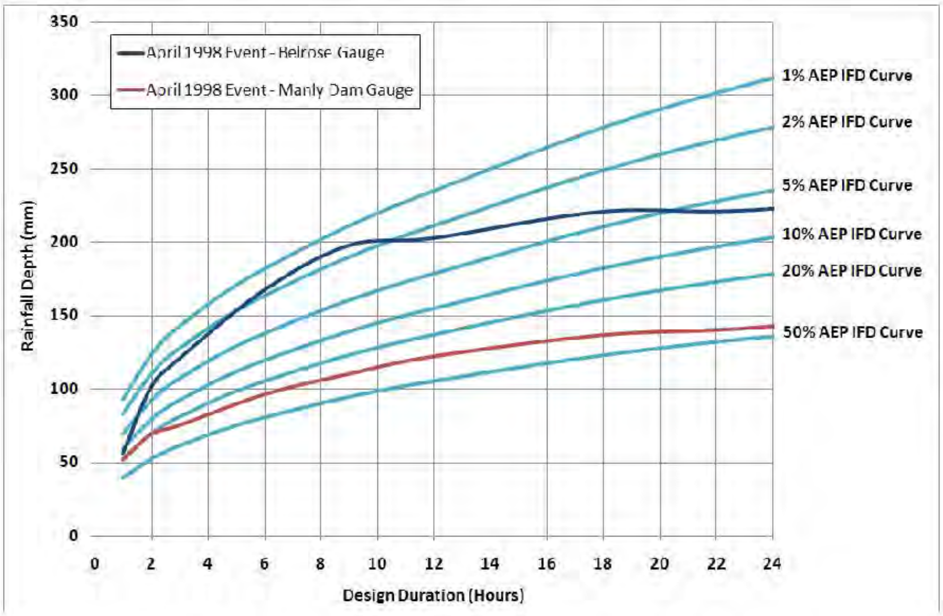
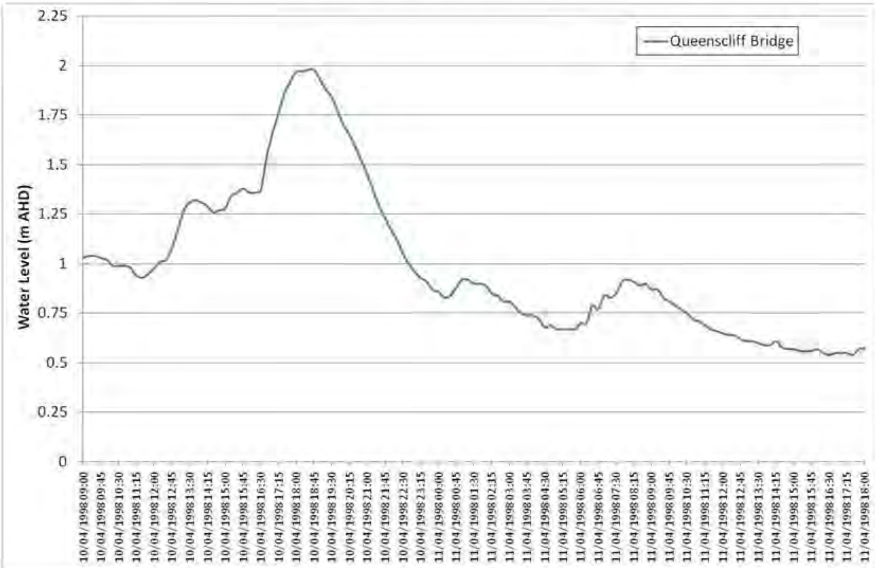


Figure 5-12 Comparison of April 1998 Rainfall with IFD Relationships

5.3.1.2 Water Level Data

There were three active water level recorders operating within the Manly Lagoon catchment during the April 1998 event – Manly Dam (located on Manly Dam), Queenscliff Bridge (Manly Lagoon) and Riverview Parade (Manly Lagoon).

The recorded water level time series at the two gauges located on Manly Lagoon for the April 1998 event is shown in Figure 5-13. The time series shown includes the initial response at the onset of the event, the peak water levels and the recession for some 20-hours after the flood peak.



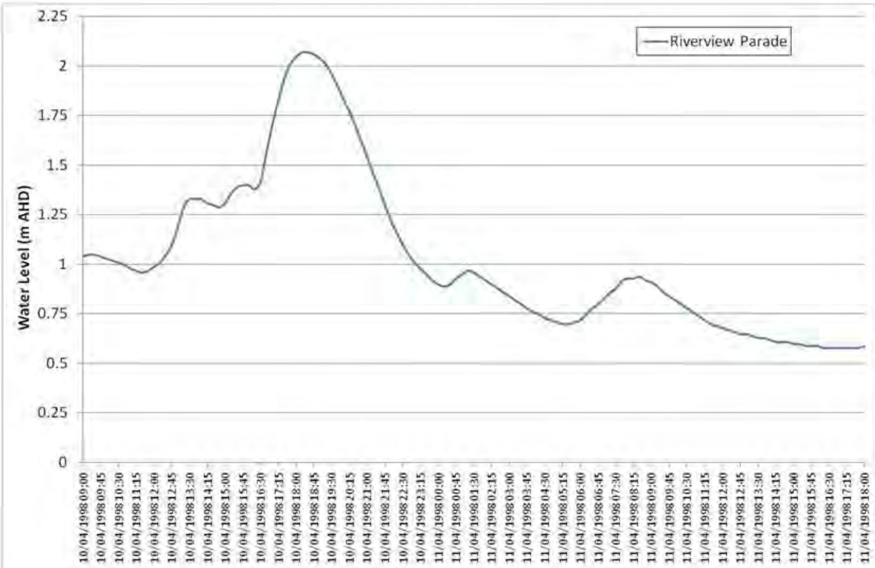


Figure 5-13 April 1998 Recorded Water Levels at Manly Lagoon

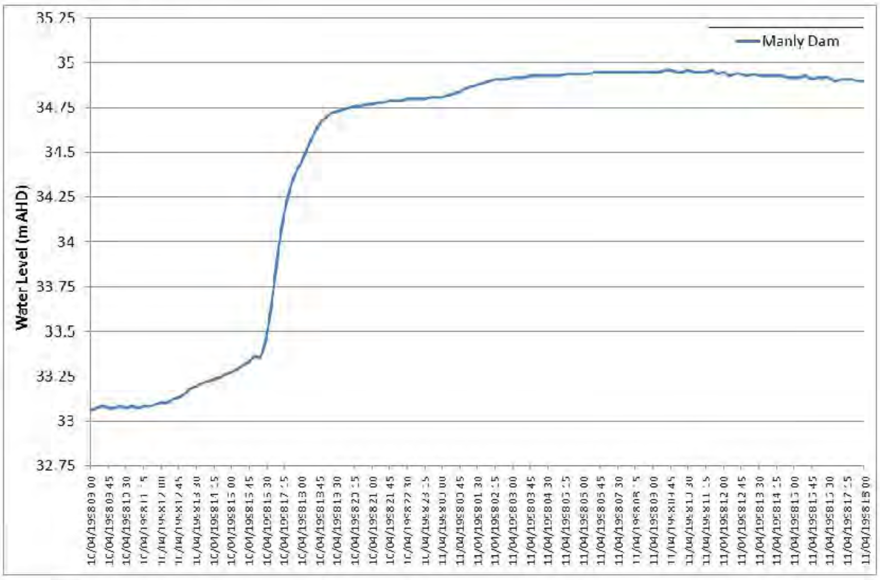


Figure 5-14 April 1998 Recorded Water Levels at Manly Dam

5.3.2 Downstream Boundary Conditions

Ocean tide (water level) data was available for the April 1998 event from a continuous tide gauge maintained by MHL at Middle Head. This water level data is considered to be representative of the ocean water levels at the Manly Lagoon entrance and as such was used as the downstream boundary for the April 1998 event. The relationship between recorded ocean water levels and recorded rainfall for the April 1998 event is shown in Figure 5-15.

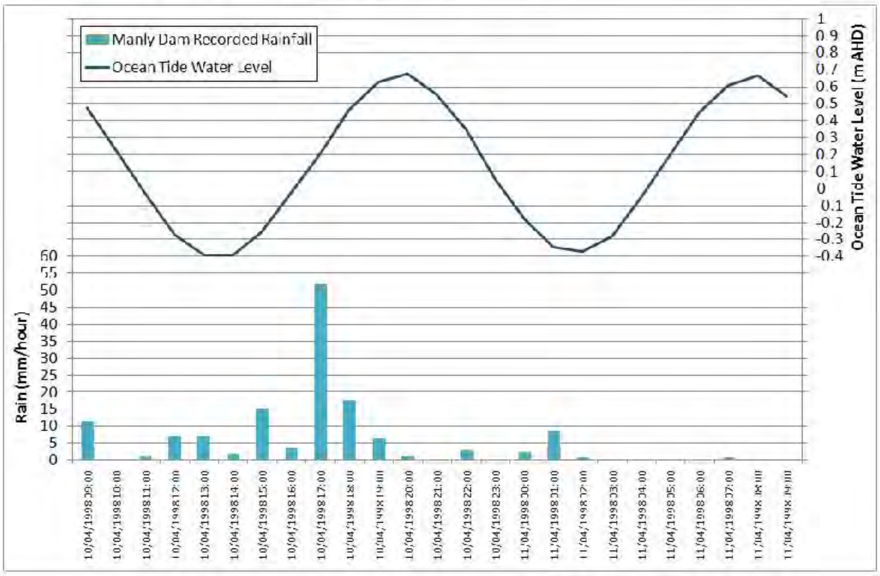


Figure 5-15 April 1998 Recorded Tidal Water Level

5.3.3 Observed and Simulated Flood Conditions April 1998

A comparison of recorded and simulated water level profiles in Manly Lagoon for the April 1998 event is shown in Figure 5-16 and Figure 5-17 for the Riverview Parade and Queenscliff Bridge gauges respectively. The simulated results generally show a reasonable comparison between the recorded and simulated profiles. Some key aspects of the simulated catchment flood behaviour include:

- Catchment runoff response – similar to the calibration for the March 2011 event, the relative timing of the observed and simulated water level hydrographs shows an excellent agreement throughout the simulated event. This shows the catchment runoff processes are being well simulated including the initial catchment response from the wetting-up period (incorporating rainfall losses) and the general rise of water levels in the Lagoon indicating a good simulation of the relative timing of the main tributary inflows.

- Peak flood levels – the peak Lagoon flood levels are well simulated in comparison to observed conditions. The initial water level condition in the Lagoon for the simulated April 1998 event is relatively high following some preceding rainfall and a relatively shoaled entrance condition. The event is of relatively short duration, rising to the peak level within approximately 8 hours of the start of the main rainfall period. The peak levels in the Lagoon are reasonably well simulated, particularly at the Queenscliff Bridge gauge. The water level gradient in the Lagoon is slightly over predicted in the model simulation such that simulated water levels at Riverview Parade are slightly higher than observed.

- Total flood volumes – the total runoff volumes represented by the total area under the water level hydrograph show good agreement between observed and simulated conditions. The simulation of runoff volumes is sensitive to the adopted rainfall distribution, which can be somewhat subjective based on the limited recorded gauge data within the catchment and large variability in rainfall across the catchment for this event. Nevertheless, despite the significant variation in rainfall across the catchment overall flood volumes have been well simulated.

Despite the differences between the observed and simulated conditions for both the March 2011 and April 1998 events, the developed models have performed reasonably well and provide a sound representation of the catchment runoff processes and resulting peak flood conditions in the Manly Lagoon catchment. Accordingly, the developed models provide a sound basis for establishing design flood conditions in the catchment.

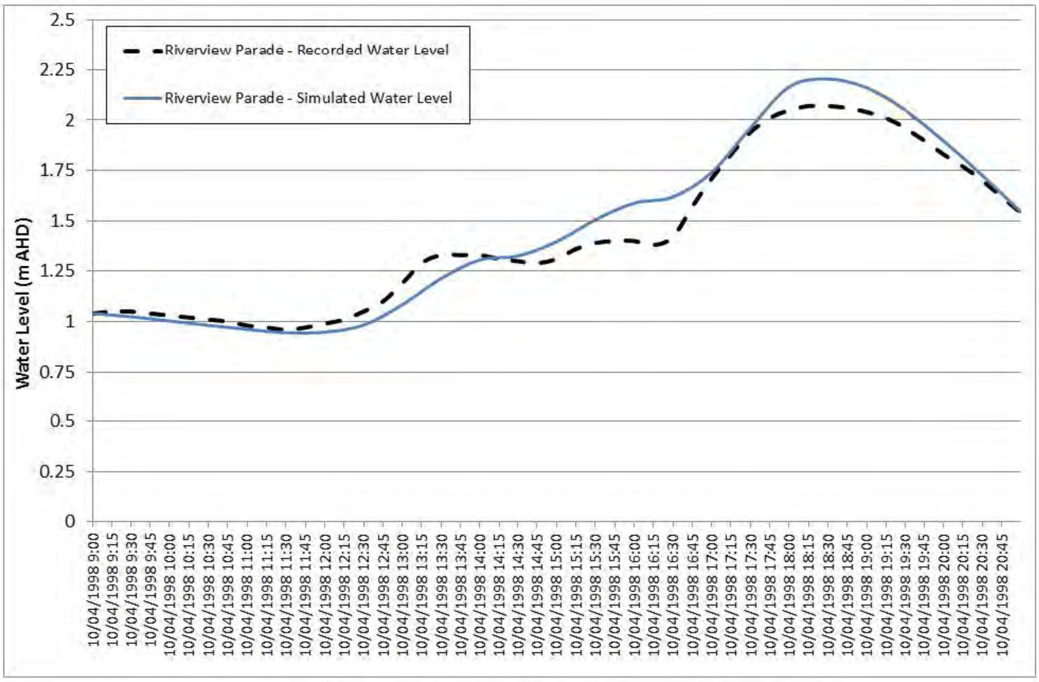


Figure 5-16 Riverview Parade Water Level Calibration – April 1998

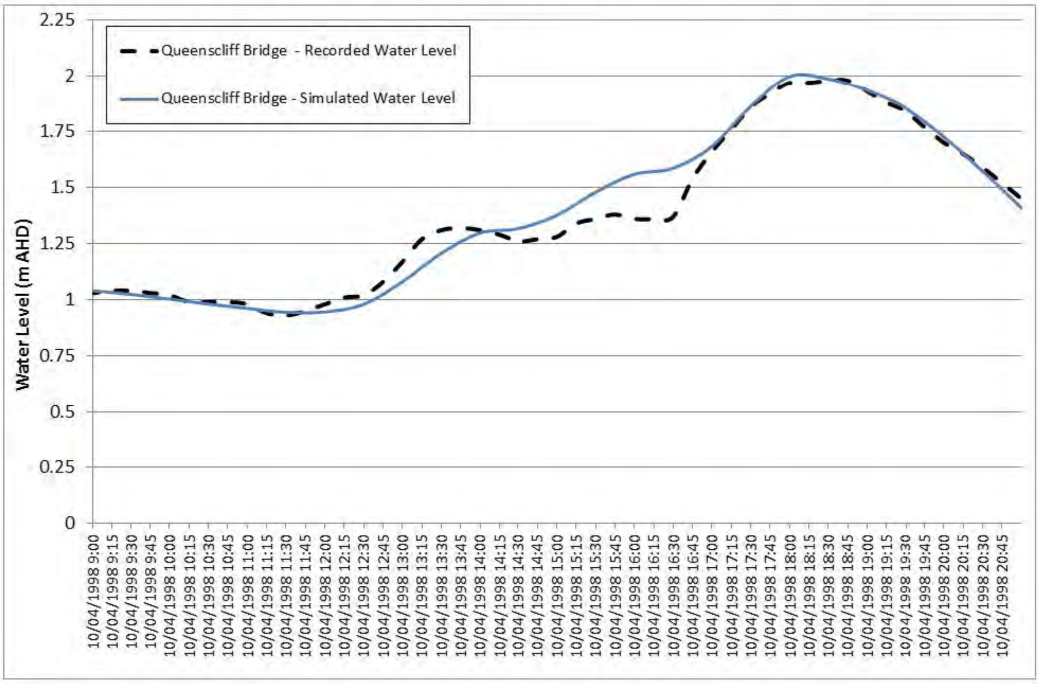


Figure 5-17 Queenscliff Bridge Water Level Calibration – April 1998

6 DESIGN FLOOD CONDITIONS

Design floods are hypothetical floods used for land use planning and floodplain risk management investigations. They are based on having a probability of occurrence specified either as:

- Annual Exceedance Probability (AEP) expressed as a percentage; or
- Average Recurrence Interval (ARI) expressed in years.

This report uses the AEP terminology. Refer to Table 6-1 for a definition of AEP and the ARI equivalent.

Table 6-1 Design Flood Terminology

AEP[1]	ARI[2]	Comments
0.1%	1,000 years	A hypothetical flood or combination of floods likely to occur on average once every 1,000 years or with a 0.1% probability of occurring in any given year
0.2%	500 years	A hypothetical flood or combination of floods likely to occur on average once every 500 years or with a 0.2% probability of occurring in any given year
0.5%	200 years	As for the 0.2% AEP flood but with a 0.5% probability or 50 year return period
1%	100 years	As for the 0.5% AEP flood but with a 1% probability or 100 year return period.
2%	50 years	As for the 0.5% AEP flood but with a 2% probability or 50 year return period.
5%	20 years	As for the 0.5% AEP flood but with a 5% probability or 20 year return period.
10%	10 years	As for the 0.5% AEP flood but with a 10% probability or 10 year return period.
20%	Approx. 5 years	As for the 0.5% AEP flood but with a 20% probability or 5 year return period.
50%	Approx. 2years	As for the 0.5% AEP flood but with a 50% probability or 2 year return period.
Extreme Flood / PMF[3]		A hypothetical flood or combination of floods which represent an extreme scenario.

1 Annual Exceedance Probability (%)
2 Average Recurrence Interval (years)
3 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

The design events simulated include the PMF event, 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment derived flooding and the 0.5%, 1%, 2%, 5%, 10% and 20% AEP events for ocean derived flooding. The 1% AEP flood is generally used as a reference flood for land use planning and control.

In determining the design floods it is necessary to take into account:

- Design rainfall parameters (rainfall depth, temporal pattern and spatial distribution). These inputs drive the hydrological model from which design flow hydrographs will be extracted as inputs to the hydraulic model;
- Design Lagoon entrance condition and berm geometry. Consideration was given to both open and closed Lagoon entrance conditions;
- Design downstream ocean boundary levels. A fully scoured entrance condition will provide for the critical case for ocean flooding, whilst for closed condition and intermediate scouring, coincident fluvial and tidal conditions may dictate flooding; and
- Initial Lagoon water level.

In determining the design floods it is necessary to take into account the critical storm duration of the catchment (small catchments are more prone to flooding during short duration storms while for large catchments longer durations will be more critical).

6.1 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R (2001) which are based on statistical analysis of recorded rainfall data across Australia. The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for Manly Lagoon is presented below.

6.1.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). These curves provide rainfall depths for various design magnitudes (up to the 1% AEP) and for durations from 5 minutes to 72 hours.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The theoretical definition of the PMP is "the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of year" (AR&R, 2001). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the "credible limit of extrapolation". That is, it is not possible to use rainfall depths determined for the more frequent events (1% AEP and less) to extrapolate the PMP. The PMP has been estimated using the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology. Durations of up to 6-hours have been considered for the PMP in accordance with the GSDM.

Table 6-2 shows the average design rainfall intensities based on AR&R adopted for the modelled events.

Table 6-2 Average Design Rainfall Intensities (mm/hr)

Duration (hours)	Design Event Frequency					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMP
0.5	76	86	100	119	133	454
1	52	60	70	83	93	333
1.5	41.0	47.5	56	66	74.5	286
2	34.6	39.6	46.2	55	62	251
3	26.9	30.8	35.8	42.5	47.6	203
6	17.5	19.9	23	27.2	30.3	135
9	13.5	15.5	18	21	24	n/a
12	11.4	12.9	14.9	17.6	19.6	n/a
24	7.42	8.46	9.81	11.6	13.0	n/a

6.1.2 Temporal Patterns

The IFD data presented in Table 6-2 provides for the average intensity that occurs over a given storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. The temporal patterns adopted in the current study are based on the standard patterns presented in AR&R (2001).

The same temporal pattern has been applied across the whole catchment. This assumes that the design rainfall occurs simultaneously across each of the modelled sub-catchments. The direction of a storm and relative timing of rainfall across the catchment may be determined for historical events if sufficient data exists, however, from a design perspective the same pattern across the catchment is generally adopted.

6.1.3 Rainfall Losses

The hydrological model parameters adopted for the design floods were similar to those used in the hydrological model calibration and validation. For the initial and continuing rainfall losses, values of 10mm and 2.5mm/hr were used for pervious areas and 2mm and 0mm/hr for impervious areas. These are consistent with the recommended ranges for design event losses in AR&R (2001).

It is noted that for calibration events that a pervious surface initial loss of 20mm was adopted. For design events however, the 10mm loss was adopted as a conservative value considering the potential for wet catchment antecedent conditions at the onset of a design rainfall event.

6.1.4 Critical Duration

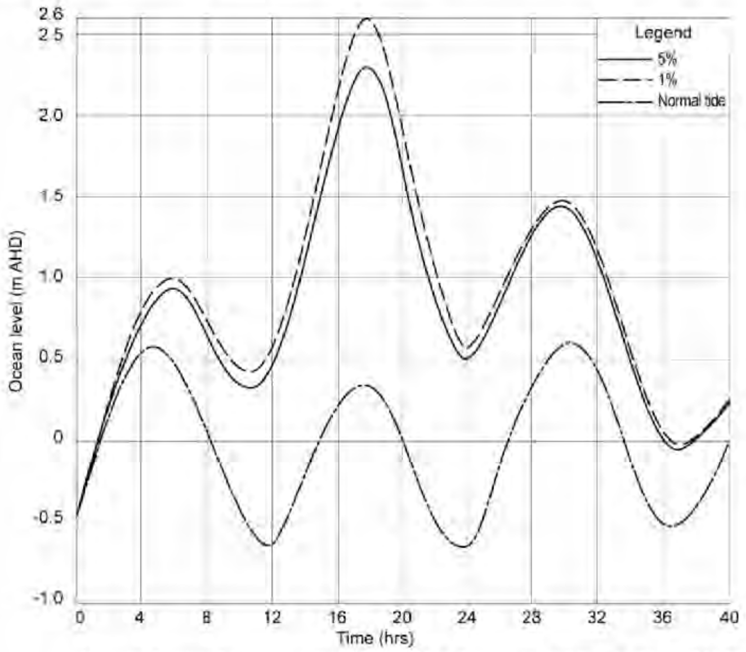
A series of model runs was carried out in order to identify the critical storm duration for the Manly Lagoon catchment. Standard durations from the 30-minute to the 24-hour events were simulated utilising the design temporal patterns from AR&R (2001). The critical storm duration event required to produce the maximum peak water levels in Manly Lagoon was found to be the 9 hour duration event.

6.2 Design Ocean Boundary

Design ocean boundaries for use in flood risk assessments are recommended by Appendix A of the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments* (DECCW, 2010). The design ocean boundaries from Figure 7.1 of this document are presented in Figure 6-1. The recommended normal ocean boundary has been adopted for the catchment derived flood events. For the ocean derived flood events, the elevated ocean boundaries have been adopted.

6.2.1 Catchment Derived Flood Events

The adopted tidal boundary for catchment derived flood events was based on the normal tide recommendation and is shown in Figure 6-2. The timing of the 0.6m AHD peak water level was adjusted to coincide with the peak catchment inflow.



Source: Figure 7.1, Appendix A, Flood Risk Management Guide (DECCW, 2010)

Figure 6-1 DECCW Recommended Design Ocean Boundaries

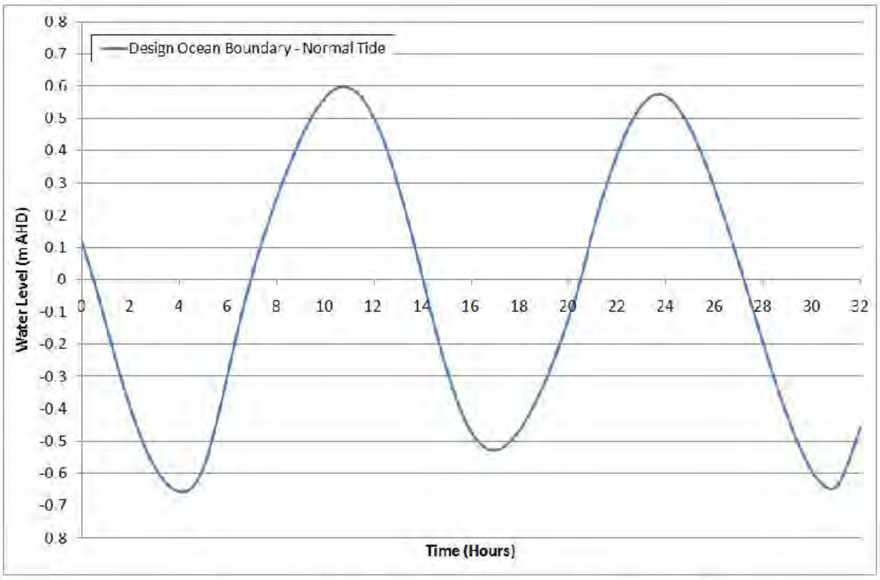


Figure 6-2 Design Ocean Boundary – Normal Tide

6.2.2 Ocean Derived Flood Events

The adopted tidal boundary for ocean derived flood events was based on the elevated tide recommendation in the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments* (DECCW, 2010). These levels include the following considerations:

- Barometric pressure set up of the ocean surface due to the low atmospheric pressure of the storm;
- Wind set up due to strong winds during the storm "piling" water upon the coastline;
- Astronomical tide, particularly the Higher High Water Solstice Springs (HHWSS); and
- Wave set up.

Adopted peak ocean boundary water levels for various magnitude storm events are shown in Figure 6-3.

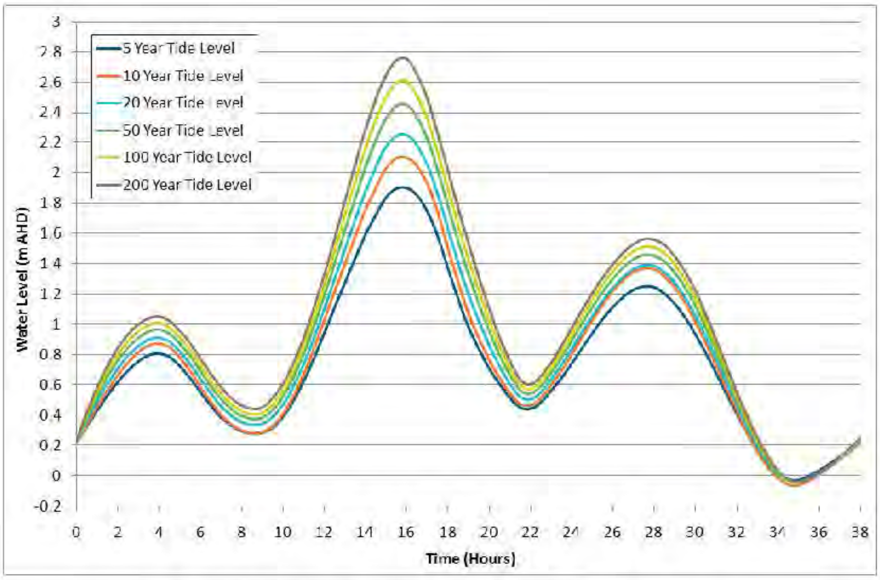


Figure 6-3 Design Ocean Boundary – Elevated Tide

6.3 Design Lagoon Entrance Condition and Berm Geometry

As discussed in 2.1.2, the Manly Lagoon entrance opening is subject to forces that act to close the entrance (waves, tides and wind) and those that act to maintain an open entrance (flood flows and dredging), which results in the Lagoon being defined as an intermittently closed and open Lake/Lagoon (ICOLL).

The entrance has been significantly modified with the construction of a concrete channel and low flow pipe system providing a permanent connection to the ocean and tidal interaction under normal conditions as shown in Figure 6-4.

The entrance of Manly Lagoon is artificially opened to mitigate flooding of nearby residential and commercial areas. A pilot channel is generally maintained in the entrance, effectively leaving a smaller “plug” which can be opened to relieve flooding in line with the current entrance management practices.

The height of the entrance berm level and the presence of the pilot channel will influence how high lagoon water levels need to reach before discharge to the ocean is initiated. The relativity between the rate of entrance scour (and thus discharge from the lake) and the rate of catchment runoff flowing into the Lagoon system will determine how high lagoon water levels reach in excess of the entrance berm level. Elevated ocean water levels may also penetrate into the lagoon, through overtopping of the entrance berm and restrict outflow.

The conditions of the entrance, including the entrance berm level, are a function of active coastal processes (wave and sediment transport). Consequently, for ICOLLs, an assessment of lagoon flood conditions requires consideration of adjacent coastal conditions.

Figure 6-4 Manly Lagoon concrete entrance channel

Figure 6-5 Scoured entrance during March 2011 event (Source: MHL)

6.3.1 Catchment Derived Flood Events

The Lagoon entrance bathymetry (with the exception of the entrance berm level) for the catchment derived flood events was obtained from the 2012 bathymetric survey and 2007 LiDAR data (as adopted for the calibration and validation events). The general entrance berm level adopted for the catchment derived flood events is 1.4m AHD.

The 1.4m AHD entrance berm level corresponds to the trigger levels for mechanical breakout under the current entrance management policy. Using this berm level provides for a highly constrained entrance and represents the worst case entrance condition (under the existing management policy) for a catchment derived flood event.

The adopted model bathymetry for the Lagoon entrance representing a closed condition is shown in Figure 6-6.

6.3.2 Ocean Derived Flood Events

The Lagoon entrance bathymetry (including entrance berm level) for the ocean derived flood events was obtained from the 2005 bathymetric survey (refer Section 5.2.4). The Lagoon entrance condition for the ocean derived flood events is shown in Figure 6-7. Using this data provides for a largely unrestricted entrance condition, as recommended for use in ocean derived flood events by Appendix A of the Flood Risk Management Guide (DECCW, 2010).

6.4 Design Initial Water Levels

Initial water levels in Manly Lagoon for design flood events have been derived based on a combination of available water level records from the MHL operated gauges located in Manly Lagoon and trigger levels for entrance opening under current entrance management regimes.

6.4.1 Catchment Derived Flood Events

The initial water level in Manly Lagoon adopted for catchment derived flood events is 1.4m AHD. This water level corresponds to the water level in Manly Lagoon at which a mechanical Lagoon breakout is initiated. An initial water level of 1.4m AHD therefore provides for the worst case initial water level for a catchment derived flood event.

6.4.2 Ocean Derived Flood Events

The initial water level in Manly Lagoon for the ocean derived flood events is based on a nominal tidal condition. The initial water level in Manly Lagoon was set to 0.2m AHD which equates to the water level at time zero for the adopted ocean tide time series (refer Section 6.2 and Figure 6-3).

Title:
Manly Lagoon Entrance Bathymetry: Catchment Derived Flood Events

Figure: 6-6

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Title:
Manly Lagoon Entrance Bathymetry: Ocean Derived Flood Events

Figure: 6-7

Rev: A

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6.5 Modelled Design Events

In consultation with The Councils a suite of design event scenarios were defined that are most suitable for future floodplain management planning in Manly Lagoon. Consideration was given to design flood events driven by both catchment and ocean processes. The potential impact of climate change on flood behaviour within Manly Lagoon is presented in Section 8.

6.5.1 Catchment Derived Flood Events

A range of design events were defined to model the behaviour of catchment derived flooding within the Manly Lagoon catchment including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP, 0.1% AEP and PMF events. The catchment derived flood events were based on the following:

- Design rainfall parameters derived from standard procedures defined in AR&R (2001);
- Normal ocean boundary as recommended in Appendix A of the Draft Flood Risk Management Guide (DECCW, 2009);
- Lagoon entrance bathymetry based on 2011 pre-dredge bathymetric survey with the berm height set to 1.4m AHD; and
- Initial water level of 1.4m AHD.

6.5.2 Ocean Derived Flood Events

A range of design events were defined to model the behaviour of ocean derived flooding within the Manly Lagoon catchment including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP and 0.5% AEP events. The ocean derived flood events were based on the following:

- No catchment rainfall;
- Elevated ocean boundary as recommended in Appendix A of the Draft Flood Risk Management Guide (DECCW, 2009);
- Lagoon entrance bathymetry representative of an open entrance condition with general bed level of the order of 0.0m AHD; and
- Initial water level of 0.23m AHD (starting level of modelled tide profile).

6.5.3 Joint Catchment and Ocean Derived Flood Events

Model simulations were undertaken considering the coincidence of catchment and ocean flooding conditions. These simulations were undertaken for the 1% AEP event using:

- 1% AEP catchment rainfall with 5% AEP design ocean condition; and
- 5% AEP catchment rainfall with 1% AEP design ocean condition.

The results of the above simulations were then compared to the design flood results for the 1% AEP catchment and 1% AEP ocean derived events in order to assess the influence of joint catchment and ocean design events on design flood levels. Different meteorological conditions drive the catchment and ocean flooding, such that a combined 1% AEP catchment event combined with a 1% AEP ocean event represents an extremely rare occurrence.

7 DESIGN FLOOD RESULTS

A range of design flood conditions were modelled, the results of which are presented and discussed below. The simulated design events included the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and 0.1% AEP events for catchment derived flooding and the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP and 0.5% events for ocean derived flooding. The PMF flood event has also been modelled for catchment derived flooding. A series of design flood maps for selected events are provided in Appendix A.

7.1 Peak Flood Conditions

7.1.1 Catchment Derived Flood Events

The design flood results are presented in a flood mapping series in Appendix A. For the simulated design events including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP, 0.1% AEP and PMF events, a map of peak flood level, depth and velocity is presented covering the modelled area.

Predicted flood levels at selected locations are shown in Table 7-1 for the full range of design event magnitudes considered. The locations of reported flood levels are shown in Figure 7-1.

Similar peak flood levels are reached over the general area of the Lagoon water body, extending from Queenscliff Bridge to the upper reaches on each tributary channel. This indicates the relative control of the entrance condition on peak flood levels across the Lagoon body. Flood levels along the tributary channels naturally increase moving up higher within the catchments.

7.1.2 Ocean Derived Flood Events

The design flood results are presented in a flood mapping series in Appendix A. For the simulated design events including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP and 0.5% AEP events, a map of peak flood level, depth and velocity is presented covering the modelled area.

Predicted flood levels at selected locations are shown in Table 7-2 for the full range of design event magnitudes considered. The locations of reported flood levels are shown in Figure 7-1.

All events are modelled with an open entrance condition (refer Section 6.3). For lower order events that occur during a closed entrance condition the berm may offer some form of flood protection. However, for large ocean derived events the entrance berm would be overtopped or in some cases destroyed. The same peak flood level is reached across the Lagoon area, corresponding to the peak ocean surge level. Accordingly there is no attenuation of the tide surge through the Lagoon body given the relatively small storage volume.

7.1.3 Joint Catchment and Ocean Derived Flood Events

Predicted peak flood levels at selected locations for the coincident catchment and ocean flooding scenarios are shown in Table 7-3. The coincident flooding scenarios presented include:

- 1% AEP catchment rainfall with 5% AEP design ocean condition; and
- 5% AEP catchment rainfall with 1% AEP design ocean condition.

Table 7-1 Modelled Peak Flood Levels for Catchment Derived Design Events

Location	Modelled Peak Flood Level (m AHD)									
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP	PMF
US Queenscliff Bridge (Manly Lagoon)	2.2	2.3	2.5	2.6	2.7	2.8	3.0	3.1	3.3	5.3
US Pittwater Rd Bridge (Manly Lagoon)	2.2	2.4	2.6	2.7	2.9	3.0	3.1	3.2	3.4	5.6
Riverview Parade (Manly Lagoon)	2.2	2.4	2.6	2.7	2.9	3.0	3.1	3.2	3.4	5.6
US Kentwell Rd Culvert (Manly Lagoon)	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	5.6
US Manly Golf Course Floodway (under Kenneth Rd)	2.5	2.7	2.9	3.0	3.3	3.3	3.5	3.7	3.8	5.7
US Condamine St Culvert (Manly Creek)	4.1	4.1	4.2	4.4	4.6	4.8	5.0	5.2	5.3	6.2
DS Condamine St Culvert (Brookvale Creek)	5.7	5.9	5.9	6.0	6.1	6.2	6.2	6.6	6.5	7.4
US Condamine St Culvert (Burnt Bridge Creek)	8.3	9.5	10.1	10.7	11.0	11.1	11.2	11.9	12.0	12.1
US Clearview Place Culvert (Brookvale Creek)	19.9	20.6	20.9	21.3	21.5	21.7	22.0	22.2	22.4	23.5
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.2	32.7	33.0	33.4	33.8	34.2	34.6	34.8	35.0	36.1
US Bangaroo St Culvert (Burnt Bridge Creek)	39.3	40.4	40.7	40.9	41.2	41.2	41.3	41.4	41.5	42.3

Title:
Design Event Peak Flood Level Reporting Locations

Figure: 7-1

Rev: A

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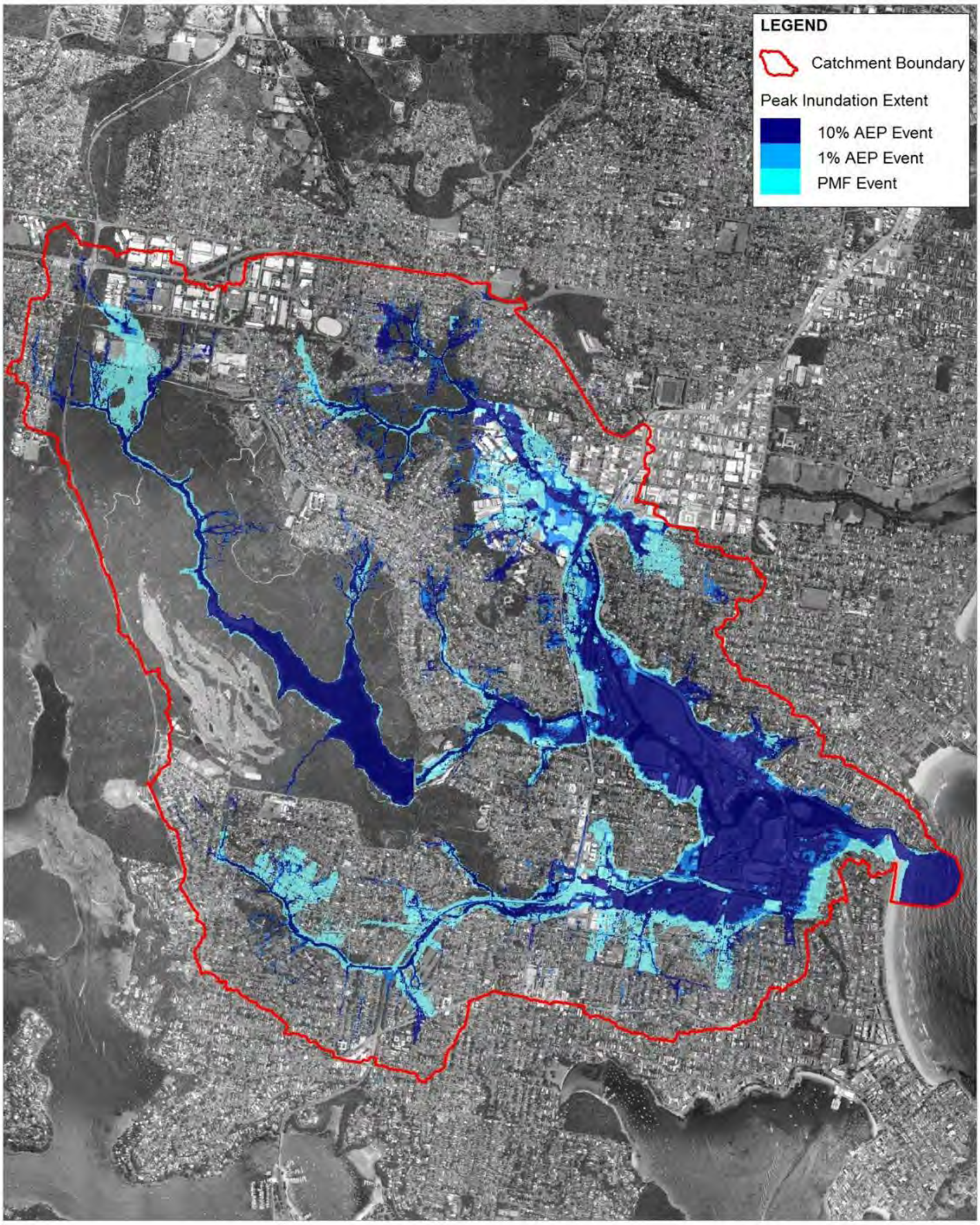
Table 7-2 Modelled Peak Flood Levels for Ocean Derived Design Events

Location	Modelled Peak Flood Level (m AHD)					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
US Queenscliff Bridge (Manly Lagoon)	1.9	2.1	2.2	2.3	2.5	2.6
US Pittwater Rd Bridge (Manly Lagoon)	1.9	2.1	2.2	2.3	2.5	2.6
Riverview Parade (Manly Lagoon)	1.9	2.1	2.2	2.3	2.5	2.6
US Kentwell Rd Culvert (Manly Lagoon)	1.8	2.0	2.1	2.4	2.5	2.6
US Manly Golf Course Floodway (under Kenneth Rd)	1.9	2.1	2.2	2.4	2.6	2.7
US Condamine St Culvert (Manly Creek)	1.9	2.1	2.2	2.4	2.6	2.7

Table 7-3 Modelled Peak Flood Levels for Joint Design Events

Location	Modelled Peak Flood Level (m AHD)			
	1% AEP 9-hour Catchment Event	1% AEP Ocean Event	1% AEP Catchment + 5% AEP Ocean	5% AEP Catchment + 1% AEP Ocean
US Queenscliff Bridge (Manly Lagoon)	2.8	2.5	3.1	2.8
US Pittwater Rd Bridge (Manly Lagoon)	3.0	2.5	3.1	2.9
Riverview Parade (Manly Lagoon)	3.0	2.5	3.1	2.9
US Kentwell Rd Culvert (Manly Lagoon)	3.1	2.5	3.2	2.9
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	2.6	3.5	3.2
US Condamine St Culvert (Manly Creek)	4.8	2.6	4.8	4.4
DS Condamine St Culvert (Brookvale Creek)	6.0	2.6	6.0	5.9
US Condamine St Culvert (Burnt Bridge Creek)	10.0	-	10.0	8.9
US Clearview Place Culvert (Brookvale Creek)	20.8	-	20.8	20.5
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	-	32.6	32.3
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1		40.1	39.4

Figure 7-2 shows the peak flood inundation extents of the 10% AEP, 1% AEP and PMF flood events. The overall extent of inundation particularly in the lower catchment around the Lagoon doesn't change significantly with increasing flood event magnitude, however, the depth of flooding increases with event severity.



Title:

Manly Lagoon Flood Study
Peak Flood Inundation Extents

Figure: 7-2

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7.2 Design Flood Hydrographs

A range of storm durations were modelled in order to identify the critical storm duration for design event flooding in the Manly Lagoon catchment. Design durations considered included the 0.5-hour, 1-hour, 1.5-hour, 2-hour, 3-hour, 4.5-hour, 6-hour, 9-hour, 12-hour, 18-hour and 24-hour durations.

Outputs from the model simulations indicate that the maximum peak inflows to Manly Lagoon are generally derived when using a design storm duration of 6 to 9 hours. In the upper reaches of some of the tributary catchments, the 1 to 2-hour duration provided for the highest peak flows.

A plot of the water level response at the location of the Kentwell Road culvert on Manly Lagoon provides a good representation of general flood response in the catchment. Figure 7-3 shows the simulated water level time series at Kentwell Road for the 1% AEP 2-hour and 9-hour storm durations. This location is approximately at the limit of where the influence of Manly Lagoon flooding ends and the local catchment flood condition becomes the dominant flooding condition. This is further illustrated in Figure 7-4 showing a plot of the critical duration for the 1% AEP event across the lower part of the catchment. Within the broader Lagoon and the lower reaches of the tributary channels, the longer 9-12 hour duration events provide for the peak flood water levels in the system. Kentwell Road on the Brookvale Creek tributary represents the approximate limit where the shorter duration 2-hour event for local flooding becomes the critical duration.

Figure 7-3 shows the flood peak for the 2-hour and 9-hour durations to be almost the same level at Kentwell Road. The 2-hour duration water level profile is largely driven by the local flooding generated in the Brookvale Creek catchment. The relatively small catchment provides for a rapid water level response to rainfall, within peak flood conditions being reached within 1-2 hours.

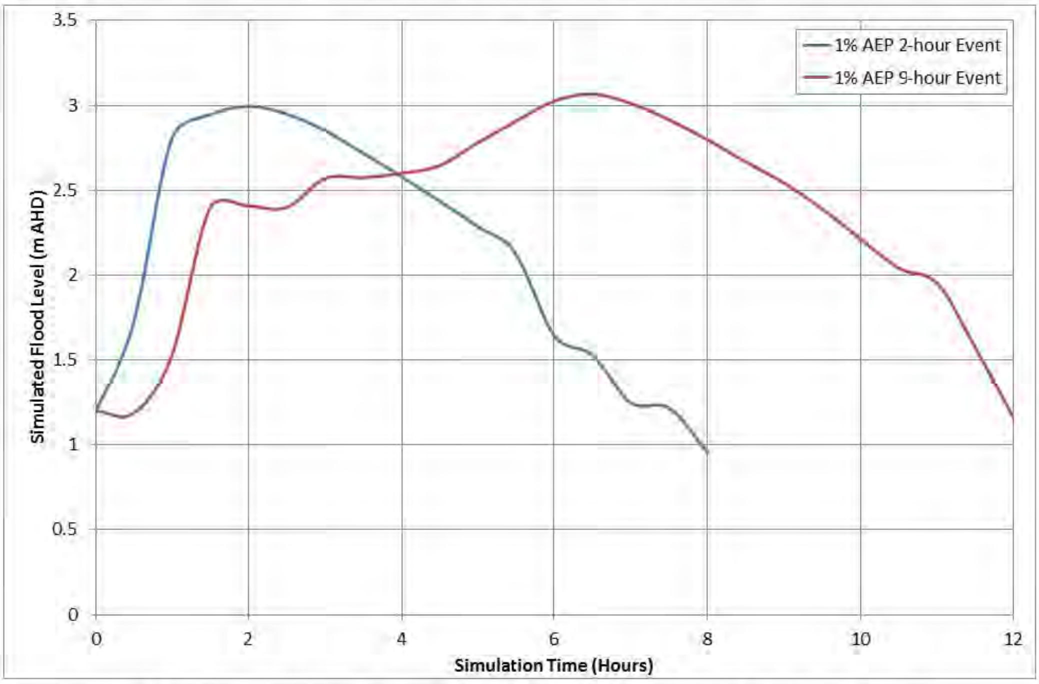
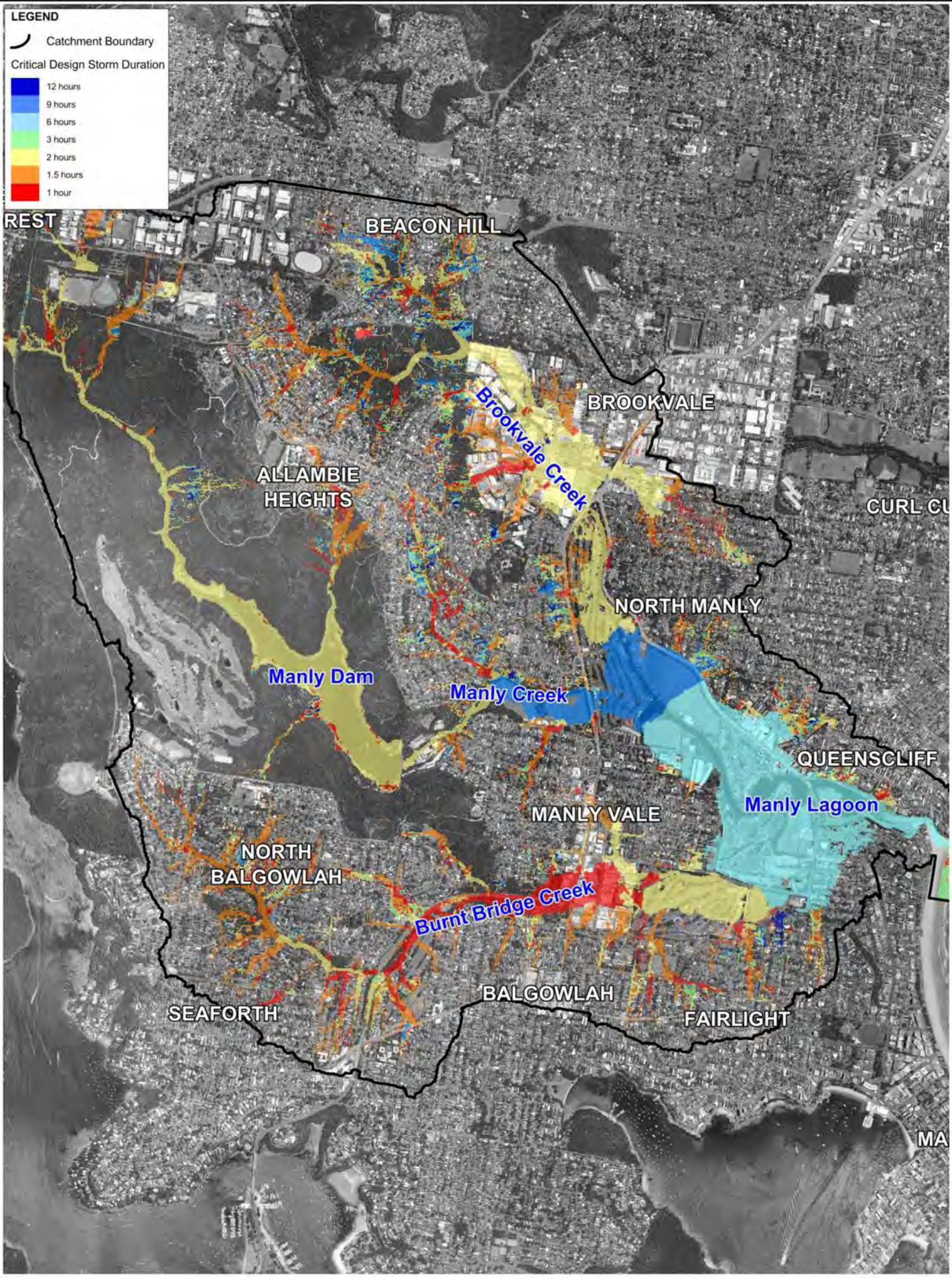


Figure 7-3 Simulated Water Level Response at Kentwell Road, Brookvale Creek



Title:
Critical Storm Duration - 1% AEP Catchment Event

Figure: 7-4
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The 1% AEP 9-hour water level time series shown in Figure 7-3 represents significantly longer storm duration with a greater overall runoff volume. The plot shows a dual peak with the local catchment contribution peaking at around 4-hours before the higher peak at around 6-hours. This later peak represents the peak flood condition being reached in the broader Manly Lagoon. Further upstream within Brookvale Creek, there is less influence from the Lagoon flood level in which short duration local catchment flooding becomes the clear dominant flooding mechanism. This type of flood behaviour is similar on the other small tributaries where the critical durations in the upper reaches are relatively short as shown in Figure 7-4.

The rapid water level rise as seen in Figure 7-3 has implications for flood planning and emergency response given the potential for limited available warning time before the onset of peak flood conditions. Critical durations are similar for most of the other design event return periods. For the PMF event, the critical duration for the broader Lagoon area is the 5-hour duration with the 0.5 and 1-hour events typically the critical duration for the local flooding in the upper tributaries.

The simulated 1% AEP 9-hour duration hydrographs for each of the main tributaries at the confluence with Manly Lagoon and the Lagoon hydrograph at Queenscliff Bridge are shown in Figure 7-5. Also shown for reference is the combined inflows to the Lagoon from the tributary catchments. The significant effect of the storage on attenuating flows through the Lagoon is evident in comparing the combined inflow hydrograph to the Queenscliff Bridge hydrograph.

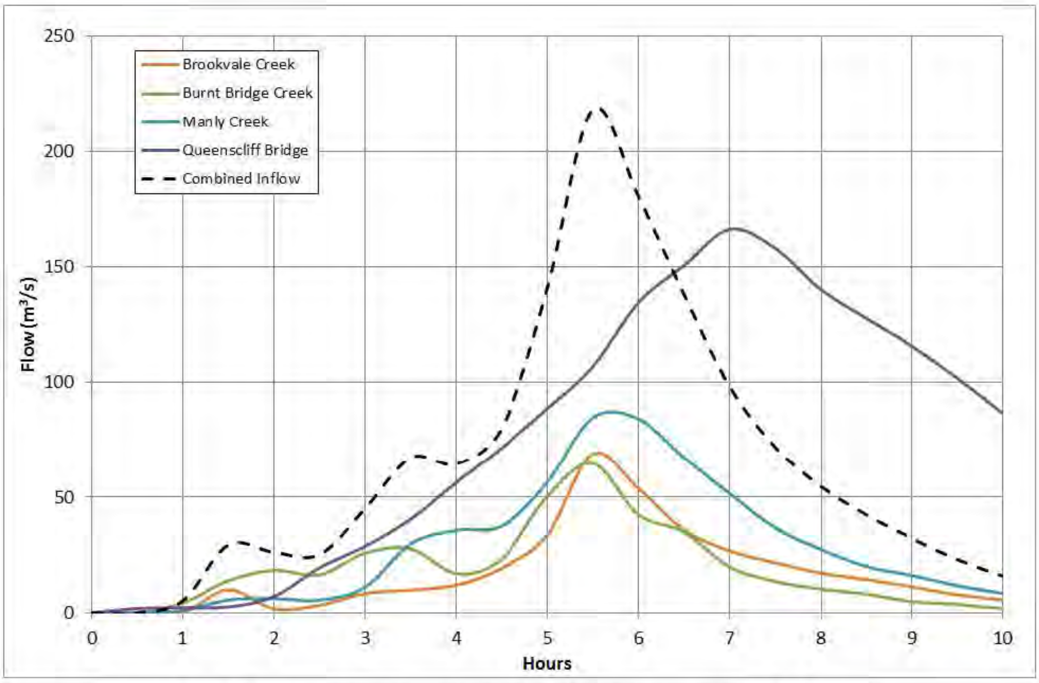


Figure 7-5 Sub-catchment Contributions to Manly Lagoon (1% AEP Event)

The rates of rise of the hydrographs are to some to degree dependent on the adopted temporal patterns across the range of design storm event durations. However, the response shown in Figure

7-5 with a rapid rise in flow over 1 to 2 hours is generally typical of the catchment response. Even shorter response times may be apparent in the upper reaches of the catchments.

For the simulated 1% AEP design event the combined peak inflow into Manly Lagoon is some 220 m^3/s. The relative inflows for other selected design event magnitudes are shown in Figure 7-6 for comparison.

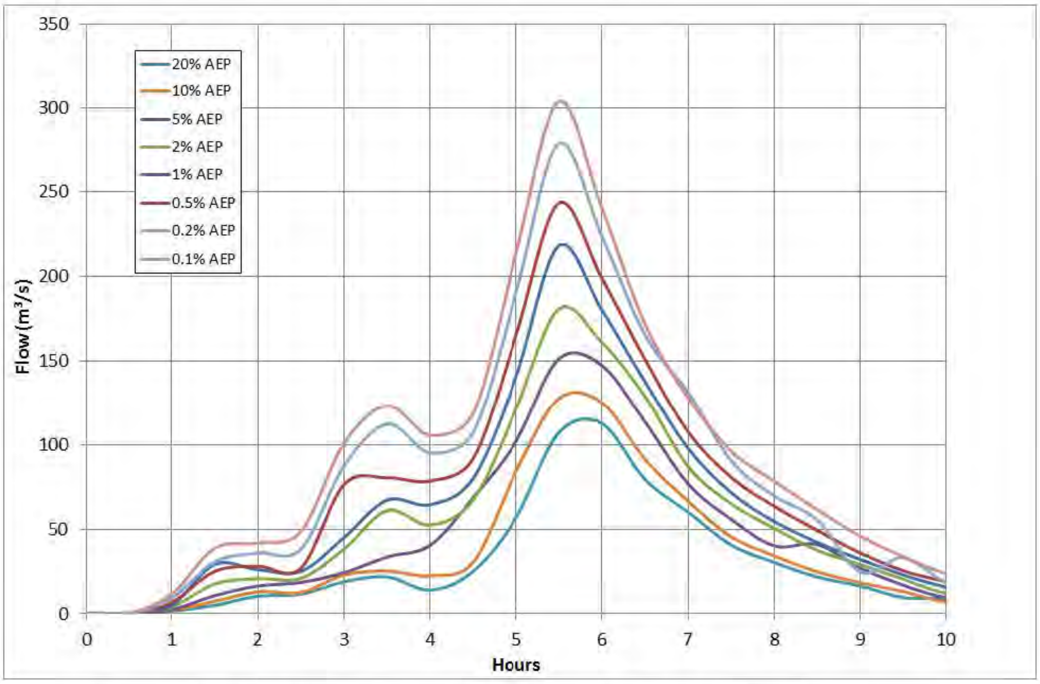


Figure 7-6 Combined Inflows to Manly Lagoon for Sample Design Events

7.3 Comparison with Previous Studies

A comparison of the peak flood levels from the current study with those of the 1992 Manly Lagoon Flood Study (MHL, 1992) (refer Section 2.2.1.1) for Riverview Parade (representative of a general Lagoon water body level) is shown in Table 7-4. .

Generally the water levels simulated between the current study and 1992 Manly Lagoon Flood Study (MHL, 1992) are of a similar order with typical variations less than 0.2m when comparing like for like model conditions (typical of order of accuracies expected through a model calibration process).

The variation in the peak flood levels between the current study and 1992 Manly Lagoon Flood Study (MHL, 1992) may be attributed to the following factors:

- Differences in modelling approach and software;
- Differences in topographical data sets;
- Assumptions in regard to design entrance conditions;

- Improved model calibration and use of historical data;
- Changes to flow structures;
- Catchment land use changes.

Table 7-4 Comparison of Peak Flood Levels to 1992 Manly Lagoon Flood Study (Riverview Parade)

Event Scenario	Peak Flood Level (m AHD)	
	Current Study	1992 Manly Lagoon Flood Study (MHL, 1992)
1% AEP Catchment Event (entrance closed)	3.0	2.7
5% AEP Catchment Event (entrance closed)	2.7	2.5
20% AEP Catchment Event (entrance closed)	2.4	2.2
PMF Event	5.6	5.1
1% AEP Catchment Event / 5% AEP Ocean Event	3.1	2.7
5% AEP Catchment Event / 1% AEP Ocean Event	2.9	2.8

The main contributions to flows in Manly Lagoon come from the largest tributary sub-catchments being Brookvale Creek, Manly Creek and Burnt Bridge Creek. A summary of the design peak flows from each tributary for the 1% AEP event are summarised in Table 7-5. Shown for comparison in the table are the peak discharges from the 1992 Manly Lagoon Flood Study (MHL, 1992).

Table 7-5 Design Peak Tributary Flows (1% AEP Event)

Sub-catchment	Peak 1% AEP Flow (m^3/s)	
	Current Study	1992 Manly Lagoon Flood Study (MHL, 1992)
Brookvale Creek	69	83
Manly Creek	84	84
Burnt Bridge Creek	65	77

7.4 Hydraulic Classifications

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

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

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 0.1m 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.

A number of approaches were considered when attempting to define flood impact categories across the Manly Lagoon catchment. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity;
- Peak flood depth;
- Peak velocity * depth (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within the Manly lagoon catchment, was based on a combination of velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 7-6.

Preliminary hydraulic category mapping for the 5% AEP, 1% AEP and PMF design events is included in Appendix A (Figures A-3, A-7 and A-11). It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 7-6 Hydraulic Categories

Floodway	Velocity * Depth > 0.5 m^2/s	Areas and flowpaths where a significant proportion of floodwaters are conveyed during a flood (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.5 m^2/s and Depth > 0.5 m	Floodplain areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.5 ms/s and Depth < 0.5 m	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

7.5 Provisional Hazard

The NSW Government's Floodplain Development Manual (2005) defines flood hazard categories as follows:

High hazard – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and

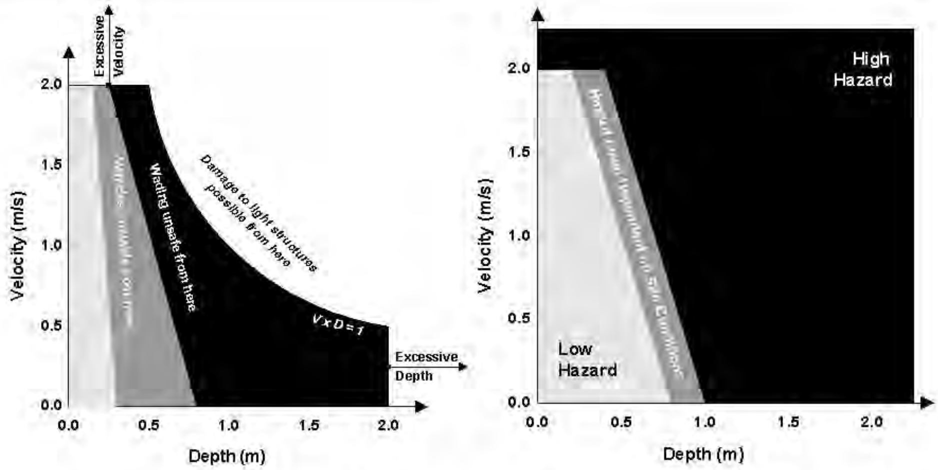
Low hazard – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

* Size of the Flood
* Rate of Rise - Effective Warning Time
* Community Awareness
* Flood Depth and Velocity
* Duration of Inundation
* Obstructions to Flow
* Access and Evacuation

The provisional flood hazard level is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat.

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 7-7.



Velocity Depth Relationships

Provisional Hazard Categories

Figure 7-7 Provisional Flood Hazard Categorisation

The provisional hydraulic hazard is included in the mapping series provided in Appendix A for the 5% AEP, 1% AEP and PMF events (Figures A-4, A-8 and A-12).

7.6 Sensitivity Tests

A number of sensitivity tests have been undertaken on the modelled flood behaviour in the Manly Lagoon catchment. In defining sensitivity tests, consideration is given to the most appropriate tests taking into account catchment properties and simulated design flood behaviour. The tests undertaken have included:

- increased hydraulic roughness;
- structure blockage;
- Lagoon entrance condition; and
- Design rainfall losess.

The rationalisation for each of these sensitivity tests along with adopted model configuration/parameters and results are summarised in the following sections. The impact of the sensitivity tests on the standard design 1% AEP flood condition is also presented in Appendix B as a series of peak water level afflux diagrams.

7.6.1 Hydraulic Roughness

Sensitivity tests on the hydraulic roughness (Manning's 'n') were undertaken by applying a 25% decrease and a 25% increase in the adopted values for the baseline design conditions. Whilst a calibration process has been undertaken with respect to available data, and adopted design parameters are within typical ranges, the inherent variability/uncertainty in hydraulic roughness warrants consideration of the relative impact on adopted design flood conditions.

The sensitivity tests have been undertaken for the 1% AEP catchment rainfall event (9 hour duration). The results of the sensitivity tests on hydraulic roughness for the 1% AEP design event are summarised in Table 7-7. The change in peak flood level conditions from the adopted design base case is also shown as afflux diagrams in Appendix A.

Table 7-7 Peak 1% AEP Flood Levels for Hydraulic Roughness Sensitivity Tests

Location	Peak Design Flood Level (m AHD)		
	Base 1% AEP Catchment	25% Decrease	25% Increase
US Queenscliff Bridge (Manly Lagoon)	2.8	2.7 (-0.2)	2.9 (0.0)
US Pittwater Rd Bridge (Manly Lagoon)	3.0	2.8 (-0.1)	3.0 (0.0)
Riverview Parade (Manly Lagoon)	3.0	2.8 (-0.1)	3.0 (0.0)
US Kentwell Rd Culvert (Manly Lagoon)	3.1	3.0 (-0.1)	3.2 (0.1)
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	3.2 (-0.2)	3.4 (0.0)
US Condamine St Culvert (Manly Creek)	4.8	4.7 (-0.1)	4.8 (0.0)
DS Condamine St Culvert (Brookvale Creek)	6.0	5.9 (-0.2)	6.1 (0.1)
US Condamine St Culvert (Burnt Bridge Creek)	10.0	10.1 (0.0)	10.0 (-0.1)
US Clearview Place Culvert (Brookvale Creek)	20.8	20.7 (-0.2)	21.0 (0.1)
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	32.6 (0.0)	32.5 (0.0)
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1	40.1 (0.0)	40.1 (-0.1)

Note: Bracketed value is change in peak flood level from base design conditions

The model simulation results show minor reductions in peak flood level (generally < 0.1m) for reduced hydraulic roughness in the lower catchment and main body of Manly Lagoon. The main areas affected are the steeper upper to mid catchment regions of the main tributary alignments. The decrease in roughness has minimal influence on inundation extents in overbank areas.

Similarly, minor increases in peak flood level in the lower catchment and main body of Manly Lagoon (generally < 0.1m) are simulated for the increased hydraulic roughness conditions applied in the sensitivity test. Again, the principal areas affected are steeper upper to mid catchment regions of the main tributary alignments with only minor changes to the flood inundation extents.

7.6.2 Structure Blockage

Structure blockages have the potential to substantially increase the magnitude and extent of property inundation through local increases in water level, redistribution of flows on the floodplain, and activation of additional flow paths. A sensitivity test on the design flood conditions has been undertaken to account for the potential for structure blockage. The following blockage assumptions were applied to structures across all watercourses for the 1% AEP catchment rainfall event (9 hour duration):

- 100% blockage for structures with a major diagonal opening width less than 6m;

- 25% bottom up blockage for structures with a major diagonal opening width greater than 6m. For bridge structures involving piers or bracings, the major diagonal length is defined as the clear diagonal opening between piers/bracings, not the width of the channel at the cross-section; and
- 100% blockage for handrails over structures where overtopping occurs.

The change in peak water levels with the assumed blockage conditions is summarised at key locations (generally corresponding to the structure locations) in Table 7-8. Mapping of the extents of the simulated afflux is included in Appendix B for the 1% AEP catchment rainfall event (9 hour duration). Table 7-8 shows the simulated peak flood level with no structure blockage, along with the change from the assumed structure blockage flood conditions shown in brackets.

Table 7-8 Peak 1% AEP Flood Levels for Structure Blockage Sensitivity Tests

Location	Peak Design Flood Level (m AHD)	
	Base 1% AEP Catchment	Blockage
US Queenscliff Bridge (Manly Lagoon)	2.8	3.0 (0.2)
US Pittwater Rd Bridge (Manly Lagoon)	3.0	3.1 (0.1)
Riverview Parade (Manly Lagoon)	3.0	3.1 (0.1)
US Kentwell Rd Culvert (Manly Lagoon)	3.1	3.1 (0.1)
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	3.2 (-0.1)
US Condamine St Culvert (Manly Creek)	4.8	5.4 (0.6)
DS Condamine St Culvert (Brookvale Creek)	6.0	5.9 (-0.1)
US Condamine St Culvert (Burnt Bridge Creek)	10.0	11.0 (1.0)
US Clearview Place Culvert (Brookvale Creek)	20.8	21.1 (0.3)
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	34.1 (1.6)
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1	40.8 (0.7)

Note: Bracketed value is change in peak flood level from base design conditions

As shown in Table 7-8 and the afflux mapping in Appendix A, the assumed blockage condition has minimal impact on flood conditions in the lower catchment and main body of Manly Lagoon. In this regard, the assumed blockage condition does not change the broader` flooding behaviour in the lower catchment. Some of the reductions in peak flood level under blockage scenarios are attributed to attenuation and redistribution of flows locally at the structure.

7.6.3 Lagoon Entrance Condition

The Manly Lagoon entrance condition is highly dynamic with potential for significant variation in the height of the entrance berm and subsequent impact on design flood behaviour. The catchment flood scenarios adopted a 1.4m AHD berm height at the entrance for the baseline conditions, representative of the current entrance management policy. Sensitivity tests on the berm condition have been undertaken for the 1% AEP catchment rainfall event (9 hour duration). These sensitivity tests provide for:

- A higher berm height of 2.5m AHD - this berm height is representative of the height to which the berm may build over a sustained period of relatively low catchment rainfall and high coastal storm activity (assumes no manual breakout of the Lagoon).
- A lower berm height of 0.0m AHD representative of generally open entrance condition.

Table 7-9 Peak 1% AEP Flood Levels for Lagoon Entrance Condition Sensitivity Tests

Location	Peak Design Flood Level (m AHD)		
	Base 1% AEP (1.4m Berm)	0.0m Berm	2.5m Berm
US Queenscliff Bridge (Manly Lagoon)	2.8	2.7 (-0.1)	3.0 (0.2)
US Pittwater Rd Bridge (Manly Lagoon)	3.0	2.8 (-0.1)	3.1 (0.2)
Riverview Parade (Manly Lagoon)	3.0	2.9 (-0.1)	3.2 (0.2)
US Kentwell Rd Culvert (Manly Lagoon)	3.1	3.0 (-0.1)	3.2 (0.2)
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	3.2 (-0.2)	3.6 (0.2)
US Condamine St Culvert (Manly Creek)	4.8	4.8 (0.0)	4.8 (0.0)
DS Condamine St Culvert (Brookvale Creek)	6.0	6.0 (0.0)	6.0 (0.0)
US Condamine St Culvert (Burnt Bridge Creek)	10.0	10.0 (0.0)	10.0 (0.0)
US Clearview Place Culvert (Brookvale Creek)	20.8	20.8 (0.0)	20.8 (0.0)
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	32.6 (0.0)	32.6 (0.0)
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1	40.1 (0.0)	40.1 (0.0)

Note: Bracketed value is change in peak flood level from standard design conditions

The entrance condition is shown to have some effect on peak flood levels, particularly around the Lagoon. In upstream areas where typical 1% AEP flood levels are in excess of 3.5m AHD, there is minimal influence on peak flood levels.

In the Lagoon area, it can be seen that higher berm levels equate to higher peak flood levels, however, the magnitude of the increase is somewhat limited by the expected scour throughout the flood event that naturally breaks open the berm.

7.6.4 Rainfall Losses

The hydrological model parameters adopted for the design floods were similar to those used in the hydrological model calibration and validation. For the initial and continuing rainfall losses, values of 10mm and 2.5mm/hr were used for pervious areas and 2mm and 0mm/hr for impervious areas. These are consistent with the recommended ranges for design event losses in AR&R (2001). Rainfall losses are to some degree dependent on antecedent catchment conditions which vary betweeb dry and wet conditions.

Sensitivity tests on the adopted rainfall losses have been undertaken for the 1% AEP catchment rainfall event (9 hour duration). These sensitivity tests provide for:

- Higher rainfall losses of 30mm initial loss and 2.5mm/hr continuing loss for previous surfaces; and
- Lower rainfall losses of 0mm initial loss and 0mm/hr continuing loss for previous surfaces

As shown in Table 7-9 and the afflux mapping in Appendix A, the assumed design rainfall losses only has minor impact on 1% AEP catchment flood conditions in the catchment.

Table 7-10 Peak 1% AEP Flood Levels for Design Rainfall Loss Sensitivity Tests

Location	Peak Design Flood Level (m AHD)		
	Base 1% AEP Catchment	Increased Losses	Decreased Losses
US Queenscliff Bridge (Manly Lagoon)	2.8	2.8 (0.0)	2.9 (0.0)
US Pittwater Rd Bridge (Manly Lagoon)	3.0	2.9 (0.0)	3.0 (0.0)
Riverview Parade (Manly Lagoon)	3.0	2.9 (0.0)	3.0 (0.0)
US Kentwell Rd Culvert (Manly Lagoon)	3.1	3.1 (0.0)	3.1 (0.0)
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	3.3 (0.0)	3.4 (0.0)
US Condamine St Culvert (Manly Creek)	4.8	4.8 (0.0)	4.8 (0.1)
DS Condamine St Culvert (Brookvale Creek)	6.0	6.0 (0.0)	6.0 (0.0)
US Condamine St Culvert (Burnt Bridge Creek)	10.0	10.0 (0.0)	10.1 (0.1)
US Clearview Place Culvert (Brookvale Creek)	20.8	20.8 (0.0)	20.8 (0.0)
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	32.6 (0.0)	32.6 (0.0)
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1	40.1 (0.0)	40.2 (0.1)

Note: Bracketed value is change in peak flood level from standard design conditions

7.7 Flood Planning Levels

Land use planning and development controls are key mechanisms by which Council can manage flood-affected areas within the study area. Such mechanisms will influence future development (and redevelopment) and therefore the benefits will accrue gradually over time. Without comprehensive floodplain planning, existing problems may be exacerbated and opportunities to reduce flood risks may be lost.

The flood planning level (FPL) is the level below which a Council places restrictions on development due to the hazard of flooding. Traditionally, floodplain planning has usually been based on the 1% AEP flood level + 0.5m freeboard for the purposes of applying floor level controls.

Climate change effects are expected to influence flood levels gradually over time, such that FPLs potentially need to accommodate higher flood level than existing conditions considering the expected lifespan of a development.

Council's adopted FPLs are specified in existing Development Control Plans. A graded set of FPLs are in place dependent on the nature of the development and the appropriate flood risk classification of the floodplain.

7.8 Model Uncertainties and Limitations

There are a number of inherent uncertainties and limitations with the modelling of environmental phenomena such as flooding. Some of the key considerations include:

- The dynamic nature of the entrance berm has a significant impact on flood levels within Manly Lagoon and the surrounding floodplain areas. The resultant flooding from catchment runoff of a given magnitude will vary depending on the entrance conditions at the onset of the event. The design conditions modelled are based on the assumption of a maximum berm height condition of 1.4m AHD in line with the existing entrance management policy.;
- The modelled flood behaviour is driven by the model geometry, derived primarily form the LiDAR dataset and channel cross section survey. Local topographic features that have not been captured by these datasets may have a local influence on flood behaviour and differ to that which has been modelled;
- The study is focused on mainstream flooding and key overland flow path. The stormwater drainage network as provided by Council survey data has been modelled;
- The land cover conditions in the catchment will change through time and changes in vegetation within the channel and on the floodplain may impact on the local flood conditions.

The flood study has established existing design flood conditions to provide the basis for subsequent floodplain risk management activities. Outcomes of the Floodplain Risk Management Study, which is the next stage of the floodplain risk management process, may provide for changes in adopted design flood levels particularly considering modifications to existing entrance management policies and implications of other potential climate change scenarios.

8 CLIMATE CHANGE ANALYSIS

In 2009, the NSW Government incorporated consideration of potential climate change impacts into relevant planning instruments. The NSW Sea Level Rise Policy Statement (DECCW, 2009) was prepared to support consistent adaptation to projected sea level rise impacts. The policy statement incorporates sea level rise planning benchmarks for use in assessing potential impacts of sea level rise in coastal areas, as well as in flood risk and coastal hazard assessments. The benchmarks are a projected rise in sea level, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100.

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 the majority of analysis and modelling tasks associated with this current Flood Study were completed 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 The Council's and BMT WBM that the potential impacts of sea level rise for the Manly Lagoon catchment were based on the best available information at hand during preparation of this report.

As discussed in Section 1.4.1, it was agreed between The Council's and BMT WBM that the sea level rise benchmarks from the 2009 NSW Sea level Rise Policy Statement be adopted based on the conclusion that it was the best available information at the time of preparation of this report.

Worsening coastal flooding impacts as a consequence of sea level rise in lowland areas such as around Manly Lagoon are of particular concern for the future. Regional climate change studies (e.g. CSIRO, 2004) indicate that aside from sea level rise, there may also be an increase in the maximum intensity of extreme rainfall events. This may include increased frequency, duration and height of flooding and consequently increased number of emergency evacuations and associated property and infrastructure damage.

The NSW Floodplain Development Manual (DIPNR, 2005) requires consideration of climate change in the preparation of Floodplain Risk Management Studies and Plans, with further guidance provided in:

- Floodplain Risk Management Guideline – Practical Consideration of Climate Change (DECC, 2007); and
- Flood Risk Management Guide – Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010).

Key elements of future climate change (e.g. sea level rise, rainfall intensity) have been incorporated into the assessment of future flooding conditions in the Manly Lagoon catchment for consideration in the ongoing floodplain risk management.

8.1 Potential Climate Change Impacts

The impacts of future climate change are likely to lead to a wide range of environmental responses in coastal lagoons such as Manly Lagoon. These are likely to manifest throughout the physical, chemical and ecological processes that drive local estuarine ecosystems.

The following changes in the physical characteristics of the Manly Lagoon system have potential influence on the flood behaviour of the system and implications for medium and long term floodplain management:

- Increase in ocean boundary water level – sea level projections provide for a direct increase in tidal and storm surge water level conditions;
- Increase in entrance berm height – typical entrance berm levels are expected to increase upward and move landward in response to sea level rise;
- Increase in initial Lagoon water level – linked to both the ocean water levels and berm heights; and
- Increase in rainfall intensity – the frequency and severity of extreme rainfall events is expected to increase.

The model configuration and assumptions adopted for each of these potential climate change impacts are discussed in the following sections.

8.1.1 Ocean Water Level

As discussed in Section 1.4.1, the sea level rise planning benchmarks provided in the NSW Sea Level Rise Policy Statement (DECCW, 2009) have been adopted for this Flood Study.

The benchmarks are a projected rise in sea level, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100 (DECCW, 2009). Based on these guidelines, design ocean boundary conditions were raised by 0.4 m and 0.9 m to assess the potential impact of sea level rise on flood behaviour in the Manly Lagoon catchment for the year 2050 and 2100 respectively.

The ocean water level boundary conditions for present day flood conditions were discussed in Section 6.2. The sea level rise allowances provide for direct increases in these ocean water levels. Table 8-1 presents a summary of adopted peak ocean water levels for a range of design events for existing water level conditions and the 2050 and 2100 sea level rise benchmarks.

Table 8-1 Design Peak Ocean Water Levels Incorporating Sea Level Rise

Event Magnitude	Water Level (m AHD)		
	Existing	2050 (+0.4 m)	2100 (+0.9 m)
20% AEP	1.90	2.30	2.80
5% AEP	2.25	2.65	3.15
2% AEP	2.45	2.85	3.35
1% AEP	2.60	3.00	3.50
0.5% AEP	2.75	3.15	3.65

8.1.2 Entrance Berm Conditions

A change in entrance berm processes is likely to result from the predicted sea level rise and changes to coastal storm intensity. From this change, a net upward shift in typical berm heights at the entrance may be expected, and therefore flood water levels will need to reach a higher level before inducing a natural breakout to the ocean (Haines and Thom, 2007). The entrance berm is also expected to shift landwards in association with sea level rise.

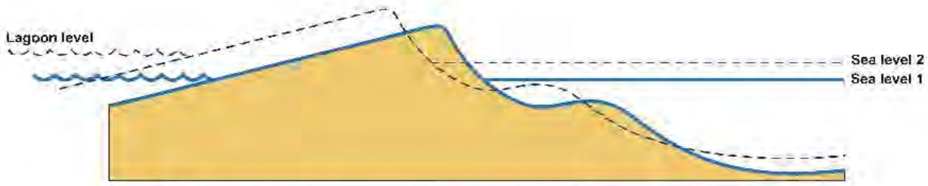


Figure 8-1 Shoreline response to increasing sea level (Hanslow *et al.*, 2000)

There are no government guidelines concerning the impact of future climatic change of entrance berm geometries.

The adopted berm height conditions for design events were discussed in Section 6.3. For catchment derived flooding, a shoaled entrance with the entrance berm set to a level of 1.4m AHD was adopted. The 1.4m AHD entrance berm level corresponds to the water level in the Lagoon that triggers a mechanical breakout to be initiated in line with the current entrance management policy.

For the purpose of this Study, a berm height increase of 0.4m and 0.9m has been adopted for the 2050 and 2100 benchmarks respectively. This increase has been applied to the adopted 1.4m AHD shoaled entrance condition adopted for existing conditions. This provides for a berm height of 1.8m AHD and 2.3m AHD for the 2050 and 2100 benchmarks respectively.

8.1.3 Initial Lagoon Water Levels

Typical initial water levels in the Lagoon are a function of the natural tidal variability and condition of the entrance channel. For catchment flooding conditions, a closed entrance condition has been simulated as typically providing for higher flood water level conditions. In periods of entrance closure, water levels in the Lagoon may build to a level of the order of 1.4m AHD before a mechanical opening is triggered. In line with the assumptions discussed above regarding increasing entrance berm levels with sea level rise, corresponding increases in initial Lagoon water levels have been adopted. Accordingly, initial Lagoon water levels of 1.8m AHD and 2.3m AHD have been adopted for the 2050 and 2100 benchmarks respectively.

For ocean derived flooding, an open entrance condition is assumed, such that Lagoon water levels are driven by the ocean tidal condition. Initial Lagoon water levels therefore reflect the relative ocean tide level at the start of the simulation period. For future flooding conditions, these levels incorporate the sea level rise allowances as discussed in Section 8.1.1.

8.1.4 Design Rainfall Intensity

Current research predicts that a likely outcome of future climatic change will be an increase in flood producing rainfall intensities. Climate Change in New South Wales (CSIRO, 2004) provides projected increases in 2.5% AEP 24h duration rainfall depths for Sydney Metropolitan catchments of up to 12% and 10%, for the years 2030 and 2070 respectively.

The NSW Government has also released a guideline (DECC, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. In line with this guidance note, additional tests incorporating 10%, 20% and 30% increases in design rainfall have been undertaken.

8.2 Climate Change Model Conditions

A range of design event simulations have been undertaken incorporating combinations of increases in ocean water levels, berm heights, initial Lagoon levels and rainfall intensities. A summary of the modelled scenarios for the 1% AEP design event condition is provided in Table 8-2.

Similar combinations have also been modelled for the nominal 5% AEP design event condition.

The modelled scenarios incorporate a full range of combinations of the impacts of:

- increases in rainfall intensity of 10% 20% and 30%; and
- sea level rise allowance of 0.4m and 0.9m.

In considering the sea level rise impacts, the modelled scenarios incorporate the appropriate increases in ocean water level, berm height and initial lagoon water levels (dependent on berm condition) as discussed in Sections 8.1.1, 8.1.2 and 8.1.3 respectively.

Table 8-2 Summary of Design Model Runs for Climate Change Considerations

Catchment Events
1% AEP 9-hour duration +10% rainfall increase (closed entrance)
1% AEP 9-hour duration +20% rainfall increase (closed entrance)
1% AEP 9-hour duration +30% rainfall increase (closed entrance)
1% AEP 9-hour duration +0.4m sea level rise (closed entrance)
1% AEP 9-hour duration +0.9m sea level rise (closed entrance)
1% AEP 9-hour duration +10% rainfall increase + 0.4m sea level rise (closed entrance)
1% AEP 9-hour duration + 20% rainfall increase + 0.4m sea level rise (closed entrance)
1% AEP 9-hour duration +30% rainfall increase + 0.4m sea level rise (closed entrance)
1% AEP 9-hour duration +10% rainfall increase + 0.9m sea level rise (closed entrance)
1% AEP 9-hour duration + 20% rainfall increase + 0.9m sea level rise (closed entrance)
1% AEP 9-hour duration +30% rainfall increase + 0.9m sea level rise (closed entrance)
Ocean Events
1% AEP ocean event + 0.4m sea level rise (open entrance)
1% AEP ocean event + 0.9m sea level rise (open entrance)
Coincident Events
1% AEP 9-hour duration +10% rainfall increase + 5% AEP ocean event (closed entrance)
1% AEP 9-hour duration +20% rainfall increase + 5% AEP ocean event (closed entrance)
1% AEP 9-hour duration +30% rainfall increase + 5% AEP ocean event (closed entrance)
1% AEP 9-hour duration + 5% AEP ocean event + 0.4m sea level rise (closed entrance)
1% AEP 9-hour duration + 5% AEP ocean event +0.9m sea level rise (closed entrance)
1% AEP 9-hour duration +10% rainfall increase + 5% AEP ocean event +0.4m sea level rise (closed entrance)
1% AEP 9-hour duration + 20% rainfall increase + 5% AEP ocean event + 0.4m sea level rise (closed entrance)
1% AEP 9-hour duration +30% rainfall increase + 5% AEP ocean event + 0.4m sea level rise (closed entrance)
1% AEP 9-hour duration +10% rainfall increase + 5% AEP ocean event + 0.9m sea level rise (closed entrance)
1% AEP 9-hour duration + 20% rainfall increase + 5% AEP ocean event + 0.9m sea level rise (closed entrance)
1% AEP 9-hour duration +30% rainfall increase + 5% AEP ocean event + 0.9m sea level rise (closed entrance)

As shown in Table 8-2, the impacts of the climate changes scenarios have been simulated for both catchment derived and ocean derived flooding conditions. Joint catchment and ocean flooding scenarios have also been simulated corresponding to the combinations assessed for existing conditions as discussed in Section 7.1.3.

As per the modelling of existing conditions, the climate change scenarios for catchment derived flooding use a closed berm condition, whilst for ocean derived events an open entrance condition is adopted. As discussed, these entrance conditions provide for the worst case condition for each of the flooding mechanisms. Given that catchment derived flooding is the dominant mechanism in terms of peak flood levels for the broader Manly Lagoon catchment, a closed berm condition has also been adopted for the simulation of the joint catchment and ocean event scenarios.

8.3 Climate Change Results

The potential impacts of future climate change were considered for the 1% AEP design event scenarios as defined in Table 8-2. The impact of potential climate change scenarios on the standard design flood condition is presented in Appendix A as a series of maps showing increase in peak flood inundation extents from the baseline (existing) conditions. Further discussion on relative increases from existing peak flood levels is provided hereunder.

The modelled peak flood levels for the catchment derived flooding considering increases in design rainfall and sea level in isolation are presented Table 8-3. The selected reporting locations were previously presented in Figure 7-1. The most significant climate change impact for Manly Lagoon will be from the predicted increase in berm height, which is in line with the 0.4m and 0.9m sea level rise benchmarks for 2050 and 2100. This impact can be observed in Table 8-3 for the locations typically within or around the foreshore of the Lagoon. Typical increases in flood level around the Lagoon are 0.2m and 0.5m for the simulated 2050 and 2100 berm height levels. The berm height conditions only affect the lower catchment, with upstream locations along the tributary channels unaffected by berm height conditions.

The upstream areas are more so impacted by increases in rainfall intensities. For increases in rainfall intensity from 10% up to 30%, peak flood level increases of between 0.2m to 0.4m are typical, depending on the nature of the channel or creek section. These increases are of similar order when comparing the difference between the existing 1% and 0.5% AEP peak flood levels as reported in Table 7-1.

Table 8-4 shows the combined impacts of increased rainfall intensity and sea level rise for various combinations. Broadly speaking, the impact in the lower Manly Lagoon catchment is a summation of the the individual influence of increased rainfall and sea level rise as shown in Table 8-3. For example, a 20% 20% increase in rainfall provides for approximately a 0.2m increase in peak Lagoon flood levels, whilst a 0.4m whilst a 0.4m sea level rise provides for a similar 0.2m increase. The combined impact of 20% rainfall increase increase and 0.4m sea levels rise on the existing 1% AEP catchment flood level as shown in

Table 8-4 is generally around 0.4m. In the upper tributary areas, beyond the influence of the general Lagoon flooding height, there is no impact associated with sea level rise, such that the combined scenario is representative of the impact of rainfall increase only. The combined 30% increase in rainfall and 0.9m sea level rise represents the most severe of the climate change scenarios modelled. The most significant impacts are for the broader Lagoon area and accordingly for property located on these lower foreshore areas. For this scenario, increases of up to 0.7m would be realised above the existing 1% AEP design catchment flood level.

Table 8-3 Modelled Peak Flood Levels for Catchment Derived Climate Change Events

Location	Modelled Peak Flood Level (m AHD)					
	Existing 1% AEP	+ 10% Rainfall	+ 20% Rainfall	+30% Rainfall	+ 0.4m SLR	+ 0.9m SLR
US Queenscliff Bridge (Manly Lagoon)	2.8	2.9 (0.1)	3.0 (0.2)	3.2 (0.3)	2.9 (0.0)	3.0 (0.2)
US Pittwater Rd Bridge (Manly Lagoon)	3.0	3.0 (0.1)	3.2 (0.2)	3.3 (0.3)	3.0 (0.1)	3.1 (0.2)
Riverview Parade (Manly Lagoon)	3.0	3.1 (0.1)	3.2 (0.2)	3.3 (0.3)	3.0 (0.1)	3.1 (0.2)
US Kentwell Rd Culvert (Manly Lagoon)	3.1	3.2 (0.1)	3.3 (0.2)	3.4 (0.3)	3.1 (0.0)	3.2 (0.1)
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	3.4 (0.1)	3.6 (0.2)	3.7 (0.3)	3.4 (0.1)	3.6 (0.2)
US Condamine St Culvert (Manly Creek)	4.8	4.9 (0.1)	5.1 (0.3)	5.2 (0.4)	4.8 (0.0)	4.8 (0.0)
DS Condamine St Culvert (Brookvale Creek)	6.0	6.1 (0.0)	6.1 (0.1)	6.2 (0.1)	6.0 (0.0)	6.0 (0.0)
US Condamine St Culvert (Burnt Bridge Creek)	10.0	10.5 (0.4)	10.8 (0.7)	10.9 (0.9)	10.0 (0.0)	10.0 (0.0)
US Clearview Place Culvert (Brookvale Creek)	20.8	21.0 (0.1)	21.1 (0.2)	21.2 (0.4)	20.8 (0.0)	20.8 (0.0)
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	32.8 (0.2)	32.9 (0.3)	33.1 (0.5)	32.6 (0.0)	32.6 (0.0)
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1	40.4 (0.3)	40.6 (0.4)	40.7 (0.5)	40.1 (0.0)	40.1 (0.0)

Note: Bracketed value is change in peak flood level from standard design conditions

Table 8-3 and

Table 8-4 show the sensitivity of the 1% AEP design catchment flood condition to potential climate change scenarios. The relative impacts on other design event magnitudes show similar characteristic in terms of increases in peak flood levels and area of influence. Additional inundation mapping for the 5% AEP design events under various climate change scenarios is included in Appendix A.

The climate change impacts on ocean derived flooding conditions are summarised in Table 8-5. These simulations are for a pure ocean flooding condition without additional rainfall inputs from the catchment. Accordingly, only locations within the Lagoon foreshores are shown with upper catchment locations excluded. As with ocean flooding results for existing conditions, there is little attenuation of the surge through the Manly Lagoon given the relatively limited storage volume in the Lagoon system. Peak flood levels in the Lagoon system therefore generally reflect the peak ocean level.

Table 8-4 Modelled Peak Flood Levels for Catchment Derived Climate Change Events

Location	Modelled Peak Flood Level (m AHD)						
	Existing 1% AEP	+0.4m SLR + 10% Rainfall	+0.4m SLR + 20% Rainfall	+0.4m SLR + 30% Rainfall	+0.9m SLR + 10% Rainfall	+0.9m SLR + 20% Rainfall	+0.9m SLR + 30% Rainfall
US Queenscliff Bridge (Manly Lagoon)	2.8	3.0 (0.1)	3.1 (0.3)	3.2 (0.4)	3.1 (0.2)	3.3 (0.4)	3.4 (0.5)
US Pittwater Rd Bridge (Manly Lagoon)	3.0	3.1 (0.2)	3.2 (0.3)	3.3 (0.4)	3.2 (0.2)	3.4 (0.4)	3.5 (0.5)
Riverview Parade (Manly Lagoon)	3.0	3.1 (0.2)	3.2 (0.3)	3.3 (0.4)	3.2 (0.2)	3.4 (0.4)	3.5 (0.5)
US Kentwell Rd Culvert (Manly Lagoon)	3.1	3.2 (0.1)	3.3 (0.2)	3.4 (0.3)	3.3 (0.2)	3.4 (0.3)	3.5 (0.4)
US Manly Golf Course Floodway (under Kenneth Rd)	3.4	3.5 (0.2)	3.7 (0.3)	3.7 (0.4)	3.6 (0.3)	3.8 (0.4)	3.7 (0.4)
US Condamine St Culvert (Manly Creek)	4.8	4.9 (0.1)	5.1 (0.3)	5.2 (0.4)	4.9 (0.1)	5.1 (0.3)	5.2 (0.4)
DS Condamine St Culvert (Brookvale Creek)	6.0	6.1 (0.0)	6.1 (0.1)	6.2 (0.2)	6.1 (0.0)	6.1 (0.1)	6.2 (0.2)
US Condamine St Culvert (Burnt Bridge Creek)	10.0	10.5 (0.4)	10.8 (0.7)	10.9 (0.9)	10.5 (0.5)	10.8 (0.7)	10.9 (0.9)
US Clearview Place Culvert (Brookvale Creek)	20.8	21.0 (0.1)	21.1 (0.2)	21.2 (0.4)	21.0 (0.1)	21.1 (0.2)	21.2 (0.4)
US Burnt Bridge Creek Deviation Culvert (Burnt Bridge Creek)	32.6	32.7 (0.2)	32.9 (0.3)	33.1 (0.5)	32.8 (0.2)	32.9 (0.3)	33.1 (0.5)
US Bangaroo St Culvert (Burnt Bridge Creek)	40.1	40.4 (0.3)	40.6 (0.4)	40.7 (0.5)	40.4 (0.3)	40.6 (0.4)	40.7 (0.6)

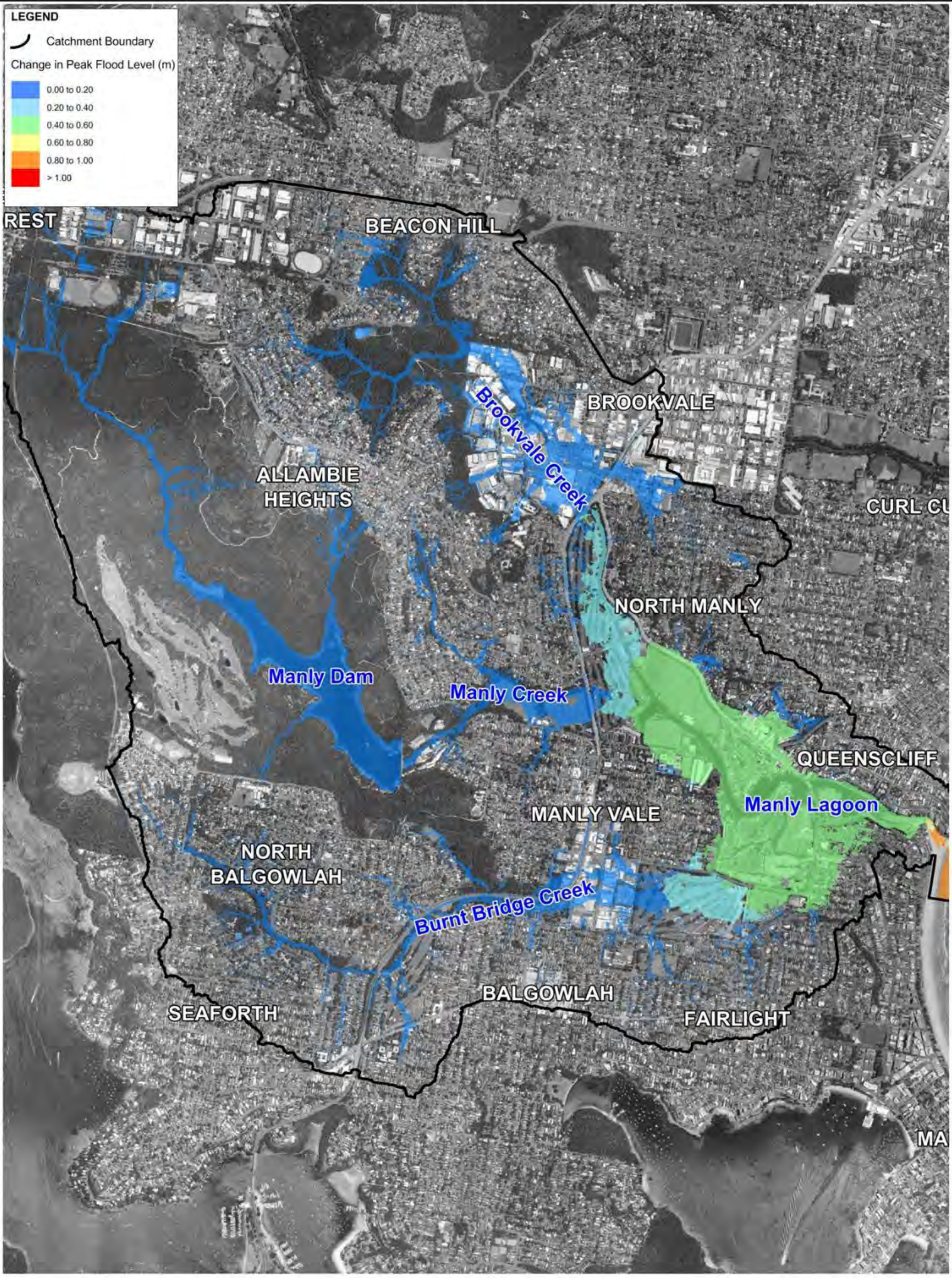
Note: Bracketed value is change in peak flood level from standard design conditions

Table 8-5 Modelled Peak Flood Levels for Ocean Derived Climate Change Events

Location	Modelled Peak Flood Level (m AHD)		
	Existing 1% AEP	1% AEP + 2050 SLR (+0.4 m)	1% AEP + 2100 SLR (+0.9 m)
US Queenscliff Bridge (Manly Lagoon)	2.5	2.9	3.4
US Pittwater Rd Bridge (Manly Lagoon)	2.5	2.9	3.4
Riverview Parade (Manly Lagoon)	2.5	2.9	3.4
US Kentwell Rd Culvert (Manly Lagoon)	2.5	2.9	3.4
US Manly Golf Course Floodway (under Kenneth Rd)	2.6	2.9	3.4
US Condamine St Culvert (Manly Creek)	2.6	2.9	3.4

Comparing the peak levels for catchment and ocean derived flooding, the catchment flooding scenarios remain the dominant flooding mechanism for the study area.

The results of the climate change analysis highlight the sensitivity of the peak flood level conditions in Manly Lagoon to potential impacts of climate change. Future planning and floodplain risk management in the catchment will need to take due consideration of the increasing flood risk under possible future climate conditions. The most significant impacts of climate change are associated with sea level rise and the corresponding increases in ocean water levels and entrance berm heights. Figure 8-2 shows the increase in flood level under a 0.9m sea level rise from the existing peak 1% AEP catchment flood level. The area of influence is significant, encompassing the entire Lagoon and foreshore areas and extending a short distance up the tributary channels.



Title:
Peak 1% AEP Flood Level Increase with 0.9m Sea Level Rise

Figure: 8-2

Rev: 0

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N 0 0.5 1km Approx. Scale

BMT WBM www.bmtwbm.com.au

Filepath : K:\N2069_Manly_Lagoon_Flood_Study\MI\Workspaces\Sensitivity_1%AEP_0_9m_SLR.wor

9 CONCLUSIONS

The objective of the Flood Study has been to undertake a detailed flooding assessment of the Manly Lagoon catchment and establish models as necessary for accurate flood level prediction. Central to this is the development of appropriate hydrological and hydraulic models.

The study program provided for a staged approach in undertaking the Flood Study, incorporating.

STAGE 1 – Data Compilation and Initial Community Consultation

STAGE 2 – Hydrological modelling

STAGE 3 – Hydraulic modelling

STAGE 4 – Climate Change Analysis

STAGE 5 – Draft Flood Study and Public Exhibition

Interim reports at these stages were produced within the study duration, culminating in the current STAGE 5 document. The Draft Flood Study has been produced for Public Exhibition, from which comment will be invited form the public.

The Stage 5 report provides full documentation of the Flood Study (including previous stages) summarising the stages completed to date. In completing the flood study, the following activities have been undertaken:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking of a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Probable Maximum Flood (PMF), 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment derived flooding and the 0.5%, 1%, 2%, 5%, 10% and 20% AEP events for ocean derived flooding; and
- Assessment of the potential impact of climate change using the latest guidelines.

The key study outputs include a full suite of design flood mapping incorporating peak flood inundation extent, flood depth, flood velocity and flood hazard for the full range of return period magnitudes assessed. This report and the key mapping outputs help to define the flood behaviour in the Manly Lagoon catchment and establish the basis for subsequent floodplain management activities.

Provided below is a summary of the key findings of the Flood Study, in particular some of the important considerations for future floodplain risk management in the catchment:

- The design flood conditions documented in the report typically provide for a small increase in previously adopted design flood conditions for Manly Lagoon. The main contributing factor to this change is the way the entrance condition has been modelled. In addition to advances in the software to simulate entrance breakout response, the initial conditions in respect to berm elevations and initial water levels in the Lagoon have been represented more conservatively in the current study.

- Longer duration events (6-9 hours) typically provide for the worst case flooding conditions in Manly Lagoon. With the Lagoon waterbody providing flood storage, events of longer duration are required to generate sufficient flood runoff volumes from the catchment to elevate Lagoon water levels. In the lower reaches of all the tributary catchments, flood levels are dominated by the Lagoon flooding conditions. The peak flood water level in the Lagoon extends a significant distance up the tributary channels. In the upper reaches of the tributary catchments, shorter duration events of the order of 2-hours provide the critical flood condition in terms of peak flood water level.

- The rise in flood water levels can be relatively fast from the catchment's response to rainfall. Even for the longer duration events providing for the highest peak flood water levels in the Lagoon, the main period of rise in Lagoon water level can occur over a few hours. The April 1998 flood event (used for model calibration in the current study) is an example of such a response in the catchment. Flood levels in the tributary catchments may also rise significantly faster owing to the shorter critical durations in these catchments. This potentially rapid inundation has implications for flood warning and emergency response, particularly in flood situations where property and access roads may be quickly inundated.

- Catchment derived flooding events represent the dominant flooding mechanism in Manly Lagoon. Whilst some ocean flooding scenarios will provide for inundation of some foreshore areas, the extent and severity of flooding is significantly less than the corresponding catchment derived event magnitude. The entrance condition has some influence on catchment flood behaviour with higher entrance berm levels providing for higher peak flood levels. The existing entrance management policy provides for manual breakout of the Lagoon entrance at defined trigger levels in preparation for imminent flooding. Irrespective of the successful implementation of a manual entrance breakout, significant flood inundation may be expected during major catchment flood events.

- There are a number of areas within the Manly Lagoon catchment which represent the most significant flood risk exposure to existing property. The worst affected areas are typically in the lower parts of the catchment and most severely impacted on by major flooding in Manly Lagoon. These areas include the foreshore areas of the Lagoon around Riverview Parade. Much of the lower floodplain area is however occupied by park lands / golf courses such that flood risk exposure of existing property is limited. Elsewhere, the Warringah Mall and Balgowlah Industrial Estate are located on the alignments of Brookvale Creek and Burnt Bridge Creek respectively. When drainage system capacities in these areas are exceeded, there is potential for overland flow through these areas.

- Peak design flood water levels are expected to progressively increase as the impacts of climate change manifest. For the Manly Lagoon catchment, potential sea level rise will provide for a worsening of existing flood conditions through higher ocean water levels (tide and storm surge), higher entrance berm and higher initial water levels in the Lagoon. Robust land use planning and development policies will be required to ensure future flood risks are not unduly exacerbated in light of predicted flood behaviour under potential climate change scenarios.

Council's existing entrance management policy is to open the entrance at a defined trigger water level (currently 1.4m AHD). With potential sea level rise, normal tide levels in the Lagoon will approach and eventually exceed the current trigger levels. Future openings would need to be at significantly higher trigger levels to be effective. Low-lying land currently impacted by flooding may also be subject to regular (or permanent) tidal inundation at some time in the future.

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APPENDIX A: DESIGN FLOOD MAPPING

APPENDIX B: COMMUNITY CONSULTATION MATERIAL

- Media Release
- Manly Daily Advertisement
- Community Newsletter
- Community Questionnaire

Media Release

August , 2011

Flood Studies for Narrabeen and Manly Lagoons

Warringah Council is seeking the community's assistance with its flood studies for Manly and Narrabeen Lagoon catchments.

"If you have information or photos of flooding around these lagoons or in their catchments, we would love to hear from you," said Warringah Mayor Michael Regan.

Warringah Council, in partnership with Manly and Pittwater Councils, is undertaking detailed flood studies of the Manly and Narrabeen Lagoon catchments to improve our understanding of flood behaviour and identify problem areas.

The aim of the studies is to:

- define existing flood behaviour
- help identify flooding problem areas in Manly and Narrabeen Lagoon catchments
- assess the impacts of climate change

The studies will also identify the impact sea level rise and rainfall intensity will have on the flood behaviour of the catchments.

"The studies will help improve council's planning and management, such as setting flood levels for development control and improving flood emergency responses.

"You can help by posting information and photos of flooding on the websites set up specifically for the Narrabeen Lagoon and Manly Lagoon flood studies," said Mayor Regan.

For more information visit warringah.nsw.gov.au

Information provided is strictly confidential and will only be used for the study.

For more information please contact the **Communications Team**
on 9942 2221 or media@warringah.nsw.gov.au

MANLY DAILY ADVERTISEMENT

Manly Lagoon Flood Study

Community Newsletter September 2011

What is the study about?

Warringah and Manly Councils are carrying out a flood study to understand flood risks in the Manly Lagoon catchment.

This includes the areas draining to Manly Lagoon covering parts of Frenchs Forest, Beacon Hill, Allambie Heights, North Balgowlah, Balgowlah, Fairlight, Manly Vale, Brookvale, North Manly and Queenscliff.

This study will update previous studies on the individual streams and provide a holistic assessment of flooding within the catchment. The study is being prepared to meet the objectives of the NSW State Government's Flood Policy.

Who is responsible?

Warringah Council will administer the study with assistance from Manly Council.

The Manly Lagoon Catchment Coordinating Committee will oversee the study, providing regular input and feedback on key outcomes. The Committee has a broad representation including Councillors, Council Staff, State Government Department representatives, stakeholder groups and community representatives.

BMT WBM, an independent company specialising in flooding and floodplain risk management, will undertake the study.

The NSW Office of Environment and Heritage is providing financial and technical assistance.

Potential Flood Risks

Flooding in Manly Lagoon comes from three general sources: significant catchment rainfall, oceanic inundation (tide and storm surge) and low-level, persistent flooding from backed up lake water when the lake entrance is closed.

The Flood Study will assess flooding behaviour in the catchment to identify the critical or worst case flood conditions for a range of flood events for both catchment and ocean flooding, including local overland flooding. Overland flows are typical in urban environments where it is not feasible to design stormwater drainage to capture very large and infrequent flood events.

For different locations within the catchment, and for different size flood events, the dominant flooding mechanism can vary, being either catchment rainfall or ocean flooding.

The condition of the entrance may have a significant influence on flood behaviour in Manly Lagoon. For catchment flooding, an effective open entrance provides for lower flood levels in comparison to a heavily shoaled or closed entrance. However, generally for ocean flooding, an open entrance condition will provide worst case conditions, through greater penetration of ocean water into the estuary under storm surge (ocean flooding) conditions.

As part of the current study, we are investigating a range of entrance conditions, both open and in various states of closure to assess the impact on flooding (under current conditions and future conditions considering potential sea level rise). Accordingly there will be some quantification of potential changes in flood conditions for various entrance states for both catchment and ocean flooding. From the floodplain risk management perspective, we need to look at a range of events from frequent "nuisance" type flooding to extreme events with significant inundation and high flood risk exposure of property and people.

Warringah Council

BMT WBM

Climate Change

The primary impacts of climate change in coastal areas are likely to result from sea level rise, which, coupled with storms, may lead to increased coastal erosion, tidal inundation and flooding.

The NSW Government recently adopted sea level rise planning benchmarks to ensure consistent consideration of sea level rise in coastal areas of NSW. These planning benchmarks are an increase above 1990 mean sea levels of 40cm by 2050 and 90cm by 2100.

For Manly Lagoon, rising sea level is expected to increase the frequency, severity and duration of flooding. This is particularly the case when the entrance is open, with potentially more ocean water flowing through the entrance and into the main body of the Lagoon.

Projected sea level rise will also result in higher sand levels at the entrance when it is closed. This means that lake levels will need to be even higher in the future in order to initiate effective break-out channels.

Another potential impact of climate change to be investigated is an increase in design rainfall intensities, which may result in increased flood flows and volumes in the catchment.

During the course of the study, the changes to flood inundation patterns under climate change scenarios will be identified to determine the increased flood risk.

Key Study Outputs

The main objective of the study is to characterise the flooding behaviour in the catchment detailing appropriate flood water level, depth and velocity distributions across the floodplain for historical and hypothetical flood event conditions.

By assessing a range of flood magnitudes, both the severity and frequency of potential flooding for individual properties can be ascertained.

Detailed computer models are developed specifically for the catchment to simulate flood behaviour. Historical flood information such as rainfall depths, peak water levels, flooded property details etc, are used to ensure the computer models are representative of the real catchment behaviour.

Flood maps across the catchment will be produced using the model results which will show the predicted extent of flooding .

The flood study results will be used to provide more effective flood planning in the catchment and will assist Councils in:

•Setting appropriate levels for development control;

•Identifying potential works to reduce existing flooding; and

•Improving flood emergency response and recovery.

Low-flow pipes at channel entrance

Artificial entrance opening (March 2000)

Community input

Community involvement in managing flood risks is essential to improve the decision making process, to identify local concerns and values, and to inform the community about the consequences of flooding and potential management options. The success of the flood planning in the Manly Lagoon catchment hinges on the community's input and acceptance of the proposals.

There are a number of ways you can be involved in the study:

•Please take a few minutes of your time to complete and return the questionnaire. This will greatly assist in collating people's knowledge and experience about previous flooding history and existing flood problem areas.

•A community information session is planned at a later stage following assessment of available floodplain management options and to collect people's ideas and opinions before coming up with the recommended plan.

•A website has been established to keep the community informed on the study progress. The website has further information on flooding in the Manly Lagoon catchment and will be updated throughout the study as new information becomes available. Community members will also be able to post their views and comments on the website so they can be considered during the course of the study.

Study timetable

Comprehensive flood studies of this nature take some time to complete, incorporating detailed technical analysis, community consultation activities, study documentation and review processes.

Set out below is an indicative timetable which the project will follow, with key project stages/milestones and their proposed completion dates.

STAGE 1 – Data Compilation and Initial Community Consultation

Completion by September 2011

STAGE 2 – Hydrological modelling

Completion by December 2011

STAGE 3 – Hydraulic modelling

Completion by July 2012

STAGE 4 – Climate Change Analysis

Completion by December 2012

STAGE 5 – Draft Flood Study and Public Exhibition

Completion by January 2013

The completion of the study will see the adoption by Council of the Final Flood Study Report following appropriate review and feedback from stakeholders.

Manly Lagoon entrance channel

Want more information?

For more information about the Manly Lagoon Flood Study , please contact:

Warringah Council
Ms Deborah Millener
Floodplain Management Officer
Ph 9942 2111

BMT WBM (Consultant)
Mr Darren Lyons
Project Manager
Ph 4940 8882

Website:
http://gis.wbmpl.com.au/ManlyLagoon/

Entrance channel (20th March 2011)

Nolans Reserve off Riverview Pde (20th March 2011)

Important Terms

Catchment flooding: is the inundation of land due to significant rainfall in the catchment. The runoff generated from the catchment flows into local creek systems and eventually into Manly Lagoon.

Overland flooding: is the inundation of land from water flowing to a water source (e.g. creek, lagoon). This may be along roadways and gutters, or natural depressions/low points and gully lines that form the drainage path.

Ocean flooding: is the inundation of land by sea water and results from one or a combination of storm surge, wave set-up and tidal conditions.

Low-level persistent flooding: is the inundation of land due to elevated lake levels in periods of entrance closure, with lake water level fluctuations due to local catchment rainfall and lake evaporation.

ICOLLs: Intermittently Closed and Open Lakes and Lagoons (such as Manly Lagoon) are separated from the ocean by a sand beach barrier or berm. This entrance barrier forms and breaks down depending on the movement and redistribution of sand and sediments by waves, tides, flood flows and winds. ICOLLs open and close to the ocean ***naturally*** in a constant but ***irregular*** cycle.

Natural breakout: Following heavy rainfall, water levels in the ICOLL rise and may eventually spill over the entrance sand berm and with sufficient force can scour an entrance channel through the beach and reopen the ICOLL to the ocean.

Artificial opening: Artificial breaching of the entrance barrier is undertaken to 'drain' the ICOLL to the ocean and lower water levels to relieve flooding of foreshore development and infrastructure or avoid the likely threat of flooding which would occur before the ICOLL entrance opens naturally.

Manly Lagoon Flood Study
Community Questionnaire September 2011

Your views and experiences are important to the study

Warringah Council (in partnership with Manly Council) is undertaking a detailed flood study of the Manly Lagoon catchment to define the existing flood behaviour and help identify flooding problem areas. The study will establish the basis for subsequent floodplain management activities to improve flood planning and management, such as setting design flood levels for development control, managing potential climate change impacts and improving flood emergency response.

We are seeking the community's help by collecting information on any flooding or drainage problems that you may have experienced in the past. Please take a minute or two to read through these questions and provide responses wherever you can. Please return this form to Warringah Council in the enclosed envelope (no stamp required). All information provided is confidential and used only for the purposes of the study.

Contact and Property Details

Name:..

Address:..

Phone or email:...

Please tick your type of property :

☐ House ☐ Unit/Flat/Apartment

☐ Business ☐ Other (please specify)

....

How long have you been at this property?

.... Years

Please keep me informed on study progress?

☐ Yes ☐ No

Previous Flooding Experience

Have you ever experienced flooding at this property?

☐ Yes ☐ No

If yes, what dates or years did this happen?

....

....

Previous Flooding Experience

Are you able to indicate the depth that flood waters reached on your property or elsewhere such as roads?

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A map is provided on the back, please mark up your property or known flooding areas. Additional space is provided to add other comments.

Do you think your property could be flooded in the future?

☐ Yes ☐ No

Photographs and Video

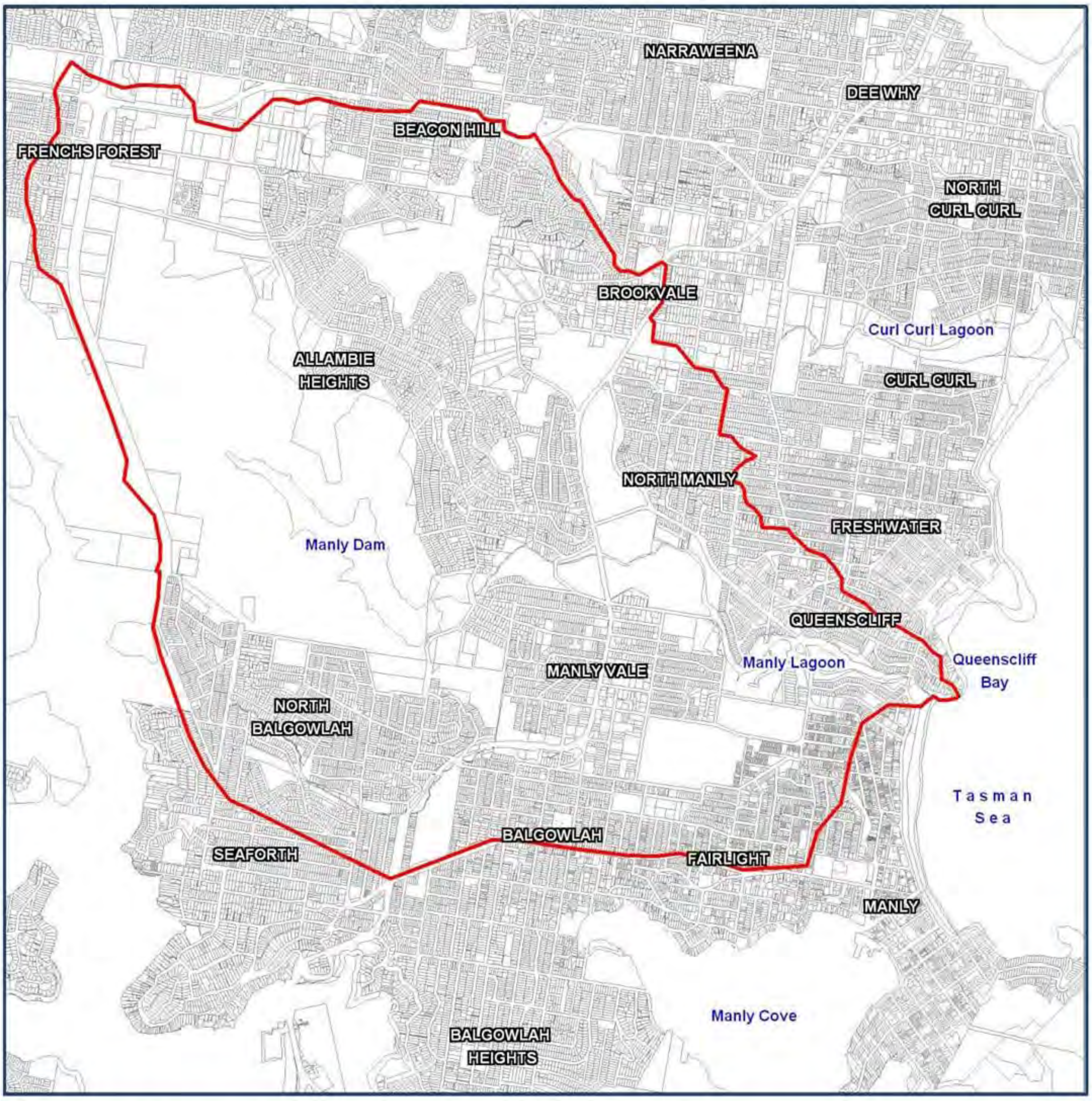
Do you have any photographs or video of flooding that you are willing to share with Council?

☐ Yes ☐ No

Photographs and video can be returned with the questionnaire or emailed to:

Darren.Lyons@bmtwbm.com.au

BMT WBM Warringah Council Manly Council



Please provide any additional comments or information that you think will help the study

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THANK YOU FOR YOUR ASSISTANCE IN COMPLETING THE SURVEY. PLEASE PROVIDE ANY ADDTIONAL INFORMATION YOU FEEL IS RELEVANT TO THE STUDY