Lake Illawarra, Mt Warrigal and Oak Flats Flood Study

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Synopsis:	**Final draft report for the Lake Illawarra, Mt Warrigal and Oak Flats Flood Study. The report covers the data collection process, community consultation, development of computer models, establishment of design flood behaviour and flood mapping.**	

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Executive Summary

Introduction

The Oak Flats, Mt Warrigal and Lake Illawarra Flood Study has been prepared for Shellharbour City Council (Council) to define the existing flood behaviour in the study catchments and establish the basis for subsequent floodplain management activities.

The primary objective of the Flood Study is to define the flood behaviour within the study area through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

Catchment Description

The catchment is fully developed and comprises predominantly low-density housing with pockets of commercial development. There are large open spaces within the catchment including Shane Lee Field, Oak Park and the Howard Fowles Sports Oval.

The catchment covers an area of approximately 7km^2 and drains into Lake Illawarra at various locations via the trunk drainage system, the largest of which discharges to Oak Park downstream of the Shellharbour City Centre. The trunk drainage network is connected to Council's minor stormwater drainage system which comprises; pipes, culverts and pits. There are a number of natural creeks and engineered swales which act as receiving waterways prior to entering Lake Illawarra.

The topography within the Lake Illawarra, Mt Warrigal and Oak Flats catchments varies from steep surface slopes in excess of 20% at Mt Warrigal to the near flat areas of Lake Illawarra and other shoreline locations. The catchment therefore has regions where surface water runoff within the road network has high velocity with shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points and flow velocities will be lower. The lower reaches of the catchment are potentially affected by elevated water levels within Lake Illawarra, in particular the suburb of Lake Illawarra.

Historical Flooding

There is no surveyed data of historic flood levels available for this study area. Model calibration and validation primarily relied upon anecdotal reports of flooding from the community, Council records and photographs of flood behaviour. Photographs cannot be assumed to record the peak flood behaviour, however, they are important for identifying flooding hotspots.

Model Development

Development of hydrologic and hydraulic models has been undertaken to simulate flood conditions in the catchments. The hydrological and hydraulic model was developed using TUFLOW two-dimensional (2D) software developed by BMT. The hydrological model provides for the simulation of the rainfall-runoff process using the catchment characteristics of the study area and historical and design rainfall data. The hydraulic model, simulates flood depths, extents and velocities in the study area. The 2D modelling approach is suited to model the complex interaction between channels and floodplains and converging and diverging of flows through structures and urban environments.

The floodplain topography is defined using a digital elevation model (DEM) derived from topographic, bathymetric and topographic survey data provided by Council.

Model Calibration and Validation

The selection of suitable historical events for calibration of computer models is largely dependent on available 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 event magnitudes to be considered.

Through consultation with Council a set of flood events were identified as being suitable for use in the model calibration and validation process. These are events of a reasonable flood magnitude, for which there are observed flood data available for comparison with the model performance. The principal event selected for model calibration was the March 2011 event, as this is the flood event with the most intense rainfall of recent years.

The November 2013 and March 2014 flood events have been selected for model validation. The November 2013 event was almost as intense as the March 2011 storm, but the March 2011 event had a greater total rainfall. It is therefore the largest recent flood event in the study area catchments in recent memory. The November 2013 and March 2014 flood events were used in model validation.

To validate the use of the rainfall-on-grid methodology, Watershed Boundary Network Modelling (WBNM) was undertaken on the Oakey Creek catchment, producing a favourable comparison.

Design Event Modelling and Output

The developed models have been applied to derive design flood conditions within the study catchments. A range of storm durations using the 2016 AR&R guidelines, were modelled in order to identify the critical storm duration for design event flooding in the catchment.

A range of design flood conditions were modelled. The simulated design events included the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF event. The model results for the design events considered have been presented in Appendix A. The flood data presented includes design flood inundation, peak flood water levels and depths.

Hydraulic categories (floodway, flood fringe and flood storage) and provisional flood hazard categories have been mapped for flood affected areas within the catchment.

Sensitivity Testing

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

- Hydraulic roughness;
- Stormwater drainage blockages;
- Rainfall losses;
- Downstream boundary

Climate Change

The potential for climate change impacts is now a key consideration for floodplain management. 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);
- Flood Risk Management Guide – Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010); and
- Australian Rainfall and Runoff: A Guide to Flood Estimation (Ball et al, 2016)

Key elements of future climate change (e.g. sea level rise, rainfall intensity) are therefore important considerations in the ongoing floodplain risk management.

In line with the guidance above, and several more recent revelations, additional tests were undertaken incorporating a 10% and a 20% increase to design rainfall in addition to an elevated tailwater condition in Lake Illawarra of 0.4 m and 0.9 m.

Flood Risks

Flooding problem areas across the study area can be isolated to three main regions, being Oakey Creek, the Lake Illawarra foreshore and the suburb of Lake Illawarra. These regions are summarised below, with specific flood areas listed beneath:

Oakey Creek:

- Properties located at the upstream side of the intersection of The Esplanade and Oakey Creek;
- Properties located on the eastern side of Leamington Road from Link Road to The Esplanade;
- Properties located upstream of the Oak Flats Bowling and Recreation Club between Kingston Street, Lake Entrance Road and New Lake Entrance Road;
- Properties located on an overland flow path running from the corner of Gordon Avenue and Marlin Road via Devonshire Crescent;
- The rear of properties located along Timbs Road and Devonshire Crescent adjacent the main tributary of Oakey Creek;
- Properties located along Birra Drive and Jilba Place; and
- Commercial properties located downstream of the Shellharbour City Centre Basin adjacent the low-point in New Lake Entrance Road.

Lake Foreshore Areas

- The lake frontage properties along Horsley Road, Newton Crescent, The Boulevarde, The Esplanade and Reddall Parade;

Lake Illawarra (suburb):

- The properties east of Shellharbour Road, bound by Peterborough Avenue to the south, View Street to the east, and Pur Pur Avenue to the north;
- The properties east of Shellharbour Road, bound by Reddall Parade and Pur Pur Avenue;
- The properties either side of Addison Avenue and Pur Pur Avenue located to the west of Shellharbour Road;
- The properties located at the low-point in Girraween Avenue adjacent Howard Fowls Oval reserve; and
- The properties either side of Kotari Parade and Corona Avenue.

Conclusions

The primary objective of the study was to undertake a detailed flood study of the Oak Flats, Mt Warrigal and Lake Illawarra catchments and to establish models as necessary for design flood level prediction

In completing the flood study, the following activities were undertaken:

- Compilation and review of existing information pertinent to the study;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Calibration of the developed models using the available flood data, including the recent events of 2011, 2013 and 2014; and
- Prediction of design flood conditions in the study area and production of design flood mapping series.

The principal outcome of the flood study is the understanding of flood behaviour in the study area and in particular design flood level information. The study provides updated and more detailed flooding information than the previous studies, to be used to inform floodplain risk management within the study area.

The modelled flood conditions sensitivity to hydraulic roughness, stormwater drainage blockage and rainfall losses were limited. However, the model results show that the suburb of Lake Illawarra and the foreshore areas of Lake Illawarra, Mt Warrigal and Oak Flats are highly susceptible to rising sea levels and downstream boundary condition. Given the significant increase in flood risk across these areas sensitive to an elevated tailwater (Lake Illawarra), the incorporation of Lake Illawarra flooding within the design flood levels should be considered for flood planning purposes, particularly for the suburb of Lake Illawarra and lake foreshore areas. It is expected that management of food risk within these areas will be one of the key focuses of future floodplain risk management activities.

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1 Introduction

The Lake Illawarra, Mt Warrigal and Oak Flats Flood Study has been prepared for Shellharbour City Council (Council) to define the existing flood behaviour in the Lake Illawarra, Mt Warrigal and Oak Flats catchment. The flood study, with guidance from Council's Floodplain Management Committee, will establish the basis for subsequent floodplain risk management activities.

The study is designed 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.

1.1 Study Location

The Lake Illawarra, Mt Warrigal and Oak Flats catchment is situated on the southern shores of Lake Illawarra within the Shellharbour City Council Local Government Area (LGA). The study area is bounded by Lake Illawarra to the north and west, Strong Reserve to the east and the suburbs of Blackbutt, Warilla and Shellharbour City Centre to the south. Figure 1-1 shows the location of the catchment within the LGA.

The catchment drains an area of approximately 7 km^2 and is fully developed consisting primarily of low to medium-density housing and commercial developments. There is a large number of open spaces within the study area including; Shane Lee Field, Alex Hoffman Park and the Howard Fowles Sports Oval. Major public infrastructure within the catchment includes; the Shellharbour Hospital, Shellharbour TAFE and a number of public schools.

1.2 The Need for Floodplain Management within the Study Area

Historical records indicate that flooding has occurred at various locations within the Lake Illawarra, Mt Warrigal and Oak Flats catchment. Prior to this current study, a comprehensive flood study has not been undertaken to determine the flood behaviour within the catchment. In order to reduce the risk to existing flood prone properties and manage the future land use of flood prone land, effective floodplain management strategies are required.

The Lake Illawarra, Mt Warrigal and Oak Flats Flood Study includes all sources of flooding (e.g. rainfall, tides and influence from Lake Illawarra) in a single state-of-the-art model. Current practice in floodplain management also requires consideration of the impact of potential climate change scenarios on design flood conditions. This includes increases in design rainfall intensities and sea level rise scenarios impacting on ocean and estuarine boundary conditions.

Accordingly, these potential changes will translate into increased design flood inundation in the catchment, such that future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

1.3 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

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the flood hazard and does not create additional flooding problems in other areas. The Policy and framework are defined in the NSW State Government's Floodplain Development Manual (2005).

The implementation of the *Flood Prone Land Policy* culminates in the preparation and implementation of a floodplain management plan in accordance with the floodplain management process (see Figure 1-2) outlined in the *Floodplain Development Manual*. Periodic reviews of floodplain management plans form part of the floodplain management process. Under the policy the management of flood liable land remains the responsibility of Local Government. The NSW State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The policy provides for technical and financial support by the NSW State Government through the five sequential steps as shown in Figure 1-2.

Steps 1 and 2 of this process form the basis of the current study to provide an understanding of the existing and future flood behaviour within the study area.

Figure 1-2 Steps of the Floodplain Management Process

1.3.1 The Floodplain Management Committee

This study has been overseen by the Floodplain Management Committee (Committee). The Committee has assisted and advised Council in the development of the Lake Illawarra, Mt Warrigal and Oak Flats Flood Study.

The Committee is responsible for recommending the outcomes of the study for formal consideration by Council. Members of the Floodplain Management Committee include representatives from the following:

- Shellharbour City Council Mayor and Councillors;
- Staff from Shellharbour City Council;
- Representatives from the NSW Office of Environment and Heritage (OEH);
- Representatives from the State Emergency Service (SES);
- Representatives from the Roads and Maritime Services (RMS);
- Other NSW government agencies; and
- Community representatives.

1.4 Study Objectives

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 Lake Illawarra, Mt Warrigal and Oak Flats Catchment for a full range of design flood events. The study provides information on flood levels, depths, velocities, flows, hydraulic categories and provisional hazard categories. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour, advise on the outcomes of the flood study and flood behaviour predictions, and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events - including the 20% AEP (~5 year ARI)[1], 10% AEP (10 year ARI), 5% AEP (20 year ARI), 2% AEP (50 year ARI), 1% AEP (100 year ARI), 0.5% AEP (200 year ARI) and the Probable Maximum Flood (PMF); and
- Examination of potential impact of climate change using the latest guidelines.

[1] AEP refers to Annual Exceedance Probability and ARI refers to Average Recurrence Interval

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

- Outline the flood behaviour within the catchments to aid in Council's management of flood risk; 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.

1.5 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 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 sensitivity testing conducted.

Section 9 details the climate change analysis.

2 Study Approach

2.1 The Study Area

2.1.1 Catchment Description

The study area is shown in Figure 2-1. The catchment is fully developed and comprises predominantly low-density housing with pockets of commercial development. There are large open spaces within the catchment including Shane Lee Field, Oak Park and the Howard Fowles Sports Oval.

The catchment covers an area of approximately 7km^2 and drains into Lake Illawarra at various locations via the trunk drainage system, the largest of which discharges to Oak Park downstream of the Shellharbour City Centre. The trunk drainage network is connected to Council's minor stormwater drainage system which comprises; pipes, culverts and pits. There are a number of natural creeks and engineered swales which act as receiving waterways prior to entering Lake Illawarra.

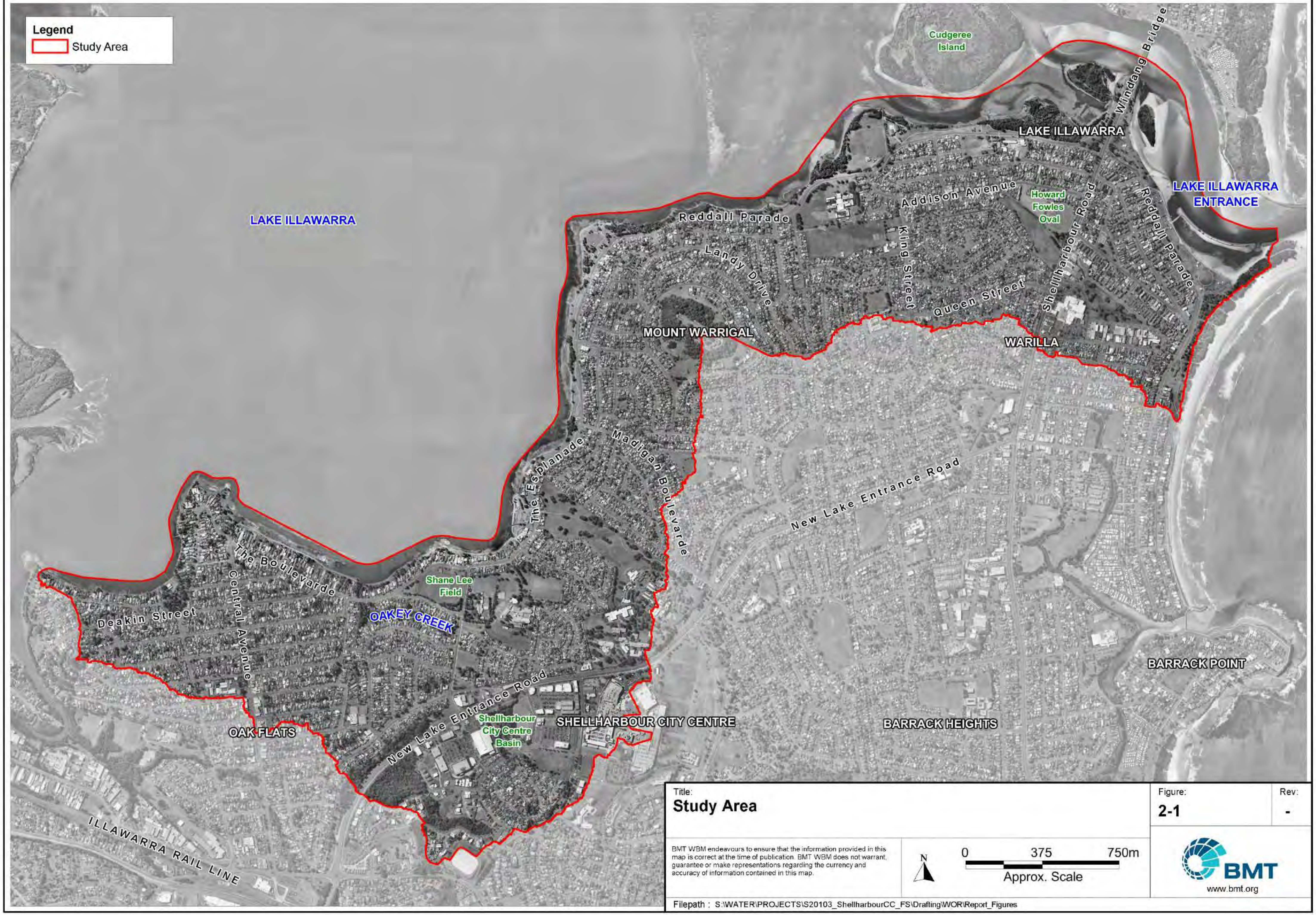
The topography within the Lake Illawarra, Mt Warrigal and Oak Flats catchments varies from steep surface slopes in excess of 20% at Mt Warrigal to the near flat areas of Lake Illawarra and other foreshore locations. The catchment therefore has regions where surface water runoff within the road network has high velocity with shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points and flow velocities will be lower. The lower reaches of the catchment are potentially affected by elevated water levels within Lake Illawarra, in particular the suburb of Lake Illawarra.

2.1.2 Stormwater Drainage System

The Shellharbour Council area was first settled with land grants in the early 19th Century. The natural drainage system comprised of earth gullies and watercourses draining to the Lake Illawarra shoreline, some still present today. As land clearing for agriculture and rapid growth followed post World War Two, the land use changed to a higher proportion of impervious surfaces leading to increased runoff volumes and peak flows.

An extensive network of stormwater drainage infrastructure exists in the study area to provide drainage of surface water runoff. The infrastructure primarily consists of a pit and pipe stormwater network, comprising kerb inlet pits, grated pits, junction pits, pipes and box culverts. The study area also contains the City Centre Basin (detention basin), situated on the southern side of New Lake Entrance Road immediately adjacent to Bunnings Warehouse.

In rainfall events where flows exceed the piped system capacity, surface water runoff is generally conveyed overland as uncontrolled flow. When this occurs, there is potential for high hazard flooding conditions resulting from combined high flow velocities and depths.



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2.1.3 Known Flooding Problems

The Lake Illawarra, Mt Warrigal and Oak Flats catchments have a history of experiencing frequent and hazardous flood events. Rising floodwaters in Lake Illawarra, coupled with high intensity, short duration bursts of localised rainfall, have caused flooding and widespread damage in recent times.

March 2011, November 2013 and March 2014 all resulted in major flooding in the Lake Illawarra, Mt Warrigal and Oak Flats catchments. Anecdotal flood information has been obtained from Community consultation and Council staff indicating that there are a number of known problem areas typified by flooding due to:

- Low-lying elevation;
- Blockage of drainage systems; and
- The role of Lake Illawarra (i.e. elevated tailwater levels, lack of defined watercourses and drainage infrastructure) with local catchment flooding.

2.2 Compilation and Review of Available Data

2.2.1 Introduction

A data compilation and review was undertaken as the first stage in this flood study to consolidate and summarise currently available data, and identify any significant data gaps that may affect the successful completion of the study. This allowed for missing data to be collected during the initial phases of the study.

The review included:

- Previous studies undertaken in surrounding catchments;
- Available water level, tide and rainfall data; and
- Register of data from historic flood events.

Council has provided digitally available information such as aerial photography, topographical data, cadastral boundaries, watercourses, and drainage networks in the form of GIS datasets.

2.2.2 Previous Studies and Investigations

Comprehensive flood modelling has not previously been undertaken for the Lake Illawarra, Mt Warrigal and Oak Flats catchments; however, a number of key studies have been completed for neighbouring catchments and water bodies. Details of previous flood studies undertaken adjacent to the study area and their relevance in the context of the current flood study are presented in the following sections.

2.2.2.1 Lake Illawarra Flood Study (Lawson and Treloar, July 2001)

The flood study report prepared by Lawson and Treloar (now Cardno) for Shellharbour City Council details the flooding behaviour in Lake Illawarra. Lake Illawarra is a shallow coastal lagoon located immediately to the north of the current study catchment and forms the main receiving body for local catchment flows.

Hydrologic modelling software RAFTS was used in determining catchment run-off and routing of flows downstream to the lake body. Hydraulic modelling software MIKE-11 was used to determine peak flood levels and extents for the lake.

Hydraulic modelling of design events was undertaken using a tailwater level equal to the Mean High Water Springs (MHWS) of the Port Kembla tide gauge (0.6 m AHD).

Design flood levels for various locations in the study area as determined by the 2001 flood study are presented below in Table 2-1.

Table 2-1 Lake Illawarra Design Flood Levels (Lawson and Treloar, 2001)

Location	Peak Flood Level (m AHD)						
	1% AEP	2% AEP	6% AEP	10% AEP	20% AEP	50% AEP	Extreme Event
Griffins Bay	2.30	2.03	1.81	1.57	1.40	1.11	3.24
Tallawarra Power Station	2.30	2.03	1.81	1.57	1.40	1.11	3.24
Horsley Inlet	2.30	2.03	1.81	1.57	1.40	1.11	3.24
Cudgeree Island Channel	2.26	1.99	1.81	1.54	1.40	1.08	3.19
Windang Bridge	2.08	1.83	1.63	1.42	1.26	0.99	2.98
Entrance Channel	1.98	1.74	1.55	1.35	1.20	0.95	2.84

2.2.2.2 *Lake Illawarra Floodplain Risk Management Study and Plan (Cardno, January 2012)*

In January 2012, the Lake Illawarra Floodplain Risk Management Study and Plan was completed by Cardno for the Lake Illawarra Authority (Wollongong and Shellharbour City Councils). The study looked at determining and managing flood risk in Lake Illawarra as well as incorporating future flood risk due to climate change.

Climate change modelling was undertaken using open source software Delft3D; a multi-dimensional (2D or 3D) hydrodynamic simulation programme. Four scenarios were assessed as part of the climate change assessment for Lake Illawarra:

(1) 0.18m SLR: Sea Level Rise of 0.18m, no change in rainfall intensity.

(2) 2050 SLR: Sea Level Rise of 0.55m, no change in rainfall intensity.

(3) 2100 SLR: Sea Level Rise of 0.91m, no change in rainfall intensity.

(4) 2050 SLR + 20%: Sea Level Rise of 0.55m, 20% increase in rainfall intensity

The study concludes by recommending planning provisions to be implemented by Council as part of the Floodplain Risk Management Plan. Table 2-2 presents the recommended flood levels to be used for flood planning purposes.

Table 2-2 Design Flood Levels to be used for Flood Planning Purposes

Location	Peak Flood Level (m AHD)								
	100 Year ARI	100 Year ARI (2050 SLR)	100 Year ARI (2100 SLR)	50 Year ARI	20 Year ARI	10 Year ARI	5 Year ARI	2 Year ARI	Extreme Event (PMF)
Griffins Bay	2.24	2.63	3.04	2.03	1.81	1.57	1.40	1.11	3.24
Tallawarra Power Station	2.24	2.63	3.04	2.03	1.81	1.57	1.40	1.11	3.24
Horsley Inlet	2.24	2.63	3.04	2.03	1.81	1.57	1.40	1.11	3.24
Cudgeree Island Channel	2.24	2.64	3.04	1.99	1.81	1.54	1.40	1.08	3.19
Windang Bridge	2.15	2.55	3.01	1.83	1.63	1.42	1.26	0.99	2.98
Entrance Channel	1.71	2.25	2.32	1.74	1.55	1.35	1.20	0.95	2.84

2.2.2.3 Dam Break Study – Shellharbour City Centre Basin (Cardno, May 2014)

Upstream of New Lake Entrance Road is a detention basin with permanent storage for wetland functionality. The Dam Break Study completed by Cardno in 2014 fulfils the failure assessment for this structure as required by the NSW Dam Safety Committee.

Based on design drawings the weir crest (high flow) was reported to be 20.6m AHD and is 45m long. The low flow outlet is a 900mm×900mm overflow pit and pipe arrangement and the permanent water level in the detention basin is 18.0m AHD. The reported data has been used to inform the current study's inclusion of the overflow pit and pipe arrangement in the hydraulic model.

In addition to the pit and pipe arrangement mentioned above, the current study has accounted for the basin weir structure and basin storage by incorporating basin survey as discussed in Section 2.2.8.

2.2.3 Council GIS Data

Digitally available GIS data such as aerial photography, cadastral boundaries and roads and drainage network information has been provided by Council. This data provides a means to distinguish between land-use types across the study area to allow spatial variation of distinct hydrologic (e.g. rainfall losses) and hydraulic properties (e.g. Manning's roughness parameter 'n'). The data has also been used to identify any potential data gaps.

2.2.4 Water Level and Ocean Tide Data

The Lake Illawarra, Mt Warrigal and Oak Flats catchments flow into Lake Illawarra which can consequently act as a significant downstream control for both overland and piped flows under local catchment flood conditions. As Lake Illawarra is an estuarine environment there is influence on water levels resulting from ocean tide conditions and Lake Illawarra catchment flooding. Accordingly, several sources of data were sought containing water level and oceanic tide conditions for this study including:

- Port Kembla tide gauge (BoM);
- Cudgeree Bay water level gauge (Manly Hydraulics Laboratory);
- Macquarie Rivulet water level gauge (Manly Hydraulics Laboratory); and
- Lake Illawarra Entrance water level gauge (Manly Hydraulics Laboratory).

A list of water level and ocean tide gauges relevant this study, the type of data available and their respective period of record are shown in Table 2-3, with the spatial distribution of the gauges shown in Figure 2-2.

Table 2-3 Water Level and Oceanic Gauges in the Vicinity of the Study Area

Station #	Station Name	Record Period	Data Type	Authority
IDO71003	Port Kembla	1991 - current	Ocean wave	BoM
214402	Macquarie Rivulet	1984 - current	Water Level	MHL
214416	Cudgeree Bay	1987 - current	Water Level	MHL
214417	Lake Illawarra Entrance	1991 - current	Water Level	MHL

For calibration and validation events, a variable tail water boundary for Lake Illawarra and Lake Illawarra entrance has been adopted based on water level records obtained from the Manly Hydraulics Laboratory's (MHL) water level gauging stations at Cudgeree Bay and Lake Illawarra Entrance.

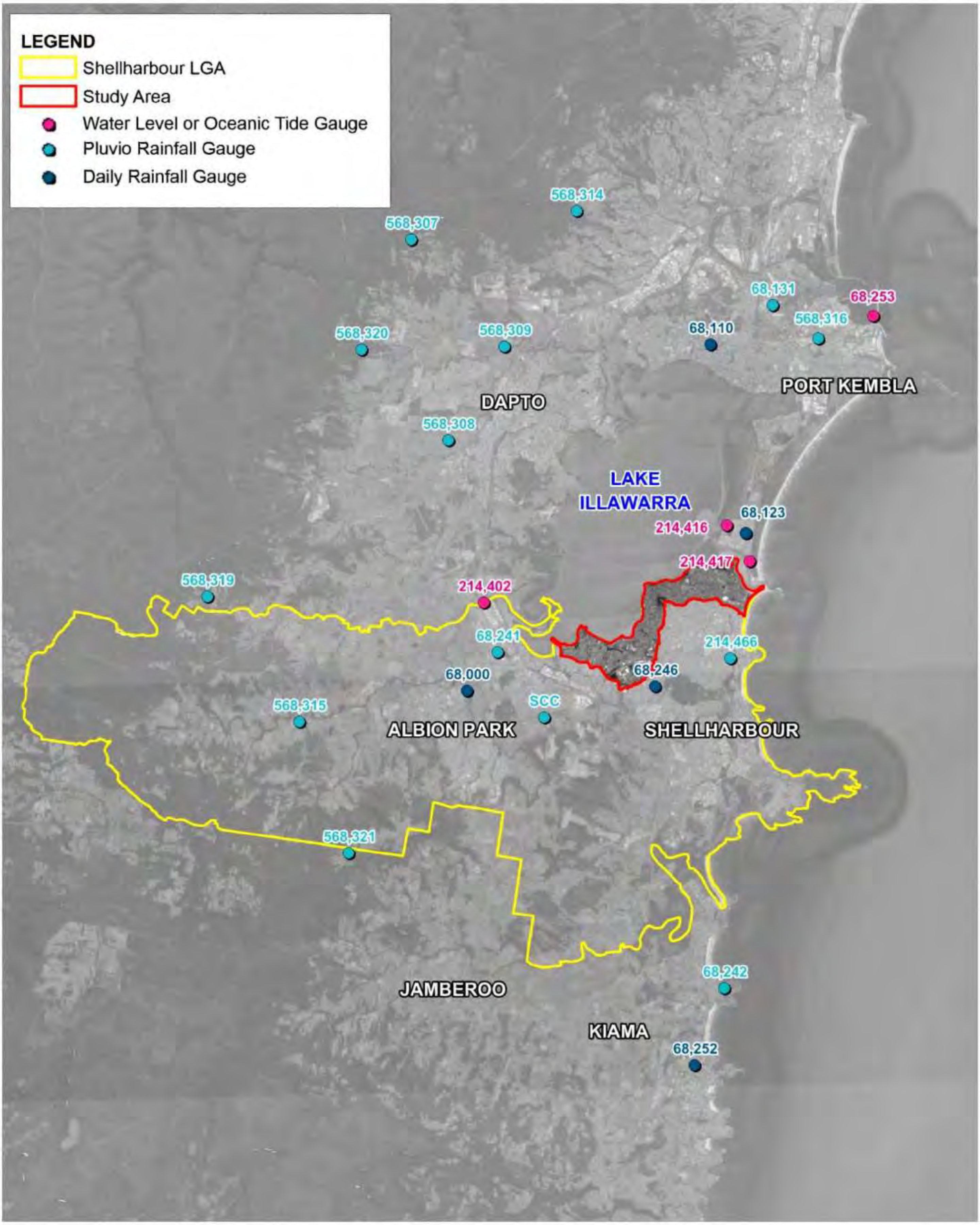
2.2.5 Historical Flood Level Data

No peak flood level survey of historic flooding is available for this study. Model calibration has therefore relied on information received from community recollections of flooding via the community engagement process detailed further in Section 3.

2.2.6 Rainfall Data

There is an extensive network of rainfall gauges across catchments draining to Lake Illawarra, the majority of which are operated by the Manly Hydraulics Laboratory (MHL) on behalf of the Office of Environment and Heritage (OEH) and the Bureau of Meteorology (BoM). There are no rainfall stations located within the study area catchment, however a number of stations operate within close proximity which have data relevant to this study.

A list of rainfall stations relevant this study, the type of data available and their respective period of record are shown in Table 2-4, with the spatial distribution of the rainfall stations shown in Figure 2-2.



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Rainfall and Water Level Gauges

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The combination of daily rainfall stations and pluvio stations has been used to define the temporal pattern of historic rainfall events and provides a sufficient rainfall data set for use in the model calibration and validation as part of this study.

Table 2-4 Rainfall Gauges in the Vicinity of the Study Area

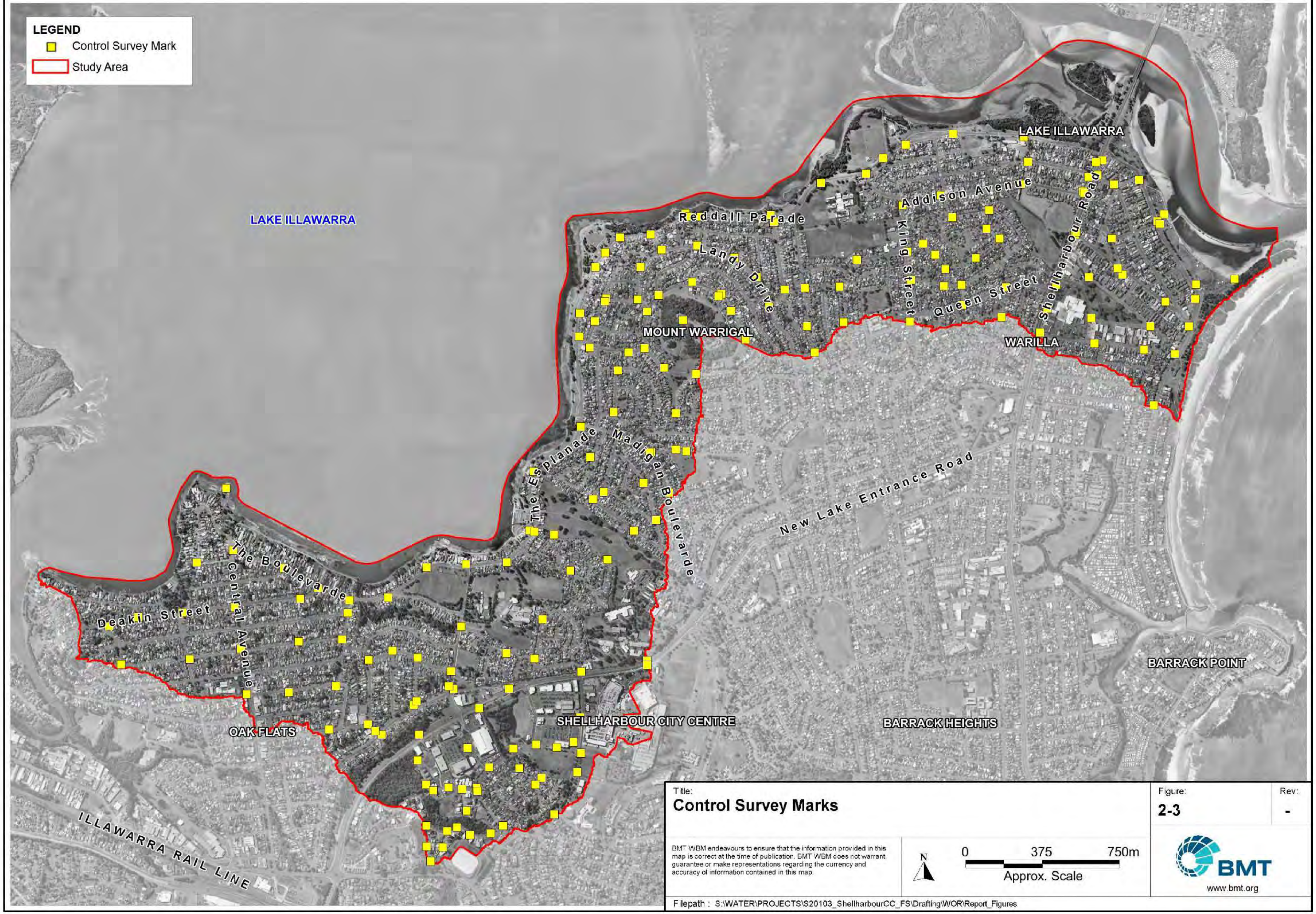
Station #	Station Name	Record Period	Data Type	Authority
214466	Little Lake	1991 - 2014	Pluvio	OEH
214467	Little Lake Entrance	2014 - current	Pluvio	OEH
568314	Mt Kembla	1985 - current	Pluvio	OEH
568307	Dombarton Loop	1985 - current	Pluvio	OEH
68131	Port Kembla (BSL Central Lab)	1963 - current	Pluvio	BoM
68110	Berkeley (Northcliffe Drive)	1962 - current	Daily	BoM
568316	Port Kembla	1983 - current	Pluvio	OEH
568309	Darkes Road	1994 - current	Pluvio	OEH
568320	Wongawilli	1983 - current	Pluvio	OEH
568308	Cleveland Road	1985 - current	Pluvio	OEH
68123	Windang Bowling Club	1962 - current	Daily	BoM
568319	Upper Calderwood	1985 - current	Pluvio	OEH
568321	Yellow Rock Road	2005 - current	Pluvio	OEH
568315	North Macquarie	1985 - current	Pluvio	OEH
68241	Albion Park (Wollongong Airport)	1999-2015 2011-2015	Daily Pluvio	BoM
68000	Albion Park Post Office	1892 - current	Daily	BoM
68246	Blackbutt (Tammar Place)	2002 – current	Daily	BoM
68242	Kiama (Bombo Headland)	2001 - current	Pluvio	BoM
68252	Kiama (Brighton St)	2003 - current	Daily	BoM
SCC	Green Meadows	2011 - current	Pluvio	SCC

2.2.7 Topographic Data

Aerial topographic survey, also known as LiDAR (Light Detection and Ranging) survey, covering the study area has been provided by Council. The survey was captured by the NSW Government's Land and Property Information (LPI) in 2011. Horizontal and vertical accuracy are 0.8m and 0.3m respectively, as quoted by the supplier.

In addition to the 2011 LiDAR data, Council has provided Airborne Laser Scanning (ALS) (another form of LiDAR) flown in 2005 by specialist surveyor AAM HATCH. The 2011 LiDAR and 2005 ALS have been cross-checked against control survey marks recorded in LPI's Survey Control Information Management System (SCIMS).

In total 197 control survey marks were analysed. Figure 2-3 shows the marks used in analysis and Table 2-5 summarises the findings in tabular format.



Title:
Control Survey Marks

Figure: 2-3

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Analysis was undertaken on each point by extracting the elevation from the two topographic sources and subtracting the surveyed elevation at these locations. A full list of survey marks and accompanying elevations are provided in Appendix D.

Table 2-5 Difference between Surveyed Elevations and Topographic Estimate

Statistic	2005 ALS	2011 LiDAR
Control Survey Marks (LPI)		
Count[1]	197	197
Maximum Difference (m)	5.39934	5.71667
Minimum Difference (m)	-7.99896	-7.93926
Average Difference (m)	-0.32238	-0.2435

[1] Number of control survey points eligible for comparison

Analysis of the 197 points for the two topographic sources indicates a reasonable correspondence between the surveyed ground levels and the ground levels estimated from the two sources. The comparison indicates that all three topographic sources fall within a general range of +-0.3m for vertical accuracy.

The results of the DEM comparison indicate that the 2011 LiDAR is the most appropriate in representing ground elevations across the study area with an average vertical accuracy of +-0.3m.

In addition to the LiDAR ground elevation survey; bathymetric survey of Lake Illawarra captured in March 2008 by OEH, has been used in the study to represent bed levels in Lake Illawarra and Lake Illawarra entrance.

Figure 2-4 shows the digital elevation model (DEM) developed for the study area using the 2011 LiDAR and 2008 Bathymetry.

2.2.8 Shellharbour City Centre Basin Survey

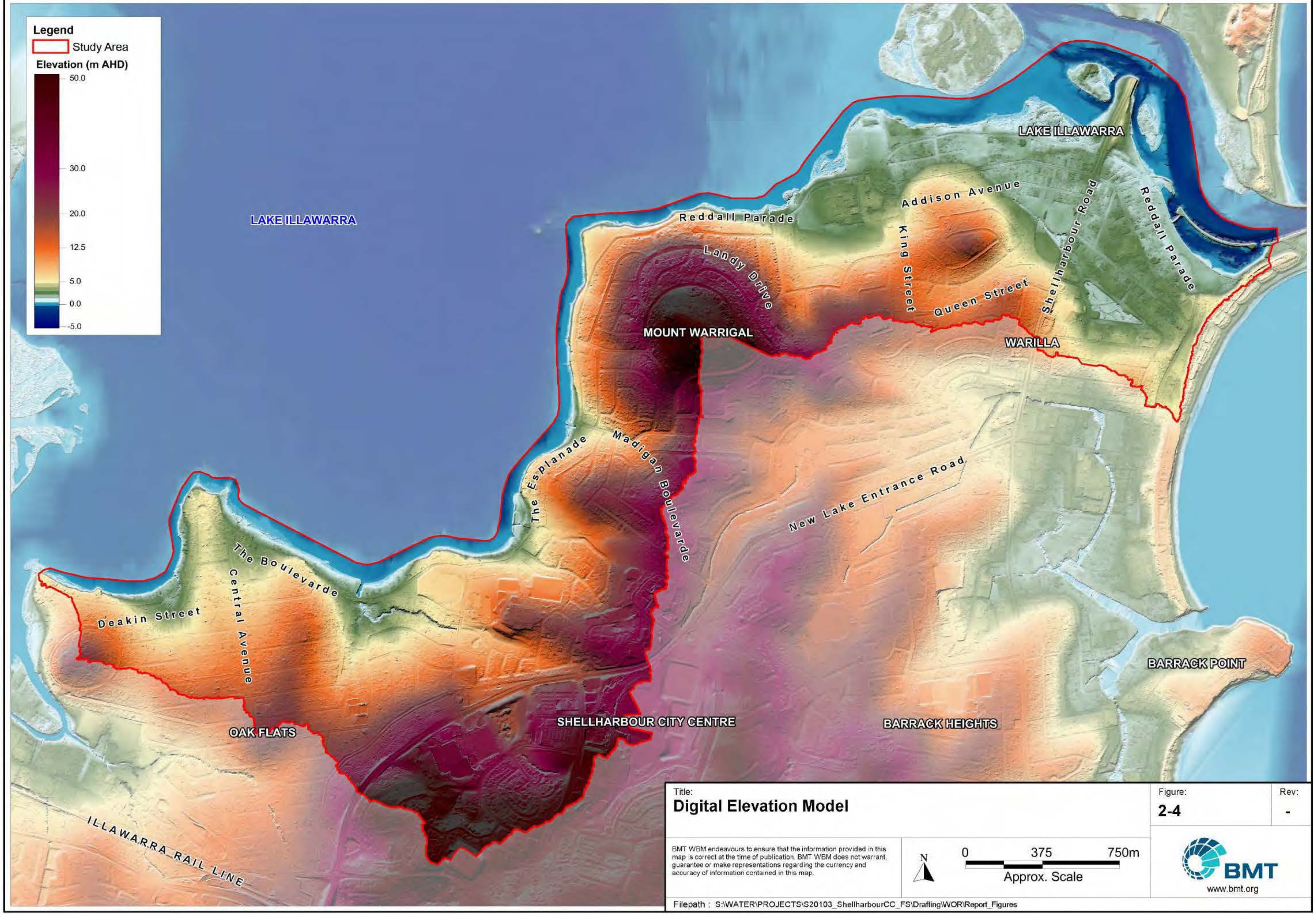
Topographic survey of the City Centre Basin undertaken by Council surveyors in June 2012 has been provided for use in the hydraulic model. The survey has been used to establish ground surface elevations of the basin and immediate surrounds.

Discussion on the incorporation of the Shellharbour City Centre Basin into the hydraulic model is provided in Section 6.5.

2.2.9 Stormwater Drainage Network

An extensive network of stormwater drainage infrastructure exists in the study area to provide drainage of surface water runoff. The infrastructure primarily consists of a pit and pipe stormwater network, a number of natural and modified channels and watercourses. Detail of the stormwater drainage network has been compiled primarily from Council's GIS database.

Council's GIS layers include details about the catchment pits, pipes and culverts. However, some concerns about the reliability of data were raised in initial phases of the study. These issues were resolved in part by commissioning survey of critical pit and pipe locations within the catchment. Further discussion on additional drainage survey is discussed below in Section 4.



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Digital Elevation Model

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2.3 Site Inspections

Site inspections have been undertaken during the course of the study to gain an appreciation of local hydraulic features and their potential influence on the flood behaviour. Some of the key observations accounted for during the site inspections included:

- Presence of local structural hydraulic controls;
- Location and characteristics of surface drainage pits and pipes;
- Location of existing development and infrastructure on the floodplain;
- Alignments and configuration of watercourses, overland flow paths and open channels;
- General nature of the contributing catchment.

This visual assessment was useful for defining hydraulic properties within the hydraulic model and ground-truthing of topographic features identified in the DEM.

2.4 Additional Drainage Survey

Following the review of available stormwater drainage network data, a number of locations were identified where additional pit and pipe survey data was required. A survey brief was prepared and a surveyor was engaged to capture the following pit and pipe details:

- Pit location coordinates;
- Reduced levels of the pit entry;
- Pit opening sizes;
- Number of pipes entering the pit;
- Number of pipes exiting the pit;
- Pipe invert levels;
- Pipe diameters; and
- Pipe material.

The survey was completed in late November 2015 after which the data was incorporated into the hydraulic model developed as part of the study.

2.5 Community Consultation

The success of a floodplain management plan hinges on its acceptance by the community, residents within the study area, and other stakeholders. 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.

2.6 Development of Computer Models

2.6.1 Hydrologic Model

Traditionally, for the purpose of a flood study, a hydrologic model is developed to simulate the rate of storm runoff from the catchment. The output from the hydrologic model is a series of flow hydrographs at selected locations such as at stormwater drainage pit inlets, which form the inflow boundaries to the hydraulic model.

In recent years the advancement in computer technology has enabled the use of the direct-rainfall approach as a viable alternative (also referred to as rainfall-on-grid). With the direct-rainfall method the design rainfall is applied directly to the individual cells of the 2D hydraulic model. This approach can be useful for overland flow studies where model results are desired in areas with small contributing catchments or catchment areas/flow paths are difficult to define due to topography. This study has adopted the direct-rainfall approach for modelling hydrology, details of which are discussed in Section 4.

Verification of the direct-rainfall approach against traditional hydrologic modelling is shown in Section 4.

2.6.2 Hydraulic Model

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

- 2D representation of the floodplain of the combined catchments (i.e. complete coverage of the total study area);
- 2D representation of the open/natural channel drainage network; and
- 1D representation of the stormwater pit/pipe network,

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

2.7 Calibration/Validation and Sensitivity Testing of Models

The hydraulic model was calibrated and validated against 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 magnitudes.

The available historical information highlighted three flood events with sufficient data to potentially support a calibration and validation process.

The calibration and validation of the hydraulic model is presented in Section 5. A series of sensitivity tests were also carried out to evaluate the model. These tests were conducted to examine the performance of the models and determine the relative importance of different hydrologic and hydraulic parameters. The sensitivity testing of the model is detailed in Section 8.

2.8 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For the study area, design floods were based on design rainfall estimates according to the recent 2016 Australian Rainfall and Runoff (AR&R) guidelines (Ball et al., 2016).

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.

2.9 Mapping of Flood Behaviour

Design flood mapping is undertaken using outputs 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 hydrodynamic model results and are also mapped. The mapping outputs are described in Section 7 and presented in separate appendices.

3 Community Consultation

3.1 The Community Consultation Process

Community consultation has been an important component of the study. The consultation has aimed to inform the community about the development of the flood study and its likely outcomes as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on community members flood experiences in the catchment and to collect feedback on concerns regarding flooding. In addition, the consultation process raises awareness about the flooding risk within the community and improves the community's receptiveness to flood related issues.

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

- Consultation with the Floodplain Management Committee;
- Distribution of a newsletter and questionnaire to landowners, residents and businesses within the study area;
- Follow up telephone conversations with a number of respondents to discuss information provided.
- An information session for the community to present technical information, inform about the flood study outcome; and (to be undertaken).
- Public exhibition of the draft Flood Study (to be undertaken).

These elements are discussed in detail in the following report sections. Copies of relevant consultation material are included in Appendix E.

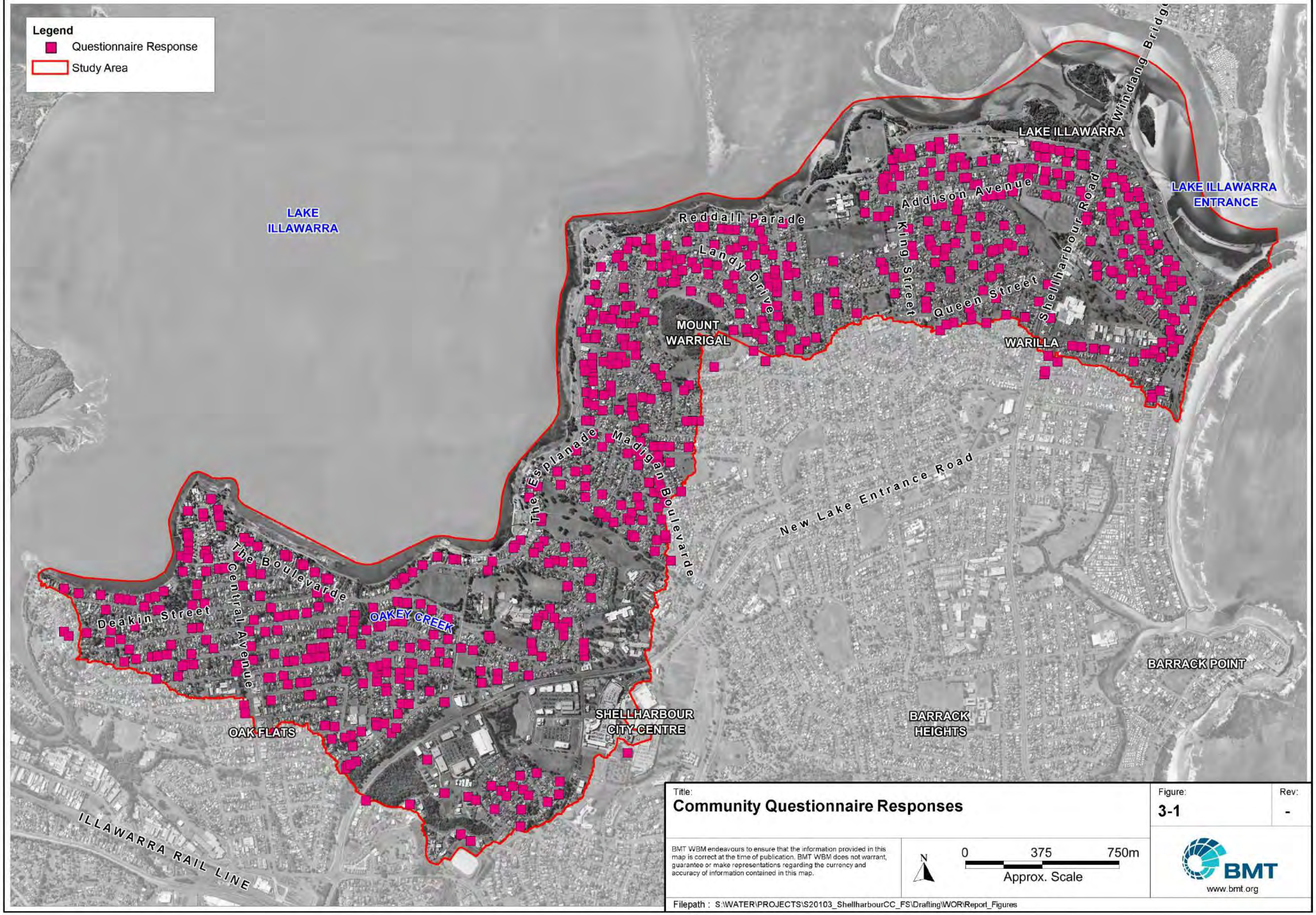
3.2 Community Questionnaire

In October 2015 an information leaflet and questionnaire was distributed by Council to all residential properties and businesses within the study area. The information leaflet provided an overview of the flood study while the questionnaire sought to collect information on the community's historical flood experiences and flooding issues of concern. Copies of the information leaflet and questionnaire are provided in Appendix E.

A total of 734 completed questionnaires were received out of the 6,284 delivered, representing a response rate of 12%. This is considered a relatively high return rate, compared to other similar studies with a typical return rate of between 5% and 10 % for initial consultation on a flood study.

The responses have been compiled into a GIS database which has been utilised to analyse the results and to provide a graphical representation of the data. Figure 3-1 is a map showing the geographical spread of respondent's locations. The map indicates a comprehensive coverage of responses across the study area.

The majority of the respondents have resided at their property for over 25 years. Where flooding was identified as an issue, the community were asked to separately report on flooding on their property and their street.



Title:
Community Questionnaire Responses

Figure: 3-1

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Property flooding experiences are summarised in Figure 3-2 and illustrated spatially in Figure 3-4. A total of 184 responses have experienced some degree of flooding within the grounds of their property, 26 of which indicated flooding above floor level.

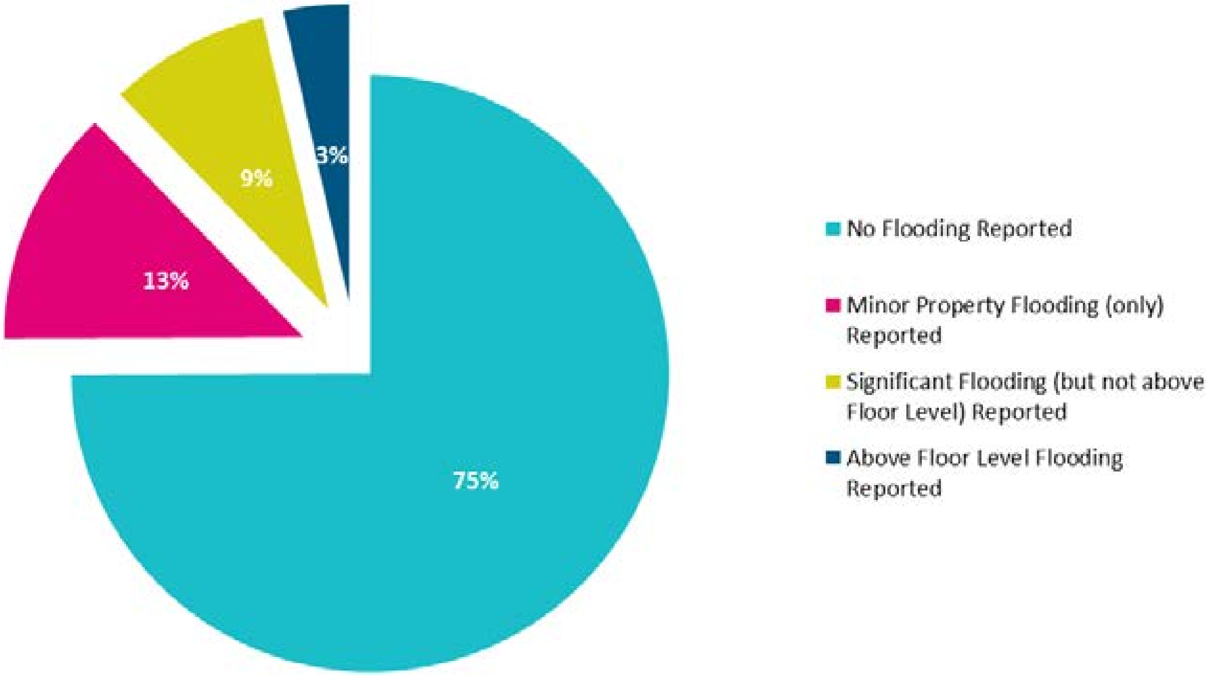


Figure 3-2 2015 Questionnaire Responses – Property Flooding Experienced

Figure 3-3 provides a summary of responses that identified flooding on their street. A total of 233 residents indicated that they had experienced flooding in their street, 140 of which reported flooding across one or both traffic lanes.

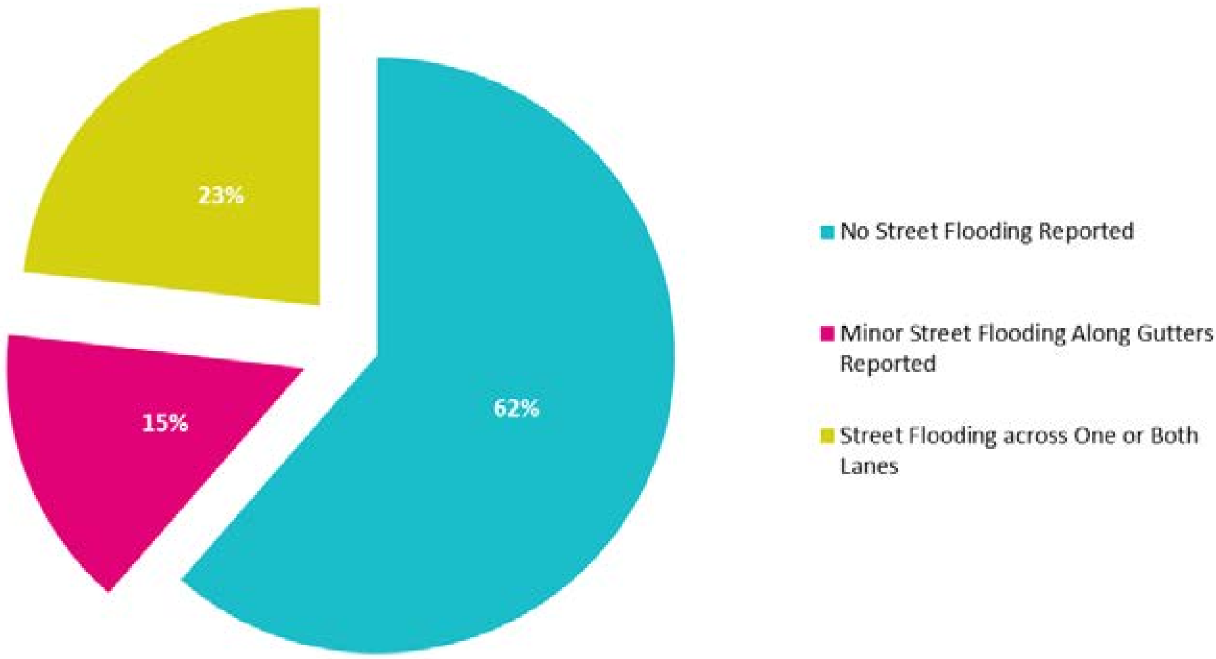
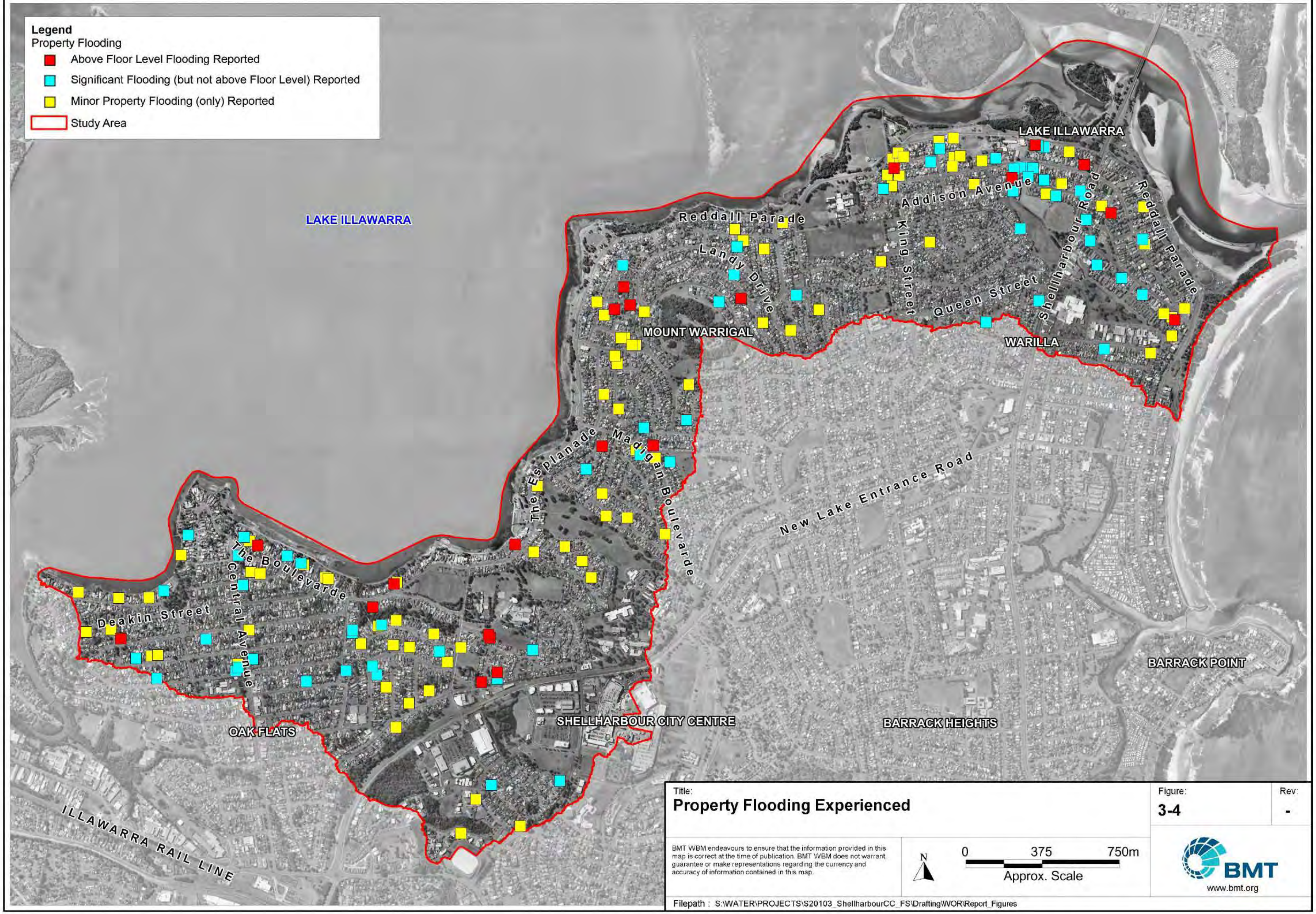


Figure 3-3 2015 Questionnaire Responses – Street Flooding Experienced



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Property Flooding Experienced

Figure: 3-4

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Comments relating to flood behaviour have been used for correlating modelled flood behaviour as part of the flood model calibration and validation. A significant number of community responses identified rainfall events in 2011, 2013, 2014 and 2015 resulting in flooding in the study area. Numerous comments included indicative flood depths; however, these are largely not attributed to specific flood events. More than 15 responses provided photos and/or indicative flood depths resulting from the March 2011 rainfall event.

A summary of the key issues raised by the community in the questionnaire responses include:

- Flooding due to under capacity of the drainage system;
- Blockage of drainage systems as a result of lack of maintenance exacerbates the flooding; and
- Previously flood issues were believed to be amplified by the Lake Illawarra entrance being closed. Residents believe that since the Lake Illawarra entrance has been opened, flood issues have reduced and/or not occurred since.

  Community suggestions for reducing flooding problems included:

- Increased maintenance of the drainage system, e.g. ensuring pits, stormwater drains and waterways are kept clear of debris; and
- Improve and upgrade stormwater and drainage infrastructure e.g. increase number of stormwater pits.

3.3 Public Exhibition of Draft Flood Study Report

3.3.1 Public Exhibition and Community Information Session Details

Yet to be completed

3.3.2 Community Response

Yet to be completed

3.4 Conclusion

Community consultation undertaken during the study has aimed to collect information on historical flooding and previous flood experience, and inform the community about the development of the flood study and its likely outcome as a precursor to floodplain management activities to follow. The key element of the consultation process involved the distribution of a questionnaire relating to historical flooding. The return rate of questionnaires was relatively high (12%), with some useful additional historical flood information obtained.

4 Model Development

With the exception of scaled physical models; computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of a flood study, a hydrologic model and a hydraulic model are developed.

The **hydrologic 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 and overland flow paths, producing flood levels, flow discharges and flow velocities.

This study has adopted the direct rainfall approach for modelling the catchment hydrology and therefore only a single TUFLOW model has been developed which implicitly performs both hydrologic and hydraulic computation.

Information on the topography and characteristics of the catchment, drainage network and floodplain 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:

- Discretisation of the catchment, drainage network, floodplain, etc.
- Incorporation of physical characteristics (stormwater pipe details, topography, structures etc.).
- Establishment of hydrographic databases (rainfall, flood flows, flood levels) for historic events.
- Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
- Verification to one or more other historic floods (verification is a check on the model's performance without further adjustment of parameters).
- 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;
- determining levels for planning control; and
- management options to assess the hydraulic impacts (as part of the floodplain risk management study).

4.1 Hydrologic Model

The hydrologic 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.

A direct-rainfall approach has been adopted in the TUFLOW hydraulic model (refer to Section 4.2 for details of the model setup). The factors given above have been represented in the model by:

- The runoff routing and hydrologic response of the catchment within the 2D model is driven by the surface type and underlying topography. Where appropriate, runoff is diverted into 1D pipe domains of the 2D/1D model (more detail is provided in Section 4.2).
- The amount and intensity of rainfall can be varied across the catchment based on available data and information.
- The antecedent moisture conditions are modelled by varying the amount of rainfall which is “lost” into the ground and “absorbed” by storages. For very dry antecedent moisture conditions, there is typically a higher initial rainfall loss.

The general modelling approach and adopted parameters are discussed in the following sections.

4.1.1 Catchment Delineation

The Lake Illawarra, Mt Warrigal and Oak Flats catchments drain an area of approximately 7km^2 via a piped stormwater drainage network to Lake Illawarra.

Discretisation of the study area into sub-catchments has not been required for this study given that rainfall is being applied directly to the 2D domain and traditional rainfall-runoff modelling is not being used. However, the delineation of the overall catchment boundary is important for defining the limits of the hydraulic model and the associated direct-rainfall input.

The hydrologic catchment boundary and the hydraulic model extent have been sufficiently extended to account for the potential interactions with the neighbouring catchments.

4.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrologic 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 36 hours 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.

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 to Figure 2-2 for rainfall gauge locations).

For design events, rainfall depths are 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 *Australian Rainfall and Runoff: A Guide to Flood Estimation* (AR&R) (Ball et al., 2016). AR&R is a national guideline for the estimation of design flood characteristics in Australia. In August 2016, Engineers Australia completed a revision of AR&R. The revision process included 21 research projects, which were designed to fill knowledge gaps that have arisen since the 1987 edition was published.

4.1.2.1 AR&R 2016

The updated procedures provide some significant changes to previous procedures. Some of the key changes in AR&R 2016 are summarise below:

- Intensity-Frequency-Duration (IFD) 2016 design rainfalls – revised IFD rainfall estimates underpin the AR&R 2016 release. The updated IFD analysis includes a significant period of additional rainfall data since the 1987 IFDs were established. The variation between 1987 and 2016 IFD design rainfall is location dependent.
- Design rainfall losses – estimation of initial and continuing loss rates (as applied in the hydrological model) are provided in AR&R 2016 as gridded spatial data. Representative losses for catchments are extracted from the database. This is a significant change from the previous approach (AR&R 1987) in which basic ranges were recommended for broad areas i.e. eastern or western NSW.
- Pre-burst rainfall – AR&R 2016 provides procedures for the consideration of pre-burst rainfalls for consideration along with design initial losses. The procedures provide for generation of tabular outputs of pre-burst rainfall for the catchment of interest based on a combination of storm duration and return period.
- Areal reduction factors – new equations have been developed as part of AR&R 2016 with regionalised parameters to define areal reduction factor for catchments based on catchment area and storm duration.
- Temporal patterns – the change in temporal patterns represents one of the most significant differences from the AR&R 2016 release. Each design duration now has a suite of 10 temporal patterns as opposed to single temporal pattern for each duration for AR&R 1987.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 5 with design events discussed in Section 7.

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 flow paths. Road networks often convey a considerable proportion of floodwaters due to the hydraulic efficiency of the road surface compared to developed areas (e.g. blocked by fences and buildings), in addition to the underground pipe network draining mainly to natural channels. Given this complex flooding environment, a 2D modelling approach is warranted for the overland flooding areas.

BMT has applied the fully 2D software modelling package TUFLOW. TUFLOW was developed in-house at BMT and has been used extensively for over fifteen years on a commercial basis by BMT.

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 flow paths using a linked 1D/2D flood modelling approach.

4.2.1 Model Configuration

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

- Topographical data coverage and resolution;
- Location of recorded data (e.g. levels/flows for calibration);
- Location of controlling features (e.g. detention basins, levees, bridges and downstream boundaries);
- Desired accuracy to meet the study's objectives; and
- Computational limitations.

With consideration to the available survey information and local topographical and hydraulic controls, a 2D model was developed incorporating the entire Lake Illawarra, Mt Warrigal and Oak Flats catchments. The model incorporates a number of natural channels and engineered swales, as well as the Shellharbour City Centre Basin. A total length of some 14km of stormwater drainage is also included within the model.

A TUFLOW 2D domain model resolution of 2m was adopted for study area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 2m cell size results in DEM elevations being sampled every 1m. This resolution was selected to give necessary detail required for accurate representation of floodplain and channel topography and its influence on overland flows.

4.2.2 Topography

The ability of the hydraulic model to provide an accurate representation of the flow distribution on the floodplain ultimately depends upon the quality of the underlying topographic model. A 1m by 1m gridded DEM was derived from the following sources:

- Bathymetric survey of Lake Illawarra undertaken in 2008;
- Light Detection and Ranging (LiDAR) survey undertaken by NSW Land and Property Information (LPI) in 2011; and
- Topographic survey for the City Centre Basin provided by Council.

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 flows that are expected to provide significant flood conveyance within the study area.

Linear features that potentially influence the flow behaviour, such as gullies and levees were incorporated into the topography using 3D 'breaklines' in TUFLOW to ensure that these were contained within the model grid and accurately represented in the model.

The resulting topography of the hydraulic model is illustrated in Figure 2-4.

4.2.3 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 (roads and urban areas, etc.) for modelling the variation in flow resistance.

Aerial photography and cadastral data supplied by Council has been used to generate the land-use surface types and roughness zones for the study area. The base land-use map used to assign the different hydraulic roughness zones across the model is shown in Figure 4-1.

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.

4.2.3.1 Representation of Buildings

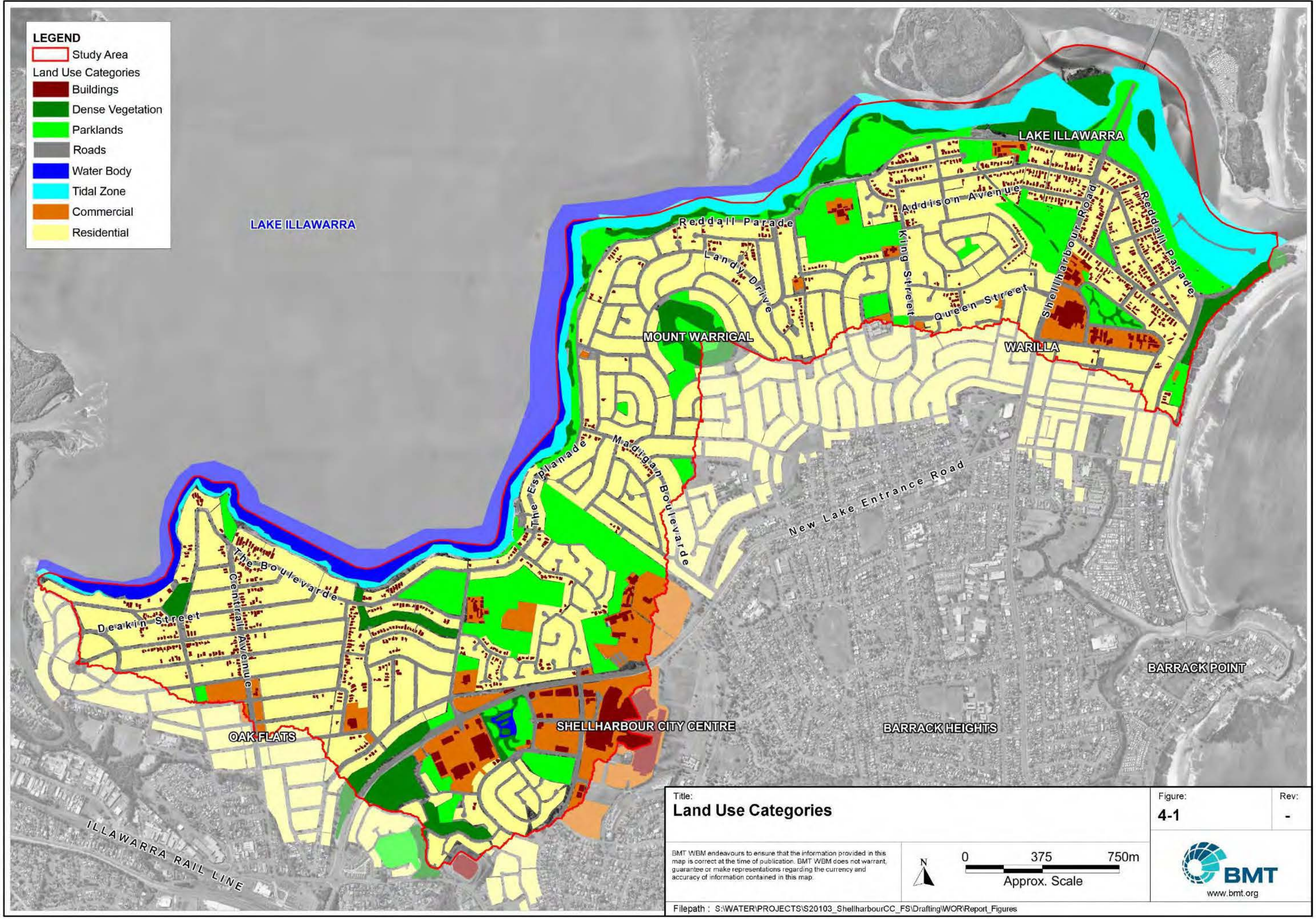
The presence of buildings and garages/sheds may impede and divert flood flows in the catchment. Buildings further reduce the available overland flood storage available due to building materials such internal and external walls and the concrete slab the building may be constructed upon. The representation of buildings is therefore particularly important in areas conveying significant volumes of flow or experiencing significant ponding depth.

As shown in Figure 4-1, buildings have not been digitised across the whole catchment. Only buildings located within a flow-path, which are likely to reduce the conveyance of floodwater, have been included in the model. Outside of flow paths, digitised 'Residential Lots' have an increased Manning's 'n' to account for the increase in frictional resistance due to the presence of buildings.

A depth-varying Manning's 'n' has been adopted for the building footprints to represent two different hydrological functions:

- the rapid and shallow run-off of water from the building's roof when a rainfall event first initiates; and
- the reduced conveyance within the building footprint due to the physical obstruction of the overland flow as flood depths increase..

Depth varying Manning's 'n' was applied as a value of 0.03 up to a flood depth of 0.03m, after which a value of 1.0 was applied for depth of flooding exceeding 0.03m.



Title:
Land Use Categories

Figure: 4-1

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The Manning's 'n' hydraulic roughness values adopted for each land use category are given in Table 4-1.

Table 4-1 Adopted Manning's 'n' Hydraulic Roughness Values

Land Use Category	Manning's 'n'
Default (areas not defined in Figure 4-1)	0.035
Residential lots (without buildings digitised)	0.060
Residential (with buildings digitised)	0.040
Commercial	0.040
Parklands	0.035
Dense Vegetation	0.100
Water Body	0.028
Tidal Zone	0.031
Roads	0.022
Buildings	1.000

4.2.4 Stormwater Drainage Network

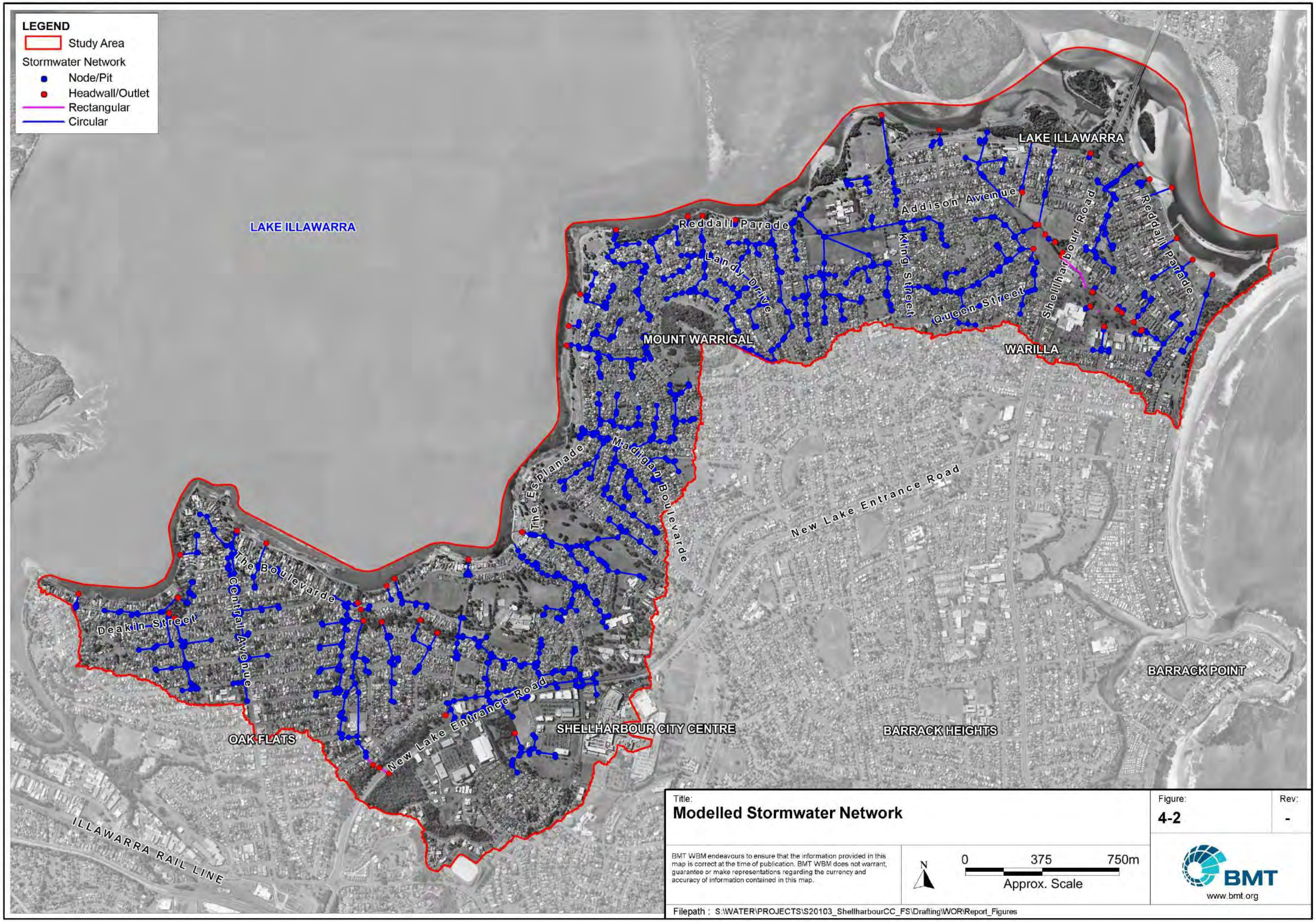
This study required the modelling of the stormwater drainage system across the catchment. Information on the pit and pipe drainage network has been compiled from a number of sources as discussed in Section 2.

Data comprising pit/pipe locations, pit inlet type/dimensions and pipe sizes was received in a number of formats including GIS layers and as survey data. These sources were used to build the necessary details of the stormwater pipe network into the TUFLOW model. Pipe size and invert levels were taken from the provided data where available. Where invert levels were not available, they were estimated from the DEM, by assuming a minimum cover of 600mm from the known pipe size.

Table 4-2 provides a summary of the stormwater infrastructure. Figure 4-2 shows the modelled stormwater network.

Table 4-2 Summary of Modelled Stormwater Infrastructure Elements in Hydraulic Model

Stormwater Infrastructure Type	Number of Elements
Circular	1130
Rectangular	32
TOTAL PIPES/CULVERTS	**1162**
Pits	996
Nodes	147
Outlets/Headwalls	72
TOTAL NODES/PITS	**1215**



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Modelled Stormwater Network

Figure: 4-2

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The modelled pipe network has a combined run length of over 38km, an example of which is shown in Figure 4-3. The figure shows the pipe invert and obvert levels relative to the ground surface level.

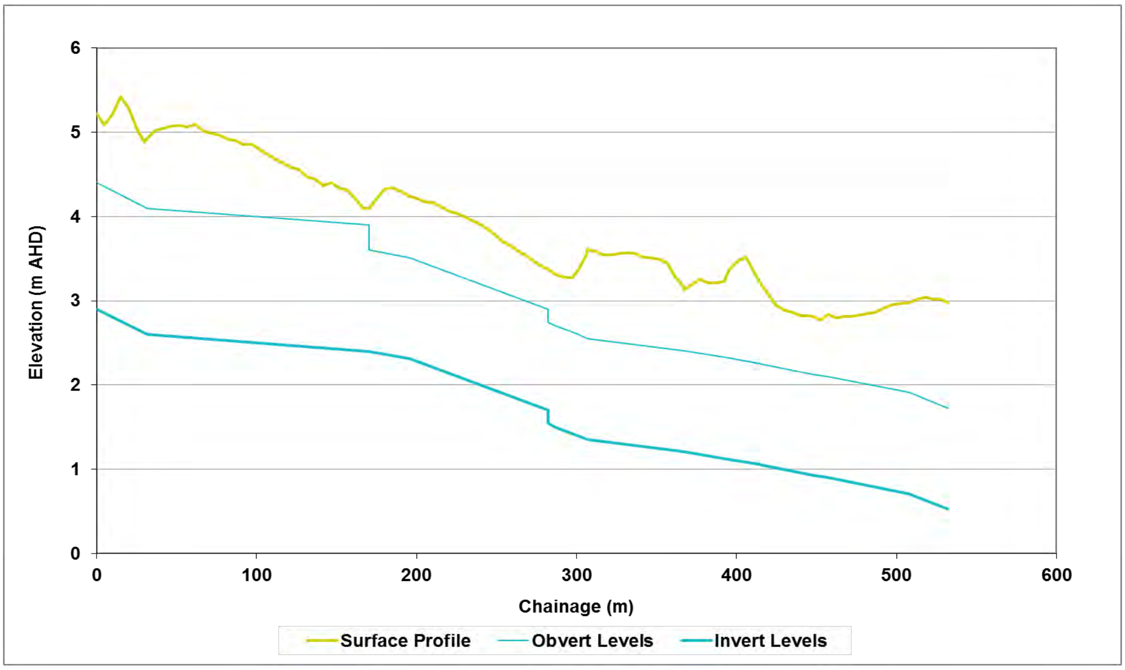


Figure 4-3 Example Drainage Line Long Section

The pipe network is represented as a 1D layer in the TUFLOW model and is dynamically linked to the 2D domain at specified pit locations, as illustrated in Figure 4-4.

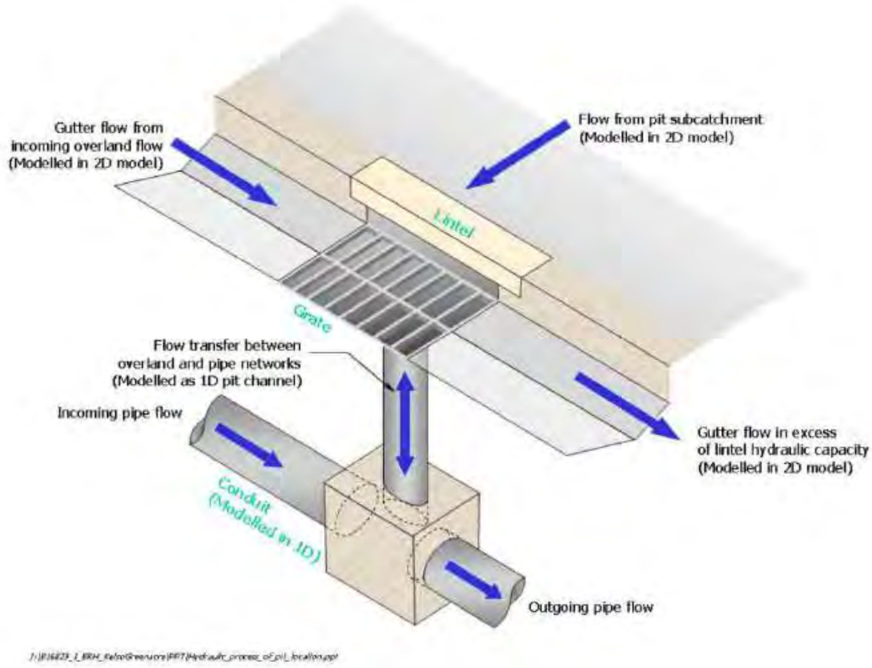


Figure 4-4 Linking Underground 1D Stormwater Drainage Network to the Overland 2D Domain

Pit inlet capacities have been modelled using lintel opening lengths and grate sizes based on the collected data. Pit inlet dimensions have been assumed where data were not available, based on site inspections and nearby pits. Pit inlet curves have been developed using an industry standard approach which rely on laboratory tests by the former NSW Department of Main Roads and are considered sufficiently reliable for the purpose of this study.

For the magnitude of events under consideration in the study, the pipe drainage system capacity is anticipated to be exceeded with the major proportion of flow conveyed in overland flow paths. Therefore, any limitations in the available pipe data or model representation of the drainage system may have limited influence on overland flow results.

4.2.5 Boundary Conditions

The model boundary conditions are derived as follows:

- Rainfall Inflow – the catchment runoff is determined through the hydrologic component of the model. With the direct-rainfall approach, rainfall is applied directly to every cell in the hydrologic catchment extent, 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 has been exceeded.
- Downstream Water Level – the downstream model limit corresponds to the water level in Lake Illawarra. A water level time series has been applied at this location for the duration of the modelled events.

The adopted water level boundary for the design events is discussed further in Section 6.

5 Model Calibration and Validation

5.1 Selection of Calibration and Validation 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.

Through consultation with Council a set of flood events were identified as being suitable for use in the model calibration and validation process. These are events of a suitable flood magnitude for which there are observed flood data available for comparison with the model performance. The principal event selected for model calibration is the March 2011 event, as this is the flood event with the most intense rainfall of recent years. There is also a reasonable amount of observed flood data available.

The November 2013 and March 2014 flood events have been selected for model validation. The November 2013 event was found to have an equivalent intensity to the March 2011 event; however, the March 2011 event had a greater total rainfall. The November 2013 and March 2014 events were identified as significant flood events during community consultation, resulting in the availability of some observed flood data for use in model validation.

5.2 March 2011 Model Calibration

5.2.1 Calibration Data

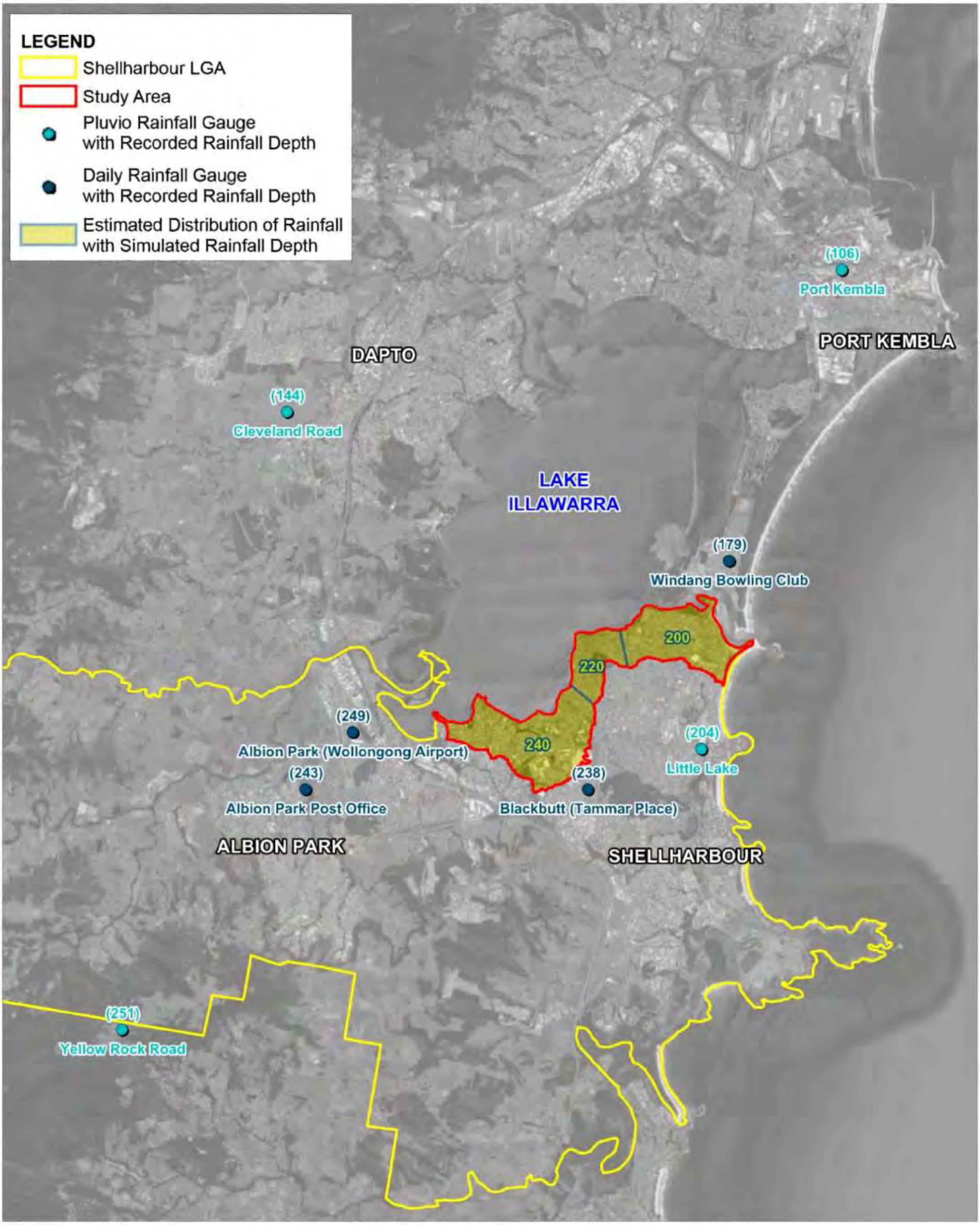
5.2.1.1 Rainfall Data

Given the lack of rainfall gauges within the study area and the often high spatial variability of short duration, intense rainfall, there remains uncertainty in the estimate of spatial rainfall variability for the study area. However, there are a number of gauges situated within the wider region that can be analysed to estimate the likely range of rainfall intensities experienced within the catchment.

Four continuous (pluvio) gauges and four daily rainfall gauges have been considered in this analysis and are summarised in Table 5-1 with the gauge locations shown in Figure 5-1. Rainfall totals have been summed over a 24-hour period starting 09:00 on the 21st of March 2011.

Table 5-1 March 2011 Event Recorded Daily Rainfall Total

Gauge Station No.	Gauge Type	Location	Approximate Locality from the Centre of Study Area	Daily Rainfall Total (mm)
214466	Pluvio	Little Lake	2.5 km to the ESE	204
568308	Pluvio	Cleveland Road	8.1 km to the NW	144
568321	Pluvio	Yellow Rock Road	11.2 km to the SW	251
568316	Pluvio	Port Kembla	9.6 km to the NE	106
68123	Daily	Windang Bowling Club	3.7 km to the NE	179



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Daily Rainfall Totals March 2011 Event

Figure: 5-1

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Gauge Reference	Gauge Type	Location	Approximate Locality from the Centre of Study Area	Rainfall (mm)
68246	Daily	Blackbutt (Tammar Place)	1.8 km to the S	238
68241	Daily	Albion Park (Wollongong Airport)	4.7 km to the WSW	249
68000	Daily	Albion Park Post Office	5.9 km to the WSW	243

Analysis of the rainfall gauges (daily and pluvio) in the immediate vicinity of the study area show that rainfall totals range from 179mm to 249mm as presented in Figure 5-1. The closest pluvio rainfall gauge is Little Lake (214466) which recorded a rainfall depth of 204mm. Albion Park (68241) and Port Kembla (568321) provided the highest (249mm) and lowest (106mm) recorded daily rainfall totals in the vicinity of the study area and show the potential range of rainfall conditions experienced across the Lake Illawarra, Mt Warrigal and Oak Flats catchments.

Figure 5-2 below shows the recorded rainfall hyetographs for the pluvio gauges listed in Table 5-1. The hyetograph includes an extended burst of heavy rainfall occurring over a 4 to 6-hour period from approximately 08:30 followed by periods of light intermittent rainfall. The most intense rainfall was recorded at the Little Lake gauge (214466) between 10:00 – 11:00 on 21st March 2011.

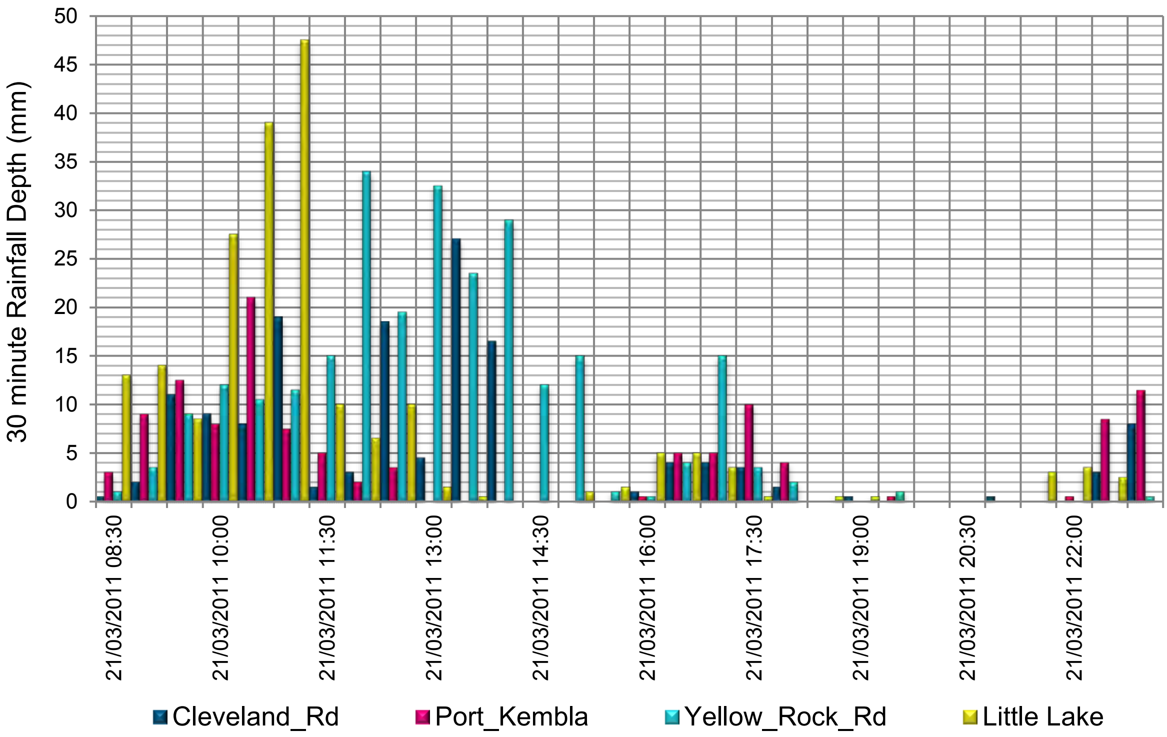


Figure 5-2 Rainfall Hyetograph – March 2011 Rainfall

In order to gain an appreciation of the relative intensity and magnitude of the March 2011 event, the recorded rainfall depth for various durations within the storm is compared with design IFD rainfall curves. Design IFD rainfall curves were sourced from the BoM based on the 2016 datasets. Figure 5-3 presents the recorded March 2011 rainfall intensities against the 2016 IFD.

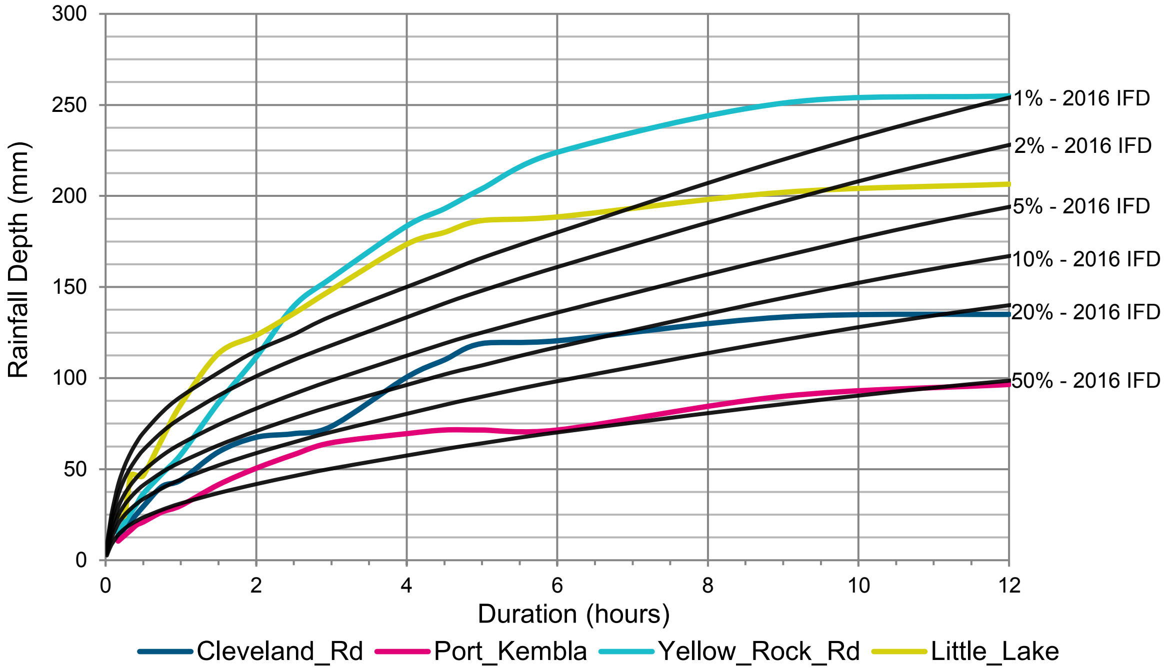


Figure 5-3 Comparison of Recorded March 2011 Rainfall with IFD Relationships

The recorded rainfall at the Little Lake gauge is estimated to be greater than a 1% AEP design intensity for durations between 0.5 to 7 hours. The recorded rainfall at the Yellow Rock Road gauge is typically in excess of the 1% AEP design intensity (2 to 12-hour duration). The recorded rainfall at the Cleveland Road gauge and the Port Kembla gauge is estimated to be between a 5% and 20% AEP and a 50% AEP design intensity respectively.

The Little Lake gauge (214466) is considered to be the most suitable to define the catchment rainfall in the TUFLOW model. The recorded daily rainfall total of 204mm represents the approximate median of the daily rainfall totals recorded in the immediate vicinity of the study area ranging from 179mm to 249mm. Additionally the Little Lake gauge recorded the most intense burst of rainfall (Figure 5-2), likely to produce a conservative estimate of flooding in the Lake Illawarra, Mt Warrigal and Oak Flats catchments. In discussion with Council, the Little Lake gauge rainfall was scaled according to the total depths shown in Figure 5-1. The variability of total rainfall depth across the catchment ranged from a total of 240mm in the west, to 220mm in the east.

5.2.1.2 Downstream Boundary Condition

In most instances of overland flooding the downstream water level conditions in the Lake will not be critical in determining upstream flood levels in the local catchment. However, for completeness the available recorded water level conditions at Cudgeree Bay (214416) and Port Kembla (IDO71003) have been used to represent the tailwater conditions within the model. The Port Kembla oceanic tide gauge has been used in place of the Lake Illawarra Entrance (214417) water level gauge as data was not available for the entrance gauge for the duration of the March 2011 event.

Figure 5-4 shows the downstream tailwater levels applied to represent Lake Illawarra (Cudgeree Bay) and Lake Illawarra Entrance (Port Kembla) conditions. The downstream tailwater levels at Cudgeree Bay and Port Kembla peak at levels of 1.08m AHD and 0.97 m AHD respectively.

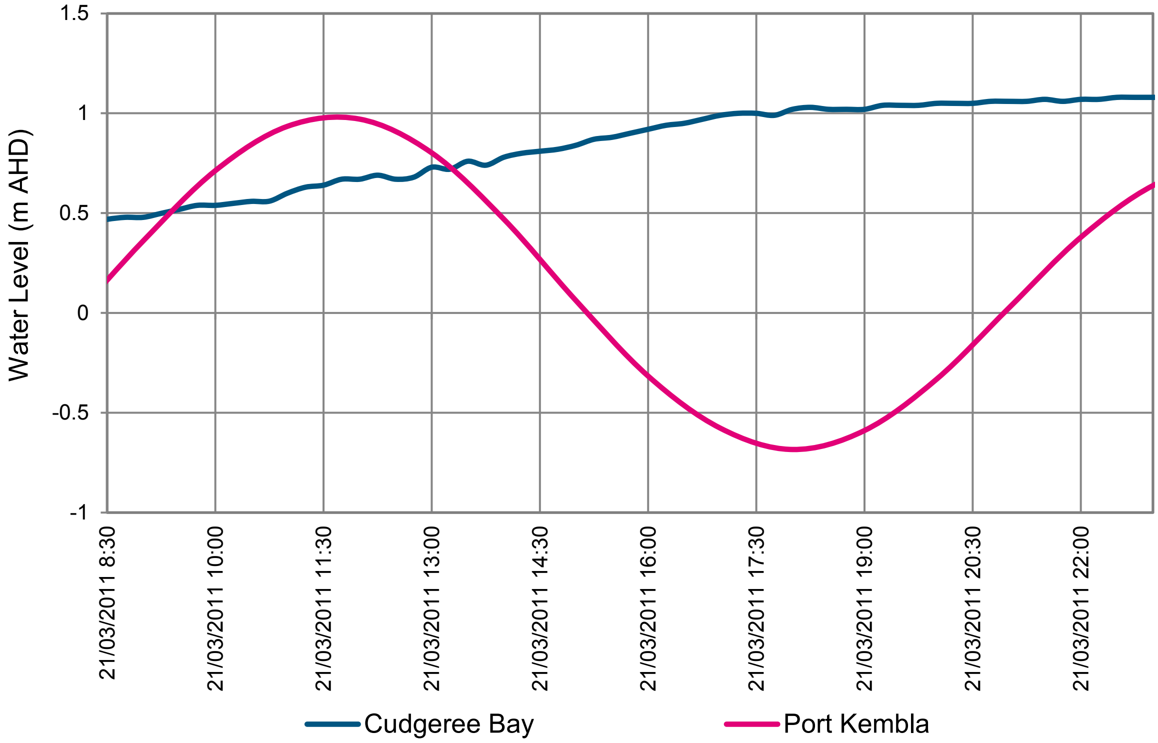


Figure 5-4 Recorded Water Level – March 2011

5.2.1.3 Flood Level Data

There are no stream gauges situated within the catchment to provide recorded water levels for the event. Data for comparison of actual flood levels is limited to anecdotal flood data and observations of the main flow path alignments and peak flood level estimates based on flood marks.

Anecdotal flood data for the March 2011 event was obtained through the community questionnaire responses (refer Section 3). Most of this data does not provide definitive flood levels, but rather indicative depths of flooding and observations of flood flow paths and inundation. The observations are useful to confirm the locations of significant modelled flow paths and depth of flooding to provide some confidence in the model representation of the observed flow condition. For some locations the available description of flooding combined with LiDAR elevation survey enables a determination of approximate flood levels.

The distribution of observed flood data for the March 2011 event compiled from the community consultation feedback is discussed further in Section 5.2.2 and presented in Figure 5-8.

5.2.1.4 Flood Photographs

Photographs depicting significant flooding as shown in Figure 5-5, Figure 5-6 and Figure 5-7 were used to confirm modelled flood behaviour as discussed in Section 5.2.2.

Figure 5-5 Addison Avenue, Lake Illawarra

Figure 5-6 Devonshire Crescent, Oak Flats

Figure 5-7 Corner Minga Avenue and Memorial Drive, Shellharbour City Centre

5.2.2 Observed and Simulated Flood Behaviour

Figure 5-8 provides simulated flood inundation depths for the calibration event for comparison to the locations of the community's flooding observations. In general, it can be seen that there is a good correlation between the locations at which significant flooding was observed and the alignment of the major flood flow paths in the TUFLOW model results. The community flooding observations have been classified into three categories; locations where general flooding was reported, locations where flood depths were reported and locations where flood photographs were taken.

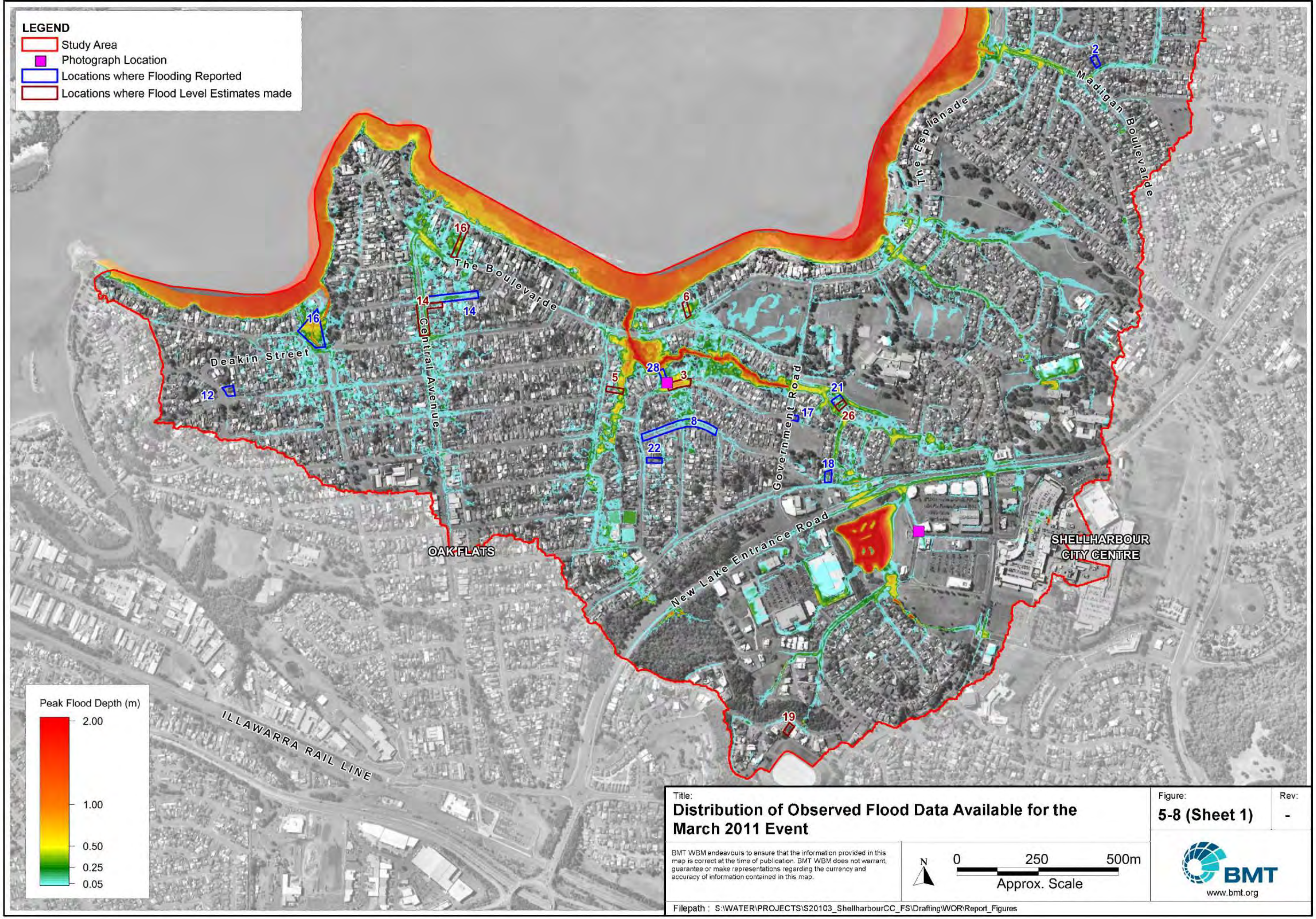
For locations where some form of flood level estimation was possible, a comparison of observed and modelled flood level is presented in Table 5-2.

Table 5-2 Comparison of Observed and Modelled March 2011 Flood Levels

Reference Location (Figure 5-8)	Location and Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled March 2011 Level (m AHD)	Difference in Flood Levels (m)
3	50 cm in property	~3.6	3.7	+0.1
4	50 cm in driveway	~3.8	3.8	0.0
5	10 cm in front yard	~4.0	4.0	0.0
6	30 cm inside the house	~2.5	2.5	0.0
9	50 cm in backyard	~2.2	2.2	0.0
11	20-30 cm	~2.0	2.2	+0.2

Reference Location (Figure 5-8)	Location and Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled March 2011 Level (m AHD)	Difference in Flood Levels (m)
14	On road and in property, 5-10 cm	~4.7	4.7	0.0
16	5 cm in ground floor, 10 cm in garage	~2.8	3.0	+0.2
19	12 cm in backyard	~79.1	79.1	0.0
20	10 cm in garage and garden	~1.9	2.2	+0.3
26	Inside dwelling up to 15cm; Run-off in yard to 10cm depth	~8.4	8.4	+0.0

It can be seen from Table 5-2 that where reasonable estimates of the peak flood level can be made from the observed data, the modelled flood level is typically within 0.1m - 0.2m of this estimate. This indicates in general the model provides for a reasonable representation of the flood behaviour at these locations considering the relative bounds of uncertainty.



Title:
Distribution of Observed Flood Data Available for the March 2011 Event

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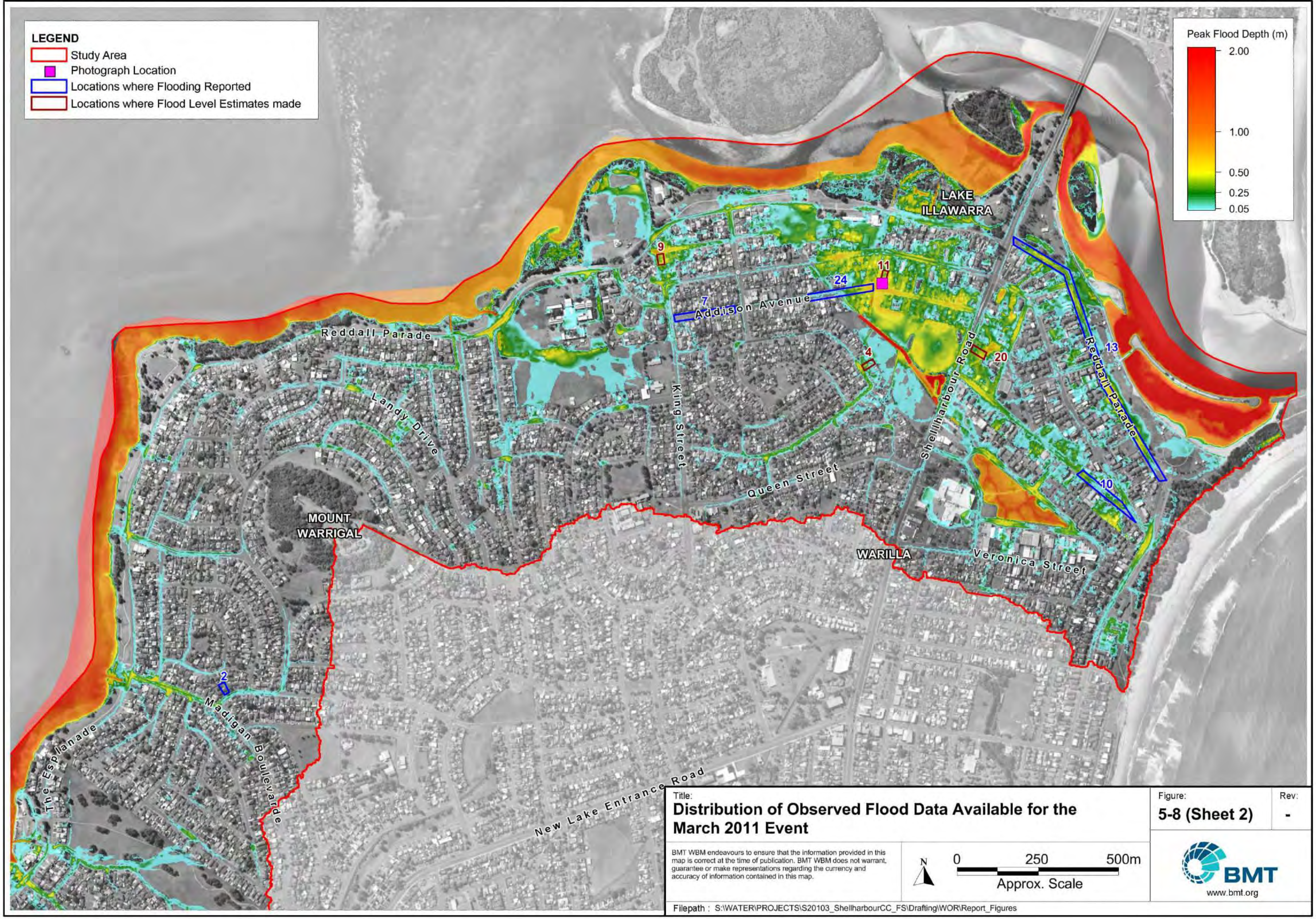

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Distribution of Observed Flood Data Available for the March 2011 Event

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5.3 November 2013 Model Validation

5.3.1 Validation Data

5.3.1.1 Rainfall Data

As noted for the March 2011 event, no rainfall gauges are located within the study area catchments, gauges situated within the wider region have been analysed to estimate the likely range of rainfall intensities experienced within the catchment.

Four pluvio gauges and three daily rainfall gauges have been considered in this analysis and are summarised in Table 5-3 with the gauge locations shown in Figure 5-9. Rainfall totals have been summed over a 24-hour period starting 09:00 on the 15th of November 2013.

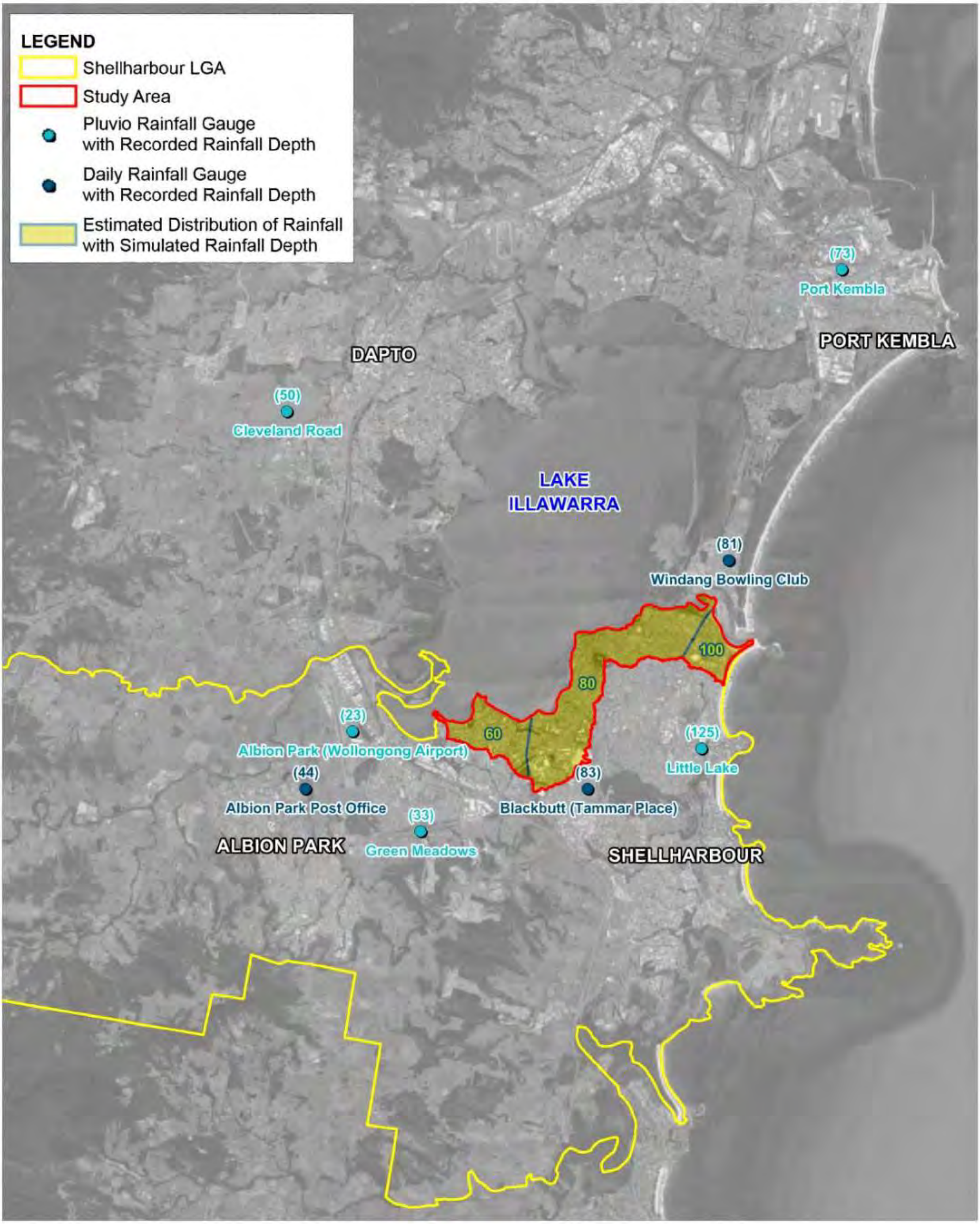
Table 5-3 November 2013 Event Recorded Daily Rainfall Total

Gauge Station No.	Gauge Type	Location	Approximate Locality from the Centre of Study Area	Daily Rainfall Total (mm)
214466	Pluvio	Little Lake	2.5 km to the ESE	125
568308	Pluvio	Cleveland Road	8.1 km to the NW	50
568316	Pluvio	Port Kembla	9.6 km to the NE	73
68241	Pluvio	Albion Park (Wollongong Airport)	4.7 km to the WSW	23
SCC	Pluvio	Green Meadows	4.3 km to the SW	33
68123	Daily	Windang Bowling Club	3.7 km to the NE	81*
68246	Daily	Blackbutt (Tammar Place)	1.8 km to the S	83*
68000	Daily	Albion Park Post Office	5.9 km to the WSW	44*

*Accumulated total over 2-3 days

Analysis of the rainfall gauges (daily and pluvio) in the immediate vicinity of the study area show recorded rainfall totals ranging from 23mm to 125mm as presented in Figure 5-9. The Little Lake pluvio gauge (214466) recorded the highest daily total of 125mm. The lowest daily total was recorded at the Albion Park pluvio gauge (68241) with a rainfall depth of 23mm. The rainfall recorded at the Little Lake gauge is shown to be extremely localised, with other gauges in the immediate area reaching a maximum recorded depth of the order of 70-80mm. It is also noted that some of the reported depths represent a cumulative total over more than 24 hours, such that the actual maximum recorded depth for the nominal 24-hour event period is likely to be less.

Figure 5-10 contains the recorded rainfall hyetographs for the pluvio gauges listed previously in Table 5-3. The recorded rainfall at each pluvio gauge is of varying depth with rainfall periods spaced approximately 2 hours apart. The varying rainfall depth and spacing between the hyetograph confirms the localised nature of the November 2013 storm which largely affected the Little Lake gauge in isolation. The most intense burst of rainfall, recorded at the Little Lake gauge (214466), occurred over a 2 hour period beginning at 22:30 on 15th November 2013.



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Daily Rainfall Totals November 2013 Event

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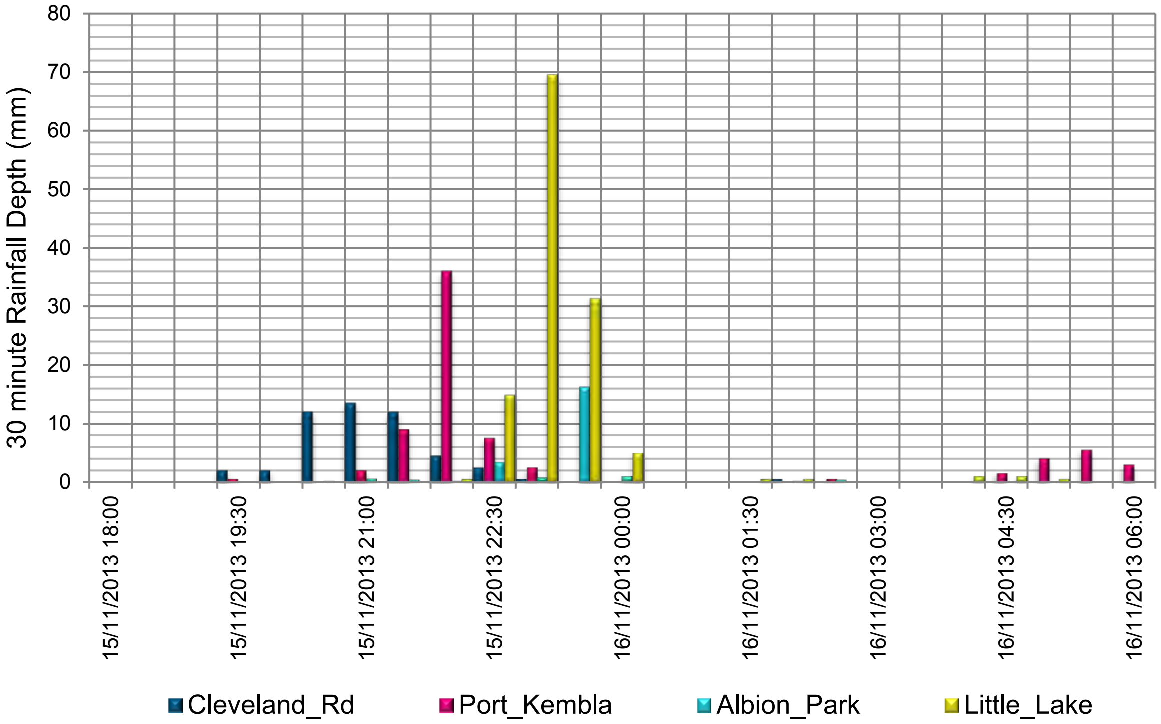


Figure 5-10 Rainfall Hyetograph – November 2013 Rainfall

In order to gain an appreciation of the relative intensity and magnitude of the November 2013 event, the recorded rainfall depth at the four pluvio gauges for various durations within the storm is compared with design IFD rainfall curves obtained from the BoM. Figure 5-11 presents the recorded November 2013 rainfall intensities against the 2016 IFD.

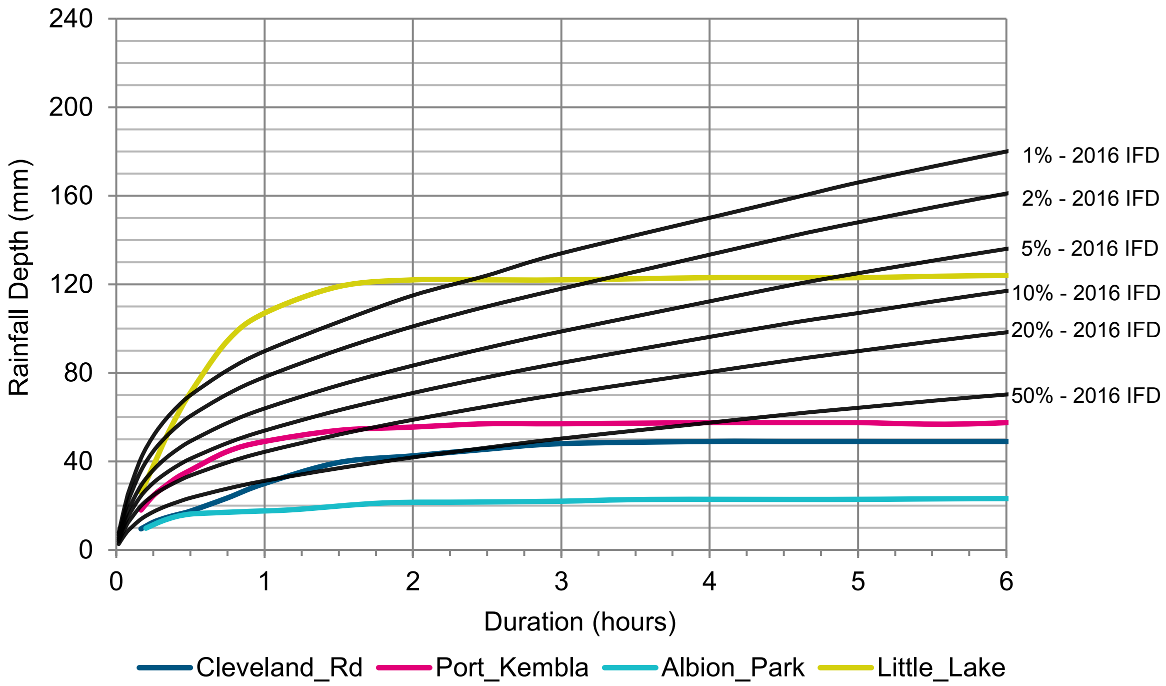


Figure 5-11 Comparison of Recorded November 2013 Rainfall with IFD Relationship

The recorded rainfall at the Little Lake gauge (214466) exceeds the design 1% AEP rainfall for durations between 0.5 to 2.25 hours. All other pluvio gauges recorded rainfalls at intensities less than a 10% AEP.

The TUFLOW model was simulated using the recorded data from the Little Lake gauge (214466). In discussion with Council, the Little Lake gauge rainfall was scaled according to the total depths shown in Figure 5-9. The variability of total rainfall depth across the catchment ranged from a total of 60mm in the west, to 100mm in the east.

5.3.1.2 Downstream Boundary Condition

Recorded water level conditions at Cudgeree Bay (214416) and at Lake Illawarra Entrance (214417) have been obtained and used to represent the tailwater conditions within the model.

Figure 5-12 shows the downstream tailwater levels applied to represent Lake Illawarra (Cudgeree Bay) and Lake Illawarra entrance conditions. The downstream tailwater levels at Cudgeree Bay and Lake Illawarra Entrance peak at levels of 0.18 AHD and 0.48 m AHD respectively.

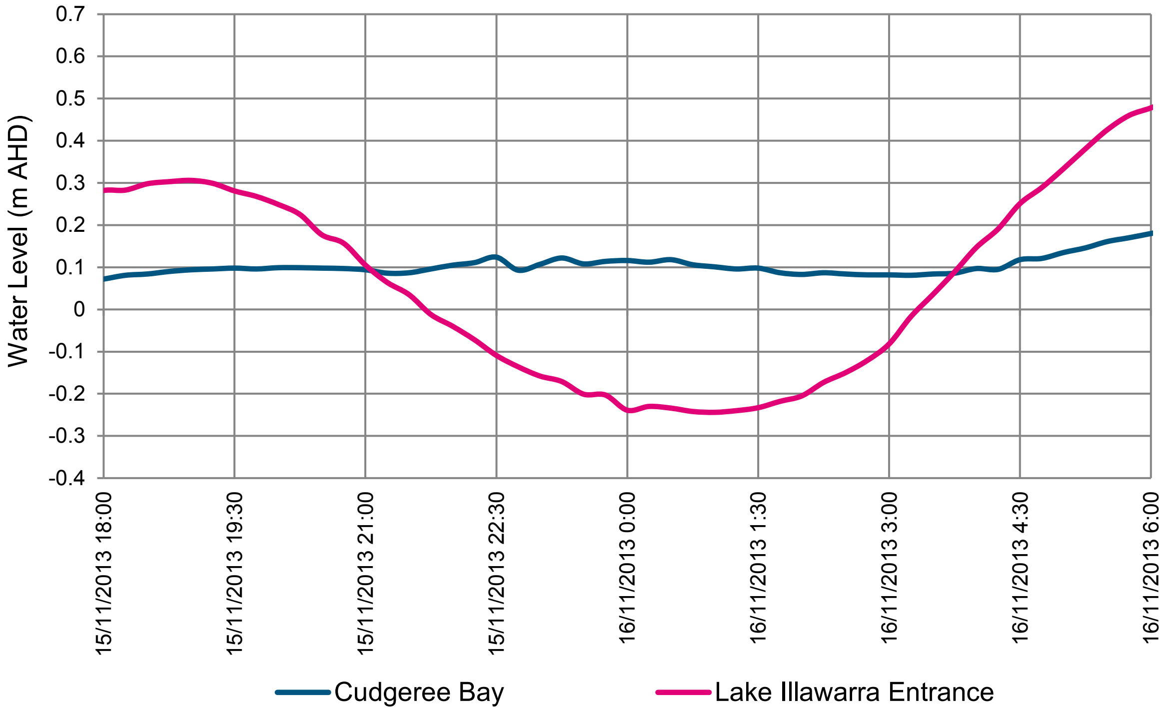


Figure 5-12 Recorded Water Level – November 2013

5.3.1.3 Flood Level Data

As noted for the March 2011 event, there are no stream gauges situated within the catchment to provide recorded water levels for the event. Data for comparison of actual flood levels is limited to anecdotal flood data and observations of the main flow path alignments and peak flood level estimates based on flood marks.

Anecdotal flood data for the November 2013 event was obtained through the community questionnaire response (refer Section 3). The responses do not provide definitive flood levels, but rather indicative depths of flooding and observations of flood flow paths and inundation. The observations are useful to confirm the locations of significant modelled flow paths and depth of flooding to provide some confidence in the model representation of the observed flow condition. For some locations the available description of flooding combined with LiDAR elevation survey enables a determination of approximate flood levels.

The distribution of observed flood data for the November 2013 event compiled from the community consultation feedback is discussed further in Section 5.3.2 and presented in Figure 5-15.

5.3.1.4 Flood Photographs

Historic flood photographs taken by Council Officers after the November 2013 event, and compiled during the data collection phase, are presented below in Figure 5-13 and Figure 5-14.

Figure 5-13 shows a water mark of approximately 200-400 mm depth along a residential fence backing onto Howard Fowles Oval. Figure 5-14 depicts a debris mark at New Lake Entrance Road, immediately downstream of the Shellharbour City Centre Basin. The simulated model results are shown in Figure 5-14 showing a good degree of correspondence between simulated and observed flood levels.

Figure 5-13 Howard Fowles Oval, Lake Illawarra

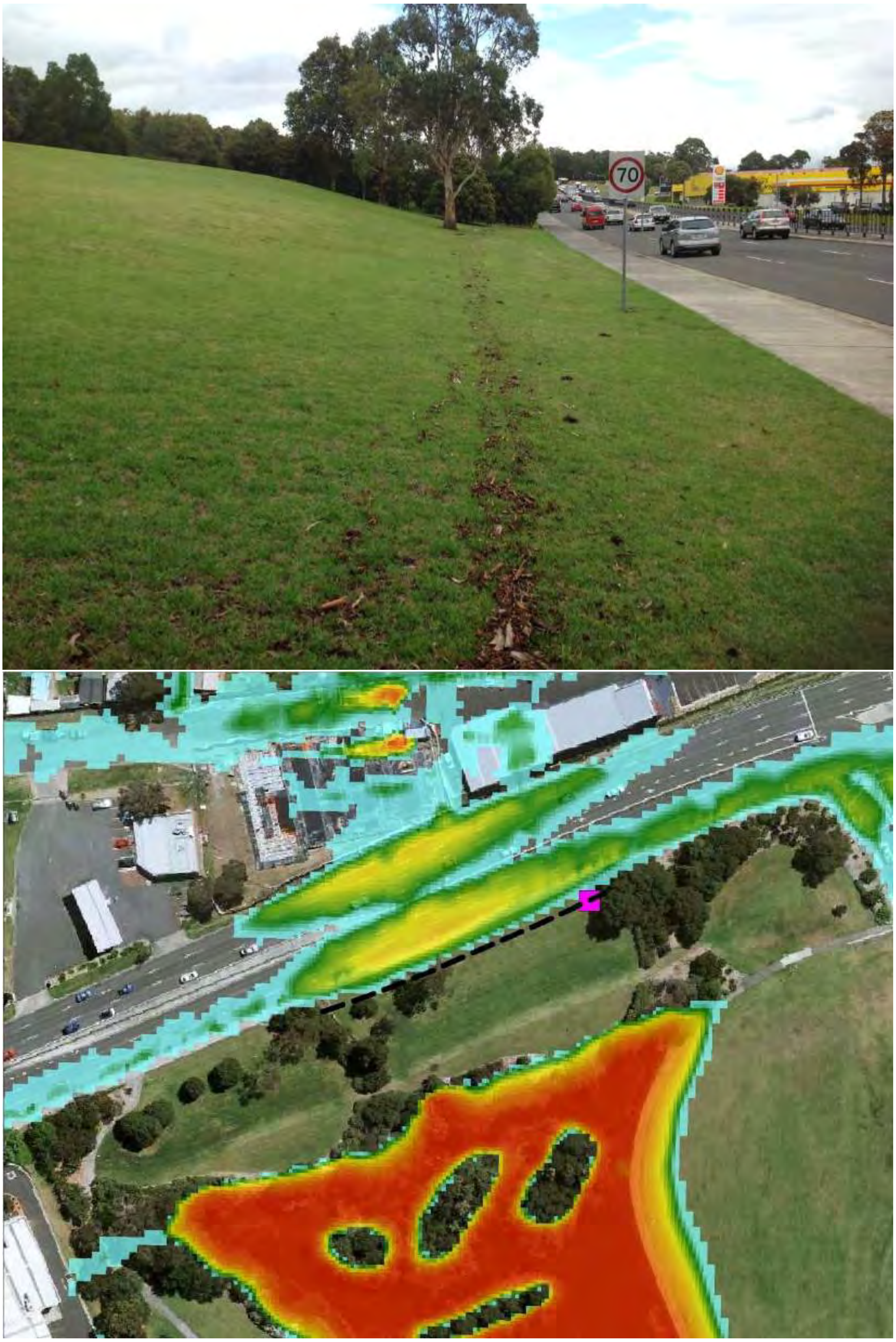


Figure 5-14 New Lake Entrance Road, Oak Flats

5.3.2 Observed and Simulated Flood Behaviour

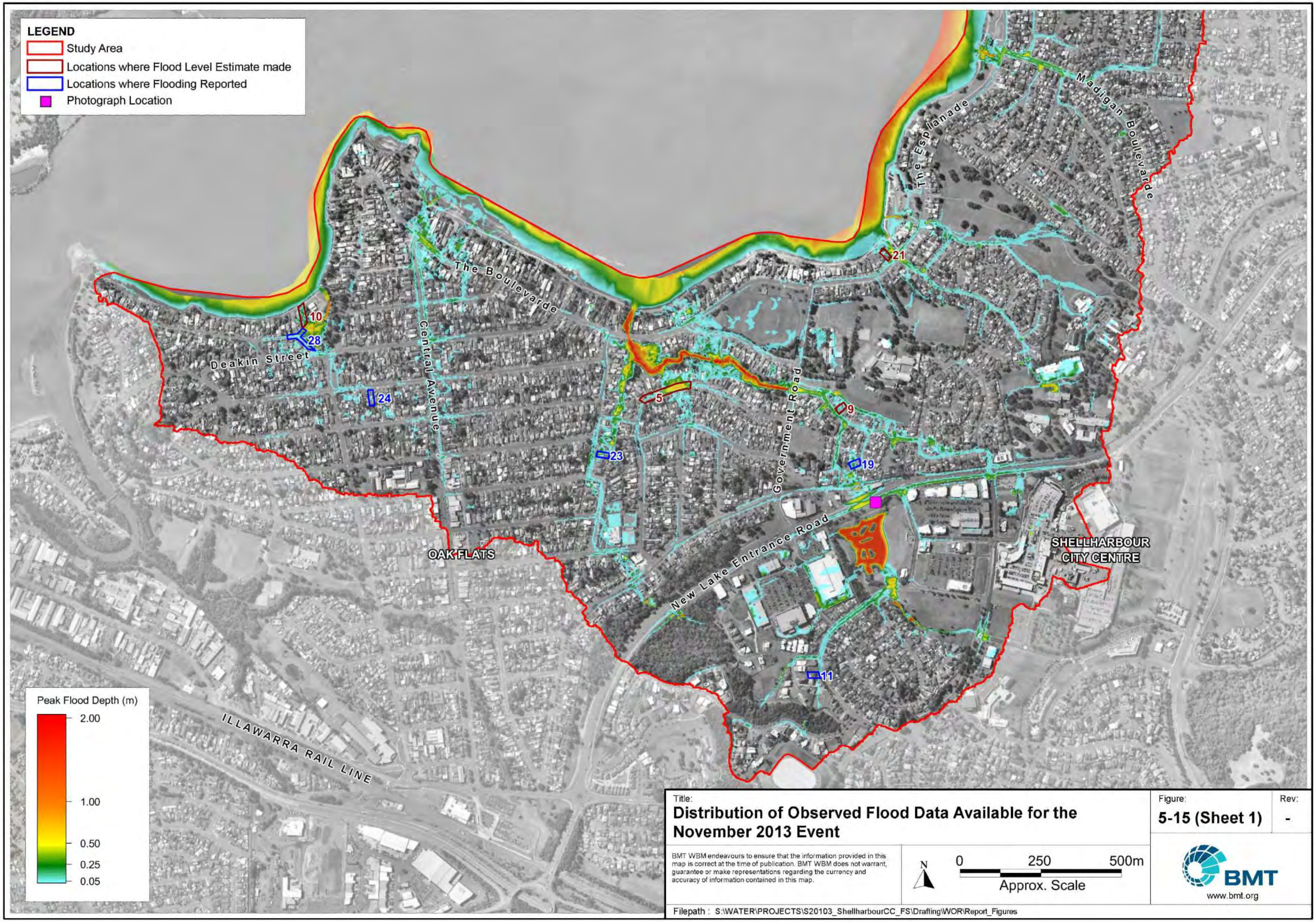
Figure 5-15 provides simulated flood inundation depths for the validation event for comparison to the locations of the community's flooding observations. In general, it can be seen that there is a correlation between the locations at which significant flooding was observed and the alignment of the major flood flow paths in the TUFLOW model results. The community flooding observations have been classified into two categories; locations where general flooding was reported and locations where flood depths were reported.

For locations where some form of flood level estimation was possible a comparison of observed and modelled flood levels is presented in Table 5-4.

Table 5-4 Comparison of Observed and Modelled November 2013 Flood Levels

Reference Location (Figure 5-15)	Location and Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled November 2013 Level (m AHD)	Difference in Flood Levels (m)
2	On road up to 50cm	~1.9	2.0	+0.1
3	On road up to 40cm	~30.5	30.6	+0.1
5	On road 30cm	~3.5	3.9	+0.4
6	50cm in backyard and garage	~2.2	2.2	0.0
7	30 cm on road	~2.2	2.4	+0.2
8	10-30cm in garage; 30cm on road	~2.1-2.4	2.1-2.4	0.0
9	Inside dwelling up to 15cm; Run-off in yard to 10cm depth	~8.5	8.5	0.0
10	45-60cm over backyard	~2.25-2.4	2.3	0.0
21	30cm on property	~3.2	3.3	+0.1
22	20-30cm in gutters	~1.7-1.8	1.8	0.0

It can be seen from Table 5-6 that where reasonable estimates of the peak flood level can be made from the observed data, the modelled flood level is typically within +0.2m of this estimate. This indicates in general the model provides for a reasonable representation of the flood behaviour at these locations considering the relative bounds of uncertainty.



Title:
Distribution of Observed Flood Data Available for the November 2013 Event

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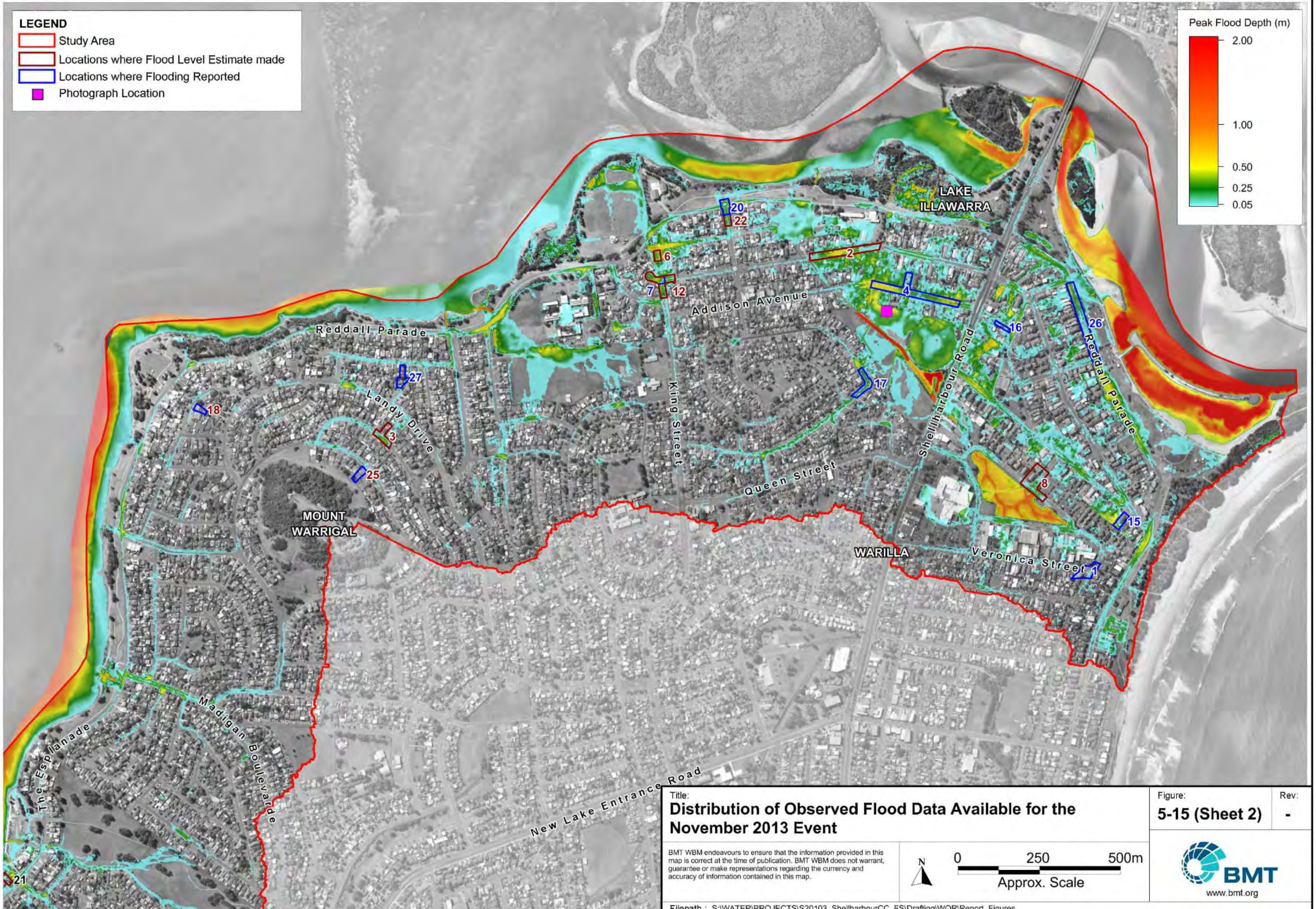

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Distribution of Observed Flood Data Available for the November 2013 Event

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5.4 March 2014 Model Validation

5.4.1 Validation Data

5.4.1.1 Rainfall Data

Given the lack of rainfall data within the study area (i.e. no rainfall gauges within the study area) and the often high spatial variability of short duration, intense rainfall, it is difficult to determine a reliable estimate of rainfall variability for the study area. However, there are a number of gauges situated within the wider region that can be analysed to understand the likely range of rainfall intensities experienced within the catchment.

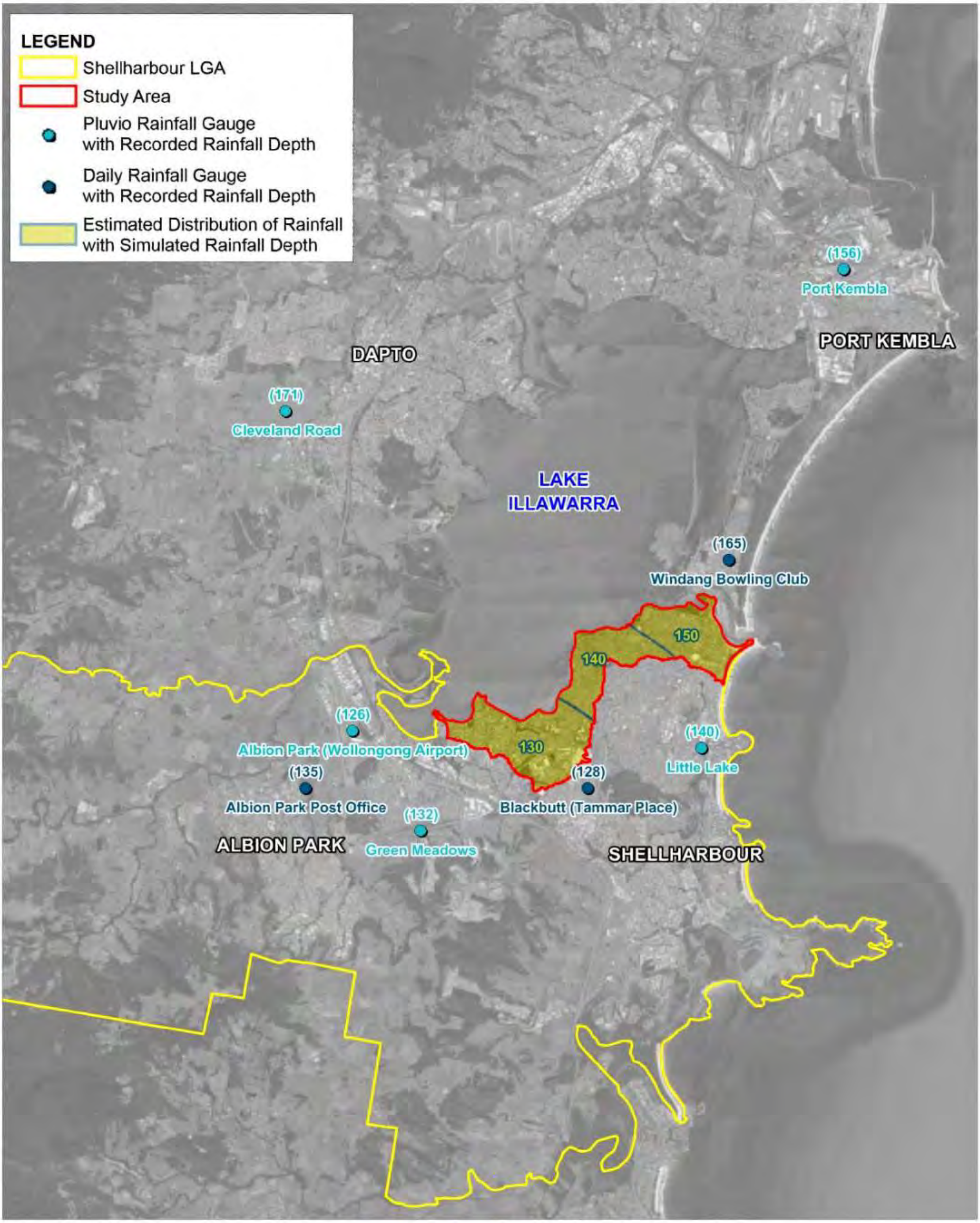
Four pluvio gauges and three daily rainfall gauges have been considered in this analysis and are summarised in Table 5-5 with the gauge locations shown in Figure 5-16. Rainfall totals have been summed over a 24 hour period starting 09:00 on the 24th of March.

Table 5-5 March 2014 Event Recorded Daily Rainfall Total

Gauge Station No.	Gauge Type	Location	Approximate Locality from the Centre of Study Area	Daily Rainfall Total (mm)
214466	Pluvio	Little Lake	2.5 km to the ESE	140
568308	Pluvio	Cleveland Road	8.1 km to the NW	171
568316	Pluvio	Port Kembla	9.6 km to the NE	156
68241	Pluvio	Albion Park (Wollongong Airport)	4.7 km to the WSW	126
SCC	Pluvio	Green Meadows	4.3 km to the SW	132
68123	Daily	Windang Bowling Club	3.7 km to the NE	165
68246	Daily	Blackbutt (Tammar Place)	1.8 km to the S	128
68000	Daily	Albion Park Post Office	5.9 km to the WSW	135

Analysis of the rainfall gauges in the vicinity of the study area show the daily rainfall totals to be fairly uniform, with a minimum of 126mm to a maximum of 171mm. In general, the recorded daily rainfall within a 6km radius of the study area was in the order of 130mm. The Green Meadows gauge (SCC) and Little Lake gauge (214466) are the closest pluvio gauges in the vicinity of the study catchments, and are likely to be most representative of the typical rainfall conditions experienced across the study area.

Figure 5-17 shows the recorded rainfall hyetographs for the pluvio gauges listed in Table 5-5. The hyetograph includes constant rainfall from 09:00 on the 24th of March 2014 until 05:00 on 25th March 2014. Two bursts of heavy rainfall occurred over a two-to-three hour period, separated by a period of around six hours. The first burst began at around 17:00, the second followed at around 00:00 on the 25th of March.



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Daily Rainfall Totals March 2014 Event

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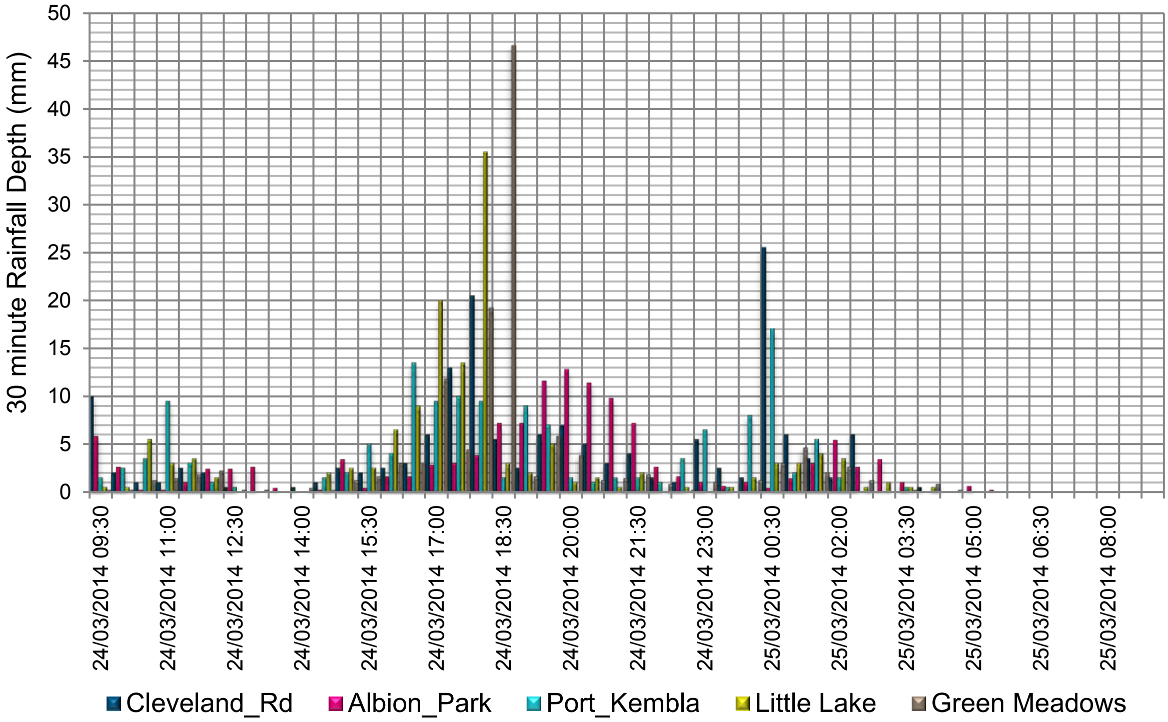


Figure 5-17 Rainfall Hyetograph – March 2014 Rainfall

In order to gain an appreciation of the relative intensity and magnitude of the March 2014 event, the recorded rainfall depth at the five pluvio gauges for various durations within the storm is compared with design IFD rainfall curves obtained from the BoM. Figure 5-18 presents the recorded March 2014 rainfall intensities against the 2016 IFD, for comparison.

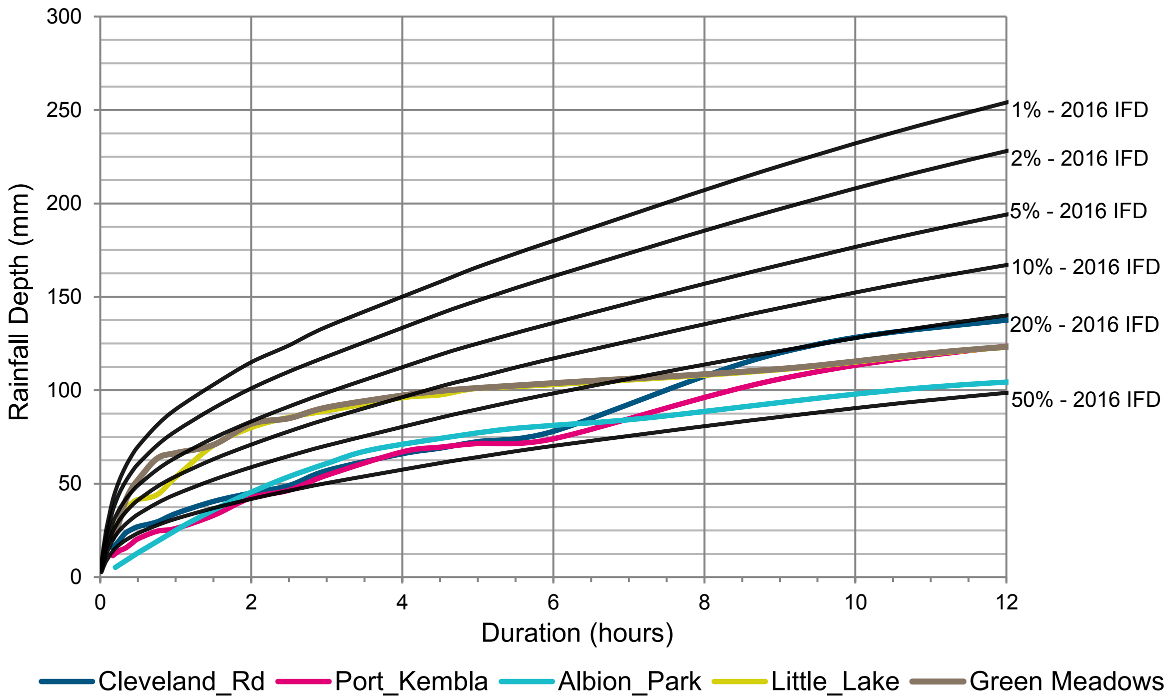


Figure 5-18 Comparison of Recorded March 2014 Rainfall with IFD Relationship

The recorded rainfall at the Port Kembla, Cleveland Road and Albion Airport pluvio gauges are in the order of the 50% AEP design intensity or lower for durations less than 6 hours. The Green Meadows gauge and the Little Lake gauge recorded the highest intensity rainfalls in the vicinity of the study area, recording depths approximate to the 5% AEP design intensity (2-hour duration).

The TUFLOW model was simulated using the recorded data from the Little Lake gauge (214466) due to its proximity to the study area. In addition, analysis of the daily rainfall totals in the vicinity of the study area indicated that the recorded rainfall in the wider region was fairly uniform. Whilst the gauge at Green Meadows recorded the highest intensity rainfall, the IFD analysis showed Green Meadows and Little Lake to be almost identical for the catchments critical 2-hour duration.

In discussion with Council, the Little Lake gauge rainfall was scaled according to the total depths shown in Figure 5-16. The variability of total rainfall depth across the catchment ranged from a total of 130mm in the west, to 150mm in the east.

5.4.1.2 Downstream Boundary Condition

Recorded water level conditions at Cudgeree Bay (214416) and at Lake Illawarra Entrance (214417) have been obtained and used to represent the tailwater conditions within the model.

Figure 5-19 shows the downstream tailwater levels applied to represent Lake Illawarra (Cudgeree Bay) and Lake Illawarra Entrance conditions. The downstream tailwater levels at Cudgeree Bay and Lake Illawarra Entrance peak at levels of 0.61 AHD and 0.66 m AHD respectively.

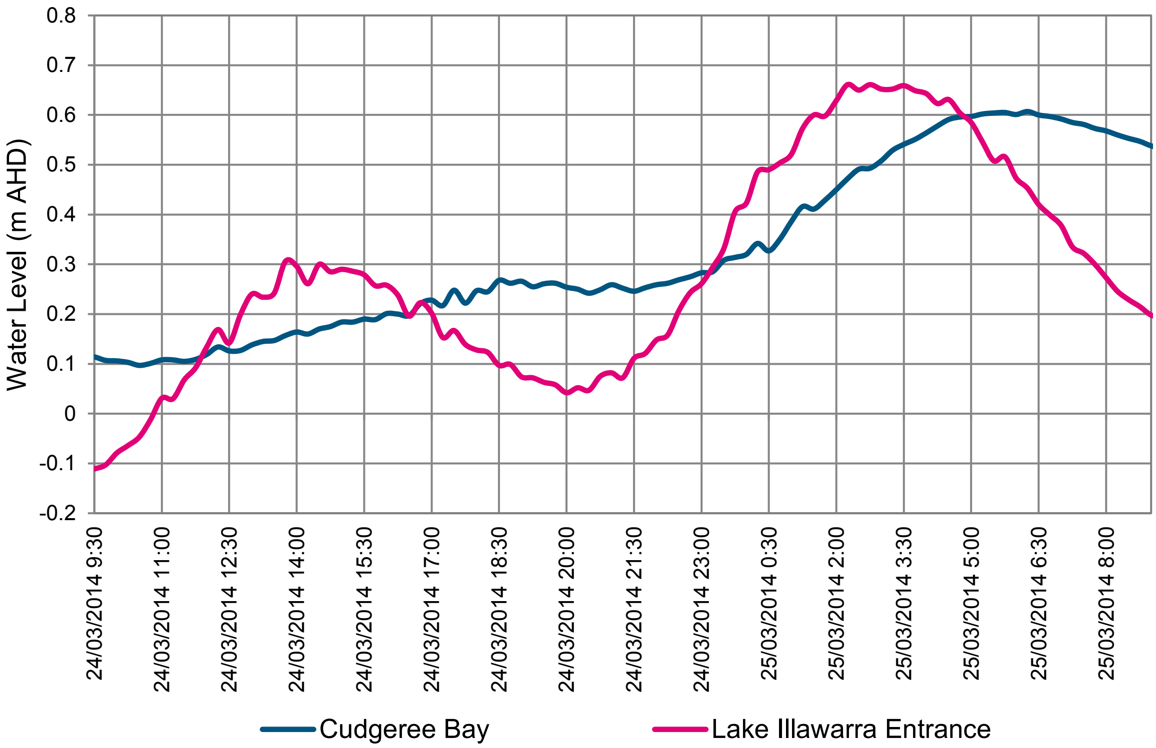


Figure 5-19 Recorded Water Level – March 2014

5.4.1.3 Flood Level Data

Anecdotal flood data for the March 2014 event was obtained through the community questionnaire response (refer Section 3). Most of this data does not provide definitive flood levels, but rather indicative depths of flooding and observations of flood flow paths and inundation. The observations are useful to confirm the locations of significant modelled flow paths and depth of flooding to provide some confidence in the model representation of the observed flow condition. For some locations the available description of flooding combined with LiDAR elevation survey enables a determination of approximate flood levels.

The distribution of observed flood data for the March 2014 event, compiled during community consultation, is discussed further in Section 5.4.2 and presented in Figure 5-21.

5.4.1.4 Flood Photographs

A flood photograph compiled during the community consultation is presented below in Figure 5-20. Photographs depicting significant flooding were used to confirm modelled flood behaviour as discussed in Section 5.4.2.

Figure 5-20 The Boulevarde, Oak Flats

5.4.2 Observed and Simulated Flood Behaviour

Figure 5-21 provides simulated flood inundation depths for the validation event for comparison to the locations of the community's flooding observations. In general, it can be seen that there is a good correlation between the locations at which significant flooding was observed and the alignment of the major flood flow paths in the TUFLOW model results. The community flooding observations have been classified into three categories; locations where general flooding was reported, locations where flood depths were reported and locations where flood photographs were taken.

For locations where some form of flood level estimation was possible a comparison of observed and modelled flood levels is presented in Table 5-6.

Table 5-6 Comparison of Observed and Modelled March 2014 Flood Levels

Reference Location (Figure 5-21)	Location and Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled March 2014 Level (m AHD)	Difference in Flood Levels (m)
1	8-10cm in backyard	~12.5	12.6	+0.1
3	1m	~16.6	16.3	-0.3
5	50cm	~3.2	3.4	+0.2
6	Max. depth 50cm	~1.8	1.7	-0.1
8	50cm in driveway	~3.8	3.8	0.0
9	15cm in backyard; and 50cm across road	~3.3; and ~3.1	3.3; and 3.1	0.0; and 0.0
10	10-15cm	~32.1	32.1	0.0
11	50cm	~2.1	2.1	0.0

It can be seen from Table 5-6 that where reasonable estimates of the peak flood level can be made from the observed data, the modelled flood level is typically within 0.1m - 0.3m of this estimate. This indicates in general the model provides for a reasonable representation of the flood behaviour at these locations considering the relative bounds of uncertainty.

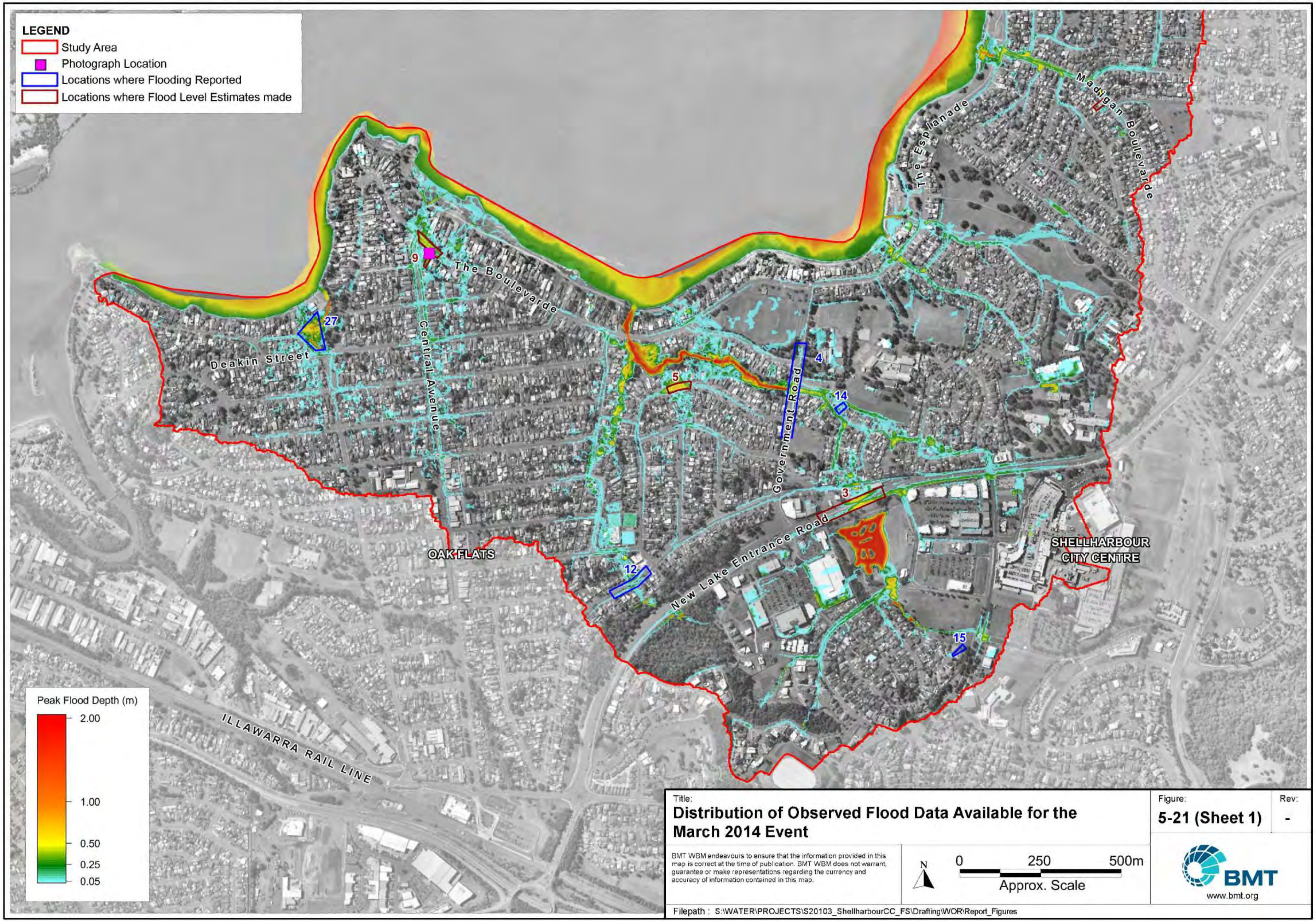
5.5 Rainfall Losses

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 total rainfall which falls in an event does not all contribute to run-off. Many precipitation loss processes occur which reduce the effective rainfall converted to run-off. Some rainfall fills depression storages on the ground surface, some is lost by interception from vegetation while some infiltrates into the ground. A conceptual model known as the “Initial Loss – Continuing Loss model” is widely used in Australia and is adopted for this study.

The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff. The initial loss signifies 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 storm event.

In defining initial loss conditions, AR&R 2016 refers to the initial loss component as a “burst loss” which considers both “pre-burst” rainfall and “storm initial loss”.



Title:

Distribution of Observed Flood Data Available for the March 2014 Event

Figure: 5-21 (Sheet 1)

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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.

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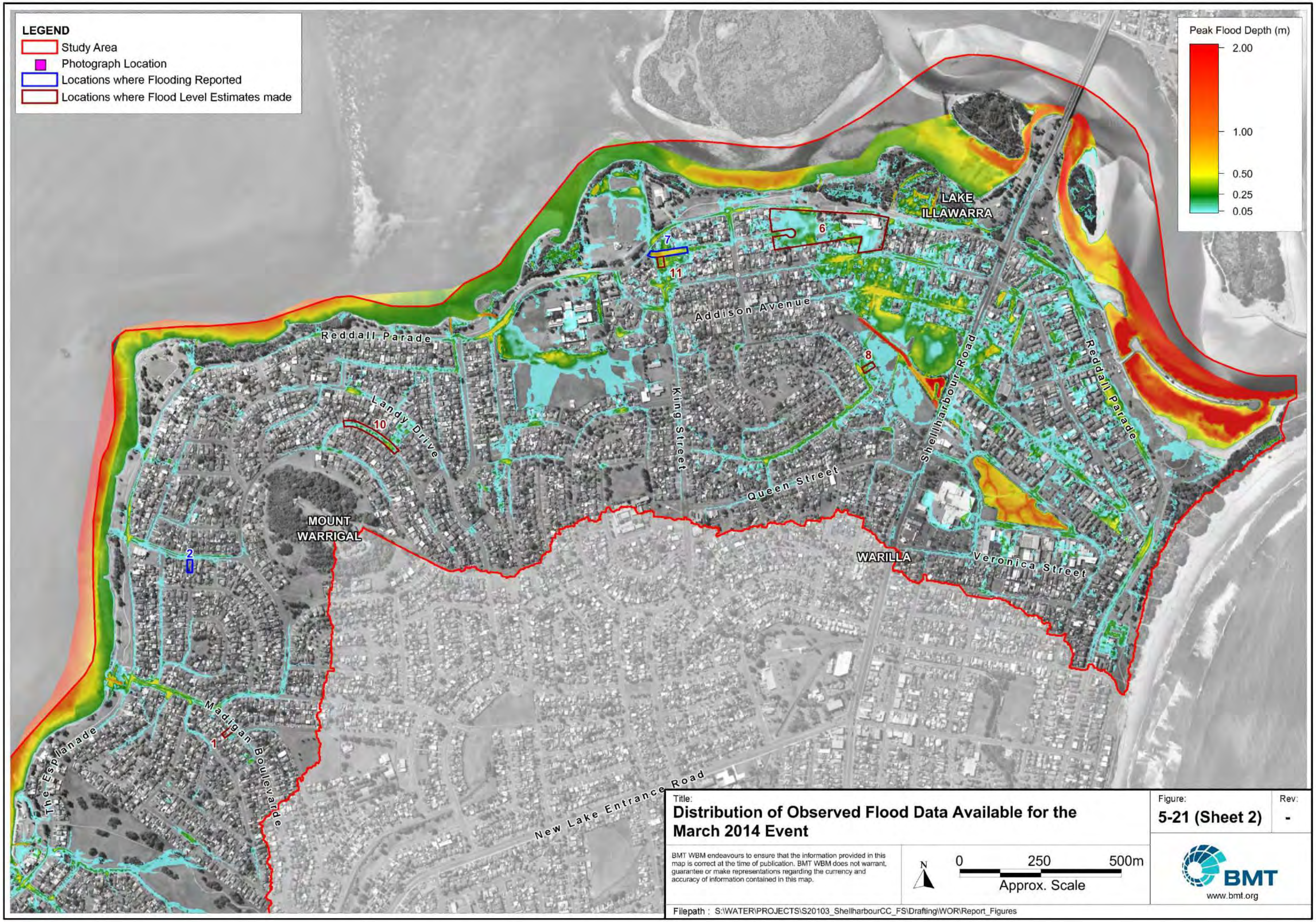

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Distribution of Observed Flood Data Available for the March 2014 Event

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5.5.1 Assessment of Calibration Events to Define Pre-burst Rainfall

Given the limited amount of flood data and bounds of uncertainty relating to loss-rates in urban environments, a definitive tuning of initial and continuing loss rates could not be undertaken during model calibration and validation. As such, an investigation into the antecedent rainfall conditions in the 48 hours preceding the historic storms (March 2011, November 2013 and March 2014) was undertaken for the Little Lake Gauge (214466), and compared to pre-burst depth tables for the Oak Flats, Mt Warrigal and Lake Illawarra centroid as defined by AR&R 2016 (Ball et. al, 2016).

Figure 5-22 presents the March 2011 main storm burst occurring at approximately 08:30 on the 21st, and the 48 hours preceding the flood event. The main storm burst produced approximately 149.5 mm of rainfall over a 3-hour period, and the preceding rainfall producing approximately 212.5 mm.

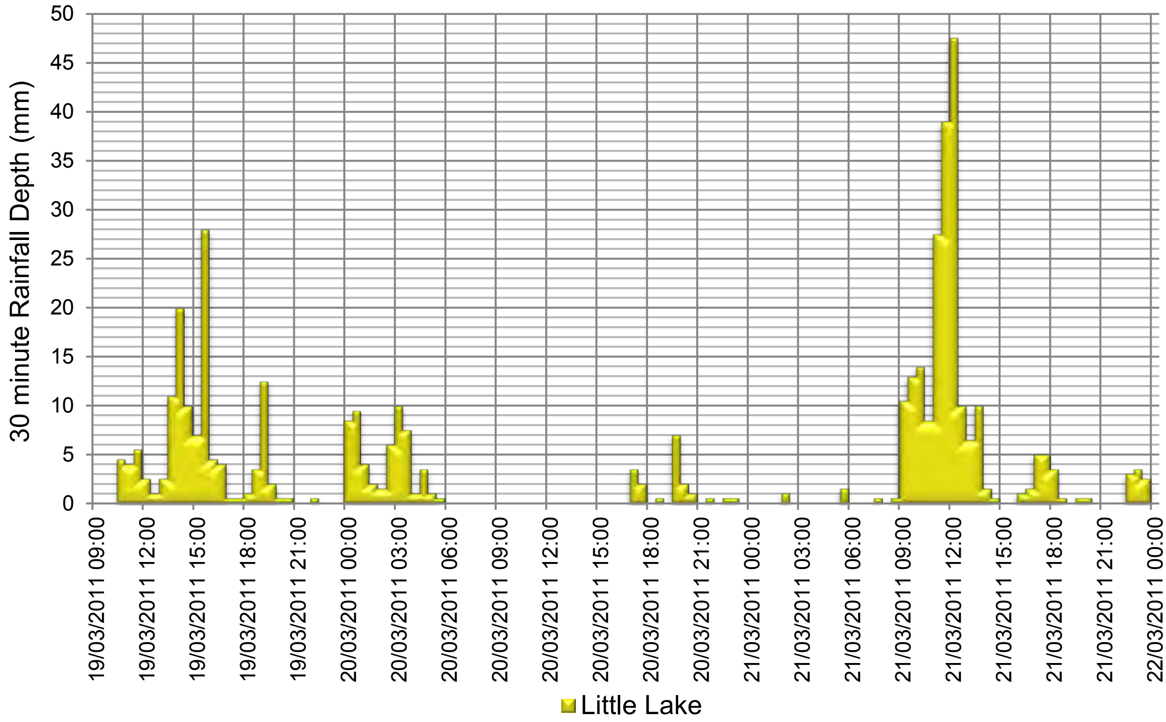


Figure 5-22 March 2011 Antecedent Rainfall Conditions Little Lake gauge (214466)

The flood producing burst, occurring over 3 hours, equates approximately to the 1% AEP. Comparing the preceding rainfall (212.5 mm), to the selection of pre-burst tables (i.e. Median, 10%, 25%, 75% and 90%) from the AR&R datahub, the table most matching the 1% AEP (3-hour duration) is the 90% Pre-burst Table, with a value of 212.4 mm (refer Table F-5, Appendix F).

Figure 5-23 presents the November 2013 main storm burst occurring at approximately 22:30 on the 15th, and the 48 hours preceding the flood event. The main storm burst produced approximately 101 mm of rainfall over a 1-hour period, and the preceding rainfall producing approximately 15.5 mm.

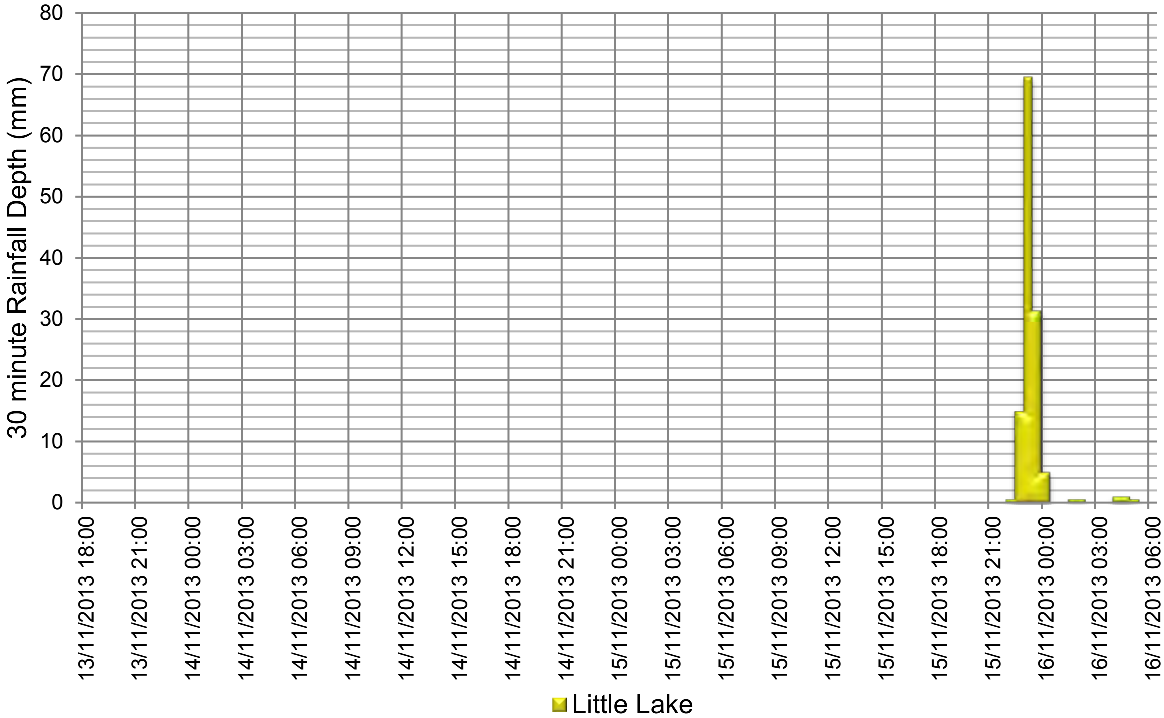


Figure 5-23 November 2013 Antecedent Rainfall Conditions Little Lake gauge (214466)

The flood producing burst, occurring over 1-hour, equates approximately to the 1% AEP. Comparing the preceding rainfall (15.5 mm), to the selection of pre-burst tables (i.e. Median, 10%, 25%, 75% and 90%) from the AR&R datahub, the table most matching the 1% AEP (1-hour duration) is either the Median Pre-burst Table, with a value of 0.9 mm (refer Table F-1, Appendix F) or 75% Pre-burst Table, with a value of 29.7 mm (refer Table F-4, Appendix F).

Figure 5-24 presents the March 2014 main storm burst occurring at approximately 16:30 on the 24th, and the 48 hours preceding the flood event. The main storm burst produced approximately 78 mm of rainfall over a 2-hour period, and the preceding rainfall producing approximately 36 mm.

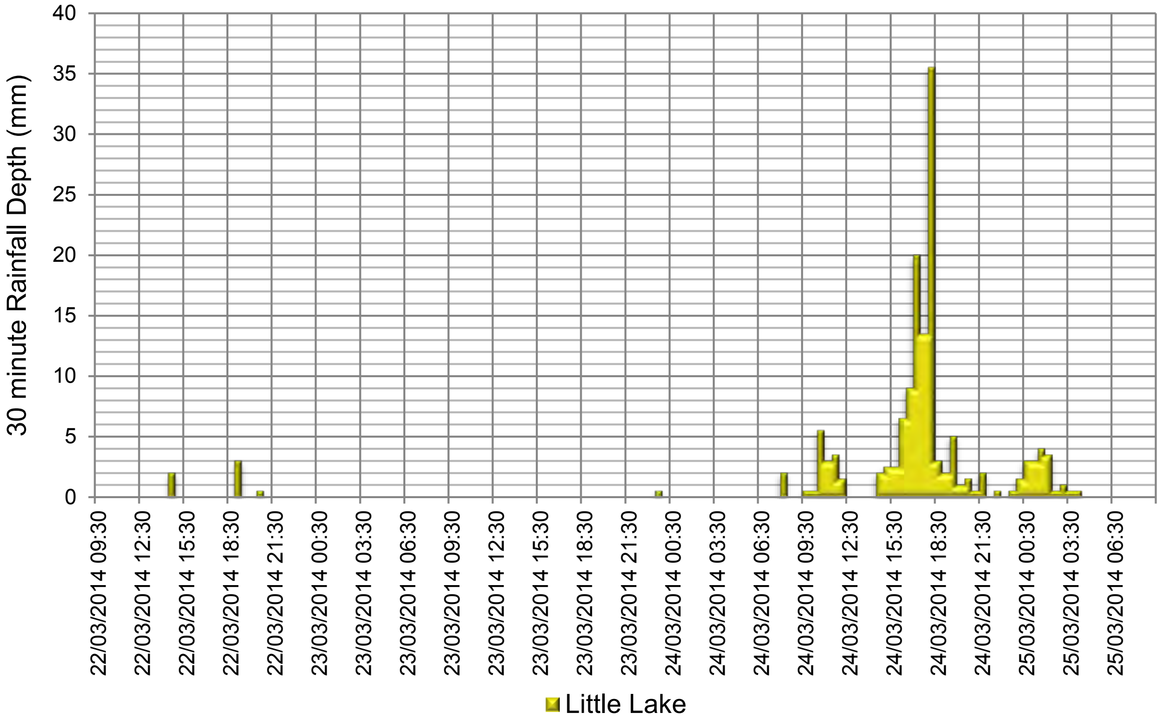


Figure 5-24 March 2014 Antecedent Rainfall Conditions Little Lake gauge (214466)

The flood producing burst, occurring over 2-hours, equates approximately to the 5% AEP. Comparing the preceding rainfall (36 mm), to the selection of pre-burst tables (i.e. Median, 10%, 25%, 75% and 90%) from the AR&R datahub, the table most matching the 5% AEP (2-hour duration) is the 75% Pre-burst Table, with a value of 47.9 mm (refer Table F-4, Appendix F).

Whilst the above analysis is not exhaustive, it does show that for the most recent three flood producing events in the Oak Flats, Mt Warrigal and Lake Illawarra catchments, the antecedent conditions have been in excess of the median pre-burst tables for the region. A summary of findings is presented below in Table 5-7.

Table 5-7 Pre-burst Depth Antecedent Conditions

Historic Event	Flood Burst (mm)	Pre-burst (mm)	Flood burst approx. AEP and duration	Pre-burst depth table
March 2011	149.5	212.5	1% AEP (3-hour)	90%
November 2013	101	15.5	1% AEP (1-hour)	75% or Median
March 2014	78	36	5% AEP (2-hour)	75%

In analysing the available data, and in consultation with Council and OEH staff, it was determined that the 75% Pre-burst depth table most matched the historic antecedent conditions for the Oak Flats, Mt Warrigal and Lake Illawarra catchments.

Design rainfall losses are further discussed in Section 6, Design Flood Conditions.

5.6 Catchment Flow Validation

The TUFLOW model developed for the study utilises the "direct-rainfall" approach for modelling the catchment hydrology (refer to Section 2.6.1). Additional hydrologic modelling of selected sub-catchments within the overall study area has been undertaken using alternative modelling methods as a validation comparison.

The validation approach involved setting up a Watershed Bounded Network Model (WBNM) for the Oakey Creek catchment. WBNM has been developed local to the study catchments and is used extensively throughout Australia to model the hydrologic response of complex watersheds.

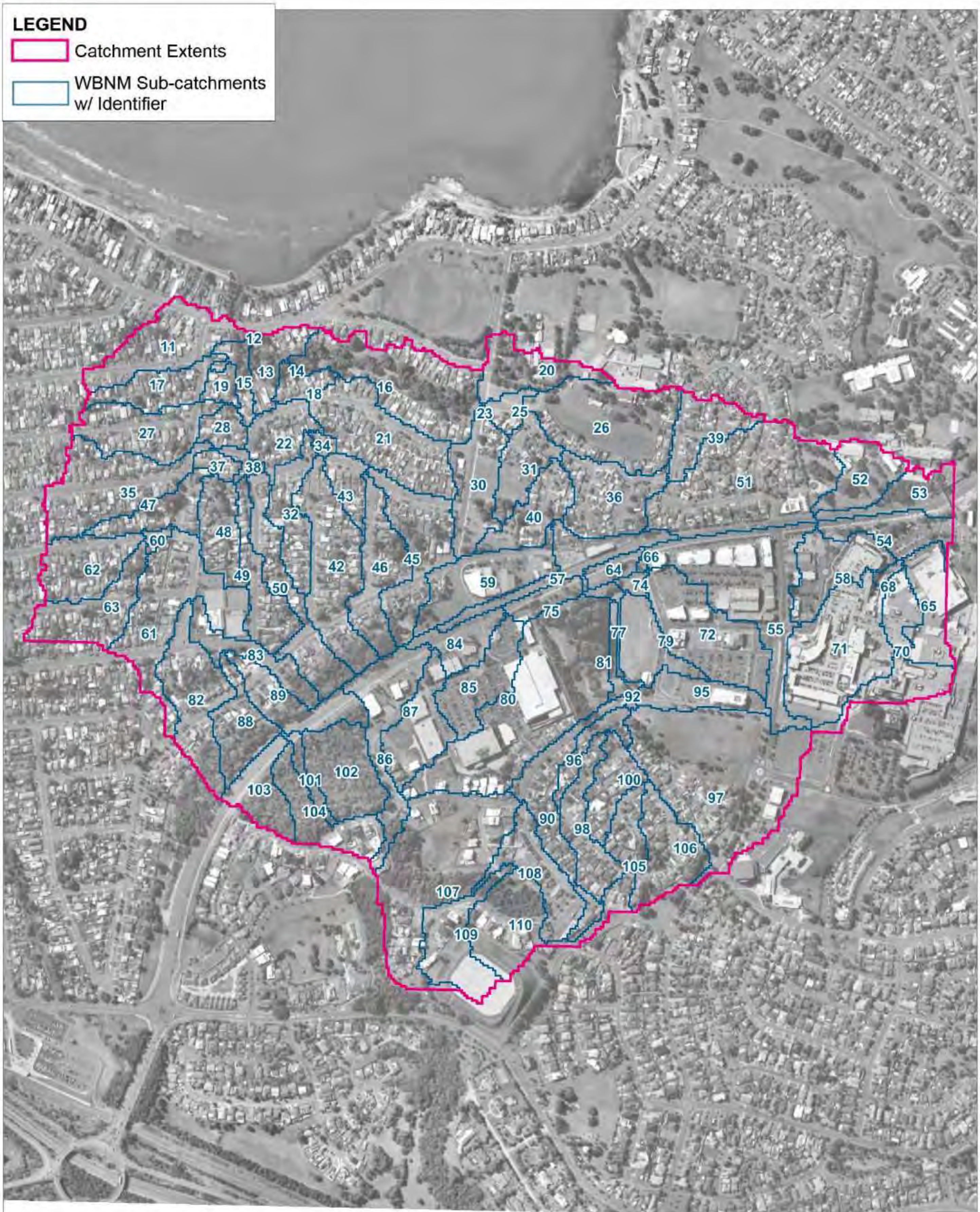
WBNM models are developed on the basis of a catchment divided into a number of sub-areas (sub-catchments) based on the stream network. This allows hydrographs to be calculated at various points within the catchment, and the spatial variability of rainfall and rainfall losses to be modelled. WBNM separates overland flow routing from channel routing, allowing changes to either or both of these processes, for example in urbanising catchments.

To validate catchment flows, the Oakey Creek catchment has been split into 100 sub-areas, as shown in Figure 5-25. The WBNM model has been developed by entering information for each sub-area such as; area, centroid, outlet, % impervious in addition to recommended catchment parameters (Table 5-8). Initial and Continuing Loss rates were 0mm and 0mm/hr respectively, and fraction impervious were directly translated from TUFLOW direct-rainfall values.

Table 5-8 WBNM Parameter Choices

WBNM Parameter	Value
Pervious Lag Parameter	1.6
Impervious Lag Parameter	0.1
Stream Lag Parameter (Road)	0.33
Stream Lag Parameter (Lot)	1.0

Simulation of the City Centre Basin in the upper Oakey Creek catchment was undertaken utilising the stage/storage/discharge relationship outlined in Table 3-3 of the Shellharbour City Centre Dam Break Study (Cardno, 2014), reproduced below in Table 5-9. A second WBNM model was developed omitting the City Centre basin from simulation as a means of determining the effect the basin has on retarding flow in the Oakey Creek catchment.



Title:
Direct Rainfall Verification
Sub-Catchments for Catchment Flow Verification

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Table 5-9 Stage Storage and Stage Discharge for City Centre Basin

Elevation (m AHD)	Storage Volume (m^3)	Discharge (m^3/s)
18.07	0	0
18.2	1460	0.65
18.4	3822	1.3
18.5	5089	1.62
18.6	6355	2.1
18.8	9063	2.58
19	11929	2.82
19.2	14952	2.92
19.4	18137	3.03
19.5	19817	3.08
19.6	21498	3.18
19.8	25057	3.28
20	28826	3.33
20.2	32816	3.47
20.4	37039	3.6
20.5	39157	3.67
20.6	41276	5.04
20.8	45544	7.79
21	50072	10.53
21.2	54851	13.27
21.4	59373	16.02
21.6	63550	18.76
21.8	67784	21.51
22	72051	24.25
22.4	76329	26.99
22.6	80613	29.74

Simulation of the runoff hydrographs in the Oakey Creek catchment has been undertaken for the following design rainfall events:

- 5% AEP, 120 minute and 540 minute duration storms; and
- 1% AEP, 120 minute and 540 minute duration storms.

Simulations were undertaken using both WBNM models (with SCC Basin and without SCC Basin) and the developed TUFLOW model.

Comparisons of the simulated catchment discharge and the cumulative volume are given in Figure 5-26 and Figure 5-27 respectively.

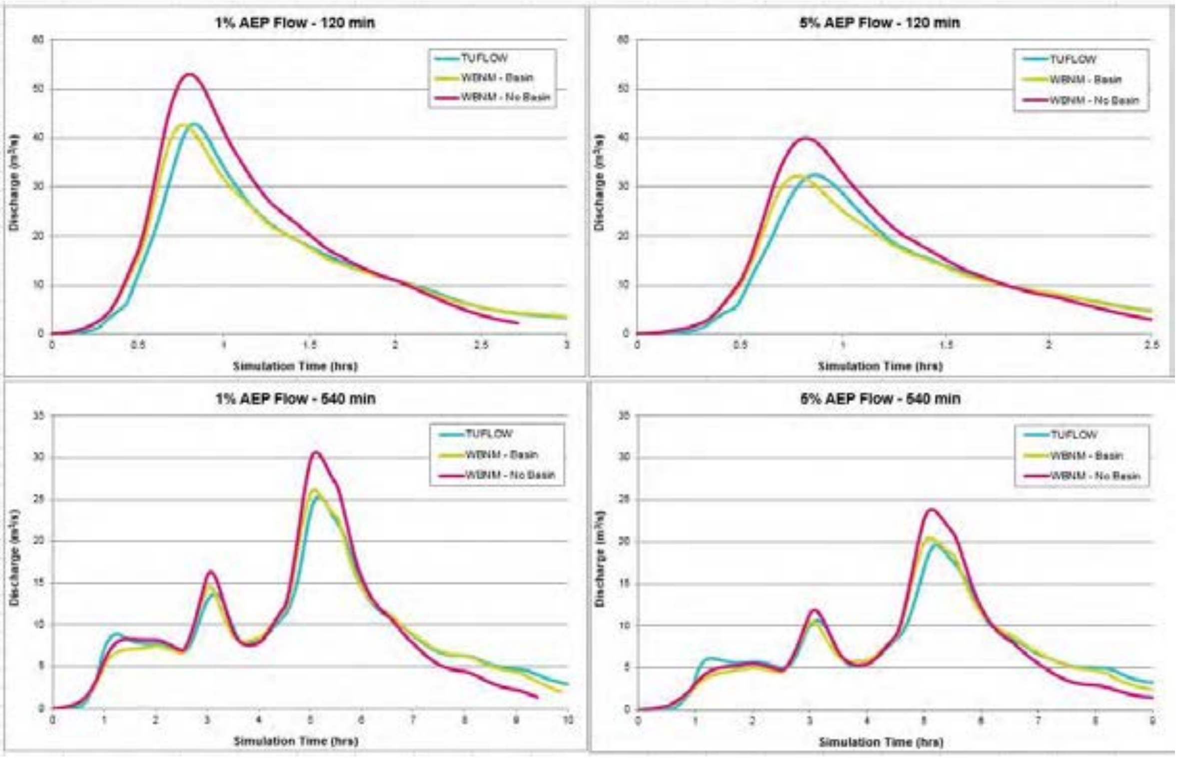


Figure 5-26 Catchment Flow Verification for the Oakey Creek Catchment

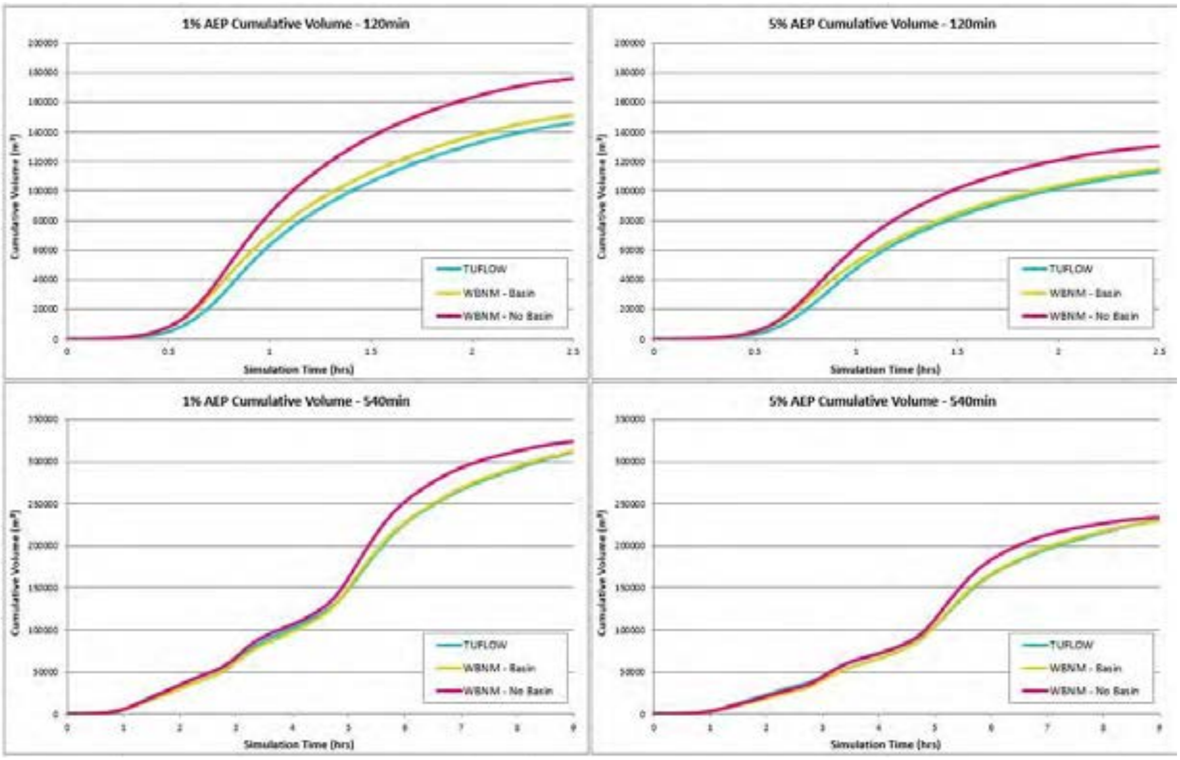


Figure 5-27 Catchment Volume Verification for the Oakey Creek Catchment

The above figures show that for the Oakey Creek catchment, the flow and cumulative volume generated by TUFLOW correlates well with the WBNM estimates. The following observations can be made:

- The TUFLOW model generally lags behind the WBNM model by approximately 5 minutes.
- WBNM produces a slightly more ‘peaky’ catchment response with marginally higher peak flows in the 1% AEP design storm; and
- The cumulative volume in the TUFLOW model is marginally lower the WBNM model, owing largely to minor depressions in the TUFLOW model DEM which cannot drain.

It can be seen from Figure 5-26 that the correlation between the TUFLOW model and the WBNM model containing the SCC Basin compare favourably. The WBNM model simulation without the SCC Basin produces a peakier catchment response as expected.

Whilst WBNM is an industry recognised software for hydrologic modelling, WBNM does not represent all the physical features within the catchment which are being modelled in the TUFLOW model (e.g. steep, paved overland flow paths), which may explain some of the differences in the calculated hydrograph shapes. Furthermore, the WBNM model cannot account for small depression storages which are captured by the 2D TUFLOW model.

To investigate the total volume lost to depression storages in the TUFLOW model, the models were re-run until the flood wave had passed completely through the model. A review of the existing model volumes indicated that the retained volume in the TUFLOW model were around 3-4% for all simulated design storms (i.e. the 20yr 120 min storm, 20yr 540 min storm, 100yr 120 min storm and 100yr 540 min storm). This represents a small portion of the total storm volume, and does not affect peak flood levels as the flood wave moves down the catchment.

The catchment flow validation exercise demonstrated a good correlation between the two modelling methods and indicates that the direct-rainfall modelling methodology adopted for the study provides a reasonable basis to assess overall flood behaviour.

5.7 Adopted Model Parameters for Design Events

The values for the Manning’s ‘*n*’ roughness developed for the defined land use categories (refer to Figure 4-1) determined through the model calibration and validation process and proposed for design event modelling are summarised in Table 5-10.

Initial losses of 1mm and continuing losses of 0mm are applied for impervious land area. Rainfall losses for pervious surfaces are 2.5mm/hr for continuing losses, whilst initial losses are varied dependant on the magnitude and storm duration. As discussed in Section 5.5, the 75% Pre-burst depth table provided the best representation of the historic antecedent conditions for the Oak Flats, Mt Warrigal and Lake Illawarra catchments and as such, have been adopted for this study.

Table 5-10 Adopted TUFLOW Model Parameters

Land Use Category	Manning's 'n'	Fraction Impervious	Pervious Area Initial Loss (mm)[1]	Pervious Area Continuing Loss (mm/h)
Residential (w/o buildings)	0.060	20%	Varied dependant on AR&R 2016 75% pre-burst depth table (refer Appendix F)	2.5
Residential (w/ buildings)	0.040	50%		2.5
Commercial	0.040	90%		0.0
Parklands	0.035	5%		2.5
Dense Vegetation	0.100	5%		2.5
Water Body	0.025	100%		0.0
Tidal Zone	0.030	100%		0.0
Roads	0.020	100%		0.0
Buildings	0.03/1.0	100%		0.0

[1] note: refer to Section 6.2.3.3 for adopted pervious area initial loss rates (burst loss)

Buildings have been digitised in the TUFLOW model when they are in a flow path and are likely to reduce the conveyance of floodwater through residential lots. A depth varying Manning's "*n*" is used in these instances so that a lower roughness value (0.03) is applied to enable an early roof runoff response to be simulated. Once a higher depth of overland flow is developed in the model, a higher roughness value (1.0) is applied to the building polygon to provide an appropriate impedance to the flow. Outside of the designated flow paths, digitised 'Residential Lots' have an increased Manning's "n" to account for the increased losses due to the presence of buildings.

5.8 Conclusion

The model calibration process has involved the development of an appropriate hydraulic model in order to best represent the flooding conditions within the study area utilising the available data. Model parameters have been adopted which are consistent with typical industry standard ranges and experiences learnt from other modelled catchments of a similar nature.

Rainfall inputs have been developed for the models for three calibration/validation events; March 2011, November 2013 and March 2014 utilising available rainfall gauge data. The March 2011, November 2013 and March 2014 model simulations have shown the adopted model configuration to perform well across a range of events, producing reasonable matches to observed flood level data where available.

Historical pre-burst rainfall depths were analysed, showing most conference with the 75% Pre-burst depth table from the AR&R 2016 online datahub.

Additional hydrologic modelling using the WBNM software was undertaken as a validation exercise to compare flows generated within the TUFLOW model. Comparison of simulated hydrographs for the Oakey Creek catchment provided for a good match in peak flows, timing and volume between the WBNM and TUFLOW estimates.

The developed TUFLOW model has been demonstrated to provide a sound representation of the catchment response to rainfall and accordingly considered to be a suitable tool for design flood estimation.

6 Design Flood Conditions

6.1 Introduction

Design floods are hypothetical floods used for planning and floodplain management investigations. Design floods are therefore not real rainfall events, rather they are values that are probabilistic in nature. They are based on having a probability of occurrence specified either as:

- Exceedances per Year (EY); or
- Annual Exceedance Probability (AEP) expressed as a percentage.

There are five broad classes of design rainfall estimates each with their own set of methodologies and datasets. Each class is categorised by frequency of occurrence, as shown below in Table 6-1.

Table 6-1 Classes of Design Rainfall

Design Rainfall Class	Frequency of Occurrence	Probability Range
Very Frequent Design Rainfalls	Very Frequent	12EY to 1EY
Intensity Frequency Duration (IFD)	Frequent	1EY to 10% AEP
Intensity Frequency Duration (IFD)	Infrequent	10% AEP to 1% AEP
Rare Design Rainfalls	Rare	1% AEP to 0.05% AEP
Probable Maximum Precipitation (PMP)	Extreme	< 0.05% AEP

In accordance with Council's brief, the simulated design events include the PMF, 0.5%, 1%, 2%, 5%, 10%, and 20% AEP events for catchment derived flooding. The 1% AEP flood is generally used as the reference flood for design flood planning levels for residential development. However, land use planning and development control considers flooding up to the PMF extent (produced by the PMP) used to define the full extent of the floodplain.

The adopted storm durations and temporal patterns are discussed in Section 6.2.4. The adopted ocean downstream boundary conditions are discussed in Section 6.3.

6.2 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R, which are based on statistical analysis of recorded rainfall data across Australia. The procedure to establish design rainfall was recently revised in 2016, updating the prior 1987/2001 guidelines. The 2016 guidelines (Ball et. al, 2016) are generally considered current best practice for design flood estimation.

The updated procedures provide for a significant departure from those released in 1987. Some of the key changes in AR&R 2016 are summarised below:

- Intensity-Frequency-Duration (IFD) 2016 design rainfalls – revised IFD rainfall estimates underpin the AR&R 2016 release. The updated IFD analysis includes a significant period of additional rainfall data since the 1987 IFDs were established. The variation between 1987 and 2016 IFD design rainfall is location dependent.
- Design rainfall losses – estimation of initial and continuing loss rates (as applied in the hydrological model) are provided in AR&R 2016 as gridded spatial data. Representative losses

for catchments are extracted from the database. This is a significant change from the previous approach (AR&R 1987) in which basic ranges were recommended for broad areas i.e. eastern or western NSW.

- Pre-burst rainfall – AR&R 2016 provides procedures for the consideration of pre-burst rainfalls for consideration along with design initial losses. The procedures provide for generation of tabular outputs of pre-burst rainfall for the catchment of interest, based on a combination of storm duration and return period.
- Areal reduction factors – new equations have been developed as part of AR&R 2016, with regionalised parameters to define areal reduction factors for catchments, based on catchment area and storm duration.
- Temporal patterns – the change in temporal patterns represents one of the most significant differences from the AR&R 2016 release. Each design duration now has a suite of 10 temporal patterns as opposed to a single temporal pattern for each duration for AR&R 1987.

The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for the Lake Illawarra, Mt Warrigal and Oak Flats catchment is presented below.

6.2.1 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 (2016). The 2016 IFDs are based on a further 30 years of additional rainfall data, have a greater range in design magnitudes (from 12 exceedances per year to 0.05% AEP), and are more accurate, combining contemporary statistical analysis in their determination.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The definition of the PMP is “the theoretical maximum precipitation for a given duration under modern meteorological conditions” (WMO, 2009). 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. The method is appropriate for durations up to 6 hours and considered suitable for small catchments (< 1000 km^2) in the Shellharbour region.

A range of storm durations from 10 minutes to 24 hours was modelled in order to identify the critical storm duration. Table 6-2 shows the design rainfall depths adopted for the modelled events.

Table 6-2 Rainfall Depths for Design Events (mm)

Duration	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	PMP
10 min	19.9	24.4	29.1	35.8	41.4	45.3	n/a
15 min	24.7	30.3	36.1	44.6	51.5	56.4	150
30 min	33.6	41.2	49.1	60.5	69.9	76.5	220
45 min	39.5	48.3	57.4	70.4	81.2	89	270

Duration	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	PMP
1.00 h	44.3	53.9	63.9	78.1	89.8	98.5	320
1.50 h	52.1	63.1	74.4	90.4	103	113	410
2.0 h	58.8	70.9	83.3	101	115	126	480
3.0 h	70.4	84.5	98.7	118	134	146	580
6.0 h	98.3	117	136	161	180	197	770
9.0 h	121	144	167	197	220	239	n/a
12.0 h	140	167	194	228	254	277	n/a
18.0 h	170	205	239	282	314	343	n/a
24.0 h	194	235	275	326	364	399	n/a

6.2.2 Areal Reduction Factors

The areal reduction factor takes into account the unlikelihood that larger catchments will experience rainfall of the same design intensity over the entire area. The Oak Flats, Mt Warrigal and Lake Illawarra catchments contain a series of smaller sub-catchments all draining to the main body of Lake Illawarra. The sub-catchments range in size from 0.1 km^2 to 1.5 km^2, the largest sub-catchment being the Oakey Creek catchment in the suburb of Oak Flats.

Due to the minor size of the sub-catchments, and as per guidance in AR&R (which does not recommend applying an ARF to catchments less than 1.0 km^2 in size), an ARF was been omitted from design flood estimation. In the case of the Oakey Creek sub-catchment, where the entire sub-catchment is 1.5 km^2 in size, the focal point for investigation is not at its outlet to Lake Illawarra, but higher within the catchment, so the omittance of an ARF is still considered appropriate.

6.2.3 Design Rainfall Losses

Utilising the AR&R 2016 guidelines, storm initial loss rates and continuing loss rates are provided as gridded spatial data, based on geographical location. The initial loss (burst loss) for a study catchment is determined based on the following:

Burst Loss = Storm Initial Loss – Pre-burst

Where, the ‘storm initial loss’ is a fixed rainfall depth and the ‘pre-burst’ rainfall depth is varied dependant on catchment location, storm duration and storm probability.

6.2.3.1 Storm Initial and Continuing Loss Rates

For the Oak Flats, Mt Warrigal and Lake Illawarra catchments (Australian Rainfall and Runoff Data Hub, 2017), the rural loss rates are as follows:

(1) Storm Initial Losses (mm) = 61.0; and

(2) Storm Continuing Losses (mm/h) = 4.3

For urban catchments (indirectly connected areas), AR&R recommends storm initial loss values of 60% to 80% of the recommended rural catchment storm initial losses, and a continuing loss value of

2.5 mm/h for catchments in both NSW and the ACT. A value of 70% of the rural catchment storm initial losses was adopted for the Oak Flats, Mt Warrigal and Lake Illawarra study area.

The adopted loss rates are provided below in Table 6-3.

Table 6-3 Adopted Rainfall Loss Parameters

Rainfall Losses	Adopted Parameter
Pervious Initial Loss	42.7 mm
Pervious Continuing Loss	2.5 mm/h
Impervious Initial Loss	1 mm
Impervious Continuing Loss	0 mm/h

6.2.3.2 Pre-burst Rainfall Depths

As discussed in Section 6.2.3, pre-burst depths are dependent on catchment location, storm duration and storm probability. The AR&R online datahub, which holds the design input data to support the ARR guidelines, hosts a selection of pre-burst depth tables (i.e. Median, 10%, 25%, 75% and 90%) relevant to catchment location. The pre-burst depth tables for the Oak Flats, Mt Warrigal and Lake Illawarra catchments are reproduced in Appendix F.

The 75% pre-burst depths were found to most replicate the antecedent catchment conditions during model calibration (refer Section 5.5), and as such have been utilised in the estimation of design rainfall. Table 6-4 below shows the varied pre-burst depths for each modelled design event and duration.

Table 6-4 75% Pre-burst Depths

min (h)	20% AEP (mm)	10% AEP (mm)	5% AEP (mm)	2% AEP (mm)	1% AEP (mm)	0.5% AEP[1] (mm)
60 (1.0)	44.3	42.0	39.8	32.4	26.8	26.8
90 (1.5)	49.1	49.5	50.0	38.4	29.7	29.7
120 (2.0)	52.7	54.0	55.2	51.0	47.9	47.9
180 (3.0)	66.0	78.2	90.0	86.1	83.1	83.1
360 (6.0)	82.1	98.8	114.8	112.2	110.3	110.3
720 (12.0)	67.1	71.9	76.5	88.9	98.2	98.2
1080 (18.0)	60.2	70.6	80.6	81.4	82.0	82.0
1440 (24.0)	41.7	49.5	56.9	82.1	101.0	101.0
2160 (36.0)	27.6	32.8	37.9	87.0	123.9	123.9
2880 (48.0)	20.2	27.7	34.9	76.2	107.1	107.1
4320 (72.0)	11.3	18.5	25.3	41.9	54.3	54.3

[1] Events rarer than 1% AEP adopt the same initial loss

6.2.3.3 Burst Loss

The calculated burst losses for the Oak Flats, Mt Warrigal and Lake Illawarra catchment utilising the value for storm initial loss (42.0 mm) and the 75% pre-burst depths is reproduced below in Table 6-5.

Table 6-5 Oak Flats, Mt Warrigal and Lake Illawarra Design Burst Loss

min (h)	20% AEP (mm)	10% AEP (mm)	5% AEP (mm)	2% AEP (mm)	1% AEP (mm)	0.5% AEP (mm)
60 (1.0)	0	0.5	2.9	10.3	15.9	15.9
90 (1.5)	0	0	0	4.3	13	13
120 (2.0)	0	0	0	0	0	0
180 (3.0)	0	0	0	0	0	0
360 (6.0)	0	0	0	0	0	0
720 (12.0)	0	0	0	0	0	0
1080 (18.0)	0	0	0	0	0	0
1440 (24.0)	1	0	0	0	0	0
2160 (36.0)	15.1	9.9	4.8	0	0	0
2880 (48.0)	22.5	15	7.8	0	0	0
4320 (72.0)	31.4	24.2	17.4	0.8	0	0

Note: Some pre-burst depths exceeded the global initial loss. In these cases, a burst loss of 0 mm was applied.

The burst losses as presented in Table 6-5 have been adopted for all design event modelling, excluding the PMF event. The PMF event modelling has adopted losses as per AR&R recommendations (Ball et. al, 2016) with an initial loss of 0 mm and a continuing loss of 1 mm/h.

6.2.4 Temporal Patterns

The IFD data presented in Table 6-2 provides the average depth of rainfall 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. Standard and non-standard temporal patterns are available from the AR&R online datahub, for each frequency of occurrence (very-frequent, frequent, infrequent, rare and extreme). Each frequency class has a suite of 10 temporal patterns per design duration.

Figure 6-1 shows the 10 temporal patterns for the 1% AEP, 720 minute duration design storm for the Oak Flats, Mt Warrigal and Lake Illawarra catchments. The 1% AEP belongs to the ‘Rare’ frequency of occurrence.

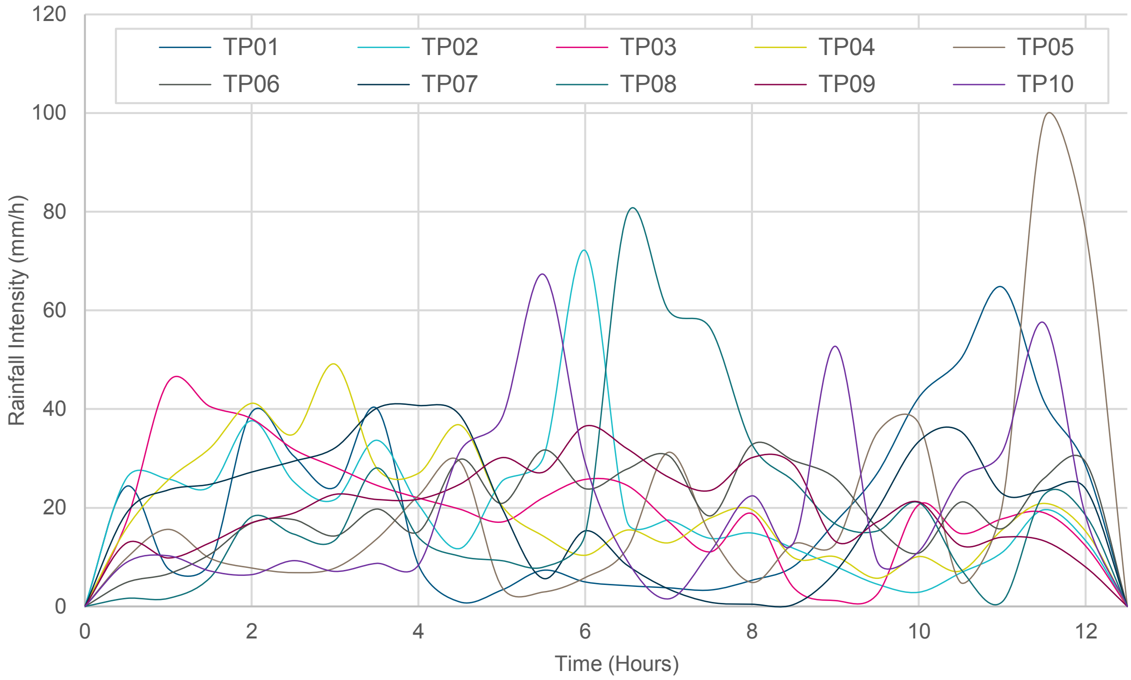


Figure 6-1 1% AEP 720-minute Duration Temporal Patterns – Oak Flats, Mt Warrigal and Lake Illawarra

The procedures for AR&R provide for the selection of the temporal pattern that gives the peak flow closest to the mean of the peak flows from all ten temporal patterns across all design durations. This method was followed to find the critical temporal pattern for each event duration.

6.2.5 Critical Mean Assessment

Design flood levels in the catchment are a combination of flooding from rainfall over the local catchment (overland flooding), as well as elevated water levels in open channels and storage areas (storage flooding). As such, two locations of interest were selected when undertaking the critical mean assessment for the study area. The locations of interest were chosen as being representative of the remaining catchment areas – one for Oakey Creek in the suburb of Oak Flats, and another for the low-lying areas of the suburb of Lake Illawarra.

To determine the critical storm duration for the two locations of interest, modelling of the frequent, infrequent and rare temporal pattern bins was undertaken for a range of storm durations from 10 minutes to 24 hours. Each duration utilised ten temporal patterns extracted from the AR&R datahub relevant to the study area.

The following process was undertaken to determine the critical mean temporal pattern for the two locations of interest:

(1) 10 temporal patterns for each duration were simulated for the frequent, infrequent and rare temporal pattern bins (i.e. 20% AEP, 5% AEP and 1% AEP);

(2) The mean flow (overland) or mean flood level (storage) was determined for each of the durations simulated;

(3) The critical mean was determined as either the highest mean flow or highest mean flood level amongst each of the durations simulated.

Figure 6-2 shows the general analysis undertaken to determine the peak flow at a representative location along Oakey Creek. The box-whisker plot indicates the median peak flow (horizontal line), mean peak flow (star) and first and third quartile peak flows (top and bottom of green box). The whiskers above and below the box represent the lowest and highest peak flows. The analysis shows that for 1% AEP, the 45-minute duration storm produces the critical mean flow.

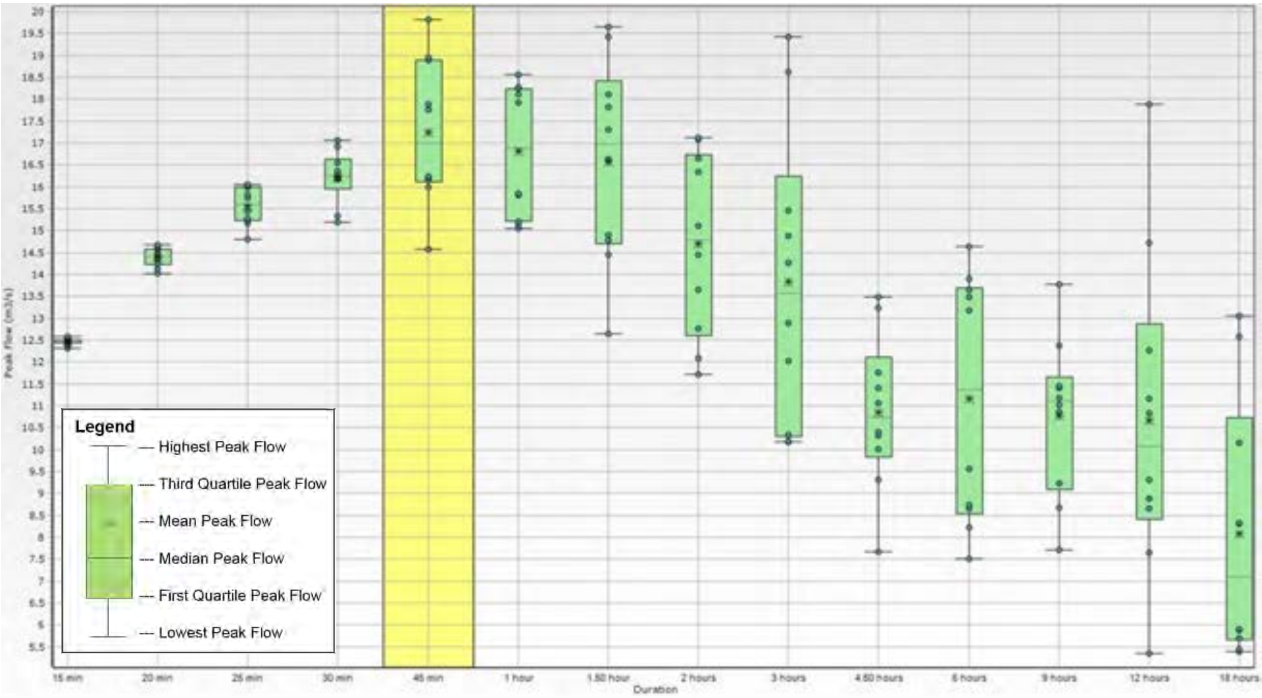


Figure 6-2 Critical Mean Flow Analysis – 1% AEP (Rare Temporal Pattern Bin)

For the design events ranging from the 20% AEP to the 0.5% AEP, the analysis determined that the 30 minute and 45 minute durations were critical for the catchment areas affected by overland flooding, and the 720 minute duration was critical for areas affected by storage flooding.

For the PMF, determined using the Generalised Short Duration Method (GSDM), the critical durations were found to be the 15 minute and 90 minute durations.

A full summary of the critical durations and associated temporal patterns derived for design event modelling is given in Section 6.6.

6.3 Design Ocean Boundary

Design ocean boundaries for use in flood risk assessments are recommended by the Flood Risk Management Guide (OEH, 2015), where the recommended design ocean water levels have been determined based on long term records from Fort Denison in Sydney Harbour. The design 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 HHWS(SS); and
- Wave set up.

OEH recommends different design ocean peak water levels are to be adopted based on the type of ocean entrance. Type A entrances are subject to little ocean tide attenuation and are not influenced by wind and wave set up. Type B estuaries are typically open but may be affected by shoaling and may have some potential for wave set up e.g. Lake Illawarra. Type C estuaries are prone to heavy shoaling and often close completely (also known as Intermittently Closed and Open Lakes and Lagoons (ICOLLS)). Peak design ocean water levels for each of the different entrance types for locations south of Crowdy Head are presented in Table 6-6. The different peak levels reflect the degree of influence of wave set up applicable to the various types of entrances.

Table 6-6 Design Peak Ocean Water Levels (OEH, 2015) for Various Entrance Types, located South of Crowdy Head

Ocean Event	Peak Ocean Water Level (m AHD)		
	Entrance Type A	Entrance Type B	Entrance Type C
5% AEP	1.4	1.9	2.35
1% AEP	1.45	2.0	2.55

For determining design flood levels, OEH recommends that the local catchment 1% AEP flood should be run in conjunction with a 5% AEP tailwater. It further recommends that the inverse scenario be run to confirm that the dominant flooding mechanism is not from downstream water levels. If the flooding from the downstream water is demonstrated to produce peak flood conditions in parts of the catchment, an envelope of both scenarios must be used to define the extent of the 1% AEP flood. In addition, it is recommended to run the 1% AEP with Indian Spring Low Water (ISLW) tailwater to determine peak velocities.

Modelling has confirmed that for the study area, particularly in the suburb of Lake Illawarra, the 1% AEP tailwater dominates the local catchment flooding. Because the tailwater flood dominates the catchment flood, an envelope is used in determining design flood results.

Given the low elevation of a significant portion of the study area it was deemed necessary to adopt a more rigorous approach than the simple assumptions for Entrance Type B as the downstream boundary (refer Table 6-6). A more locally appropriate downstream boundary level was determined using the design flood levels recommended in the Lake Illawarra Floodplain Risk Management Study (2012), refer Table 2-1. The downstream boundary levels have been applied as a constant water level boundary condition over time, varying spatially along the Lake Illawarra foreshore. Table 6-7 shows the adopted tailwater levels.

Table 6-7 Design Peak Ocean Water Levels

Design Flood Event	Catchment Event	Ocean Event (Lake Illawarra)	Water Levels (m AHD)
20% AEP	20% AEP	HHWS (SS)	0.23 (Lake Illawarra) 0.6 (Lake Illawarra Entrance)

Design Flood Event	Catchment Event	Ocean Event (Lake Illawarra)	Water Levels (m AHD)
10% AEP	10% AEP	HHWS (SS)	0.23 (Lake Illawarra) 0.6 (Lake Illawarra Entrance)
5% AEP	5% AEP	HHWS (SS)	0.23 (Lake Illawarra) 0.6 (Lake Illawarra Entrance)
2% AEP	2% AEP	50% AEP	0.95 - 1.11
1% AEP	1% AEP 1% AEP 5% AEP	HHWS (SS) 5% AEP 1% AEP	0.23 - 0.60 1.55 - 1.81 1.71 - 2.24
0.5% AEP	0.5% AEP	1% AEP	1.71 - 2.24
PMF	PMF	1% AEP	1.71 - 2.24

[1]HHWS (SS) = High High Water Springs (Solstice Spring)

6.4 Blockage Scenarios

6.4.1 Blockage of Hydraulic Structures

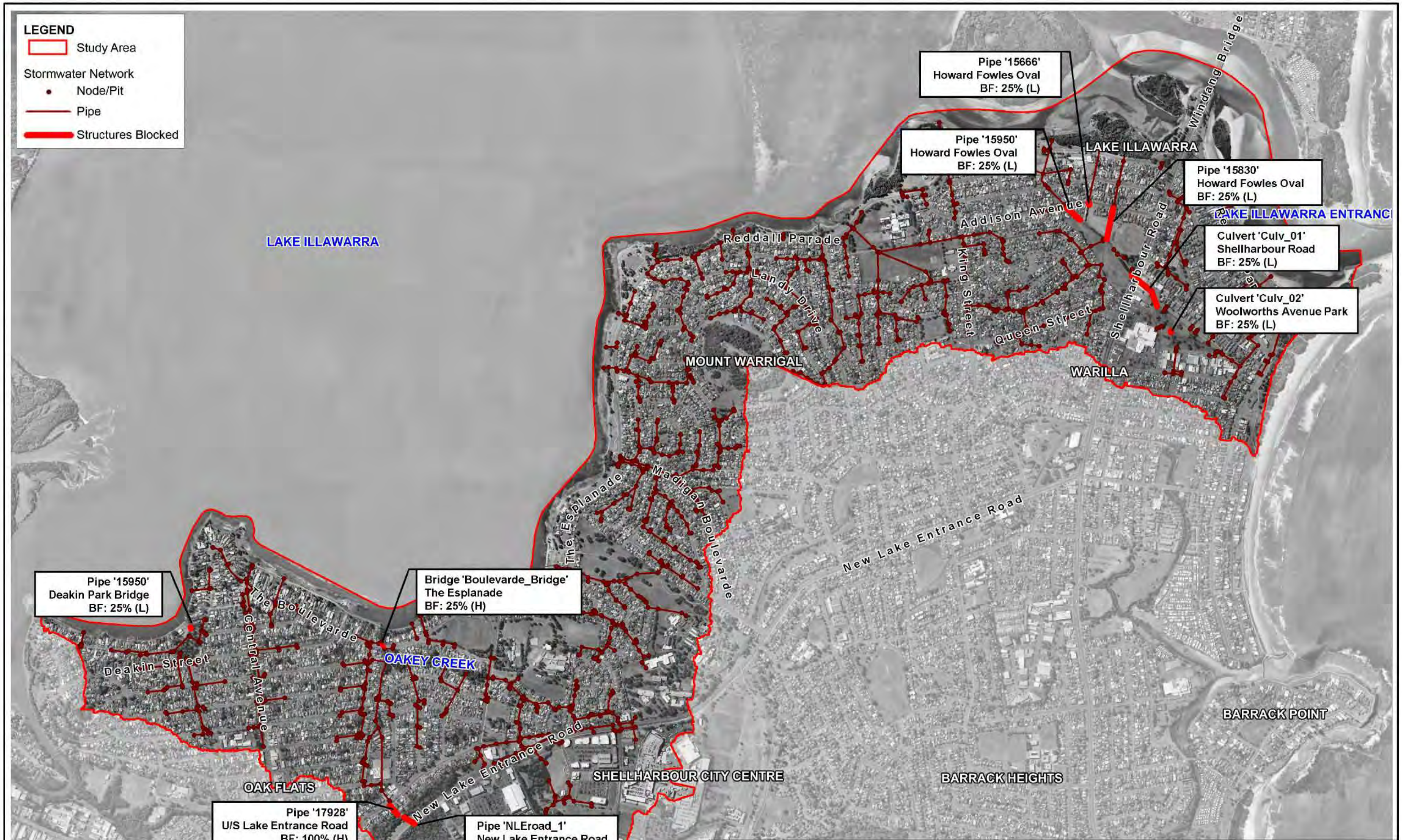
During flood events, structure blockages can significantly increase local flood levels. The adopted methodology for determining appropriate consideration of blockages is that proposed in Chapter 6: Blockage of Hydraulic Structures, Book 8 in Australian Rainfall and Runoff - A Guide to Flood Estimation (2016).

The types of structures or drainage elements affected by blockage can generally be grouped as follows:

- Bridges and Culverts;
- Drainage system inlets and pipes;
- Open channels and waterways;
- Overland flow paths; and
- Weirs and dams.

Under AR&R guidelines, appropriate blockages to consider for design flood conditions are based on a number of criteria relating to the nature of the source catchment, in order to determine at-site debris potential. For the Oak Flats, Mt Warrigal and Lake Illawarra catchments, the potential for hydraulic structure blockage was determined as ranging from low to high.

Nine structures in the Oak Flats, Mt Warrigal and Lake Illawarra catchments were assessed for appropriate levels of blockage for the simulation of design flood behaviour. The location of these structures is shown in Figure 6-3, together with their adopted relative blockage factors (BF) and AEP Adjusted Debris Potential at Structure (low, medium or high).



Title:
Structure Blockage - Design Event Case

Figure: 6-3

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Design blockage levels across all AEPs were determined based on the 1% AEP only, i.e. blockage was not adjusted for event magnitude. This method of blockage estimation is likely conservative for higher probability storms (i.e. less than 1% AEP), however given the small number of structures considered for design blockage and the relative bounds of uncertainty in blockage estimation, this approach was deemed appropriate.

The recommended method for the application of inlet blockage has been determined using the information in Table 6.6.6 of AR&R (2016), reproduced below in Table 6-8.

Table 6-8 Most Likely Inlet Blockage Levels - B_{DES}%

Control Dimension	AEP Adjusted Debris Potential at Structure		
	High	Medium	Low
W < L_{10}	100%	50%	25%
W >= L_{10} (5m) <= 3*L_{10}	20%	10%	0%
W > 3*L_{10}	10%	0%	0%

L_{10} is the length for which the longest 10% of potential blockage items exceed. This has been taken as around the length of a car, being approximately 5 m. W is the width of the pipe or conduit.

Consideration has been given to barrel blockage by using the information in Table 6.6.8 of AR&R (2016), reproduced below in Table 6-9

Table 6-9 Most Likely Depositional Blockage Levels – B_{DES}%

Likelihood that Deposition will Occur	AEP Adjusted Non Floating Debris Potential (Sediment) at Structure		
	High	Medium	Low
High	100%	60%	25%
Medium	60%	40%	15%
Low	25%	15%	0%

For conduit blockage AR&R (2016) recommends that flooding is assessed using an envelope of maximums from an “all clear” scenario and a “guideline blocked” scenario. AR&R also recommends giving consideration to the interaction between multiple culverts, where any culvert/bridge could be ‘all clear’ or ‘guideline blocked’ (i.e. a combination of blockage scenarios). However, given the small number of structures and the lack of contiguous watercourses in the study area, a simple envelope of “all clear” and “guideline blocked” was deemed appropriate.

Industry standard pipe and culvert losses have been applied at all relevant conduits, specifically:

(1) An entry and exit loss of 0.5 and 1.0 respectively; and

(2) Height and width contraction coefficients of 0.6 and 0.9 for culverts and 0 and 1.0 for pipes.

For the stormwater drainage network, sensitivity to conduit blockage has been assessed by modelling a 100% blockage of all conduits, refer Section 8.

6.4.2 Pit Inlet Blockages

In consultation with Council, a pit blockage of 50% for sag pits and 20% for on-grade pits has been adopted in design event modelling. Catchment sensitivity to pit blockage has been assessed by modelling a blockage of 0%, refer Section 8.

6.5 Shellharbour City Centre Basin

The design flood conditions for the Shellharbour City Centre Basin are presented below in Table 6-10.

Table 6-10 Shellharbour City Centre Design Parameters

Basin Condition	Value
Initial Water Level	18.0 mAHD
Outlet Elevation (Primary Pit)	18.0 mAHD
Outlet Elevation (Secondary Pit)	18.0 mAHD
Outlet Blockage Parameter	50%
Outlet Discharge	Refer Table 5-9

As above in Section 6.4.2, sensitivity to outlet blockage will be tested, modelling an outlet blockage of 0%, refer Section 8.

6.6 Modelled Design Events

6.6.1 Catchment Derived Flood Events

The catchment derived flood events that have been simulated for the design flood scenarios are summarised in Table 6-11.

Table 6-11 Modelled Design Flood Events

Event Magnitude	Overland Critical Duration	Storage Critical Duration
20% AEP	45min	12h
10% AEP	30min	12h
5% AEP	30min	12h
2% AEP	30min	12h
1% AEP	30min	12h
0.5% AEP	30min	12h
PMF	15min & 90min	-

The selected temporal pattern selected for each design event and duration is shown in Table 6-12 and plotted in Appendix G.

Table 6-12 Temporal Pattern Selected

Event Magnitude	Overland Critical Duration	Storage Critical Duration
20% AEP	5960	6212
10% AEP	5917	6202
5% AEP	5917	6202
2% AEP	5910	6197
1% AEP	5910	6197
0.5% AEP	5910	6197

6.6.2 Design Flood Extents Filtering

Due to the nature of the rainfall-on-grid hydraulic modelling, it was deemed appropriate to filter the design flood extents. Foremost the results were filtered to remove sheet flow from the final design extents such that only regions of significant flood depth or of significant velocity-depth product were included. Similar methodologies have been included in other catchments within Shellharbour LGA and were used to inform the filtering methodology for the Oak Flats, Mt Warrigal and Lake Illawarra study area. The methodology is as follows:

(1) Areas where depth does not exceed 0.15 m were removed from the design flood extents;

(2) Areas where the velocity depth product (i.e. V x D) exceeds 0.10 m^2/s were re-instated; and

(3) Flood islands with an area of less than 250 m^2 were removed.

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 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP and 0.5% AEP. The PMF event has also been modelled. The impact of future climate change on flooding in the study area was also considered for the 1% AEP design flood event.

The design flood results are presented in Appendix A. For the simulated design events including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF events, a map of peak flood level, depth and velocity is presented covering the modelled area.

7.1 Peak Flood Conditions

7.1.1 Catchment Derived Flood Events

Predicted flood levels at selected locations (refer Figure 7-1) are shown in Table 7-1 for the full range of design flood events considered.

Table 7-1 Modelled Peak Flood Levels (m AHD) for Design Flood Events

ID	Location	Flood Event Frequency						
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
1	Reserve Road	2.3	2.4	2.4	2.4	2.5	2.5	2.8
2	The Boulevarde	3.1	3.2	3.2	3.2	3.2	3.3	3.5
3	Parkes Street	10.9	10.9	10.9	11.0	11.0	11.0	11.1
4	New Lake Entrance Road	33.6	33.6	33.6	33.7	33.7	33.7	33.9
5	Kingston Street	18.0	18.1	18.1	18.1	18.1	18.1	18.3
6	Link Road	4.5	4.6	4.6	4.6	4.7	4.7	5.1
7	Oakey Creek	2.1	2.3	2.4	2.6	2.7	2.9	3.4
8	Devonshire Street	3.4	3.5	3.5	3.6	3.7	3.7	4.2
9	Government Road	6.7	6.8	6.9	6.9	7.0	7.0	7.4
10	Jilba Place	11.1	11.3	11.3	11.4	11.5	11.5	12.1
11	New Lake Entrance Road	16.2	16.3	16.3	16.3	16.3	16.3	16.5
12	Shellharbour City Basin	19.1	19.1	19.2	19.6	19.8	20.1	21.1
13	Cygnet Avenue	23.4	23.5	23.5	23.6	23.6	23.6	24.1
14	Alinga Drive	3.2	3.3	3.3	3.3	3.4	3.4	3.7
15	Madigan Boulevard	3.3	3.4	3.5	3.5	3.5	3.6	4.0
16	MacKenzie Avenue	7.4	7.5	7.5	7.5	7.5	7.5	7.7
17	Landy Drive	30.2	30.3	30.3	30.3	30.3	30.3	30.5

ID	Location	Flood Event Frequency						
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
18	Konrads Road	2.8	2.8	2.8	2.8	2.8	2.8	2.9
19	Reddall Parade	2.1	2.2	2.2	2.3	2.3	2.3	2.6
20	Ponsford Street	10.0	10.1	10.1	10.2	10.2	10.2	10.4
21	Bradman Avenue	6.3	6.3	6.4	6.4	6.4	6.4	6.6
22	Kotari Parade	2.0	2.0	2.1	2.1	2.3	2.3	2.4
23	Lake Illawarra South Public School	1.7	1.7	1.7	1.8	2.2	2.2	2.3
24	Addison Avenue	2.0	2.0	2.1	2.1	2.3	2.3	2.6
25	Reddall Parade	1.5	1.5	1.5	1.5	2.2	2.2	2.3
26	Howard Fowles Oval	2.0	2.0	2.1	2.1	2.3	2.3	2.6
27	Girraween Avenue	3.8	3.8	3.8	3.9	3.9	3.9	4.2
28	Peterborough Avenue	2.0	2.0	2.0	2.1	2.2	2.3	2.6
29	View Street	1.3	1.3	1.4	1.4	2.0	2.0	2.0
30	Windang Street	1.5	1.5	1.5	1.7	2.0	2.0	2.0
31	Keith Fletcher Park	2.1	2.1	2.2	2.3	2.4	2.5	2.8
32	Osborne Parade	3.3	3.3	3.4	3.4	3.5	3.5	3.8

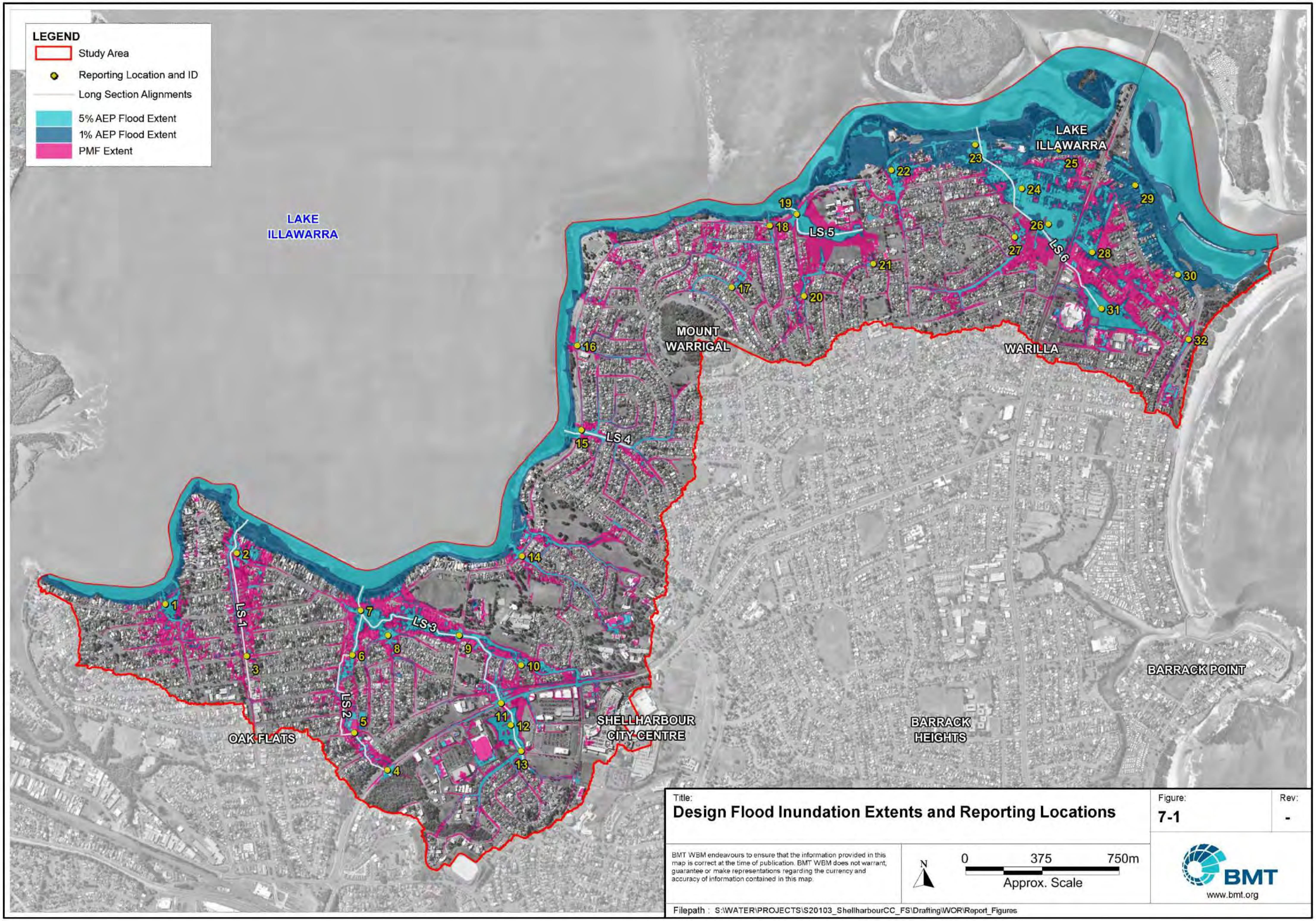
Longitudinal profiles (see Figure 7-1 for alignments) showing predicted flood levels at locations throughout the Oak Flats, Mt Warrigal and Lake Illawarra catchment are shown in Appendix B.

Figure 7-1 shows the design flood inundation extents for the 5% AEP, 1% AEP and PMF events. For the Oak Flats and Mt Warrigal catchments, the flood extents for the 5% AEP event and 1% AEP event are largely confined to road reserves, however some isolated areas of residential inundation occur in the lower catchment reaches. The suburb of Lake Illawarra is affected by extensive flooding of its low-lying regions, particularly those areas of residential and commercial development adjacent Howard Fowles Oval, Keith Fletcher Park and the Lake foreshore. For the PMF event, overland inundation occurs extensively across the entire study area.

7.1.2 Tidal Inundation

The NSW Sea Level Rise Policy Statement (DECCW, 2009) provided projected increases in mean sea level for NSW of 0.4m and 0.9m, by the years 2050 and 2100 respectively. These increases are no longer prescribed by the state government, however have been adopted as a means of mapping the tidal inundation in lieu of further guidance.

The results of the tidal inundation mapping for the current, 2050 and 2100 planning horizons are presented in Figure 7-2. The modelled tidal inundation scenario does not account for catchment derived flooding, rather accounting for an increase to the tidal plane only.



Title:
Design Flood Inundation Extents and Reporting Locations

Figure: 7-1

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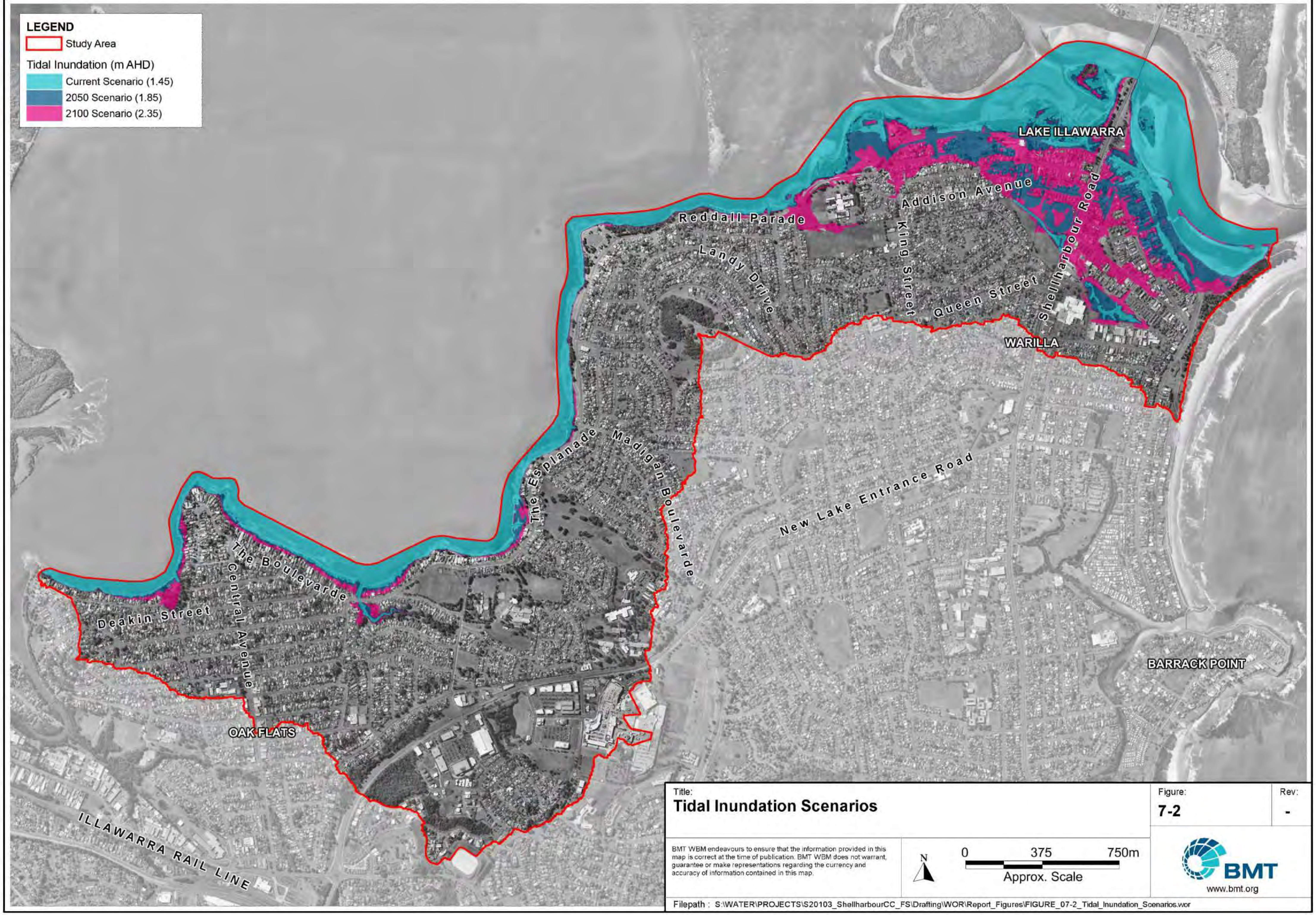

Title: **Tidal Inundation Scenarios**

Figure: **7-2**

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Figure 7-2 shows that for the majority of the study area, in particular the Oak Flats and Mt Warrigal areas, tidal inundation is restricted to foreshore areas located adjacent remnant waterway outlets. The exception being the suburb of Lake Illawarra, where a large number of properties are exposed to tidal inundation for the 2050 and 2100 planning horizons.

7.2 Hydraulic Classification

There are no prescriptive methods for determining what parts of the floodplain constitute flood ways, flood storages and flood fringes. Descriptions of these terms within the NSW Floodplain Development Manual (DIPNR, 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.

The provisional hydraulic categorisation in other Shellharbour flood studies is generally based on the findings of Howells et al, 2003. The approach to defining provisional hydraulic categories as part of this study has therefore been defined by the criteria proposed by Howells et al, 2003:

Floodway is defined as areas where:

- Velocity x depth greater than 0.25 m^2/s and velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

Flood storage areas were identified as those areas which do not operate as floodways but where the depth of inundation exceeded 0.25 m.

Flood fringe is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined.

The results of applying the above criteria were reviewed and minor adjustments made to ensure continuity of the floodway was maintained.

Preliminary hydraulic categorisation mapping for all modelled design events is included Appendix A.

7.3 Provisional Hazard Categories

The Updating National Guidance on Best Practice Flood Risk Management (NFRAG, 2014) considers a holistic approach to consider flood hazards to people, vehicles and structures. It recommends a composite six-tiered hazard classification, reproduced in Figure 7-3.

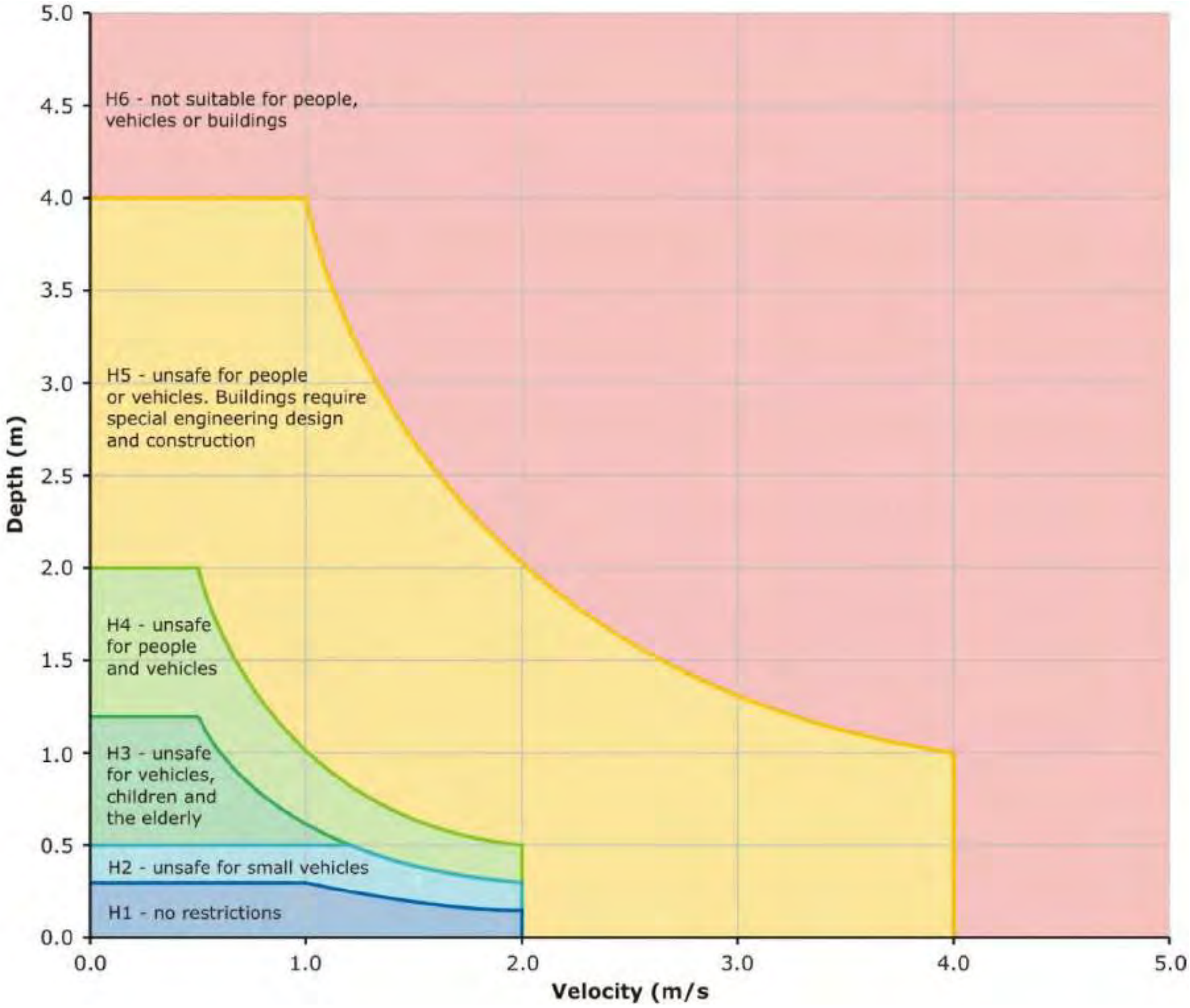


Figure 7-3 Combined Flood Hazard Curves

The six hazard classifications are summarised below in Table 7-2.

Table 7-2 Combined Flood Hazard Curves – Vulnerability Thresholds

Hazard Classification	Description
H1	Relatively benign flow conditions. No vulnerability constraints.
H2	Unsafe for small vehicles.
H3	Unsafe for all vehicles, children and the elderly.
H4	Unsafe for all people and vehicles.
H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

Hazard Classification	Description
H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.

Provisional hazard category mapping is included in Appendix A and is presented for all modelled design events.

7.4 Flood Emergency Response Classification

The SES classifies communities according to the impact that flooding has on them. The primary purpose for doing this is to assist SES in the planning and implementation of response strategies. Flood impacts relate to where the normal functioning of services is altered due to a flood, either directly or indirectly, and relates specifically to the operational issues of evacuation, resupply and rescue.

Flood Islands

Flood Islands are inhabited areas of high ground within a floodplain which are linked to the flood free valley sides by only one access / egress route. If the road is cut by floodwaters, the community becomes an island, and access to the area may only be gained by boat or aircraft. Flood islands are classified according to what can happen after the evacuation route is cut as and are typically separated into:

- High Flood Islands;
- Low Flood Islands

A *High Flood Island* include sufficient land located at a level higher than the limit of flooding (i.e., above the PMF) to provide refuge to occupants. During flood events properties may be inundated and the community isolated, however, as there is an opportunity for occupants to retreat to high ground, the direct risk to life is limited. If it will not be possible to provide adequate support during the period of isolation, evacuation will have to take place before isolation occurs.

The highest point of a *Low Flood Island* is lower than the limit of flooding (i.e., below the PMF) or does not provide sufficient land above the limit of flooding to provide refuge to the occupants of the area. During flood events properties may be inundated and the community isolated. If floodwater continues to rise after it is isolated, the island will eventually be completely covered. People left stranded on the island may drown.

Trapped Perimeter Areas

Trapped Perimeter Areas are inhabited areas located at the fringe of the floodplain where the only practical road or overland access is through flood prone land and unavailable during a flood event. The ability to retreat to higher ground does not exist due to topography or impassable structures. Trapped perimeter areas are classified according to what can happen after the evacuation route is cut as follows.

High Trapped Perimeter Areas include sufficient land located at a level higher than the limit of flooding (i.e., above the PMF) to provide refuge to occupants. During flood events properties may be inundated and the community isolated, however, as there is an opportunity for occupants to retreat to high ground, the direct risk to life is limited. If it will not be possible to provide adequate support during the period of isolation, evacuation will have to take place before isolation occurs.

Low Trapped Perimeter Areas is lower than the limit of flooding (i.e., below the PMF) or does not provide sufficient land above the limit of flooding to provide refuge to the occupant's people of the area. During a flood event the area is isolated by floodwater and property may be inundated. If floodwater continues to rise after it is isolated, the area will eventually be completely covered. People trapped in the area may drown.

Areas Able to be Evacuated

These are inhabited areas on flood prone fringe areas that are able to be evacuated. However, their categorisation depends upon the type of evacuation access available, as follows.

Areas with Overland Escape Route are those areas where access roads to flood free land cross lower lying flood prone land. Evacuation can take place by road only until access roads are closed by floodwater. Escape from rising floodwater is possible but by walking overland to higher ground. Anyone not able to walk out must be reached by using boats and aircraft. If people cannot get out before inundation, rescue will most likely be from rooftops.

Areas with Rising Road Access are those areas where access roads rising steadily uphill and away from the rising floodwaters. The community cannot be completely isolated before inundation reaches its maximum extent, even in the PMF. Evacuation can take place by vehicle or on foot along the road as floodwater advances. People should not be trapped unless they delay their evacuation from their homes. For example, people living in two storey homes may initially decide to stay but reconsider after water surrounds them.

These communities contain low-lying areas from which people will be progressively evacuated to higher ground as the level of inundation increases. This inundation could be caused either by direct flooding from the river system or by localised flooding from creeks.

Indirectly Affected Areas

These are areas which are outside the limit of flooding and therefore will not be inundated nor will they lose road access. However, they may be indirectly affected as a result of flood damaged infrastructure or due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services and they may therefore require resupply or in the worst case, evacuation.

Overland Refuge Areas

These are areas that other areas of the floodplain may be evacuated to, at least temporarily, but which are isolated from the edge of the floodplain by floodwaters and are therefore effectively flood islands or trapped perimeter areas. They should be categorised accordingly, and these categories used to determine their vulnerability.

Note that Flood Management Communities identified as Overland Refuge Areas on Low Flood Island have been classified according to the SES Flow Chart for Flood Emergency Response Classification.

These are areas where vehicular evacuation routes are inundated before residential areas of the Community.

7.4.1.1 Local Classification

Suburb of Oak Flats and Mt Warrigal Catchments

Being an urbanised area, it is difficult to provide an appropriate classification, as the local flood conditions to each individual property will vary for varying event magnitudes and may be highly spatially variable. However, the flooding within the catchment is principally overland flow, with limited out-of-bank mainstream flooding. Given the relatively steep nature of the catchment and the extensive network of roads, the most appropriate classification would be ***Areas with Rising Road Access***. However, the roadways would often have hazardous conditions during a major flood and so it may be safer for people to remain in their homes. These properties would then be ***High or Low Flood Islands*** if surrounded by flood waters, or ***High or Low Trapped Perimeter Areas*** if located on the edge of the floodplain.

As per the provisional hazard categories discussed in Section 7.3 and mapped in Appendix A, the inundated roadways (inclusive of verge, pavement etc.) contain regions of H1-H2 hazard classification (or lower). Evacuees could therefore evacuate on-foot via rising road access during storm events.

However, as the majority of carriageways (kerb to kerb section of road) can also contain H3 hazard and above, it may be safer for residents to take refuge in their homes, rather than evacuate along potentially hazardous and grid-locked roads. The exception to this is buildings that would be at risk of collapse due to structural damage during the flood. It is therefore recommended that the local flood emergency response classification be given further consideration with the relevant authorities (SES) during the next stage of the floodplain management process, the Floodplain Risk Management Study and Plan.

Suburb of Lake Illawarra Catchments

The exception to the above is the suburb of Lake Illawarra, where catchment conditions are dominated by rising flood waters from the Lake Illawarra and flood inundation at these events is expected to last for hours or days rather than minutes as in the Oak Flats and Mt Warrigal catchments. These properties would then be ***High or Low Flood Islands*** if surrounded by flood waters, or ***High or Low Trapped Perimeter Areas*** if located on the edge of the floodplain.

Maps of the 1% AEP and PMF Flood Emergency Response Classification for the Oak Flats, Mt Warrigal and Lake Illawarra study area are included in Appendix A. It is noted that flood depths in the PMF event rarely exceed 1.0 m, much of which can be attributed to the elevated tailwater conditions in Lake Illawarra during design event modelling. With this in mind, and as per the potential hazard of evacuating via dangerous road conditions, it is recommended that the local flood emergency response classification be given further consideration during the next stage of the floodplain management process, the Floodplain Risk Management Study and Plan.

7.5 Potential Flooding Problem Areas

Figure 7-4 shows the potential flooding problem areas for the Oak Flats, Mt Warrigal and Lake Illawarra catchment. The map shows:

1) Properties that have modelled flood inundation above 300 mm within their cadastral boundary (greater than 5%) at the 1% AEP event; and
2) Properties which have been intersected by the 1% AEP extent.

It helps to provide an overview of where potential flooding problems are located within the catchment.

Flooding problem areas across the study area can be isolated to three main regions, being Oakey Creek, the Lake Illawarra foreshore and the suburb of Lake Illawarra. These regions are summarised below, with specific flood areas listed beneath:

Oakey Creek:

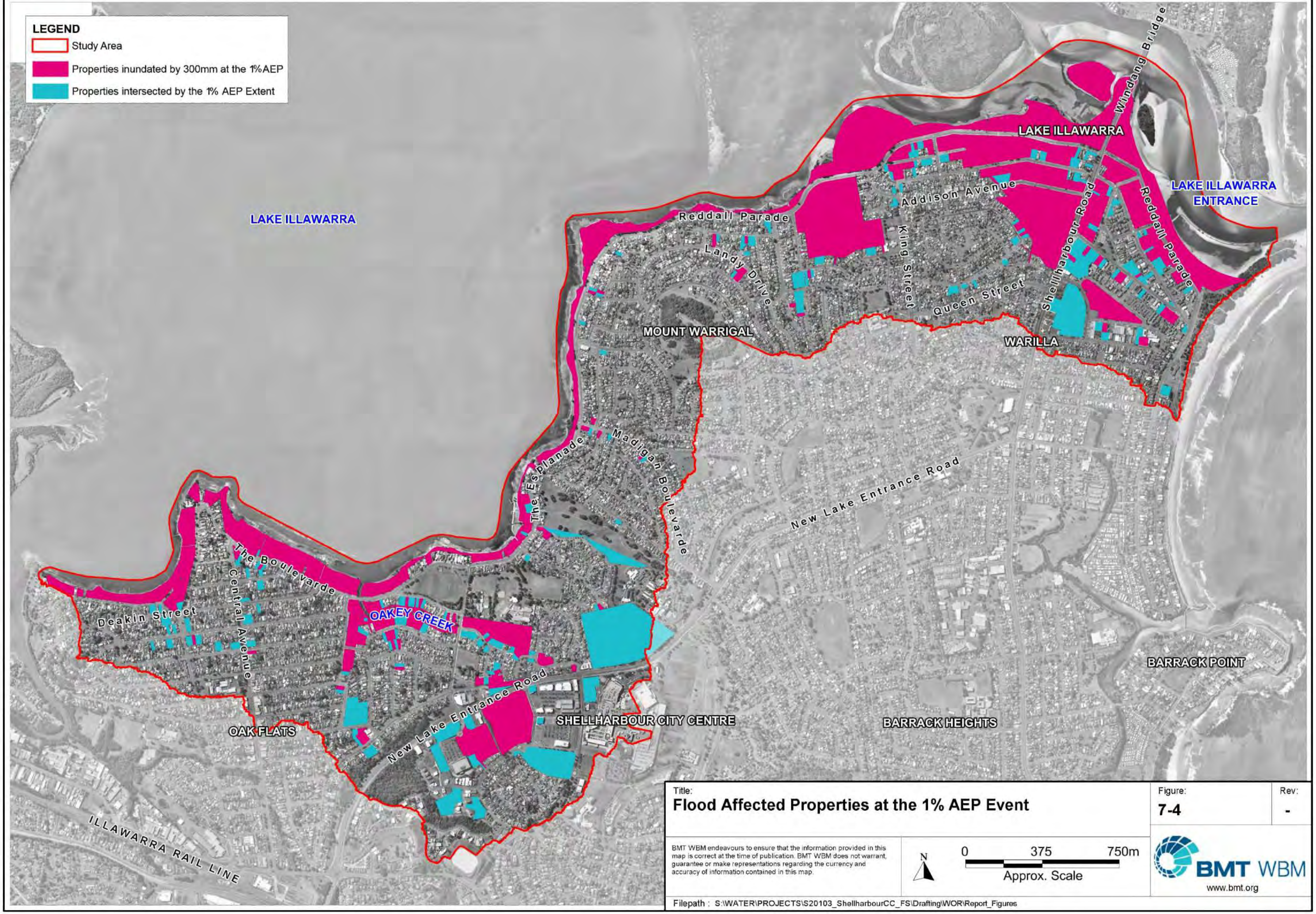
- Properties located at the upstream side of the intersection of The Boulevarde and Oakey Creek;
- Properties located on the eastern side of Leamington Road from Link Road to The Esplanade;
- Properties located upstream of the Oak Flats Bowling and Recreation Club between Kingston Street, Lake Entrance Road and New Lake Entrance Road;
- Properties located on an overland flow path running from the corner of Gordon Avenue and Marlin Road via Devonshire Crescent;
- The rear of properties located along Timbs Road and Devonshire Crescent adjacent the main tributary of Oakey Creek;
- Properties located along Birra Drive and Jilba Place; and
- Commercial properties located downstream of the Shellharbour City Centre Basin adjacent the low-point in New Lake Entrance Road.

Lake Foreshore Areas:

- The lake frontage properties along Horsley Road, Newton Crescent, The Boulevarde, The Esplanade and Reddall Parade;

Lake Illawarra (suburb):

- The properties east of Shellharbour Road, bound by Peterborough Avenue to the south, View Street to the east, and Pur Pur Avenue to the north;
- The properties east of Shellharbour Road, bound by Reddall Parade and Pur Pur Avenue;
- The properties either side of Addison Avenue and Pur Pur Avenue located to the west of Shellharbour Road;
- The properties located at the low-point in Girraween Avenue adjacent Howard Fowls Oval reserve; and
- The properties either side of Kotari Parade and Corona Avenue.



Title:
Flood Affected Properties at the 1% AEP Event

Figure: 7-4

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The flooding problem areas in Oak Flats and Mt Warrigal are a result of either; a flow path running through the property overland from an upstream area, or as a result of the Lake Illawarra tailwater condition (i.e. rising waters from Lake Illawarra). A small number of properties, particularly those located at the Oakey Creek outlet to Lake Illawarra, are subject to both methods of inundation.

The flooding problem areas in the suburb of Lake Illawarra are subject to inundation caused by the flood waters inability to discharge as a result of the Lake Illawarra tailwater condition or unfavourable topographic conditions.

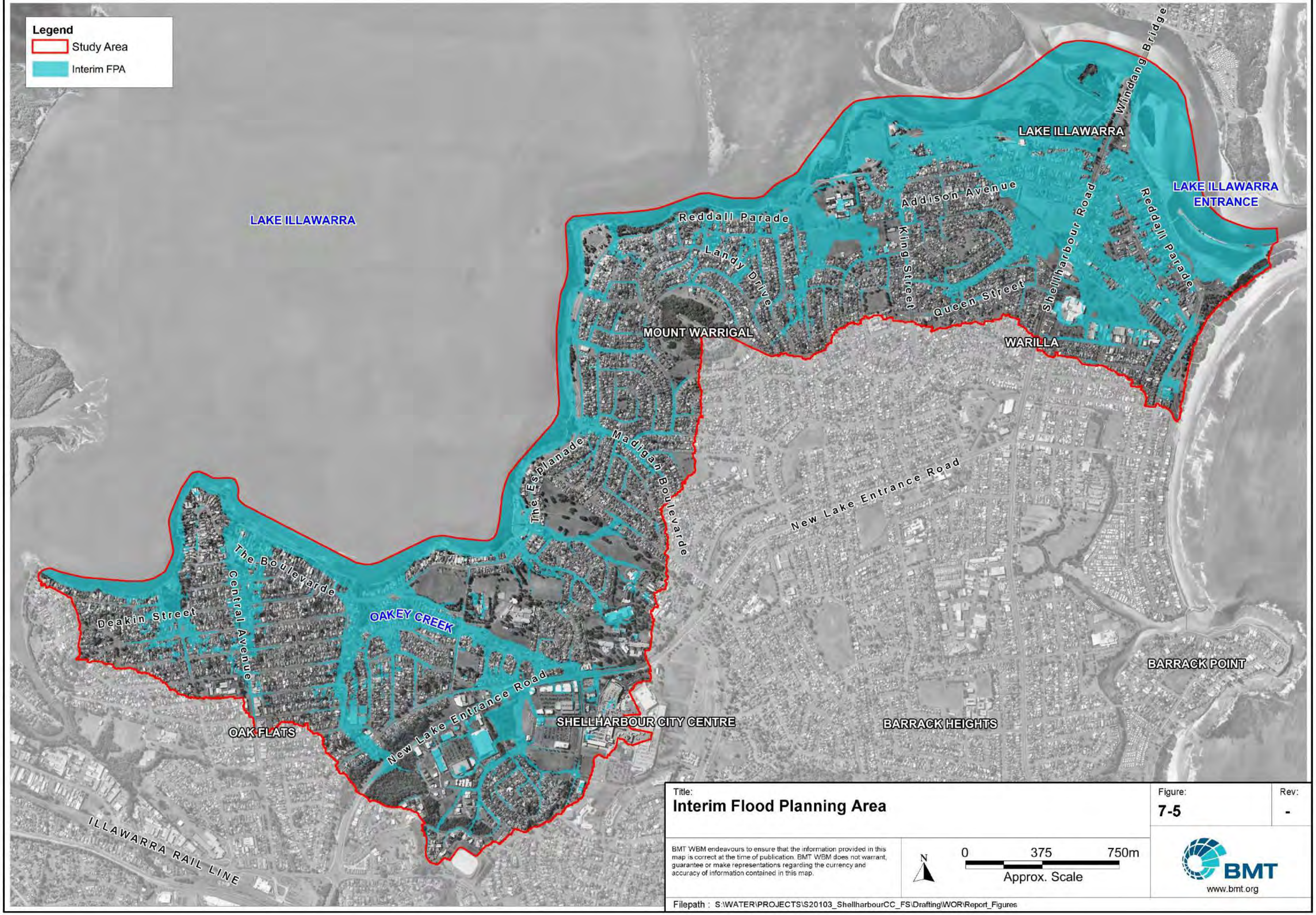
7.6 Preliminary Residential Flood Planning Level

Flood Planning Levels (FPLs) are used for planning purposes, and directly determine the extent of the Flood Planning Area (FPA), which is the area of land subject to flood-related development controls. The FPL is the level below which a Council places restrictions on development due to the hazard of flooding. Traditional floodplain planning has relied almost entirely on the definition of a singular FPL, which has usually been based on the 1% AEP flood level, for the purposes of applying floor level controls.

An FPA is typically derived through the addition of a nominated freeboard allowance (typically 0.5m) to the modelled 1% AEP flood level. Through spatial analysis within a GIS platform this level is then projected horizontally until it intersects with the LiDAR DEM to provide the associated area of extent over which the FPL and associated planning controls should apply.

The above process was undertaken for the Oak Flats, Mt Warrigal and Lake Illawarra catchments, however in the majority of catchment reaches, the addition of a 0.5m freeboard exceeded the level of the PMF. It was therefore determined that the PMF extent appropriately defined the interim FPA, until such time that a detailed assessment of uncertainties and a review of freeboard is undertaken during the next stage of the floodplain management process, the Floodplain Risk Management Study and Plan.

Figure 7-5 shows the interim FPA for the Oak Flats, Mt Warrigal and Lake Illawarra study area.



Title:
Interim Flood Planning Area

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7-5

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8 Sensitivity Testing

Several sensitivity analyses were undertaken in order to assess the variability in design flood conditions that may occur if different parameters were adopted in design event modelling. An envelope of the 1% AEP 30-minute and 720-minute design storm was utilised for the purposes of sensitivity assessment. A typical downstream boundary (HHWSS), with no consideration of coincident flooding, was utilised for the purposes of sensitivity testing.

The following parameters were assessed:

- Hydraulic roughness: The models hydraulic roughness was increased and decreased by 20%;
- Stormwater drainage blockages:
    - A blockage of 100% of pipes/culverts was applied; and
    - Pit blockage was decreased to 0%.
- Rainfall losses: The median and 90% pre-burst depth tables were utilised in the calculation of storm initial losses; and
- Downstream boundary

The sensitivity analyses results are mapped in Appendix C presenting the change in peak flood level for the 1% AEP event.

8.1 Hydraulic Roughness

The sensitivity of modelled peak flood levels to the adopted Manning's 'n' roughness values were tested for the 1% AEP design event. Roughness values for all materials types within the floodplain were increased and decreased by 20%.

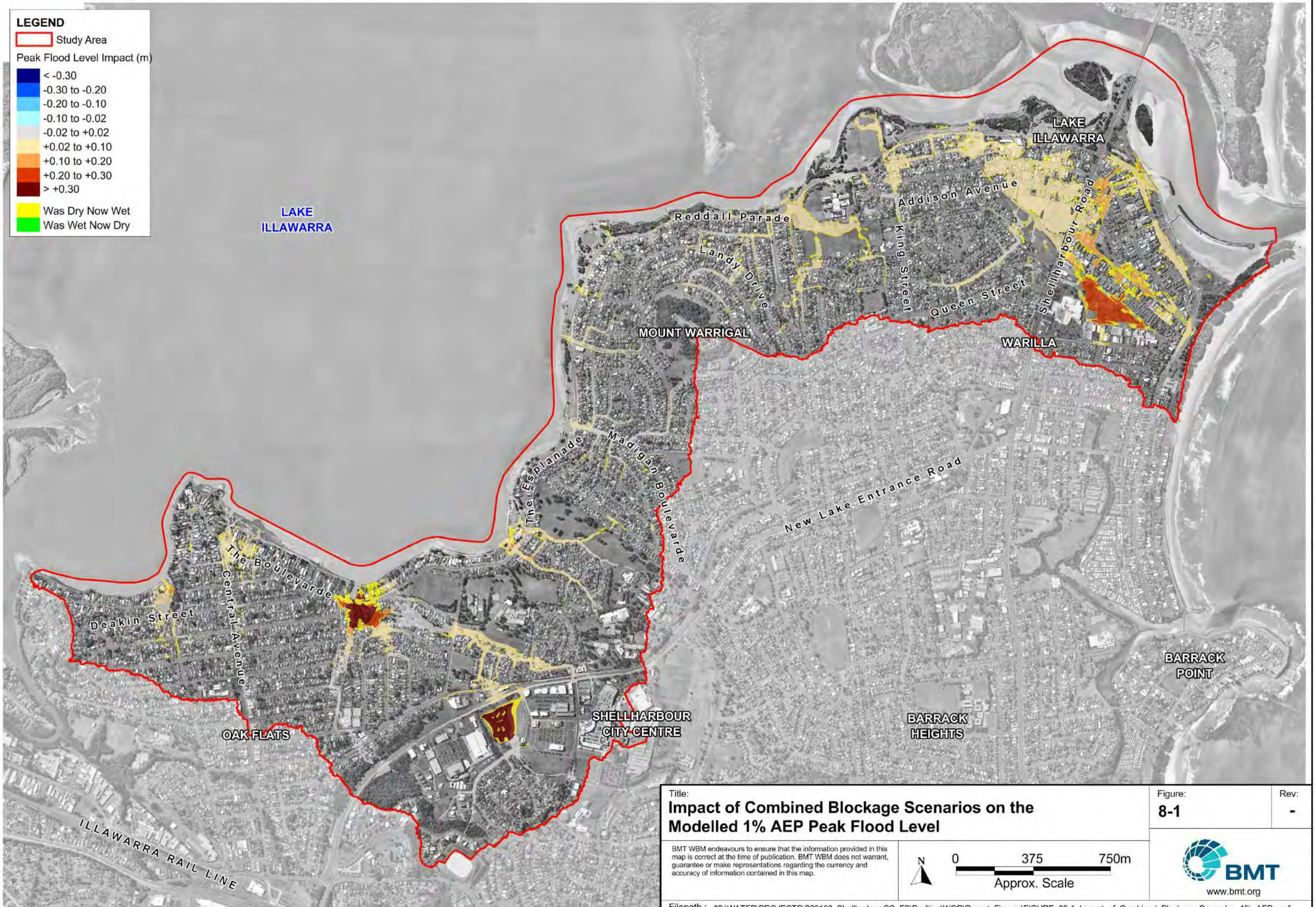
Impact mapping showing the change in peak flood level utilising a 20% increase and decrease in Manning's n roughness are mapped in Appendix C. Tabulated peak modelled flood levels are presented in Table 8-1 at the end of this Section.

8.2 Stormwater Drainage Blockages

As discussed previously in Section 6.4, pit inlet and structure blockage are an important consideration of the design flood modelling. Blockages were assessed using a total of two separate model simulations:

- Application of a 100% blockage to the stormwater drainage network (pipes, culverts and bridges); and
- Application of 0% pit inlet blockage.

Figure 8-1 presents the spatial distribution of peak blockage impacts of the combined two modelled blockage scenarios for the 1% AEP event. It highlights areas that are particularly exposed to increased flood risk through potential blockage of structures.



Title:
Impact of Combined Blockage Scenarios on the Modelled 1% AEP Peak Flood Level

Figure: 8-1

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The mapping indicates that whilst there are localised increases in flood level of greater than 0.3 m (Shellharbour City Basin, the intersection of Oakey Creek and The Boulevarde) the majority of the study area catchments experience increases no greater than 0.1 m. Areas that are particularly exposed to increased flood risk through potential blockage of structures include:

- Properties situated either side of The Boulevarde at the intersection of The Boulevarde and Oakey Creek (~0.4 m); and
- Properties situated in the low-lying suburb of Lake Illawarra, in particular those on the eastern side of Shellharbour Road adjacent Grove Circuit and Peterborough Avenue (~0.2 m).

Impact mapping showing the change in peak flood level for the blockage conditions in isolation, in addition to the combined condition shown above in Figure 8-1 are provided in Appendix C. Tabulated peak modelled flood levels are presented in Table 8-1 at the end of this Section.

8.3 Rainfall Losses

As discussed earlier in Section 5.5, the 75% pre-burst depths were found to most replicate the antecedent catchment conditions during model calibration, and were subsequently used in the estimation of design rainfall for the study catchments (refer Section 6.2). However, noting the often variability of such parameters, sensitivity testing on the 1% AEP was undertaken utilising the median pre-burst depths and 90% pre-burst depths (refer Appendix F for pre-burst depth tables).

Impact mapping showing the change in peak flood level utilising the 90% and median pre-burst depth tables are provided in Appendix C. Tabulated peak modelled flood levels are presented in Table 8-1 at the end of this Section.

8.4 Downstream Boundary

The adopted downstream boundary conditions were discussed in Section 6.3. They consider a coincident flood condition in Lake Illawarra and the study area runoff. For the 1% AEP design event this was a combination of:

- The 1% AEP and 5% AEP Lake Illawarra tailwater level of 1.55 - 1.81m AHD;
- The 5% AEP and 1% AEP Lake Illawarra tailwater level of 1.71 - 2.24m AHD; and
- The 1% AEP and HHWSS Lake Illawarra tailwater level of 0.23 – 0.60m AHD.

The impact of adopting a typical downstream boundary (HHWSS), with no consideration of coincident flooding, was simulated for the 1% AEP event.

Impact mapping showing the change in peak flood level is provided in Appendix C. Peak modelled flood levels are presented in Table 8-1 at the end of this Section.

8.5 Conclusion

The impact of the model sensitivity tests considered for the 1% AEP event is summarised in Table 8-1, in terms of modelled peak flood levels at the reporting locations identified in Figure 7-1.

Table 8-1 Modelled Peak Flood Levels (m AHD) for Sensitivity Tests

ID	Location	Modelled Condition for the 1% AEP Event								
		HHWSS TWL	+20% 'n'	-20% 'n'	0% Pit Block	100% Pipe Block	Combined Blockage	90% Pre-Burst	Median Pre-Burst	Design
1	Reserve Road	2.5	2.5	2.4	2.5	2.5	2.5	2.5	2.4	2.5
2	The Boulevarde	3.2	3.2	3.2	3.2	3.3	3.3	3.2	3.2	3.2
3	Parkes Street	11.0	11.0	11.0	11.0	11.0	11.0	11.0	10.9	11.0
4	New Lake Entrance Road	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.6	33.7
5	Kingston Street	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
6	Link Road	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.6	4.7
7	Oakey Creek	2.7	2.7	2.7	2.7	3.1	3.1	2.8	2.6	2.7
8	Devonshire Street	3.7	3.7	3.6	3.7	3.7	3.7	3.7	3.6	3.7
9	Government Road	7.0	7.0	6.9	7.0	7.0	7.0	7.0	6.9	7.0
10	Jilba Place	11.5	11.5	11.5	11.5	11.6	11.6	11.5	11.4	11.5
11	New Lake Entrance Road	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
12	Shellharbour City Basin	19.8	19.8	19.8	19.7	20.9	20.9	19.8	19.8	19.8
13	Cygnet Avenue	23.6	23.6	23.6	23.6	23.6	23.6	23.6	23.5	23.6
14	Alinga Drive	3.4	3.4	3.4	3.3	3.5	3.5	3.4	3.3	3.4
15	Madigan Boulevard	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.5	3.6
16	MacKenzie Avenue	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
17	Landy Drive	30.3	30.3	30.3	30.3	30.4	30.4	30.4	30.3	30.3
18	Konrads Road	2.8	2.9	2.8	2.8	2.9	2.9	2.8	2.8	2.8
19	Reddall Parade	2.3	2.3	2.3	2.3	2.4	2.4	2.3	2.2	2.3
20	Ponsford Street	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.1	10.2
21	Bradman Avenue	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
22	Kotari Parade	2.1	2.1	2.1	2.1	2.2	2.2	2.1	2.1	2.3
23	Lake Illawarra South Public School	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.2
24	Addison Avenue	2.2	2.2	2.1	2.1	2.2	2.2	2.2	2.2	2.3
25	Reddall Parade	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.2
26	Howard Fowles Oval	2.2	2.2	2.1	2.2	2.2	2.2	2.2	2.2	2.3
27	Girraween Avenue	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
28	Peterborough Avenue	2.1	2.1	2.1	2.1	2.2	2.2	2.1	2.1	2.2

ID	Location	Modelled Condition for the 1% AEP Event								
		HHWSS TWL	+20% 'n'	-20% 'n'	0% Pit Block	100% Pipe Block	Combined Blockage	90% Pre-Burst	Median Pre-Burst	Design
29	View Street	1.4	1.5	1.4	1.4	1.5	1.5	1.4	1.4	2.0
30	Windang Street	1.7	1.7	1.7	1.6	1.7	1.7	1.7	1.7	2.0
31	Keith Fletcher Park	2.4	2.4	2.4	2.4	2.6	2.6	2.4	2.4	2.4
32	Osborne Parade	3.5	3.5	3.5	3.4	3.6	3.6	3.5	3.4	3.5

9 Climate Change Analysis

9.1 Climate Change Considerations

The potential for climate change impacts is now a key consideration for floodplain management. 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);
- Flood Risk Management Guide – Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010); and
- Australian Rainfall and Runoff: A Guide to Flood Estimation (Ball et al, 2016)

Key elements of future climate change (e.g. sea level rise, rainfall intensity) are therefore important considerations in the ongoing floodplain risk management.

9.2 Potential Climate Change Impacts

9.2.1 Ocean Water Level

The NSW Sea Level Rise Policy Statement (DECCW, 2009) provided projected increases in mean sea level for NSW of 0.4m and 0.9m, by the years 2050 and 2100 respectively. These increases are no longer prescribed by the state government but have been adopted for the purpose of this study in the absence of other suitable recommendations. Therefore, design ocean boundaries have been raised by 0.4m and 0.9m to assess the potential impact of sea level rise on flood behaviour in the study catchments.

9.2.2 Design Rainfall Intensity

In 2007 the NSW 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% (typically 10%, 20% and 30%). Future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

The Intergovernmental Panel on Climate Change (IPCC) is the leading body for the assessment of climate change globally. Since its establishment in 1988, the IPCC have released five climate change reports, the most recent of which is known as the 'Fifth Assessment Report' known as AR5 which was realised in four parts between September 2013 and November 2014. This report supersedes the four previous IPCC reports. The AR5 provides a thorough discussion about climate change science, with the outcome of the study focused strongly on the documentation of the likely impacts of climate change in the global context.

The documented impacts were representative of broad geographical regions (i.e. polar and equatorial regions) and were based on a range of future greenhouse gas emissions and concentration scenarios (IPCC, 2013). These future scenarios are referred to as known as

Representative Concentration Pathways (RCPs). They focus on the ‘concentrations’ of greenhouse gases that lead directly to a changed climate, and include a ‘pathway’ – the trajectory of greenhouse gas concentrations over time to reach a particular radiative forcing at 2100. The four RCPs cover a range of emission scenarios with and without climate mitigation policies. For example, RCP8.5 is based on minimal effort to reduce emissions. Particular focus is given to RCP4.5 (low emissions pathway) and RCP8.5 (high emissions pathway).

Utilising the outcomes of the Intergovernmental Panel on Climate Change IPCC research, CSIRO and the Australian Bureau of Meteorology have prepared tailored climate change projection reports for Australian regions (known as clusters) including the East Coast region. The *East Coast Cluster Report – Climate Change Projections for Australia’s Natural Resource Management Regions* (Dowdy et al, 2015).

Various future climate scenarios (RCPs) are considered based on a range of future greenhouse gas emissions and concentration scenarios. Dowdy et al. (2015) includes projected changes in heavy rainfall events including the potential increase in 20-year return period maximum 1-day rainfall as shown in Figure 9-1. The blue and purple columns in Figure 9-1 represent the RCP4.5 and RCP8.5 scenarios respectively. The relative change in the 20-year return level of maximum 1-day rainfall is approximately 18% for the low-emissions pathway (RCP4.5) and 25% for the high-emissions pathway (RCP8.5).

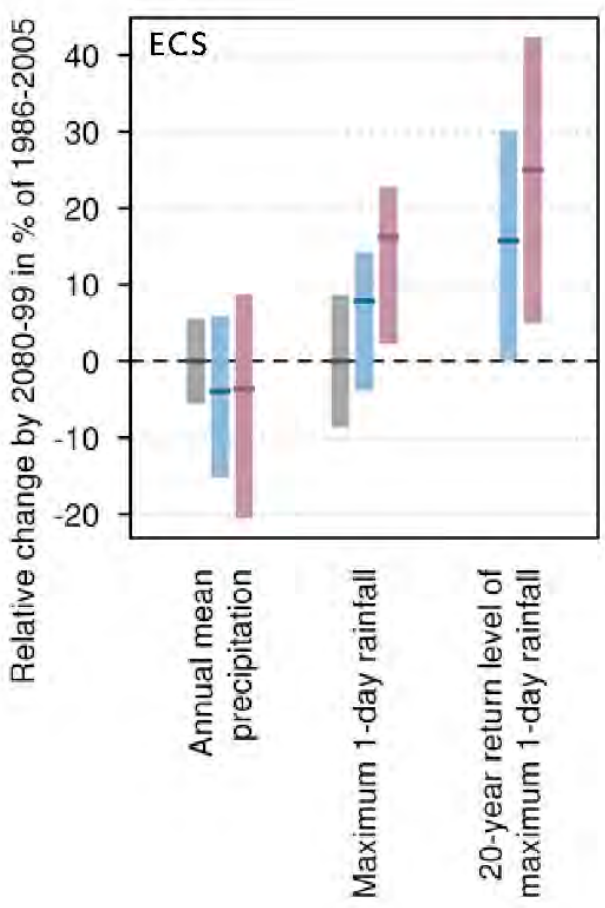


Figure 9-1 Projected Changes in Rainfall (Dowdy et al, 2015)

Chapter 6 of the newly released AR&R guidelines (2016) provides further consideration and guidance on potential climate change influence utilising the RCP projections and relationship to design rainfall intensity. The guidelines recommend the choice of RCP4.5 because lower representative concentration pathways require ambitious global emissions reductions and where the additional expense can be justified on socioeconomic and environmental grounds, the maximum consensus case for the high concentration pathway RCP8.5 should also be considered.

Interim climate change factors for the study area were accessed from the AR&R datahub which supports the 2016 AR&R guidelines. For the RCP4.5 pathway the percentage increase in rainfall is estimated to be 5.6% for the year 2050 and 7.6% for the year 2090. For the RCP8.5 pathway (the highest concentration pathway), the percentage increase in rainfall is estimated to be 7.2% for the year 2050 and 16.1% for the year 2090.

9.3 Climate Change Model Conditions

Noting the variance in estimated rainfall increases due to climate change, it was determined to utilise an increase in rainfall of 10% and 20% which aligns with flood studies conducted in Shellharbour, whilst also capturing the potential range in rainfall increase based off the AR&R guidelines.

In line with the above guidance, additional tests incorporating a 10% and a 20% increase to design rainfall have been undertaken in addition to an increase lake level of 0.4 m and 0.9 m.

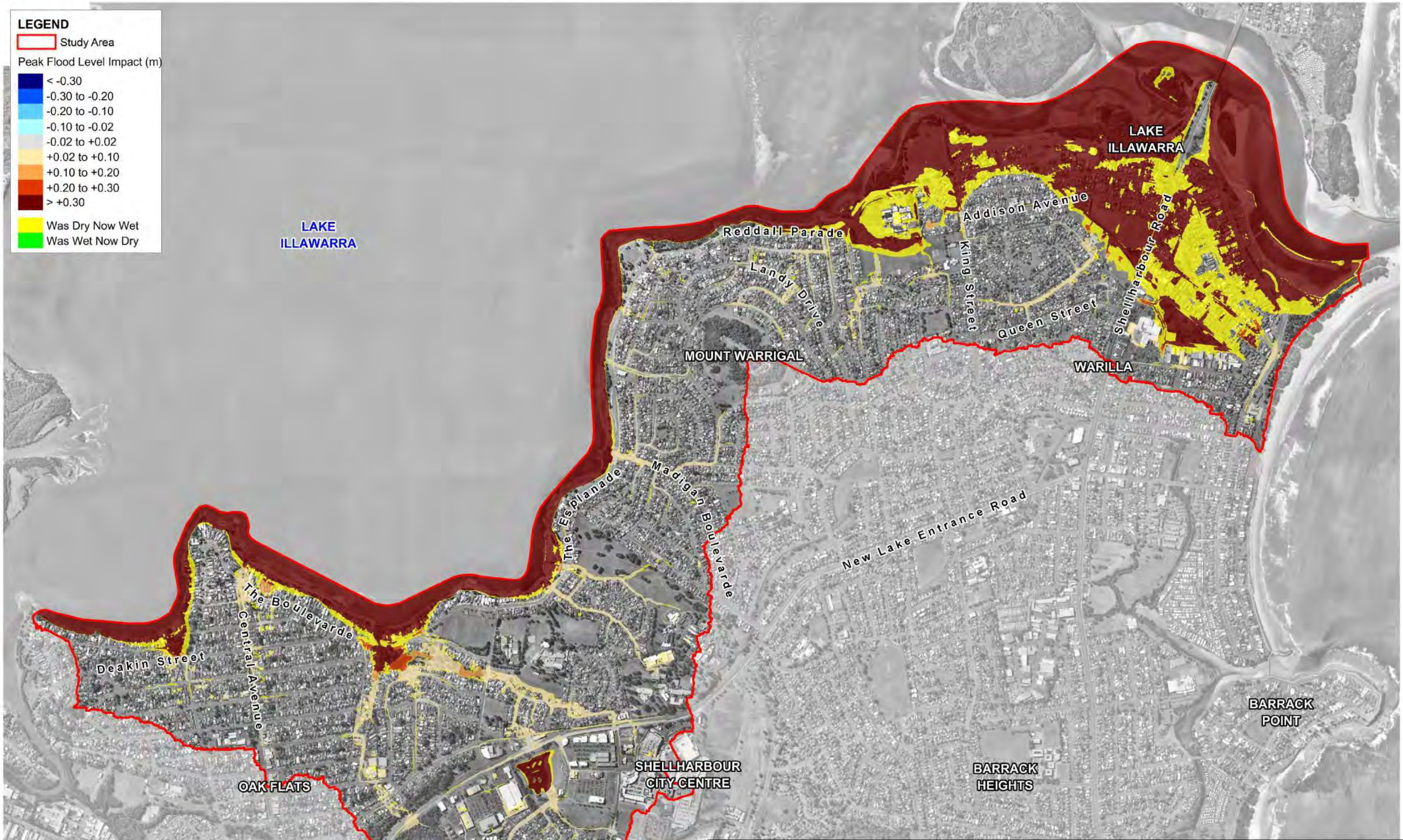
9.4 Climate Change Results

Figure 9-2 presents the spatial distribution of impacts of potential climate change (20% rainfall increase and 0.9 m sea level rise) for the 1% AEP event. It highlights areas that are particularly exposed to increased flood risk due to sea level rise or increased rainfall intensity.

Impact mapping showing the change in peak flood level for the remaining climate change scenarios, in addition to the combined condition shown below in Figure 9-2, are provided in Appendix C. Tabulated peak modelled flood levels for the climate change scenarios are presented in Appendix C for the locations shown in Figure 7-1.

The model results show that the suburb of Lake Illawarra and the foreshore areas of Lake Illawarra, Mt Warrigal and Oak Flats are highly susceptible to the impact of rising sea levels. The suburb of Lake Illawarra is especially subject to increases in inundation extent and flood levels due to its relatively low elevation (~2-4 mAHD).

Flood level impacts due to an increase in rainfall intensity are less significant, owing to the majority of overland flow being conveyed via the road system, however there are some regions which experience an increase of up to 0.2-0.3 m such Oakey Creek. Across the majority of the catchment for the 10% and 20% increases in rainfall the estimated increase in flood level is less than the 0.5m that is typically adopted as a freeboard for Flood Planning Levels.



Title:
1% AEP Climate Change Peak Flood Level Impacts
Rainfall 20% + SLR 2100

Figure: 9-2

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Table 9-1 Modelled Peak Flood Levels (m AHD) for Climate Change Sensitivity

ID	Location	Modelled Condition for the 1% AEP Event								
		Design	10% Rainfall Increase	20% Rainfall Increase	2050 SLR (2.63 m AHD)	2100 SLR (3.04 m AHD)	10% & 2050	10% & 2100	20% & 2050	20% & 2100
1	Reserve Road	2.5	2.5	2.5	2.7	3.0	2.7	3.0	2.7	3.0
2	The Boulevarde	3.2	3.3	3.3	3.2	3.2	3.3	3.3	3.3	3.3
3	Parkes Street	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
4	New Lake Entrance Road	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.7	33.7
5	Kingston Street	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
6	Link Road	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
7	Oakey Creek	2.7	2.8	2.9	2.9	3.1	2.9	3.1	2.9	3.1
8	Devonshire Street	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
9	Government Road	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
10	Jilba Place	11.5	11.5	11.6	11.5	11.5	11.5	11.5	11.6	11.6
11	New Lake Entrance Road	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
12	Shellharbour City Basin	19.8	20.1	20.5	19.8	19.8	20.1	20.1	20.5	20.5
13	Cygnet Avenue	23.6	23.6	23.7	23.6	23.6	23.6	23.6	23.7	23.7
14	Alinga Drive	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
15	Madigan Boulevard	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
16	MacKenzie Avenue	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
17	Landy Drive	30.3	30.4	30.4	30.3	30.3	30.4	30.4	30.4	30.4
18	Konrads Road	2.8	2.8	2.8	2.8	3.0	2.8	3.0	2.8	3.0
19	Reddall Parade	2.3	2.3	2.3	2.6	3.0	2.6	3.0	2.6	3.0
20	Ponsford Street	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
21	Bradman Avenue	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
22	Kotari Parade	2.3	2.2	2.2	2.6	3.0	2.6	3.0	2.6	3.0
23	Lake Illawarra South Public School	2.2	1.8	1.8	2.6	3.1	2.6	3.1	2.6	3.1
24	Addison Avenue	2.3	2.2	2.2	2.6	3.0	2.6	3.0	2.6	3.0
25	Reddall Parade	2.2	1.5	1.6	2.6	3.0	2.6	3.0	2.6	3.0
26	Howard Fowles Oval	2.3	2.2	2.2	2.6	3.0	2.6	3.0	2.6	3.0
27	Girraween Avenue	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
28	Peterborough Avenue	2.2	2.1	2.1	2.6	2.9	2.6	2.9	2.6	2.9

ID	Location	Modelled Condition for the 1% AEP Event								
		Design	10% Rainfall Increase	20% Rainfall Increase	2050 SLR (2.63 m AHD)	2100 SLR (3.04 m AHD)	10% & 2050	10% & 2100	20% & 2050	20% & 2100
29	View Street	2.0	1.5	1.5	2.4	2.8	2.4	2.8	2.4	2.8
30	Windang Street	2.0	1.7	1.7	2.4	2.8	2.4	2.8	2.4	2.8
31	Keith Fletcher Park	2.4	2.4	2.4	2.7	3.0	2.7	3.0	2.7	3.0
32	Osborne Parade	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

10 Conclusions

The primary objective of the study was to undertake a detailed flood study of the Oak Flats, Mt Warrigal and Lake Illawarra catchments and to establish models as necessary for design flood level prediction.

In completing the flood study, the following activities were undertaken:

- Compilation and review of existing information pertinent to the study;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Calibration of the developed models using the available flood data, including the recent events of 2011, 2013 and 2014; and
- Prediction of design flood conditions in the study area and production of design flood mapping series.

The principal outcome of the flood study is the understanding of flood behaviour in the study area and in particular design flood level information. The study provides updated and more detailed flooding information than the previous studies, to be used to inform floodplain risk management within the study area.

Flooding problem areas across the study area can be isolated to three main regions, being Oakey Creek, the Lake Illawarra foreshore and the suburb of Lake Illawarra. These regions are summarised below, with specific flood areas listed beneath:

Oakey Creek:

- Properties located at the upstream side of the intersection of The Esplanade and Oakey Creek;
- Properties located on the eastern side of Leamington Road from Link Road to The Esplanade;
- Properties located upstream of the Oak Flats Bowling and Recreation Club between Kingston Street, Lake Entrance Road and New Lake Entrance Road;
- Properties located on an overland flow path running from the corner of Gordon Avenue and Marlin Road via Devonshire Crescent;
- The rear of properties located along Timbs Road and Devonshire Crescent adjacent the main tributary of Oakey Creek;
- Properties located along Birra Drive and Jilba Place; and
- Commercial properties located downstream of the Shellharbour City Centre Basin adjacent the low-point in New Lake Entrance Road.

Lake Foreshore Areas:

- The lake frontage properties along Horsley Road, Newton Crescent, The Boulevarde, The Esplanade and Reddall Parade;

Lake Illawarra (suburb):

- The properties east of Shellharbour Road, bound by Peterborough Avenue to the south, View Street to the east, and Pur Pur Avenue to the north;
- The properties east of Shellharbour Road, bound by Reddall Parade and Pur Pur Avenue;
- The properties either side of Addison Avenue and Pur Pur Avenue located to the west of Shellharbour Road;
- The properties located at the low-point in Girraween Avenue adjacent Howard Fowls Oval reserve; and
- The properties either side of Kotari Parade and Corona Avenue.

The modelled flood conditions sensitivity to hydraulic roughness, stormwater drainage blockage and rainfall losses were limited. However, the model results show that the suburb of Lake Illawarra and the foreshore areas of Lake Illawarra, Mt Warrigal and Oak Flats are highly susceptible to rising sea levels and downstream boundary condition. Given the significant increase in flood risk across these areas sensitive to an elevated tailwater (Lake Illawarra), the incorporation of Lake Illawarra flooding within the design flood levels should be considered for flood planning purposes, particularly for the suburb of Lake Illawarra and lake foreshore areas. It is expected that management of food risk within these areas will be one of the key focuses of future floodplain risk management activities.

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12 Acknowledgements

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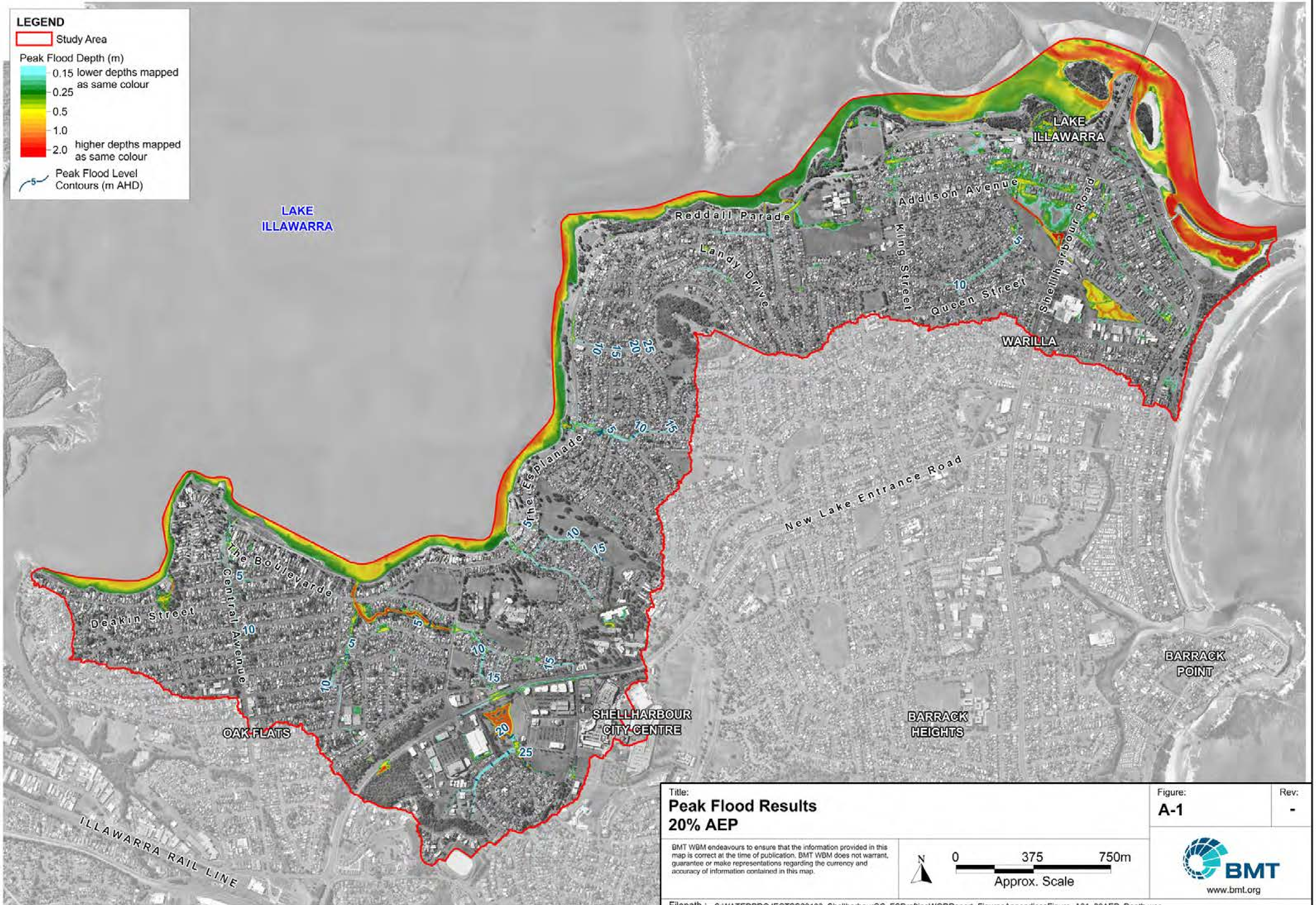
- Shellharbour City Council;
- Manly Hydraulic Laboratory;
- New South Wales Office of Environment and Heritage

Appendix A Design Flood Mapping



Title:
Peak Flood Results
20% AEP

Figure: **A-1**

Rev: **-**

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Approx. Scale

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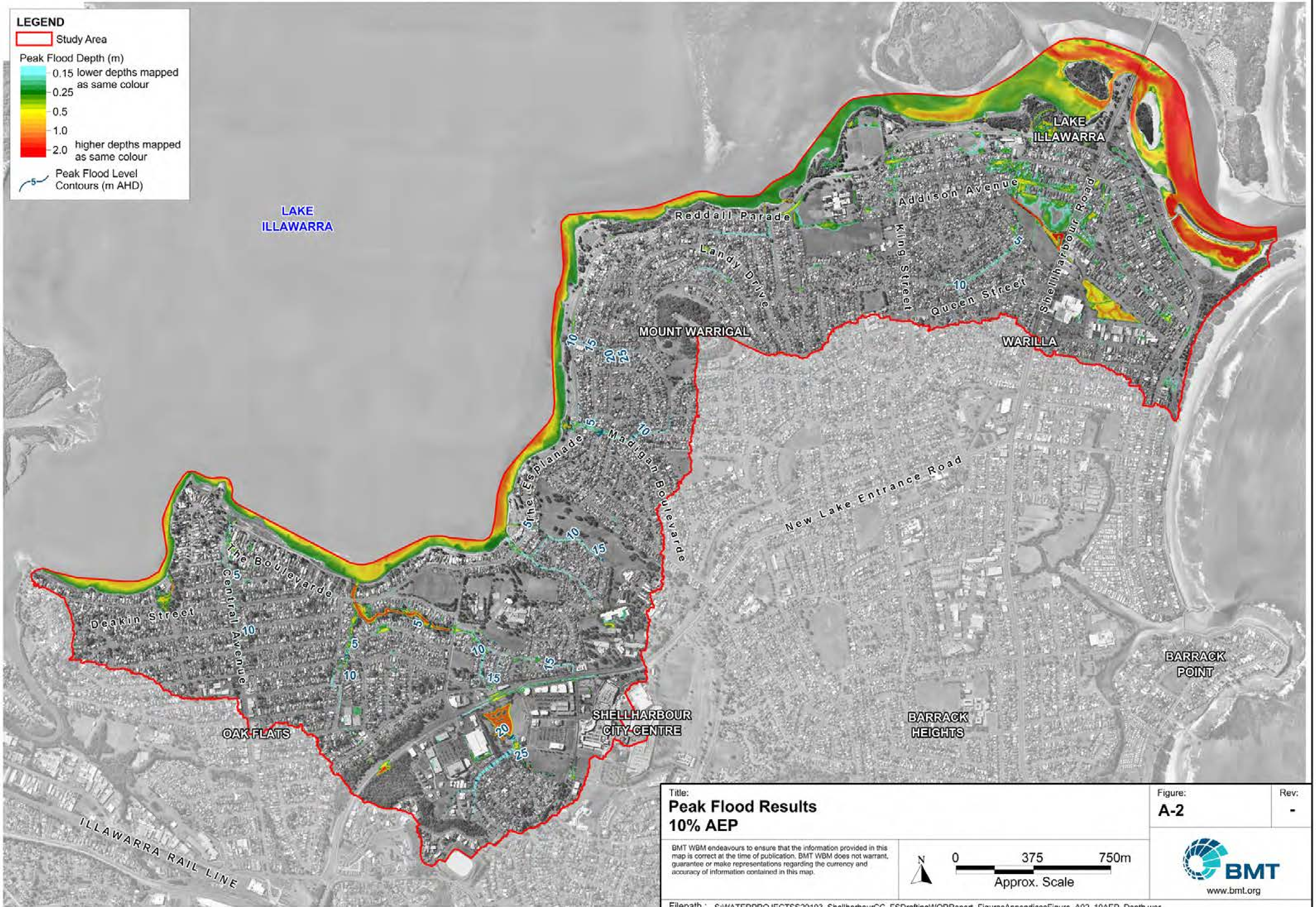

Title:
Peak Flood Results
10% AEP

Figure: **A-2**

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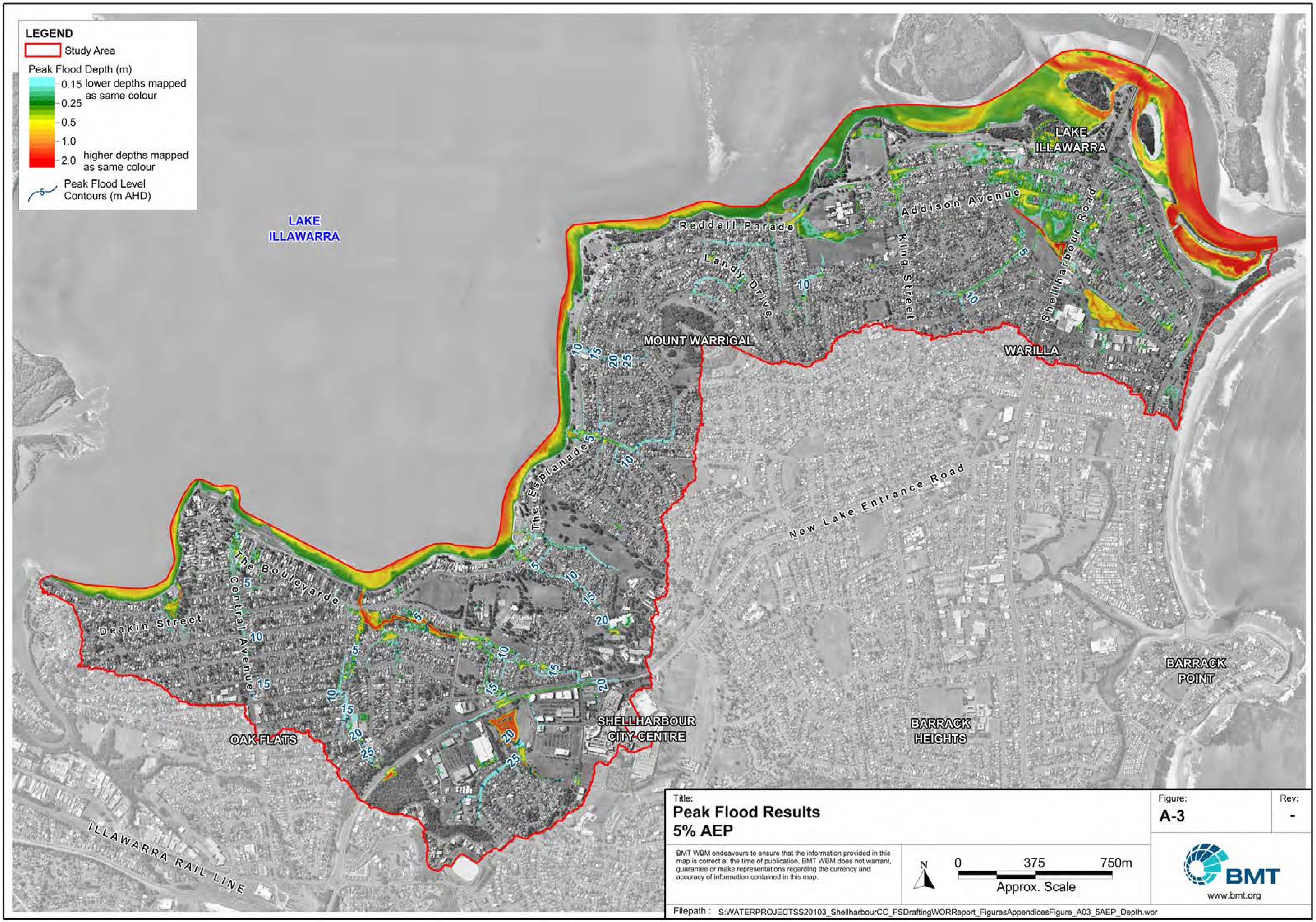

Title: **Peak Flood Results 5% AEP**

Figure: A-3

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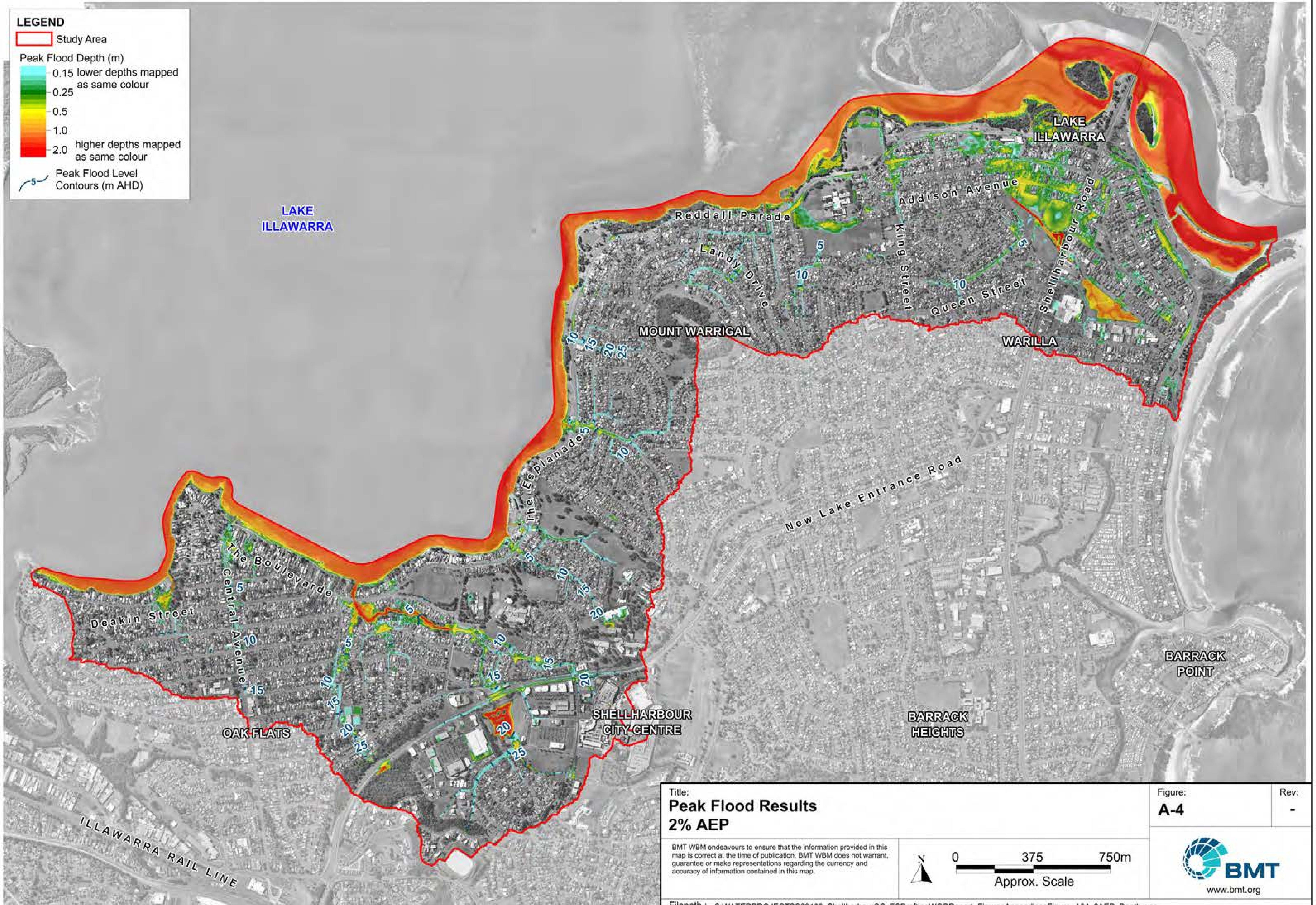

Title:
Peak Flood Results
2% AEP

Figure: A-4

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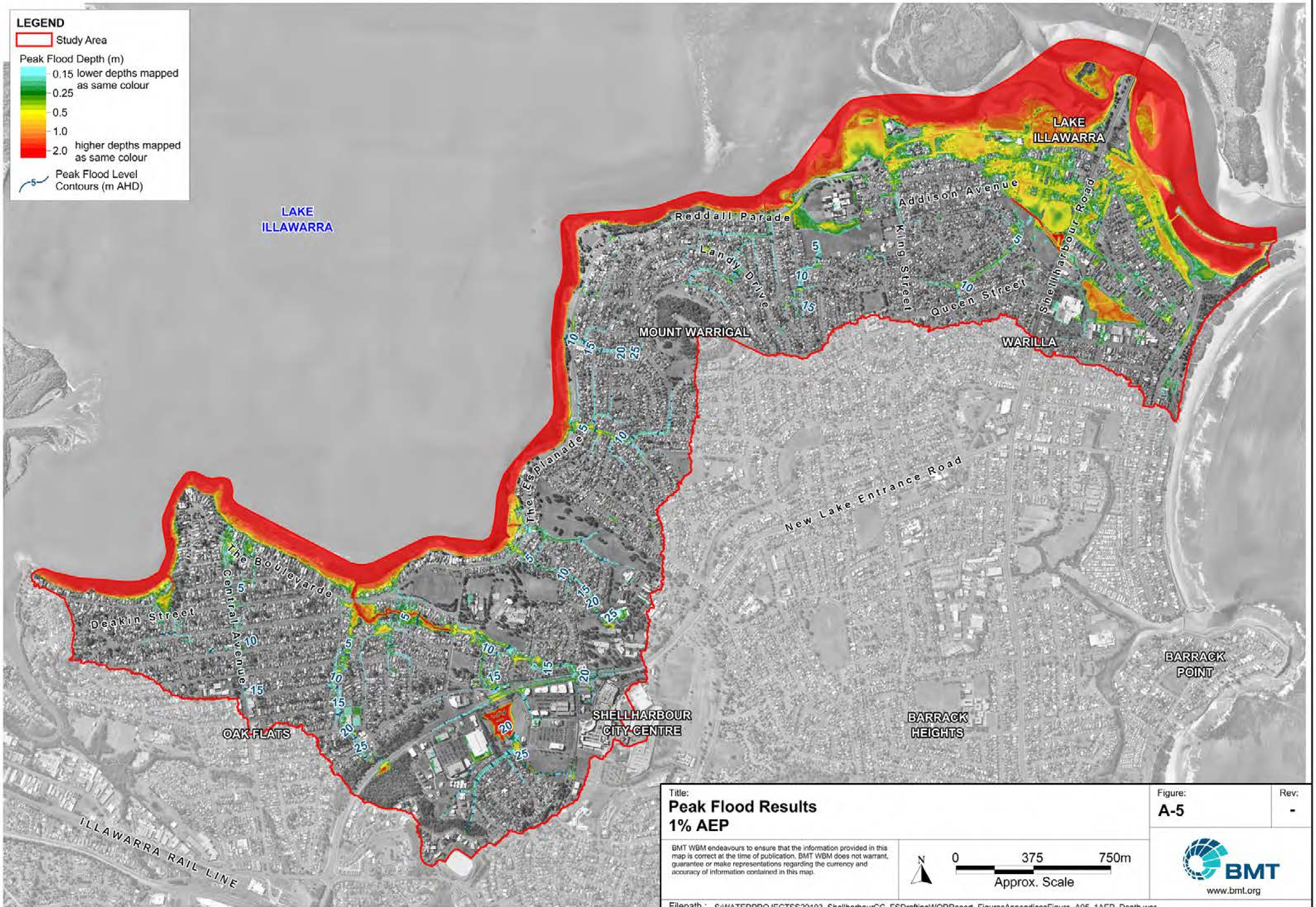

Title:
Peak Flood Results
1% AEP

Figure: **A-5**

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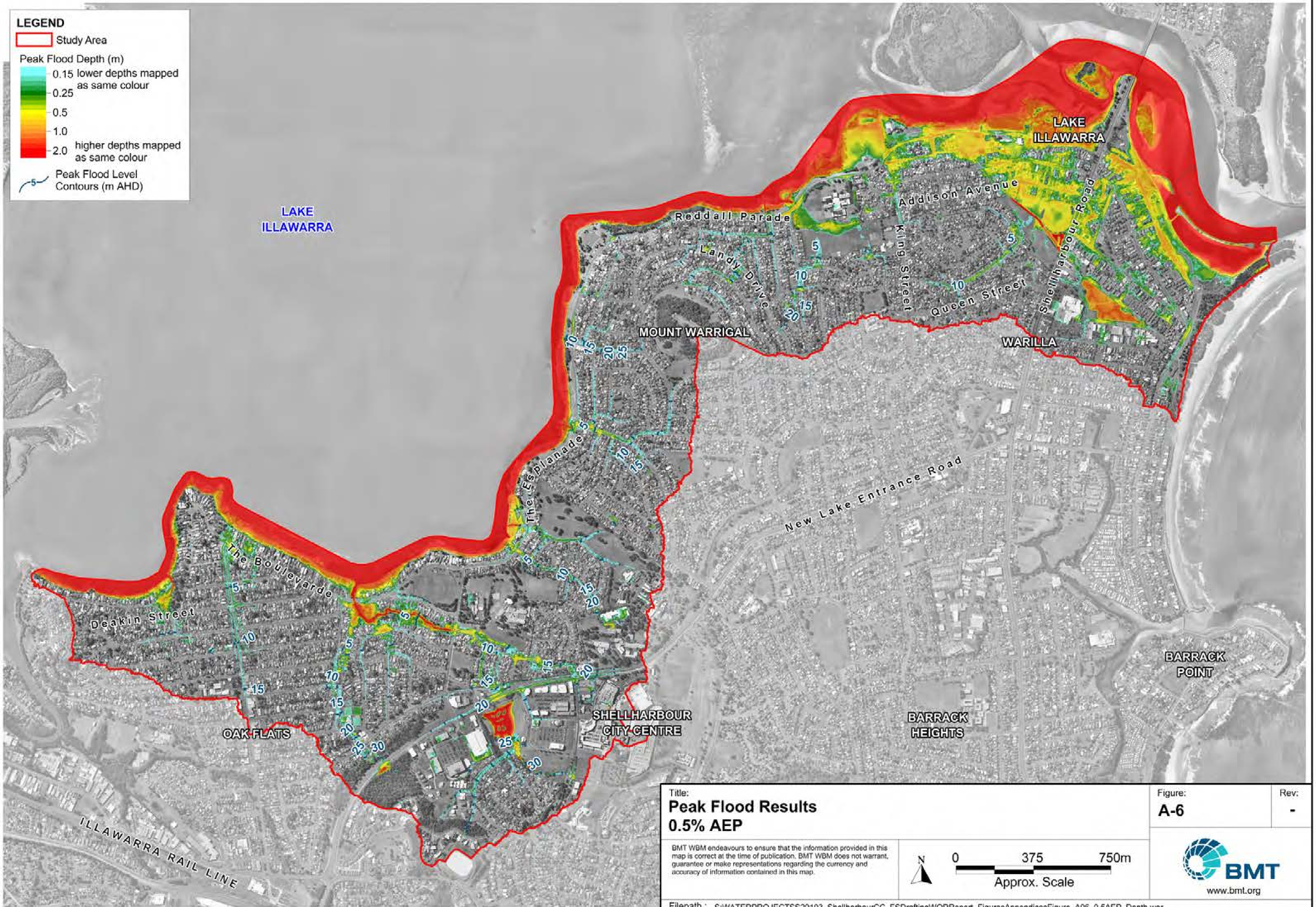

Title:
Peak Flood Results 0.5% AEP

Figure: A-6

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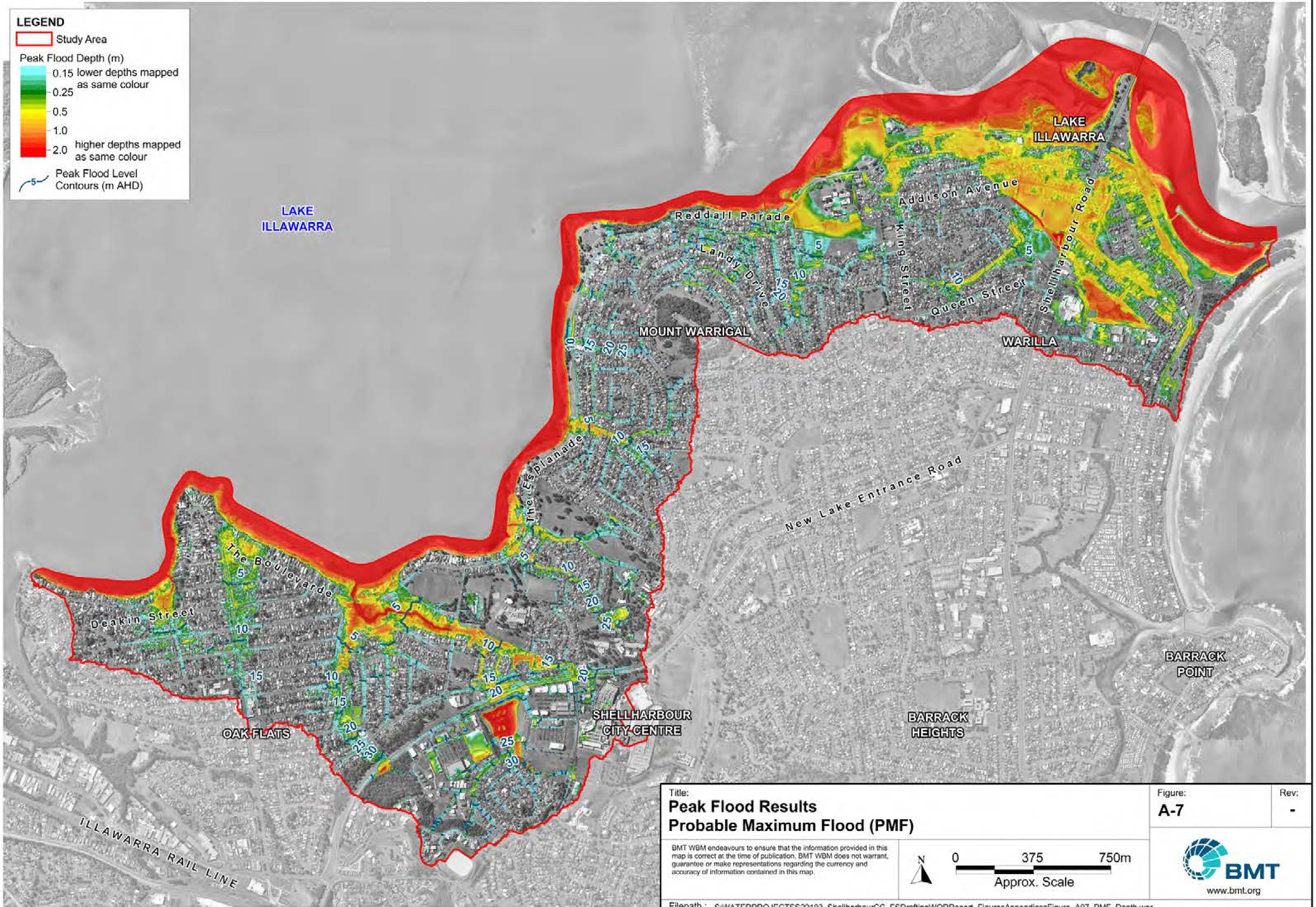

Title:
Peak Flood Results
Probable Maximum Flood (PMF)

Figure: A-7

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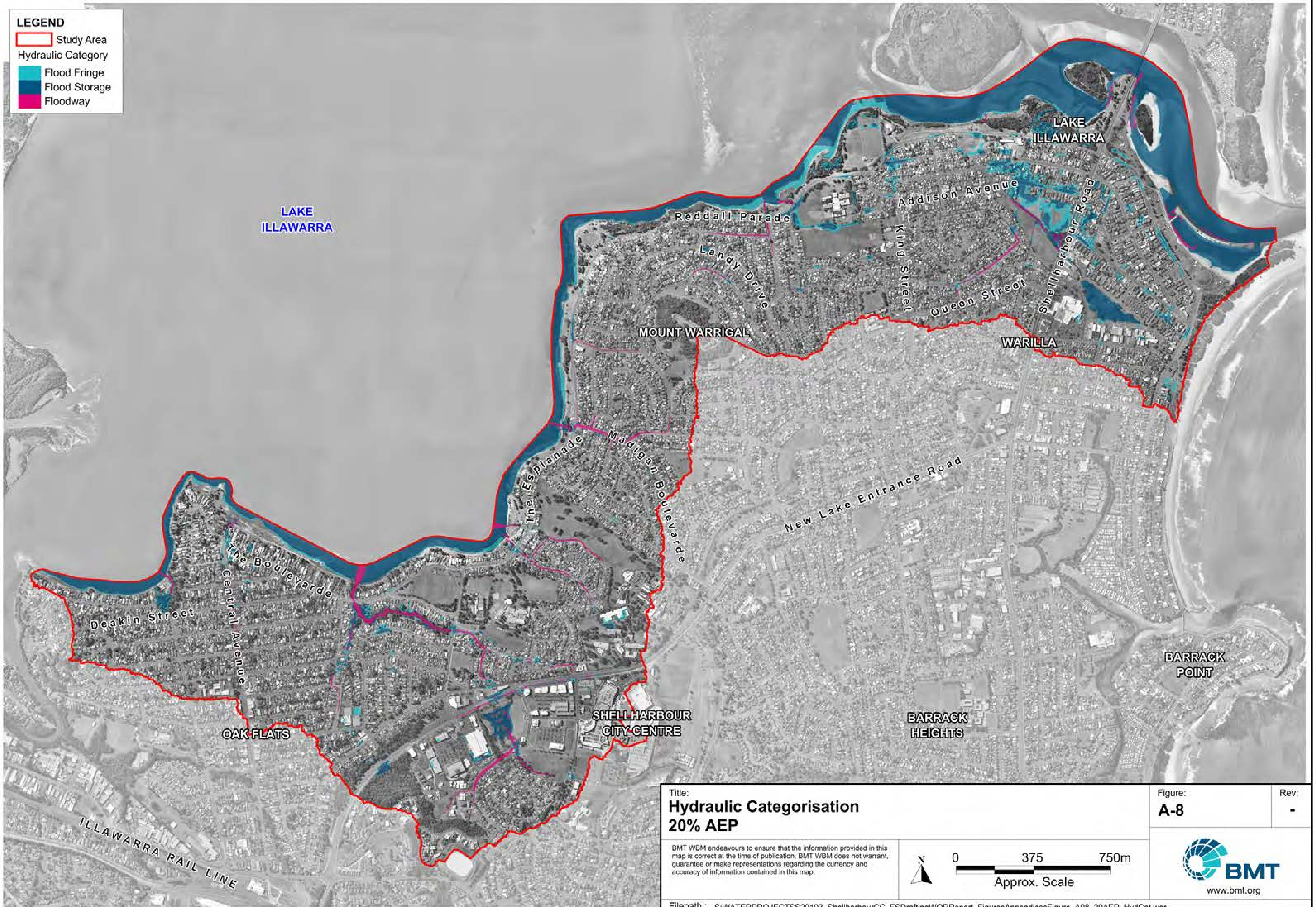

Title:
Hydraulic Categorisation 20% AEP

Figure: A-8

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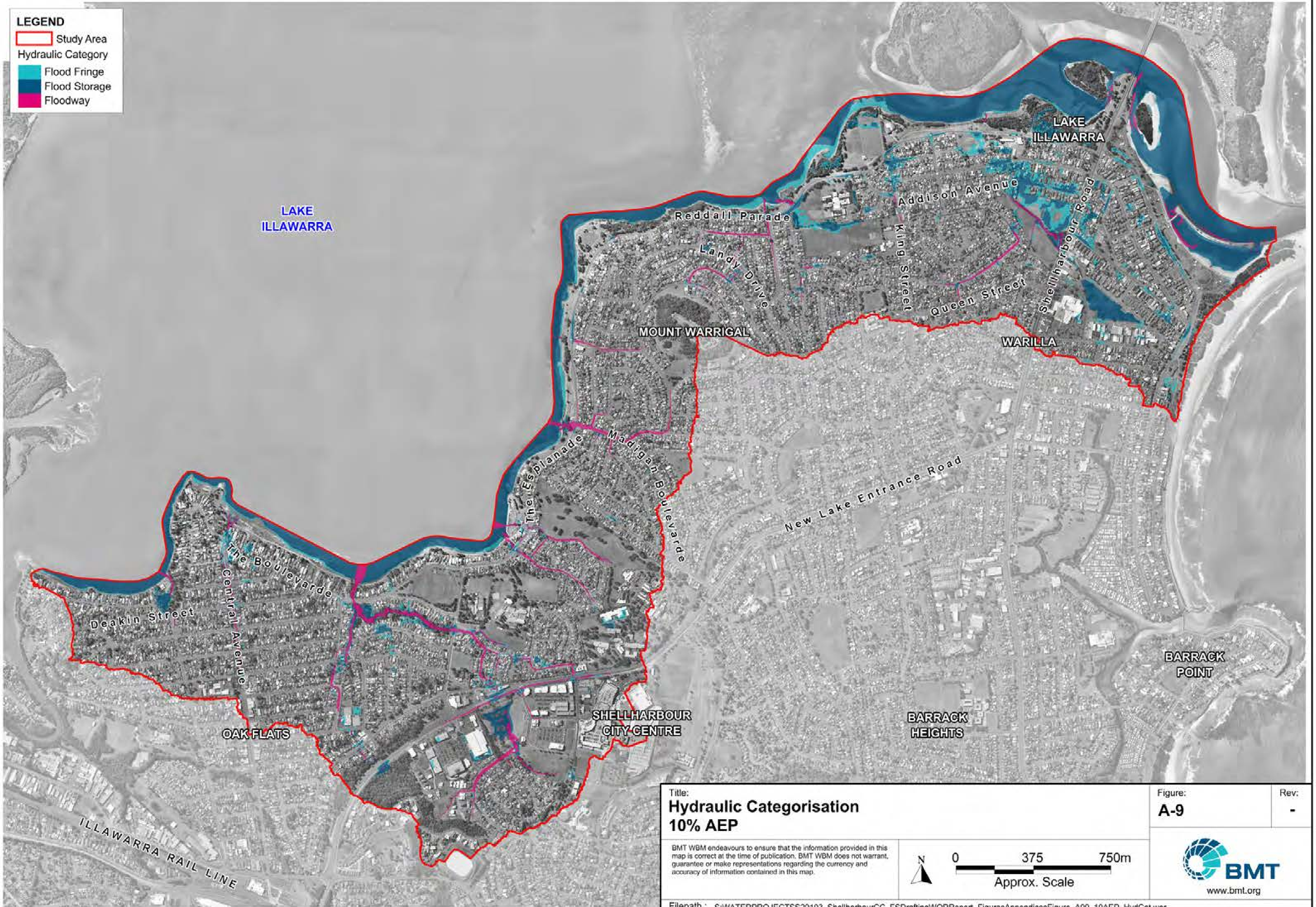

Title:
Hydraulic Categorisation 10% AEP

Figure: A-9

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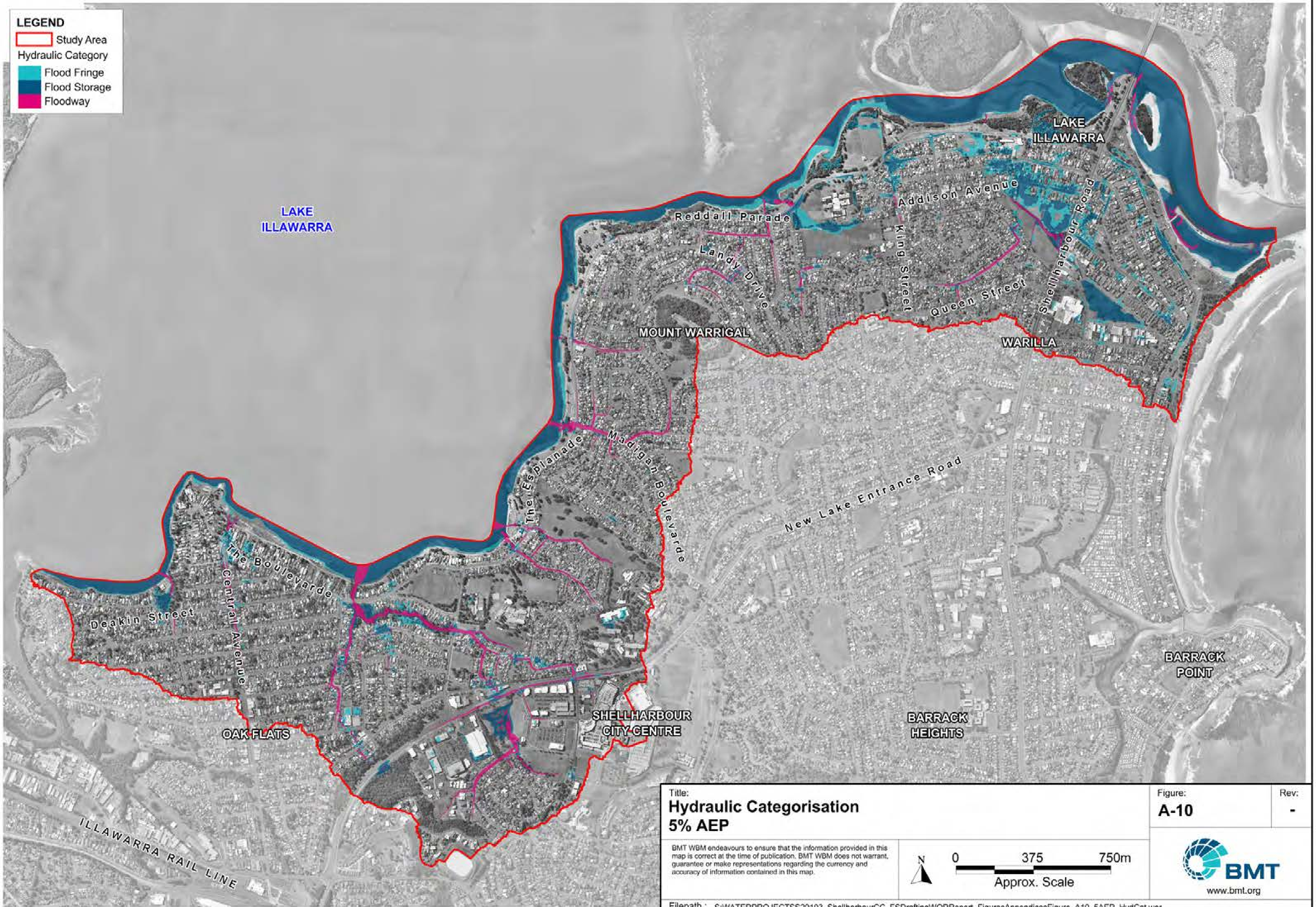

Title:
Hydraulic Categorisation
5% AEP

Figure: **A-10**

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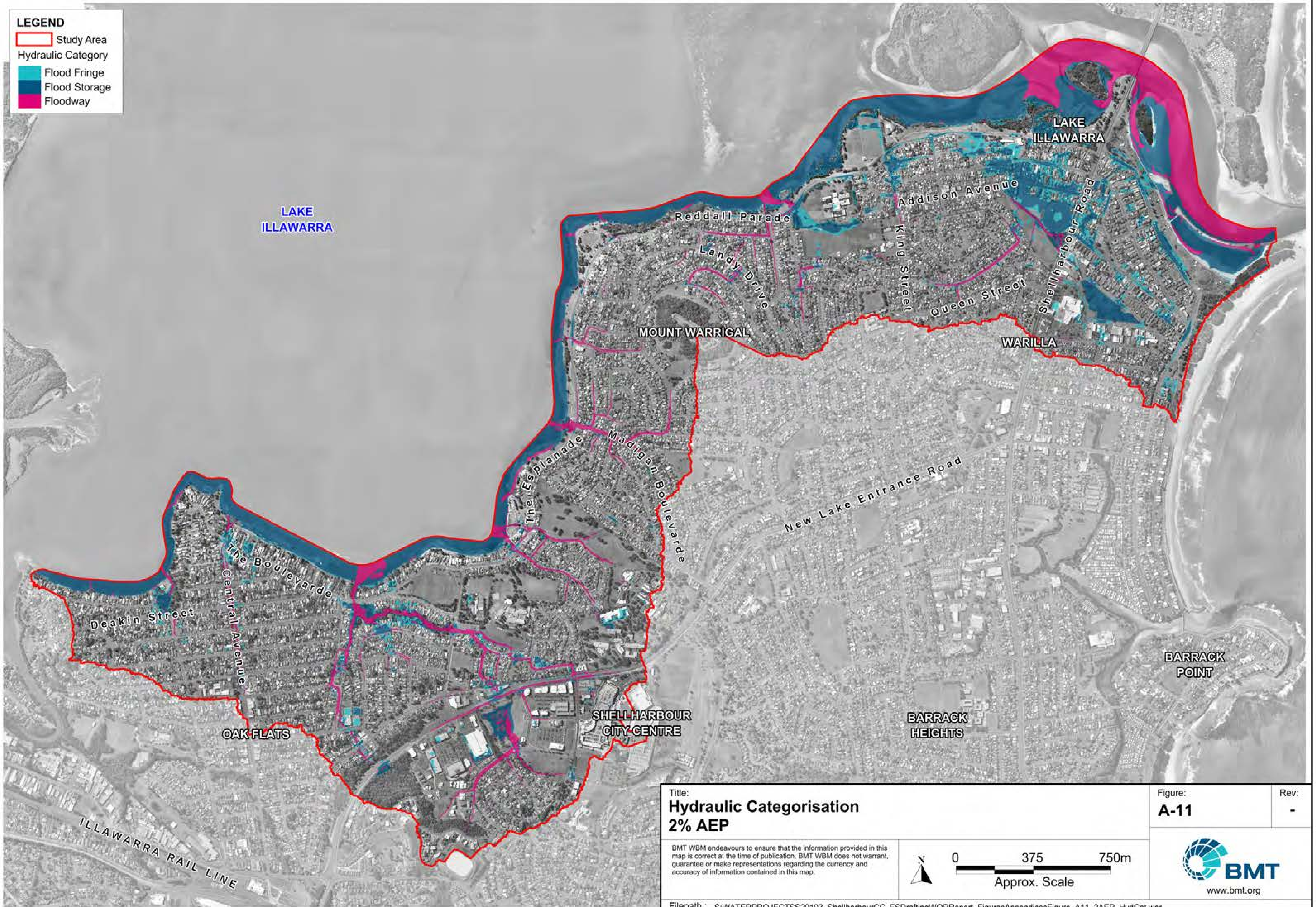

Title:
Hydraulic Categorisation
2% AEP

Figure:
A-11

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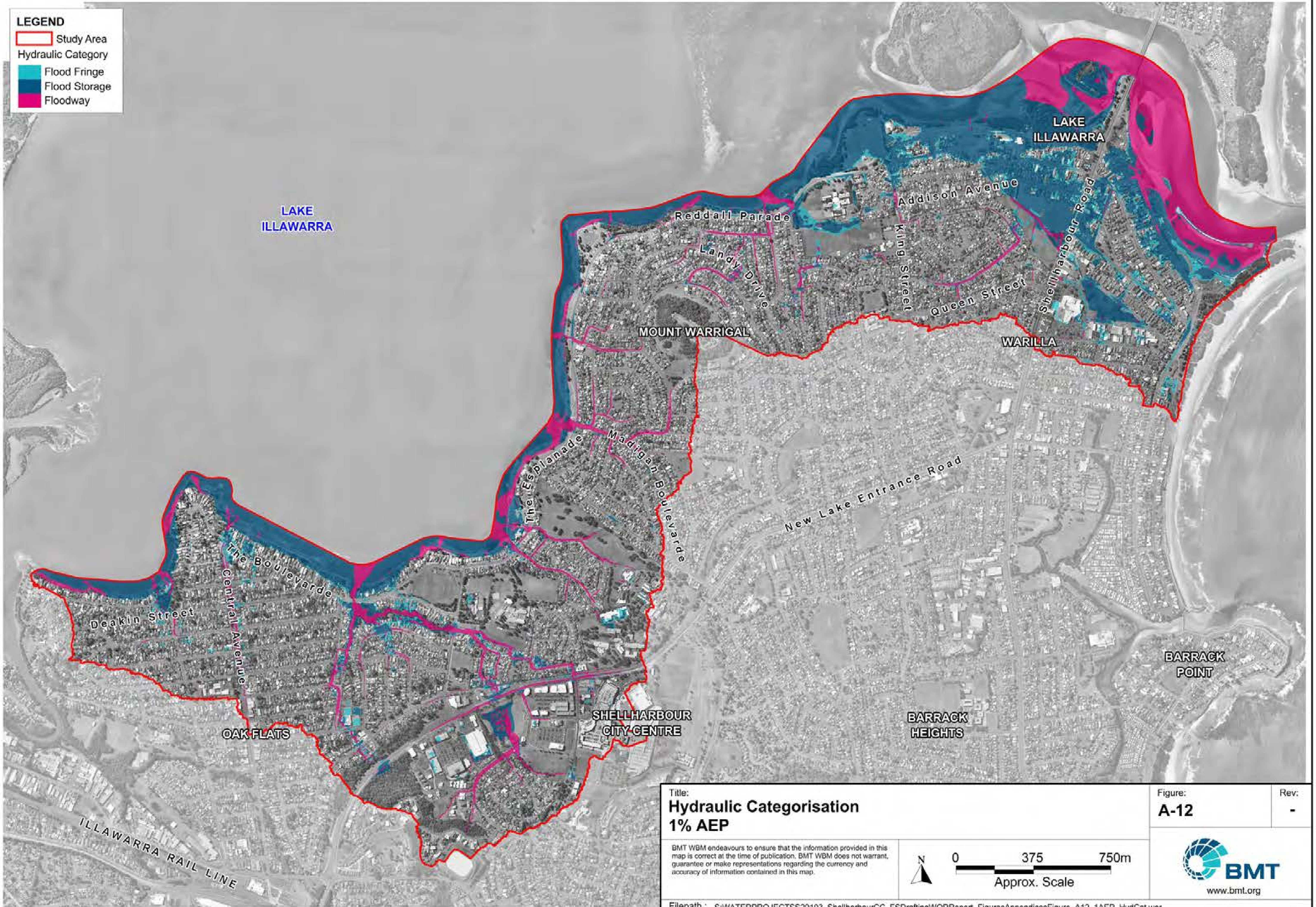

Title:
Hydraulic Categorisation
1% AEP

Figure: A-12

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Title:

Hydraulic Categorisation
0.5% AEP

Figure: **A-13**

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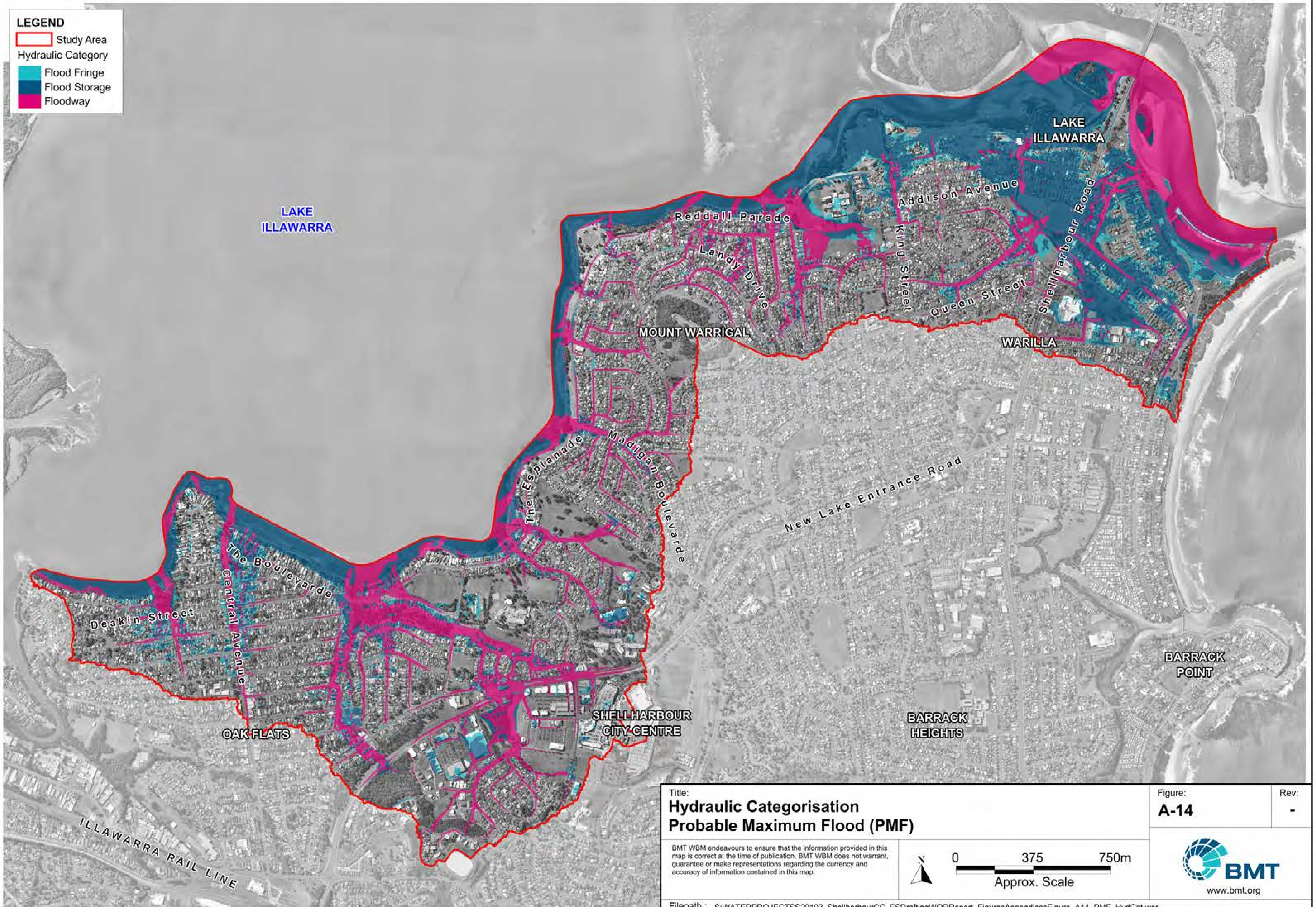

Title:

Hydraulic Categorisation Probable Maximum Flood (PMF)

Figure: A-14

Rev: -

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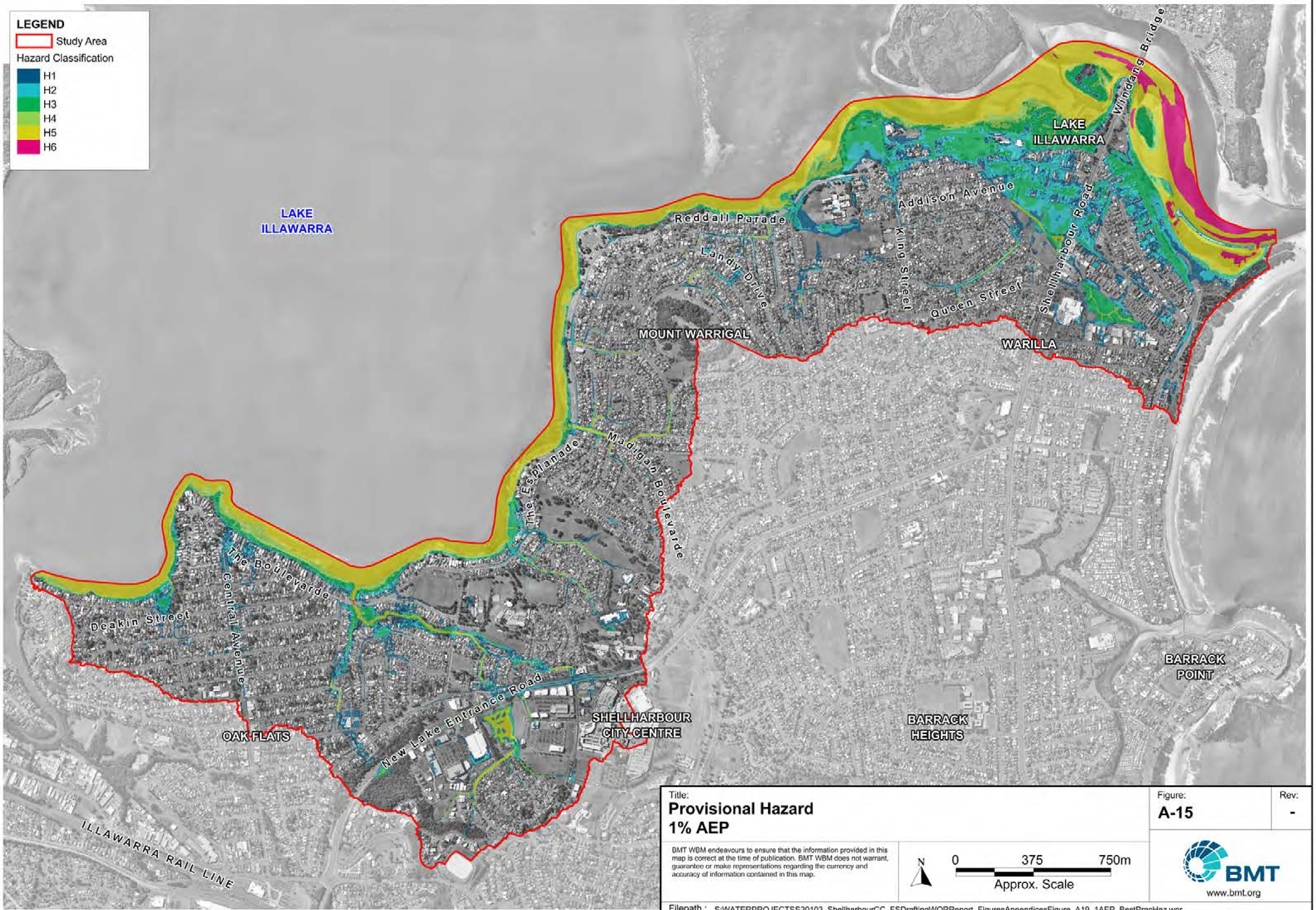

Title:
Provisional Hazard
1% AEP

Figure: **A-15**

Rev: **-**

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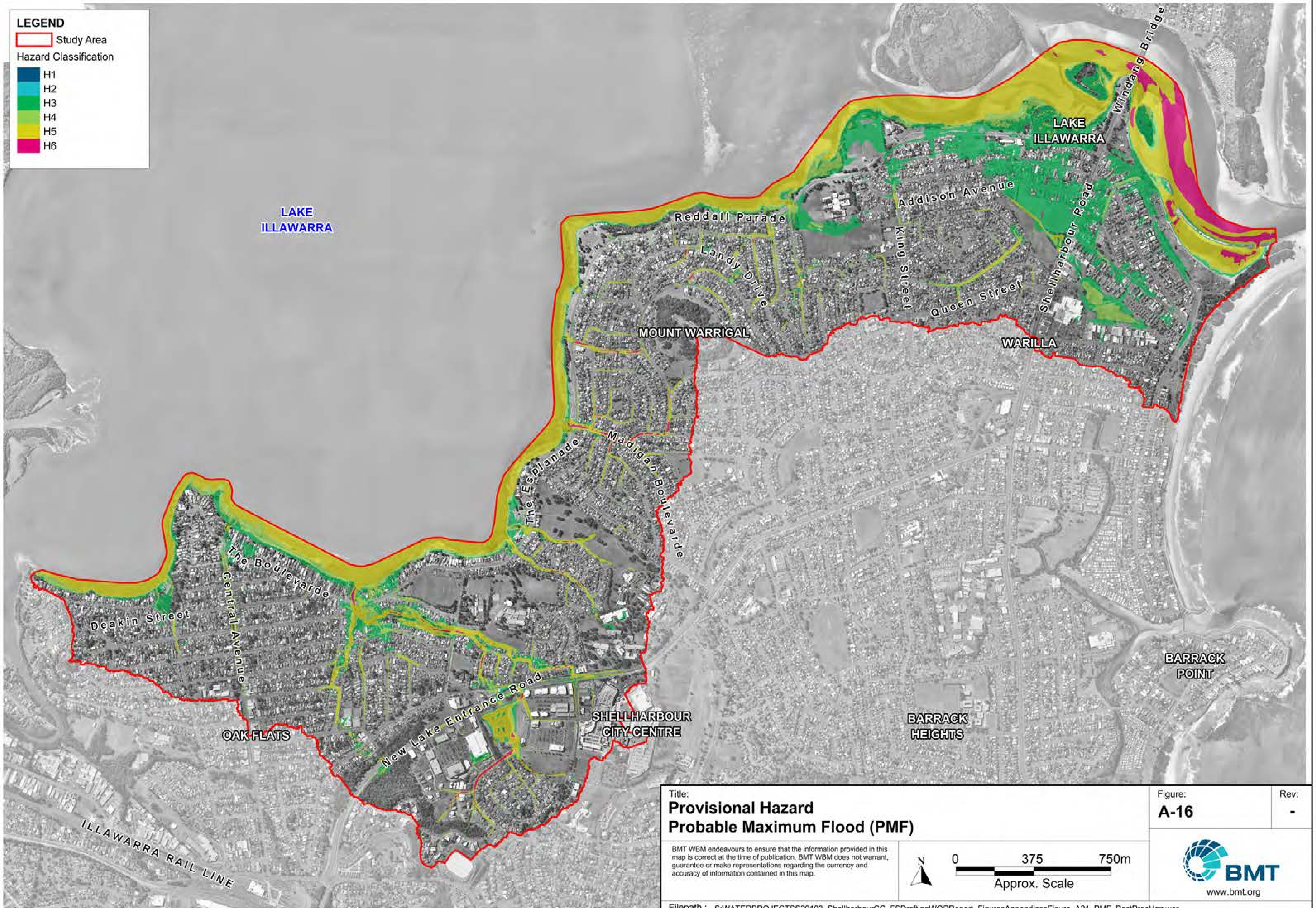

Title:
Provisional Hazard Probable Maximum Flood (PMF)

Figure: **A-16**

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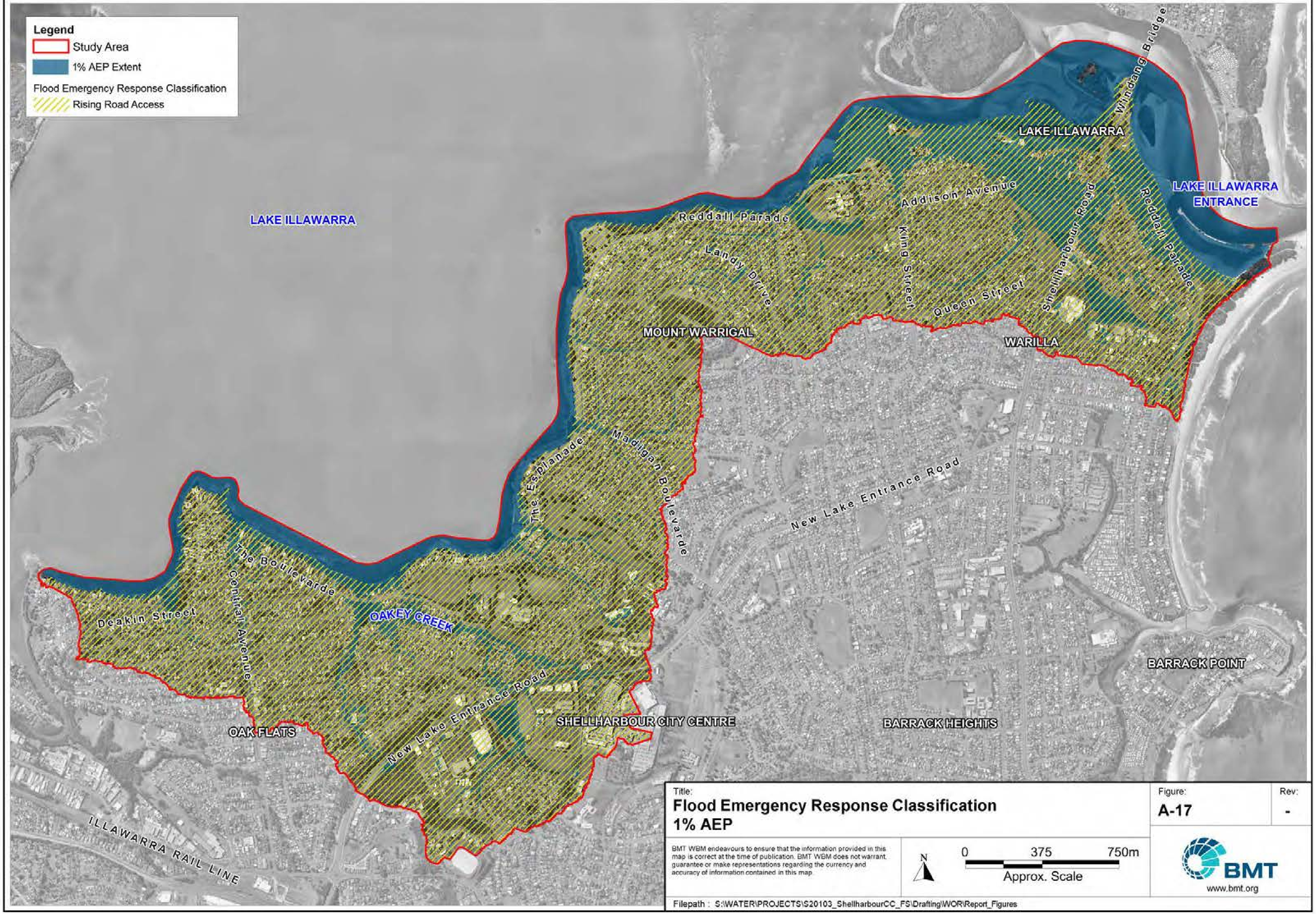

Title:
Flood Emergency Response Classification
1% AEP

Figure:
A-17

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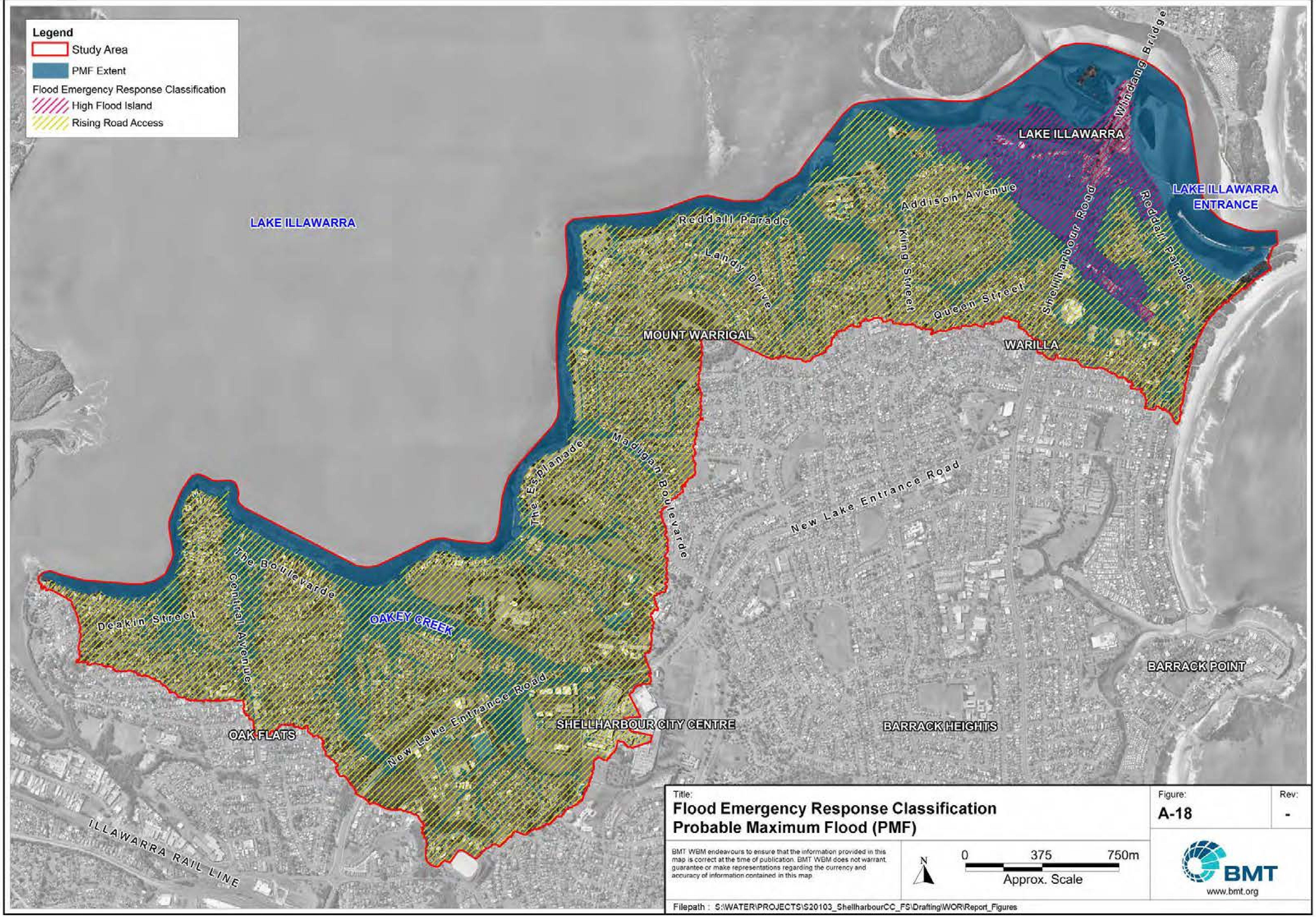

Title:
Flood Emergency Response Classification
Probable Maximum Flood (PMF)

Figure: **A-18**

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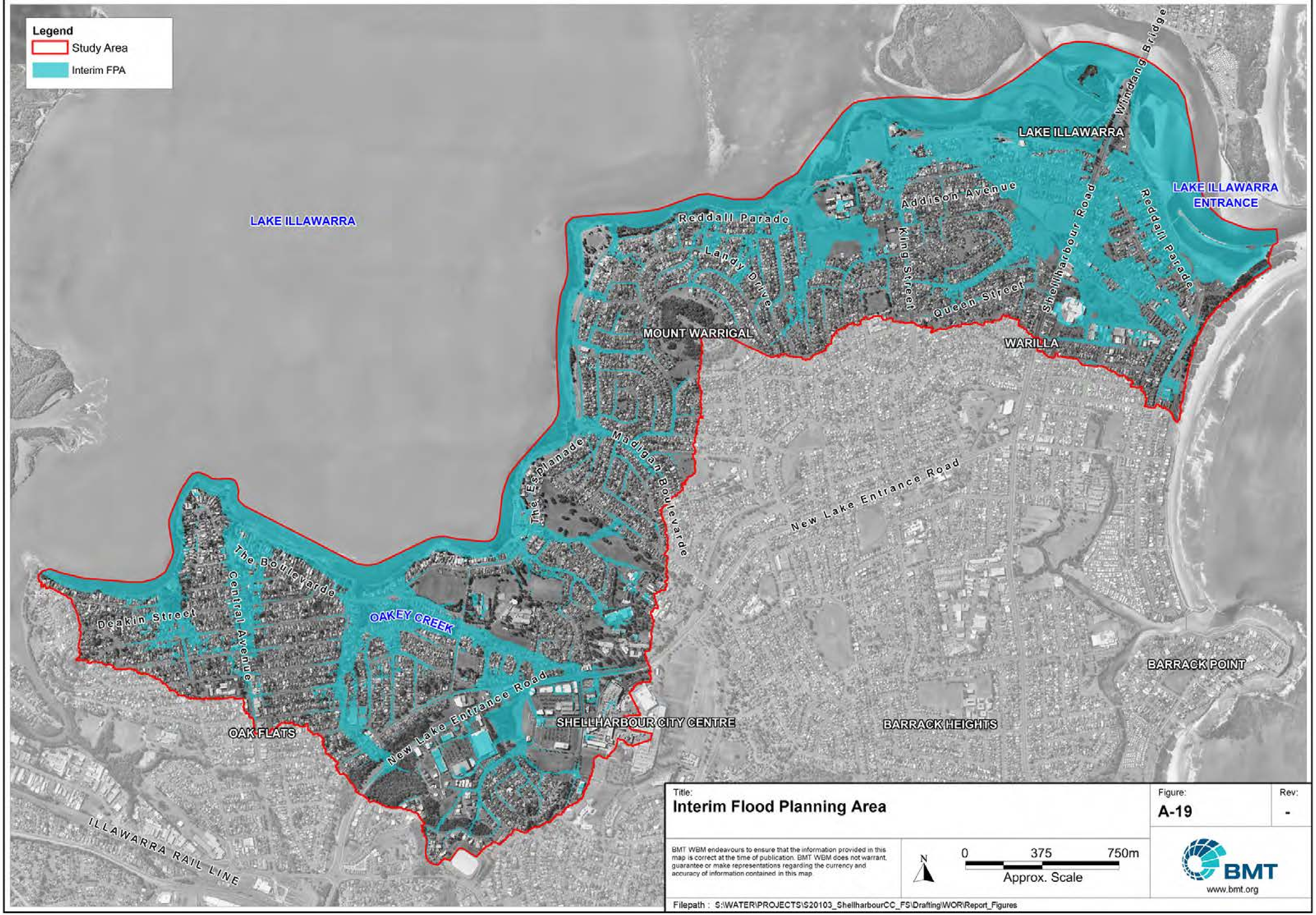

Title:
Interim Flood Planning Area

Figure: **A-19**

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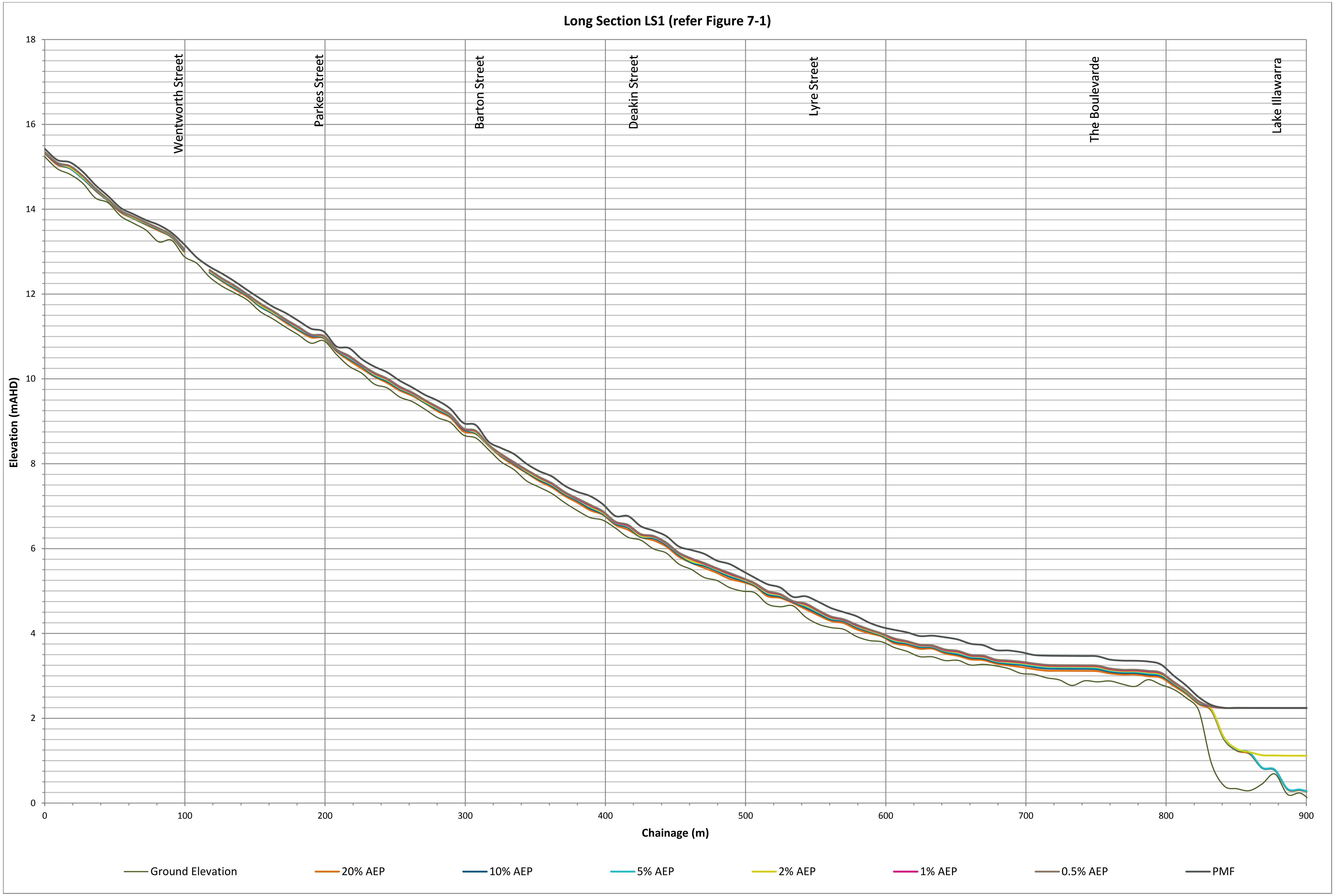
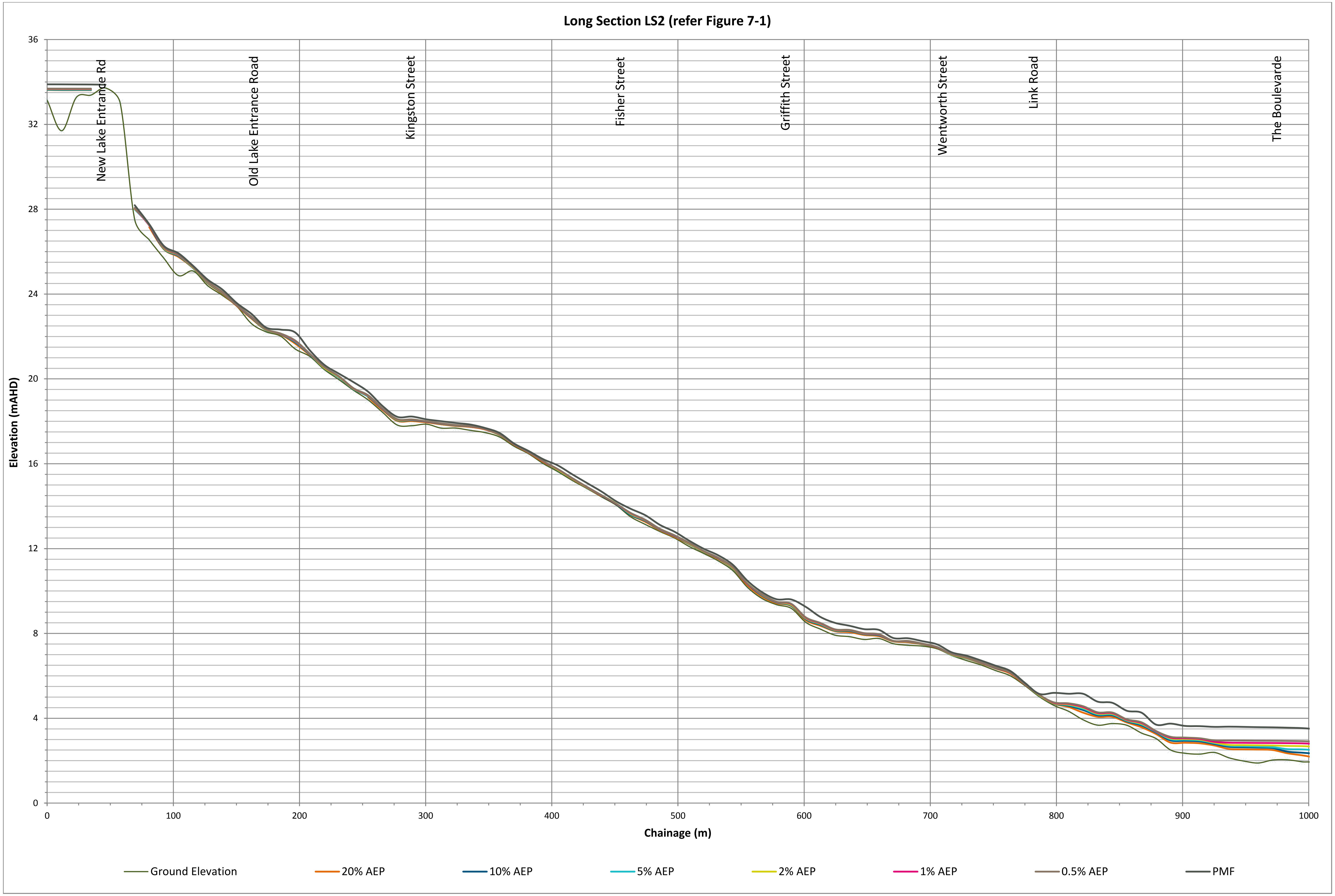
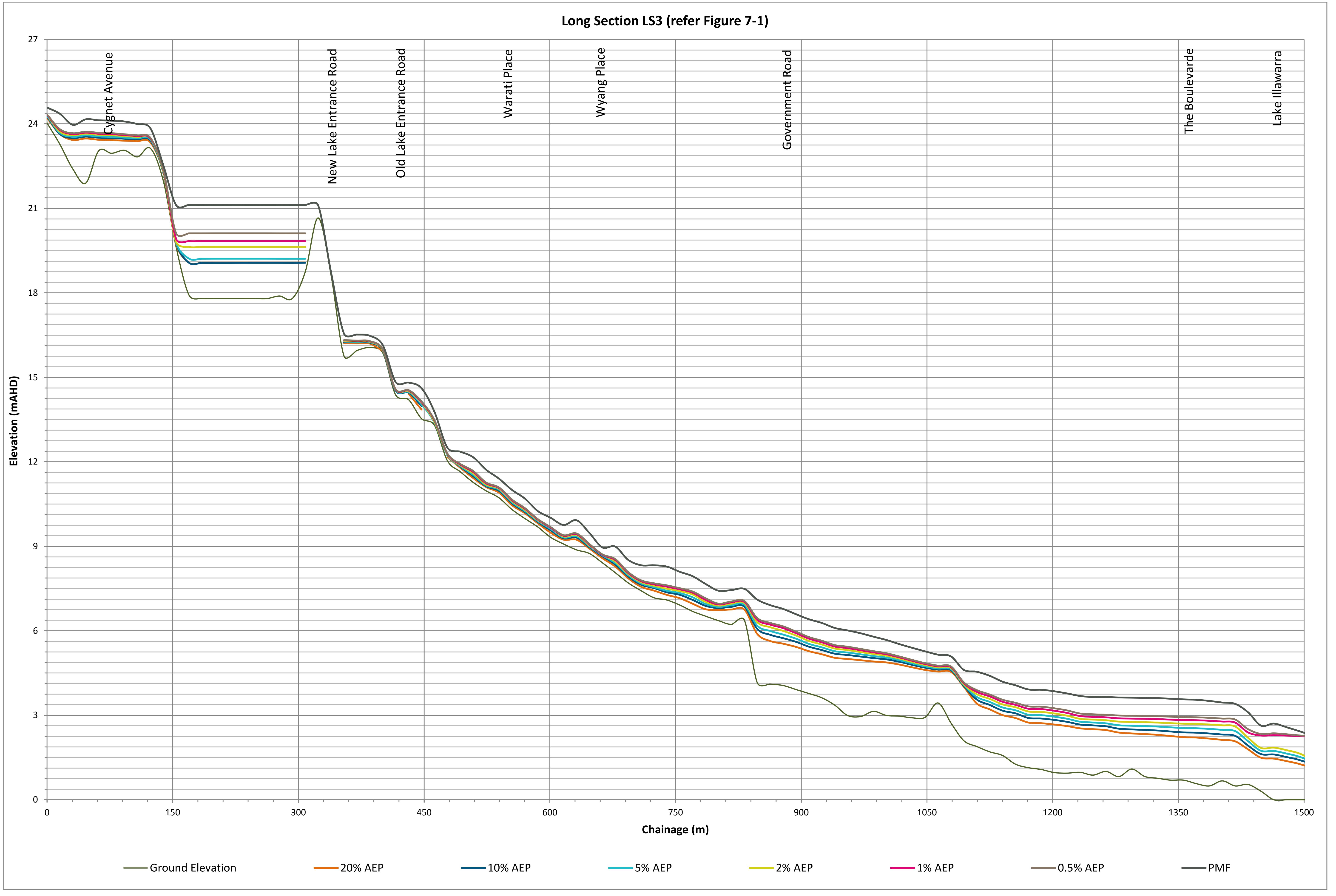
Appendix B Design Long-Sections

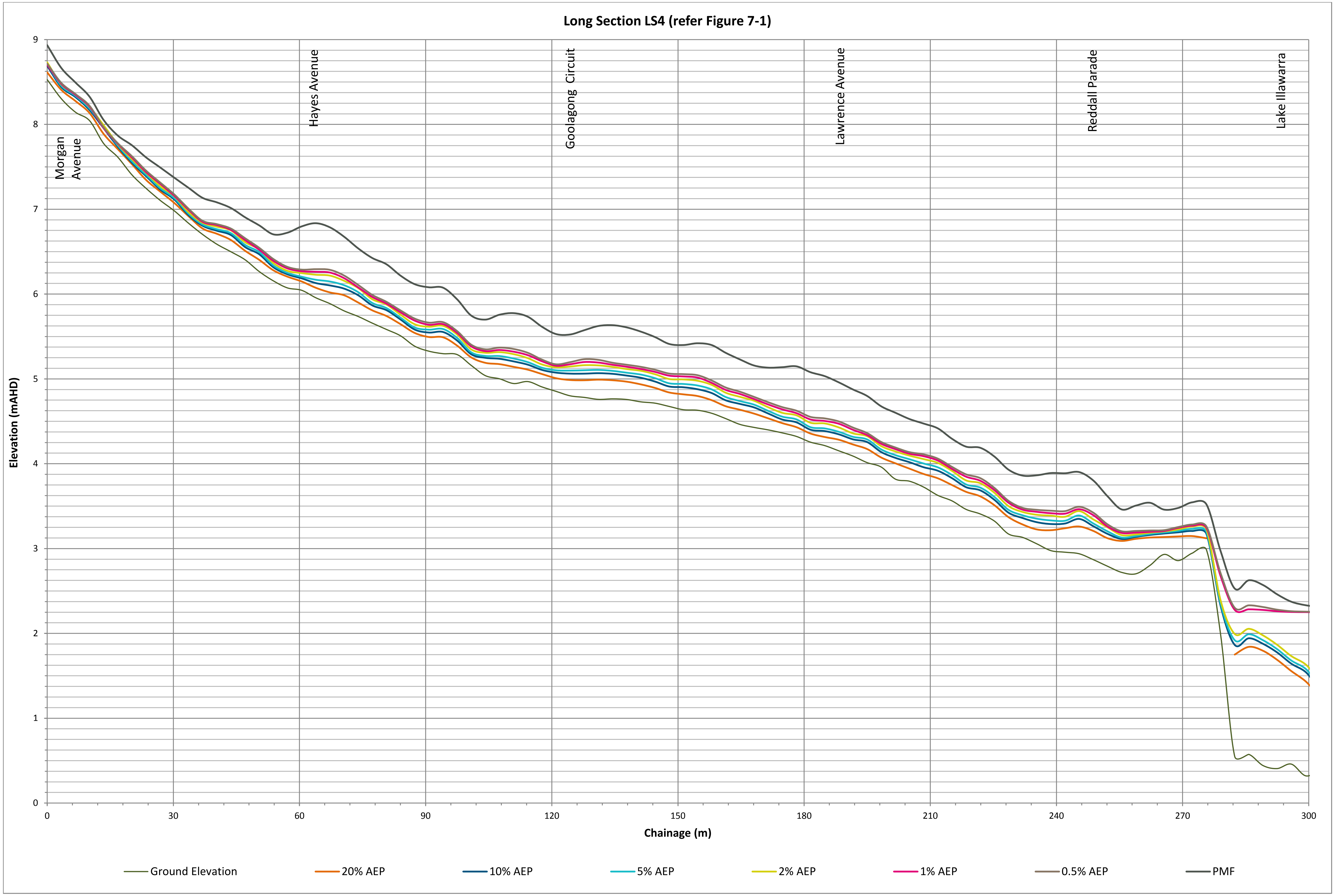


Long Section LS1 (refer Figure 7-1)
Elevation (mAHD)
Chainage (m)
Wentworth Street
Parkes Street
Barton Street
Deakin Street
Lyre Street
The Boulevarde
Lake Illawarra
0
2
4
6
8
10
12
14
16
18
0
100
200
300
400
500
600
700
800
900
Ground Elevation
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF

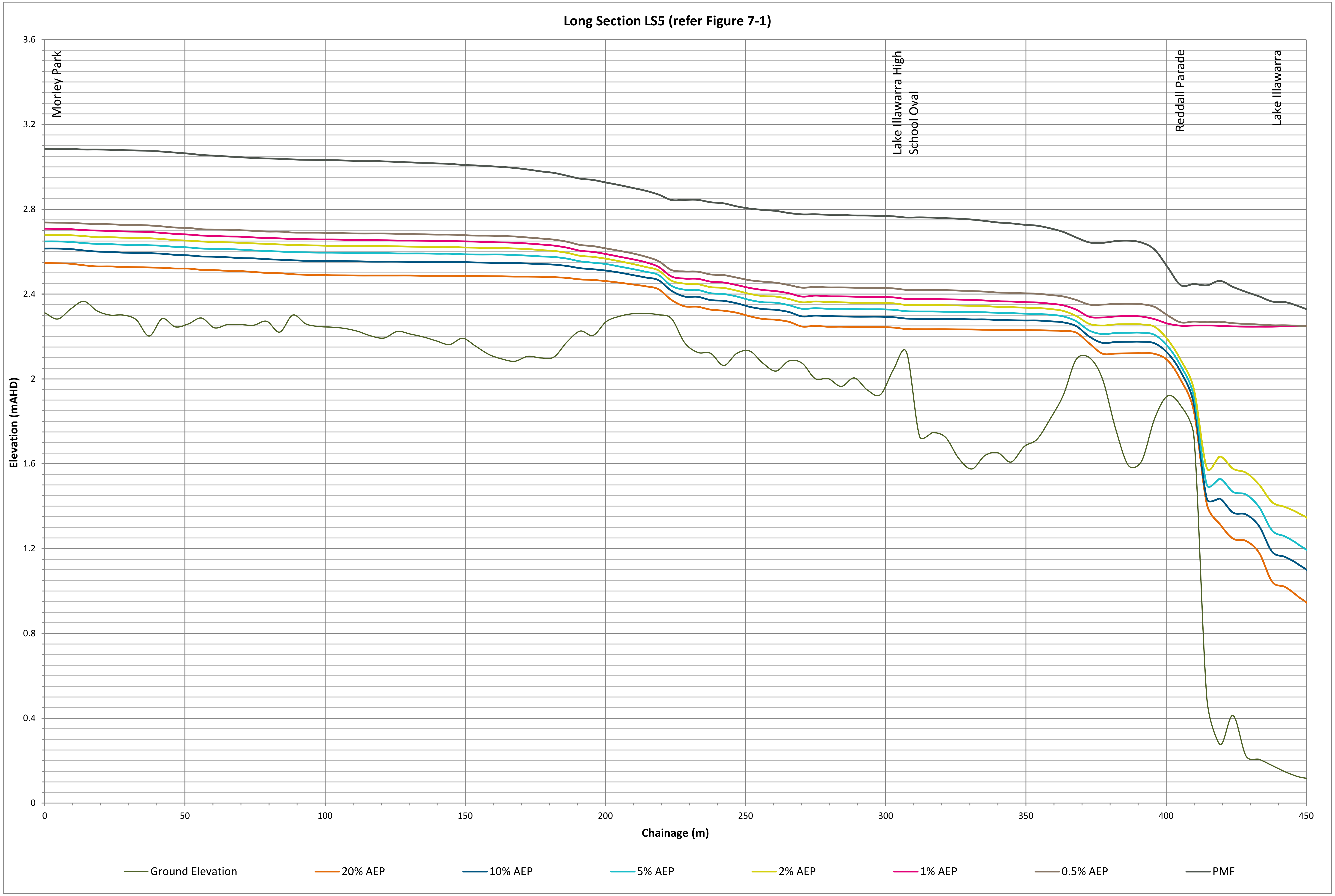

Long Section LS2 (refer Figure 7-1)
Elevation (mAHD)
Chainage (m)
New Lake Entrance Rd
Old Lake Entrance Road
Kingston Street
Fisher Street
Griffith Street
Wentworth Street
Link Road
The Boulevarde
0
4
8
12
16
20
24
28
32
36
0
100
200
300
400
500
600
700
800
900
1000
Ground Elevation
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF



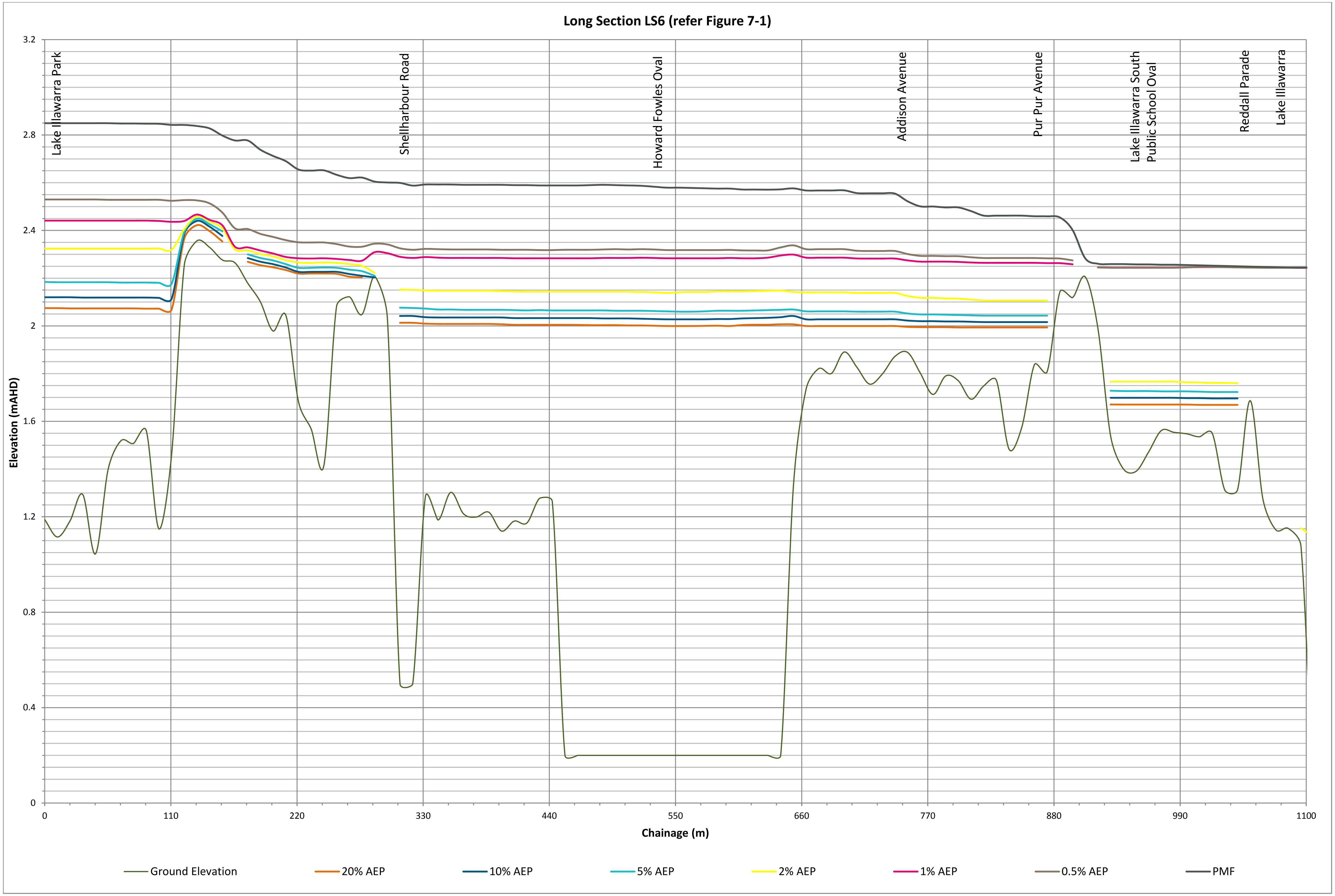
Long Section LS3 (refer Figure 7-1)
Cygnet Avenue
New Lake Entrance Road
Old Lake Entrance Road
Warati Place
Wyang Place
Government Road
The Boulevarde
Lake Illawarra
Elevation (mAHD)
27
24
21
18
15
12
9
6
3
0
0
150
300
450
600
750
900
1050
1200
1350
1500
Chainage (m)
Ground Elevation
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF



Long Section LS4 (refer Figure 7-1)
Morgan Avenue
Hayes Avenue
Goolagong Circuit
Lawrence Avenue
Reddall Parade
Lake Illawarra
Elevation (mAHD)
Chainage (m)
0
1
2
3
4
5
6
7
8
9
0
30
60
90
120
150
180
210
240
270
300
Ground Elevation
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF



Long Section LS5 (refer Figure 7-1)
Morley Park
Lake Illawarra High School Oval
Reddall Parade
Lake Illawarra
Elevation (mAHD)
Chainage (m)
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
0
50
100
150
200
250
300
350
400
450
Ground Elevation
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF



Long Section LS6 (refer Figure 7-1)
Elevation (mAHD)
Chainage (m)
Lake Illawarra Park
Shellharbour Road
Howard Fowles Oval
Addison Avenue
Pur Pur Avenue
Lake Illawarra South Public School Oval
Reddall Parade
Lake Illawarra
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
0
110
220
330
440
550
660
770
880
990
1100
Ground Elevation
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
PMF

Appendix C Sensitivity Tests – Flood Impact Mapping

Title:
1% AEP Peak Flood Level Impacts
Decrease in Manning's 20%

Figure: C-1

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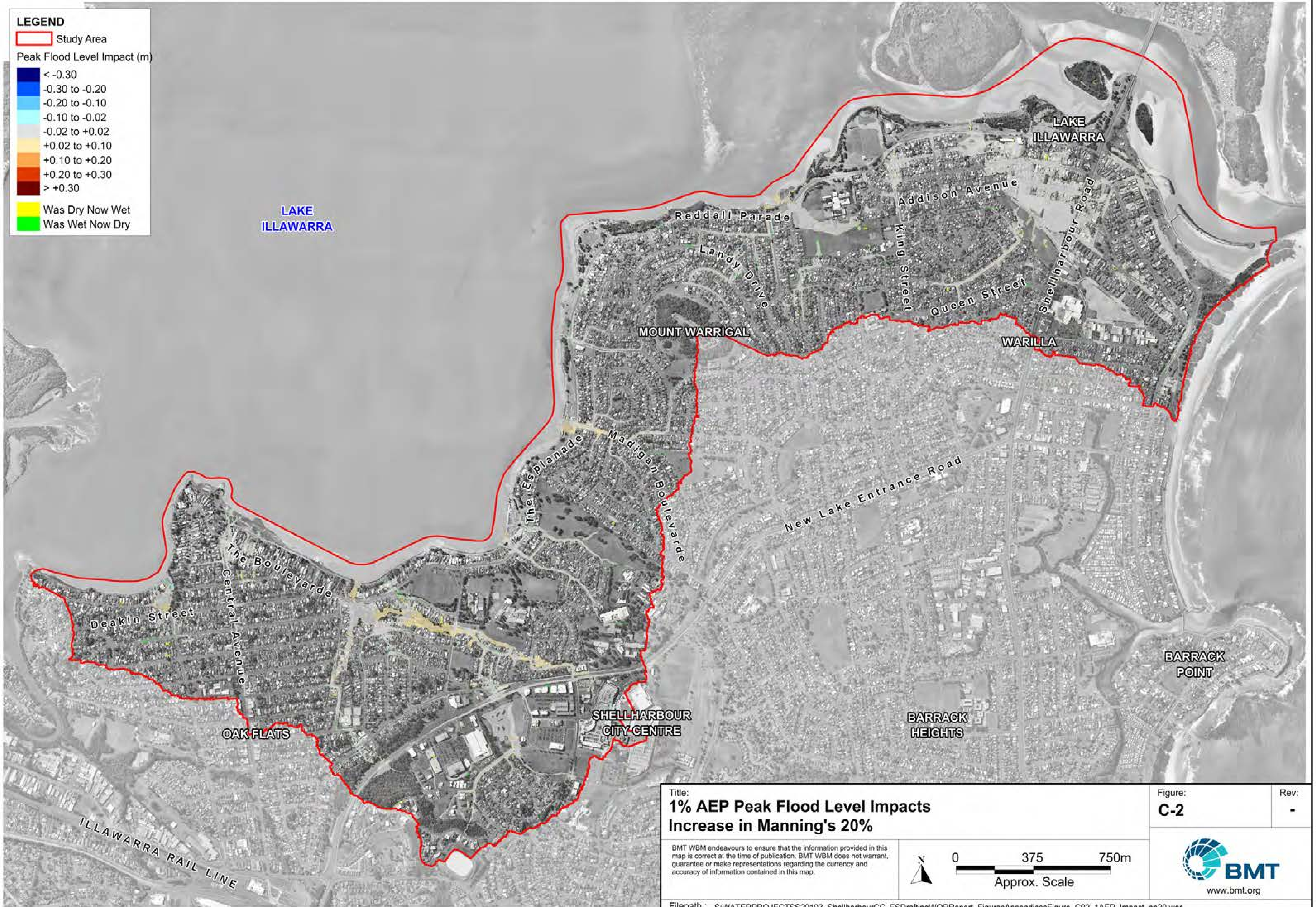
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C01_1AEP_Impact_nm20.wor



Title:
1% AEP Peak Flood Level Impacts Increase in Manning's 20%

Figure: C-2

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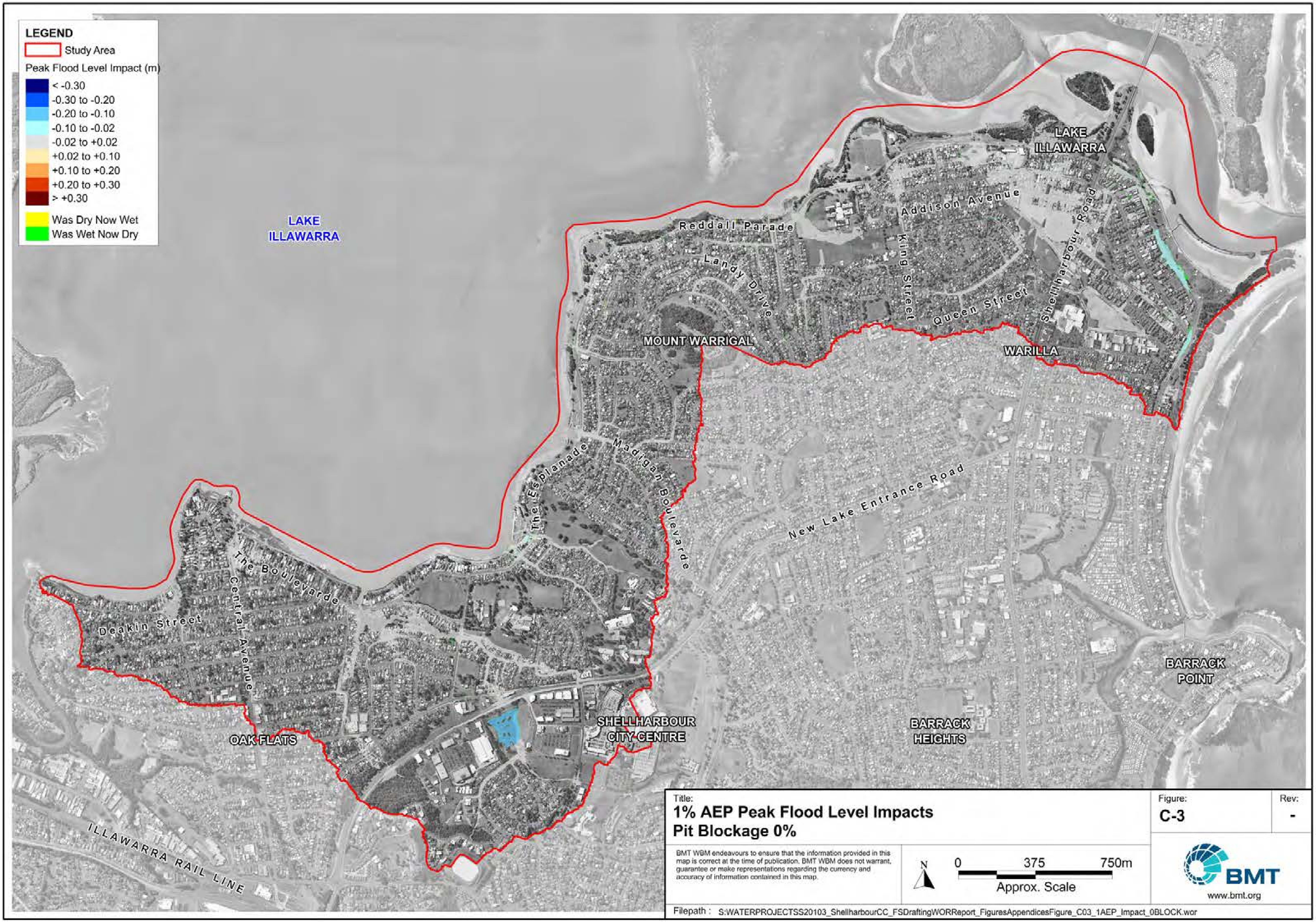
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C02_1AEP_Impact_np20.wor



Title:
1% AEP Peak Flood Level Impacts
Pit Blockage 0%

Figure: C-3

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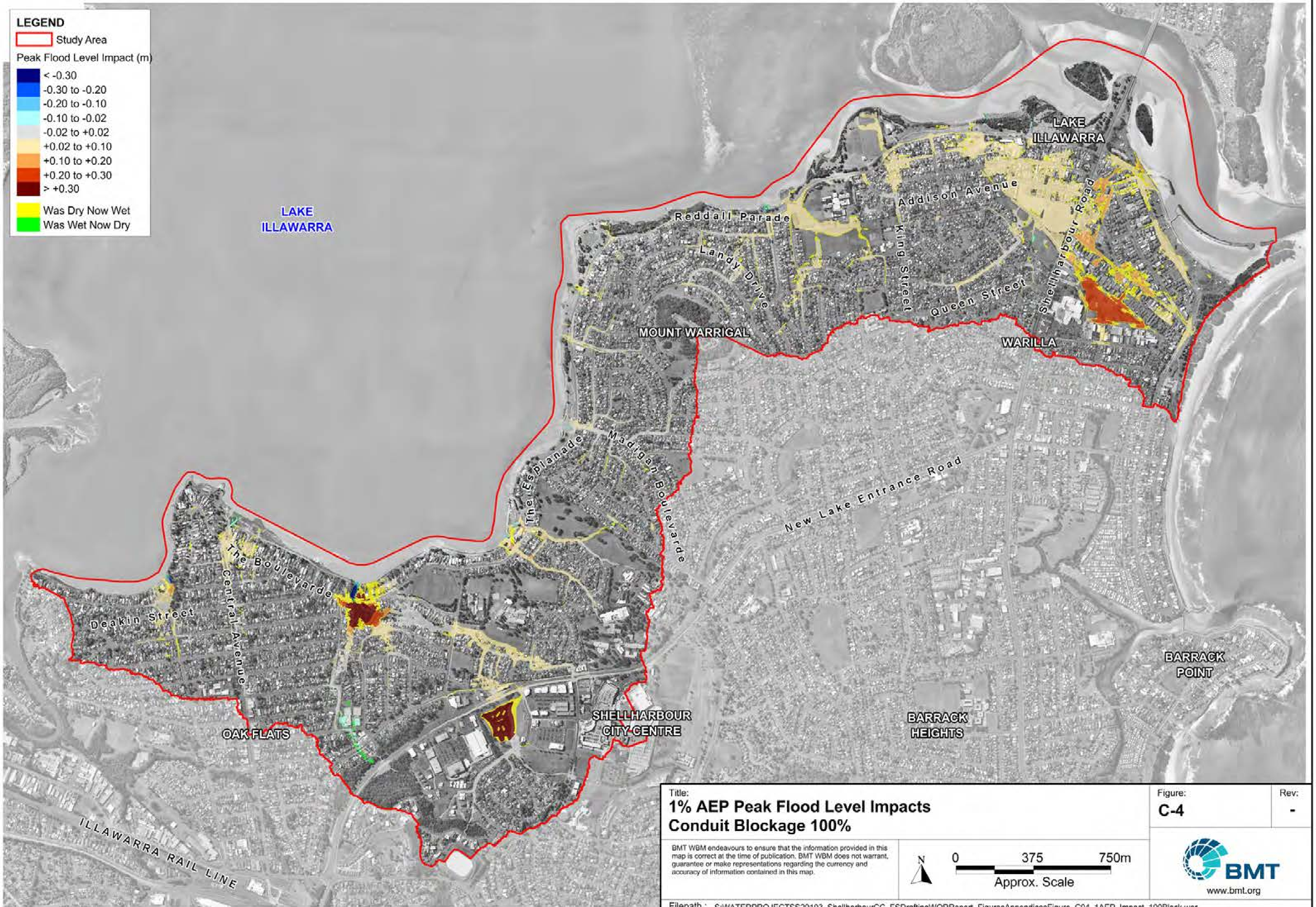
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C03_1AEP_Impact_0BLOCK.wor



Title:
1% AEP Peak Flood Level Impacts Conduit Blockage 100%

Figure: C-4

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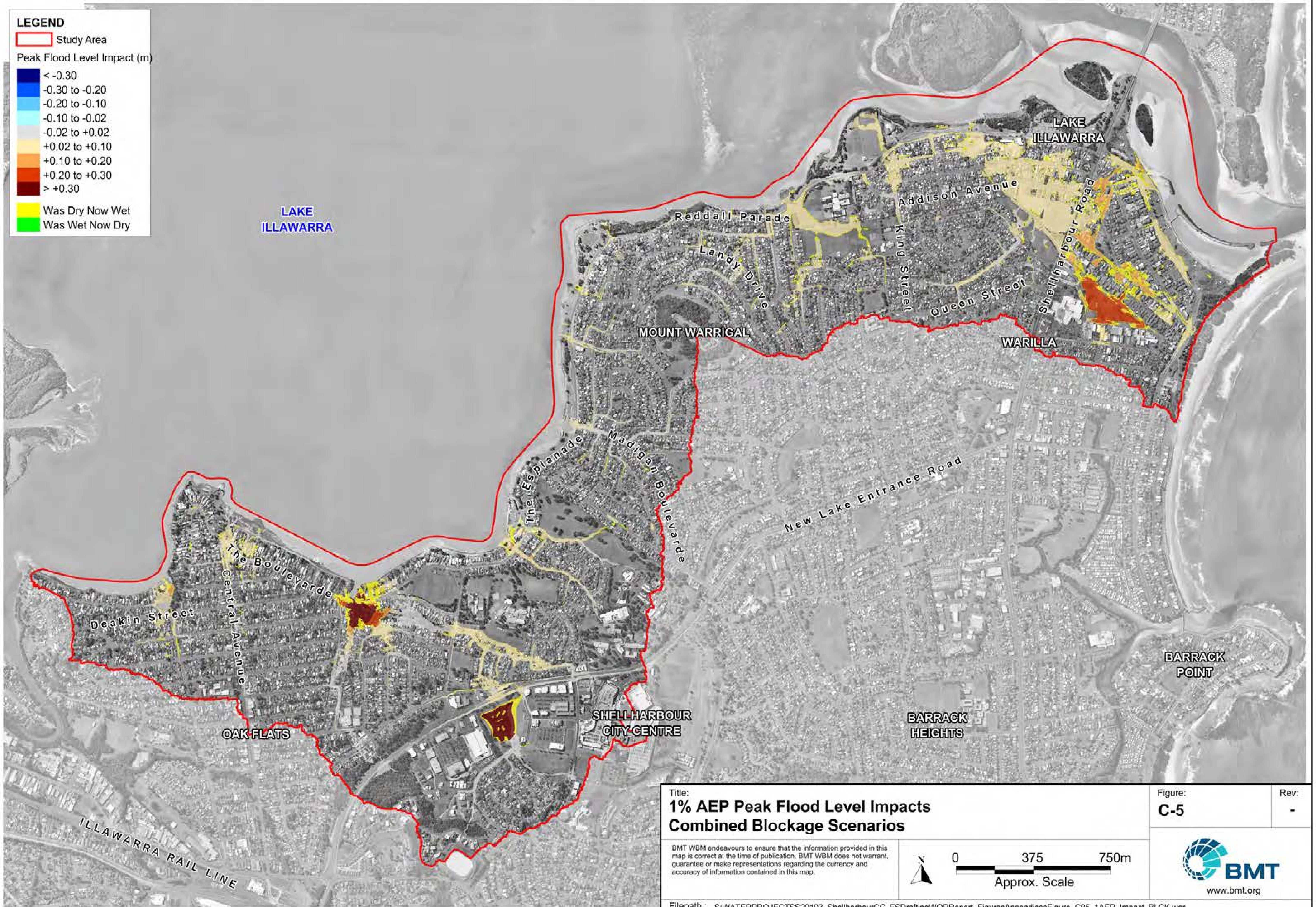
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C04_1AEP_Impact_100Block.wor



Title:

1% AEP Peak Flood Level Impacts
Combined Blockage Scenarios

Figure: C-5

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N

0 375 750m

Approx. Scale

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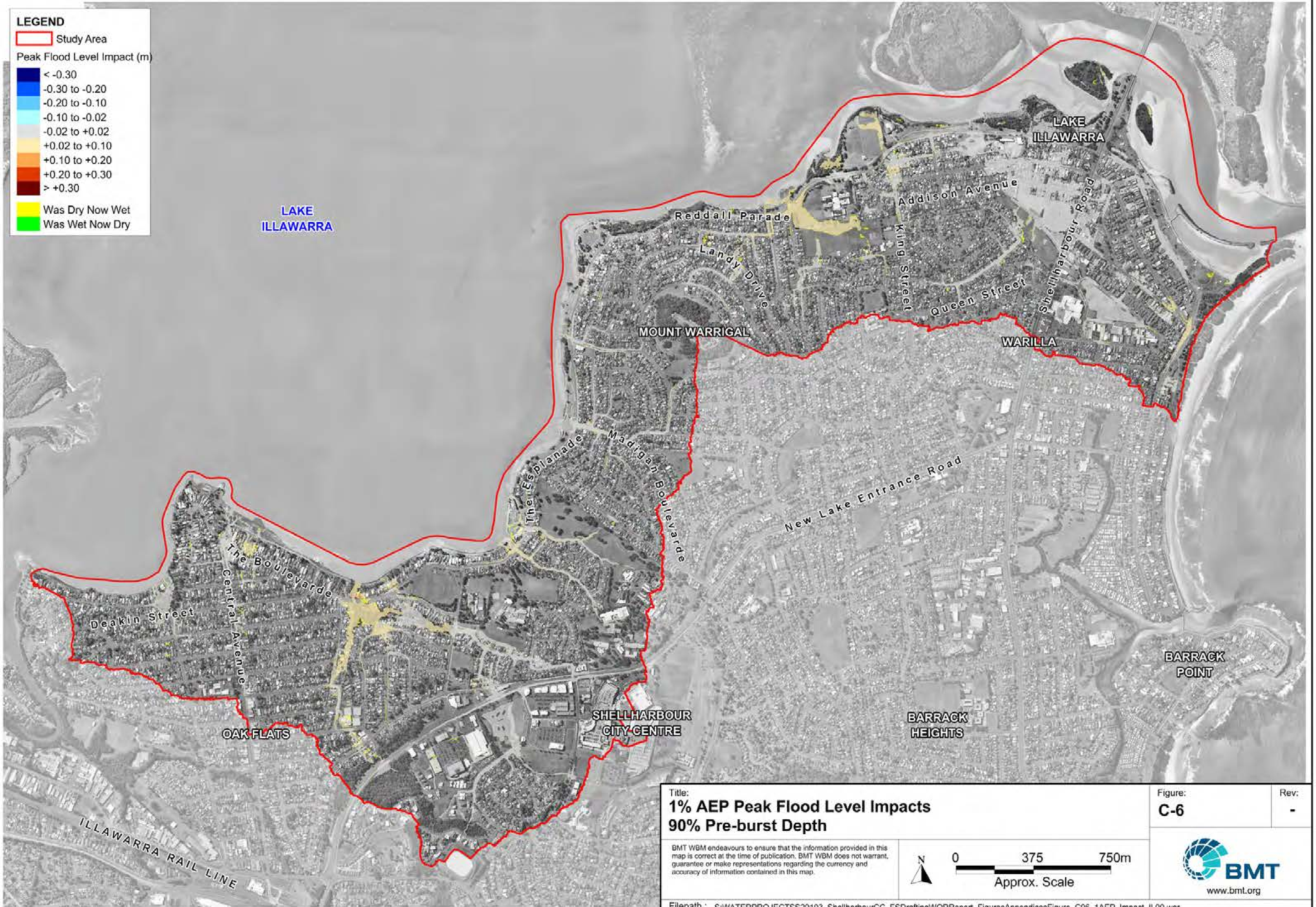
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C05_1AEP_Impact_BLCK.wor



Title:
1% AEP Peak Flood Level Impacts
90% Pre-burst Depth

Figure: **C-6**

Rev: **-**

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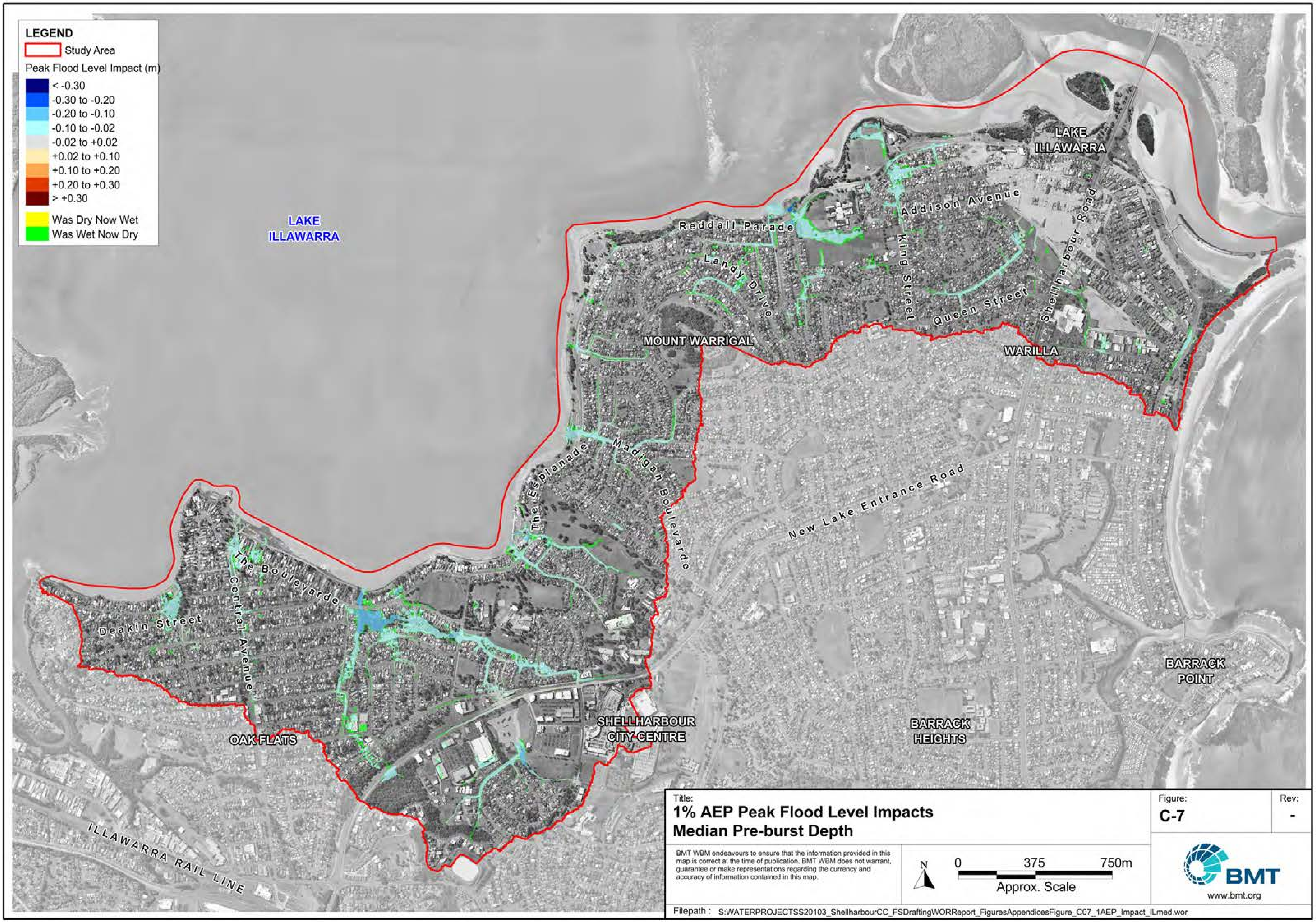
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C06_1AEP_Impact_IL90.wor


LEGEND
Study Area
Peak Flood Level Impact (m)
< -0.30
-0.30 to -0.20
-0.20 to -0.10
-0.10 to -0.02
-0.02 to +0.02
+0.02 to +0.10
+0.10 to +0.20
+0.20 to +0.30
> +0.30
Was Dry Now Wet
Was Wet Now Dry
LAKE ILLAWARRA
LAKE ILLAWARRA
Reddall Parade
Addison Avenue
King Street
Landy Drive
Queen Street
Shellharbour Road
MOUNT WARRIGAL
WARILLA
The Esplanade
Madigan Boulevarde
New Lake Entrance Road
The Boulevarde
Central Avenue
Deakin Street
SHELLHARBOUR CITY CENTRE
OAK FLATS
BARRACK HEIGHTS
BARRACK POINT
ILLAWARRA RAIL LINE
Title:
1% AEP Peak Flood Level Impacts
Median Pre-burst Depth
Figure:
C-7
Rev:
-
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N
0
375
750m
Approx. Scale
BMT
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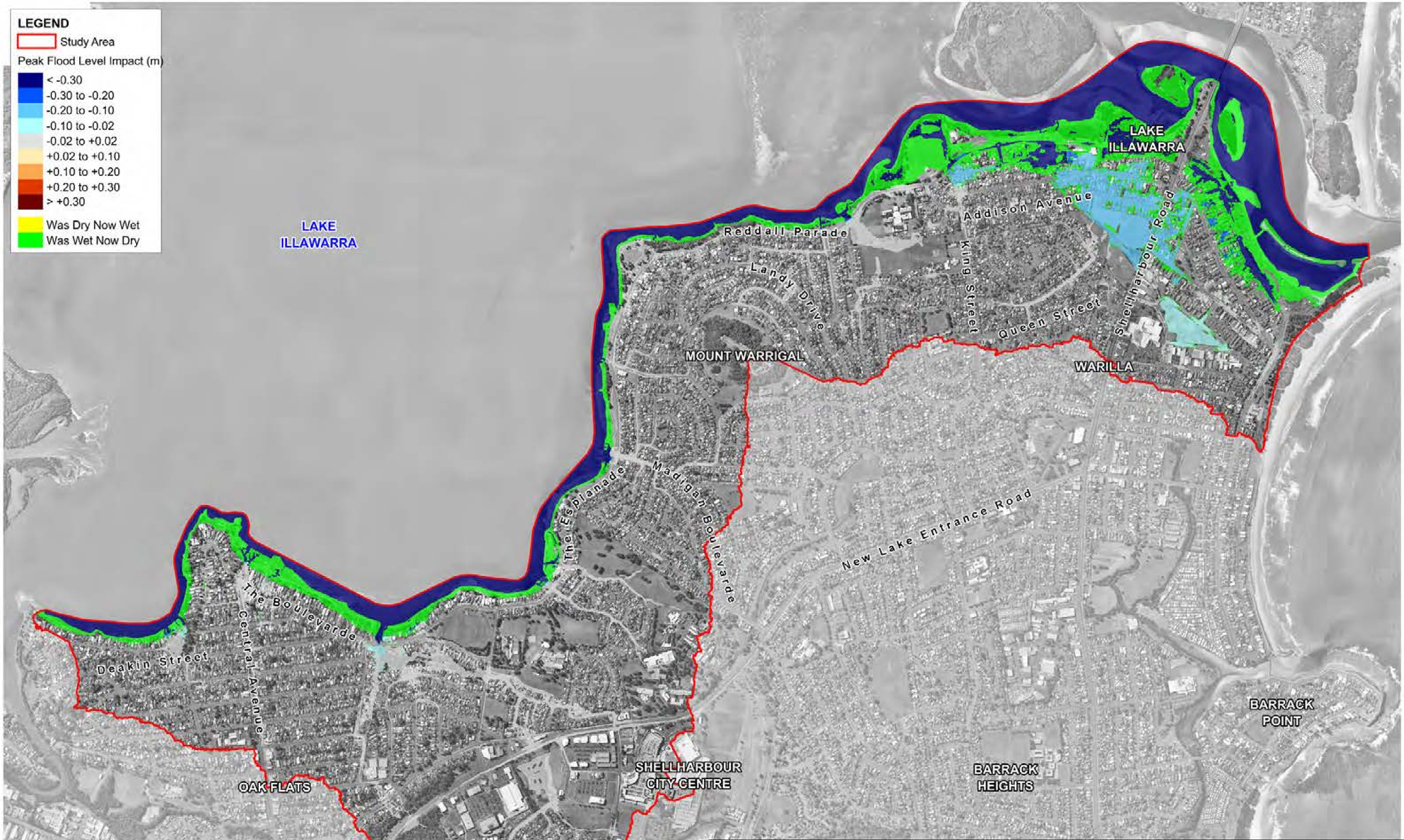
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C07_1AEP_Impact_ILmed.wor



Title:
1% AEP Peak Flood Level Impacts HHWSS Tailwater Level

Figure: C-8

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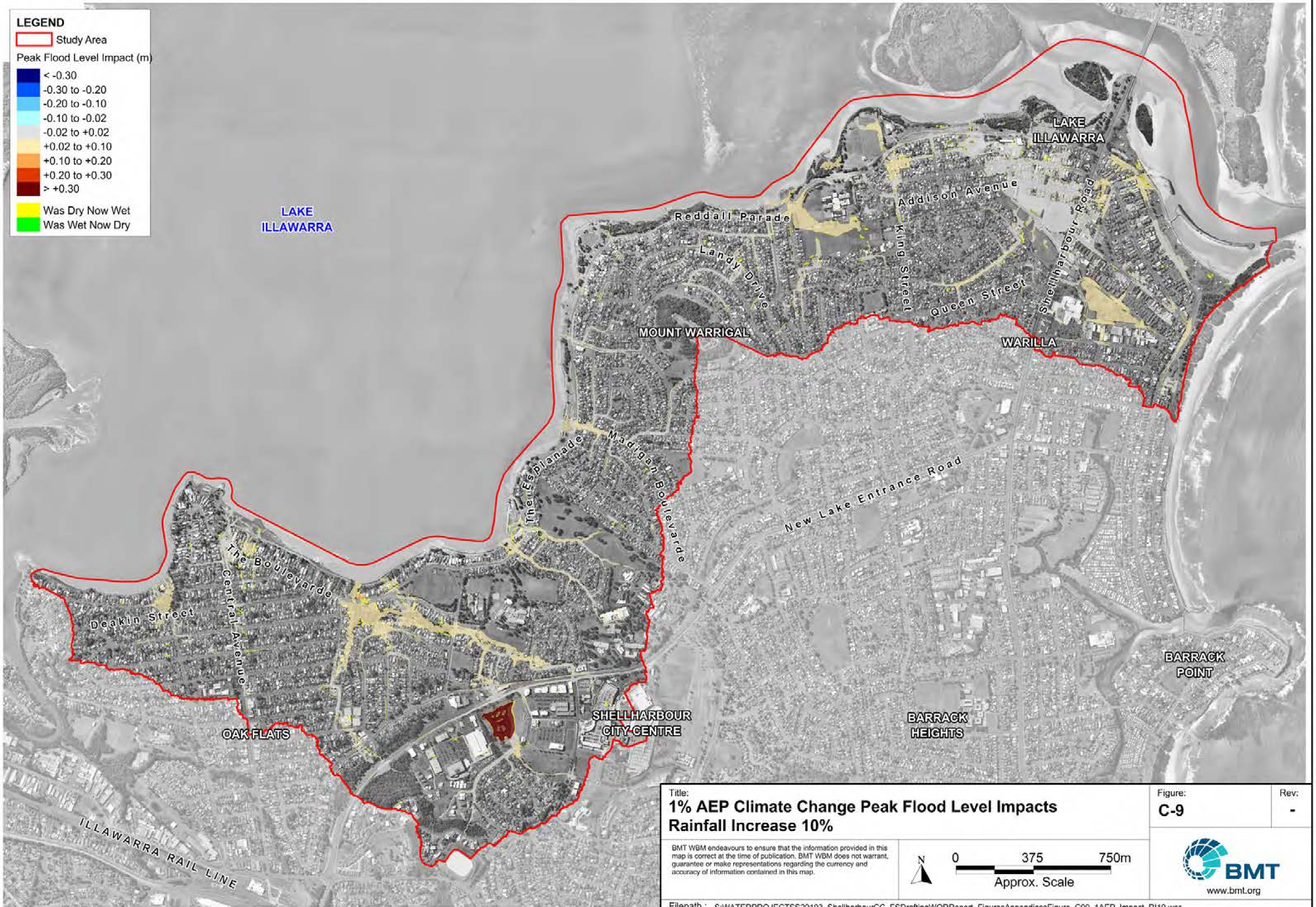
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C08_1AEP_Impact_HHWSS.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts Rainfall Increase 10%

Figure: C-9

Rev: -

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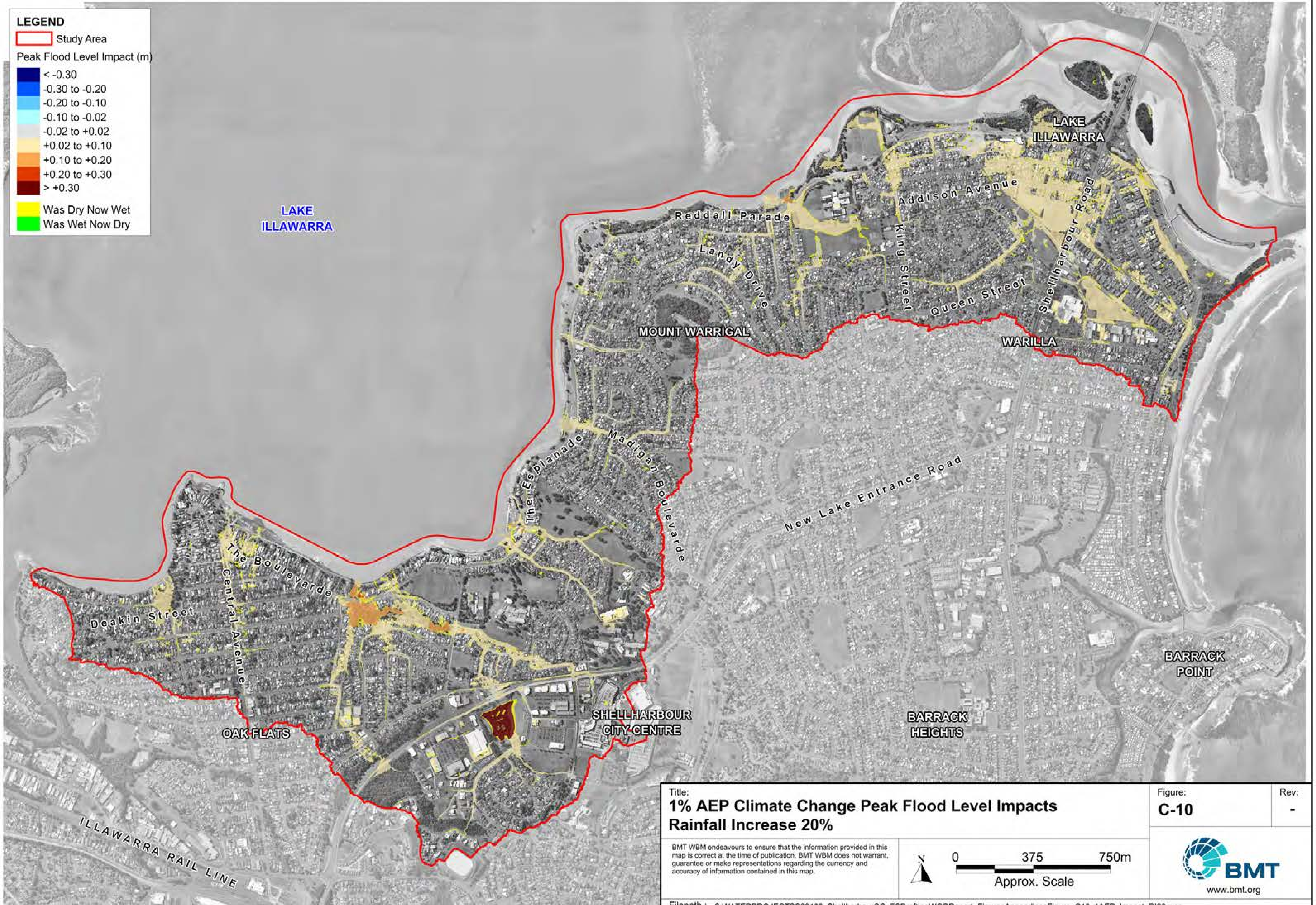
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C09_1AEP_Impact_RI10.wor



Title:

1% AEP Climate Change Peak Flood Level Impacts Rainfall Increase 20%

Figure: C-10

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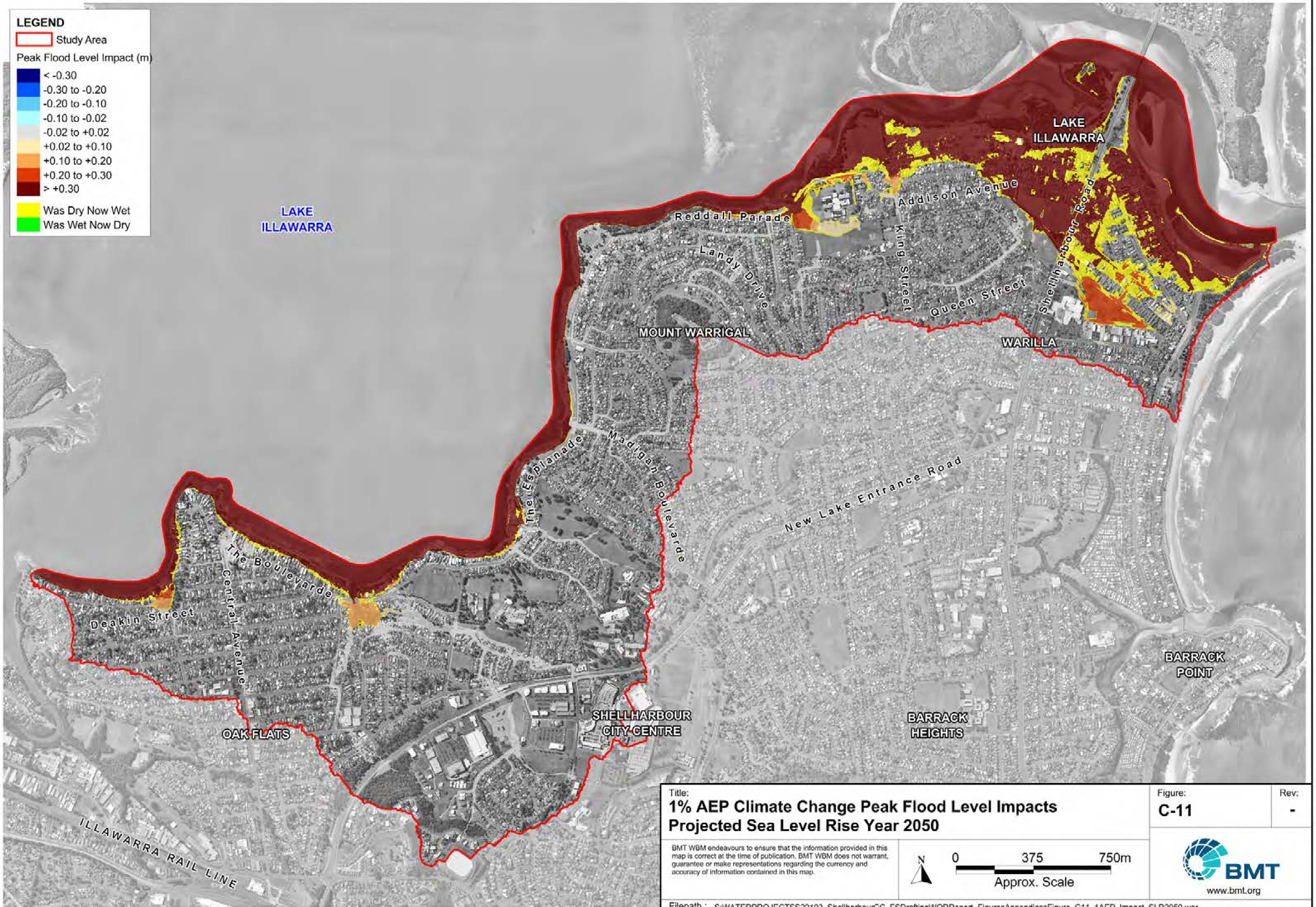
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C10_1AEP_Impact_RI20.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts
Projected Sea Level Rise Year 2050

Figure: C-11

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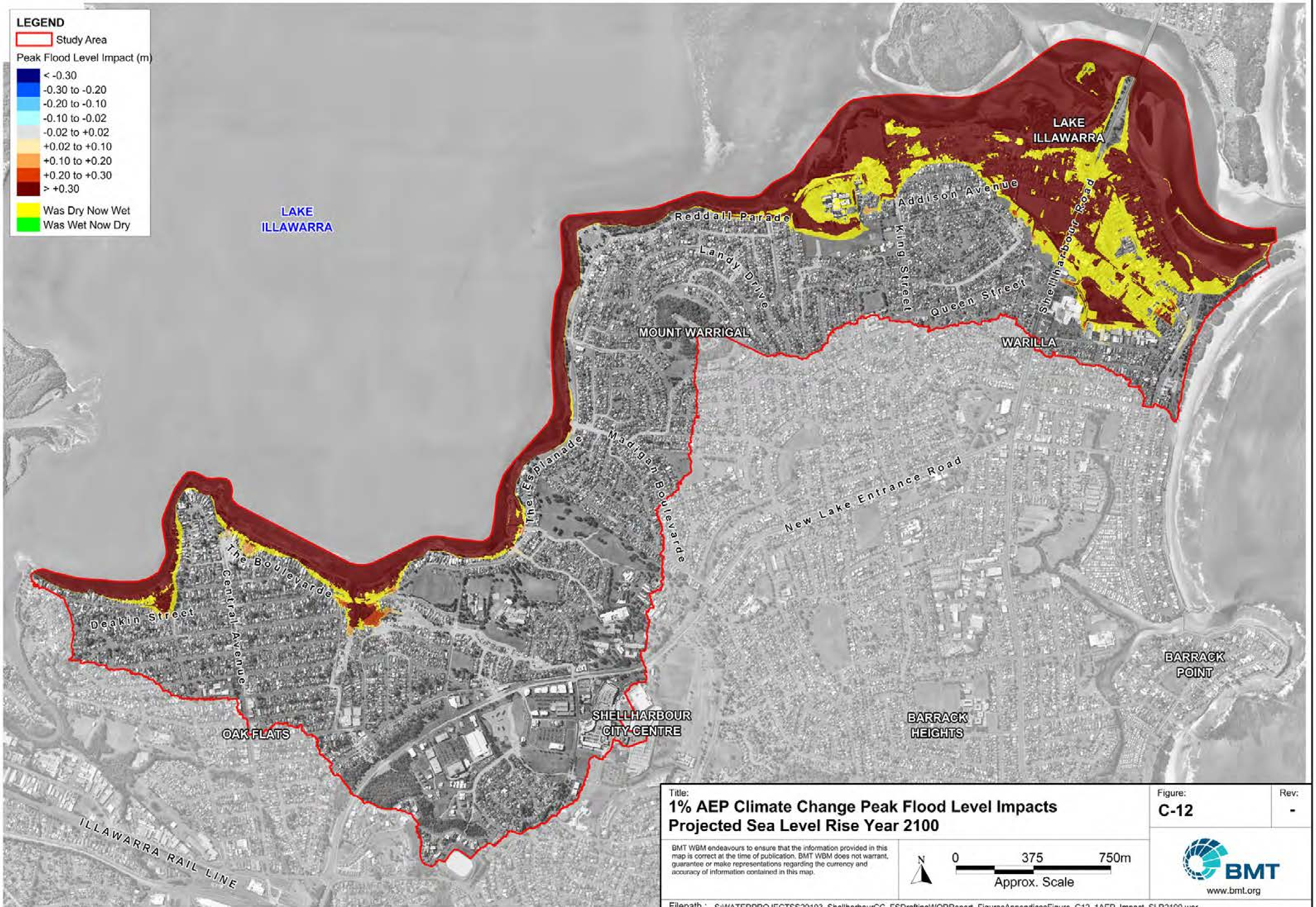
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C11_1AEP_Impact_SLR2050.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts
Projected Sea Level Rise Year 2100

Figure: **C-12**

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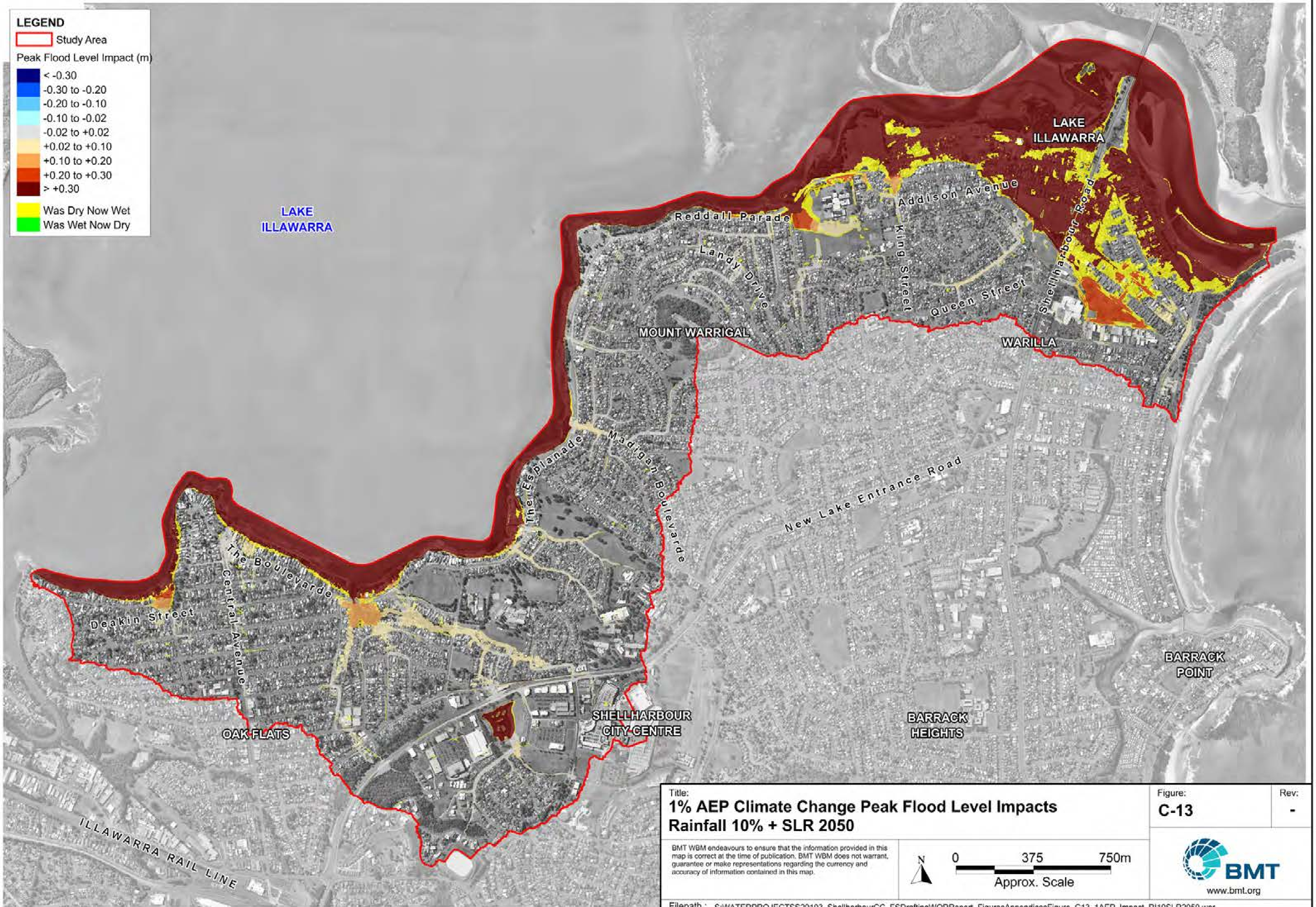
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C12_1AEP_Impact_SLR2100.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts Rainfall 10% + SLR 2050

Figure: **C-13**

Rev: **-**

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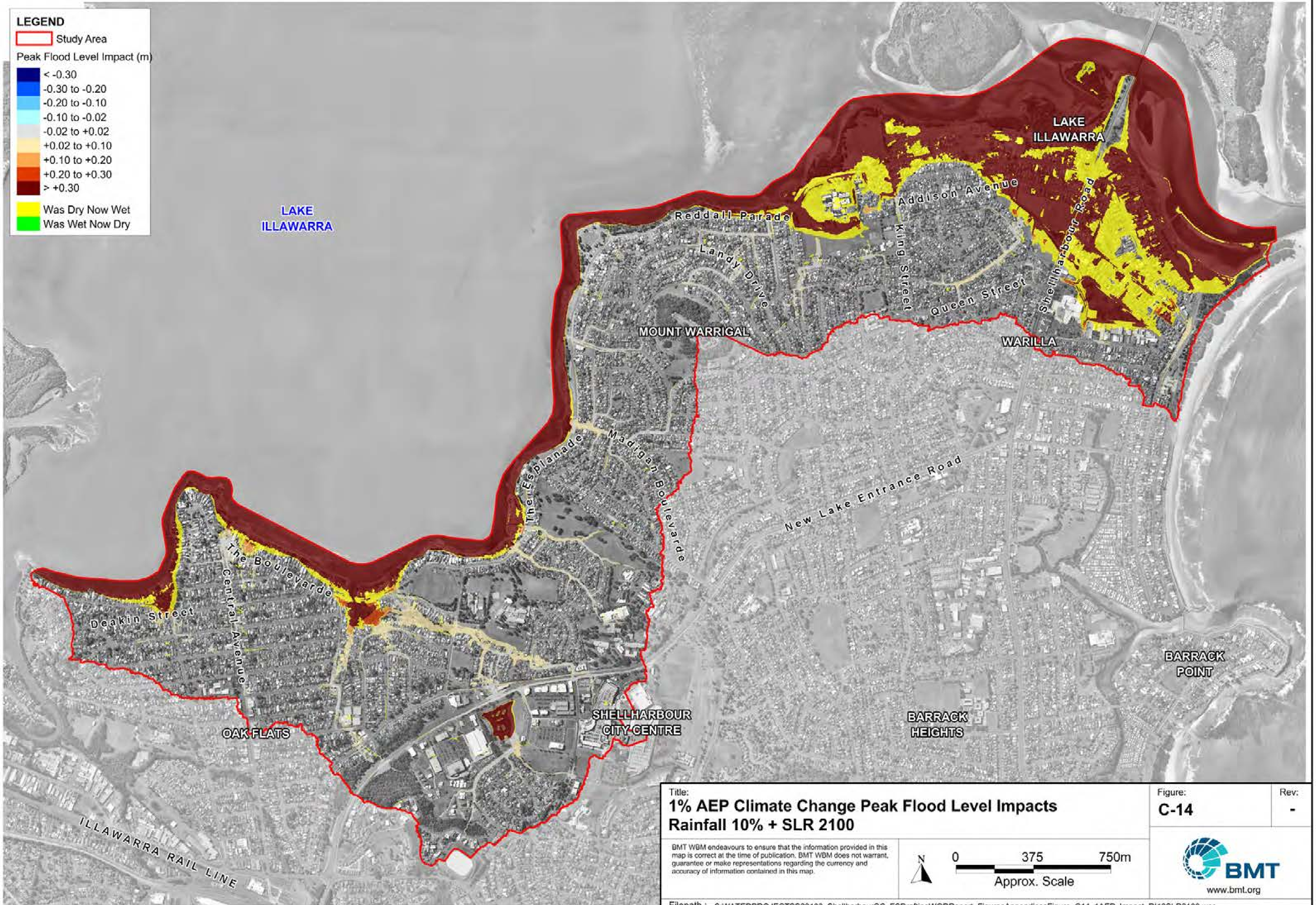
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C13_1AEP_Impact_RI10SLR2050.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts Rainfall 10% + SLR 2100

Figure: C-14

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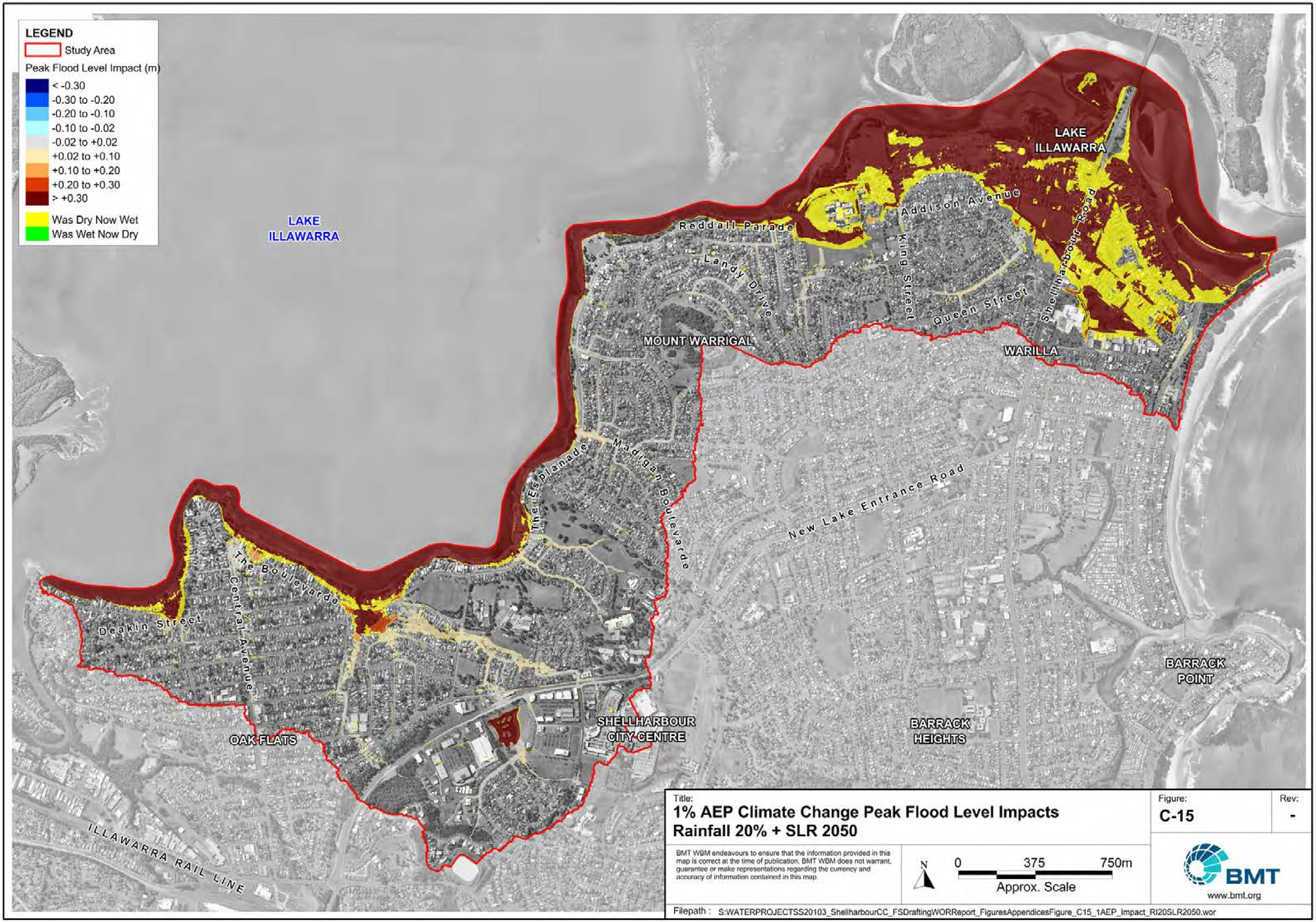
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C14_1AEP_Impact_RI10SLR2100.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts
Rainfall 20% + SLR 2050

Figure: **C-15**

Rev: **-**

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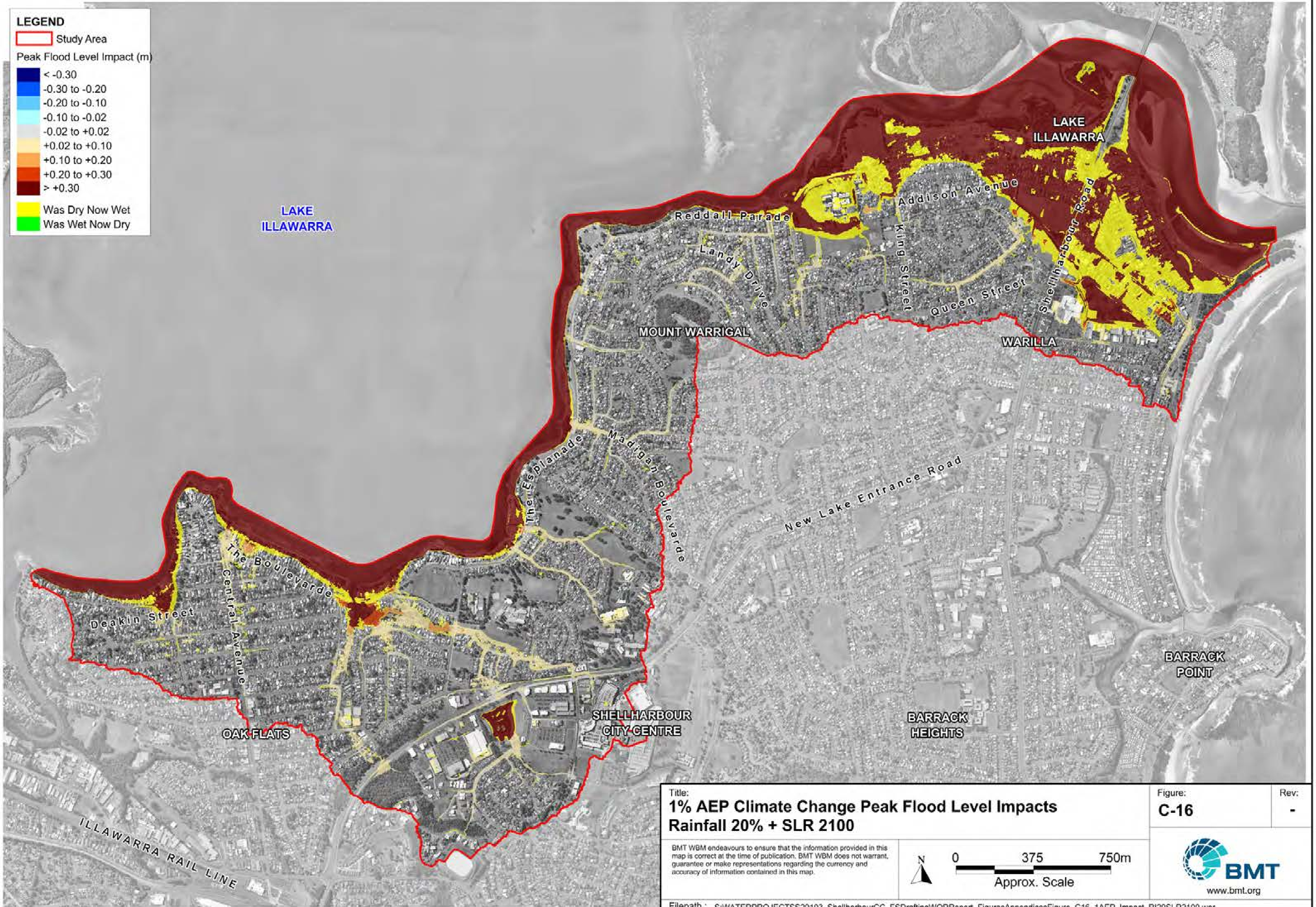
Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C15_1AEP_Impact_RI20SLR2050.wor



Title:
1% AEP Climate Change Peak Flood Level Impacts Rainfall 20% + SLR 2100

Figure: C-16

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Filepath : S:WATERPROJECTSS20103_ShellharbourCC_FSDraftingWORReport_FiguresAppendicesFigure_C16_1AEP_Impact_RI20SLR2100.wor

Appendix D Analysis of Control Survey Marks

Survey Mark	Easting	Northing	Surveyed Elevation	2005 ALS	2005 ALS Difference	2011 LiDAR	2011 LiDAR Difference
PM10189	302045	6174456	28.20	28.40	0.20	28.44	0.24
PM10190	302215	6175223	42.13	42.18	0.05	42.39	0.26
PM10191	302041	6175616	6.65	6.20	-0.45	6.41	-0.24
PM14874	304530	6175199	3.92	3.93	0.01	4.33	0.41
PM14908	304430	6174930	3.31	3.45	0.14	3.72	0.40
PM14909	304327	6174680	4.48	4.78	0.30	4.89	0.40
PM14911	304037	6174982	3.25	3.48	0.23	3.56	0.32
PM14912	304279	6174951	4.00	4.00	0.00	4.27	0.28
PM14913	303807	6175152	8.15	8.30	0.14	8.43	0.28
PM14914	303849	6175268	5.11	5.22	0.11	5.41	0.30
PM14915	304383	6175186	2.45	2.68	0.23	2.77	0.33
PM14916	304173	6175318	1.89	1.90	0.01	2.15	0.26
PM14917	304122	6175495	2.19	2.37	0.18	2.44	0.25
PM14918	304533	6175270	1.85	2.08	0.24	2.31	0.46
PM14919	304255	6175780	0.95	1.13	0.18	1.30	0.35
PM14920	304008	6175795	10.00	2.40	-7.60	2.54	-7.46
PM14921	303980	6175724	10.00	2.00	-8.00	2.06	-7.94
PM14922	303679	6175760	1.36	1.33	-0.03	1.58	0.22
PM14923	303100	6175656	3.74	3.85	0.11	3.90	0.16
PM14924	303006	6175885	1.72	2.00	0.28	1.96	0.25
PM14925	303346	6176004	1.37	1.40	0.03	1.55	0.18
PM14926	303692	6175990	1.57	1.68	0.11	1.77	0.20
PM14927	303137	6175088	16.37	16.50	0.13	16.68	0.31
PM14932	303583	6175110	16.84	17.01	0.16	17.20	0.35
PM14933	303390	6175169	11.23	11.27	0.03	11.41	0.18
PM14937	303303	6175261	9.70	9.83	0.14	9.96	0.27
PM14938	303458	6175399	13.66	13.80	0.14	13.99	0.33
PM14939	303511	6175541	11.55	11.77	0.22	11.82	0.27
PM14940	303343	6175598	12.05	12.29	0.25	12.39	0.34
PM14941	303259	6175414	14.35	14.57	0.22	14.67	0.32
PM14942	303201	6175467	12.17	12.34	0.18	12.41	0.24
PM14943	303712	6175869	1.81	1.99	0.18	2.10	0.29

Survey Mark	Easting	Northing	Surveyed Elevation	2005 ALS	2005 ALS Difference	2011 LiDAR	2011 LiDAR Difference
PM14945	302472	6175574	2.68	3.15	0.47	3.21	0.52
PM14946	302793	6175258	12.21	12.30	0.09	12.40	0.19
PM14947	302876	6175392	7.14	6.95	-0.19	7.01	-0.13
PM14948	302624	6175253	9.70	9.75	0.04	9.91	0.21
PM14949	302634	6175067	17.48	17.57	0.09	17.74	0.26
PM14955	302450	6175160	21.97	22.20	0.23	22.24	0.28
PM14964	301874	6174452	13.64	15.20	1.56	15.09	1.44
PM14970	302264	6175142	45.31	45.54	0.23	45.65	0.33
PM14971	302074	6175282	37.58	37.70	0.12	37.91	0.32
PM14972	301854	6175137	41.21	41.42	0.20	41.54	0.32
PM14973	301842	6174959	30.11	29.75	-0.36	29.81	-0.30
PM14974	301523	6175015	6.88	7.90	1.03	7.99	1.11
PM14975	301651	6175424	9.81	9.86	0.05	10.11	0.30
PM14976	301871	6175514	11.95	12.06	0.12	12.28	0.33
PM14977	302115	6175601	6.84	6.85	0.01	7.14	0.29
PM14978	301599	6175090	13.21	13.35	0.14	13.49	0.29
PM14979	301809	6175196	32.82	33.00	0.18	32.98	0.16
PM14980	301925	6175439	22.90	23.37	0.47	23.21	0.31
PM14981	302280	6175401	19.39	19.58	0.20	19.70	0.31
PM16675	300559	6173072	23.26	23.43	0.17	23.53	0.28
PM16676	300716	6173218	21.10	21.15	0.05	21.27	0.17
PM16677	300909	6173294	18.71	19.10	0.39	19.18	0.47
PM16678	301854	6173435	33.19	29.70	-3.49	29.62	-3.57
PM16680	301531	6174576	2.63	2.80	0.17	2.86	0.23
PM16681	301301	6174356	7.95	8.24	0.29	8.37	0.42
PM16682	301281	6174070	3.75	3.25	-0.50	3.31	-0.44
PM16683	301169	6173913	4.16	4.20	0.04	4.29	0.13
PM16684	300970	6173905	5.78	5.80	0.02	6.02	0.25
PM16685	300778	6173890	4.96	5.20	0.24	5.28	0.32
PM16686	300590	6173741	2.94	3.08	0.14	3.16	0.22
PM16687	300402	6173729	2.57	2.55	-0.02	2.57	0.00
PM16688	300248	6173790	5.92	5.97	0.05	6.18	0.25
PM16689	300083	6173884	5.48	5.59	0.10	5.68	0.20
PM16690	299834	6173972	2.90	3.00	0.10	3.12	0.22

Survey Mark	Easting	Northing	Surveyed Elevation	2005 ALS	2005 ALS Difference	2011 LiDAR	2011 LiDAR Difference
PM16691	300161	6173736	10.33	10.41	0.08	10.57	0.24
PM16692	299842	6173695	6.40	6.38	-0.02	6.55	0.15
PM16693	299370	6173647	4.92	4.90	-0.02	5.11	0.19
PM16694	299227	6173602	11.20	11.38	0.17	11.46	0.26
PM16695	299288	6173416	12.04	12.10	0.06	12.15	0.11
PM16696	299622	6173440	8.66	8.80	0.14	8.92	0.26
PM16697	299872	6173492	10.37	10.44	0.07	10.56	0.20
PM16698	300153	6173528	15.81	15.90	0.09	15.97	0.16
PM16699	300366	6173539	5.13	5.10	-0.04	5.08	-0.06
PM16700	300336	6173310	9.29	9.57	0.28	9.62	0.34
PM16701	300107	6173279	19.07	19.14	0.07	19.26	0.19
PM16702	299900	6173270	15.42	15.61	0.19	15.66	0.24
PM16708	300302	6173097	18.18	18.29	0.11	18.41	0.22
PM16709	300491	6173124	18.53	18.60	0.07	18.64	0.12
PM21644	300887	6173308	18.31	18.40	0.08	18.49	0.18
PM21645	300898	6173382	14.86	14.91	0.05	15.13	0.28
PM21646	300610	6173483	6.15	6.20	0.05	6.15	0.01
PM21647	300495	6173437	6.17	6.33	0.15	6.41	0.24
PM21674	304075	6175875	2.50	2.76	0.25	2.69	0.19
PM21699	299800	6174275	1.05	1.10	0.05	1.22	0.17
PM36944	301643	6174257	20.71	22.45	1.74	22.40	1.69
PM46177	301494	6173036	46.61	44.70	-1.91	44.79	-1.82
PM50261	304052	6175805	2.00	2.40	0.40	2.43	0.43
PM50262	304151	6175348	2.00	2.14	0.14	2.26	0.26
PM50263	301866	6174450	15.00	14.62	-0.38	14.58	-0.42
PM50264	303987	6175715	2.00	1.99	-0.01	2.19	0.19
PM82047	304376	6175613	1.36	1.50	0.14	1.60	0.24
PM85927	300394	6173667	10.00	3.30	-6.70	3.43	-6.57
PM9605	301854	6173411	32.95	30.25	-2.70	30.36	-2.59
SS108611	300978	6173008	29.20	29.05	-0.15	29.24	0.04
SS11598	304497	6175065	3.33	3.31	-0.01	3.48	0.16
SS11600	303770	6175034	8.70	8.70	-0.01	8.64	-0.06
SS11601	303941	6175511	1.78	1.71	-0.07	1.81	0.02
SS11602	304344	6175578	1.42	1.45	0.04	1.52	0.10

Survey Mark	Easting	Northing	Surveyed Elevation	2005 ALS	2005 ALS Difference	2011 LiDAR	2011 LiDAR Difference
SS11603	304131	6175758	1.72	1.83	0.11	1.76	0.04
SS11604	303287	6175704	8.01	8.00	-0.01	8.09	0.08
SS11605	303115	6175951	1.81	1.77	-0.03	1.82	0.02
SS11606	303123	6175429	10.48	10.43	-0.04	10.56	0.08
SS11611	303605	6175256	14.40	14.40	0.00	14.48	0.08
SS11614	303389	6175269	8.75	8.79	0.04	8.80	0.05
SS11615	303310	6175345	11.69	11.70	0.01	11.72	0.03
SS11616	303574	6175494	8.47	8.41	-0.06	8.47	0.00
SS11617	303523	6175633	6.77	6.72	-0.05	6.75	-0.02
SS11684	302700	6175765	2.52	2.41	-0.12	2.56	0.04
SS11685	302526	6175244	12.75	12.71	-0.04	12.79	0.04
SS11686	302673	6174938	29.28	29.18	-0.11	29.30	0.02
SS11687	302812	6175086	23.50	23.40	-0.10	23.52	0.02
SS11701	301960	6174253	31.45	31.51	0.06	31.59	0.13
SS11702	301994	6174464	20.00	24.85	4.85	24.92	4.92
SS11705	302335	6175002	53.29	53.15	-0.15	53.36	0.07
SS11706	302201	6175213	40.00	43.39	3.39	43.33	3.33
SS11707	301910	6175216	43.46	43.42	-0.04	43.45	-0.02
SS11708	301936	6174863	42.37	42.41	0.04	42.52	0.14
SS11709	301573	6174961	10.95	10.81	-0.14	10.96	0.01
SS11710	301526	6175130	7.27	7.25	-0.02	7.30	0.03
SS11711	301602	6175354	7.98	8.00	0.02	7.98	0.00
SS11712	301721	6175499	8.93	9.20	0.27	9.18	0.25
SS11713	302053	6175602	10.00	6.55	-3.45	6.63	-3.37
SS11714	301654	6175202	13.67	13.90	0.23	13.77	0.10
SS11715	301822	6175354	24.65	24.56	-0.09	24.69	0.03
SS11716	302099	6175459	21.01	21.03	0.02	21.06	0.05
SS11717	302389	6175306	20.79	20.69	-0.10	20.74	-0.05
SS118673	300779	6172527	84.21	84.29	0.08	84.32	0.11
SS121395	304356	6175565	0.00	1.40	1.40	1.38	1.38
SS123327	300926	6172620	77.48	77.62	0.14	77.51	0.03
SS123334	301092	6172592	73.45	73.53	0.08	73.57	0.12
SS123347	300989	6172583	80.00	76.24	-3.76	76.25	-3.75
SS126427	300857	6172524	86.14	86.20	0.06	86.23	0.09

Survey Mark	Easting	Northing	Surveyed Elevation	2005 ALS	2005 ALS Difference	2011 LiDAR	2011 LiDAR Difference
SS126430	300797	6172455	85.26	85.31	0.05	85.39	0.13
SS126437	300877	6172603	79.74	79.80	0.06	79.91	0.17
SS126442	300777	6172629	81.37	81.44	0.07	81.53	0.16
SS13116	300736	6173448	8.99	8.93	-0.06	9.05	0.06
SS13117	301713	6174536	5.95	6.02	0.07	6.14	0.19
SS13269	300527	6173091	21.40	21.42	0.01	21.53	0.12
SS13281	300730	6173237	19.74	19.79	0.05	19.88	0.15
SS13283	304044	6175868	3.00	2.60	-0.40	2.57	-0.43
SS13298	301898	6174120	31.79	31.79	0.01	31.85	0.06
SS134796	300776	6172829	60.00	56.75	-3.25	56.42	-3.58
SS134798	300973	6172701	60.00	54.55	-5.45	54.51	-5.49
SS136367	300811	6172799	60.00	58.95	-1.05	57.72	-2.28
SS136369	300886	6172815	50.00	48.85	-1.15	48.96	-1.04
SS136371	300734	6172948	50.00	44.70	-5.30	45.00	-5.00
SS136372	301021	6172811	40.00	37.15	-2.85	37.34	-2.66
SS136373	300951	6172806	40.00	42.20	2.20	41.21	1.21
SS163400	301305	6173443	10.00	11.30	1.30	11.40	1.40
SS163401	301399	6174048	10.00	6.48	-3.52	6.47	-3.54
SS163402	299586	6173668	10.00	3.27	-6.73	3.42	-6.58
SS163403	301660	6173927	20.00	15.02	-4.98	15.05	-4.95
SS163404	301343	6173635	19.18	19.19	0.01	19.22	0.04
SS163406	301648	6175186	14.00	13.73	-0.27	13.84	-0.16
SS163407	301304	6174062	10.00	4.19	-5.81	4.22	-5.78
SS163408	302923	6175811	2.00	2.64	0.64	2.68	0.68
SS163409	301480	6173872	10.00	8.46	-1.54	8.54	-1.46
SS163410	301711	6174850	20.00	19.28	-0.72	19.36	-0.64
SS163413	301167	6173470	10.00	10.07	0.07	10.20	0.20
SS163414	301790	6174067	20.00	21.94	1.94	22.07	2.07
SS163415	302878	6175389	6.00	6.79	0.79	6.79	0.79
SS163416	299656	6173912	10.00	3.90	-6.10	4.09	-5.92
SS163418	301691	6174648	10.00	9.79	-0.21	9.79	-0.21
SS163419	303141	6175292	10.00	12.10	2.10	12.29	2.29
SS163420	302092	6174833	40.00	45.40	5.40	45.72	5.72
SS163422	301836	6174301	20.00	23.10	3.10	23.27	3.27

Survey Mark	Easting	Northing	Surveyed Elevation	2005 ALS	2005 ALS Difference	2011 LiDAR	2011 LiDAR Difference
SS163424	301578	6174428	10.00	10.55	0.55	10.58	0.58
SS163425	301765	6174939	20.77	20.70	-0.07	20.83	0.06
SS163426	302458	6175609	10.00	2.41	-7.59	2.54	-7.46
SS163428	301994	6174641	20.00	21.68	1.68	21.75	1.75
SS163429	301590	6174222	22.25	22.20	-0.05	22.29	0.04
SS37505	303947	6175525	2.00	1.91	-0.09	2.02	0.02
SS41868	304721	6175296	2.00	1.40	-0.60	1.76	-0.24
SS43793	300741	6173072	33.75	33.70	-0.06	33.73	-0.03
SS43796	304021	6175106	2.00	2.40	0.40	2.53	0.53
SS43797	304309	6175067	2.00	2.25	0.25	2.30	0.30
SS43798	304010	6175305	2.00	2.05	0.05	2.16	0.16
SS53135	301034	6173203	17.93	17.80	-0.13	17.98	0.04
SS53137	301179	6173297	15.94	15.87	-0.08	15.99	0.05
SS53407	301413	6173010	41.11	41.10	-0.01	41.38	0.27
SS56954	301313	6173024	28.54	28.45	-0.10	28.39	-0.15
SS56958	301152	6172628	66.30	66.30	0.00	66.32	0.02
SS62838	301402	6172683	53.00	52.99	-0.01	52.92	-0.08
SS62950	301083	6172913	31.87	31.79	-0.09	31.86	-0.02
SS62951	301201	6173003	24.50	24.50	0.00	24.61	0.11
SS62952	301026	6172798	37.78	37.66	-0.13	37.89	0.11
SS62953	301532	6172983	46.63	46.62	-0.02	46.64	0.01
SS66369	300947	6173599	10.00	6.38	-3.62	6.37	-3.64
SS81551	301338	6172861	32.27	32.30	0.03	32.45	0.18
SS81552	301309	6172829	35.80	35.81	0.01	35.93	0.14
SS82898	301527	6173158	38.20	38.13	-0.07	38.14	-0.05
SS82899	301534	6173379	18.28	18.28	0.01	18.35	0.07
SS84877	301230	6172909	28.96	28.91	-0.05	28.98	0.02
SS84878	301513	6172890	46.59	46.61	0.02	46.44	-0.15
TS10355	302030	6175096	88.30	80.62	-7.68	80.80	-7.50

Appendix E Community Newsletter and Questionnaire

Shellharbour
CITY COUNCIL

Community Questionnaire

Shellharbour City Council is undertaking the Lake Illawarra, Mt Warrigal & Oaks Flats Flood Study to examine flooding problem areas. The study will establish the basis for subsequent floodplain management activities. We are seeking the community's input by collecting information on any flooding or drainage problems that you may have experienced in the past.

Please take a few minutes to read through these questions and provide responses wherever you can. Please mail this questionnaire by 27th November 2015 in the enclosed envelope (no stamp required) or scan and mail it to Paul.Dunne@bmtwbm.com.au. Alternatively, an online version of the survey questions can be found on Shellharbour City Councils website http://www.shellharbour.nsw.gov.au. All information provided is confidential and used only for the purposes of the study.

Contact and Property Details

Name: ______________________________

Address: ______________________________

____

Phone or email: ______________________________

Can we contact you for more information?

☐ Yes ☐ No

Please tick your type of property:

☐ Residential property

☐ Non residential property

How long have you been at this property?

________ Years

Previous Flooding Experience

Have you experienced flooding at this property?

☐ Yes - inside the main dwelling above the floor level

☐ Yes - significant flooding within the property grounds but not inside the main dwelling

☐ Yes - minor flooding within a small portion of the property grounds only

☐ No

Have you experienced flooding on your street?

☐ Yes - across one or both lanes of traffic

☐ Yes - minor along gutters

☐ No

If yes, does this occur regularly, i.e. several times a year?

☐ Yes ☐ No

If you answered yes to any of the above questions on your previous flooding experience, can you provide further information on this flood event in the table below

Flood event date or year	Are you able to indicate the depth that flood waters reached on your property or elsewhere such as roads? Please attach a sketch where appropriate.

If needed, please provide additional information on your previous flooding experience on additional pages.

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 mailed with this questionnaire or emailed to Paul.Dunne@bmtwbm.com.au (all photos and videos will be returned).

Shellharbour City Council
Lamerton House, Lamerton Crescent, Shellharbour City Centre, Locked Bag 155, Shellharbour City Centre, NSW 2529
http://www.shellharbour.nsw.gov.au/

Privacy and Personal Information Protection Notice

The information on this form is being collected by Shellharbour City Council for the purpose of forming the Lake Illawarra Mt Warrigal and Oak Flats catchments flood study. Your personal information will be used by Council staff for the purpose of understanding the flood behaviour within the study area. This completed form will be placed on a relevant file and/or saved in Council's electronic records management system. You may apply to Council for access to this information. Requests for correction of your personal information can be made under the Privacy & Personal Information Protection Act 1998. Please see Council's Privacy Management Plan or contact the Council's Public Information Officer for more information.

Shellharbour
CITY COUNCIL

Lake Illawarra, Mt Warrigal & Oaks Flats Catchments
FLOOD STUDY

What is the study about?

The Lake Illawarra, Mt Warrigal and Oak Flats catchments have experienced flooding in the past and will experience flooding in the future.

Council is committed to reducing the social and economic damages of flooding in accordance with the New South Wales Flood Prone Land Policy and process outlined in the NSW Government's 2005 Floodplain Development Manual.

To achieve this commitment, Shellharbour City Council with financial support from the NSW Government has engaged specialist flood consultants, BMT WBM to undertake the first 2 stages of the NSW Floodplain Risk Management Process (see next page). To oversee this process, Council has appointed an advisory Floodplain Risk Management Committee. The Committee has a broad representation including Councillors, Council staff, State Government representatives, stakeholder groups and community representatives and provides input and feedback on key outcomes.

The first stage of this Process is data collection. This includes reviewing previous reports and collecting new information about past flood events, flood heights, rainfall, land use, topography, channel geometry, culvert and bridge capacity etc.

The second stage is the flood study. This study will use information collected with advanced computer modelling techniques to simulate complex flood behaviour within the catchment providing information such as water depths, velocities and hazards for a range of flood events.

The third stage is the flood risk management study. With community participation this study identifies and examines a range of options to manage the identified flood risks considering social, economic, environmental, legislative and technical trade-offs.

The fourth stage is the flood risk management plan. This plan is a strategic Council document that prioritises floodplain management measures and improves Councils and other stakeholders (including the community's) ability to make informed decisions about the management of flood prone land. It also provides a strong mechanism for Council to apply for State and Commonwealth funding to implement the identified floodplain management measures.

Map of the Lake Illawarra, Mt Warrigal & Oaks Flats Flood Study Area

BMT WBM

Lake Illawarra, Mt Warrigal & Oaks Flats Catchments

FLOOD STUDY

The Floodplain Risk Management Process

This process is overseen by the Floodplain Risk Management Committee which is established by the local Council and includes community groups and state agency specialists.

1. Data Collection — Compilation of existing data and collection of additional data.

2. Flood Study — Defines the nature and extent of the flood problem.

3. Floodplain Risk Management Study — Determines options in consideration of social, ecological and economic factors relating to flood risk.

4. Floodplain Risk Management Plan — Preferred options publicly exhibited and subject to revision in light of responses. Formally approved by the Council after public exhibition and any necessary revisions due to public comments.

5. Implementation of Plan — Implementation of flood reponse and property modification measures (including mitigation works, planning controls, flood warnings, flood readiness and response plans, etc.) by Council.

The orange elements in the flow chart detail the steps being carried out as part of this review of the Lake Illawarra, Mt Warrigal & Oaks Flats catchments.

How Can You Help

The specialist flood consultants BMT WBM are currently completing stage 1 and 2 of the process. If you have any information on previous flooding in the Lake Illawarra, Mt Warrigal and Oak Flats catchment areas including photographs, video, stories and flood marks we would like to hear from you. If you could complete the attached community questionnaire and return it to Council or BMT WBM it would be greatly appreciated.

Once the flood modelling, mapping and draft report is completed later this year, we will consult with you again to gain your views and feedback on the draft report. The views and feedback you provide will be considered when preparing the final flood study report which will go to Council early next year.

Want more information?

For further information about the Lake Illawarra, Mt Warrigal & Oaks Flats Catchments Flood Study, please contact one of our project team members:

Adam De Clouett
Team Leader Water Engineering & Design
02 4221 6111
Adam.DeClouett@shellharbour.nsw.gov.au

Paul Dunne
Project Manager
02 8960 7755
Paul.Dunne@bmtwbm.com.au

Appendix F Pre-burst Depths and Ratios

Website: http://data.arr-software.org/

Time Accessed: 20 July 2018 08:12PM

Version: 2018_v1

F.1 Median Pre-burst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

Table F-1 Median Pre-burst Depths and Ratios

min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
60 (1.0)	13.6	10.9	9.2	7.5	3.2	0.0
	-0.44	0.25	0.17	0.12	0.04	0
90 (1.5)	13.4	10.4	8.4	6.5	2.8	0.0
	0.36	0.2	0.13	0.09	0.03	0
120 (2.0)	7.5	8.0	8.3	8.7	4.2	0.9
	0.18	0.14	0.12	0.1	0.04	0.01
180 (3.0)	9.7	11.1	12.0	12.8	7.2	2.9
	0.19	0.16	0.14	0.13	0.06	0.02
360 (6.0)	13.6	20.3	24.7	29.0	14.1	3.0
	0.19	0.21	0.21	0.21	0.09	0.02
720 (12.0)	19.3	21.5	23.0	24.4	34.4	41.8
	0.2	0.15	0.14	0.13	0.15	0.16
1080 (18.0)	12.8	19.5	24.0	28.3	25.0	22.5
	0.11	0.12	0.12	0.12	0.09	0.07
1440 (24.0)	5.2	11.8	16.2	20.4	25.9	29.9
	0.04	0.06	0.07	0.07	0.08	0.08
2160 (36.0)	2.3	4.6	6.1	7.6	19.5	28.5
	0.02	0.02	0.02	0.02	0.05	0.06
2880 (48.0)	0.0	0.9	1.5	2.1	15.5	25.5
	0	0	0.01	0.01	0.04	0.05
4320 (72.0)	0.0	0.0	0.0	0.0	2.1	3.7
	0	0	0	0	0	0.01

F.2 10% Pre-burst Depths

Values are of the format depth (ratio) with depth in mm

Table F-2 10% Pre-burst Depths and Ratios

min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
60 (1.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
90 (1.5)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
120 (2.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
180 (3.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
360 (6.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
720 (12.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
1080 (18.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
1440 (24.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
2160 (36.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
2880 (48.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
4320 (72.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0

F.3 25% Pre-burst Depths

Values are of the format depth (ratio) with depth in mm

Table F-3 25% Pre-burst Depths and Ratios

min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
60 (1.0)	0.5	0.3	0.1	0.0	0.0	0.0
	0.02	0.01	0	0	0	0
90 (1.5)	0.7	0.4	0.2	0.0	0.0	0.0
	0.02	0.01	0	0	0	0
120 (2.0)	0.5	0.3	0.1	0.0	0.0	0.0
	0.01	0.01	0	0	0	0
180 (3.0)	0.3	0.1	0.1	0.0	0.0	0.0
	0.01	0	0	0	0	0
360 (6.0)	0.5	0.3	0.2	0.0	0.0	0.0
	0.01	0	0	0	0	0
720 (12.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
1080 (18.0)	0.0	0.3	0.5	0.7	0.3	0.0
	0	0	0	0	0	0
1440 (24.0)	0.0	0.0	0.0	0.0	1.2	2.1
	0	0	0	0	0	0.01
2160 (36.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0
2880 (48.0)	0.0	0.0	0.0	0.0	0.8	1.4
	0	0	0	0	0	0
4320 (72.0)	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0

F.4 75% Pre-burst Depths

Values are of the format depth (ratio) with depth in mm

Table F-4 75% Pre-burst Depths and Ratios

min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
60 (1.0)	47.7	44.3	42.0	39.8	32.4	26.8
	1.53	1	0.78	0.62	0.41	0.3
90 (1.5)	48.4	49.1	49.5	50.0	38.4	29.7
	1.31	0.94	0.79	0.67	0.43	0.29
120 (2.0)	50.7	52.7	54.0	55.2	51.0	47.9
	1.21	0.9	0.76	0.66	0.51	0.42
180 (3.0)	47.4	66.0	78.2	90.0	86.1	83.1
	0.94	0.94	0.93	0.91	0.73	0.62
360 (6.0)	56.8	82.1	98.8	114.8	112.2	110.3
	0.81	0.84	0.84	0.84	0.7	0.61
720 (12.0)	59.8	67.1	71.9	76.5	88.9	98.2
	0.61	0.48	0.43	0.39	0.39	0.39
1080 (18.0)	44.5	60.2	70.6	80.6	81.4	82.0
	0.37	0.35	0.35	0.34	0.29	0.26
1440 (24.0)	30.0	41.7	49.5	56.9	82.1	101.0
	0.22	0.22	0.21	0.21	0.25	0.28
2160 (36.0)	19.6	27.6	32.8	37.9	87.0	123.9
	0.13	0.12	0.12	0.12	0.22	0.28
2880 (48.0)	8.9	20.2	27.7	34.9	76.2	107.1
	0.05	0.08	0.09	0.09	0.17	0.21
4320 (72.0)	0.6	11.3	18.5	25.3	41.9	54.3
	0	0.04	0.05	0.06	0.08	0.09

F.5 90% Pre-burst Depths

Values are of the format depth (ratio) with depth in mm

Table F-5 90% Pre-burst Depths and Ratios

min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
60 (1.0)	102.2	123.0	136.8	150.1	146.2	143.3
	3.28	2.78	2.54	2.35	1.87	1.6
90 (1.5)	109.6	117.9	123.3	128.6	115.3	105.4
	2.97	2.26	1.95	1.73	1.28	1.02
120 (2.0)	111.0	154.9	184.0	211.8	172.7	143.4
	2.65	2.63	2.59	2.54	1.72	1.25
180 (3.0)	122.1	152.3	172.3	191.5	203.5	212.4
	2.43	2.16	2.04	1.94	1.72	1.59
360 (6.0)	106.7	137.5	157.8	177.4	198.4	214.1
	1.52	1.4	1.34	1.3	1.23	1.19
720 (12.0)	108.2	135.3	153.2	170.4	192.1	208.3
	1.1	0.97	0.92	0.88	0.84	0.82
1080 (18.0)	73.3	118.9	149.1	178.0	181.4	183.9
	0.62	0.7	0.73	0.75	0.64	0.59
1440 (24.0)	63.3	93.9	114.2	133.7	154.1	169.5
	0.47	0.48	0.49	0.49	0.47	0.47
2160 (36.0)	52.5	84.2	105.2	125.3	157.7	182.0
	0.34	0.37	0.38	0.38	0.4	0.41
2880 (48.0)	43.2	69.4	86.7	103.3	120.6	133.5
	0.25	0.27	0.28	0.28	0.27	0.27
4320 (72.0)	9.2	41.2	62.4	82.7	98.0	109.5
	0.05	0.15	0.18	0.2	0.19	0.19

Appendix G Selected Design Temporal Patterns

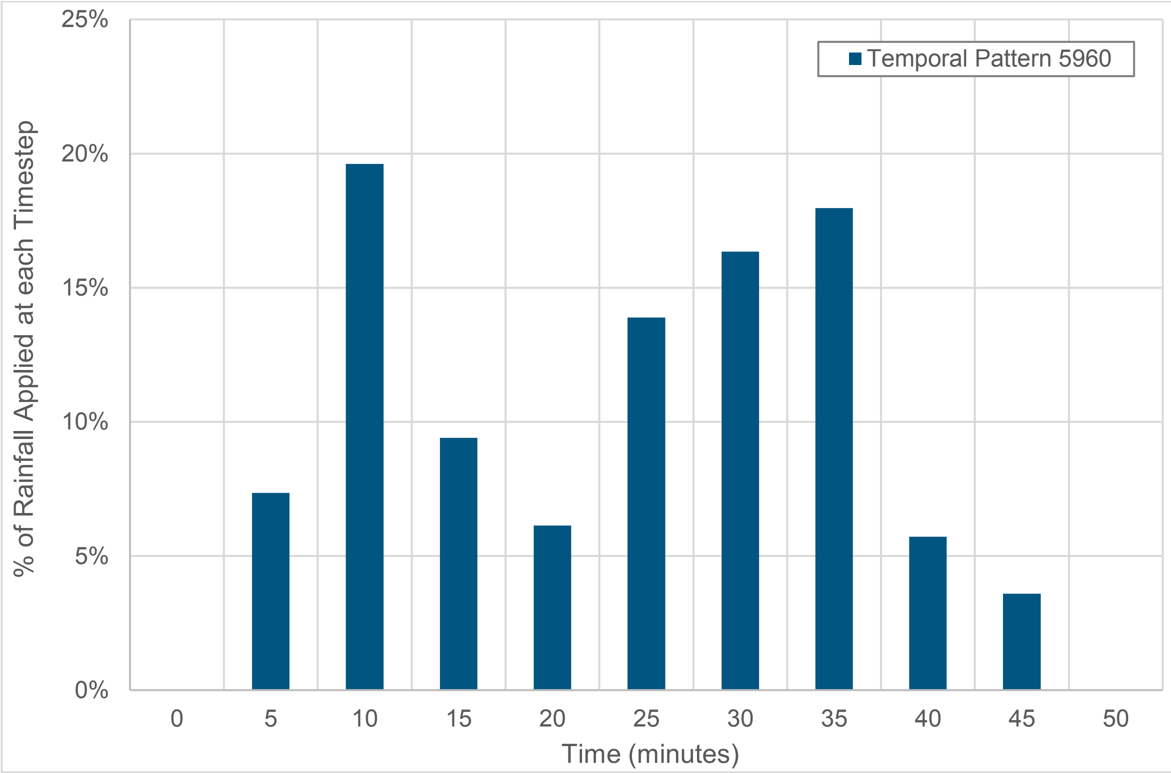

Figure G-1 Frequent Temporal Class (1EY to 10% AEP) - 45 Minute Temporal Pattern 5960

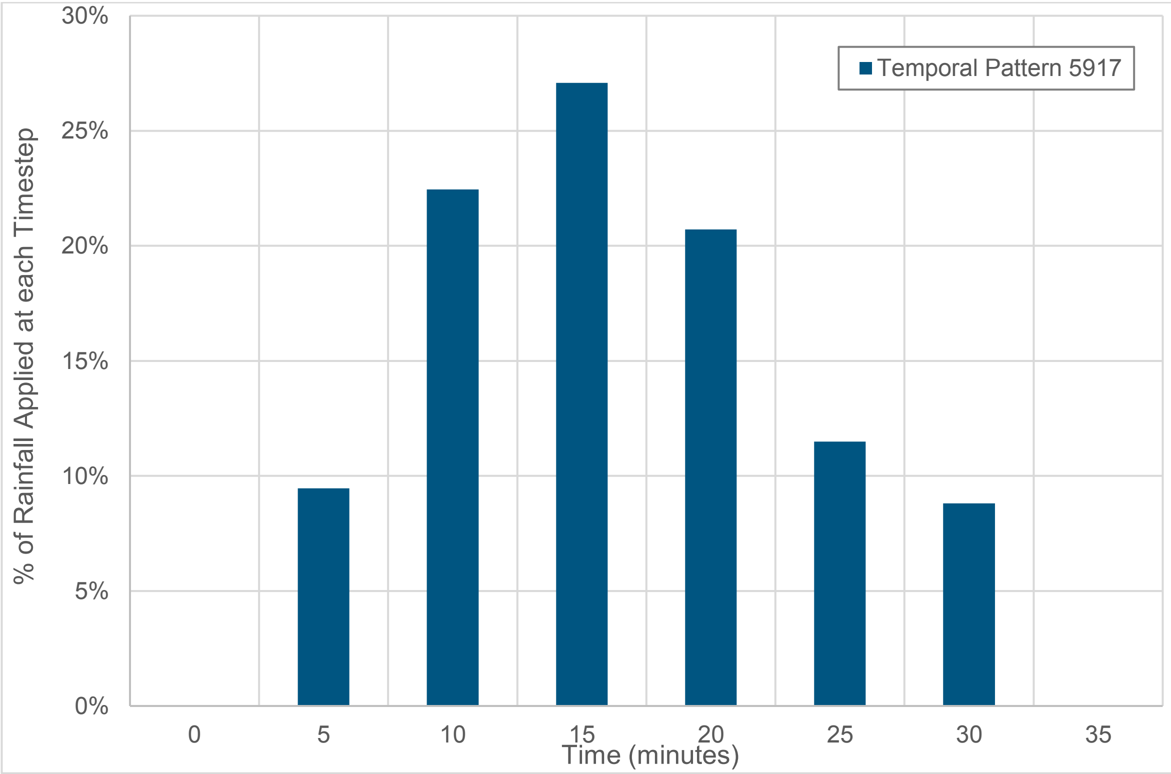

Figure G-2 Infrequent Temporal Class (10% AEP to 1% AEP) - 30 Minute Temporal Pattern 5917

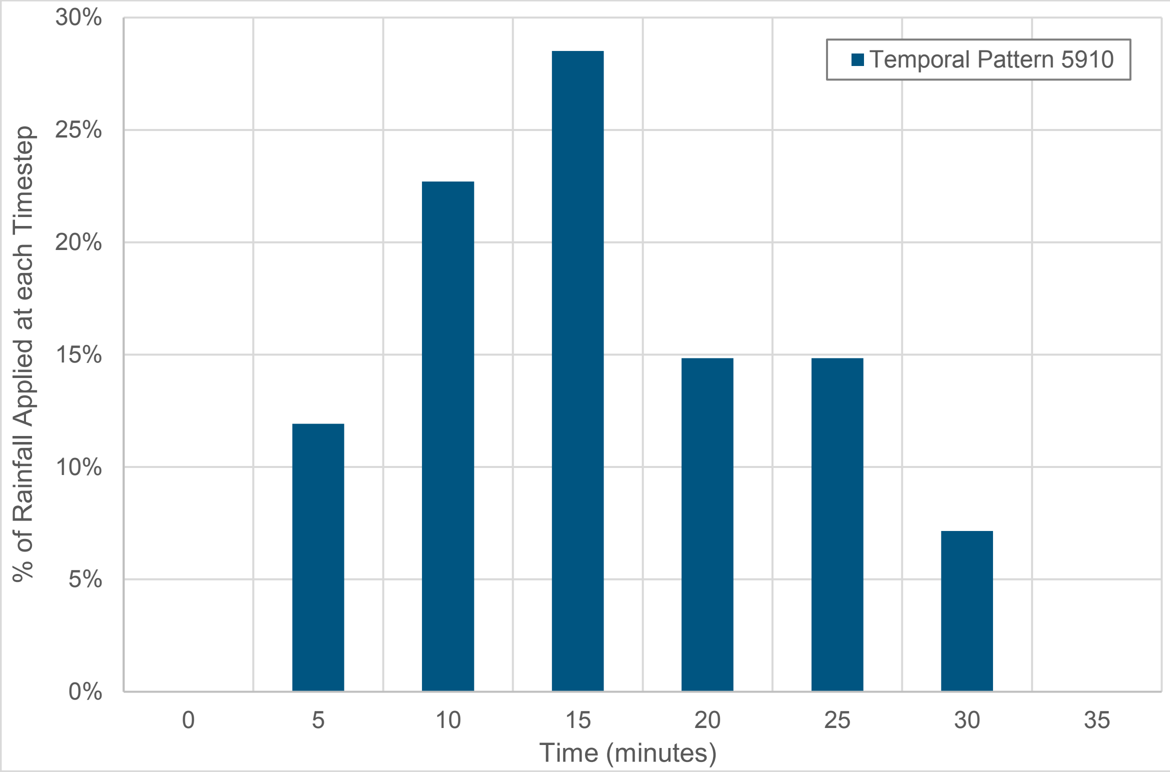

Figure G-3 Rare Temporal Class (1% AEP to 0.05% AEP) - 30 Minute Temporal Pattern 5910

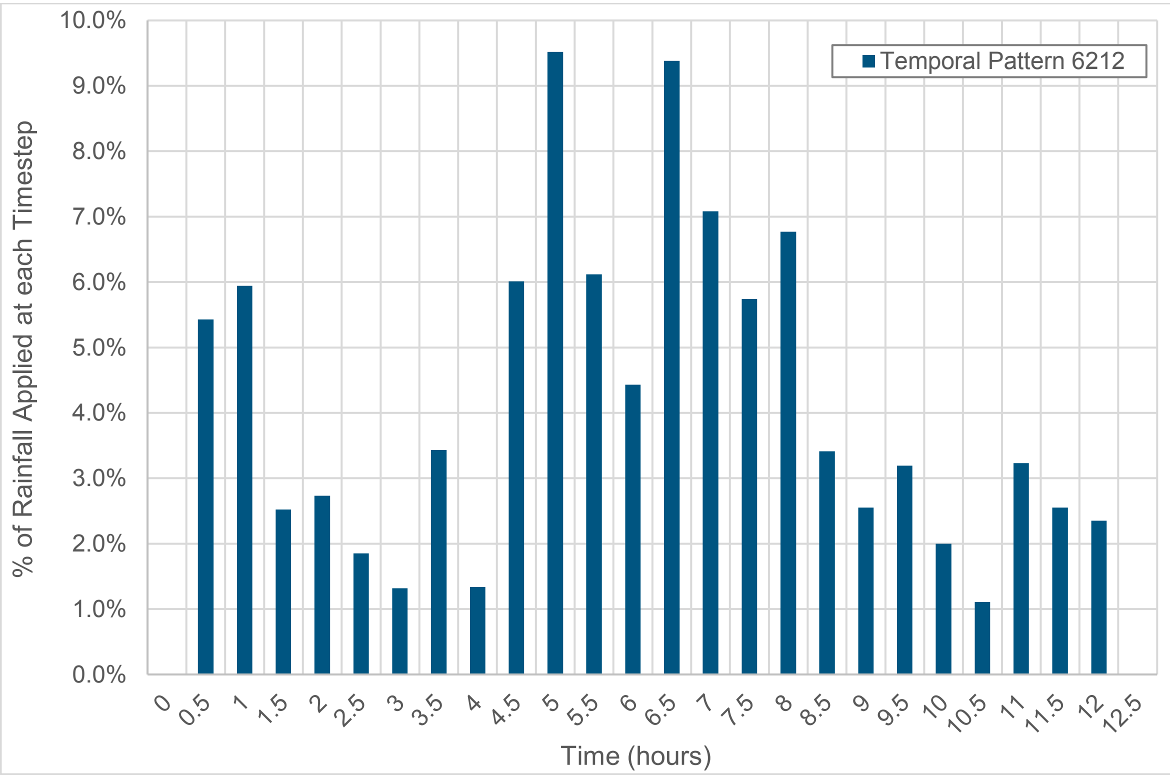

Figure G-4 Frequent Temporal Class (1EY to 10% AEP) - 12 Hour Temporal Pattern 6212

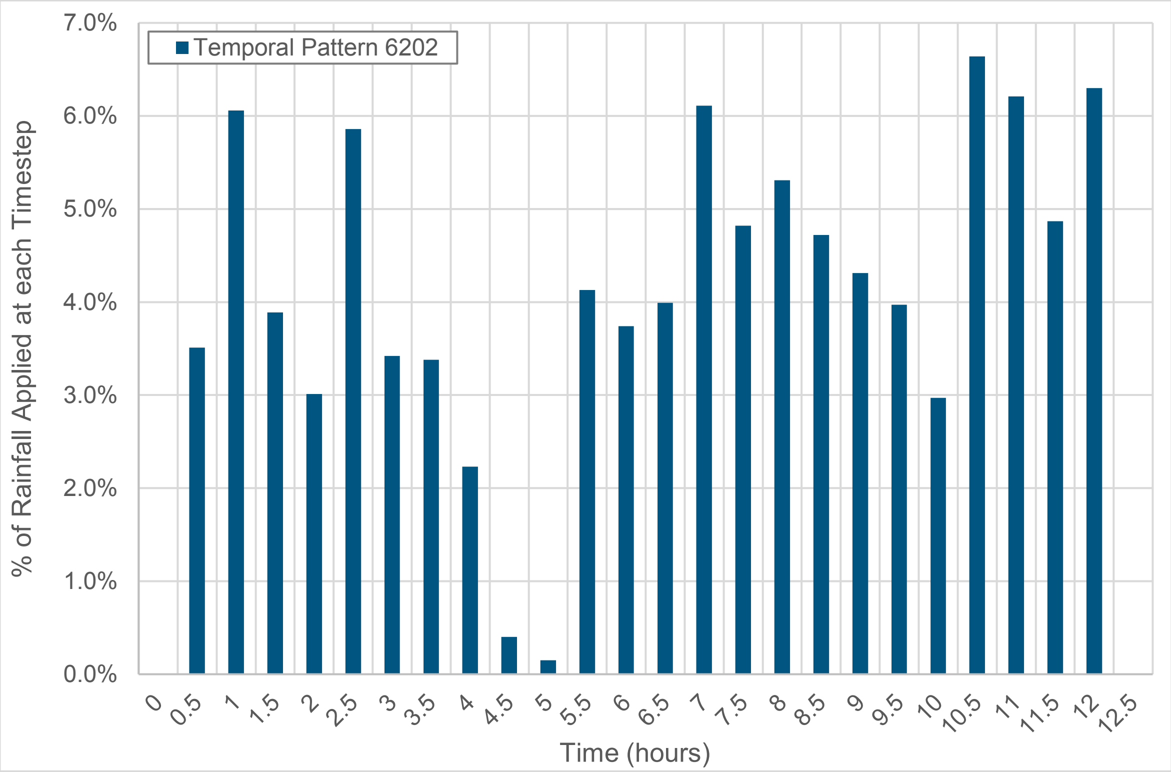

Figure G-5 Infrequent Temporal Class (10% AEP to 1% AEP) - 12 Hour Temporal Pattern 6202

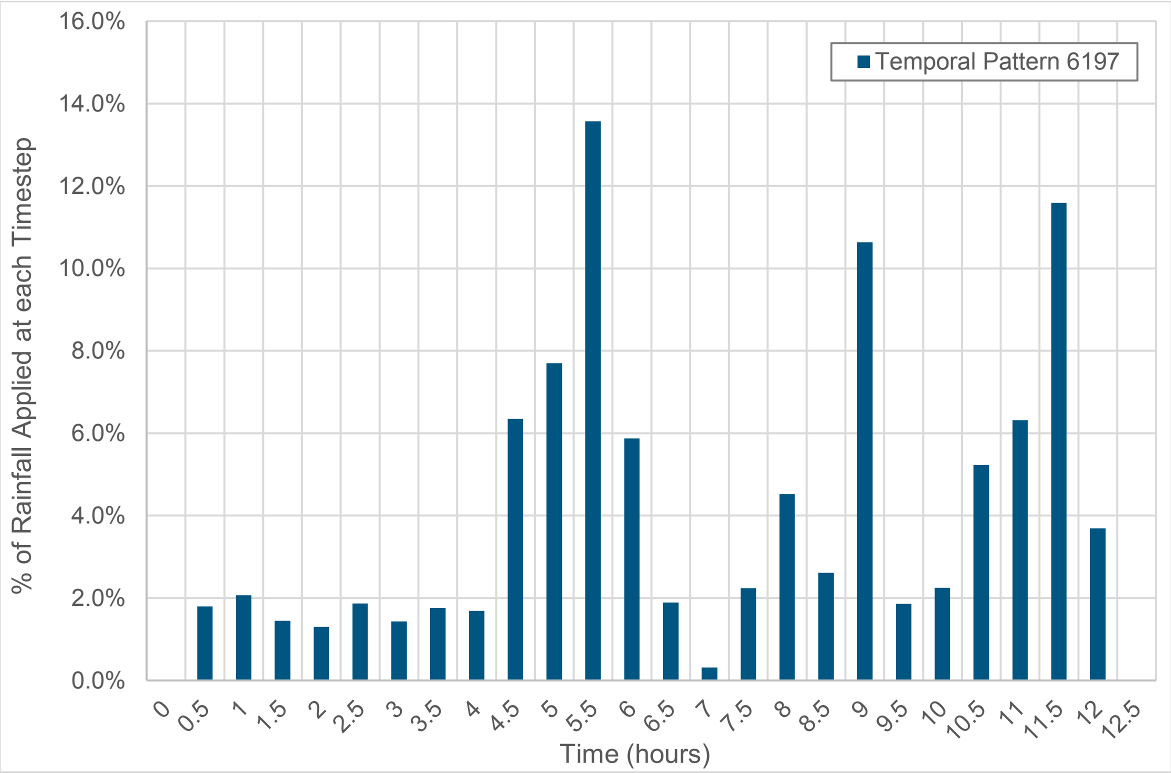

Figure G-6 Rare Temporal Class (1% AEP to 0.05% AEP) - 12 Hour Temporal Pattern 6197

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