NSW GOVERNMENT | Public Works
Manly Hydraulics Laboratory

Flooding of Avalon town centre, 1976 Source: Avalon Beach Historical Society

AVALON TO PALM BEACH FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

FINAL REPORT

Report MHL2321
June 2017

NORTHERN BEACHES COUNCIL

A division of the Office of Finance and Services

Avalon to Palm Beach Floodplain Risk Management Study and Plan

Final Report

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Foreword

In New South Wales the prime responsibility for local planning and the management of flood liable land rests with local government. To assist local government with floodplain management, the NSW Government has adopted a Flood Prone Land Policy in conjunction with the *Floodplain Development Manual*.

The Policy is directed at providing solutions to existing flood problems and to ensure that new development is compatible with the flood hazard and does not create additional flood problems.

The Policy sets out five sequential stages in the process of floodplain management:

Stage	Summary
1. Data Collection	Input to enable preparation of properly informed studies.
2. Flood Study	Technical assessment to define the nature and extent of flooding.
3. Floodplain Risk Management Study	Comprehensive evaluation of management options with respect to existing and proposed development.
4. Floodplain Risk Management Plan	Formal adoption by Council of a management plan for floodplain risks.
5. Implementation of the Plan	Measures undertaken to reduce the impact of flooding on existing development, and implementing controls to ensure that new development is compatible with the flood hazard.

This *Floodplain Risk Management Study and Plan* (FRMS&P) includes a review of the Flood Study, an investigation of what can be done to minimise the effects of flooding in the form of the *Floodplain Risk Management Study* and the recommendation of a strategy in the form of the *Floodplain Risk Management Plan*.

Pittwater Council commissioned NSW Public Works in May 2014 to prepare this report, with PolisPlan as a subconsultant providing town planning input.

Council has prepared this document with financial assistance from the NSW Government through the Office of Environment and Heritage (OEH). This document does not necessarily represent the opinions of the NSW Government or OEH.

The assistance of the Avalon to Palm Beach Floodplain Risk Management Working Group and officers from Pittwater Council and OEH in preparing this document is gratefully acknowledged.

Executive Summary

Description of Study

Pittwater Council commissioned NSW Public Works, with financial assistance from the NSW State Government, to prepare the *Avalon to Palm Beach Floodplain Risk Management Study and Plan*. The study area extends from Bilgola Beach in the south to Palm Beach in the north, and includes Avalon town centre and Careel Creek, which have experienced serious flooding in the past.

Pittwater Council has been managing flood risks within the study area over many years. Among other measures, a detention basin has been built in Avalon Golf Course, culverts to convey Careel Creek flows under Barrenjoey Road at North Avalon have been built, Council's DCP ensures that proposed developments in the floodplain consider flood risk, the *Northern Beaches Flood Information Network* has been established and the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16* is being implemented. The current study draws upon state-of-the-art flood modelling techniques to reassess potential flood problems and to re-evaluate the suite of available floodplain management measures to better manage the risk to life and property posed by flooding.

The study was overseen by the Avalon to Palm Beach Floodplain Risk Management Working Group, which comprises of councillors and staff from Council, officers from the NSW Office of Environment and Heritage, the NSW State Emergency Service, NSW Roads and Maritime Services and Sydney Water, local stakeholder groups and several community representatives. There has also been opportunity for residents and businesses within the study area to provide input to the investigation through the engagement process (see Chapter 6).

Principal Outcomes

The principal outcomes of this study include:

- A consolidated Flood Study (Chapter 7), with estimates of flood extents, levels, depths and velocities for the 20% Annual Exceedance Probability (AEP), 5% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and probable maximum flood (PMF) events;
- Mapping of the high, medium and low Flood Risk Precincts and of Flood Life Hazard categories used for applying Pittwater 21 DCP (Chapter 7);
- Definition of the flood problem by construction of a property database and assessment of building inundation, road inundation, evacuation 'hot spots' and flood damages; about 219 dwellings and 101 other buildings would be flooded above floor in the 1% AEP event, though generally to shallow depths (median < 0.2m); the estimated average annual damages is $5.2 million and the net present value of damage is $77.1 million (Chapter 8);
- Further definition of the flood problem by a formal risk assessment; this shows that catastrophic damage to houses is largely confined to very rare events (medium risk) but

moderate damage is expected in frequent events (high risk); areas of pronounced risk in the study area include Pittwater Palms retirement village, the Avalon town centre and the Elaine Avenue precinct (Chapter 9);

- An assessment of potential floodplain management measures (Chapter 10) and detailed evaluation of flood modification options (Chapter 11), property modification options (Chapter 12) and response modification options (Chapter 13);
- An assessment of the potential impacts of climate change (Chapter 14);
- A recommended Floodplain Risk Management Plan (FRMP) for the Avalon to Palm Beach study area (Chapter 15).

Floodplain Risk Management Plan

The draft Avalon to Palm Beach FRMP is presented in Table 15.1 and Figure 15.1. The recommended measures have been selected from a range of available options, after an assessment of the impacts on flooding, as well as economic, environmental and social considerations.

The recommended measures are summarised below:

Flood modification measures

- Catalpa Reserve detention basin;
- Toongarri Reserve detention basin (subject to environmental issues being satisfactorily addressed)

Property modification measures

- Prepare a scoping study including floor level survey, consultation and site inspections to further assess feasibility of establishing a small voluntary house redevelopment/flood proofing scheme
- Amend Council's Flood Compatible Building Guidelines as suggested; prepare a one-page, graphic summary of the Guidelines
- Review and adopt the revised flood risk management provisions of Pittwater 21 DCP including freeboards for the study area

Response modification measures

- Improve flood warning system:
  - Continue to promote the Northern Beaches Flood Information Network website;
  - Alarm the Avalon Golf Course rain gauge so that it issues email/SMS when rain triggers are reached;
  - Consider installing a second real-time rain gauge in the vicinity of Bilgola Plateau Public School;
  - Include Avalon Palm Beach Business Chamber Inc. on the recipient list for alerts when

rainfall triggers reached;

- NSW SES to transition towards a system where people living or working in the floodplain can opt in for receiving emails/SMS;
- Devise appropriate messages to accompany the rainfall alerts

• Improve emergency response planning:
  - Local Emergency Management Committee (LEMC) to consider information in the Avalon to Palm Beach FRMS&P in completing the Manly-Warringah-Pittwater EMPLAN
  - NSW SES to prepare Pittwater Local Flood Sub-Plan
  - Encourage and assist key floodplain exposures to prepare and update their own flood emergency plans

• Build upon the Northern Beaches Flood and Coastal Storm Education Strategy 2012–16:
  - Develop a library or mobile display using historical flood photos, modelled flood extents and appropriate messaging;
  - Develop an accessible flood emergency plan template suitable for use by Avalon Beach businesses, in conjunction with Avalon Palm Beach Business Chamber Inc.;
  - NSW SES to hold a Business FloodSafe Breakfast in conjunction with Avalon Palm Beach Business Chamber Inc.;
  - NSW SES to conduct 'meet-the-street' type events for residents at Pittwater Palms retirement village and at south Elaine Ave/east Central Road;
  - Engage with students at Barrenjoey High School to help them understand flood behaviour near the school and to promote safe responses;
  - Install signage indicating entrances to evacuation shelters in Avalon commercial district;
  - Install signage in flood prone carparks in Avalon commercial centre and Bilgola Beach;
  - Install flood depth indicators at ~4 low-points on Barrenjoey Road;
  - Install signage in any detention basins where flooding could pond.

Funding

The total capital cost of implementing the Plan is about $2.0M, comprised mainly of the Catalpa Reserve detention basin ($660K) and the Toongarri Reserve detention basin ($1,250K). The basins alone would produce benefits (damage savings) of $2.8M, yielding a benefit-cost ratio (BCR) of ~1.5. The number of houses flooded above floor level in the 1% AEP flood would be reduced by 11.

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1. Introduction

1.1 Background

NSW Public Works was engaged by Pittwater Council (Council) to undertake the Avalon to Palm Beach Floodplain Risk Management Study and Plan (FRMS&P).

The project was comprised of a number of stages, as described below:

- Stage 1: Data Collection, Review, Survey and Community Consultation Plan
- Stage 2: Environmental and Social Characteristics of the existing flood behaviour and Economic impact of flooding of flood prone land
- Stage 3: Risk to Life Assessment and Review of Current Emergency Response Arrangements/Options
- Stage 4: Identification and assessment of property and flood modification management options
- Stage 5: Implications of climate change on flooding behaviour and proposed management options.

The study has defined the flood problem in the study area, identified and assessed options to manage the flood risk to property and life, and investigated the implications of potential future climate change on flood behaviour in the study area including its potential impact on proposed management options.

1.2 The Study Area

The study area comprises a number of catchments in the north of the Pittwater LGA, from Bilgola Beach in the south to Palm Beach in the north as shown in Figure 1.1. This area includes the Avalon town centre and Careel Creek which have experienced flooding historically.

Figure 1.1 – Study area location

1.3 The NSW Floodplain Risk Management Process

The Avalon to Palm Beach FRMS&P has been prepared in accordance with the New South Wales Government's *Floodplain Development Manual* (2005). The manual guides implementation of the NSW Government's *Flood Prone Land Policy* (2005), the primary objective of which is to:

> *reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.*

Under the policy, primary responsibility for floodplain risk management rests with local government. Financial and technical assistance is provided to councils by the NSW Government's Office of Environment and Heritage (OEH).

The *Floodplain Development Manual* defines the following steps in the Floodplain Risk Management Process:

- Formation of a Floodplain Risk Management Committee
- Data Collection
- Flood Study Preparation
- Floodplain Risk Management Study Preparation
- Floodplain Risk Management Plan Preparation
- Floodplain Risk Management Plan Implementation.

Pittwater Council is responsible for management of flood prone land throughout the Pittwater Local Government Area (LGA). The Careel Creek Floodplain Working Group was established by Council in October 2012 as an advisory body to Pittwater Council on matters concerning the development, implementation and review of the *Careel Creek Catchment Flood Study* (WMA 2013). The Pittwater Overland Flow risk Management Community Working Group was established in May 2013 as an advisory body for the *Pittwater Overland Flow Mapping and Flood Study* (Cardno 2013). In accordance with the floodplain risk management process, Council has overseen the completion and adoption these documents to define flood behaviour and risk throughout the study area. Flood modelling associated with these studies has been updated in the current study and provided a basis from which options to manage flood risk were assessed.

Council engaged NSW Public Works to complete the Floodplain Risk Management Study and Floodplain Risk Management Plan phases of the process for the Avalon to Palm Beach study area. The ultimate outcome of the study is the delivery of this Floodplain Risk Management Study and Draft Plan, with the draft plan detailing options recommended for adoption by Council in managing flood risk.

The Avalon to Palm Beach Floodplain Risk Management Working Group (the Working Group) was formed by Council in 2014 to fulfil the functions of a Floodplain Risk Management Committee as described in the *Floodplain Development Manual* (NSW Government 2005).

The Working Group comprises of representatives from:

- Pittwater Council
- NSW Office of Environment and Heritage (OEH)
- NSW State Emergency Services (SES)
- NSW Roads and Maritime Services (RMS)
- Sydney Water
- Local stakeholder groups
- Local residents.

The initial information letter regarding the study included an invitation to residents to nominate themselves as community representatives in the Working Group.

1.4 Previous Floodplain Risk Management Measures

Floodplain risk management is an ongoing process and Pittwater Council has been managing flood risk within the study area over many years.

Council's *Pittwater 21 Development Control Plan* (DCP) includes flood-related development controls which ensure that proposed developments in the floodplain appropriately consider flood risk (see Section 3.5). Pittwater Council, in conjunction with Warringah and Manly councils, has also established the *Northern Beaches Flood Information Network*, and implemented the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16*.

A prior iteration of the floodplain risk management process undertaken by Pittwater Council included the *Careel Creek Drainage Catchment Flood Study* (Lawson and Treloar 1999), the *Careel Creek Floodplain Management Study* (Lawson and Treloar and Nelson Consulting 2000), and the *Careel Creek Floodplain Risk Management Plan* (Lawson and Treloar and Nelson Consulting 2002). As an outcome of this process, amongst other measures, a detention basin has been built in Avalon Golf Course (completed in 2005), and enlarged culverts have been built to convey Careel Creek flows under Barrenjoey Road at North Avalon (completed in 2007). These measures have helped to reduce the potential severity of flooding in Avalon town centre and the lower Careel Creek catchment.

The current FRMS&P was carried out in response to:

- The continued development of computer technology and hydraulic modelling software (along with topographic data capture technology) which has enabled the use of 2D computer models to provide detailed flood extent and depth mapping over relatively large areas;
- The occurrence of, and availability of data from, flood events which occurred subsequent to the 1999 Flood Study and have helped inform current flood modelling. Of particular note is the flood event that occurred on 3 February 2008;
- Changes within the study area that may influence flood behaviour including the construction of the Avalon Golf Course Detention basin, the Careel Creek culvert enlargement, and changes in land development;

- The need to assess and manage flood risk posed by overland flow flooding beyond the Careel Creek catchment.

Flooding results in significant impacts in New South Wales in terms of economic damage and emotional distress. Considering the history of flooding in the area (see Section 2.3) and the potential for more severe floods to occur (see Chapter 8), flooding remains a significant risk within the Avalon to Palm Beach study area.

1.5 Outline

The structure of the report is set out in Table 1.1. Part A describes the context for the study, Part B describes the flood behaviour and risks, Part C describes the identification, assessment and evaluation of potential floodplain management measures to better manage the risk, Part D describes the influence of climate change and Part E presents a list of recommended options in the form of the draft Avalon to Palm Beach Floodplain Risk Management Plan.

Table 1.1 – Outline of report

Chapter	Outline of Content of Section
Part A: Context	
1. Introduction	Describes context of the study
2. Catchment Characteristics	Describes topography, urban development, flood history, environmental issues, heritage issues and social profile of study area
3. Urban Planning Context	Describes existing State and local legislation and policies relevant to land use planning in the study area
4. Impact of Flood Affectation on Property Values	Describes a literature review to assess the impact of flood affectation on property values
5. Local Emergency Planning Context	Describes Local Flood Sub-Plan, emergency services capability and response strategy in the study area
6. Community Consultation	Describes findings from the community and stakeholder engagement process
Part B: Flood Behaviour and Impacts	
7. Flood Behaviour	Describes flood behaviour, flood risk precinct mapping and flood life hazard category mapping within the study area
8. Defining the Flood Problem	Assesses the impacts of flooding in terms of building inundation, road inundation, evacuation constraints and tangible damages
9. Risk Assessment	Assesses risks (in terms of likelihoods and consequences of flooding) for the study area as a whole and suspected 'hot spots'
Part C: Floodplain Risk Management Measures	
10. Preliminary Identification and Assessment of Options	Describes the process used for preliminary identification and assessment of floodplain risk management (FRM) options
11.Flood Modification Measures	Evaluates detention basins and drainage upgrades
12. Property Modification Measures	Evaluates voluntary house purchase, voluntary house raising or redevelopment, flood-proofing and revisions to planning policies
13. Response Modification Measures	Evaluates improvements to flood warning systems, emergency response planning and flood education
Part D: Climate Change	
14. Implications of Climate Change	Assesses the potential impacts of climate change on flood behaviour and the influence of climate change on proposed FRM options
Part E: Draft Floodplain Risk Management Plan	
15. Draft Floodplain Risk Management Plan	Describes the recommended floodplain risk management measures

2. Catchment Characteristics

2.1 Site Description

The study area covers an area of approximately 9 km^2 including the suburbs of Bilgola, Avalon, Clareville, Whale Beach and Palm Beach. The area comprises of a number of small catchments where overland flow flooding can occur, and the larger 4.3 km^2 Careel Creek catchment which is subject to both overland flow flooding and mainstream creek flooding. The study area is bounded by Pittwater to the west, the Tasman Sea to the east, and Bilgola Plateau to the south.

The topography of the catchment is depicted in a Digital Elevation Model (DEM) derived from Airborne Laser Scanning (ALS) survey as shown in Figure 2.1. The highest elevation of 150 m AHD lies on the southern boundary within Angophora Reserve which drains predominantly to the Careel Creek catchment. There are a number of other hills and ridges in the study area which generally fall away steeply toward the ocean and Pittwater, with a number of small but well defined valleys evident. More gentle slopes are found within the lower Careel Creek catchment, with relatively flat low lying land bounding the creek channel. Other low lying areas include foreshore areas of Bilgola Beach, Clareville Beach, Careel Bay, Whale Beach and Palm Beach.

Careel Creek drains to the Pittwater estuary at Careel Bay. The downstream reaches of the creek consist of a natural channel, lined by mangroves for much of its length. In the upper reaches of this natural section, bank erosion and deposition of sediment on the creek bed are evident.

From the vicinity of Barrenjoey High School heading upstream, the Careel Creek channel is concrete lined, initially with significant in-stream vegetation (reeds and grasses). Council has noted scour of the creek bed at the transition between the concrete lined and natural creek sections. A gross pollutant trap is located upstream of the footbridge near the southern end of Central Road. At its upstream end after the Barrenjoey Road (south) crossing, the concrete channel converts into a closed box culvert, passing below Woolworths Avalon and continuing toward the south-west.

Two main branches of the Careel Creek catchment occur upstream of Avalon town centre. The southern branch originates in Angophora Reserve and passes through the Ruskin Rowe area, conveying flows through an open channel then passing into a large pipe system under the Pittwater Palms retirement village. The western branch conveys flows through a trunk drainage system, with excess flows passing overland through an easement between properties on Central Road and Avalon Parade.

In the smaller catchments of the study area, flows are conveyed through a combination of pit and pipe systems and overland flows. In a number of catchments flows drain through well-defined valleys while in other catchments flow paths are less well defined and may occur along roadways and through properties.

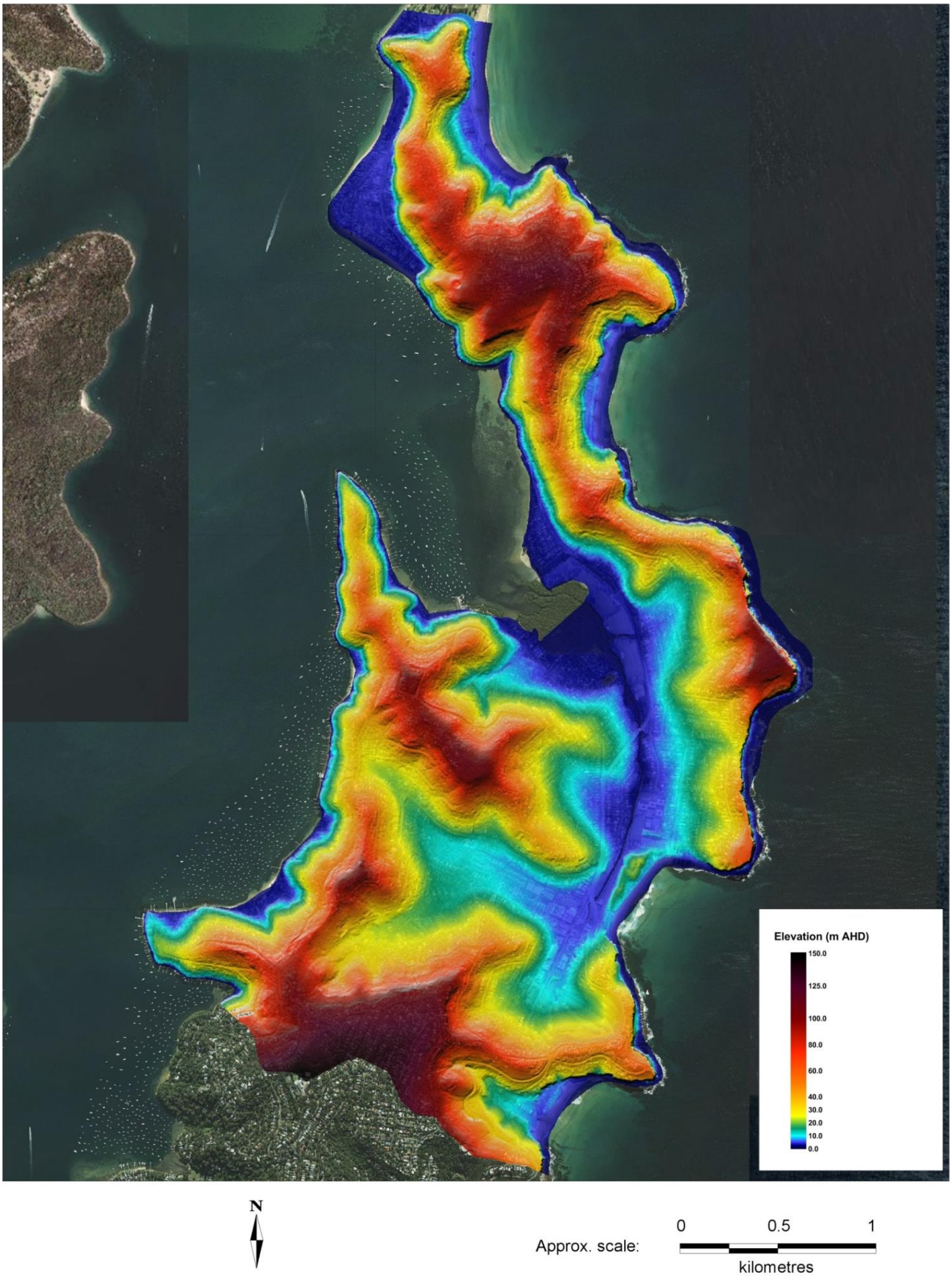


Figure 2.1 – Digital Elevation Model

2.2 Urban Development

The Guringai people had lived in Pittwater for thousands of years when Europeans arrived in 1788 and soon displaced them. Aboriginal lands were granted to European settlers in the study area from the 1830s (Table 2.1). Some land was cleared for cultivation and to provide timber for building and fuel. Later in the century Pittwater became a farming district, grazing sheep, cattle, horses and pigs and producing butter, milk, vegetables, fruit and wheat. Table 2.1 shows that Avalon was subdivided from 1921 but Figure 2.2 shows that the village was relatively small in 1927. Only since the 1950s has Pittwater become predominantly residential in character as a suburban region of Sydney.

Current land use zonings in the study area are shown in Figure 2.3. Most land is dedicated to low density residential development (‘E4’ and ‘R2’) with a small area near Avalon town centre of medium density residential. A number of retirement villages are located within the study area, notably Pittwater Palms just upstream of Avalon town centre. Commercial development is concentrated primarily in the Avalon town centre, while there are no major industrial developments. There are a number of schools within the area and a significant amount of recreational open space including various sporting fields, bowling greens and golf courses. Several nature reserves also fall within the study area including Angophora Reserve.

Table 2.1 – Timeline describing urban growth
Source: Lawrence (2006)

Year	Event
1830s	Land grants at Careel Bay
1832	Grant of 1200 acres covering Whale Beach, Careel Bay, Clareville, Avalon and Bilgola
1870s	House built at Bilgola Beach
1912	Land auctions at Palm Beach
1913-18	Various land auctions including Clareville, Careel Bay
1920-21	General store built at junction of Barrenjoey Road and Avalon Parade
1921	First land subdivisions at Avalon Auctions at Whale Beach
1922-23	Land sales at Bilgola
1930s	Avalon Private Picnic and Camping Grounds established
1933	First Post Office at Avalon opened
1938	Angophora Reserve opened
1950	Avalon Beach Public School opened Ruskin Rowe subdivided
1968	Barrenjoey High School opened

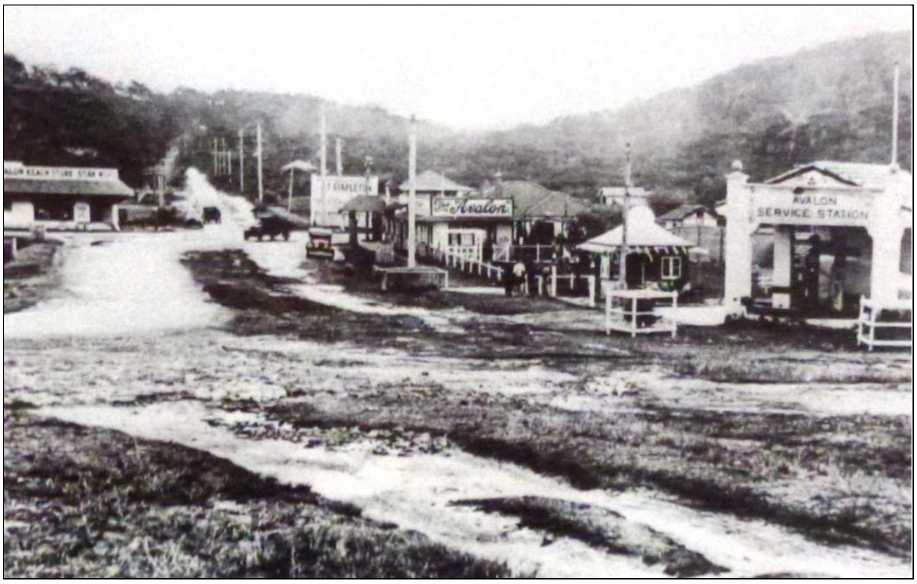


Figure 2.2 – Avalon Village c.1927 looking west up Avalon Parade
Source: Lawrence (2006, p.11)

2.3 Flood History

Most descriptions of historical flooding in the study area are for Careel Creek. Table 2.2 reports the dates and consequences of known floods plus other dates when rainfall maxima suggest that flooding may have occurred. This has been populated by reference to Bureau of Meteorology daily rainfalls proximate to the study area, the National Library of Australia's newspaper database, to microfilm copy of the Manly Daily held at the State Library of NSW, and to the records of the Avalon Beach Historical Society.

Serious flooding of Careel Creek is reported in 1925, 1948, 1952, 1953, 1973, 1976 (see Figure 2.4) and 1977. Council's records indicate that Careel Creek floods also occurred in 1975, 1984, 1987, 1989, 1990, 1997, 1998 and 2008. Flooding in Careel Creek originates from both mainstream flooding due to elevated levels in Careel Creek, and overland flow flooding which can occur as concentrated stormwater runoff makes its way to, bypasses or overflows from drainage systems.

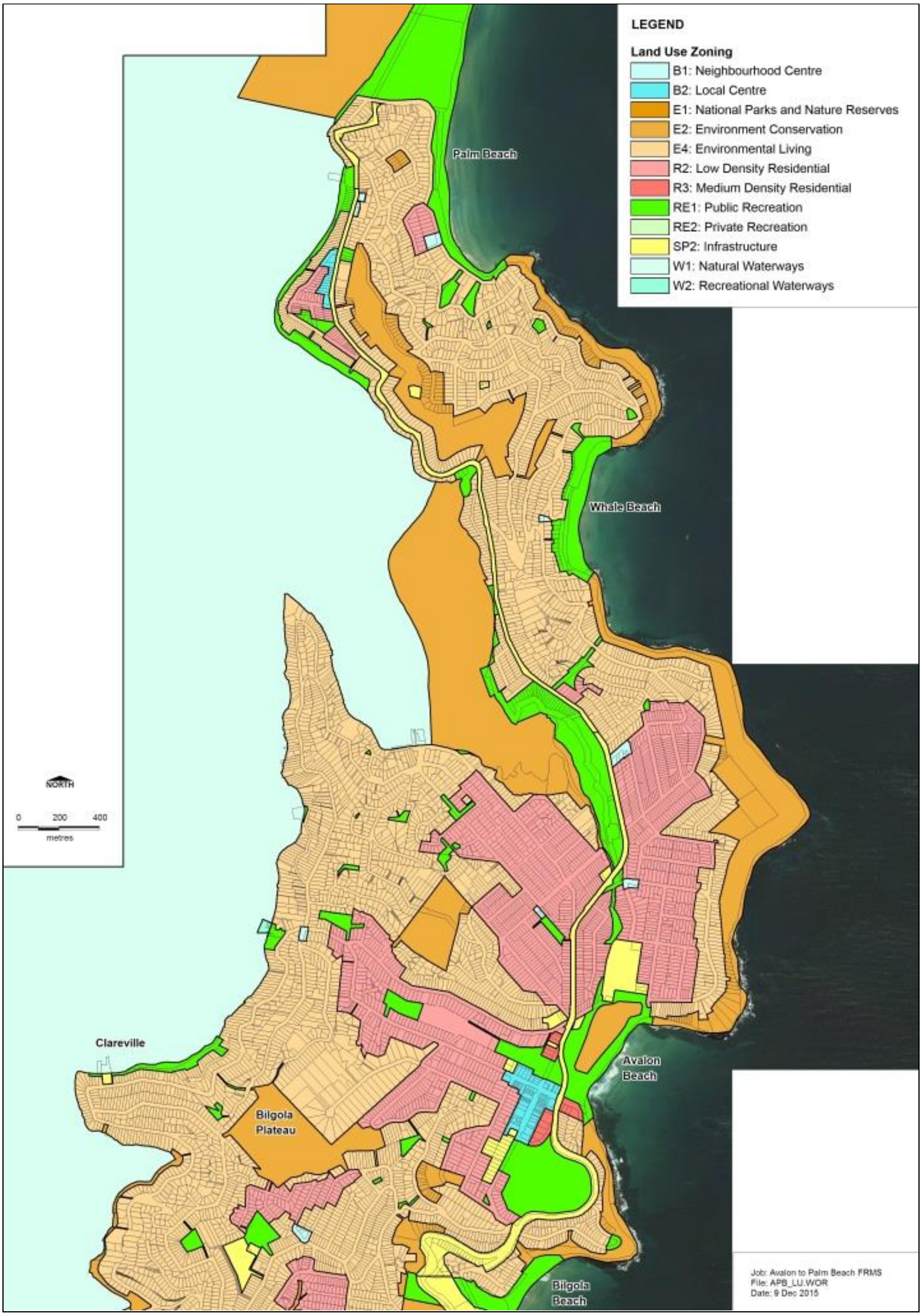


Figure 2.3 – Current land use

Table 2.2 – Avalon to Palm Beach flood history

Date	Daily Rainfall (mm)			Description
	① #66079	② #66128	③ #66053	
1925 May 25?	n/a	n/a	n/a	Avalon: water lapping at doorsteps of houses on the flats (SMH)
1948 Jan 1	n/a	n/a	n/a	Avalon: campers washed out when ground flooded by 0.9m of water (SMH)
1952 Jul 26	n/a	n/a	n/a	Avalon: 1.2m of water swept through camping reserve and wrecked tents of 30 families (SMH)
1953 May 2	n/a	n/a	n/a	Avalon: Campers had to wade through chest-deep water to reach high ground, carrying children; cabin carried 90 metres; rose to 1.2m deep in cabins within 2 hours (SH)
1953 May 6	n/a	n/a	n/a	Avalon: Tents washed out to sea by floodwaters; children carried to safety through the 'racing' water; stormwater, in places 0.9m deep, raced through the shopping centre; 0.6m deep in Le Clerq's general merchandise store in Avalon Parade; great rush of water through Avalon Parade; one car carried almost 180 metres (SMH)
1959 Feb 19	149	n/a	n/a	
1961 Nov 19	151	n/a	n/a	
1962 May 13	111	n/a	n/a	
1963 May 7	109	n/a	n/a	
1963 Aug 30	102	n/a	n/a	
1964 Mar 7	107	n/a	n/a	
1966 Apr 27	102	n/a	n/a	
1969 Feb 11	129	103	n/a	
1969 Apr 17	81 (16th)	111 (17th)	n/a	
1969 Nov 14	100	94	n/a	
1972 Jan 15	n/a	112	n/a	
1973 Apr 9	130	32	n/a	Shops and houses flooded to depth of about 0.45m when Careel Creek backed up and overflowed; furniture and floor coverings damaged including in Elaine Avenue houses (SMH)
1975 Feb 23	n/a	115	n/a	
1975 Mar	n/a	?	n/a	Flooding in Careel Creek catchment (Lawson & Treloar, 1999)
1976 (Jul 1?)	n/a	63 (1st) 59 (2nd)	n/a	Avalon: photos show serious flooding in shopping centre (ABHS, cited in WMAwater, 2013, App A)
1977 Mar 1	n/a	25 (1st) 70 (2nd)	n/a	Avalon: flash flood trapped scores of people inside stores in shopping centre; water a metre deep in Barrenjoey Road; up to ankle height in stores (CTs); $1 million+ damage to carpets, wallpaper and stock in shopping centre; water several feet deep in houses in Elaine Avenue; Bilgola Plateau: torrent came through front door of Stromboli Place residence (MD)
1977 Mar 4	n/a	117 (4th)	n/a	Avalon: flooded, when 50mm of rain fell in an hour (MD)
1978 Jan 29	n/a	191	n/a	Peninsula: local flooding in many areas (MD)
1983 Dec 17	n/a	104	n/a	
1984 Nov	n/a	31 (6th) 55 (7th) 81 (8th)	n/a	Flooding in Careel Creek catchment (Lawson & Treloar, 1999)

Date	Daily Rainfall (mm)			Description
	① #66079	② #66128	③ #66053	
1986 Aug 6	n/a	87 (5th) 111 (6th)	n/a	
1987 Oct 24	n/a	139 (25th)	n/a	Flooding in Careel Creek catchment (WMAwater, 2013)
1987 Nov 11	n/a	165 (11th) 108 (12th	n/a	Whale Beach: nine properties in Barrenjoey Road flooded; Moby Dick Surfers Club in Whale Beach Road inundated by overland flows causing ~$1500 damage to carpets (MD)
1988 Jan 17	n/a	155	n/a	
1988 Feb 14	n/a	114	n/a	
1988 Apr 30	n/a	150 (30th) 93 (1st)	n/a	Palm Beach: Whale Beach Road seriously damaged (MD)
1988 Jul 6	n/a	154	n/a	Avalon and Careel Bay: Severe wind damage and minor flooding (MD)
1989 Jan 6	n/a	88 (7th)	n/a	Flooding in Careel Creek catchment (WMAwater, 2013)
1989 Jun 21	n/a	106	n/a	
1990 Feb 6	n/a	n/a	n/a	Flooding in Careel Creek catchment (Lawson & Treloar, 1999)
1996 Aug 31	116	n/a	n/a	
1997 Jan	32 (29th) 46 (30th)	n/a	n/a	Flooding in Careel Creek catchment (Lawson & Treloar, 1999)
1997 Feb 12	108	n/a	n/a	
1998 Apr 10	154 (11th)	185 (11th)	n/a	Flooding in Careel Creek catchment (WMAwater, 2013)
1998 May 18	101	96	n/a	
1998 Aug 7	200 (7th - 2 day) 110 (8th)	74 (6th) 117 (7th) 112 (8th)	n/a	
1999 Feb 25	99 (2 days)	120	n/a	
2002 Feb 4	100	115	n/a	
2006 Jan 16	59	103	n/a	
2006 Feb 27	71	118	101	
2008 Feb 3	106 (4th)	66 (4th)	108 (4th)	Avalon: flooding of main shopping centre (MD); Careel Bay: localised flooding (MD); Bilgola Plateau: some yards flooded
2011 Mar 20	120	80	139	Flooding reported at Narrabeen (MD)
2013 Jan 29	118	70	116	Flooding reported at Wakehurst Parkway (MD)
2013 Jun 24	95 (2 days)	119	91	
2015 Apr 21	94 (21st) 97 (22nd)	78 (21st) 90 (22nd)	82 (22nd)	Avalon: pockets of business centre under water (MD)

Key:
① Avalon Beach (Palmgrove Road), No. 66079, 1958-
② Palm Beach (Sunrise Road), No. 66128, 1965-
③ Avalon (Wollstonecraft Road), No. 66053, 2001-
ABHS = Avalon Beach Historical Society
CTs = Canberra Times
MD = Manly Daily
SH = Sun Herald
SMH = Sydney Morning Herald

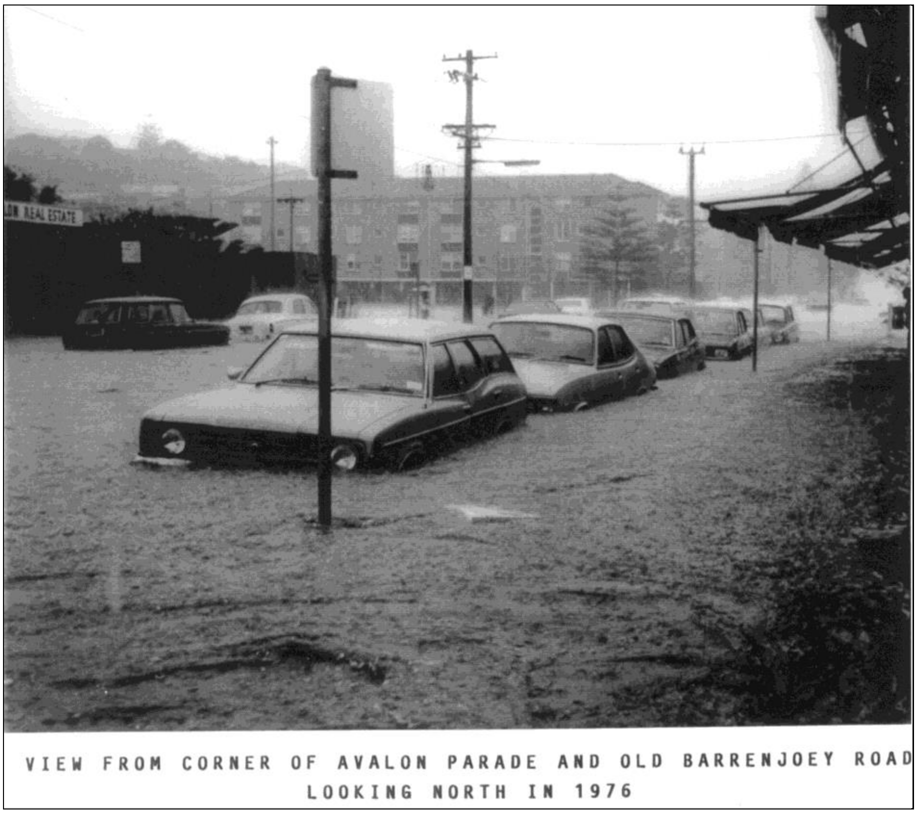


Figure 2.4 – Flooding of Avalon Town Centre, 1976
Source: Avalon Beach Historical Society

2.4 Environmental Issues

It is important to understand the environmental assets within a catchment because they may:

- be adversely impacted by flooding;
- affect flood behaviour by impeding flood flows;
- be a constraint to implementing some flood mitigation options; or
- be able to be enhanced when implementing some flood mitigation options.

Figure 2.5 shows the distribution of vegetation communities in the study area. Much of the original vegetation has been altered or disturbed through urbanisation. But there are still significant areas of bushland and reserves, and some endangered ecological communities (EECs), including Littoral Rainforest in Angophora Reserve and Pittwater Spotted Gum Forest in Angophora Reserve and Catalpa Reserve. Toongarri Reserve includes an area of Coastal Flats Swamp Mahogany Forest (not endangered). Lower Careel Creek has areas of Estuarine Swamp Oak Forest and Estuarine Mangrove Forest.

Figure 2.6 shows the distribution of reported sightings of threatened species in the study area, over the past 20 years or so. The bush-stone curlew was sighted several times in the lower Careel Creek corridor.

Council has also mapped wildlife corridors across the LGA.[1] These are remnant habitat, regenerated habitat or artificially created habitat that link larger areas of wildlife habitat. In the study area, there is an area between Angophora Reserve and Stapleton Park categorised as a high priority wildlife corridor essential to fauna movement. This includes properties along Ruskin Rowe and Toongarri Reserve. Indeed, volunteers planted a wildlife corridor in Toongarri Reserve. There is also a 'high priority' corridor on the western side of Barrenjoey Road near the Careel Bay Ovals.

Much of the study area is mapped as 'biodiversity' on the biodiversity maps in Pittwater LEP 2014. The LEP requires that Council considers the impacts of a proposed development on fauna, flora and habitat before determining a development application.[2]

Acid Sulphate Soils (ASS) is the common name given to naturally occurring soils that contain iron sulfides. Problems arise when these naturally occurring sulfides are disturbed and exposed to air, creating sulfuric acid. The sulfuric acid can drain into waterways and cause severe environmental damage and damage to steel and concrete structures.

Pittwater LEP 2014 includes acid sulfate soils maps.[3] The Careel Creek corridor downstream of the (northern) Barrenjoey Road crossing and properties in Etival Street and Currawong Avenue are rated as 'Class 2', which according to the LEP may require development consent for works below the natural ground surface.[4] Areas near John Street and George Street, Avalon, and near Iluka Road, Palm Beach, are rated as 'Class 3', which may require development consent for works more than 1 metre below the natural ground surface. There is a relatively large swathe of Careel Creek floodplain between about Toongarri Reserve and Catalina Crescent that is rated as 'Class 4', as well as a narrow band near Ocean Road, Palm Beach, which may require development consent for works more than 2 metres below the natural ground surface.

All the above environmental issues may represent constraints upon the potential flood mitigation works that are identified and evaluated in this study.

[1] See http://www.pittwater.nsw.gov.au/environment/native_animals/wildlife_corridors and http://portal.pittwater.nsw.gov.au/common/Output/DataworksAccess.aspx?id=KaW59fUR%252frM%253d&ext=pdf
[2] Pittwater LEP 2014 Clause 7.6
[3] See http://www.pittwater.nsw.gov.au/property/planning_controls/pittwater_local_environment_plan
[4] Pittwater LEP 2014 Clause 7.1

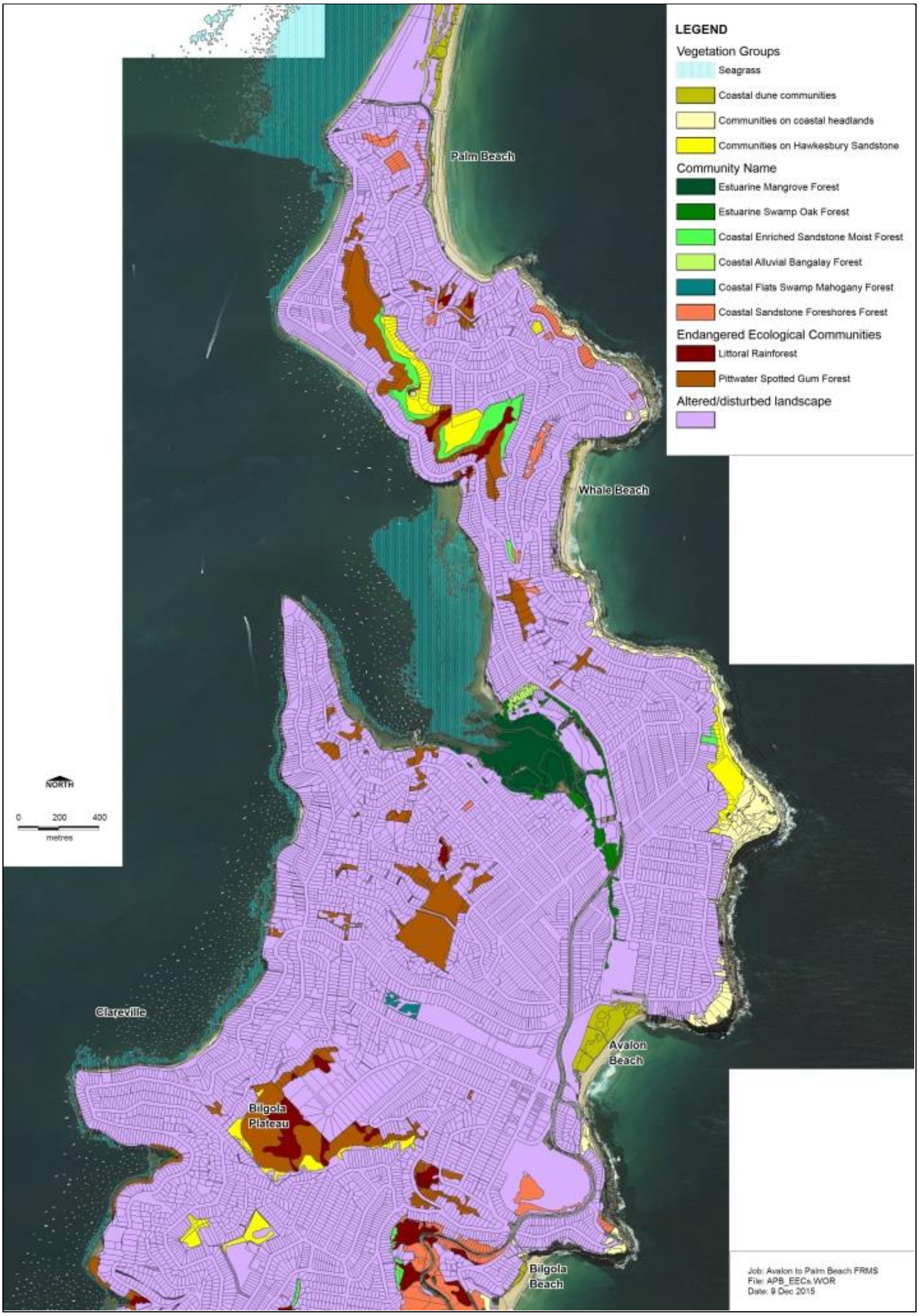


Figure 2.5 – Vegetation communities including EECs
Data source: Council

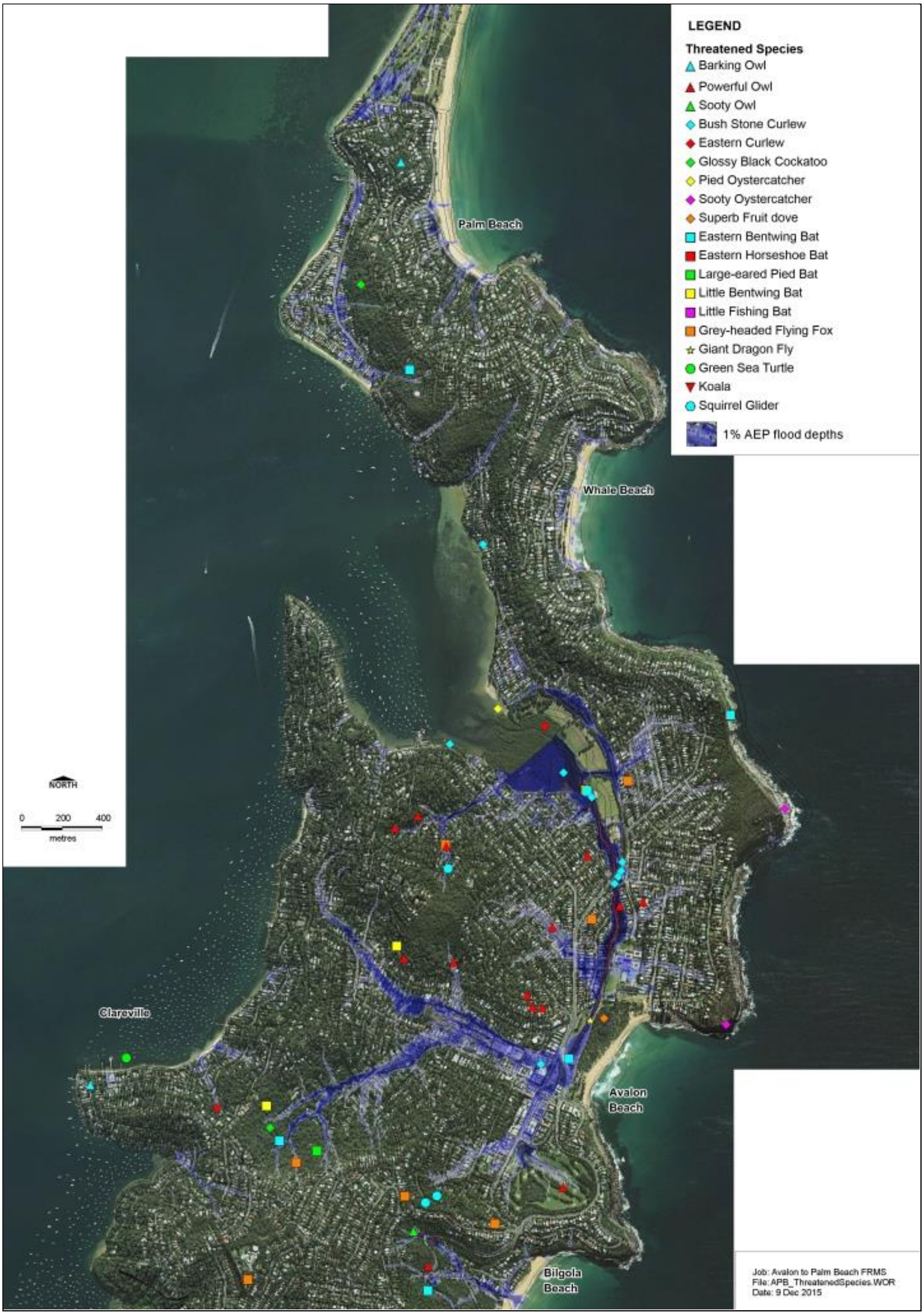


Figure 2.6 – Threatened species
Data source: Council

2.5 Heritage Issues

A number of items of heritage significance are located in the study area. Table 2.3 lists designated heritage items from the Pittwater LEP 2014 that are located within the 1% AEP floodplain, including a few shops and houses and large natural reserves in Avalon and Bilgola. Flooding can also impinge upon three Heritage Conservation Areas (HCAs) within the study area: the Florida Road (Palm Beach), Ocean Road (Palm Beach) and Ruskin Rowe (Avalon) HCAs. Parts of the study area have a very high potential for Aboriginal heritage (Figure 2.7) including Catalpa Reserve, Toongarri Reserve and the Careel Creek corridor below Barrenjoey High School.

Any proposed floodplain risk management measures need to be sympathetic to heritage values. Pittwater LEP 2014 Clause 5.10 stipulates that development consent is required for a range of proposed activities including demolishing, moving or altering the exterior of a heritage item, Aboriginal object or item within a heritage conservation area.

Table 2.3 – Heritage items within the 1% AEP floodplain
Source: Pittwater LEP 2014 Schedule 5 Part 1

Suburb	Item Name	Address	SHI No
Avalon Beach	Corner shop (excluding interior and rear additions)	25, 29 and 33 Avalon Parade	2270078
Avalon Beach	Cafe and exterior of corner shops	47 Old Barrenjoey Road	2270084
Avalon Beach	Angophora Reserve	93 Palmgrove Road	2270107
Bilgola	Drainage and bridge structures	15–21 Bilgola Avenue	2270009
Bilgola	Street trees—Norfolk Island Pines (*Araucaria heterophylla*) and Canary Island Date Palms (*Phoenix canariensis*)	Bilgola Avenue and Allen Avenue	2270030
Bilgola	Grove of Cabbage Tree Palms (*Livistona australis*)	The Serpentine and Barrenjoey Road (Bilgola Valley)	2270031
Palm Beach	Barrenjoey House (restaurant and accommodation)	1106 Barrenjoey Road	2270076
Palm Beach	Norfolk Island Pines (*Araucaria heterophylla*)	Barrenjoey Road, Pittwater Park (opposite Barrenjoey House)	2270037
Palm Beach	“Kookaburra” (house)	79 Florida Road	2270066
Palm Beach	“Florida House”	81 Florida Road	2270089
Palm Beach	Spotted Gums and Cabbage Tree Palms (*Corymbia maculata* and *Livistona australis*)	33–34 and 38 Ocean Road, Hordern Park and Wiltshire Park	2270452
Palm Beach	Norfolk Island Pines (*Araucaria heterophylla*)	Ocean Road, within road reserve	2270038
Whale Beach	Norfolk Island Pines (*Araucaria heterophylla*)	Whale Beach Ocean Reserve (adjoining The Strand)	2270035

Figure 2.7 – Aboriginal heritage
Data source: Council

2.6 Social Profile

A general understanding of the makeup of the community potentially affected by flooding is an essential factor in the development of floodplain management measures. For example, a relatively affluent community might be more willing to fund flood mitigation measures. An area with a high proportion of senior citizens might need to give special attention to evacuation constraints. The cultural diversity, internet usage and population turnover in an area will inform the design of flood education programs and resources.

Accordingly, a basic social profile of the community in the Avalon to Palm Beach statistical area shown in Figure 2.8 was developed from the 2011 Census data and is detailed in Table 2.4.

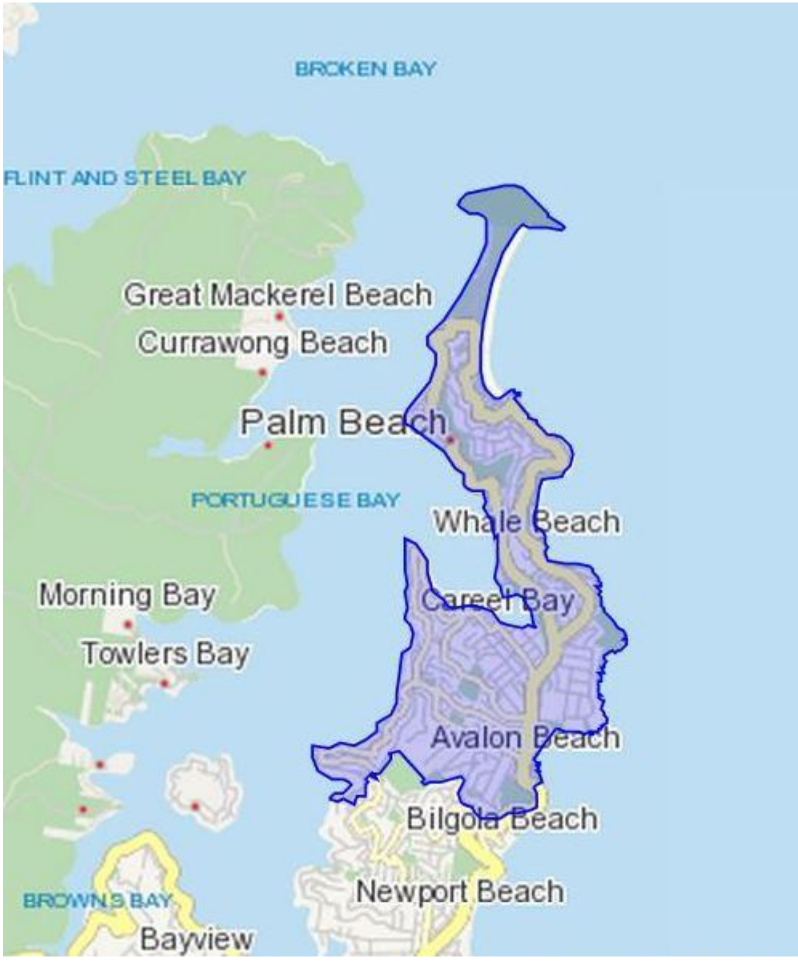


Figure 2.8 – Avalon to Palm Beach Statistical Area
Source: Australian Bureau of Statistics, 2011 Census

Table 2.4 – Census data for study area compared to NSW
Source: 2011 Census Basic Community Profiles, www.censusdata.abs.gov.au/

Topic	Avalon to Palm Beach Statistical Area Level 2	NSW
SELECTED PERSON CHARACTERISTICS [B01]: % of persons		
Total persons	12,197	6,917,658
Aged 14 years and under	20%	19%
Aged 15-24 years	11%	13%
Aged 65 years and over	18%	15%
Aboriginal/Torres Strait Islander	0.3%	2%
Australian born	77%	69%
Born overseas	23%	26%
Speaks English only at home	94%	72%
Speaks other language at home	6%	22%
Completed year 12	66%	41%
Completed year 10	21%	21%
Did not attend school	0.1%	1%
SELECTED MEDIANS AND AVERAGES [B02]		
Median age	45	38
Median total household income ($/week)	$1,798	$1,237
Median mortgage repayment ($/month)	$3,000	$1,993
Median rent ($/week)	$530	$300
Average household size	2.7	2.6
LANGUAGE SPOKEN AT HOME [B13a,b]		
Other language speakers as % of all persons (results shown >2.0%)	None >2% (German 1%)	Chinese 4% Arabic 3% Indo-Aryan 2%
NUMBER OF MOTOR VEHICLES BY DWELLINGS [B29]: % of occupied private dwellings		
Dwellings with 0 motor vehicles	3%	10%
Dwellings with 1 motor vehicle	31%	38%
Dwellings with 2 motor vehicles	47%	34%
Dwellings with 3+ motor vehicles	17%	15%
HOUSEHOLD COMPOSITION BY NUMBER OF PERSONS USUALLY PRESENT [B30]: % of occupied private dwellings		
One person usually resident	20%	24%
DWELLING STRUCTURE [B31]: % of total private dwellings		
Separate house	64%	63%
Semi-detached, row or terrace house, townhouse etc	7%	10%
Flat, unit or apartment	9%	17%
Unoccupied private dwellings	21%	10%

Topic	Avalon to Palm Beach Statistical Area Level 2	NSW
TENURE TYPE BY DWELLING STRUCTURE [B32]: % of occupied private dwellings		
Fully owned	42%	33%
Being purchased	36%	33%
Rented	20%	30%
TYPE OF INTERNET CONNECTION [B35]: % of occupied private dwellings		
No internet connection	10%	20%
SELECTED LABOUR FORCE AND EDUCATION [B37]: % of total labour force or % of persons aged 15 years and over		
Unemployment	4%	6%
Labour force participation	63%	60%
POPULATION CONTINUITY [B38,B39]: % of persons aged 1 and over or % of persons aged 5 years and over		
Same usual address 1 year ago	83%	81%
Same usual address 5 years ago	60%	57%
OCCUPATION [B44]: % of employed persons aged 15 years and over		
Managers	19%	13%
Professionals	29%	23%
Technicians and trades workers	13%	13%
Community and personal service workers	9%	9%
Clerical and administrative workers	13%	15%
Sales workers	9%	9%
Machinery operators and drivers	2%	6%
Labourers	5%	9%

The following is a brief discussion of a selection of statistics which may have relevance to:

- Vulnerability to flood impacts;
- Ability to receive information before, during or after a flood;
- Ability to comprehend communications in relation to flooding;
- Ability to recover from flooding.

Age and Household Structure

Compared to the NSW average, the Avalon to Palm Beach area has a similar proportion of children aged less than 14 and youth aged 15 to 24 and a higher proportion of senior citizens aged 65 or over. Children may require assistance during a flood. Youth may need to be targeted with education messages to discourage unsafe behaviours during flooding, such as 'surfing' in stormwater channels. The 18% of the population that is 65 or over may be particularly vulnerable to the impacts of flooding with communication and mobility challenges and find it difficult to recover after a flood. This will be particularly the case if they live alone as 20% of households do.

Cultural and Linguistic Diversity

Compared to the NSW average, the Avalon to Palm Beach area has low levels of cultural and linguistic diversity, with 94% of persons speaking only English at home. This suggests that any communications or education messages could be confined to English.

Education

Compared to the NSW average, very few persons did not attend school, and a high proportion completed Year 12. This indicates relatively high education levels and a capacity to absorb technical information (if well written).

Employment and Income

Compared to the NSW average, a slightly higher proportion of the Avalon to Palm Beach population participates in the labour force and a lower proportion is unemployed. Median household incomes are $1,798 per week which puts them about $29,000 per annum above the NSW State median. Factoring in either monthly mortgage repayments or weekly rental, people within the area tend to have more disposable income (compared to the NSW average) to meet other routine expenditure, and potentially to invest in measures to reduce their flood risk exposure through property modification or preparedness actions, or to recover following a flood.

Motor Vehicle Ownership

Compared to the NSW average, a relatively low proportion of dwellings in the Avalon to Palm Beach statistical area lack a motor vehicle, and a high proportion have multiple vehicles. Nevertheless, people in dwellings without a vehicle might struggle to evacuate, should it be required.

Home Ownership

Compared to the NSW average, a relatively high proportion of dwellings are owner occupied, and low proportion is rented. Home ownership could be relevant to willingness to participate in property modification options.

Internet Access

Compared to the NSW average, a low proportion of dwellings in the Avalon to Palm Beach statistical area do not have an internet connection. This suggests that the movement to provide flood education and warning messages by internet (perhaps to mobile devices) could have a broad reach in this area. But more conventional methods of engagement may continue to be required for about 10% of the community, probably especially for older residents.

Population Continuity

The proportion of people who lived at the same address both 1 year prior to the Census and 5 years prior to the Census is similar to the NSW average. The relative infrequency of serious flood hazards, combined with a turnover of population, means that a majority would not have experienced significant floods, and that flood awareness and readiness would – in the absence of measures to counter this trend – be expected to be low.

3. Urban Planning Context

Appropriate land use planning is one of the most effective measures available to floodplain managers, both to reduce existing flood risks as redevelopment occurs, and to control future risk. The management and development of flood prone land must be undertaken within the current NSW legislative, policy and planning framework. This chapter summarises relevant legislation and policy. This provides a basis for the review of land use planning in the study area in Section 12.4.

3.1 Environmental Planning and Assessment Act 1979

3.1.1 General

The NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) creates the mechanism for development assessment and determination by providing a legislative framework for development and protection of the environment from adverse impacts arising from development. The EP&A Act outlines the level of assessment required under State, regional and local planning legislation and identifies the responsible assessing authority.

Prior to development taking place in NSW a formal assessment and determination must be made of the proposed activity to ensure it complies with relevant planning controls and, according to its nature and scale, conforms with the principles of environmentally sustainable development.

3.1.2 Section 94 Development Contributions

Section 94 of the EP&A Act enables councils to collect contributions from developers for the provision of infrastructure that is necessary as a consequence of development. This can include roads, drainage, open space and community facilities. Each council must develop a Section 94 Contributions Plan which demonstrates a quantifiable link between the development intensification and the need for the additional infrastructure as well as a detailed costing of such infrastructure and formulae to be used to determine contributions from each type of development.

Pittwater Section 94 Contributions Plan for Residential Development was adopted on 2 November 2015. This caps monetary contributions for new residential development at $20,000 per dwelling/lot. Most of this contribution is directed to open space, bushland and recreation facilities.

3.1.3 Section 117 Directions – Direction No. 4.3 (Flood Prone Land)

Pursuant to the EP&A Act, Section 117 Direction No. 4.3 (Flood Prone Land) was reissued on 31 July 2007 by the Minister for Planning replacing all existing directions previously in operation. This applies to councils that contain flood prone land within their Local Government Area and any draft LEP that creates, removes or alters a zone or provision that affects flood prone land.

Key objectives of Direction No. 4.3 are:

- To ensure that development of flood prone land is consistent with the NSW Government's Flood Prone Land Policy and the principles of the *Floodplain Development Manual* 2005 (including the *Guidelines for Development Controls on Low Flood Risk Areas*); and
- To ensure that the provisions of an LEP on flood prone land are consistent with flood hazard and includes consideration of the potential flood impacts both on and off the subject land.

Under Direction 4.3, when preparing draft LEPs, Councils must not include provisions that apply to the flood planning areas which:

- permit development in floodway areas;
- permit development that will result in significant flood impacts to other properties;
- permit a significant increase in the development of that land;
- are likely to result in a substantially increased requirement for government spending on flood mitigation measures, infrastructure or services; or
- permit development to be carried out without development consent except for the purposes of agriculture, roads or exempt development.

The Direction also requires that Councils must not impose flood related development controls above the residential flood planning level for residential development on land, unless a relevant planning authority provides adequate justification for those controls to the satisfaction of the Director-General.

3.1.4 Section 149 Planning Certificates

Council issues Section 149 certificates under the *Environmental Planning and Assessment Regulations 2000* (Clause 279 and Schedule 4(7A)). The primary function of the Section 149 certificate notation is as a planning tool for notification that the land is affected by a policy that restricts development due to the likelihood of a risk, in this instance, flood hazard.

3.2 State Environmental Planning Policies (SEPPs)

SEPPs are the highest level of planning instrument and generally prevail over Local Environmental Plans.

3.2.1 SEPP (Housing for Seniors or People with a Disability) 2004

State Environmental Planning Policy (Housing for Seniors or People with a Disability) 2004 aims to encourage the provision of housing (including residential care facilities) that will increase the supply of residences that meet the needs of seniors or people with a disability. This is achieved by setting aside local planning controls that would prevent such development.

Clause 4(6) and Schedule 1 indicate that the policy does not apply to land identified in another environmental planning instrument (such as Pittwater LEP 2014) as being, amongst other descriptors, a floodway or high flooding hazard.

3.2.2 SEPP (Infrastructure) 2007

State Environmental Planning Policy (Infrastructure) 2007 aims to facilitate the effective delivery of infrastructure across the State by identifying development permissible without consent. *SEPP (Infrastructure) 2007* allows Council to undertake stormwater and flood mitigation work without development consent.

3.2.3 SEPP (Exempt and Complying Development Codes) 2008

A very important SEPP is *State Environmental Planning Policy (Exempt and Complying Development Codes) 2008*, which defines development which is exempt from obtaining development consent and other development which does not require development consent if it complies with certain criteria.

Clause 1.5 of the SEPP defines a 'flood control lot' as 'a lot to which flood related development controls apply in respect of development for the purposes of dwelling houses, dual occupancies, multi dwelling housing or residential flat buildings (other than development for the purposes of group homes or seniors housing)'. These development controls may apply through a LEP or DCP. Exempt development is not permitted on flood control lots but some complying development is permitted.

Clause 3.36C states that complying development is permitted on flood control lots where a Council or professional engineer can certify that the part of the lot proposed for development is not a flood storage area, floodway area, flow path, high hazard area or high risk area. The SEPP specifies various controls in relation to floor levels, flood compatible materials, structural stability (up to the PMF if on-site refuge is proposed), flood affectation, safe evacuation, car parking and driveways.

3.3 NSW Flood Related Manuals

3.3.1 Floodplain Development Manual, 2005

The *Floodplain Development Manual* 2005 (the Manual) was gazetted on 6 May 2005 and relates to the development of flood liable land. It incorporates the NSW Flood Prone Land Policy, which aims to reduce the impacts of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods. To implement this policy and achieve these objectives, the Manual develops a merit based framework to assist with floodplain risk management. The Manual confirms that responsibility for management of flood risk remains with local government. It assists councils in their management of the use and development of flood prone land by providing guidance in the development and implementation of local floodplain risk management plans.

3.3.2 Guideline on Development Controls on Low Flood Risk Areas, 2007

The *Guideline on Development Controls on Low Flood Risk Areas – Floodplain Development Manual* (the Guideline) was issued on 31 January 2007 as part of Planning Circular PS 07-003 at the same time as the Section 117 Directive described in Section 3.1.3. The Guideline is intended to be read as part of the *Floodplain Development Manual*.

It stipulates that '*unless there are exceptional circumstances, councils should adopt the 100 year flood as the FPL for residential development*' and that '*unless there are exceptional circumstances, councils should not impose flood related development controls on residential development on land … that is above the residential FPL*'.

Flood related development controls are not defined but would include any development standards relating to flooding applying to land, that are a matter for consideration under Section 79C of the EP&A Act.

The Guideline states that councils should not include a notation for residential development on Section 149 certificates for land above the residential FPL if no flood related development controls apply to the land. However, the Guideline does include the reminder that councils can include 'such other relevant factors affecting the land that the council may be aware [of]' under Section 149(5) of the EP&A Act.

In proposing a case for exceptional circumstances, a council would need to demonstrate that a different FPL was required for the management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood. Justification for exceptional circumstances would need to be agreed by relevant State Government departments prior to exhibition of a draft local environmental plan or a draft development control plan that proposes to introduce flood related development controls on residential development.

Grounds for applying flood related development controls on residential development to land above the flood planning area in the Avalon to Palm Beach study area are considered in Section 12.4.1.

3.4 Pittwater Local Environmental Plan 2014

Pittwater Local Environmental Plan 2014 (also referred to as Pittwater LEP 2014) is the statutory planning instrument that establishes what forms of development and land use are permissible and/or prohibited on all land within the Pittwater Local Government Area. Pittwater LEP 2014 is made up of the written instrument and a series of maps. It was gazetted on 30 May 2014, and came into effect on 27 June 2014.

Flood planning and floodplain risk management are addressed in Clauses 7.3 and 7.4. These are reproduced below. Clause 7.3 relates to land at or below the flood planning level. Clause 7.4 relates to land between the flood planning level and the PMF. The flood planning level has been carefully defined to allow divergence from the standard 1% AEP plus 0.5m freeboard level. Flood planning levels for the Avalon to Palm Beach FRMS&P are proposed in Section 12.4.2. The land uses to which Clause 7.4 applies are noted, including the exclusion of standard residential accommodation.

7.3 Flood planning

(1) The objectives of this clause are as follows:

(a) to minimise the flood risk to life and property associated with the use of land,

(b) to allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change,

(c) to avoid significant adverse impacts on flood behaviour and the environment.

(2) This clause applies to land at or below the flood planning level.

(3) Development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development:

(a) is compatible with the flood hazard of the land, and

(b) will not significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and

(c) incorporates appropriate measures to manage risk to life from flood, and

(d) will not significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and

(e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

(4) A word or expression used in this clause has the same meaning as it has in the Floodplain Development Manual (ISBN 0 7347 5476 0) published by the NSW Government in April 2005, unless it is otherwise defined in this clause.

(5) In this clause:

flood planning level means the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metres freeboard, or other freeboard determined by an adopted floodplain risk management plan.

floodplain risk management plan has the same meaning as it has in the Floodplain Development Manual (ISBN 0 7347 5476 0), published in April 2005 by the NSW Government.

7.4 Floodplain risk management

(1) The objectives of this clause are as follows:

(a) in relation to development with particular evacuation or emergency response issues—to enable evacuation of land subject to flooding in events exceeding the flood planning level,

(b) to protect the operational capacity of emergency response facilities and critical infrastructure during extreme flood events.

(2) This clause applies to land between the flood planning level and the level of the probable maximum flood, but does not apply to land subject to the discharge of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard, or other freeboard determined by an adopted floodplain risk management plan.

(3) Development consent must not be granted to development for the following purposes on land to which this clause applies unless the consent authority is satisfied that the development will not, in flood events exceeding the flood planning level, affect the safe occupation of, and evacuation from, the land:

(a) caravan parks,

(b) child care centres,

(c) correctional centres,

(d) educational establishments,

(e) emergency services facilities,

(f) group homes,

(g) hospitals,

(h) residential care facilities,

(i) respite day care centres,

(j) seniors housing,

(k) tourist and visitor accommodation.

(4) In this clause:

flood planning level means the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metres freeboard, or other freeboard determined by an adopted floodplain risk management plan.

probable maximum flood has the same meaning as it has in the Floodplain Development Manual (ISBN 0 7347 5476 0), published in 2005 by the NSW Government.

Note. The probable maximum flood is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation.

3.5 Pittwater 21 Development Control Plan

Development Control Plans (DCPs) set the standards, controls and regulations that apply when carrying out development or building work within Pittwater. They support *Pittwater LEP 2014*, which regulates the uses that are permissible on the land.

Pittwater 21 DCP was first adopted by Council on 8 December 2003 and came into force on 1 February 2004. The DCP has since been amended 19 times (to 14 November 2015).

Sections of *Pittwater 21 DCP* related to flooding are listed in Table 3.1. Sections B3.11 to B3.24 (excluding B3.23) set out the flood-related development controls according to various combinations of flood category (1, 2 or 3), hazard (low, high, minor overland flow, major overland flow) and land use (low density residential, etc.).

Section B3.23 sets out controls to manage the effects of climate change where intensification of development is proposed. The proponent is to prepare a Flood Risk Management Report that includes an assessment of climate change, both for sea level rise and sea level rise combined with increased rainfall.

Section B3.25 sets out controls to manage risk to life based on the mapped Flood Life Hazard category and land use. This has the effect of ensuring that where the Flood Life Hazard category is significant (H3-H4 or greater), new developments shall design for shelter-in-place where safe evacuation cannot be provided.

Appendix 8 sets out the Flood Risk Management Policy for development in Pittwater, including objectives, application, definitions, sources of flood information and flood risk management measures. The definitions include those for flood categories and hazard and overland flow.

Appendix 15 provides further information to Section B3.25, related to Flood Emergency Response planning, that is, to either evacuation or shelter-in-place. Importantly, 'high risk areas' in the meaning of Clause 3.36C of the *Exempt and Complying Development Codes SEPP 2008* are defined as areas of Flood Life Hazard category of H3-H4 or greater.

Council commissioned PolisPlan to review and redraft the flood risk management provisions of Pittwater 21 DCP, parallel to the completion of this Avalon to Palm Beach FRMS&P. Key aspects of the proposed revision are described in Section 12.4.2.

Table 3.1 – Flood-related sections of Pittwater 21 DCP

Section	Heading
B3.11	Flood Hazard - Flood Category 1 - Low Hazard - Low Density Residential
B3.12	Flood Hazard - Flood Category 1 - Low Hazard - Medium Density Residential
B3.13	Flood Hazard - Flood Category 1 - Low Hazard - Shop Top Housing, Business and Industrial Development
B3.14	Flood Hazard - Flood Category 1 - Low Hazard - Other Development
B3.15	Flood Hazard - Flood Category 1 - Low Hazard - Subdivision
B3.16	Flood Hazard - Flood Category 1 - High Hazard - Low Density Residential
B3.17	Flood Hazard - Flood Category 1 - High Hazard - Medium Density Residential
B3.18	Flood Hazard - Flood Category 1 - High Hazard - Shop Top Housing, Business and Industrial Development
B3.19	Flood Hazard - Flood Category 1 - High Hazard - Other Development
B3.20	Flood Hazard - Flood Category 1 - High Hazard - Subdivision
B3.21	Flood Hazard - Flood Category 2 - All Development except residential accommodation (with the exception of shop top housing, seniors housing and group homes)
B3.22	Flood Hazard - Flood Category 3 - Overland Flow Path - Major
B3.23	Climate Change (Sea Level Rise and Increased Rainfall Volume)
B3.24	Flood Hazard - Flood Category 3 - Overland Flow Path - Minor
B3.25	Flood Hazard - Flood Emergency Response planning
Appendix 8	Flood Risk Management Policy for Development in Pittwater
Appendix 15	Flood Emergency Response Planning for Development in Pittwater Policy

4. Impact of Flood Affectation on Property Values

A common complaint against the release of flood information is a presumed adverse effect on housing values. Council asked the NSW Public Works team to assess whether identifying a property as flood prone on their section 149(2) notification affects property value. In order to investigate this in greater depth than would have been possible under the auspices of this study alone, Risk Frontiers provided some financial support for a more extensive review of research that has sought to answer the question. This work was presented at the 2015 Floodplain Management Association National Conference (Yeo et al., 2015).

Governments around Australia recognise that in order to manage risks, people first need to be informed about risks that may affect their property. The *National Strategy for Disaster Resilience* (COAG, 2011, p.8) states that 'risks should be openly discussed in order to anticipate and manage them'. Accordingly, flood risk information is increasingly being made available, including on-line.

Insurers in Australia are also increasingly using elevation data, flood hazard data and building location and floor height data to offer risk-based premiums.

In theory, a rational consumer could use the flood risk information available from Government or incorporated into insurance premiums to shape their offer of purchase, potentially resulting in a discount for flood-prone properties and a premium for flood-free properties.

However, the review of international and local studies assessing the question of the effect of flood information on housing values found only limited evidence to support the theory. Some findings of this work are presented below:

- About 70% of studies (mostly from USA) show that houses located within the 1% AEP floodplain are discounted when compared to equivalent houses located outside that floodplain, often related to previous flooding. The other 30% of studies show the opposite: flood-prone houses enjoy a premium. Other factors such as aspect, views and direct water frontage are strong drivers of value and may outweigh flood risk.
- Actual flooding is a strong signal of flood risk, causing a short-lived fall in value of flooded properties of about 6% after the Brisbane flood in 2011.
- Disclosure of flood risk via maps or regulations does not necessarily cause an adverse effect on property values. The impact of flood risk designation on growth in residential property markets was found to be *non-existent* in the UK. A study from New Zealand found that the release of flood extent maps *reduced* the discounting effect of being in a floodplain from -6% to -2% because buyers could make more informed decisions. The various forms of flood risk disclosure partly explain the varied results – a discounting effect appears more likely when disclosure is *mandatory*, *transparent* and occurs *early* in the transaction process.

Based on the research context, it is possible to make some inferences about the effect of flood risk disclosure on housing markets in NSW.

First, the human attributes of amnesia and myopia are just as prevalent in Australia as elsewhere, with the result that housing values for flood-prone locations may typically ride well above their true risk-adjusted price.

Second, local supply and demand equations in Sydney are often so energetic that any flood risk effect will be suppressed. This is likely amplified with increasing proportions of auctions to total sales.

Third, for the most part disclosure regimes at work in Australia appear to be broadly similar to the ad-hoc discovery of flood risk described for the UK, where floodplain designation was found to have no impact. While an increasing amount of flood information is available, simply placing it in the public domain does not guarantee that the information will be noticed and used. Although it is mandatory to indicate on Section 149(2) certificates whether any flood-related development controls exist, it is doubtful that this information is *transparent* and questionable as to how *early* in the transaction process a purchaser might procure and interrogate it.[5]

Fourth, it is unclear whether the greater availability of flood insurance and the pricing of premiums based on risk are being reflected in property values. This may depend to what extent prospective buyers investigate the cost of flood insurance, and weigh its importance, prior to making an offer of purchase. Even if insurance is a factor, many insurers undertake independent assessments of flood risk. If and when councils provide their typically higher resolution data to insurers, it is said that premiums often *decrease* substantially.

In summary, while it is possible that Council's flood mapping could have an impact on property values, the above evidence indicates that this is by no means certain. What is known with some certainty is that actual flooding is much more likely to have a discounting effect, though this is typically short-lived. By providing mapping products now, Council is seeking to inform homeowners of the risk so that they can design flood compatible dwellings that will prove resilient to future flooding and thereby retain their value.

[5] Note also that insurers typically do not use information from Section 149 property certificates to calculate risk or set premiums.

5. Local Emergency Planning Context

5.1 Plans

The NSW State Flood Plan (NSW SES, 2015) is a sub-plan of the State Emergency Management Plan (EMPLAN). The Plan sets out State-wide responsibilities and arrangements for mitigating flooding, managing floodplains, preparing for floods, flood warning, response including evacuation, and recovery.

However, at the current time there is no Local Flood Sub-Plan for Pittwater LGA. Plans are underway to prepare a combined Flood Plan for Manly, Warringah and Pittwater, but this is still a few years away. Flood intelligence from the Avalon to Palm Beach FRMS will be a vital input to this process going forward (see Section 13.2.1).

The only specific flood plan for the Northern Beaches addresses flooding of Narrabeen Lagoon, which is not within the current study area. There is a Local Disaster Plan (DISPLAN) for Manly, Warringah and Pittwater dated August 2005, which covers multiple hazards including flooding. The DISPLAN is in the process of being updated to an Emergency Management Plan (EMPLAN). It is recommended that this update consider comments on the DISPLAN as provided in Section 13.2.1.

5.2 Capability

The NSW SES Warringah/Pittwater Unit is based at Terry Hills. Although at the time of writing there are almost 100 volunteer members, the SES recognises that the northern perimeter of the LGA is not well serviced. The current situation is that flooding in the study area is likely to occur prior to attendance by NSW SES members (unless the few members who live within the study area are present and able to assist).

Other emergency services may have more opportunity to assist the community during flooding. Fire and Rescue NSW has a fire station at 689 Barrenjoey Road (67 Old Barrenjoey Road), Avalon Beach. This site is located close to the major risk exposures in the study area including the Avalon commercial district and Elaine Avenue. It is understood that personnel are trained to a Level 1 'reach/throw' rescue capability, which may involve throwing a rope to people in need. Personnel would also be able to call in a helicopter (level 4 rescue), which is anticipated to arrive in six minutes. Nonetheless, in a flood emergency it is likely that people from many different quarters of the study area and beyond may require assistance (including for traffic accidents), and it may be physically impossible for the two available fire trucks to attend to every request for assistance in a timely manner.

The Ambulance Service of NSW also has a station in Avalon on the corner of Barrenjoey Road and Central Road. It is understood that the ambulance service is also accredited for rescue operations. But this ambulance station does not have 24/7 capability.

While there is some emergency service capacity at Avalon, these resources are finite. Also, the rate of rise in an extreme event may be very quick (even 15 minutes). For these reasons, it is likely that people in flood prone areas will need to take responsibility for their own safety and that of their neighbours.

5.3 Response Strategy

A major point of contention in contemporary emergency management policy and practice relates to the advantages and disadvantages of evacuation compared to sheltering-in-place, particularly for flash flood catchments such as those identified in the Avalon to Palm Beach study area.

AFAC's (2013) *Guideline on Emergency Planning and Response to Protect Life in Flash Flood Events* is considered to represent best practice on this issue. It recognises that the safest place to be in a flash flood is well away from the affected area. Evacuation is the most effective strategy, provided that evacuation can be safely implemented. Properly planned and executed evacuation is demonstrably the most effective strategy in terms of a reliable public safety outcome.

However, AFAC recognises that evacuating too late may be worse than not evacuating at all because of the dangers inherent in moving through floodwaters, particularly fast-moving flash flood waters. If evacuation has not occurred prior to the arrival of floodwater, taking refuge inside a building may generally be safer than trying to escape by entering the floodwater.

Nevertheless, AFAC argues that remaining in buildings likely to be affected by flash flooding is not low risk and should never be a default strategy for pre-incident planning: 'where the available warning time and resources permit, evacuation should be the primary response strategy' (p.4).

The risks of a 'shelter-in-place' strategy include:

- Floodwater reaching the place of shelter (unless the shelter is above the PMF level);
- Structural collapse of the building that is providing the place of shelter (unless the building is designed to withstand the forces of floodwater, buoyancy and debris in a PMF);
- Isolation, with no known basis for determining a tolerable duration of isolation;
- People's behaviour (drowning if they change their mind and attempt to leave after entrapment);
- People's mobility (not being able to reach the highest part of the building);
- People's personal safety (fire and accident); and
- People's health (pre-existing condition or sudden onset e.g. heart attack).

For evacuation to be a defensible strategy, the risk associated with the evacuation must be lower than the risk people may be exposed to if they were left to take refuge within a building which could either be directly exposed to or isolated by floodwater (Opper et al., 2011). Pre-incident planning therefore needs to include a realistic assessment of evacuation timelines (both time available and time required for evacuation), including assessment of resources available. Successful evacuation strategies require a warning system that delivers enough lead time to accommodate the operational decisions, the mobilisation of the necessary resources, the warning and the movement of people at risk.

Effective evacuation typically requires lead times of longer than just a couple of hours and this creates a dilemma for flash flood emergency managers. Due to the nature of flash flood catchments, flash flood warning systems based on detection of rainfall or water level generally yield short lead times (often as short as 30 minutes) and as a result provide limited prospects for using such systems to trigger planned and effective evacuation.

Initiating evacuation of large numbers of people from areas prone to flash flooding based only on forecasts may be theoretically defensible in a purely risk-avoidance context but it is likely to be viewed as socially and economically unsustainable. Frequent evacuations in which no flooding occurs, which statistically will be the outcome of forecast-based warning and evacuation, could also lead to a situation where warnings are ignored by the community.

Flood behaviour, impacts and risks in the Avalon to Palm Beach study area are described in Part B of this report. The following salient features are noted:

- Relatively shallow depths of flooding in the 1% AEP event;
- Rapid rates of rise (e.g. peaking in Avalon CBD 0.5–1.0 hour after the storm commences);
- Short duration;
- Flooding of many roads;
- Limited emergency services capacity (Section 5.2).

Although there is scope for marginal improvements to flood warning systems (see Section 13.1), the inescapably 'flashy' nature of flooding in the study area suggests that it will always be difficult to ensure people in the floodplain evacuate prior to flooding of roads. In many cases, it may be safer to shelter-in-place above the reach of floodwater. Council's ongoing application of its *Flood Emergency Response Planning for Development in Pittwater Policy* (Appendix 15 of Pittwater 21 DCP) should ensure that where safe evacuation cannot be guaranteed, new housing in areas where the PMF is expected to reach hazardous depths and velocities will be required to design for shelter-in-place through elevated PMF refuges and resilient building structures.

It is noted however, that the depths and velocities in a PMF would pose a threat to some existing houses and people sheltering in those houses. These areas are identified in Section 7.6, and will require early evacuation until the houses are redeveloped to lessen the risk.

6. Community Consultation

6.1 Consultation Process

Consultation provides an opportunity for various stakeholders, including the community, to collaborate together in developing the Avalon to Palm Beach FRMS&P. Engaging the community throughout the process provides both an opportunity to garner useful feedback and ideas regarding potential floodplain management measures, and to increase community acceptance of the floodplain risk management plan.

The consultation program for the FRMS&P has included the following activities:

- Inception and progress meetings between the consultant and Council
- Meetings of the Avalon to Palm Beach Floodplain Risk Management Working Group
- Consultation with agencies and stakeholders
- Website
- Letter and questionnaire for property owners
- Letter and questionnaire for business proprietors
- Public Exhibition of the Draft Avalon to Palm Beach FRMS&P Report including:
  - Community information sessions
  - Collation and review of community submissions.

These activities are described at greater length below.

6.2 Working Group

The Avalon to Palm Beach Floodplain Risk Management Study & Plan Working Group (the Working Group) was formed by Council in order to provide a forum that brings together the diverse expertise and community knowledge that is needed to address technical, social, economic and ecological issues concerning floodplain risk management in the study area. The Working Group fulfils the functions of a Floodplain Risk Management Committee as described in the *Floodplain Development Manual* (NSW Government, 2005).

The Working Group comprises of representatives from:

- Pittwater Council
- NSW Office of Environment and Heritage (OEH)
- NSW State Emergency Services (SES)
- Roads and Maritime Services (RMS)
- Sydney Water
- Local stakeholder groups
- The local community.

The initial letter about the study invited residents to nominate themselves as community representatives in the Working Group.

The Working Group has met regularly to hear progress reports by the consultant, and to provide direction as the study progressed. The Working Group has provided a valuable mechanism for the views of many interested parties to be represented. The main agenda items at each meeting are summarised in Table 6.1.

6.3 Agency/Stakeholder Consultation

The consultant has engaged with a number of relevant agencies and stakeholders with an interest in the study, as listed in Table 6.2.

6.4 Website

A website was developed to provide information about the study including a link to the online survey (Figure 6.1).

6.5 Letter and Questionnaires

6.5.1 Community Letter and Questionnaire

On 30 June 2014, Council distributed 1978 letters to all property owners (excluding Council or Government) identified as being flood affected (i.e. within the PMF extent). The letter alerted residents and businesses to the on-line survey that was then available to complete. A copy of the letter is included in Appendix A of this report.

The survey was also advertised through social media and through the Pittwater community noticeboard in the Manly Daily.

From 1 July 2014 to 31 September 2014 an online survey was made available seeking community input about historic flood flooding and ideas about floodplain management options in the study area. The survey is included in Appendix A. A hardcopy of the survey was mailed to a number of residents on request.

A total of 22 responses were received (20 residential, 2 commercial). This low response rate (1.1%) could reflect a relatively recent survey for the Careel Creek Catchment Flood Study (2012) and significant community engagement during public exhibition of the Pittwater Overland Flow Mapping and Flood Study (2012–13), as well as low interest in flooding.

Table 6.1 – Meetings of the Working Group

Date	Main agenda items
30 Oct 2014	Induction; reasons for the study; initial community consultation results
5 Mar 2015	Flood model update; updated community consultation results; damages assessment preliminary results
4 Jun 2015	Defining the flood problem: building inundation, damages estimation, sensitive uses; effect of notations on property values
3 Sep 2015	Defining the flood problem: flood hazard, road inundation, evacuation constraints, risk assessments; option identification
12 Nov 2015	Detailed option evaluation
18 Feb 2016	Review of draft FRMS&P

Table 6.2 – Agency/stakeholder consultation summary

Agency/stakeholder	Mode of contact	Issues
Pittwater Council	Committee meetings, telephone, email	Multiple
NSW OEH	Committee meetings	General
NSW SES Warringah-Pittwater Unit	Committee meetings	Flood response planning
NSW SES Sydney Northern Region	Telephone	Flood response planning
NSW SES State Headquarters	Email	Flood response planning, historic requests for assistance
Sydney Water	Telephone, email	Flood risk to sewage pump stations
Bureau of Meteorology	Email	Flood warning system
Avalon Beach Chamber of Commerce	Committee meetings, telephone, email	Engaging business community in study
Avalon Beach Historical Society	Telephone, email	Information about historical floods
Barrenjoey High School	Email	Local flood risk
Palm Beach – Whale Beach Residents Association	Committee meetings	Local flood risk
Pittwater Palms retirement village	Site meeting	Local flood risk

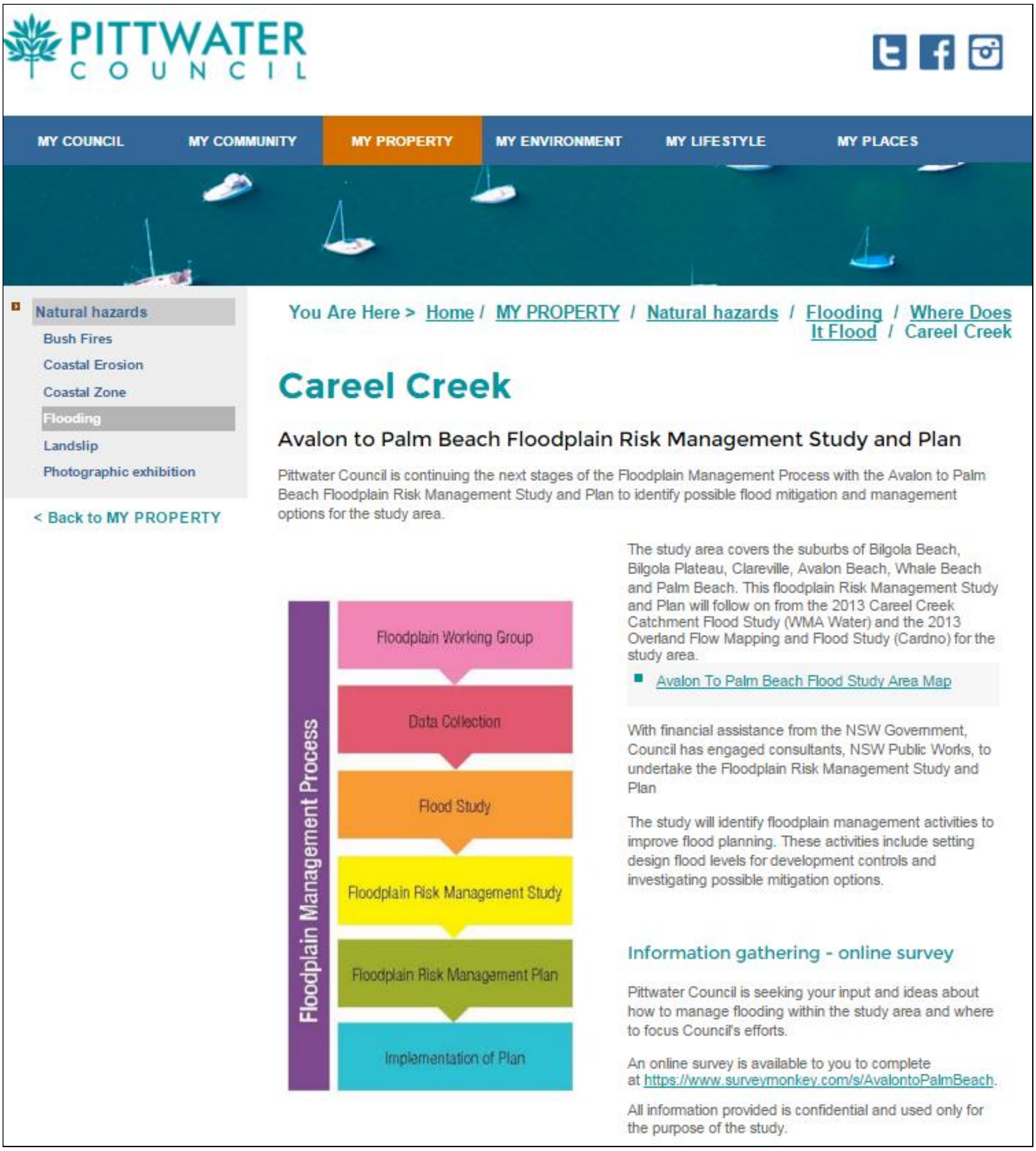


Figure 6.1 – Study website

Five respondents described previous flooding of their property including flooding of a house in Elaine Avenue, Avalon, in the 1970s (consistent with Table 2.2) and flooding of basement garages to a modern unit complex in Barrenjoey Road, Palm Beach, in 2012 and 2013, which damaged goods and lifts. Overland flows were observed down the side of a house in Lower Plateau Road, Bilgola Plateau, in February 2008. Those who indicated that their property had not previously flooded are for the most part located on land with a low or no flood risk, and so would not be expected to have observed flooding over the duration of their residence. However, there were a few a long-term residents, such as one who had lived at a Burrawong Road Avalon address since 1966, who might have been expected to have observed inundation over that time. Likely, residents of properties affected by shallow overland flow that caused no damage did not commit that event to memory or do not consider the event to represent 'flooding'.[6]

Apart from what is described above, no one identified any adverse effects of flooding on houses, businesses, personal health or the environment.

Respondents suggested that the following options be considered:

- Apply WSUD or other means to limit impervious cover in the catchment
- Detention basins
- Clear stormwater drains
- Increase pipe size
- Alter/manage Careel Creek including:
  - Widen bottlenecks
  - Pipe creek flows to the ocean or underground storage
  - Reconsider revegetating creek banks with species that provide resistance to flow
  - Check and clear obstructions in creek channel to prevent blockage at bridge
- Appropriate application of flood zonings.

A number of questions sought to gauge respondents' use and understanding of Council's DCP. Eight respondents (36%) had previously referred to the flood or estuarine controls. Six of these (75%) found these controls easy to read and understand. The other two found it difficult. Most respondents did not know the meaning of Flood Category 1, 2 and 3 areas, as featured in the current DCP. Most respondents supported somewhat lower minimum floor level controls for new commercial developments and redevelopments.

About half the respondents had used Council's online property information page to look up flood hazard mapping for their property. Most of these found this an easy process.

Fewer than half the respondents had used Council's online property enquiry page to look up the flood hazard for their property. Most of these found this a difficult process.

Fewer than half the respondents were aware that Council offered a Flood Information Request service.

Several respondents used the 'other comments' section to emphasise that they believed their property had no flood risk.

6.5.2 Business Letter and Questionnaire

In attempt to increase interest in the study from the Avalon business community, a separate letter was prepared and issued via the Avalon Beach Chamber of Commerce. The letter directed business proprietors to a unique business survey that could be completed online or as a hardcopy. The letter and questionnaire are included in Appendix A.

[6] A technical fault meant that no answers to question 5 were saved via the on-line survey.

A total of 13 complete or partial responses were received. Most respondents (62%) did not know the mapped flood hazard at their business premises. Most respondents (54%) considered that flooding could cause moderate or major damage and disruption. Only three respondents indicated that they had taken some measures to prepare their business for flooding, including written a flood emergency plan (1), raised the floor level (1), installed flood-compatible floor coverings and/or furnishings (1) and purchased insurance to cover the risk of inundation (1). Eight respondents expressed some interest or strong interest in Council developing a template flood emergency plan to help them assess and prepare for flooding. Seven respondents expressed some interest or strong interest in attending a Business FloodSafe breakfast (with SES input) to help them be ready for flooding.

Few ideas about how to manage the flood/overland flow risk were received. One respondent argued that the threat was not strong enough to warrant a major plan. Another suggested that changes to Avalon Golf Course had helped. Two respondents suggested that better drainage would assist.

Only one respondent had previously referred to the estuarine or flood hazard controls for businesses in Council's 21 DCP. There was equal support for and against changing the controls relating to floor levels required for changes of use to existing businesses or for new development in Avalon.

6.6 Public Exhibition

The final stage of the community consultation for this study is the public exhibition of the draft Avalon to Palm Beach FRMS&P report. This document will be exhibited for a period of four weeks, so that the community has a further opportunity to comment on the recommended floodplain management measures.

7. Flood Behaviour

7.1 Previous Flood Studies

7.1.1 Careel Creek Catchment Flood Study

The *Careel Creek Catchment Flood Study* (WMA Water 2013) encompasses the 4.3 square kilometre Careel Creek catchment in the south-central portion of the Avalon to Palm Beach study area. The study provides an assessment of flood behaviour under existing conditions at the time of the study.

7.1.2 Pittwater Overland Flow Mapping and Flood Study

The *Pittwater Overland Flow Mapping and Flood Study* (Cardno 2013) aimed to identify properties and areas potentially affected by overland flow rather than 'mainstream' flooding. The study encompasses the entire Pittwater LGA excluding undeveloped areas of the Ku-Ring-Gai Chase National Park. The study provided a prioritisation of catchments for future detailed flood studies.

7.2 Flood Model Extension

Numerical computer models have been adopted as the primary means of investigating flood behaviour throughout the Avalon to Palm Beach study area. When used carefully, modern computer models allow simulation of flood behaviour over large areas in a cost efficient and reliable manner.

As part of the current Floodplain Risk Management Study it was determined that it would be advantageous to update previous modelling, essentially through extension of the existing Careel Creek TUFLOW model to include those parts of the Avalon to Palm Beach study area previously modelled using SOBEK. Benefits of the model update include:

- Apparent model boundary effects evident in previous flood mapping have been addressed.
- Impacts of the pit and pipe drainage network of flood behaviour have been specifically modelled throughout the entire study area. This improves confidence in overland flow model results and negates possible inaccuracies and confusion over the approach adopted in the *Pittwater Overland Flow and Mapping Study* to approximate the impact of pits and pipes on flood levels for the 100 year ARI design event.
- The entire study area has been modelled using a single model platform. Model results are therefore directly comparable throughout the study area and assessment of the impact of any proposed mitigation works can be undertaken in a consistent manner.

The model development, calibration and validation, and result processing are described in detail in Appendix B, with floodplain mapping presented in Appendix C. In summary:

- The extended TUFLOW model was adequately calibrated against surveyed flood levels for the February 2008 flood event, and verified against simulated flood levels and flows from the 2013 Careel Creek TUFLOW model.
- Flood conditions for the PMF, 0.2%, 0.5%, 1%, 5% and 20% AEP design events have been investigated in this study. Critical design storm durations were adopted as per the *Careel Creek Catchment Flood Study* (WMA Water 2013) and comprise a 120 minute duration for the 0.2%, 0.5%, 1%, 5% and 20% AEP events, and a 60 minute duration for the PMF.
- Flood levels in low lying foreshore areas of the study area as well as discharge from Careel Creek are influenced by the coinciding water level in Pittwater and the ocean. A 1% AEP ocean water level boundary (1.45 m AHD) was adopted for the PMF, 0.2%, 0.5% and 1% AEP events, while for the smaller AEP events a tailwater of 0.95 m was adopted (mean Highest High Water Solstice Springs for Sydney). These tailwater levels were determined with reference to *Development of Practical Guidance for Coincidence of Catchment Flooding and Oceanic Inundation* (Toniato et. al 2014).
- The use of the direct rainfall method in TUFLOW results in all active model cells being 'wet' or inundated. Filtering is therefore required to improve interpretation of flooding. A filtering methodology was developed and applied to all mapping consisting of velocity and depth thresholds and removal of small isolated 'ponds' of inundation.
- A suite of flood maps was produced including peak flood depths, peak flood levels, peak flood velocities, hydraulic flood hazard and hydraulic categories.

7.3 Summary of Flood Behaviour

The study area comprises of a number of small catchments where overland flow flooding can occur, and the larger 4.3 km^2 Careel Creek catchment which is subject to both overland flow flooding and mainstream creek flooding. The nature and impact of flooding differs throughout the area, associated largely with differences in the size and topography of the various catchments, as well as the nature of development and effectiveness of drainage infrastructure.

Flooding in the study area is 'flashy' in nature, with flood levels rising rapidly in response to relatively short durations of high intensity rainfall as opposed to extended periods of rainfall of lower intensity. For example, in the simulated 1% AEP 120 minute duration design event, flood levels in the Avalon CBD peak within 0.5-1.0 hour after the storm commences, while flood levels higher in the catchment may peak even more rapidly. The potential for rapid inundation of properties and numerous roads in response to short durations of rainfall means that time available to disseminate flood warning is limited, and that emergency response may occur after the event. Flood waters generally recede quite quickly following the simulated storms except in some low lying areas where flooding persists for a number of hours.

The study area contains various small, steep catchments which drain rapidly toward receiving waters (Pittwater in the west, or the Tasman Sea in the east) through small well defined valleys. The impact of flooding in such catchments (e.g. Clareville, Dark Gully, Palm Beach south) is generally low except where development has encroached upon these natural drainage lines (e.g. Hudson Parade, Clareville). Bilgola Beach and the Therry Street (Avalon) area represent larger versions of such catchments, with high velocity flows posing significant risks.

The very flat, low lying foreshore areas around Currawong Avenue (Careel Bay), Iluka Road and Waratah Road (Palm Beach) may be subject to fairly widespread but relatively shallow and slow moving inundation. Overland flows draining from the small steep catchments above collect in these areas and drainage is limited by a lack of gradient to Pittwater.

Various forms and severities of flooding are evident throughout the Careel Creek catchment. Major overland flow paths form through Ruskin Rowe and between Central Road and Avalon Parade, as floodwaters make their way to or overwhelm drainage infrastructure. These flow paths combine in the vicinity of Pittwater Palms and continue through the Avalon CBD before entering the channelized section of Careel Creek immediately east of the Woolworths carpark. An additional overland flow path enters the Avalon CBD from the south, with flooding along Old Barrenjoey Road during the 1% AEP event classified as 'high hazard'. Areas along the banks of Careel Creek are subject to inundation from mainstream flooding caused by elevated flood levels in the creek. Elaine Avenue, on the western bank of Careel Creek is the area worst impacted by mainstream flooding. A number of other areas are also impacted by overland flows draining to Careel Creek including flow paths between Albert Road, Burrawong Road and Barrenjoey Road; between North Avalon Road, Tasman Road and Catalina Crescent, and; between Edwin Avenue, Elvina Avenue, and Barrenjoey Road.

7.4 Hydraulic Categories

Hydraulic categorisation is a useful tool in assessing the suitability of land use and development in flood-prone areas. The Floodplain Development Manual (NSW Government, 2005) describes the following three hydraulic categories of flood-prone land:

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

These qualitative descriptions do not prescribe specific thresholds for determining the hydraulic categories in terms of model outputs, and such definitions may vary between floodplains depending on flood behaviour and associated impacts. For the purposes of the Avalon to Palm Beach Floodplain Risk Management Study and Plan, hydraulic categories have been defined as per the criteria in Table 7.1. These criteria were defined in the *Careel Creek Catchment Flood Study* (WMA 2013). NSW Public Works have reviewed these criteria, particularly the definition of floodway with respect to simulated flow behaviour, and found them to be appropriate and in-line with industry practice (e.g. Howell et al. 2003).

Table 7.1 - Hydraulic category criteria

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s AND Velocity > 0.25 m/s OR Velocity > 1.0 m/s AND Depth > 0.15 m	Flowpaths and channels where a significant proportion of flood flows are conveyed
Flood Storage	Depth > 0.5 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows
Flood Fringe	Depth < 0.5 m, Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

Hydraulic category mapping for the PMF, 1% and 20% AEP design events is presented in Appendix C.

7.5 Flood Risk Precincts

One of the most important outputs from the Avalon to Palm Beach Floodplain Risk Management Study & Plan is the definition and mapping of flood risk precincts used for application of Pittwater 21 DCP. The proposed definitions of the flood risk precincts are set out below:

> ***Low Flood Risk Precinct*** means all *flood prone land* (i.e. subject to inundation by the PMF) not identified within the High or Medium flood risk precincts.
>
> ***Medium Flood Risk Precinct*** means all *flood prone land* that is (a) within the 1% AEP Flood Planning Area; and (b) is not within the high flood risk precinct.
>
> ***High Flood Risk Precinct*** means all *flood prone land* (a) within the 1% AEP Flood Planning Area; and (b) is either subject to a high hydraulic hazard or is within the floodway.

Mapping of the High and Medium Flood Risk Precincts requires outputs from three processes:

- Mapping of the 1% AEP Flood Planning Area, which includes land:
  - below the 1% AEP mainstream flood level + 0.5 m freeboard extended to intersect surrounding topography; or
  - inundated by overland flooding of greater than 0.15 m depth during the 1% AEP or a Velocity x Depth > $0.3m^2/s$; or
  - within 5 metres horizontal distance of an area inundated by overland flooding of greater than 0.3 m depth during the 1% AEP
- Definition of high and low provisional hydraulic hazard by mapping flood depths, velocities and depth-velocity product for the 1% AEP event, as per Figure 7.1;

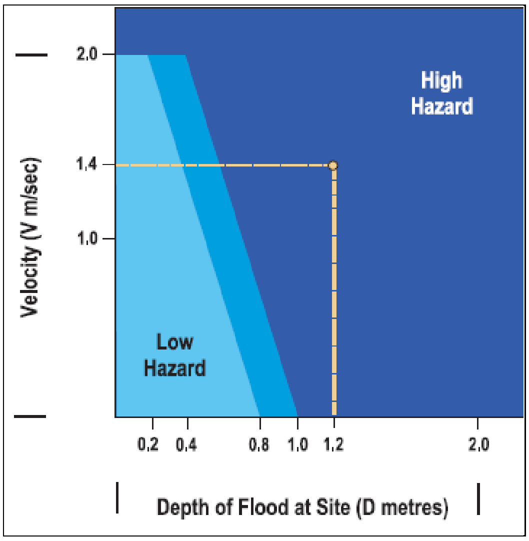


Figure 7.1 – Provisional hydraulic hazard
Source: *Floodplain Development Manual* (NSW Government 2005) Figure L2.
Note: In Pittwater, the area of 'transitional' hazard is counted as high hazard

- Hydraulic categorisation of the 1% AEP floodplain into floodways, flood storage and flood fringe areas (see Section 7.4);

An assessment of factors contributing to the 'true' hazard for the 1% AEP event has also been undertaken, in accordance with Section L6 of the *Floodplain Development Manual* (NSW Government, 2005). These factors are summarised for the Avalon to Palm Beach study area in Table 7.2.

Table 7.2 – Hazard Classification

Factor	Comment
Size of the flood	The size or magnitude of the flood affects depths and velocities. Relatively low flood hazard is associated with more frequent, minor floods while less frequent, major floods are more likely to present a high hazard situation. In the study area, high hydraulic hazard in the PMF is considerably more extensive than in the 1% AEP flood particularly for the Careel Creek floodplain.
Depth and velocity of floodwaters	The depth and velocity of floodwaters are key determinants of flood hazard and are used to map the provisional hydraulic hazard.
Rate of rise of floodwaters	Rate of rise of floodwaters is relative to catchment size, soil type, slope and land use cover. It is also influenced by the spatial and temporal pattern of rainfall during events. Rapid rates of rise make effective responses more difficult. In the study area, rate of rise is generally rapid.
Duration of flooding	The greater the duration of flooding the more disruption to the community and potential flood damages. A short period of inundation may allow some materials to dry and recover whereas a long duration may cause damages beyond repair. In the study area, durations are short.
Effective warning time	The effective warning time is the time available for people to undertake appropriate actions prior to floodwaters preventing those actions. Given the small catchment sizes and rapid rise of floodwaters in the study area, the effective warning time is short.
Evacuation problems	Evacuation may be difficult because of flooding along the evacuation route, bottlenecks and the time of day and weather conditions. An example in the study area is the Pittwater Palms retirement village which is serviced by a single driveway subject to high hazard flooding.
Flood readiness	Communities with low levels of flood awareness and readiness are more likely to respond inappropriately to flooding. Because significant flooding has not been experienced in the study area for many years, flood readiness is judged to be low.
Type of development	The type of flood prone development will to some degree correspond to population density, the level of occupant awareness and occupants' ability to evacuate safely. Different development controls are applied to different land uses in recognition of the varied risk tolerance by land use. Schools with young children pose a greater risk. Residents of retirement villages may require assistance to evacuate, and flooding could induce a higher incidence of health-related emergencies. The study area contains a number of such sensitive land uses that pose a greater hazard.

Consideration has been given to upgrading areas of Medium FRP to High FRP to account for the true flood hazard, particularly Low Flood Island or Low Trapped Perimeter flood emergency response categories (see Section 8.4). However, the typically short duration of flooding in the study area suggests that upgrading properties simply on the basis of evacuation constraints may be overly risk averse. It is also technically difficult to apply a balanced and consistent method for upgrading. The particularly policy context for Pittwater Council should also be considered. Council allows for shelter-in-place in appropriate circumstances (see Section 5.3). In the proposed revisions to the DCP, the permissible land uses and the planning and development controls are not as different between the High and Medium FRPs as is often the case (in other Council DCPs). Council has a separate process for managing risk to life through evacuation or shelter-in-place, which does not depend on the definition of FRPs. So the particular policy context that applies in the study area suggests that the need for upgrading areas to High FRP on the basis of evacuation constraints is less pronounced than for other LGAs.

Nonetheless, it was considered appropriate to upgrade small areas (<1000 m^2) of Medium FRP entirely surrounded by High FRP to the higher FRP. Some smoothing has been undertaken to remove small specks (<20 m^2) of High FRP that are likely to be manifestations of tiny anomalies in the DEM.

Figure 7.2 plots the proposed Flood Risk Precincts.

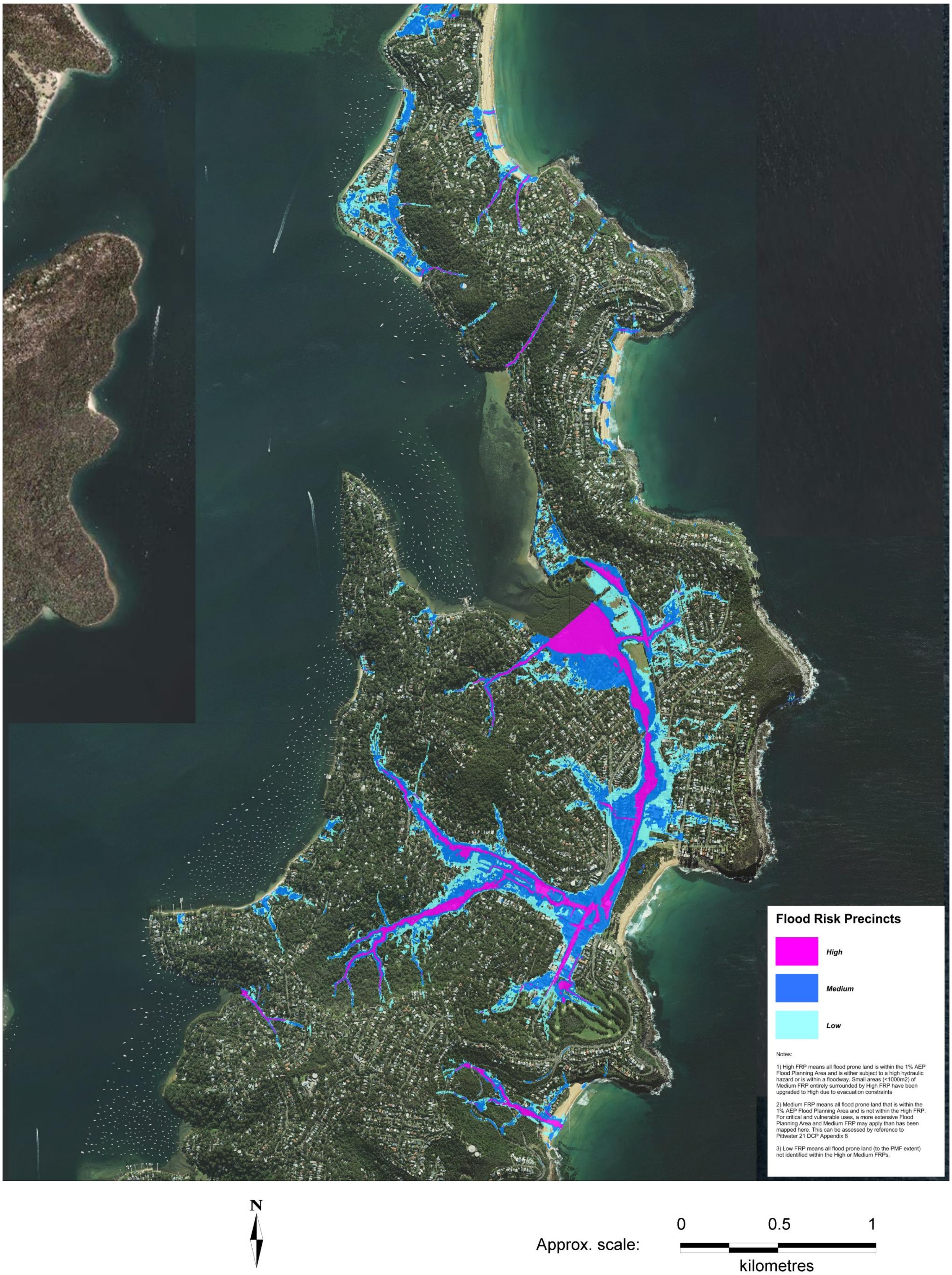


Figure 7.2 – Flood risk precincts

7.6 Flood Life Hazard Categories

A starting point for the assessment of Flood Life Hazard categories is to better understand the flood hazard. National Best Practice Guidelines present a set of hazard vulnerability curves shown in Figure 7.3. This shows how flood depths, velocities and depth-velocity product threaten the stability of vehicles, pedestrians and buildings.

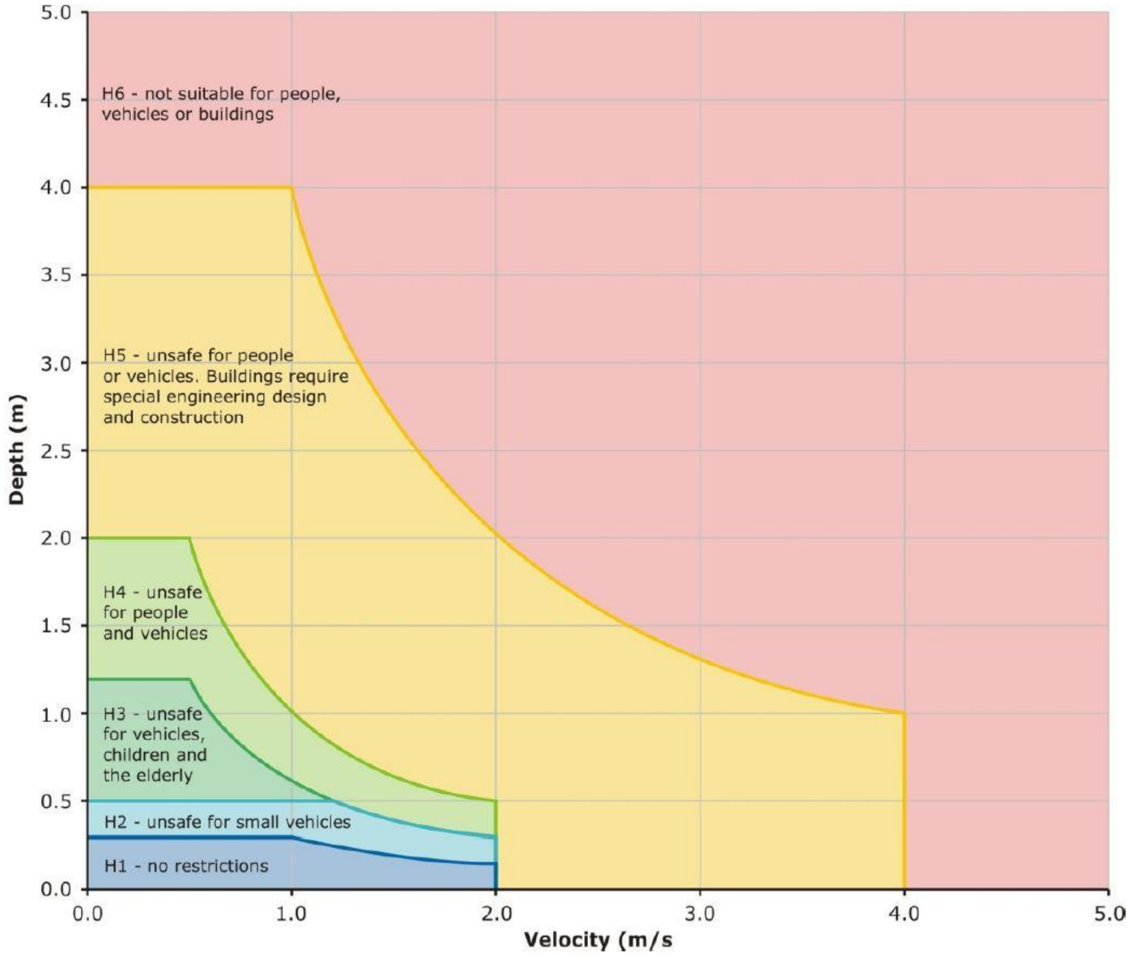


Figure 7.3 – General flood hazard vulnerability curves
Source: NFRAG (2014)

The above hazard vulnerability categories have been mapped for the 1% AEP and the PMF for the entire study area and are presented in Figure 7.4 and Figure 7.5.

Figure 7.4 – Flood hazard in the 1% AEP

Figure 7.5 – Flood hazard in the PMF

Flood hazard categories for the PMF are used for assessing risks in Council's *Flood Emergency Response Planning for Development in Pittwater Policy* (Appendix 15 of Pittwater 21 DCP). Following the *Pittwater LGA Flood Risk to Life Classification Study* (Cardno, 2015), for flood hazard categories H1 and H2, the Flood Life Hazard is considered acceptable and the policy does not apply (see Table 7.3). For flood hazard categories H3 to H5, the Flood Life Hazard is considered tolerable provided development is consistent with the policy. For flood hazard category H6, shelter-in-place is considered unacceptable (and likely it would be very difficult to provide for safe evacuation).

Table 7.3 – Flood risk assessment outcomes summary
Source: *Flood Emergency Response Planning for Development in Pittwater Policy*

Adopted Emergency Response	Flood Life Hazard Category			
	H1 - H2	H3 – H4	H5	H6
Evacuation				
Shelter-in-Place				

Where, Green = Acceptable risk, flood emergency response planning policy does not apply;

Yellow = Tolerable risk, flood emergency response planning policy applies for all development; and,

Orange = Unacceptable risk, no development should be permitted in these areas due to severe flood

Flood Life Hazard (FLH) categories are presented for the study area in Figure 7.6. The LGA-wide mapping prepared for the *Flood Risk to Life Classification Study* (Cardno, 2015) upgraded areas of H1–H2 entirely surrounded by H3–H4 to the higher category due to evacuation constraints, so the same process has been employed for this study.

Areas subject to H6 hazard conditions in the PMF are seen to be relatively confined. Private property affected by H6 includes, in the Careel Creek catchment, the open channel flowing through two properties at the north-eastern end of Ruskin Rowe, two properties at the eastern end of Central Road and one property at the north-eastern end of William Street and, outside the Careel Creek catchment, two properties on the flow path from Lower Plateau Road to Hudson Parade. Only at one of these properties (the eastern end of Central Road) does the existing building footprint substantially intersect with the H6 mapped area, which suggests that it may be at considerable risk of failure during the PMF. This also suggests that early evacuation from this building is essential since sheltering-in-place (even in a raised dwelling) may not sufficiently mitigate the risk.

Areas subject to H5 hazard conditions in the PMF are considerably more extensive. Some of the areas where existing dwellings substantially intersect with H5 include properties in Elaine Avenue south of about Eastbourne Avenue, the southern end of Catalina Crescent, the northeastern end of William Street, and one property in Hudson Parade (Refuge Cove).

Avalon Bowling Club is also subject to H5 hazard conditions in the PMF, as are shops on the southern side of the Woolworths building. Most of the carparks servicing Avalon shopping centre (near the bowling green, RSL club and Woolworths) are subject to H5 conditions and would be very dangerous for people attempting to access their vehicles.

Another area of note subject to H5 hazard conditions (and even H6 in places) is the public carparks servicing Bilgola Beach, both west and east of The Serpentine, heading down the road towards the Surf Lifesaving Club. While the flow path is relatively narrow, and able-bodied adults should be able to escape to higher ground to the south, a sudden storm on a summer afternoon could mobilise many vehicles, which would in turn pose serious hazards to people and vehicles and a café located near the beach.

H4 hazard conditions affect parts of the floodplain adjacent to H5. These are areas where the depths make it unsafe for people and vehicles. It includes a sizeable area near the corner of Avalon Parade and Old Barrenjoey Road in the heart of Avalon's shopping centre. Barrenjoey Montessori School and part of the grounds of Barrenjoey High School are also subject to H4 conditions in a PMF.

7.7 Potential Impacts of Climate Change

The potential impacts of climate change on flooding in the study area are discussed in Chapter 14.

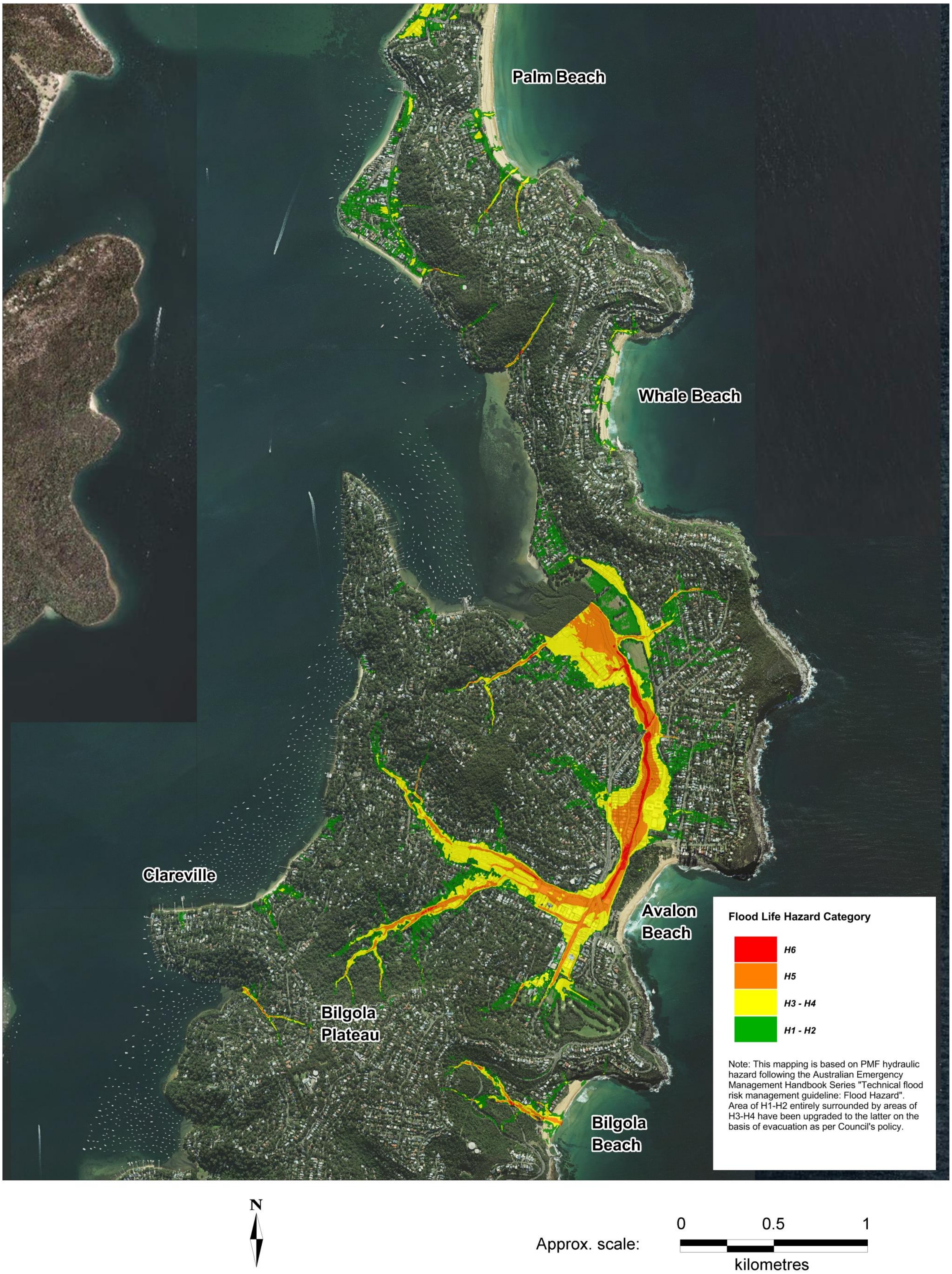


Figure 7.6 – Flood Life Hazard category

8. Defining the Flood Problem

8.1 Property Database

A flood damages database was prepared for the Avalon to Palm Beach study area. The database allows assessment of the potential impacts of flooding in terms of inundation of buildings and economic impacts associated with flood damages. Assessment of the economic impacts of flooding provides a baseline for the economic assessment of various flood risk management measures.

As a first step, all properties in the cadastral database within the floodplain (i.e. affected by the PMF) were identified. Those properties where the building footprint was clearly outside the floodplain or above the PMF level were removed from the database. For the remaining properties a tag point was created (generally at a point near the building's front door, depending on local flood behaviour) where representative information on ground level, floor level and peak flood levels could be assigned and assessed. Ground levels were estimated using the Digital Elevation Model (DEM) developed for the flood model, based on Aerial Laser Scanning (ALS) data captured in 2007. ALS data typically has a vertical accuracy in the order of +/- 0.15 m. Floor heights above the ground were estimated using Google Street View in order to derive floor levels. Where floor heights were not visible, a floor height of 0.2m was assigned based on the most common floor height reported in a floor level survey conducted for parts of the Careel Creek catchment in 2010.[7] A site inspection was undertaken to verify selected floor heights. This included much of the Avalon commercial district plus nearby residences.

Other attributes that were collected are listed in Table 8.1. This includes the number of residential units and the number of stories in a house, which are required for the assessment of residential damages. It also includes assignation of value categories and estimation of ground floor areas for each business within the commercial sector.

OEH's method for assessing residential flood damages requires houses be split into three categories for the application of three different stage-damage curves:

- Single story high set (applied where floor level > 1.5m higher than ground level, coded '1' in the property database)
- Single storey low set/slab-on-ground (coded '2')
- Two storey (coded '3').

[7] In general, the 2010 floor level survey was not judged to be of high quality. Numerous coordinates did not correspond to the listed street address. Only a portion of the surveyed data was judged to be of adequate reliability to be used directly for this study.

For commercial/industrial land uses, the type of activity was split into one of six codes for the application of six different stage-damage curves:

- Commercial low (CL)
- Commercial medium (CM)
- Commercial high (CH)
- Industrial low (IL)
- Industrial medium (IM)
- Industrial high (IH)

Table 8.1 – Attributes recorded in property database

Attribute	Source/Comment
Easting/Northing	▪ Derived from GIS, with digitised points for each main building(s) on a lot based on 2013 aerial photography
Lot/DP	▪ Council
Address	▪ Council
Zoning	▪ Council
Land use (residential or non-residential)	▪ Council's Zoning and Street View
Number of residential units	▪ Council ▪ Street View (to estimate number of ground level units within PMF flood extent and to confirm applicable residential damage code)
Number of stories for residential uses	▪ Some from 2010 survey ▪ Street View
Commercial/industrial value (high, medium, low)	▪ Site inspections (Avalon commercial district) ▪ Street View
Commercial/industrial floor area (m^2)	▪ Building floor areas estimated using aerial photography and GIS ▪ Site inspections used to ascertain number of businesses within buildings
Construction type (brick, fibro or cladding)	▪ Some from 2010 survey ▪ Street View
Ground level (m AHD)	▪ Extracted from DEM (3m cell size)
Floor height (m)	▪ Estimated where surveyed data from 2010 survey not accepted ▪ Street View ▪ Where not viewed, 0.2m adopted for residential
Floor level (m AHD)	▪ Some surveyed levels from 2010 survey ▪ Inspection of DA for one address ▪ Mostly estimated levels based on the addition of a floor height to the ground level
Design flood levels (20%, 5%, 1%, 0.5% and 0.2% AEP, PMF)	▪ Flood surface grids derived by flood modelling for this study

Flood surfaces for the PMF, 0.2% AEP, 0.5% AEP, 1% AEP, 5% AEP and 20% AEP design events were used to extract flood levels at tag points for each building in the database.

The use of a buffer to identify the maximum flood level with 3 metres of the building's tag point was investigated. It was found that both the number of inundated buildings and the depths of over-floor flooding increased, sometimes significantly. This was found to be largely the result of higher peak flood levels being selected upslope of the tag point in steep areas such that the depth of over-floor flooding identified was often greater than the peak flood depth in the vicinity of the tag point. It was therefore considered that a more appropriate representation of the potential for over-floor flooding of a building was to adopt the peak flood levels *at* the tag point only.

8.2 Inundation Patterns

8.2.1 Residential

Based on the flood depth recorded at the tag point for each building, the numbers of residential and non-residential properties flooded above floor in each design event are listed in Table 8.2. This analysis counts each unit in a multi-unit block, and each business within a business building, as a separate entity, which has a significant effect on the resultant numbers. In particular, Pittwater Palms retirement village has 66 ground floor independent living units, 64 of which are estimated to be flooded over floor in the PMF (10% of the total flooded in that event), and 44 of which are estimated to be flooded over floor in a 1% AEP event (20% of the total flooded in that event).

This assessment shows that 71 houses or home units are estimated to be flooded over floor in the 20% AEP event. This increases to 215 for the 1% AEP event. However, Table 8.3 shows that these depths are typically quite shallow, with median depths less than 0.1m up to and including the 0.5% AEP event. Figure 8.1 demonstrates that the inundation at about 90% of the 219 houses/units flooded over floor in the 1% AEP event is not expected to exceed over floor depths of 0.3m. The high sensitivity of this assessment to the estimated floor levels is confirmed by Table 8.4. It shows that lowering the adopted floor levels by 0.1m would increase the number of houses/units flooded over floor in the 1% AEP event by 173; raising the adopted floor levels by 0.1m would decrease the number flooded over floor in the 1% AEP event by 115.

The distribution of buildings flooded by different design events is shown in Figure 8.2. This shows that houses could be inundated by overland flows across a wide area, which reflects the nature of the study area with many different flow paths draining runoff from the elevated ‘spine’ to the ocean during intense rainfall. Nevertheless, observing houses/units estimated to be inundated over floor in the 20% or 5% AEP events, there are some ‘hot-spots’ where three or more such properties are located:

- Palm Beach
  - Flow path from Beach Road to Pittwater via Waratah Road;
  - Flow path from heights to Barrenjoey Road opposite about Nabilla Road;
  - Flow path from Barrenjoey Road to Pittwater via southern end of Iluka Road;
  - Flow path from Barrenjoey Road to Pittwater via Currawong Road;
- Avalon Beach
  - Flow path between Albert Road, Burrawong Road and Barrenjoey Road;
  - Flow path between North Avalon Road, Tasman Road and Catalina Crescent;
  - Flow path from Therry Street to George Street;
  - Flow path from Careel Bay Crescent to Pittwater;
  - Flow path from Avalon Parade to Katandra Close;
  - Flow path from Avalon Parade to Careel Creek through Pittwater Palms;
  - Flow path from Dress Circle Avenue to Bellevue Avenue; and
- Bilgola
  - Flow paths between Barrenjoey Road and The Serpentine.

Figure 8.3 shows the distribution of buildings according to the depth of above floor flooding in the 1% AEP event. Only two houses/units are flooded to depths exceeding 0.5m; one is located in Pittwater Palms retirement village and the other is located upstream of the Barrenjoey Road crossing near North Avalon Road. In addition to the problem areas identified by the frequency of inundation, areas with houses that could experience flood depths in the 1% AEP event exceeding 0.3m are listed below:

- Elaine Avenue, Avalon Beach;
- Barrenjoey Road opposite Careel Bay Ovals, Avalon Beach; and
- Hudson Parade, Clareville.

Table 8.2 – Number of houses/units and business premises/public sector buildings flooded over floor by design event

	20% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Residential	73	146	219	256	294	640
Non-residential	31	71	101	104	113	171

Table 8.3 – Above floor flood depths (m) by design event

		20% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Residential	Max	0.41	0.48	0.81	0.96	1.16	2.90
	Mean	0.10	0.11	0.13	0.14	0.16	0.38
	Median	0.06	0.09	0.09	0.10	0.12	0.18
Non-residential	Max	0.47	0.66	0.87	0.88	0.94	1.88
	Mean	0.15	0.17	0.21	0.25	0.28	0.71
	Median	0.14	0.15	0.20	0.24	0.28	0.67

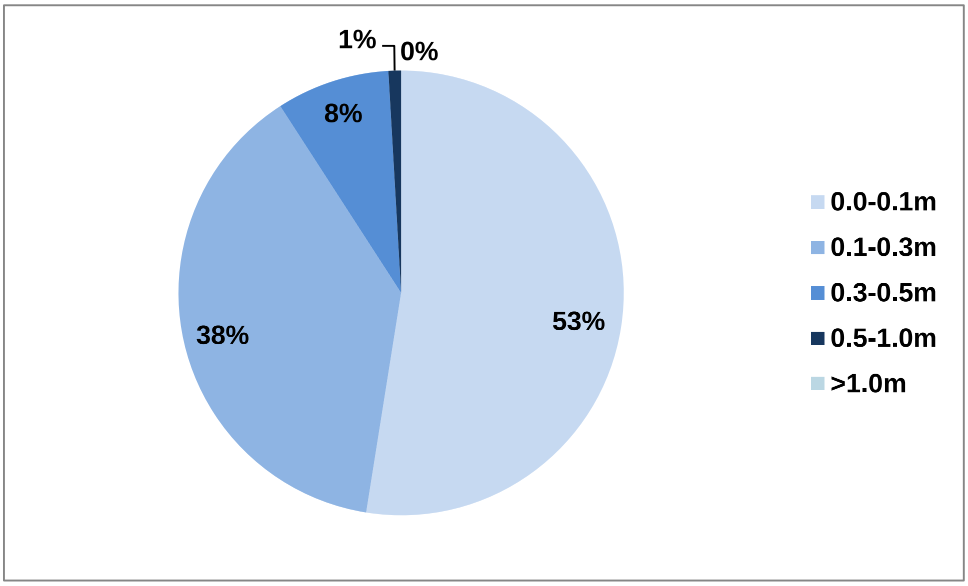


Figure 8.1 – Above floor flood depth categories, residential sector, 1% AEP event

Table 8.4 – Number of houses/units and business premises/public sector buildings by above floor depth in 1% AEP event

Depth over (below) floor in 1% AEP event	Residential	Non-residential
-0.1-0.0m	173	19
0.0-0.1m	115	27
0.1-0.3m	84	53
0.3-0.5m	18	17
0.5-1.0m	2	4

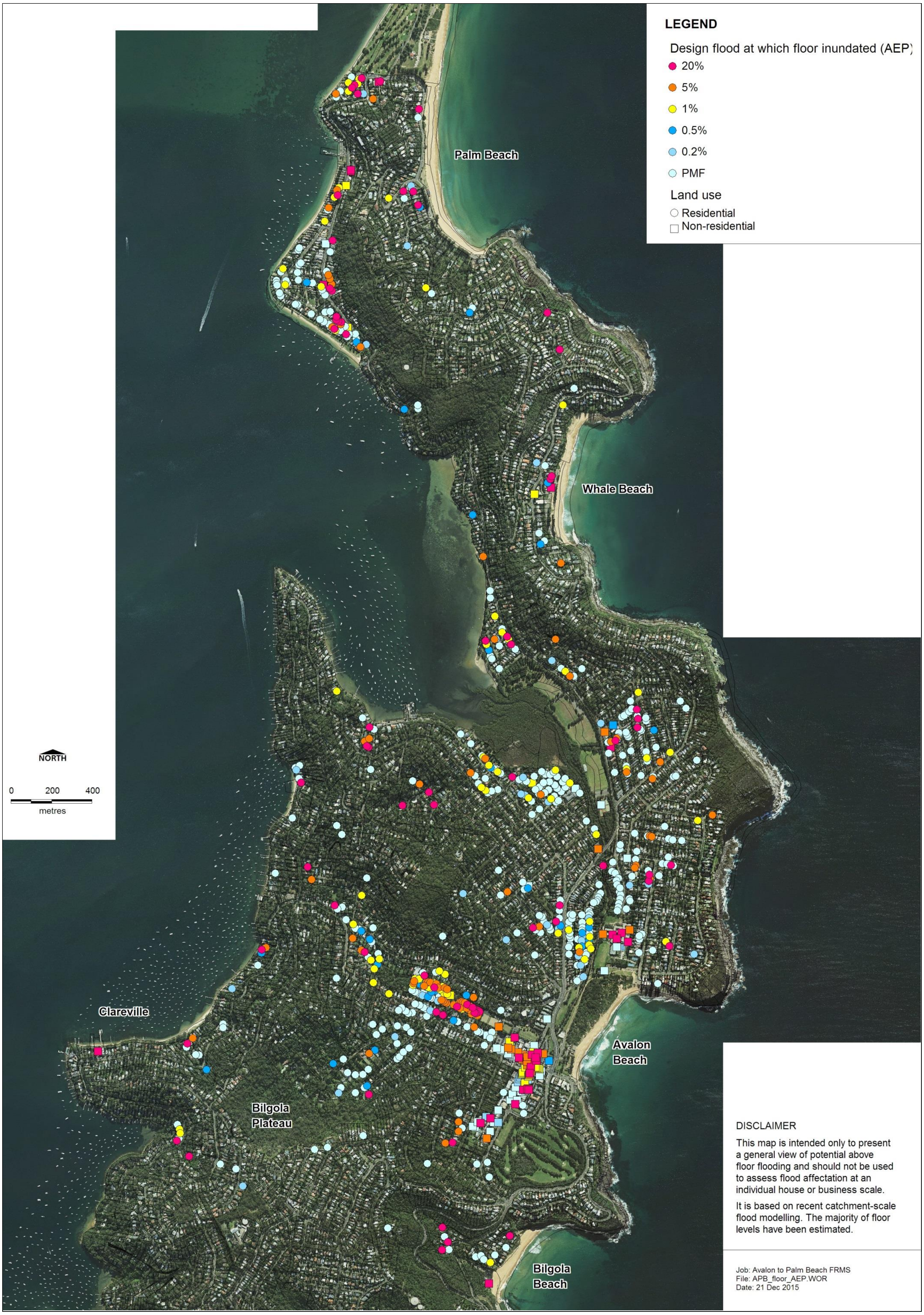


Figure 8.2 – Buildings flooded over floor by design event

Figure 8.3 – Depth of above floor flooding in 1% AEP event

8.2.2 Non-Residential

Table 8.3 shows that 31 business premises or public sector buildings are estimated to be flooded over floor in the 20% AEP event. This increases to 101 for the 1% AEP event. Again, Table 8.4 shows that these depths are typically rather shallow, with median depths less than 0.3m up to and including the 0.2% AEP event. Few premises are expected to be flooded to depths exceeding 0.5m in the 1% AEP event, including one along Whale Beach Road at Whale Beach and three near the corner of Avalon Parade and Old Barrenjoey Road (see Figure 8.3). An additional 17 premises would be inundated to depths exceeding 0.3m in the 1% AEP event. Figure 8.3 shows that these are concentrated in the Avalon commercial district. Closer views of the frequency of inundation and depths of inundation in the 1% AEP event in the Avalon town centre are presented in Figure 8.4 and Figure 8.5.[8] Descriptions and photos of historic flooding at Avalon (Section 2.3) confirm that floods have caused serious damage in this area in the past.

8.2.3 Critical Infrastructure/Sensitive Uses

Special attention is given to land uses with a higher sensitivity to flooding. The NSW SES now explicitly lists these uses in local flood plans. Below is a description of the flood affectation for a number of critical or sensitive uses that have been identified as being within the mapped floodplain in the study area. Sites within the floodplain are mapped in Figure 8.6.

Electricity Substation

Careel Bay Zone Substation is located on the left bank of Careel Creek on the downstream side of the Barrenjoey Road (north) crossing, opposite North Avalon Road. Flood modelling suggests that it is not expected to be inundated from Careel Creek in events up to and including the 0.2% AEP flood. Depths in the PMF could reach 0.7m in the north-eastern section of the site.

The site could be inundated in more frequent events by local overland flows from the southwest. These could reach depths of about 0.2m in the 5% AEP event but are not expected to increase much above that even in rarer storm rainfalls up to the 0.2% AEP event.

Further consultation with Ausgrid is needed to confirm the potential consequences of inundation in terms of loss of service or other impacts.

[8] Note that some points represent multiple businesses in the same building with the same floor level.

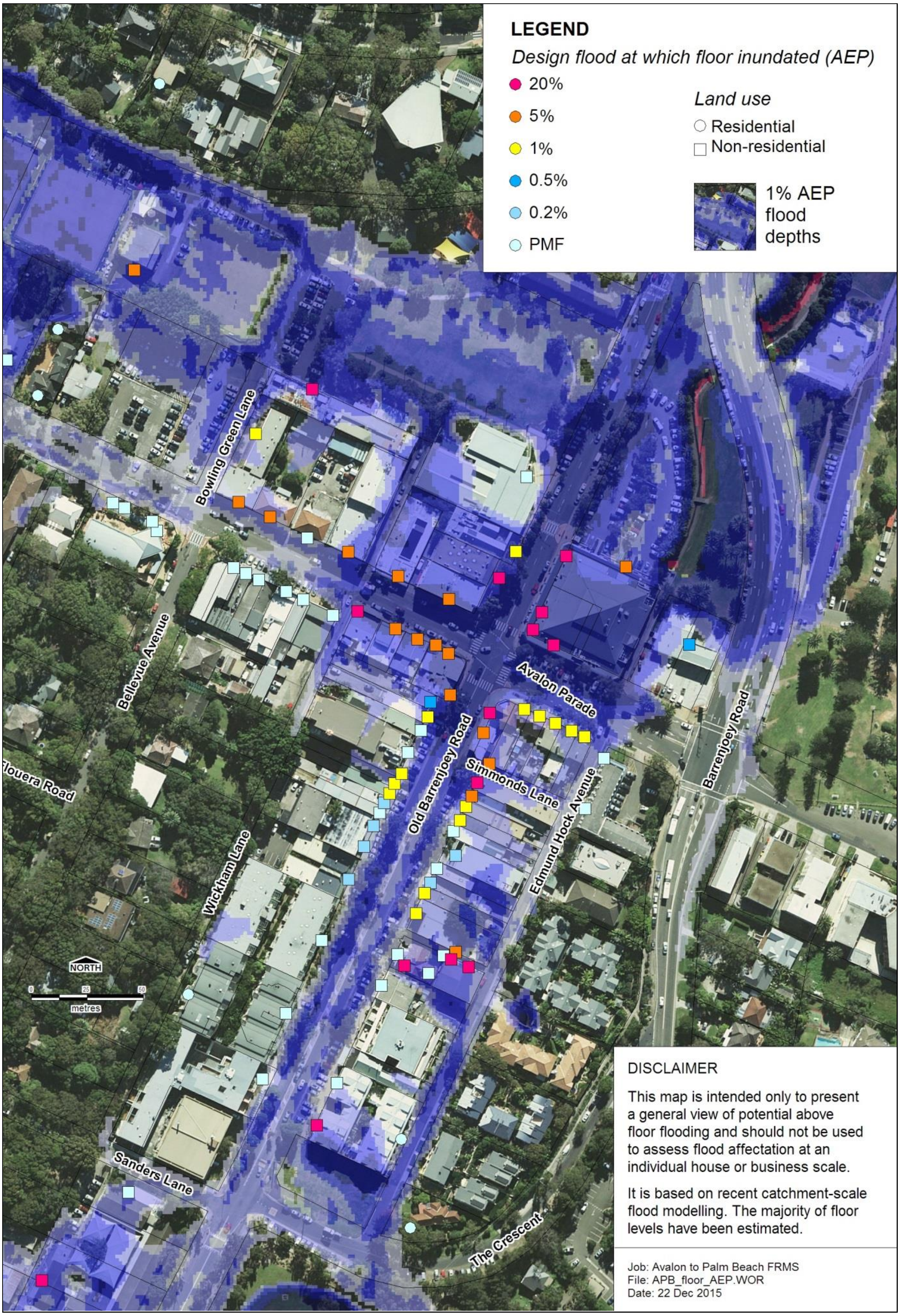


Figure 8.4 – Buildings flooded over floor by design event, Avalon shopping centre

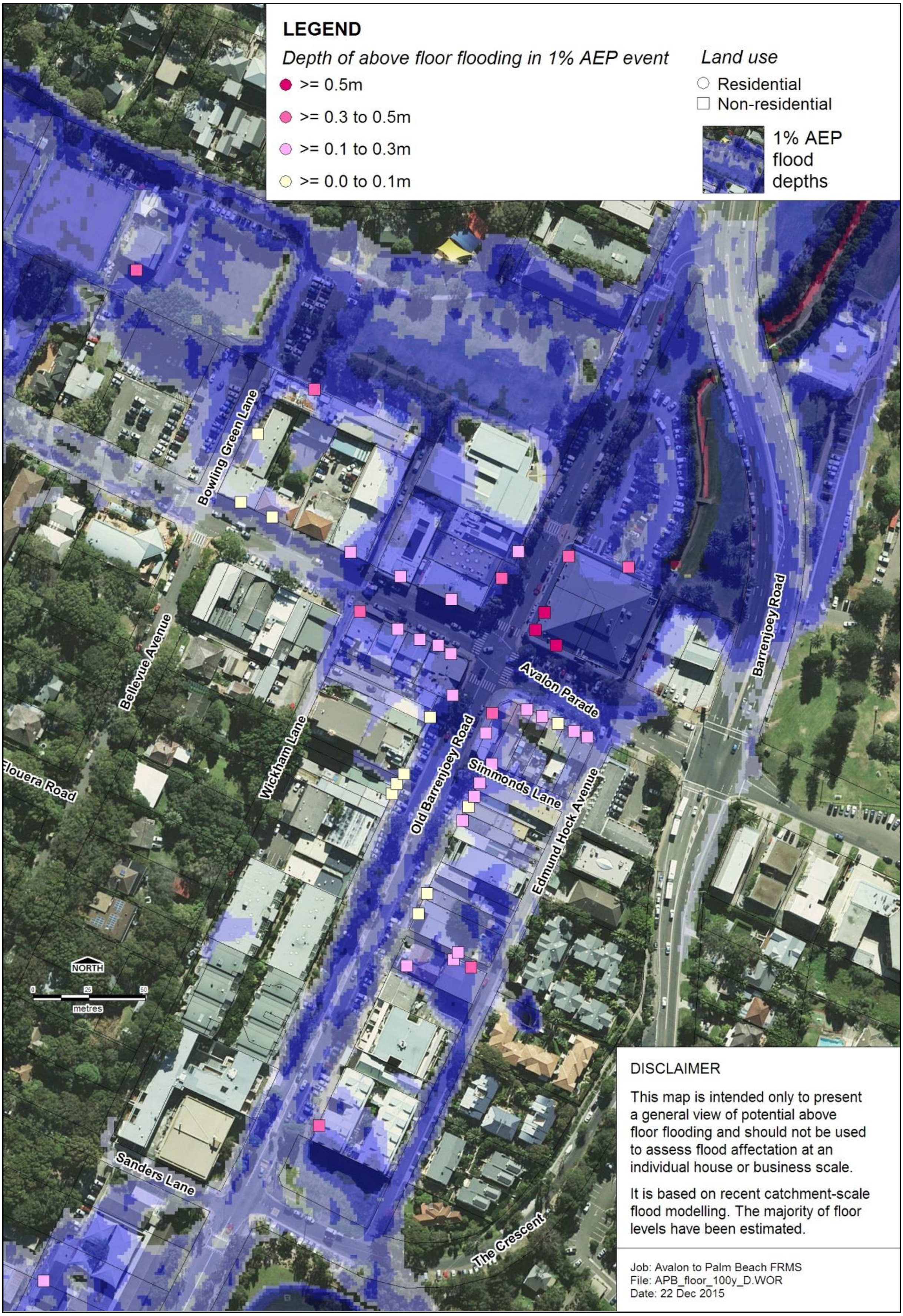


Figure 8.5 – Depth of above floor flooding in 1% AEP event, Avalon shopping centre

Sewage Pump Stations

Based on information supplied by Sydney Water, three sewage pump stations in the study area could be inundated in relatively frequent floods, though only to shallow depths (Table 8.5). Up to eight sewage pump stations could be inundated in the PMF, including one station (SP0460) located next to Careel Creek at the south-western end of Barrenjoey High School where the depth could exceed 1.4m.

As the pumping units at these stations are all submersible, they will not be impacted by flooding. The main impact of flooding on these stations is damage caused by immersion of the electrical kiosks. Based on Sydney Water estimates of the level at each pumping station where the electrical kiosk will first be impacted, Table 8.5 includes a colour code showing whether flooding is likely to have an impact on electrical equipment, which could take days or weeks to repair. The Whale Beach unit is particularly vulnerable.

Compared to daily peak dry weather flow, during significant wet weather the peak flow can increase by a factor of four or more. This can cause the in-flow to exceed the pumping capacity of the station and result in overflow of highly diluted sewage to the environment. Overflow is likely during the sort of extreme wet weather events that would cause flooding.

Table 8.5 – Design flood depth at sewage pump stations within study area

Site Code	Location	Depth over ground (m)					
		20% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
SP0532	Beach Rd, Palm Beach	n/a	n/a	n/a	n/a	n/a	0.17
SP0911	33-34 Ocean Rd, Palm Beach	0.13	0.17	0.20	0.21	0.23	0.34
SP0943	256A Whale Beach Rd, Whale Beach	0.09	0.11	0.11	0.12	0.12	0.16
SP0509	6A Currawong Ave, Palm Beach	n/a	n/a	n/a	n/a	n/a	0.27
SP0537	18A Joseph St, Avalon Beach	n/a	n/a	n/a	n/a	n/a	0.45
SP0525	40A Paradise Ave, Avalon Beach	n/a	n/a	n/a	0.04	0.05	0.05
SP0523	30 Delecta Ave, Clareville	0.14	0.16	0.18	0.19	0.21	0.30
SP0460	22 Central Rd, Avalon Beach	n/a	n/a	n/a	n/a	n/a	1.42

Legend: Flood level below first electrical impact
Flood level at first electrical impact
Flood level above first electrical impact

Telecommunications

Telstra's Avalon Exchange is located at 13 Old Barrenjoey Road, Avalon Beach. The floor level is expected to be just above the maximum flood level.

Emergency Services

Avalon Fire Station is located at 67 Old Barrenjoey Road (alternatively, 689 Barrenjoey Road), Avalon Beach. It is not modelled as being inundated above floor in events up to and including the 0.2% AEP flood. However, in a PMF it would be inundated to a depth of about 0.8m, which could compromise its operations.

Schools

A number of pre-schools and schools within the study area could be directly impacted by flooding. These are listed in Table 8.6, including the ages and numbers of children enrolled at each school. Based on available information[9], some buildings at Avalon Public School and Barrenjoey High School could be inundated above floor by shallow flooding in frequent events, but some buildings are known to be well above PMF level. Avalon Beach House Pre-School is estimated to be inundated above floor from at least the 5% AEP flood. The Kindy Childcare Centre is expected to be flooded from at least the 1% AEP flood. In addition to the risk of direct inundation of grounds or buildings, there is a risk for parents or carers attempting to gain access to these schools during floods. The threat of road inundation and isolation is considered in Section 8.3.

Table 8.6 – Pre-schools and schools affected by flooding

Name	Address	Age of children	No. of children	AEP of first AFF	AFF depth in PMF	Other
The Kindy Childcare Centre	35 John St	2½–4	20	1% AEP	~0.5m	
KU Avalon Pre-School	118A Avalon Pde	3–6	40	n/a	n/a	Grounds flood-prone
Avalon Beach House Pre-School	50 Old Barrenjoey Rd	1½–5	28	5% AEP	~0.4m	
Palm Beach Kindergarten	1053 Barrenjoey Rd	3–5	29	n/a	n/a	Grounds flood-prone
Barrenjoey Montessori School	2B Tasman Rd	3 mnths – 9 (yr 4)	80	PMF	~0.7m	
Avalon Public School	11 Old Barrenjoey Rd	Primary (~4–12)	850	20% AEP to n/a	~0.5m (max)	Contains buildings above PMF
Barrenjoey High School	1-3 Coonanga Rd	High (~12–18)	780	20% AEP to PMF	~1.3m (max)	Contains levels above PMF

Note:
AFF = above floor flooding

[9] Some building floors were not sighted. Survey of floors for critical infrastructure and sensitive uses is recommended to confirm their flood liability.

Retirement Village/Residential Care Facility

Pittwater Palms retirement village is located at 82 Avalon Parade, Avalon Beach, and provides 127 independent living units and 41 serviced apartments. While surveyed floor levels are not available, an inspection shows that many ground floor units are close to ground level. In the 20% AEP event, it is estimated that nine units would be inundated to shallow depths (<0.3m) and in the 1% AEP event, 58 units would be flooded over floor, to a maximum depth of about 0.6m. The PMF is estimated to flood about 72 units, up to 1.2m deep. Fortunately first floor units would be above flooding, but people on the ground floor may not find it straight forward to access the higher level. In the event of a fire or medical emergency during a flood, access to or egress from the facility could be difficult due to water flowing along the driveway. In the 1% AEP event, flood flows along the entrance driveway and some internal roads are classified as a high hydraulic hazard according to Figure 7.1 and as H3–H5 according to Figure 7.3, which are not safe for pedestrians or vehicles.

Avalon House Nursing Home is located at 14-16 John Street, Avalon Beach, and provides beds for 80 residents. The ground floor level is set relatively high at 2.85m AHD compared to the surrounding floodplain and is modelled to be inundated only in events considerably rarer than the 0.2% AEP (1 in 500 chance in a year) flood. However, access to the William Street entrance could be lost in the 1% AEP event, requiring use of the John Street entrance. In the PMF, the ground floor would be flooded to a depth of about 0.4m on average.

Pet Shelters

Avalon Veterinary Hospital is located at 710 Barrenjoey Road, Avalon Beach. It is situated in a significant overland flow path originating near Whale Beach Road, flowing westwards across Albert Road, Burrawong Road and Barrenjoey Road. Modelling suggests that the hospital would be flooded to a depth of about 0.1m in the 20% AEP event, to a depth of 0.3m in the 1% AEP event, and to a depth of 0.8m in the PMF. Access to and egress from the vet's is also likely to be compromised.

Chelsea Lane Pets and Supplies is a pet shop located at 4/48 Old Barrenjoey Road, Avalon Beach. It is situated in a significant overland flow path draining the area to the south. Modelling indicates that the shop floor would be flooded to a depth of about 0.1m in the 20% AEP event, to a depth of about 0.25m in the 1% AEP, and to a depth of 0.5m in the PMF.

Figure 8.6 – Location of critical infrastructure and sensitive uses

8.3 Road Inundation

An assessment of the frequency and hazard of road inundation is important for understanding the risk of vehicles becoming unstable, posing a risk to life for their drivers and passengers. It is also important for understanding evacuation risks, informing the classification of communities according to flood emergency response planning considerations. Measures to increase the flood immunity of critical roads could be considered as a result of this assessment.

Figure 8.7 describes the flood hazard for 32 road low-points, for three design events (20% AEP, 5% AEP and 1% AEP). Hazard category 'H3' (and H4–H6) is considered unsafe for all vehicles whereas 'H2' is considered unsafe for small vehicles (see Figure 7.3). Table 8.7 details the results including for the PMF. This table also includes an assessment of the time to peak and duration of above-road inundation for the modelled 1% AEP flood (note that the results are sensitive to the adopted critical duration and temporal patterns used in the model). The table also includes an estimate of the importance of each road and the implications of its temporary closure.

Some roads would be unsafe to traverse even in very frequent events like the 20% AEP event. Particularly noteworthy is Barrenjoey Road at several locations between the Careel Bay ovals and Palm Beach. Parts of Ruskin Rowe in Avalon and The Serpentine in Bilgola could also be cut.

In the 5% AEP flood, the northbound lanes of Barrenjoey Road near the Avalon shopping centre would be flooded to unsafe depths. Egress from Pittwater Palms retirement village would be lost.

In the 1% AEP flood, more roads would be cut to all traffic including the busy Avalon Parade/ Old Barrenjoey Road intersection and Bowling Green Lane, which forms the evacuation route from several carparks. The southern part of Elaine Avenue would be cut off. Barrenjoey Road at Bilgola Bends could be cut due to high flow velocities. Hudson Parade at Clareville would be cut due to the combined hazard of flood depths and velocities.

In the PMF, all assessed road low-points experience H3+ hazard conditions, including both carriageways of Barrenjoey Road near the service station at Avalon.

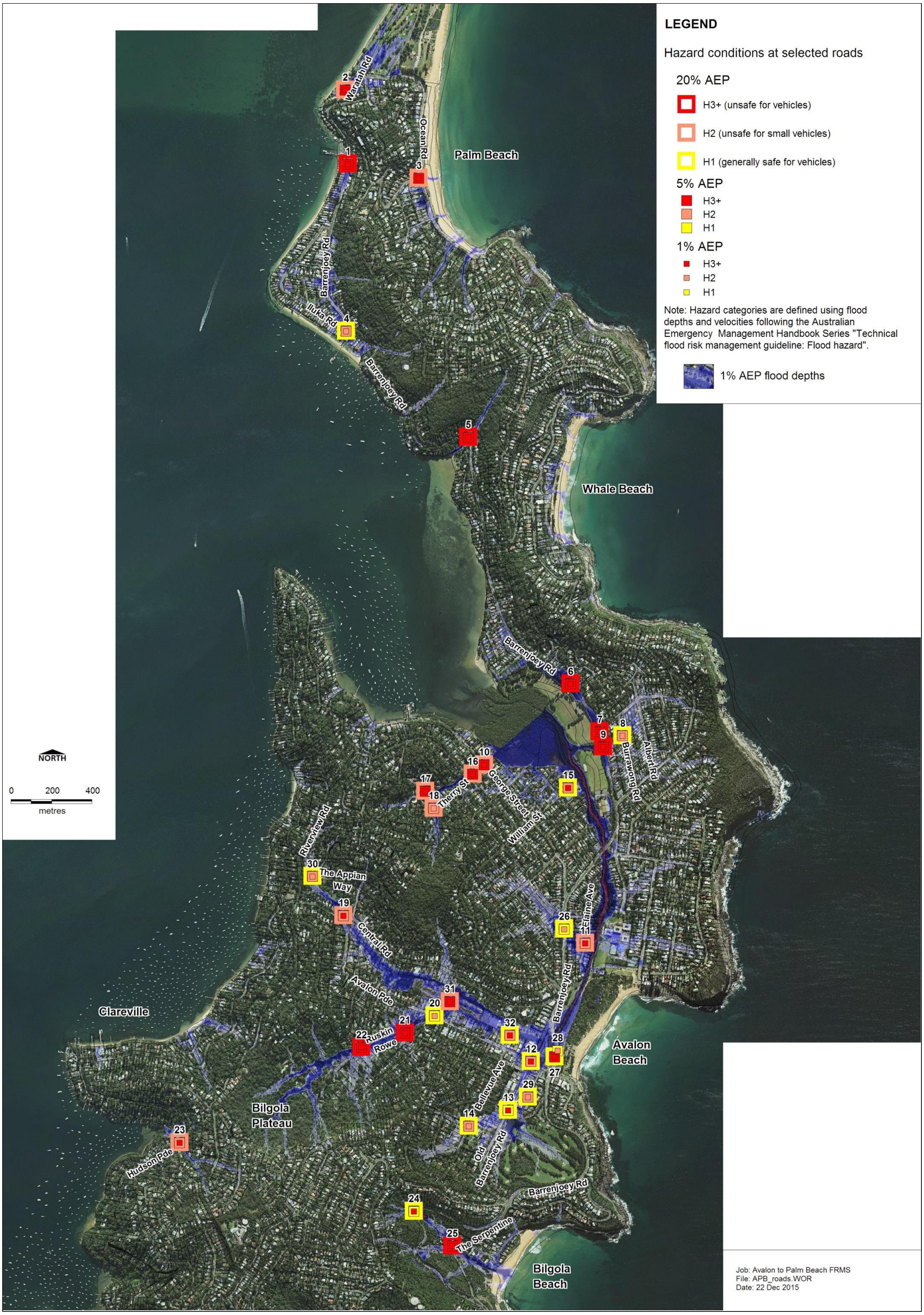


Figure 8.7 – Flood hazard at road low-points

Table 8.7 – Flood hazard and exposure at road low-points

MHL ID (Fig 8.7)	Location of road low-point	Elevation (m AHD)	20% AEP				5% AEP				1% AEP						PMF				AADT	Comments
			D (m)	V (m/s)	D*V	Haz Class	D (m)	V (m/s)	D*V	Haz Class	D (m)	V (m/s)	D*V	Haz Class	Time to peak (hrs)	Dur (hrs)	D (m)	V (m/s)	D*V	Haz Class		
1	Barrenjoey Rd near Palm Beach Ferry	1.92	0.62	0.11	0.05	H3+	0.66	0.13	0.07	H3+	0.69	0.16	0.08	H3+	0.67	>4.0	0.84	0.29	0.14	H3+	5340	Key route to northern Palm Beach; alternative access available
2	Waratah Rd, Palm Beach	1.97	0.47	0.05	0.01	H2	0.53	0.07	0.03	H3+	0.60	0.09	0.05	H3+	0.83	>4.0	0.93	0.29	0.26	H3+		Cul-de-sac: ~15 properties isolated (part Low Trapped Perimeter)
3	Palm Beach Rd/Ocean Rd intersection	4.08	0.48	0.08	0.03	H2	0.53	0.09	0.05	H3+	0.56	0.12	0.07	H3+	0.67	2.9	0.70	0.36	0.25	H3+	2349	Alternative access available
4	Iluka Rd, Palm Beach	1.75	0.28	0.26	0.07	H1	0.33	0.28	0.09	H2	0.38	0.30	0.10	H2	0.75	4.0	0.53	0.38	0.20	H3+		Minor road
5	Barrenjoey Rd opp. No. 900 (Palm Beach)	20.85	0.11	2.23	0.22	H3+	0.13	2.69	0.32	H3+	0.15	3.13	0.43	H3+	0.67	~2.7	0.33	4.30	1.33	H3+		Key route to Palm Beach; alternative access available
6	Barrenjoey Rd opp. No. 746 (Avalon)	1.78	0.80	0.07	0.01	H3+	0.96	0.07	0.01	H3+	1.15	0.08	0.02	H3+	2.0	>4.0	1.42	0.38	0.11	H3+		Key route to Whale Beach and Palm Beach; alternative access via Whale Beach Rd
7	Barrenjoey Rd/Careel Head Rd intersection	2.23	0.56	0.12	0.06	H3+	0.70	0.12	0.07	H3+	0.83	0.13	0.08	H3+	0.83	~2.3	1.30	0.74	0.71	H3+		Key route to Whale Beach and Palm Beach; alternative access via Whale Beach Rd
8	Burrawong Rd opp. No. 29	5.21	0.26	1.13	0.29	H1	0.35	1.17	0.41	H2	0.42	1.22	0.52	H2	0.71	~1.8	0.74	1.68	1.24	H3+		Some properties may lose access; alternative routes available for sector
9	Barrenjoey Rd opp. No. 712A (Avalon)	2.25	0.53	0.32	0.14	H3+	0.68	0.40	0.24	H3+	0.81	0.49	0.34	H3+	0.79	~2.0	1.31	1.07	1.22	H3+		Key route to Whale Beach and Palm Beach; alternative access via Whale Beach Rd
10	George St/Therry St intersection	2.96	0.21	1.57	0.32	H2	0.24	2.06	0.49	H3+	0.26	2.53	0.65	H3+	0.75	1.7	0.43	4.44	1.93	H3+		Isolates properties in western George St
11	Elaine Ave near Nos 45, 47	2.98	0.42	0.51	0.19	H2	0.48	0.62	0.27	H2	0.65	0.71	0.34	H3+	1.13	4.0	2.67	1.12	2.17	H3+		Cul-de-sac: 12 properties isolated (Low Flood Island)
12	Old Barrenjoey Rd/Avalon Pde intersection	4.82	0.24	0.82	0.17	H1	0.42	1.15	0.38	H2	0.56	1.47	0.64	H3+	0.96	2.3	1.65	2.86	2.34	H3+		Significant intersection in commercial centre
13	Old Barrenjoey Rd/The Crescent intersection	7.79	0.09	1.30	0.13	H1	0.14	1.86	0.28	H1	0.20	2.24	0.45	H3+	0.75	2.2	0.58	3.26	1.91	H3+		Significant intersection near commercial centre and school
14	Bellevue Avenue, Avalon	15.63	0.27	1.36	0.30	H1	0.31	1.72	0.44	H2	0.33	1.95	0.54	H2	0.67	~3.0	0.45	2.42	0.95	H3+		Minor road
15	William St near Avalon Nursing Home	1.63	0.25	0.22	0.04	H1	0.39	0.47	0.06	H2	0.58	0.56	0.10	H3+	1.21	~3.0	1.48	1.04	0.75	H3+		Cul-de-sac: 4 properties isolated; alternative access to Nursing Home via John St
16	Therry St near Patrick St	6.26	0.26	1.83	0.50	H2	0.32	2.06	0.67	H3+	0.38	2.27	0.83	H3+	0.67	2.2	0.66	2.58	1.71	H3+		Some properties may lose access; alternative routes available for sector
17	Therry St near No. 46	11.21	0.46	0.24	0.11	H2	0.55	0.30	0.17	H3+	0.61	0.38	0.24	H3+	0.63	~3.0	0.91	0.76	0.70	H3+		Cul-de-sac: 10 properties isolated (mostly High Trapped Perimeter)
18	Therry St near No. 20	12.70	0.34	0.71	0.22	H2	0.41	0.89	0.34	H2	0.46	0.98	0.43	H2	0.63	~3.0	0.73	1.52	1.08	H3+		Cul-de-sac: 42 properties isolated (mostly High Trapped Perimeter)
19	Central Rd near Avalon Pde	20.21	0.40	0.75	0.30	H2	0.46	0.96	0.44	H2	0.51	1.14	0.58	H3+	0.67	1.5	0.77	1.91	1.48	H3+		Central Rd is important link road
20	Avalon Pde/Ruskin Rowe intersection	11.12	0.12	0.90	0.12	H1	0.19	1.17	0.23	H1	0.24	1.22	0.30	H2	0.75	0.8	0.49	1.73	0.85	H3+		Avalon Pde is important link road
21	Ruskin Rowe opposite No. 6	13.76	0.24	2.19	0.40	H3+	0.28	2.21	0.46	H3+	0.32	2.22	0.59	H3+	0.75	3.7	0.67	2.36	1.32	H3+		Cul-de-sac: ~44 properties isolated (mostly High Trapped Perimeter)
22	Ruskin Rowe opposite No. 18A	18.10	0.19	2.51	0.62	H3+	0.25	2.73	0.86	H3+	0.31	3.03	1.11	H3+	0.71	1.9	0.64	4.11	2.85	H3+		Cul-de-sac: ~29 properties isolated (mostly High Trapped Perimeter)
23	Hudson Pde opposite No. 276	24.03	0.36	0.94	0.35	H2	0.41	1.14	0.47	H2	0.45	1.34	0.62	H3+	0.67	~3.0	0.69	2.22	1.57	H3+		Alternative access available via Lower Plateau and Wandeen Rds
24	Barrenjoey Rd at Bilgola Bends	43.64	0.11	1.36	0.11	H1	0.14	1.98	0.22	H1	0.16	2.34	0.32	H3+	0.67	0.5	0.24	4.20	0.89	H3+		Key route from Newport to Avalon, Whale Beach, Palm Beach; alternative routes available
25	The Serpentine, Bilgola	13.34	0.15	2.14	0.31	H3+	0.20	2.36	0.46	H3+	0.24	2.51	0.59	H3+	0.67	1.75	0.45	3.09	1.38	H3+		Some properties may lose access; alternative routes available for sector
26	Barrenjoey Rd opposite No. 588 (Avalon)	4.63	0.19	1.10	0.17	H1	0.23	1.39	0.27	H1	0.26	1.57	0.35	H2	n/a	n/a	1.01	2.33	0.86	H3+		Key route to North Avalon, Whale Beach, Palm Beach; alternative circuitous route may be available via Hudson Pde, Riverview Rd etc

MHL ID (Fig 8.7)	Location of road low-point	Elevation (m AHD)	20% AEP				5% AEP				1% AEP						PMF				AADT	Comments
			D (m)	V (m/s)	D*V	Haz Class	D (m)	V (m/s)	D*V	Haz Class	D (m)	V (m/s)	D*V	Haz Class	Time to peak (hrs)	Dur (hrs)	D (m)	V (m/s)	D*V	Haz Class		
27	Barrenjoey Rd north-bound north of Avalon Pde	4.58	0.14	0.29	0.04	H1	0.54	0.34	0.05	H3+	0.65	0.42	0.08	H3+	n/a	n/a	1.78	0.84	0.25	H3+		Key route to North Avalon, Whale Beach, Palm Beach; alternative circuitous route may be available via Hudson Pde, Riverview Rd etc
28	Barrenjoey Rd south-bound, north of Avalon Pde	4.87	n/a	n/a	n/a	n/a	0.25	0.26	0.07	H1	0.35	0.50	0.18	H2	n/a	n/a	1.49	0.74	0.49	H3+		Key route from North Avalon, Whale Beach, Palm Beach; alternative circuitous route may be available via Hudson Pde, Riverview Rd etc
29	Edmund Hock Avenue	6.64	0.29	0.63	0.15	H1	0.41	0.94	0.34	H2	0.49	1.13	0.49	H2	n/a	n/a	0.81	1.75	1.33	H3+		Minor road
30	The Appian Way low-point	25.74	0.27	0.38	0.11	H1	0.34	0.44	0.16	H2	0.38	0.48	0.19	H2	n/a	n/a	0.56	0.77	0.45	H3+		Cul-de-sac: isolates ~50 properties (mostly High Trapped Perimeter)
31	Access to Pittwater Palms	8.68	0.37	0.72	0.23	H2	0.55	0.96	0.45	H3+	0.71	1.05	0.60	H3+	n/a	n/a	1.47	1.59	1.15	H3+		Cuts off access to retirement village
32	Bowling Green Lane low-point	5.60	0.23	0.54	0.12	H1	0.44	1.11	0.47	H2	0.58	1.47	0.84	H3+	n/a	n/a	1.24	1.91	2.32	H3+		Cuts off cars in car park

Notes:

For hazard classification refer to Figure 7.3; yellow shading describes criteria corresponding to H2; pink shading describes criteria corresponding to H3+

Time to peak and durations of flooding over road low-points are derived from modelled time series outputs, which are not available for all locations

AADT = annual average daily traffic; the brown shading reflects estimated relative importance of the route in terms of traffic volumes and flood risk considerations, with dark brown for most important

Stage hydrographs at five locations are presented from Figure 8.8 to Figure 8.12. The **rate of rise** can be very rapid. For most design events at Barrenjoey Road at Palm Beach, the flow rises 0.6–0.7m to peak within about 40 minutes of the commencement of the storm; the PMF rises there to peak within 20 minutes (Figure 8.8). For Barrenjoey Road opposite Careel Bay ovals, the flow rises to peak within 1.5–2.5 hours for most design events, but in less than 30 minutes for the PMF (Figure 8.9). For Elaine Avenue, flooding peaks within 50–70 minutes of the storm's commencement (Figure 8.10). For the intersection of Avalon Parade and Old Barrenjoey Road, flooding peaks within about an hour, except for the PMF (37 minutes) (Figure 8.11). For Ruskin Rowe, most floods peak within 45 minutes but the PMF peaks within 20 minutes (Figure 8.12).

The **duration** of flooding varies according to site. Barrenjoey Road is seen to be flooded for more than four hours at Palm Beach (Figure 8.8) and opposite the Careel Bay ovals where drainage is evidently obstructed (Figure 8.9). The depth of flooding at the Elaine Avenue low point would exceed 0.2m for 1.5 hours for all design events but the PMF (Figure 8.10). A similar duration applies at the intersection of Avalon Parade and Old Barrenjoey Road (Figure 8.11). Ruskin Rowe is also expected to be flooded for a few hours (Figure 8.12).

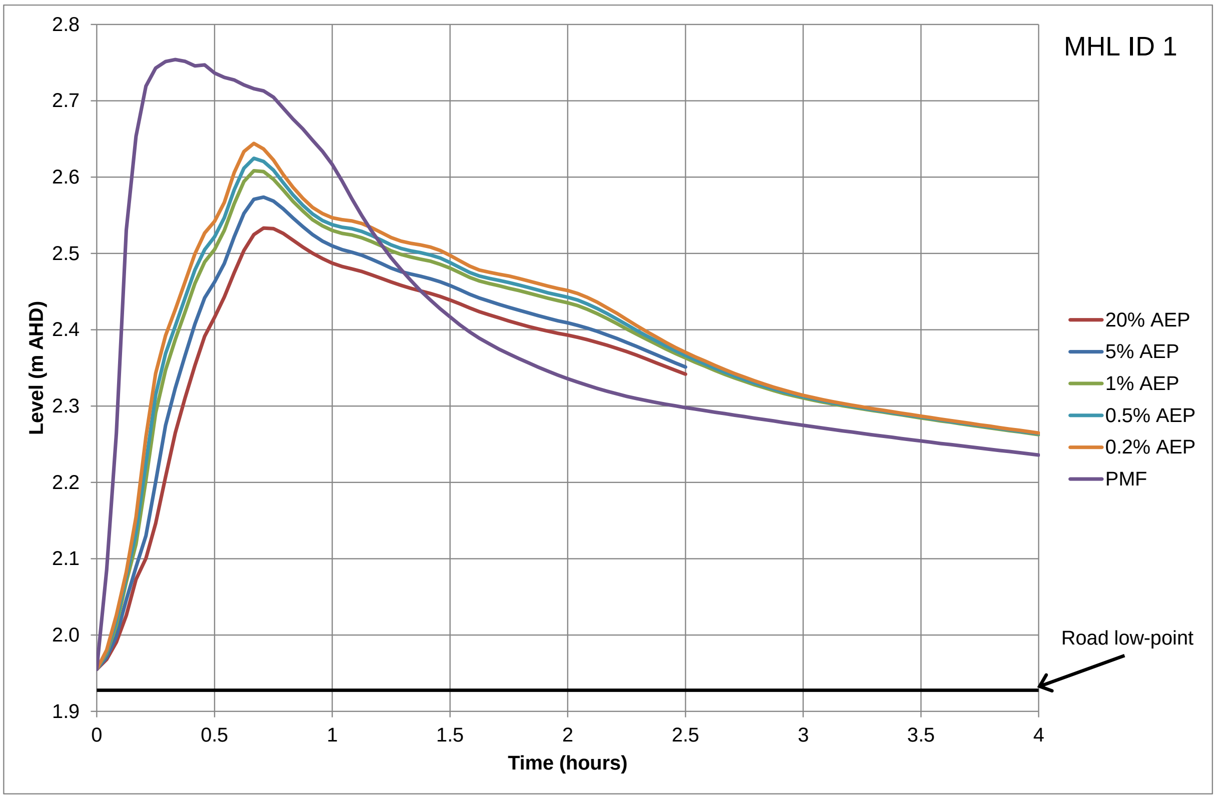


Figure 8.8 – Stage hydrographs, Barrenjoey Road at Palm Beach

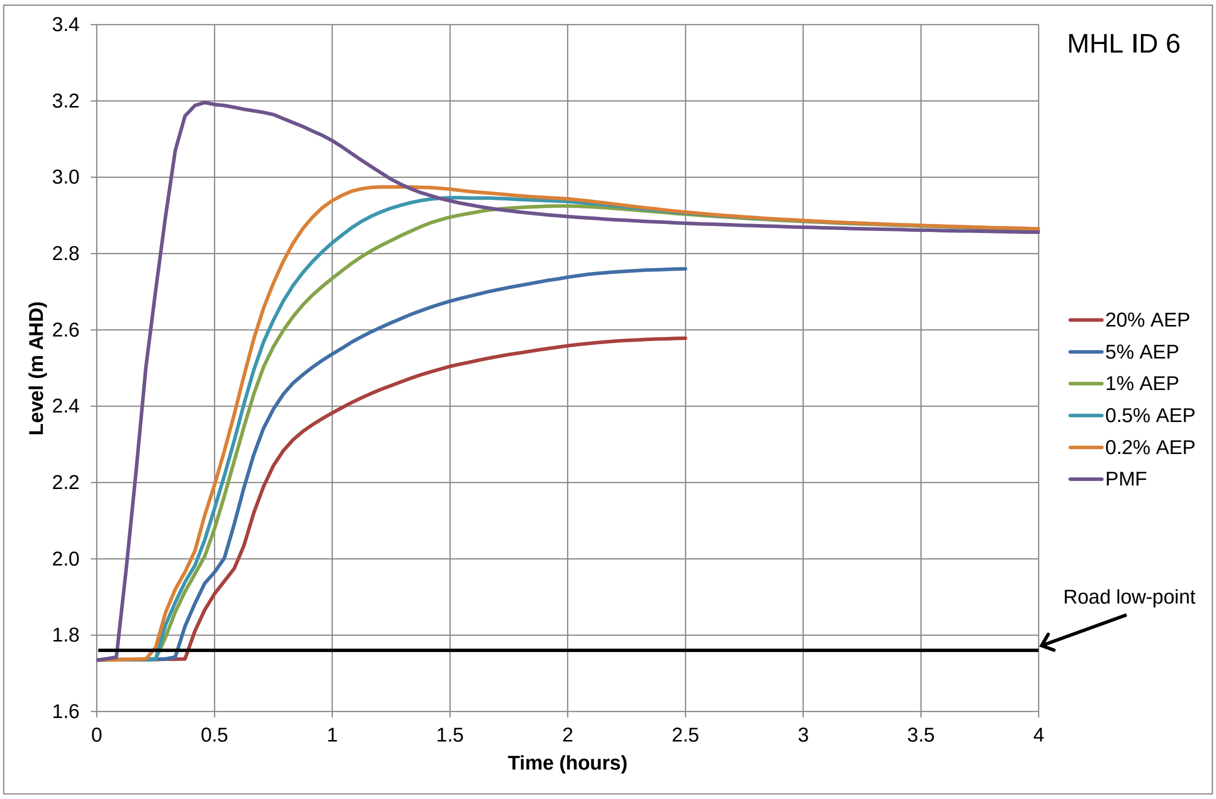


Figure 8.9 – Stage hydrographs, Barrenjoey Road adjacent to Careel Bay ovals

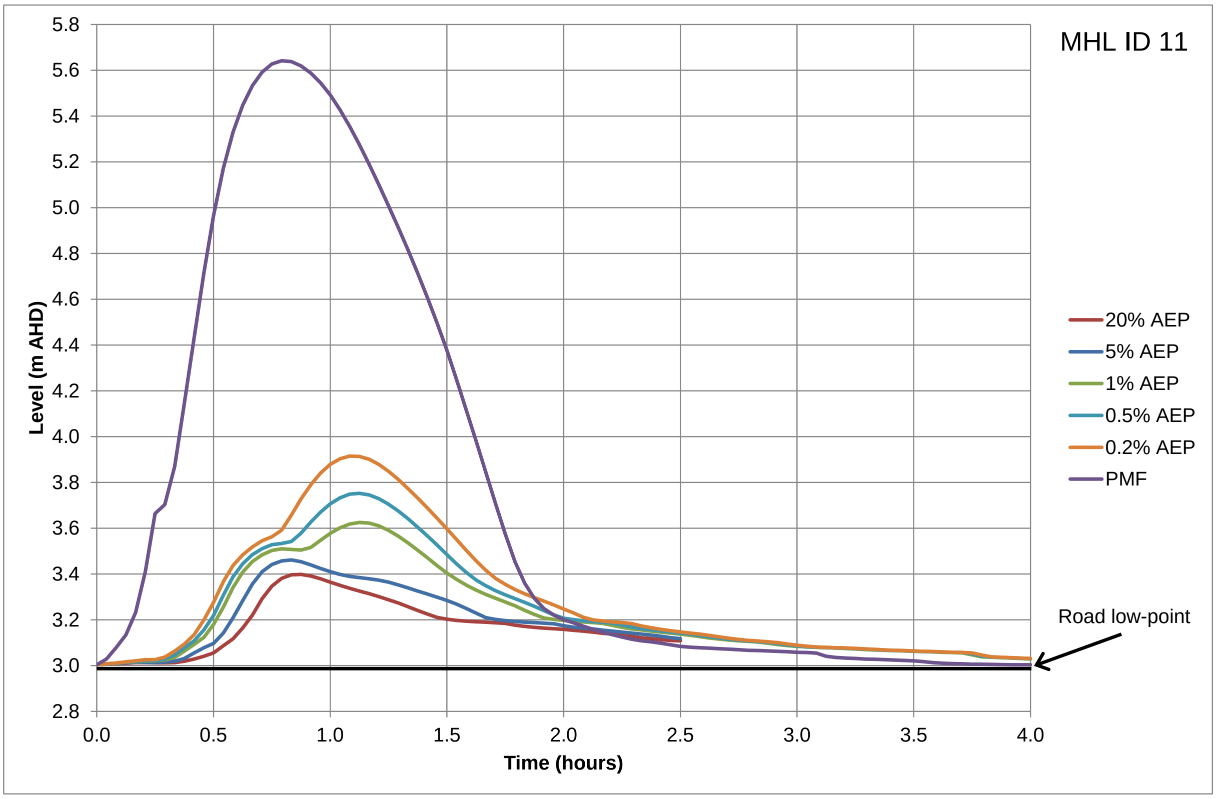


Figure 8.10 – Stage hydrographs, Elaine Avenue

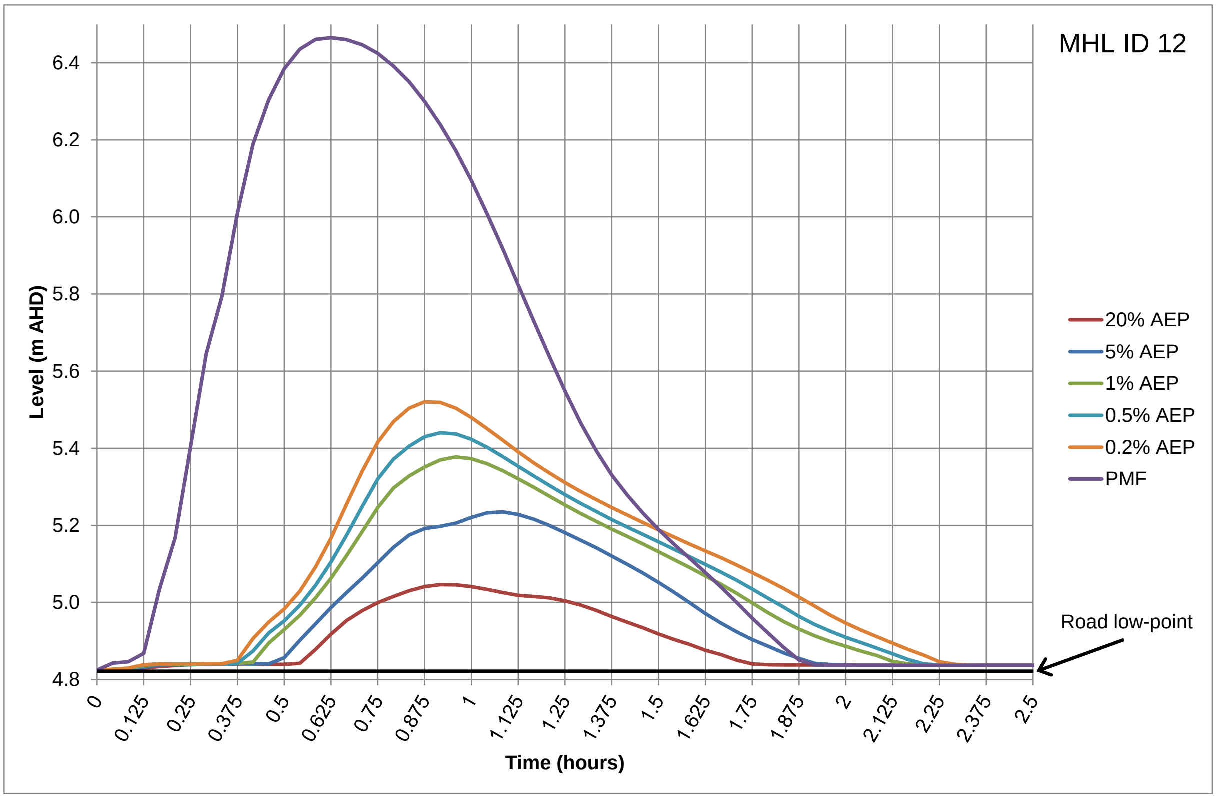


Figure 8.11 – Stage hydrographs, intersection Avalon Parade/Old Barrenjoey Road

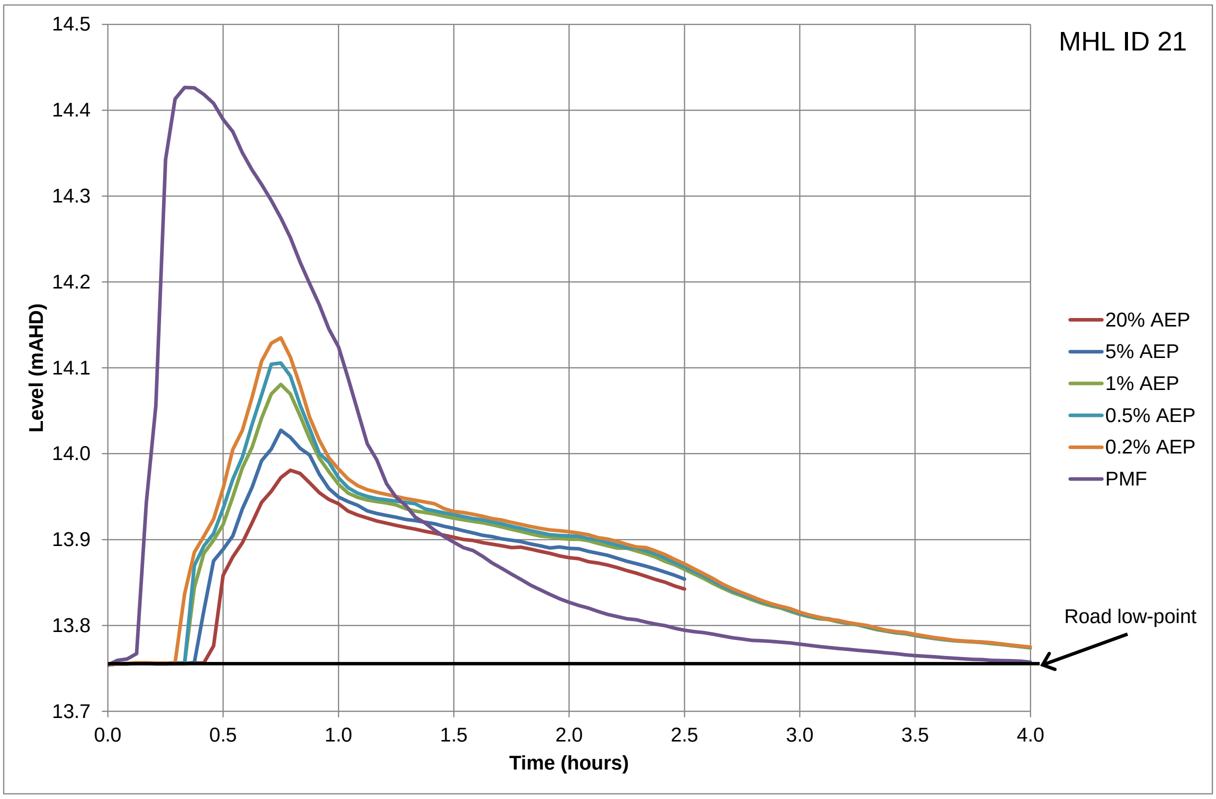


Figure 8.12 – Stage hydrographs, Ruskin Rowe

8.4 Evacuation Constraints

In order to assist in the planning and implementation of response strategies, the NSW SES in conjunction with OEH developed guidelines to classify communities according to the ease of evacuation (DECC, 2007). The guidelines classify communities as either ‘Flood Islands’ (either ‘High Flood Island’ if isolated but not flooded or ‘Low Flood Island’ if first isolated then flooded), Trapped Perimeter (either ‘High’ if isolated but not flooded or ‘Low’ if first isolated then flooded), Overland Escape Route, Rising Road Access or Indirectly Affected areas.

In the Avalon to Palm Beach study area, the generally steep terrain and the many overland flow paths that drain this terrain result in a large number of High Flood Islands or High Trapped Perimeter areas that will be isolated for relatively short durations and would not be expected to require resupply. These have not been mapped. Some High Trapped Perimeter areas are identified in the ‘Comments’ column of Table 8.7, including Therry Street, Ruskin Rowe and The Appian Way.

Attention has instead been focussed on mapping Low Flood Islands and Low Trapped Perimeter areas since these are the areas where risk to life is heightened because, during a rising flood, egress may first be cut off, prior to inundation of the land. In this mapping, hazard categories H1 and H2 have been disregarded, because Council’s *Flood Emergency Response Planning for Development in Pittwater Policy* (Appendix 15 of Pittwater 21 DCP) recognises that this hazard presents an acceptable risk. Indeed, Figure 7.3 shows that egress on foot and in vehicles (except small vehicles) in H1 and H2 flood conditions presents low risk. Judgment has been exercised where blocks comprise a mix of H1–H2 and H3–H6 hazard categories. A WaterRIDE project was developed for the PMF to better show the dynamic progression of floods, seeing where properties are isolated prior to inundation. However, the project interval of 15 minutes limits the precision of this exercise. It is assumed that people will not be able to evacuate to adjacent properties over fences. Some consideration has been given to building locations on a block affected by flooding, but no consideration has been given to building styles. A raised building effectively represents a Low Flood Island if the floor level is not above PMF. Or a raised building may facilitate shelter-in-place where the floor level is above PMF and the structure can withstand PMF forces (effectively representing a High Flood Island when viewed at a fine scale). Mapping Flood Emergency Response Planning classes is to a degree a subjective exercise. Nevertheless it serves to highlight areas most at risk in the event of severe flooding where people fail to evacuate early or shelter in houses unsuitable for that purpose.

Figure 8.13 plots the locations of areas identified as Low Flood Island or Low Trapped Perimeter in the PMF. Some of the key areas are described below:

- **Central Road, Avalon Beach**. Two building footprints towards the western end of Central Road are subject to H3+ hazard conditions and road egress would be cut by H5 conditions. These properties are therefore considered Low Flood Island.
- **Ruskin Rowe, Avalon Beach**. Parts of several properties are first surrounded by floodwater before the ground is flooded (Low Flood Island).

- **Pittwater Palms retirement village, Avalon Beach**. Flooding of Avalon Parade at the entrance to the village and of the access roads within the village means that access to and egress from Pittwater Palms will be lost prior to inundation of virtually the entire property in an extreme flood. This represents a Low Flood Island.
- **Avalon Commercial District**. Flooding on the northern side of the commercial centre along Bowling Green Lane and through Dunbar Park, along the southern and western sides along Avalon Parade and Old Barrenjoey Road, and along the eastern side down Edmund Hock Avenue and past the Woolworths building, means that the area within these boundaries may be first isolated by flooding then inundated, representing a dangerous Low Flood Island setting in an extreme flood.
- **Elaine Avenue, Avalon Beach**. Flow from a local overland flow catchment to the west of Elaine Avenue can cut egress from the southern part of the street (at MHL ID No. 11 in Figure 8.7). The isolated area may then be flooded to severe depths, setting this area apart as one of the most serious Low Flood Islands in the study area.
- **Barrenjoey Road, Avalon Beach**. About seven properties along a part of Barrenjoey Road parallel to Elaine Avenue are subject to H3+ flooding, have H3+ flooding on the road outside their properties, and, in view of the road gradients, cannot be categorised as Rising Road Access, so are categorised as Low Flood Island.
- **John Street/William Street, Avalon Beach**. A block of 14 properties bounded by John Street, William Street and Careel Creek is classified as a Low Flood Island. Another nine properties in John Street and Toorak Place are wholly or partly classified as Low Trapped Perimeter.
- **Burrawong Road/Barrenjoey Road, Avalon Beach**. The flow path from Albert Road to Burrawong Road to Barrenjoey Road opposite the Careel Bay ovals results in a loss of access to about seven properties that are subject to H3+ flooding, including a townhouse development.
- **Therry Street, Avalon Beach**. Although the PMF flow path down Therry Street is relatively narrow, two properties are largely flooded by H3+ hazard conditions and access would also be lost, marking these out as Low Flood Perimeter.
- **The Serpentine, Bilgola Beach**. One property in The Serpentine, plus its access, is subject to H3+ hazard conditions, so is classified as a Low Trapped Perimeter area.
- **Hudson Parade, Clareville**. One property in the Refuge Cove area, plus its access, is subject to H5 hazard conditions, so is classified as a Low Trapped Perimeter area.
- **Waratah Road, Palm Beach**. Parts of nine properties are classed as Low Trapped Perimeter because they are inundated to H3+ hazard conditions and the road is also not expected to be trafficable. This number would increase if coastal flooding from Pittwater is concurrent with the overland flow inundation.

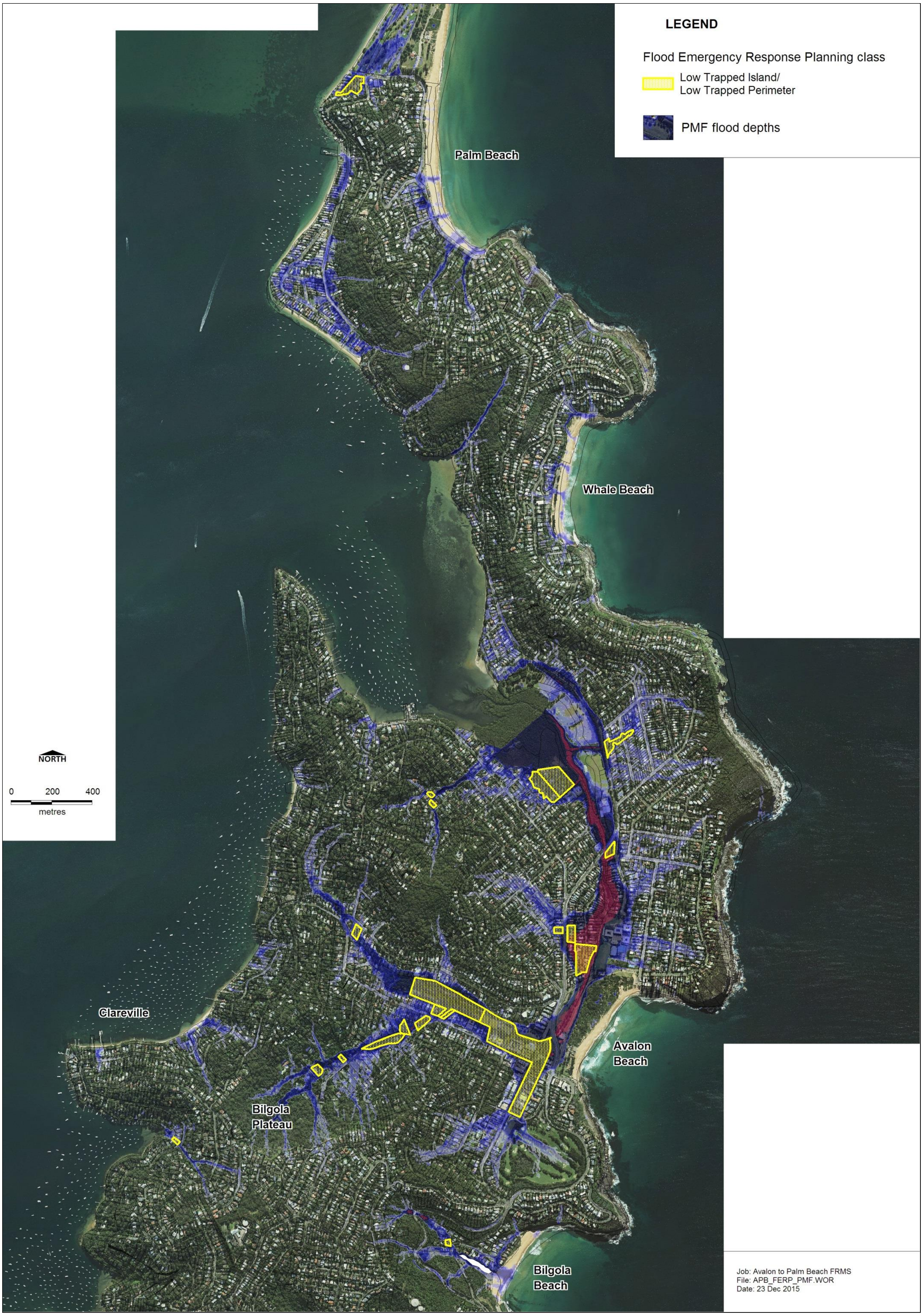


Figure 8.13 – Low flood islands or low trapped perimeter areas in PMF

8.5 Types of Flood Damage

The definitions and methodology used in estimating flood damages are well established. Figure 8.14 summarises all the types of flood damages examined in this study. The two main categories are tangible and intangible damages. Tangible flood damages are those that can be more readily evaluated in monetary terms. Intangible damages relate to the social cost of flooding and therefore are much more difficult to quantify.

Tangible flood damages are divided further into direct and indirect damages. Direct flood damages relate to the loss or loss in value of an object or a piece of property caused by direct contact with floodwaters, flood-borne debris or sediment deposited by the flood. Indirect flood damages relate to loss in production or revenue, loss of wages, additional accommodation and living expenses, and any extra outlays that occur because of the flood.

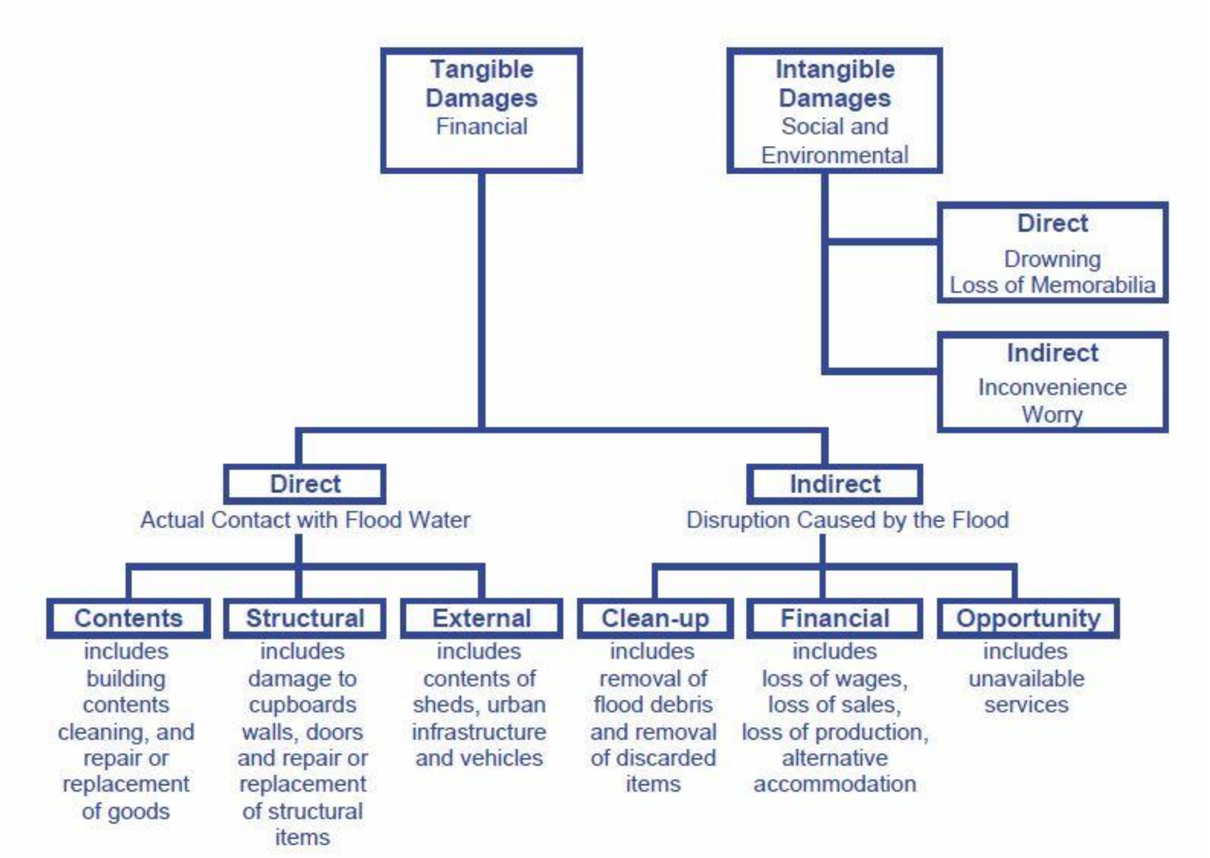


Figure 8.14 – Types of flood damage
Source: *Floodplain Development Manual* (NSW Government, 2005)

8.6 Basis of Flood Damages Calculations

Flood damages have been estimated by applying one of several stage-damage curves to every property included in the database. These curves relate the amount of flood damage that would potentially occur at different depths of inundation, for a particular property type, whether residential or commercial/industrial.

8.6.1 Residential

In October 2007, the then Department of Environment and Climate Change (now OEH) released Guidelines to facilitate a standard methodology for assessing residential flood damages. This involves tailoring stage-damage data for the particular floodplain of interest, and is recommended for use throughout NSW so that the results from one floodplain can be compared with another.

Inputs for the Avalon to Palm Beach study area are listed in Table 8.8, together with explanations for each selection. The resultant stage-damage data are provided in Appendix D of this report.

It is noted that the OEH residential stage-damage curves make allowance for both clean-up costs ($4,000 per flooded house) and the cost of time in alternative accommodation. Recent research for Hawkesbury-Nepean flood mitigation assessments suggests that an allowance of only 5% is warranted for additional indirect costs for the residential sector, and this allowance has been applied for this study.

Table 8.8 – Input variables for residential damages assessment

Input	Value	Explanation
Regional Cost Variation Factor	1.0	Rawlinsons
Post late 2001 adjustments	1.68	Changes in AWE from Nov 2001 to Nov 2014
Post Flood Inflation Factor	1.40	Regional city
Typical Duration of Immersion	1 hour	Flash flooding scenario
Building Damage Repair Limitation Factor	0.85	Short duration
Typical House Size	165 m^2	Sample of houses
Contents Damage Repair Limitation Factor	0.75	Short duration
Level of Flood Awareness	Low	*Northern Beaches Flood & Coastal Storm Education Strategy*
Effective Warning Time	0 hour	Flash flooding scenario with small catchments
Typical Table/Bench Height	0.90	Standard
External Damage	$6,700	Standard
Clean-up costs	$4,000	Standard
Likely Time in Alternative Accommodation	2 weeks	Typically shallow flooding
Additional Accommodation Costs	$220	Standard

8.6.2 Commercial/Industrial

No standard stage-damage curves have been issued for commercial and industrial damages. The stage-damage relationships used to estimate these damages in this study are based on investigations by Water Studies (1992) and incorporated into WaterRide. Stage-damage data were factored up to November 2014 values using changes in Average Weekly Earnings (AWE). The stage-damage data are reported in $\$/m^2$ for each of six value categories (see Appendix D). Research suggests that commonly adopted commercial and industrial stage-damage data may err on the low side, particularly for a place like Avalon where there are several specialist stores likely to contain higher-value contents that the shops – predominately from inland NSW towns – where the damage data was first derived.

Recent research for Hawkesbury-Nepean flood mitigation assessments suggests that an allowance of 50% for indirect costs for the commercial sector – covering clean-up costs and disruption to trade – is appropriate.

8.6.3 Other

In some previous floodplain risk management studies, OEH has advised that damages to **infrastructure** (roads etc) be estimated as 15% of total direct residential and commercial/ industrial damages. This allowance has been included as a separate item for this study.

A number of studies also include basic stage-damage assumptions to cater for damage to **motor vehicles**. However, OEH has made clear that damages to vehicles should not influence the BCR of potential flood reducing measures, which are particularly intended to address damages to houses and to a lesser extent businesses (and associated livelihoods). Accordingly, no allowance has been made to assess damage to vehicles for this study.

Flooding can have various impacts on people's **health**, both physical and emotional. These include stress-related ailments, influenza, viral infections, heart problems and back problems (from lifting and cleaning). Consultation conducted for the current study has not yielded any information about the health-related impacts of flooding. This is not surprising since serious floods have not been observed for many years. Although it is difficult to quantify the cost of disruption, illness, injury and hospitalisation, in keeping with advice previously received from OEH, social damages have been estimated (as a separate item) as 25% of 'total damages', which are interpreted as the sum of direct residential damages and direct non-residential damages.

8.7 Economic Analysis

An economic appraisal is required for all proposed capital works in NSW, including flood mitigation measures, in order to attract funding from the State Government's Capital Works Program. The NSW Government has published two Treasury Policy Papers to guide this process: *NSW Government Guidelines for Economic Appraisal* (NSW Treasury, 2007a) and a summary in *Economic Appraisal Principles and Procedures Simplified* (NSW Treasury, 2007b).

An economic appraisal is a systematic means of analysing all the costs and benefits of a variety of proposals. In terms of flood mitigation measures, benefits of a proposal are generally quantified as *the avoided costs associated with flood damages*. The avoided costs of flood damage are then compared to the capital (and on-going) costs of a particular proposal in the economic appraisal process.

Average annual damage (AAD) is a measure of the cost of flood damage that could be expected each year by the community, on average. It is a convenient yardstick to compare the economic benefits of various proposed mitigation measures with each other and the existing situation. Figure 8.15 describes how AAD relates to actual flood losses recorded over a long period. For the current study, AAD is assessed using the potential damages derived for each design event. It is assumed that damages to buildings can commence at the 50% AEP event; the PMF is set to an ARI of once in 100,000 years.

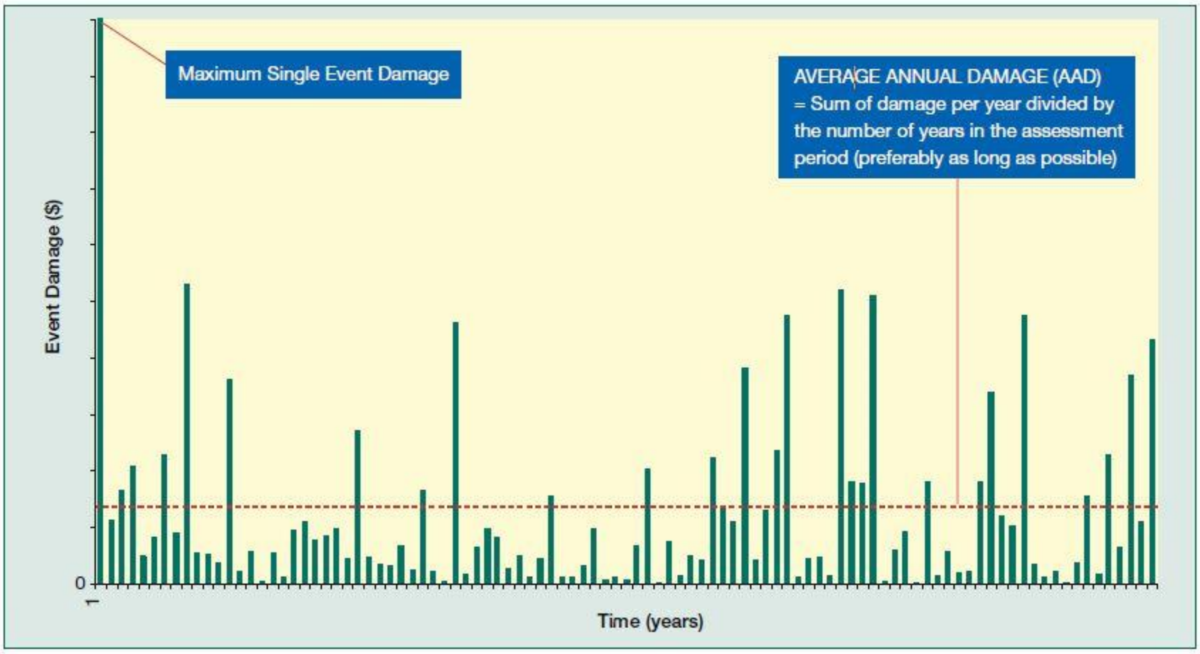


Figure 8.15 – Randomly occurring flood damage as annual average damage
Source: *Managing Flood Risk through Planning Opportunities* (HNFMSC, 2006a)

The present value of flood damage is the sum of all future flood damages that can be expected over a fixed period (usually 50 years) expressed as a cost in today's value. The present value is determined by discounting the future flood damage costs back to the present day situation, using a discount rate (typically 7%).

A flood mitigation proposal may be considered to be potentially worthwhile if the benefit–cost ratio (the present value of benefits divided by the present value of costs) is greater than 1.0. In other words, the present value of benefits (in terms of flood damage avoided) exceeds the present value of (capital and on-going) costs of the project.

However, whilst this direct economic analysis is important, it is not unusual to proceed with urban flood mitigation schemes largely on social grounds, that is, on the basis of the reduction of intangible costs and social and community disruption. In other words, the benefit–cost ratio could be calculated to be less than 1.0.

8.8 Summary of Flood Damages

Calculated flood damages and AAD for the Avalon to Palm Beach study area are presented in Table 8.9 and Table 8.10. Distinctive features include:

- The 20% AEP flood is expected to cause damages of $10.3 million;
- The 1% AEP flood is expected to cause damages of $29.0 million;
- The annual average damage within the study area is about $5.2 million, which is a measure of the cost of flood damage that could be expected each year, on average, by the community;
- The net present value of damages (discounted at 7% over a 50 year period) is $77.1 million, which represents the maximum sum that could be spent on flood mitigation measures if an economic benefit/cost ratio of 1.0 is required and all flood damages can be avoided. The reality is that mitigation works to address damages from events as rare as the PMF are rarely pursued;
- By far the largest contributor to flood damages is direct residential damage. This reflects the inundation patterns, with many more houses flooded above floor level than businesses (Table 8.2). It also reflects the OEH residential stage-damage data which allow in excess of $11K damage per house for below-floor inundation. It is also likely to reflect the adopted commercial/industrial stage-damage data, which are believed to err on the low side.

Table 8.9 – Summary of flood damage by design event

Flood Event	Predicted Actual Damage in Flood Event ($2014)	Average Annual Damage ($2014) *	Present Value of Damage ($2014) *
20% AEP	$10.3M	$5.2M	$77.1M
5% AEP	$20.3M		
1% AEP	$29.0M		
0.5% AEP	$33.5M		
0.2% AEP	$38.6M		
PMF	$80.3M		

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years

Table 8.10 – Components of flood damage for the Avalon to Palm Beach study area (AAD)

	Damage Component	Method Assessed	Cost ($2014)	
A.	Direct Residential Damage	DECC (2007) curves	$2701K	52%
B.	Indirect Residential Damage	5% of A	$135K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	$682K	13%
D.	Indirect Commercial Damage	50% of C	$341K	7%
E.	Infrastructure Damage	15% of (A + C)	$507K	10%
F.	Social Damage	25% of (A + C)	$846K	16%
	TOTAL AAD		**$5.2M**	100%

9. Risk Assessment

9.1 Risk Assessment for Study Area

Flood risk is understood as the product of the likelihood and consequences of a hazard occurring. It is useful to gain an appreciation of the overall flood risk in the Avalon to Palm Beach study area, as well as to identify the locations where the risk is greatest and investments to better manage that risk are most urgent. This chapter presents a risk assessment, drawing upon the methods described in the *National Emergency Risk Assessment Guidelines* (NEMC, 2010) and *Managing Flood Risk through Planning Opportunities* (HNFMSC, 2006a). Table 9.1 presents a risk matrix prepared using these resources. The allocation of design floods to each likelihood descriptor draws mainly on table 3 of the *National Emergency Risk Assessment Guidelines*, modified to align with the design flood information available for this study. Consequence descriptors are defined using above-floor flood depth bands following Figure 43 of *Managing Flood Risk through Planning Opportunities*. These depth categories are chosen because they relate to structural damage of a house. The allocation of risk descriptors to each likelihood/consequence combination follows table 4 of the *National Emergency Risk Assessment Guidelines*.

Table 9.2 plots the number of dwellings within each likelihood/consequence category for the Avalon to Palm Beach study area as a whole. The depths of flooding relative to dwelling floor levels were extracted for each required design event using the property database described in Section 8.1. Table 9.2 shows that nowhere in the study area is the combination of the frequency of flooding and the depth of above-floor inundation such as to define an *extreme* risk of damage to house structures. The risk is assessed as *high* for 92 dwellings, largely because of the frequency of flooding. Catastrophic damage to dwelling structures is, with two exceptions, anticipated only in events rarer than the 0.5% AEP event such as the PMF, which, because the likelihood is very rare, translates to a medium *risk* (or a *low* risk if the risk matrix used in *Managing Flood Risk through Planning Opportunities* is adopted).

Table 9.2 may be used to provide a rough guide to the risk of drowning in houses in the study area. The depths corresponding to the ‘catastrophic’ consequence roughly approximate the H4+ hazard categories in Figure 7.3, which are dangerous for people. From the modelled design floods, apart from two houses, only in the PMF do depths exceed the danger level of 1.0m (at 64 houses), with above-floor depths reaching 2.0–3.0m at eight houses in this very rare event. These houses are concentrated in Elaine Avenue. An inspection of the property database indicates that 20% of houses flooded to depths of more than 1.0m in the PMF have a second storey, which could facilitate shelter-in-place, although the assessment of Flood Life Hazard in Section 7.6 shows that a substantial part of the Elaine Avenue area is subject to H5 hazard conditions in the PMF, which requires special construction to ensure houses can withstand the forces of floodwater. Nor can evacuation from the southern part of Elaine Avenue be assured because it is a Low Flood Island. Given the characteristic rapid rises in Careel Creek (e.g. Figure 8.10), there could be considerable loss of life in a PMF, which according to table 2 of the *National Emergency Risk Assessment Guidelines* would constitute a ‘catastrophic’ consequence but only a medium risk due to the very rare likelihood of such a flood.

Table 9.1 – Risk matrix for structural damage to houses

Likelihood level		Consequence level				
		Insignificant	Minor	Moderate	Major	Catastrophic
		d < 0.0	d = 0.0–0.1m	d = 0.1–0.5m	d = 0.5–1.0m	d > 1.0m
PMF	**Very rare**	Low	Low	Low	Low	Medium
0.2% AEP	**Unlikely**	Low	Low	Medium	Medium	High
1% AEP	**Possible**	Low	Low	Medium	High	High
5% AEP	**Likely**	Low	Medium	High	High	Extreme
20% AEP	**Almost certain**	Medium	Medium	High	Extreme	Extreme

Table 9.2 – Risk matrix for structural damage to houses in study area
Note: numbers show number of dwellings in each likelihood/consequence category

Likelihood level		Consequence level				
		Insignificant	Minor	Moderate	Major	Catastrophic
		d < 0.0	d = 0.0–0.1m	d = 0.1–0.5m	d = 0.5–1.0m	d > 1.0m
PMF	**Very rare**	544	220	260	96	64
0.2% AEP	**Unlikely**	593	131	153	8	2
1% AEP	**Possible**	456	115	102	2	0
5% AEP	**Likely**	338	87	59	0	0
20% AEP	**Almost certain**	204	44	29	0	0

A risk to life also exists to drivers and their passengers who attempt to traverse flooded roads. The frequency, depth-velocity, time to peak and duration of flooding for several road low-points is assessed in Section 8.3. Many roads are flooded to peak level only 40 minutes after the commencement of the storm. This suggests it would be impractical to formally close every road in good time, and commends education to promote wise driving behaviours.

A risk to life also exists to pedestrians. Areas where significant numbers of pedestrians could intersect with H3+ hazard conditions include the Avalon commercial district and the Bilgola Beach public carparks.

9.2 Hazard and Risk at Key Locations

NSW SES has developed a matrix for assessing flood risks, presented in Figure 9.1. This plots the likelihood of occurrence against the consequences of occurrence, with the consequences defined either in terms of flood damage related to depth of inundation over building floors or in terms of the potential for fatalities and injuries to people. It is noted that one of the designated likelihoods ('Possible') relates to the 50 year ARI (2% AEP) design flood event, which has not been modelled for the Avalon to Palm Beach study area, so the 5% AEP was used as a substitute. The 20% AEP design flood has been adopted for the 'Very Likely' category, the 1% AEP flood for the 'Unlikely' category and the PMF for the 'Rare' category. Flood damages are estimated using the property database described in Section 8.1 to extract above-floor depths of flooding at buildings.

This document can be used to identify the level of risk, potential hazards or property damage and help to prioritise any control measures. Consider the likelihood and consequences for each of the identified hazards and use the table to obtain the risk level.

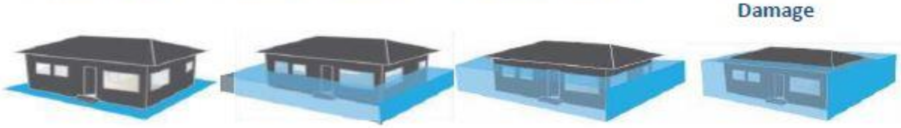
Flood & Storm catergories are adapted from US FEMA Damage Classification System for wind, storm, flood.

CONSEQUENCES OF OCCURRING	Catastrophic	Severe	Major	Moderate	Minor
People	Many injuries fatalities and widespread medical attention required	Extensive injuries hospitalisation possible fatalities, long term disability	Medical treatment required but no fatalities	Minor injuries no fatalities first aid treatment required	No injuries or fatalities little or no personal support required
Storm Damage	Most solid and all light structures destroyed; Metal structures will be toppled or crushed.	Some solid structures are destroyed; most sustain exterior and interior damage (roofs missing, interior walls exposed); many light structures are destroyed. Metal structures may show misalignment and bending	Solid structures sustain exterior damage (e.g., missing roofs or roof segments); many light structures are destroyed, many are damaged or displaced. Metal structures may not show any damage.	Generally superficial damage to solid structures (e.g., loss of tiles or roof shingles); some light structures are damaged or displaced	No visible or discernible damage
Flood Damage	Flood height over 2.0m above the floor*.	Flood height above floor* between 1.0 and 2.0m above the floor.	Flood height above floor* and up to 1.0m above the floor.	Flood height below floor	No visible or discernible damage
	A	B	C	D	E

LIKELIHOOD OF OCCURING		A	B	C	D	E
Certain to occur Expected to occur in all circumstances (every time)	1	Extreme (X)	Extreme (X)	High (H)	Medium (M)	Low (L)
Very Likely Will probably occur in most circumstances (1-5)	2	Extreme (X)	High (H)	High (H)	Medium (M)	Low (L)
Possible Might occur at some time (1 in 50)	3	Extreme (X)	High (H)	Medium (M)	Low (L)	Low (L)
Unlikely Unlikely to occur but could happen (1 in 100)	4	High (H)	Medium (M)	Low (L)	Low (L)	Low (L)
Rare May occur but only in rare and exceptional circumstances	5	Medium (M)	Low (L)	Low (L)	Low (L)	Low (L)

FLOOD DAMAGE CATERGORIES

Minor Damage | Moderate Damage | Extensive Damage | Catastrophic Damage



STORM DAMAGE CATEGORIES

Minor Damage | Moderate Damage | Extensive Damage | Catastrophic Damage

** Flood Height Above Floor only includes habitable rooms, in a residential situation, defined as: "a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom" (Source: p22, Floodplain Development Manual). Under this definition sheds, garages, laundries or verandas are generally excluded.*

Figure 9.1 – NSW SES risk assessment method

A list of key locations to be assessed was selected after consultation with Council. The consequences reported here relate to the worst affected building(s) within the designated area. Results of the flood risk assessment for these areas are set out in Table 9.3. These results are discussed below. A number of other factors are also relevant to assessing risk to life (Smith et al., 2009), which are also considered and described below. These factors include:

- Population at risk
- Warning time
- Evacuation constraints
- Shelter-in-place constraints (e.g. number of storeys)
- Population characteristics (e.g. age, mobility, transience)
- Flood experience

Table 9.3 – Risk assessment for key locations (based on flood damage)

Location	Likelihood	Consequence	Risk	Maximum risk
Ruskin Rowe	Very likely	Moderate	Medium	Medium
	Possible	**Major**	**Medium**	
	Unlikely	Major	Low	
	Rare	Severe	Low	
Pittwater Palms retirement village	Very likely	**Major**	**High**	High
	Possible	Major	Medium	
	Unlikely	Major	Low	
	Rare	Severe	Low	
Avalon commercial district	Very likely	**Major**	**High**	High
	Possible	Major	Medium	
	Unlikely	Major	Low	
	Rare	Severe	Low	
Elaine Ave	Very likely	Moderate	Medium	Medium
	Possible	Major	Medium	
	Unlikely	Major	Low	
	Rare	**Catastrophic**	**Medium**	
Albert Rd to Barrenjoey Rd	Very likely	**Major**	**High**	High
	Possible	Major	Medium	
	Unlikely	Major	Low	
	Rare	Major	Low	
Therry St	Very likely	**Major**	**High**	High
	Possible	Major	Medium	
	Unlikely	Major	Low	
	Rare	Major	Low	

Ruskin Rowe

One house in Ruskin Rowe is estimated to be just flooded over floor in the 5% AEP flood, which corresponds to a *medium* risk using the SES risk matrix. Only this one, same house is flooded over floor up to the 1% AEP event, and still to a very shallow depth (<0.1m) (*low* risk). In the PMF, several more houses are expected to be flooded over floor, including one apparently to a depth exceeding 1.0m, which still translates to a *low* risk. So based on damage at buildings, the maximum risk is *medium*. Other risk factors are summarised below:

Table 9.4 – Ruskin Rowe summary of risk factors

Factor	RRR	Explanation
Population directly at risk	Low risk	relatively few houses
Warning constraints	High risk	very short warning time
Evacuation constraints	High risk	road is high hazard floodway; some low flood islands
Shelter-in-place constraints	Medium risk	typically but not universally suitable
Population dependency (e.g. age, transience)	Low risk	standard housing
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, these other factors, particularly the relatively low number of people directly at risk from flooding of their houses, suggest that the risk is relatively **low**.

A house at the corner of Ruskin Rowe and Avalon Parade has an open channel flowing through it (H6 hazard category in the PMF), which would appear to cut off access from a house at the rear of the lot to Ruskin Rowe. Depending on internal design, there might be egress to Avalon Parade. Any blockage of the Avalon Parade culvert could amplify flooding.

Pittwater Palms retirement village

Eight unit blocks in Pittwater Palms retirement village are estimated to be flooded over floor to shallow depths (<0.1m) in the 20% AEP event, which translates to a *high* risk (and another unit is estimated to flood to a depth of 0.3m). Flood depths do not increase substantially up to and including the 0.2% AEP flood, so the risk of damage for the 5% AEP and 1% AEP floods is *medium* and *low*, respectively. Depths at a few buildings could reach 1.2m in the PMF, which translates to *low* risk. So based on damage at buildings, the maximum risk is *high*, driven by above-floor flooding in frequent events. Other risk factors are summarised below:

Table 9.5 – Pittwater Palms summary of risk factors

Factor	RRR	Explanation
Population directly at risk	High risk	127 independent living units and 41 serviced apartments
Warning constraints	High risk	very short warning time
Evacuation constraints	High risk	driveway and internal roads are high hazard floodways; low flood island
Shelter-in-place constraints	Medium risk	2nd storey is available but not internally accessible except for Lodge
Population dependency (e.g. age, transience)	High risk	retirement accommodation including reduced mobility
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, these other factors, particularly the relatively high number of aged people directly at risk from flooding of their units, confirm that the risk is relatively **high**.

Avalon Commercial District

Several shops in the Avalon Commercial District are estimated to be flooded over floor to relatively shallow depths (<0.5m) in the 20% AEP event, which translates to a *high* risk. (The largest depths are in shops on the southern and western sides of the Woolworths building). Depths do not exceed 1.0m for events up to and including the 0.2% AEP flood, so the risk of damage for the 5% AEP and 1% AEP floods is *medium* and *low*, respectively. The maximum depth in the PMF is almost 1.9m, which translates to *low* risk. Based on damage, the maximum risk is *high*. Other risk factors are summarised below:

Table 9.6 – Avalon commercial district summary of risk factors

Factor	RRR	Explanation
Population directly at risk	High risk	potentially large numbers at certain times of day
Warning constraints	High risk	very short warning time
Evacuation constraints	High risk	roads are high hazard floodways; low flood islands
Shelter-in-place constraints	Medium risk	some opportunities e.g. Avalon Library
Population dependency (e.g. age, transience)	High risk	high transience – shoppers may behave irrationally in the event of flooding
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, these other factors, particularly the relatively high number of transient people potentially at risk, confirm that the risk is relatively **high**.

Elaine Avenue

Moderate damage could occur to properties in the 20% AEP event when yards are flooded, which translates to *medium* risk. One house is estimated to be just flooded in the 5% AEP event, which translates to *medium* risk. A few more houses are flooded over floor to shallow depths (<0.3m) in the 1% AEP flood, which translates to *low* risk. But in the PMF, several houses would sustain catastrophic damage when flooded to depths of more than 2.0m, which, given the low probability, translates to a *medium* risk. Based on damage, the maximum risk is *medium*. Other risk factors are summarised below:

Table 9.7 – Elaine Avenue summary of risk factors

Factor	RRR	Explanation
Population directly at risk	Medium risk	significant number of houses directly at risk
Warning constraints	High risk	short warning time; slightly longer time to rise compared to upstream
Evacuation constraints	High risk	low flood island in south Elaine Ave
Shelter-in-place constraints	High risk	significant PMF depths; 20% of buildings flooded by more than 1m in PMF are multi-storey
Population dependency (e.g. age, transience)	Low risk	standard housing
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, these other factors, particularly the evacuation constraints and the significant PMF depths, suggest that the risk is **medium–high**.

Albert Road to Barrenjoey Road flow path

A few houses in Albert Road and townhouses in Burrawong Road, plus the Veterinary Hospital in Barrenjoey Road, are flooded by overland flows to relatively shallow depths in all modelled events from the 20% AEP flood to the PMF (maximum ~0.8m). When this major consequence is tied to the various likelihoods, the maximum risk is *high*, driven by above-floor flooding in frequent events. Other risk factors are summarised below:

Table 9.8 – Albert Road to Barrenjoey Road summary of risk factors

Factor	RRR	Explanation
Population directly at risk	Low risk	few houses
Warning constraints	High risk	very short warning time
Evacuation constraints	High risk	townhouse driveway is high hazard floodway
Shelter-in-place constraints	Low risk	low depths in PMF; some multi-storey
Population dependency (e.g. age, transience)	Medium risk	potential visitors to vet; pets
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, these other factors, particularly the relatively low number of people directly at risk from flooding of their houses, suggest that the risk is **medium** rather than high.

Therry Street

A few houses in Therry Street are flooded by overland flows to relatively shallow depths in all modelled events from the 20% AEP flood to the PMF (maximum ~0.7m). When this major consequence is tied to the various likelihoods, the maximum risk is *high*, driven by above-floor flooding in frequent events. Other risk factors are summarised below:

Table 9.9 – Therry Street summary of risk factors

Factor	RRR	Explanation
Population directly at risk	Low risk	few houses
Warning constraints	High risk	very short warning time
Evacuation constraints	High risk	road cut by high hazard floodways; low flood islands
Shelter-in-place constraints	Low risk	low depths in PMF
Population dependency (e.g. age, transience)	Low risk	standard housing
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, these other factors, particularly the relatively low number of people directly at risk from flooding of their houses, suggest that the risk is **medium** rather than high.

Bilgola Beach carparks

A small and very steep local overland flow catchment drains towards Bilgola Beach. Flood modelling shows that a high hazard floodway can flow through the public carparks that service the beach. Although the flow path is relatively narrow, and able-bodied adults should be able to escape to higher ground to the south, a sudden storm on a summer afternoon could mobilise many vehicles, which would in turn pose serious hazards to people and vehicles and a café located near the beach. Risk factors are summarised below:

Table 9.10 – Bilgola Beach carparks summary of risk factors

Factor	RRR	Explanation
Population directly at risk	Medium risk	potentially significant number at peak season/time
Warning constraints	High risk	very short warning time
Evacuation constraints	Low risk?	overland escape route to the south
Shelter-in-place constraints	High risk	no opportunities
Population dependency (e.g. age, transience)	High risk	high transience – visitors may behave irrationally in the event of flooding
Flood inexperience	High risk	little flood experience

RRR = relative risk rating

Overall, particularly given the potential for fast-rising, high velocity flows and significant numbers of visitors unfamiliar with flooding, the risk is considered **medium**.

10. Preliminary Identification and Assessment of Floodplain Risk Management Options

In accordance with the 2005 Floodplain Development Manual, NSW Public Works has investigated a range of floodplain risk management measures that aim to reduce the social, environmental and economic impacts of flooding in the Avalon to Palm Beach study area.

Floodplain risk management measures may be classified into three groups:

- *Flood modification measures* – measures that modify the behaviour of the flood itself, typically through structural works that reduce flood levels or velocities, or exclude floodwaters from areas that would otherwise flood;
- *Property modification measures* – measures that modify existing development (e.g. voluntary purchase schemes, voluntary house raising schemes, flood proofing) and/or ensure appropriate future development of property and community infrastructure through application of flood-related development controls;
- *Response modification measures* – measures that modify the response of the community to better cope with a flood event (e.g. flood warning, emergency management, community flood education).

Initially a full list of potential options was developed in consideration of:

- Distribution of high flood risk areas, potential over floor flooding and flood damages,
- Hydraulic flood behaviour, existing drainage capacity and the availability of open space for storage
- Community input from the community questionnaire and Avalon to Palm Beach FRM Working Group
- Pittwater Council recommendations
- Review of recommended options from Careel Creek Floodplain Risk Management Plan (Lawson and Treloar 2002)
- Review of Council flood policy and flood-related development controls
- Review of emergency response and evacuation issues.

Figure 10.1 shows the locations of mappable flood risk management options including flood modification options and flood warning. No feasible flood modification measures were identified in the study area north of the Careel Creek catchment, which reflects the topography of that area. The catchments are typically very small, with very steep gradients in the upper catchments and very flat gradients in the low lying foreshore areas. This results in the sparse nature of flood affectation which limits the number of properties that could benefit from any particular option and therefore limits the economic merit of those options. In addition, the steep nature of the upper catchments presents difficulties in capturing flows with pits and piping and does not provide appropriate sites for detention storage. In the flat, low-lying foreshore areas, opportunity to alleviate flooding through drainage infrastructure is limited by a lack of gradient to the receiving waters.

In order to formulate preferred management options for inclusion in a floodplain risk management plan, the advantages and disadvantages of all options must be assessed in a comparative manner. The decision process involves assessment of multiple, potentially conflicting objectives. A matrix is a useful tool for formalising a multi-criteria analysis so that the options that best satisfy the various objectives can be identified. The multi-criteria assessment matrix developed for this study is shown in Table 10.1. The criteria were developed and weighted in consideration of Appendix G of the NSW Floodplain Development Manual, Pittwater Council recommendations, and the study team's engineering judgement and industry experience. A score from 1 to 5 is given to each option for each criterion to assess the benefits or disbenefits it would be expected to provide.

The resulting preliminary assessment of options is presented in Table 10.2. This assessment helped identify which options warranted further investigation. Options that were considered worthy of further investigation or requiring further explanation are described and discussed in following chapters.

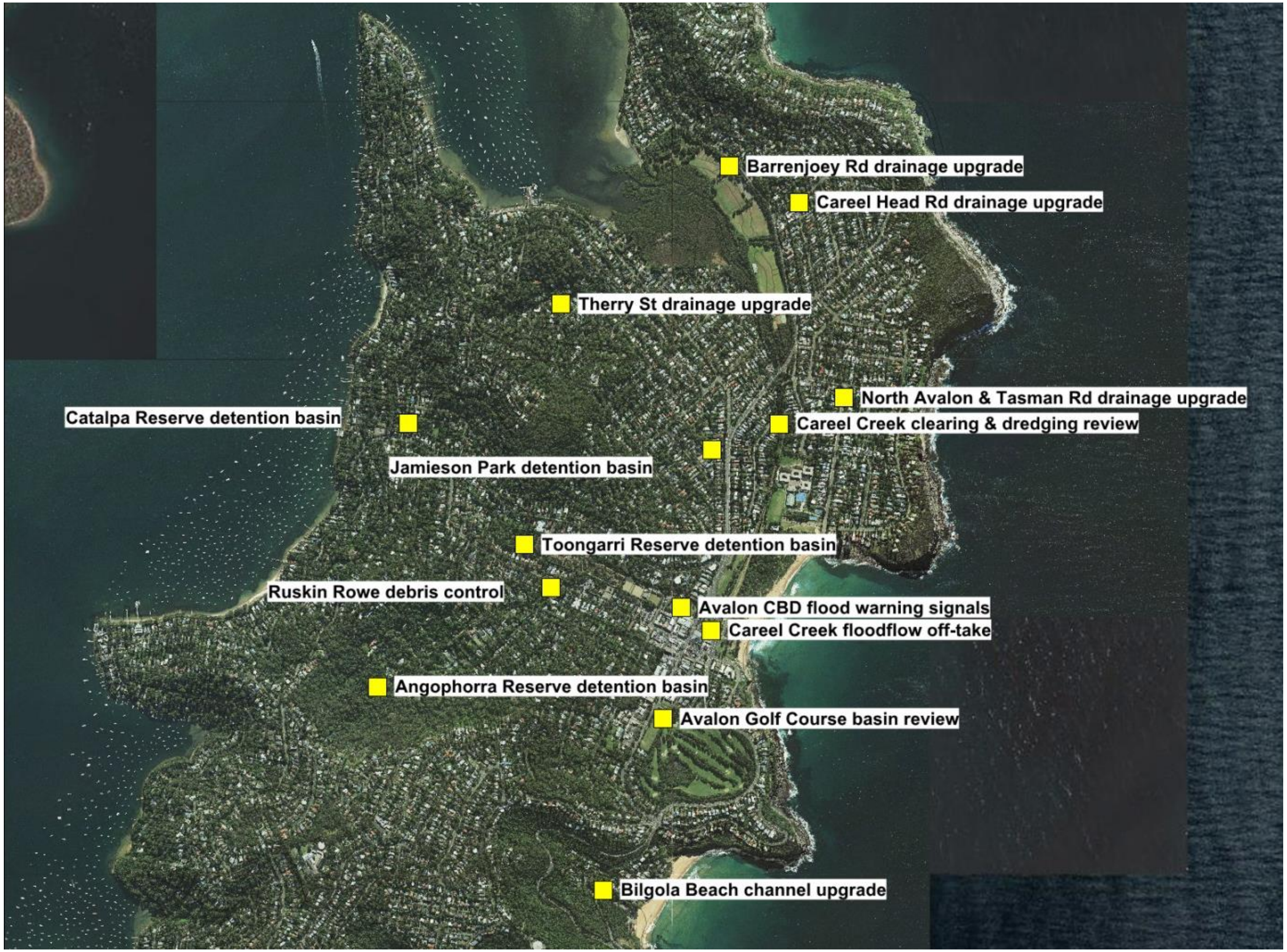


Figure 10.1 – Location of preliminary flood risk management options

Table 10.1 – Option assessment criteria

Item	Score				
	1	2	3	4	5
	Negative		Neutral	Positive	
Impact on Flood Behaviour (Hydraulic Hazard)	Significant increase in hydraulic hazard	Some increase in hydraulic hazard	Neutral	Some decrease in hydraulic hazard	Significant decrease in hydraulic hazard
Number of Properties Benefited	>5 properties negatively impacted	1-5 properties negatively impacted	Neutral	1-5 properties positively impacted	>5 properties positively impacted
Technical Feasibility	Significant issues (unproven, high risks)	Some issues (complex, some difficulty)	Minor issues	Negligible issues	No issues (proven, well established, no risks)
Economic Merit (benefit/cost ratio)	Very low (0-0.5)	Low (0.5-0.8)	Neutral (0.8-1.2)	High (1.2-2.0)	Very high (>2)
Financial Feasibility (funding, Government assistance & grants)	Very unlikely to receive funding	Unlikely to receive funding	Neutral	Likely to receive funding	Very likely to receive funding
Environmental and Ecological Benefits	Significant disbenefits	Some disbenefits	Neutral	Some benefits	Significant benefits
Impact on Risk to Life	Significant increase in risk to life	Some increase in risk to life	Neutral	Some decrease in risk to life	Significant decrease in risk to life
Impacts on SES	Significant disbenefit to SES	Some disbenefit to SES	Neutral	Some benefit to SES	Significant benefit to SES
Long-term Performance (design life & climate change)	Very low	Low	Neutral	High	Very high
Legislative & Permissibility Requirements (including political & administrative issues)	Significant issues affecting implementation	Some issues affecting implementation	Minor issues affecting implementation	Negligible issues affecting implementation	No issues affecting implementation
Social Impact / Community Acceptance	Majority against, minimal support	Some against	Neutral	Some for	Majority for, few opposed

Table 10.2 – Preliminary option assessment matrix shown from highest to lowest ranking

Option	Assessment Criteria										
	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Economic Merit	Financial Feasibility	Environmental and Ecological Benefits	Impact on Risk to Life	Impacts on SES	Long-term Performance	Legislative & Permissibility Requirements	Social Impact / Community Acceptance
Flood Education	3	3	5	5	5	3	5	5	4	4	4
Flood Warning for Avalon CBD	3	3	4	5	5	3	5	5	4	4	4
Flood Emergency Response Plan template for Commercial Sector	3	3	5	5	5	3	4	4	4	5	4
Implement updated flood risk management DCP	3	3	5	5	5	3	5	4	5	4	2
Flood-proofing brochures	3	3	5	5	5	3	3	3	4	5	4
Detention Basin in Catalpa Reserve	4	4	4	4	4	2	3	3	4	3	4
Detention Basin in Toongarri Reserve	4	5	2	4	4	2	3	3	4	2	4
Voluntary House Raising Scheme	3	5	2	3	3	3	4	3	4	2	3
Jamieson Park Detention Basin upgrade	4	4	2	2	4	3	3	3	4	3	4
Therry Street drainage upgrades	4	4	3	1	3	3	3	3	4	3	4

Option	Assessment Criteria										
	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Economic Merit	Financial Feasibility	Environmental and Ecological Benefits	Impact on Risk to Life	Impacts on SES	Long-term Performance	Legislative & Permissibility Requirements	Social Impact / Community Acceptance
Careel Head Road drainage upgrades	4	4	3	2	3	3	4	3	3	2	3
Regular clearing of large tree stems from Careel Creek channel	4	3	4	3	3	2	3	3	3	2	4
Debris Control upstream of Ruskin Rowe culvert	3	3	3	2	4	3	4	3	4	3	3
Improved drainage from Barrenjoey Road through Careel Bay Oval, North Avalon	4	4	4	2	4	2	3	3	2	2	3
Augmentation of Golf Course basin	4	3	3	2	3	3	3	3	4	2	3
Voluntary House Purchase Scheme	3	4	4	1	1	3	4	4	5	3	2
Drainage upgrades North Avalon Rd, Tasman Rd & Catalina Cres.	3	4	2	2	3	3	3	3	4	2	3
Flood compatible riparian vegetation along Careel Creek	3	3	4	3	3	3	3	3	2	2	3
Careel Creek Flood Off-take Pipe	5	5	1	3	2	1	4	3	2	1	1
Raise footbridge / pipe crossing of lower Careel Creek	4	3	3	2	3	3	3	3	3	2	3

Option	Assessment Criteria										
	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Economic Merit	Financial Feasibility	Environmental and Ecological Benefits	Impact on Risk to Life	Impacts on SES	Long-term Performance	Legislative & Permissibility Requirements	Social Impact / Community Acceptance
Toongarri Reserve swale	3	3	3	2	3	3	3	3	4	3	3
Improve flushing of lower Careel Creek to address odours	3	3	2	2	1	3	3	3	4	3	5
Install flood compatible fencing on properties within the floodplain	3	3	4	2	2	3	3	3	3	3	2
Detention Basin in Angophora Reserve upstream of Ruskin Rowe	4	3	2	2	3	2	3	3	4	2	2
Dredging & clearing of the lower reaches of Careel Creek	4	4	2	2	3	1	3	3	2	1	3
Bilgola Beach open channel enlargement & erosion control	3	3	2	2	3	2	3	3	3	2	3
Widening of Careel Creek "bottlenecks"	3	3	2	2	3	2	3	3	3	2	2
John Street levee	3	3	3	1	3	2	3	3	2	2	2

11. Flood Modification Options

11.1 Introduction

Based upon the preliminary multi-criteria assessment described in Chapter 10, flood modification options deemed to warrant further consideration are evaluated in this chapter. Particular focus is given to detention basins and drainage upgrades. An analysis of benefit-cost ratio (BCR) has been undertaken for a number of these options. The results are shown in Table 11.1, together with an assessment of the benefits each option provides in terms of reduction of the incidence of above-floor flooding.

11.2 Detention Basins

Detentions basins, also known as detention storages or retarding basins, are areas of open space or ponds that collect and temporarily store floodwaters for release at a controlled rate. This results in reduced peak flow rates and levels downstream and typically more efficient utilisation of the existing trunk drainage network capacity. The options considered in this study are 'dry' basins which fill intermittently during floods and drain when the flood has passed.

The majority of open space in the Avalon to Palm Beach study area is located low in the catchment within the Careel Creek floodplain, and opportunities for detention storage are therefore limited. Potential detention basin sites have been identified at Catalpa Reserve, Toongarri Reserve, Jamieson Park and Angophora Reserve, and are assessed below along with augmentation of the existing Avalon Golf Course basin.

Table 11.1 – Flood modification options BCR assessment & premises protected

	Base Case	Catalpa Reserve Detention Basin	Toongarri Reserve Detention Basin	Catalpa & Toongarri Reserve Detention Basins	Jamieson Park Detention Basin	Careel Head Rd Drainage Upgrades	Barrenjoey Rd Drainage Upgrades	TherrySt Drainage Upgrades
Residential								
Reduction in no. houses flooded over floor in 1% AEP	*219**	6	5	11	3	1	2	0
Reduction in no. houses flooded over floor in 5% AEP	*146**	3	9	11	2	2	1	0
Reduction in no. houses flooded over floor in 20% AEP	*73**	0	0	0	1	2	0	0
Residential AAD	$2,701,494	$2,670,759	$2,651,016	$2,623,625	$2,680,982	$2,668,835	$2,692,365	$2,699,555
Residential NPV (7%, 50y)	$39,984,134	$39,529,233	$39,237,011	$38,831,612	$39,680,535	$39,500,746	$39,849,008	$39,955,435
Direct Res Benefits (reduced NPV of flood damages)	-	$454,901	$747,123	$1,152,521	$303,599	$483,388	$135,126	$28,698
Non-residential								
Reduction in no. premises flooded over floor in 1% AEP	*101**	4	4	4	0	0	0	0
Reduction in no. premises flooded over floor in 5% AEP	*71**	0	1	1	0	0	0	0
Reduction in no. premises flooded over floor in 20% AEP	*31**	0	0	0	0	0	0	0
Non-residential AAD	$681,670	$672,778	$642,846	$641,491	$681,670	$681,258	$681,670	$681,670
Non-residential NPV (7%, 50y)	$10,089,229	$9,957,613	$9,514,603	$9,494,550	$10,089,229	$10,083,130	$10,089,229	$10,089,229
Direct Non-res Benefits (reduced NPV of flood damages)	-	$131,616	$574,626	$594,679	$0	$6,099	$0	$0
Total (including direct residential and non-residential, indirect residential and non-residential, infrastructure and social)								
Total AAD	$5,212,341	$5,150,879	$5,065,380	$5,023,090	$5,182,598	$5,164,201	$5,199,103	$5,209,529
Total NPV (7%, 50y)	$77,146,530	$76,236,853	$74,971,412	$74,345,483	$76,706,311	$76,434,029	$76,950,598	$77,104,917
Total benefits (reduced NPV of flood damages)	-	$910,000	$2,175,000	$2,800,000	$440,000	$712,500	$196,000	$42,000
Estimated Capital Cost	-	$660,000	$1,250,000	$1,910,000	$1,375,000	$1,400,000	$500,000	$500,000
Benefit-cost ratio	-	**1.4**	**1.75**	**1.5**	**0.3**	**0.5**	**0.4**	**0.1**

**Total number of houses/premises flooded over floor for base case*

11.2.1 Catalpa Reserve basin

Catalpa Reserve provides a potential site for detention storage, with open space available along one of the major flow paths feeding into Careel Creek (see Figure 11.1).

While limited storage could be provided relatively easily by constructing an embankment along the southern boundary of the park, additional excavation would be required to provide sufficient storage for flood mitigation, along with additional pits and pipes as current capacity is already exceeded in the 1% AEP design flood event.

Flood modelling of this option was undertaken to assess the benefits of a basin in alleviating downstream flooding and reducing flood damages. The scenario modelled was relatively modest, with a typical embankment height of 0.5-1.0 m and excavation depths of 0.5-1.0 m over an 1800 m^2 area, so as to maintain public amenity of the reserve and limit residual risk (see Figure 11.2). Opportunity to increase basin storage may be possible through a detailed design process. Some trees would need to be removed or relocated to construct this option. New trees and shrubs could be planted within the basin to compensate for this.

For the 1% AEP design event the modelled basin reduces peak flood levels by over 0.1 m in a number of adjacent properties, while reductions of over 0.05 m were observed over a relatively large area including properties as far downstream as Pittwater Palms. For the 20% AEP event reductions in flood levels were more pronounced at adjacent properties (> 0.18 m) and immediately downstream (> 0.10 m), however benefits became negligible moving further downstream toward Pittwater Palms.

The significance of these reductions in peak flood levels is well illustrated by the information regarding reductions in flood damages and protection of properties from over floor flooding presented in Table 11.1. It is estimated that the Catalpa Reserve basin would protect 3 houses from over floor flooding in the 5% AEP event, and 6 houses and 4 non-residential premises in the 1% AEP event, resulting in reductions in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $910,000. The capital cost of this option is estimated at $660,000, resulting in a benefit-cost ratio (BCR) of 1.4.

This option demonstrates high economic merit and is therefore recommended in the draft Floodplain Risk Management Plan. If adopted, the detailed design would need to minimise environmental impact and maintain or improve public amenity of the reserve.

Figure 11.1 – View looking south-west across Catalpa Reserve

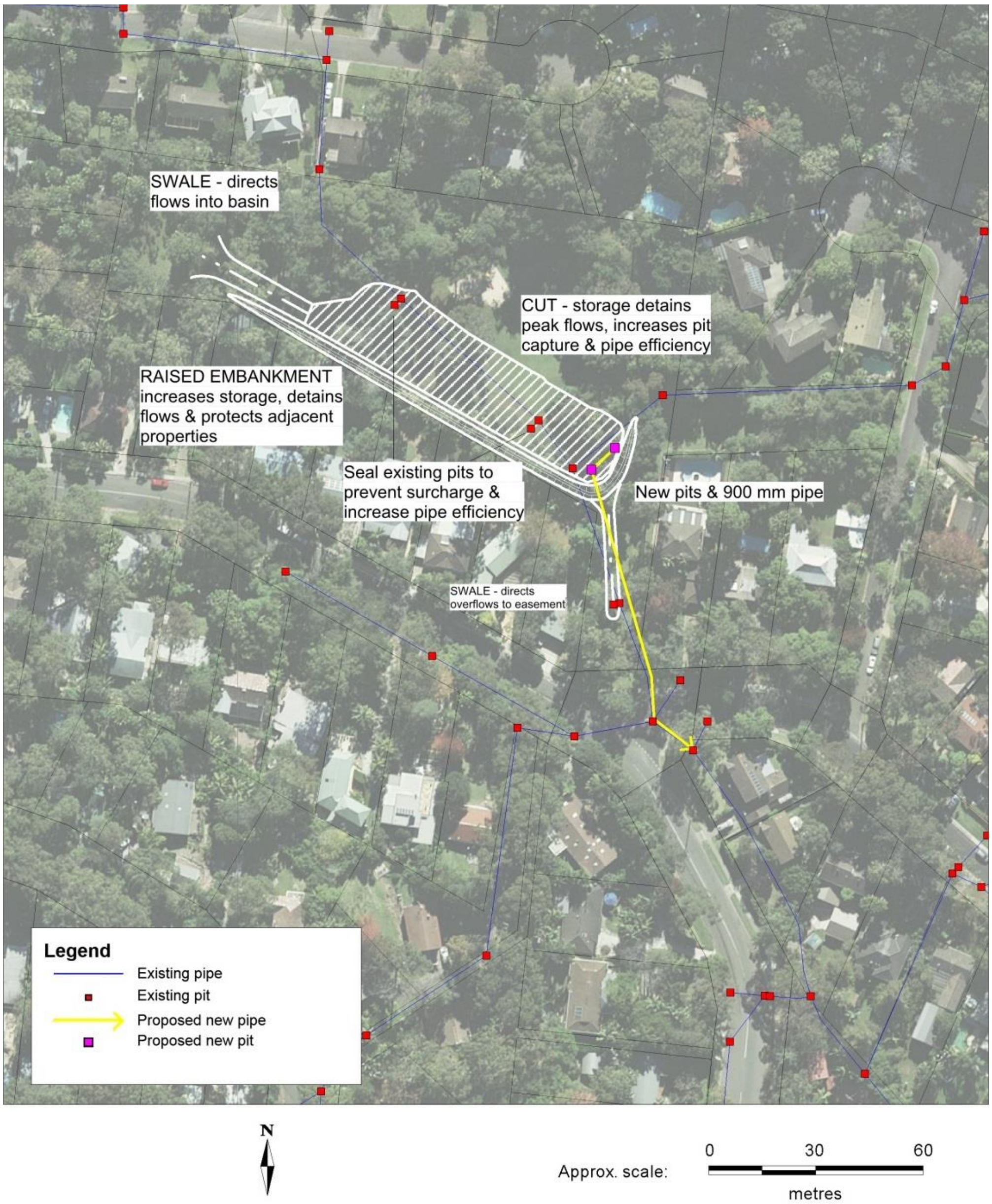


Figure 11.2 – Catalpa Reserve detention basin conceptual layout

11.2.2 Toongarri Reserve basin

Toongarri Reserve (see Figure 11.3) represents the largest available area of open space higher in the catchment that may provide an appropriate site for detention storage. It is located along one of the major flow paths to Careel Creek, approximately 400 metres downstream from Catalpa Reserve.

While Toongarri Reserve has a significant area available, there are a number of limitations to the volume of detention storage that could be achieved. Due to the nature of the surrounding topography it does not appear feasible to increase storage by means of a raised embankment within the reserve as this may worsen flooding of low lying properties along Central Road and impede flow paths entering the reserve from Avalon Parade. Increase in storage through excavation has therefore been investigated but the practicable depth of excavation is limited by the need to maintain a head gradient between the basin and the existing trunk drainage system to limit surcharging during storms and such that the basin drains following events.

Flood modelling of this option was undertaken to assess the benefits of a basin in alleviating downstream flooding and reducing flood damages. The scenario modelled involved excavation to depths ranging from 0.5-1.5 m over an area of approximately 9,000 m^2 with modification to existing pit RLs possibly needed (see Figure 11.4).

It is noted that the reserve is relatively densely vegetated and that the proposed concept would require significant disturbance or removal of this vegetation which is classified as Coastal Flats Swamp Mahogany Forest (Figure 2.5). Toongarri Reserve also forms part of a high priority wildlife corridor (Section 2.4). Detailed design of the basin should look to minimise the impact on vegetation, and stands of trees and vegetation could be located within the detention basin to compensate for any loss. It is recommended that further investigation of the environmental impact of this option be undertaken to confirm its feasibility.

For the 1% AEP design event, the modelled basin reduced peak flood levels by 0.05-0.10 m throughout the upper portion of Pittwater Palms and adjacent properties as far downstream as Avalon Bowling Club. Lesser reductions were observed over a large area including up to 0.05 m in Careel Creek itself. For the 20% AEP event, reductions in flood levels were more pronounced immediately downstream of the basin (reductions typically > 0.10 m but as high as 0.50 m). While this effect is largely limited to the major flow path toward Dunbar Park, this represents a significant local reduction in hazard. Localised reductions in flood levels of greater than 0.05 m are also seen in the vicinity of Avalon RSL Club and the Avalon Recreation Centre.

Table 11.1 indicates that the reductions in peak flood levels provided by the Toongarri Reserve basin would result in the protection of 9 houses and 1 non-residential building from over floor flooding in the 5% AEP event, and 5 houses and 4 non-residential buildings in the 1% AEP event, representing reductions in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $2.2 M. The capital cost of this option is estimated at $1.25 M, resulting in a BCR of 1.75.

Figure 11.3 – View looking south across Toongarri Reserve

Figure 11.4 – Toongarri Reserve detention basin conceptual layout

This option demonstrates high economic merit and is therefore recommended in the draft Floodplain Risk Management Plan, subject to additional investigation of environmental impacts and community acceptance. If adopted, the detailed design would need to minimise environmental impact and maintain or improve public amenity of the reserve.

11.2.3 Catalpa Reserve and Toongarri Reserve basins in combination

As Catalpa and Toongarri reserves are located along the same flow path the combined benefits of detention basins in both reserves were investigated, with flood modelling incorporating both options as described in the above sections.

Modelled reductions in flood levels between Catalpa Reserve and Toongarri Reserve were as per the Catalpa Reserve detention basin option while downstream of Toongarri Reserve additional benefits were observed for the 1% AEP and 5% AEP events. For the 1% AEP design event peak flood levels were reduced by up to 0.15 m in the upper half of Pittwater Palms and adjacent properties, with flood levels lowered by an additional several centimetres in comparison to the Toongarri Reserve detention basin alone. Additional benefits in the lower half of Pittwater Palms, through the Avalon CBD and in Careel Creek were less pronounced with flood levels generally reduced by a further 1 to 2 cm in comparison to the Toongarri Reserve only option and by 0.02-0.07 m overall. For the 20% AEP event additional benefits downstream of Toongarri Reserve were negligible in comparison to the Toongarri Reserve basin alone.

The implications of these reductions in flood levels are summarised in Table 11.1. As per the individual basin options, the combined basin option would not protect any houses from over-floor flooding in the 20% AEP event, but would protect 11 houses and 1 non-residential building in the 5% AEP event, and 11 houses and 4 non-residential buildings in the 1% AEP event. This, along with reductions in the depth of over-floor flooding at other buildings, would result in reductions in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $2.8 M. The capital cost of this option is estimated at $1.9 M, resulting in a BCR of 1.5.

This option demonstrates high economic merit and is recommended in the draft Floodplain Risk Management Plan, subject to additional investigation of environmental impacts and community acceptance, particularly regarding the Toongarri Reserve basin. If adopted, the detailed design should look to minimise environmental impact and maintain or improve public amenity of the reserves.

11.2.4 Jamieson Park basin

Jamieson Park (see Figure 11.5) represents a third, smaller area of open space located upstream of a number of flood affected properties along Barrenjoey Road. The area currently contains a series of pits located within small depressions in the sloped terrain with small downstream embankments to help direct flow to the pits and provide a very minor amount of detention storage. The existing system is not sufficiently designed to prevent flooding of downstream properties even in a 20% AEP event.

Figure 11.5 – View of Jamieson Park looking north-west

Figure 11.6 – Jamieson Park detention basin conceptual layout

The sloped nature and limited width of Jamieson Park presents difficulties in achieving a storage capacity sufficient to provide significant flood benefits downstream and negates the feasibility of a single large detention storage structure. Flood modelling of this option was therefore based upon a concept similar to the existing condition with a series of small storage basins created by additional excavation of the existing depressions and increases in embankment height along with re-contouring and swales to better direct flows into the park and away from adjacent properties (see Figure 11.6). This alone was found to provide very limited benefit as the modest achievable storages quickly overflowed and the capacity of existing piping was overwhelmed. Additional piping was investigated to enhance the flood benefits of the basins, including installation of new piping all the way to Careel Creek via Eastbourne Avenue and representing a significant capital cost.

For the 1% AEP design event the modelled scenario reduced peak flood levels by just over 0.10 m on a few downstream properties with reductions of over 0.05 m across several more properties. For the 20% AEP event reductions in flood levels occur over a similar extent to the 1% AEP event, with levels lowered by 0.05-0.08 m.

The significance of these reductions in peak flood levels is illustrated in the information provided in Table 11.1. The Jamieson Park basin would protect 1 house from over floor flooding in the 20% AEP event, 2 houses in the 5% AEP event, and 3 houses in the 1% AEP event resulting in reductions in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $440,000. The capital cost of this option is estimated at $1.4 M, resulting in a BCR of 0.3.

Due to its limited flood mitigation benefits, particularly relative to its capital cost, the construction of additional detention storage at Jamieson Park is not supported.

11.2.5 Angophora Reserve basin

Angophora Reserve is a large, heavily forested area located upstream of Ruskin Rowe which is zoned as Environmental Protection in the Pittwater LEP. The potential of a detention basin in this area was investigated as it would provide opportunity to lessen flood risk through the Ruskin Rowe area and Pittwater Palms.

Difficulties associated with the construction of a detention basin in this area were readily apparent due to the densely vegetated nature of, and lack of access roads to, potential basin sites. Additionally, three main flow paths pass through Angophora Reserve before joining behind Ruskin Rowe. The combined peak flow through these three branches is approximately 13 m^3/s during the 1% AEP event compared to a peak of approximately 30 m^3/s through Ruskin Rowe just upstream of Avalon Parade. It is thus likely that detention basins on at least two of these branches would be required to see any significant flood benefits downstream.

Based upon a preliminary assessment it was surmised that this option would have significant environmental impact in terms destruction of vegetation, would cause significant disturbance to residents during construction, and would be unlikely to have a favourable BCR. The construction of a detention basin in Angophora Reserve is therefore not supported.

11.2.6 Augmentation of Avalon Golf Course basin

The potential to augment the existing detention basin in the lower Avalon Golf Course was investigated as an option to alleviate flooding in the Avalon CBD.

It was found that the existing basin already provides a significant storage volume and that, with peak depths of around 1.5 m in the 1% AEP event, the additional residual risk associated with increasing basin storage height may negate the value of the increment in flood benefit. The installation of additional piping between the detention basin and the Careel Creek concrete channel near Avalon Woolworths could provide flood benefits to the Avalon CBD, particularly Edmund Hock Avenue, however the capital cost to do so would be high resulting in an unfavourable BCR. The augmentation of the Golf Course detention basin is therefore not supported.

11.3 Drainage Upgrades

Opportunities to alleviate flooding problems by the upgrade of existing drainage systems or construction of new drainage systems have been investigated throughout the study area and are discussed below.

11.3.1 Careel Head Road

This option was investigated to alleviate flooding along a flow path between Albert Road, Burrawong Road and Barrenjoey Road, where several properties could potentially be affected by over floor flooding in events as frequent as the 20% AEP.

Existing piping in this area passes through private properties along Albert, Burrawong and Barrenjoey Roads. Upgrading the capacity of piping to cope with large floods would therefore cause significant disruption to residents and businesses. It also appears that opportunity to increase pit capture capacity in the area may be limited. The majority of overland flows in this area come westward down Careel Head Road or southward from Dolphin Crescent and across Careel Head Road before passing through properties on Careel Head, Albert, Burrawong and Barrenjoey Roads. As such a drainage scheme was devised aiming to capture flows along Careel Head Road before they pass overland through the properties. In addition to providing additional pit capture and pipe capacity, this scheme reduces the loading on existing pits and pipes and reduces disruption to residents during construction.

The concept modelled (see Figure 11.7) includes new piping and several pits along Careel Head Road discharging to the western side of Barrenjoey Road, and blockage of two existing pipes that direct stormwater from Careel Head Road toward the existing trunk drainage line (therefore reducing loading on the existing drainage line). For the 1% AEP design event the drainage upgrades reduced peak flood levels by around 0.05 m across more than a dozen properties and by around 0.11 m on 4 properties. Flood benefits were more pronounced in the 20% AEP with reductions in flood level of 0.05-0.10 m across around a dozen properties, and reductions of 0.10-0.20 m on several properties.

Figure 11.7 – Careel Head Road drainage upgrade conceptual layout

Table 11.1 indicates that the reductions in peak flood levels provided by the Careel Head Road drainage upgrades would result in the protection of 2 houses from over floor flooding in the 20% AEP and 5% AEP events, and 1 house in the 1% AEP event, with reductions in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $710,000. The capital cost of this option is estimated at $1.4 M resulting in a BCR of 0.5. This option is therefore not supported due to low economic merit.

11.3.2 Barrenjoey Road (adjacent Careel Bay Oval)

Flood modelling indicates that during floods water banks up behind the raised Careel Bay Oval inundating Barrenjoey Road and, in larger flood events, adjacent properties. The drainage option investigated consists of a large capacity pipe draining floodwater from the western side of Barrenjoey Road to Careel Creek near Careel Bay.

The Department of Land and Water Conservation (DLWC) Acid Sulphate Soil Risk Maps indicate that there is a high probability of occurrence of acid sulphate soils (ASS) in this area. If present, ASS would be encountered at depths below the fill used to raise Careel Bay Oval and would require appropriate testing and assessment, treatment and disposal per a site specific Acid Sulphate Soil Management Plan.

Flood modelling indicates that for the 1% AEP design event the drainage upgrades would reduce peak flood levels by up to 0.5 m along Barrenjoey Road and several adjacent properties, preventing over-floor flooding of two houses. For the 5% AEP design event peak flood levels would be reduced by up to 0.47 m resulting in the protection of one house from over-floor flooding. For the 20% AEP event peak flood levels along Barrenjoey Road were also significantly reduced but no houses were flooded over floor in this event under existing conditions.

Table 11.1 indicates that reductions in the net present value of flood damages (at 7% discount rate over 50 years) associated with this option would be approximately $196,000. The capital cost of this option is estimated at $500,000, resulting in a BCR of 0.4.

Based upon a BCR of 0.4, this option does not demonstrate a high level of economic merit. While it would provide significant local reductions in flood levels for a section of Barrenjoey Road, this road is flooded in a number of other locations so this option alone would not significantly improve emergency response access. This option is therefore not supported.

11.3.3 Therry Street

Flood modelling indicates that two properties on Therry Street could be impacted by over-floor flooding in events as frequent as the 20% AEP event. A drainage upgrade option aimed at alleviating flooding in Therry Street was developed involving the provision of additional piping through an existing drainage easement with an additional headwall on the eastern side of the street and an additional large kerb inlet pit on the western side.

Flood modelling indicates that for the 1% AEP design event the drainage upgrades would reduce peak flood levels by up to 0.12 m on the two worst affected properties. Flood benefits are more pronounced in the 20% AEP with reductions of up to 0.26 m and 0.12 m on these properties.

While over floor flooding of houses would not be entirely prevented by this option, the depth of over floor flooding would be reduced considerably. According to Table 11.1 reductions in the net present value of flood damages (at 7% discount rate over 50 years) associated with this option would be approximately $42,000. The capital cost of this option is estimated at $500,000 resulting in a BCR of less than 0.1.

This option has an unfavourable BCR and therefore is not recommended for implementation. Given the limited number of properties benefited, property modification options at Therry Street may provide better value.

11.3.4 Careel Creek offtake

An option considered for alleviating flooding of properties adjacent to Careel Creek was the construction of a large capacity pipe to offtake flood flows from Careel Creek and discharge them to the ocean.

While this option may provide significant flood benefits, a preliminary assessment identified several issues including:

- significant environmental impacts both during construction and potentially long-term due to changes in the Careel Creek flood regime (e.g. increased sedimentation of the channel, reduced ecologically beneficial inundation of the floodplain);
- high capital cost of construction;
- on-going costs and technical issues associated with maintaining a clear pipe;
- likely community opposition.

The construction of a flood offtake pipe from Careel Creek is therefore not supported.

11.3.5 Careel Creek Culvert upgrades

Feedback from the community questionnaire suggested that the widening of 'bottle-necks' in Careel Creek be investigated to alleviate flood problems. The primary potential bottlenecks in Careel Creek are the Barrenjoey Road south (near Avalon CBD) and Barrenjoey Road north (near Avalon Parade) culverts.

Flood modelling results for the 1% AEP design event show peak flood levels of around 5.2 m AHD upstream of the Barrenjoey Road south culvert and 4.7 m AHD downstream, indicating that there is a backwater effect at the crossing. The effect on flood levels and duration appears to be limited to the Avalon Woolworths and car park area. Under current conditions modelling shows that Barrenjoey Road would be overtopped for approximately 45 minutes by depths of up to 0.4 m at the road's low point. This overtopping accounts for a significantly larger proportion of flow than that which passes through the existing twin 1.35 m diameter culverts (peak flows of approximately 25 m^3/s and 9 m^3/s respectively). Even if the existing culvert capacity were to be doubled it is estimated that reductions in flood levels upstream and across Barrenjoey Road would be minor and may be offset by increases in flood level downstream. Capital costs associated with this option would also be high and the BCR is unlikely to be favourable. The upgrade of the Barrenjoey Road south culverts is therefore not supported.

Culverts at the Barrenjoey Road north crossing were upgraded as an outcome of the 2001 Careel Creek Floodplain Risk Management Plan and consist of three 3.6 m wide by 3.0 m high box culverts. Flood modelling results indicate that the existing culvert capacity is sufficient to prevent overtopping of Barrenjoey Road during the 1% AEP event and that little to no backwater effect occurs at the culverts, with peak flood levels of approximately 3.1 m upstream of Barrenjoey Road and 3.0 m downstream. The upgrade of the Barrenjoey Road north culverts is therefore not supported.

11.3.6 North Avalon Road, Tasman Road and Catalina Crescent

Flood modelling identified an overland flow path between North Avalon Road, Tasman Road and Catalina Crescent, which may cause over floor flooding of a number of properties in floods as frequent as the 20% AEP event. The feasibility of drainage upgrades to alleviate flooding in the area was therefore investigated.

Given the presence of significant drainage structure already in place along North Avalon Road and Tasman Road, the limited number of properties which may experience flood benefits, and the high capital cost and low economic merited exhibited by other drainage upgrades investigated, it was concluded that this option would not have a favourable BCR and is therefore not supported.

11.3.7 Bilgola Beach open channel

A number of properties in Bilgola Beach adjacent to an existing open channel are flooded, while the road and car park can be subject to high hazard flows. The feasibility of augmenting the existing open channel to address these issues has been considered.

The existing open channel is concrete-lined with approximate dimensions of 1.5 m wide by 1.5 m deep, and is located on private property passing through gardens and beneath fences and footbridges. Based upon peak simulated flood flows for the 1% AEP design event it is estimated that the channel dimensions would need to be upgraded to approximately 1.5 m deep by 4 m wide or equivalent to provide any significant flood benefits. This would cause significant disruption to residents and their properties and would carry a high capital cost. Flood benefits of the upgrade would be limited in terms of reduction in flood damages as only one property is estimated to be flooded over floor in events more frequent than the 0.2% AEP flood. This option would therefore have a very low BCR and is not supported.

11.4 Summary

An analysis of benefit-cost ratio (BCR) has been undertaken for a number of flood modification options that were deemed to warrant further investigation based upon the preliminary multi-criteria assessment in Chapter 10.

The detention basin options at Catalpa Reserve (BCR = 1.4) and in particular Toongarri Reserve (BCR = 1.75) show strong economic merit, including in combination (BCR = 1.5). The flood modification options involving drainage upgrades show limited economic merit, with the Careel Head Road upgrades having the highest BCR of 0.5.

Recommendation:

The most beneficial flood modification options that may warrant inclusion in the Avalon to Palm Beach Floodplain Risk Management Plan are the construction of detention basins in Catalpa Reserve and Toongarri Reserve. These options demonstrate a significant level of flood benefit and economic merit through the reduction of flood damages with BCRs of 1.4 and 1.75 respectively, and 1.5 if implemented in combination.

Further investigation of environmental impacts and community acceptance are recommended for the Toongarri Reserve option. The reserve is relatively densely vegetated and forms part of an important wildlife corridor. Construction would require considerable disturbance and/or removal of this vegetation.

In both cases, if adopted, the detailed designs should look to minimise environmental impact and maintain or improve public amenity of the reserves.

12. Property Modification Options

Property modification measures involve modifying or removing existing properties from flood affected areas and imposing controls on future property and infrastructure development. These are aimed at steering inappropriate development away from areas with a high potential for damage and ensuring that potential damage to developments likely to be affected by flooding is limited to acceptable levels by means of minimum floor levels, flood proofing requirements, etc.

12.1 Voluntary House Purchase (VP)

For existing properties which face a high flood hazard and where no significant reduction of the hazard is practicable, the physical removal of the building from the property, or its demolition, may be the only alternative. Voluntary house purchase (often referred to as 'VP') is an expensive option generally reserved for sites where the risk to life is unacceptable.

Consideration has been given to the eligibility and practicality of VP in the Avalon to Palm Beach study area.

OEH has prepared *Guidelines for Voluntary Purchase Schemes* (OEH, 2013a). This describes the eligibility criteria for NSW Government funding for VP schemes, which include:

- no other feasible flood risk management options are available to address the risk to life at the property;
- residential properties and not commercial and industrial properties;
- buildings were approved and constructed prior to 1986;
- properties are located either 1) within high hazard areas where there is a significant risk to life for occupants and those who may have to evacuate or rescue them, 2) within a floodway where the removal of the house may be part of a floodway clearance program aimed to reduce the significant impacts caused by the existing development on flood behaviour elsewhere in the floodplain, or 3) within the footprint of a proposed flood mitigation measure or where a flood mitigation measure may result in a significant increase in flood risk to a house that cannot be protected.

Inclusion of a property in a council's VP scheme places no obligation on the owner to sell the property or on the council or NSW Government to fund the purchase of the property. Owner participation in the scheme is voluntary and there are limitations on the availability of funding.

Considering the eligibility of residential properties within the study area, there are about 14 houses that significantly intersect the 1% AEP floodway, including in Barrenjoey Road downstream of Jamieson Park, Burrawong Road, Therry Street, Hudson Parade and The Serpentine. It is difficult to judge what changes to flood behaviour would occur with the removal of these houses. If the houses are elevated on piers to allow flow to travel underneath, there might be no change. If the houses are slab on ground and function as obstructions slowing the flow, it is possible that their removal could worsen flooding downstream even if providing local benefits. Generally it is judged that it would be difficult to justify VP in this study area on the grounds of being located in a floodway, which is expected to have limited benefit.

Nor could VP be justified on the basis of being within the footprint of a proposed mitigation measure.

A few houses are located within the draft High Flood Risk Precinct, which is primarily based on areas of high hydraulic hazard in the 1% AEP event. In general, depths of above floor inundation in the study area are relatively shallow, which suggests that the risk to life is not excessive and might be more cost effectively managed through redevelopment or flood proofing than VP. For example, for the 1% AEP event, only two dwellings are estimated to be flooded above floor by more than 0.5m – one in Pittwater Palms retirement village and another in Barrenjoey Road where residents have access to a second storey. In the 0.2% AEP event, only nine dwellings are estimated to be flooded above floor by more than 0.5m (mostly <0.6m), including three in Elaine Avenue. Of the modelled design floods, only in the PMF would the numbers of houses and units flooded to serious depths increase substantially, with 159 estimated to be flooded over floor by more than 0.5m, 63 of these by more than 1.0m, particularly in Elaine Avenue and Catalina Crescent. Only at one property located at the eastern end of Central Road does the hazard in a PMF pose a considerable risk of building failure (Section 7.6). But VP is not typically justified on the basis of PMF hazard, since given the floodplain exposures across the State, VP schemes that used such a low bar could not be funded.

The impracticality of a State-funded VP scheme in the Avalon to Palm Beach study area is underlined by the median house prices in Table 12.1.

Table 12.1 – Median house prices in study area
Source: realestate.com.au, updated 12/10/2015

Suburb	Median house price	3 BR house	4 BR house
Avalon Beach	$1,300,000	$1,255,000	$1,365,000
Whale Beach	$2,355,000	n/a	n/a
Palm Beach	$2,100,000	$1,452,500	$2,650,000
Bilgola Beach	No data	No data	No data
Clareville	$1,665,000	n/a	$1,650,000

12.2 Voluntary House Raising (VHR) or Redevelopment

Raising houses with low-set floor levels has proved to be an effective floodplain management measure for various locations throughout NSW.

Advantages of house raising include:

- reducing tangible flood damages and alleviating anxiety about future floods;
- providing under-house space for non-habitable uses such as garages and laundries; and
- an enhanced resale value.

Disadvantages of house raising include:

- an altered streetscape unless all the houses in an area are raised;
- difficult access for some people (e.g. elderly, people with a disability); and
- people living in raised houses are often less likely to evacuate, which can exacerbate risk to life in rare floods that overtop the raised floor or when people panic with water below the house.

Various forms of house raising schemes can be considered. The easiest form of house raising occurs where houses are of either timber or fibro construction. Fairfield Council's experience in Prospect Creek has shown that such houses can be raised by 1-2m for a cost of about $80K.

Physically raising houses of brick veneer or full brick construction is more costly, and in most cases impractical. Fairfield Council developed a scheme for such 'difficult' houses whereby a limited subsidy was available to homeowners to demolish and rebuild a new house with appropriate building controls in accordance with the flood risk management provisions in the DCP (Frost & Rice, 2003).

OEH has prepared *Guidelines for Voluntary House Raising (VHR) Schemes* (OEH, 2013). This describes the eligibility criteria for NSW Government funding of VHR schemes including:

- not located in floodways;
- limited to areas of low flood hazard;[10]
- the suitability of individual houses for raising;[11]
- residential properties and not commercial and industrial properties;
- buildings were approved and constructed prior to 1986;
- properties cannot be benefiting substantially from other floodplain mitigation measures;
- VHR should generally return a positive net benefit in damage reduction relative to its cost (benefit–cost ratio greater than 1).

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[10] The Guideline does not stipulate the design event upon which hazard is based, but presumably 1% AEP is intended.

[11] The Guideline does not explicitly discuss the possibility of funding 'knock down and rebuild', but Fairfield's experience suggests that this variant of VHR may be eligible for State funding.

Inclusion of a house in a VHR scheme as part of a FRMP adopted by the council places no obligation on the owner of the property to raise the house or on the council or NSW Government to fund the raising. Owner participation in the scheme is voluntary and there are limitations on the availability of funding.

Consideration has been given to a potential VHR scheme for the Avalon to Palm Beach study area. The following points are noted:

- Assessment is made difficult by a lack of certainty over floor levels (many were estimated), the suitability of houses (some could not be seen via Street View) and the age of houses, which is one of the criteria for eligibility. Houses for which floor heights have not been viewed have been excluded from the preliminary assessment described here. If it is decided to pursue a VHR scheme, detailed survey will be required to capture this information.
- Houses in floodways or regions of high hazard are not regarded as sufficient reason to disqualify their inclusion in this assessment. Modelling for the Avalon to Palm Beach study area depicts many overland flowpaths, which often convey relatively modest flows and for which design options may be available to provide conveyance around or under buildings. A building located in a floodway or region of high hazard does not necessarily mean that the structural integrity of a raised building would be threatened, or that people would be trapped.
- Houses in Hudson Parade, Central Road and Katandra Close that would have some benefit from the proposed Catalpa Reserve and Toongarri Reserve detention basins are excluded from this assessment. Units in Pittwater Palms have also been excluded.
- The generally shallow depths of flooding and low flood height range associated with overland flow inundation suggest that for many houses the flood risk might be more efficiently addressed through flood proofing techniques.

A sample assessment was done using a threshold of more than 0.1m of water above floor in the 20% AEP event, since damage to property is closely aligned with frequency of above floor inundation. The list of known candidates for inclusion in a VHR and/or flood-proofing scheme is shown in Table 12.2. All of these houses are slab on ground and/or brick and most are two-storey, so none are suitable for house raising, but could be knocked down and rebuilt to flood compatible standards. Or flood proofing techniques could be applied to either prevent the ingress of water into a dwelling ('dry' flood proofing) or so as to minimise damage to the structure and fittings of a dwelling when flooded ('wet' flood proofing). An assessment of a potential strategy to reduce the frequency of inundation is listed, based on an initial judgement of whether a diversion of floodwater around a building or property through dry flood proofing is likely to have a significant adverse impact on conveyance of overland flows (this would need to be confirmed through modelling at a later stage). The benefits are assessed assuming that redeveloped houses are built with the lowest habitable floor levels 0.1m above the PMF (which is not unrealistic given the low flood height range in these overland flow catchments) and that 'dry' flood proofing is able to block depths of inundation up to 0.5m over the ground level. It is found that the various works would yield benefits (reductions in net present value of damage over 50 years with a 7% discount) of more than $1.5M.

Table 12.2 – List of potential candidates for VHR or flood-proofing

Street	Suburb	No. storeys	Floor	Wall	1% AEP depth (m)	20% AEP depth (m)	Draft Recommendation
Therry St	Avalon Beach	1	Slab	Brick	0.39	0.28	Dry flood proof
Therry St	Avalon Beach	2	Slab	Brick	0.44	0.30	Dry flood proof
Allen Ave	Bilgola Beach	2	Slab	Cladded	0.18	0.15	Dry flood proof
Hudson Pde	Clareville	2	not seen	Brick	0.34	0.24	Dry flood proof
Barrenjoey Rd	Palm Beach	1	Slab	Brick	0.32	0.26	Redevelop or wet flood proof
Waratah Rd	Palm Beach	2	Slab	Brick	0.41	0.27	Redevelop or wet flood proof

If 'dry' flood proofing can be achieved for $100K/house and redevelopment for $400K/house (conservative allowances), the costs would be $1.2M, yielding a benefit-cost ratio (BCR) of 1.2. If adopted, it might be appropriate for the land owner to contribute a portion of the costs of flood proofing or redevelopment, which would give them ownership of the process.

The precise works would need to be investigated and tailored to each location and dwelling structure and would likely require some modelling for dry flood proofing. Also, since participation in VHR schemes is by definition voluntary, the views of the owners would need to be canvassed. It is also doubtful that a large scheme across the LGA would be financially viable for Council. But this preliminary analysis suggests that options are available and, if able to be funded, would provide significant economic benefits in terms of reduced flood damages. It is recommended that Council undertake a scoping study including floor level survey and consultation.

Recommendation:

Prepare a scoping study including floor level survey, consultation and site inspections to further assess the feasibility of establishing a small voluntary house redevelopment/flood proofing scheme (Council).

12.3 Flood-proofing

Individual properties can be modified to reduce the impacts of flooding through flood-aware design. Particularly for the relatively shallow depths of inundation observed in most floods in the Avalon to Palm Beach study area, flood proofing measures may substantially reduce damages to building structures and fittings. A book called *Reducing Vulnerability of Buildings to Flood Damage* (HNFMSC, 2006) details the many ways buildings and components can be designed to minimise the impact of flooding. Pittwater Council has condensed this thorough document into a 26 page, online resource offering guidance to homeowners (Pittwater Council, 2014). A brief review of this document is provided in Table 12.3.

Table 12.3 – Review of Council's Flood Compatible Building Guidelines

Page	Comment
7	'Given the limited availability of comprehensive domestic flood insurance…' This could be amended to reflect the broader availability of domestic flood insurance in 2015.
10	'Maximise flow across your property using flood compatible fences, etc.' This statement could be counter-intuitive for residents untrained in hydrology who might want to *prevent* flow entering their properties. Alternative wording is, 'Use flood compatible fencing to reduce the chance of water rising to dangerous depths behind barriers'.
13	The description of minimum floor levels may require revision in view of the proposed changes to the DCP.
13	Typo: 'which can potentially increases [sic] water flow'.
14	The absorbency of construction materials is likely to be less important for the short duration floods typically experienced in Pittwater catchments (though Narrabeen Lagoon flooding needs to be considered). The table in the source document is based on 96 hour immersion.
16,23	The figures and photos would benefit from captions.
17	Particle board could swell after any immersion. The related section of the source document suggests that inundation of more than *one* day will compromise strength.
20	Joinery and fittings do not relate to Section 5.5 of the source document as indicated but to Section 6.1.
21	It might be preferable to have the 'materials' row first in the table (as per the source document) because it relates to all types of fittings.
21	'Selecting particle board cupboards may be appropriate and cost effective because its replacement can be the cheapest'. While this may be true, the high susceptibility of particle board should also be stated. Alternative wording is, 'Particle board cupboards damage easily but may be cheapest to replace'.
23	Typo: 'there may be damage [sic] pipes, pumps and electrical systems'.
25	'Maximise flow across your property using flood compatible fences, etc.' See earlier comment.

It is hard to know how widely this resource is used. Council could record the number of times the document is downloaded. Whilst the 26 page guideline is much more accessible than the very comprehensive source document, there is merit in attempting to make the core design principles of the guideline even more accessible. For example, a single A3 page could feature two diagrams comparing a flood resilient design to a flood susceptible design. This would require compromises because much information would need to be omitted, but a single, attractive, 'entry level' page might enjoy greater circulation and more success in influencing house design and construction.

While the guidelines may help reduce flood damages for future dwellings, there may also be opportunity for owners of existing houses to flood proof their dwellings to some extent. Fairfield City Council provided subsidies of up to $20K for double-brick or two storey houses (i.e. houses unable to be raised) to assist in flood proofing the lower ground floor by raising electrical power points, installing a water sensor device to shut off power, replacing building materials liable to flood damage, and constructing local flood walls so long as adjoining properties were not adversely affected (Frost & Rice, 2003). It is, however, doubtful that a similar scheme across the LGA would be financially viable for Pittwater Council. But this preliminary analysis suggests that options are available and, if able to be funded, would provide significant economic benefits in terms of reduced flood damages. It is recommended that Council undertake a scoping study to investigate this option further.

Recommendations:

- Amend Pittwater Council's Flood Compatible Building Guidelines as suggested (Council)
- Prepare a one-page, graphic summary of the Guidelines (Council)
- Recognise the cost-effectiveness of flood proofing techniques and further investigate specific design options through a proposed scoping study (Council)

12.4 Planning Policy Revision

12.4.1 Pittwater LEP 2014

Exceptional circumstances

Pittwater LEP 2014 is described in Section 3.4. One requirement of the Avalon to Palm Beach FRMS&P is to determine if and where ‘exceptional circumstances’ are appropriate for flood related development controls on residential development on land outside the residential flood planning area, in terms of the *Guideline on Development Controls on Low Flood Risk Areas* (Section 3.3.2). Potential reasons cited for ‘exceptional circumstances’ include local flood behaviour, associated flood hazards and flood history.

The need for exceptional circumstances may be considered by comparing the extent of the 1% AEP Flood Planning Area (FPA) with Flood Life Hazard (FLH) categories based on the PMF. The *Flood Emergency Response Planning for Development in Pittwater Policy* (Appendix 15 of Pittwater 21 DCP), aimed at managing risk to life through evacuation or shelter-in-place, applies for FLH categories including and exceeding H3 (Section 7.6). The comparison indicates that there are:

- *no* areas where land subject to FLH category H6 lies outside the 1% AEP FPA;
- *very few* areas where land subject to FLH category H5 is not already contained within the 1% AEP FPA (for residential zoned land, this includes portions of one property located in the eastern portion of Central Road and one property located at the northern end of Catalina Crescent, Avalon); and
- *few* areas where land subject to FLH category H3-H4 is not contained within the 1% AEP FPA (for residential zoned land, this area is largely confined to portions of properties in Avalon Parade including Pittwater Palms, Central Road, Elaine Avenue, Barrenjoey Road parallel to Elaine Avenue, Catalina Crescent and Bangalley Way, Avalon).

If, in the future, Council wishes to apply its *Flood Emergency Response Planning Policy* to the few areas of FLH categories H3+ that are located *beyond* the 1% AEP FPA, ‘exceptional circumstances’ approval may be required[12]. Grounds for exceptional circumstances in this area near Elaine Avenue/Catalina Crescent include:

- Significantly increased depths of flooding in extreme events (2.67m in the PMF compared to 0.65m in the 1% AEP flood at the low point in Elaine Avenue – MHL ID #11 in Table 8.7);
- Rapid rates of rise (Figure 8.10);
- Low flood islands (Figure 8.13);
- Limited emergency services capacity (Section 5.2);
- The above features of flooding point to challenging evacuation, which therefore requires shelter-in-place to manage the risk to life in extreme floods, which therefore requires an area of floor be provided above the PMF level in a building that can structurally withstand PMF inundation.

[12] At the time of writing, Council devotes most attention to ensuring that sensitive uses such as seniors living and childcare are developed appropriate to the flood risk.

If Council successfully applies for ‘exceptional circumstances’, Pittwater LEP 2014 Clause 7.4 would be amended to include residential uses among those for which the consent authority must be satisfied that a proposed development will not affect the safe occupation of, and evacuation from the land. The DCP codifies the policy by which Council assesses how a proposed development achieves Council’s ‘satisfaction’.

Zoning suitability

A map of current zoning in the study area is provided in Figure 2.3. An assessment was undertaken to establish what proportion of land affected by the high, medium and low flood risk precincts (Figure 7.2) was given over to various land use zones. The results are presented in Figure 12.1.

About 59% of land within the high flood risk precinct is zoned for Environment Conservation (E2) or Public Recreation (RE1). This is fitting for land where there are significant flood risks. About 31% of land within the high flood risk precinct is zoned for Low Density Residential (R2) or Environmental Living (E4). But a reasonable proportion of the latter appears to occur on roadways rather than on private property.

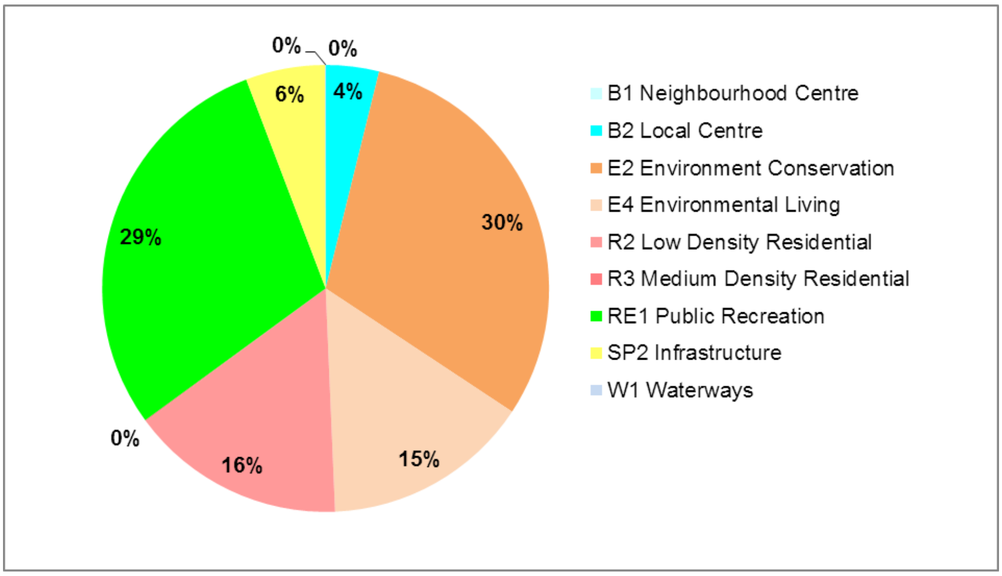
A lower proportion of land within the medium flood risk precinct is dedicated to environmental conservation or recreational uses (28%) and a higher proportion is dedicated to residential uses (59%).

An even lower proportion of land within the low flood risk precinct is dedicated to environmental conservation or recreational uses (25%) and a higher proportion to residential uses (65%).

This trend of an increasing proportion of land zoned for environmental conservation and recreational uses with increasing flood hazard suggests that *broadly* the LEP zonings are appropriate to the flood risk. But on a smaller scale, some residential properties are substantially intersected with the high flood risk precinct, including:

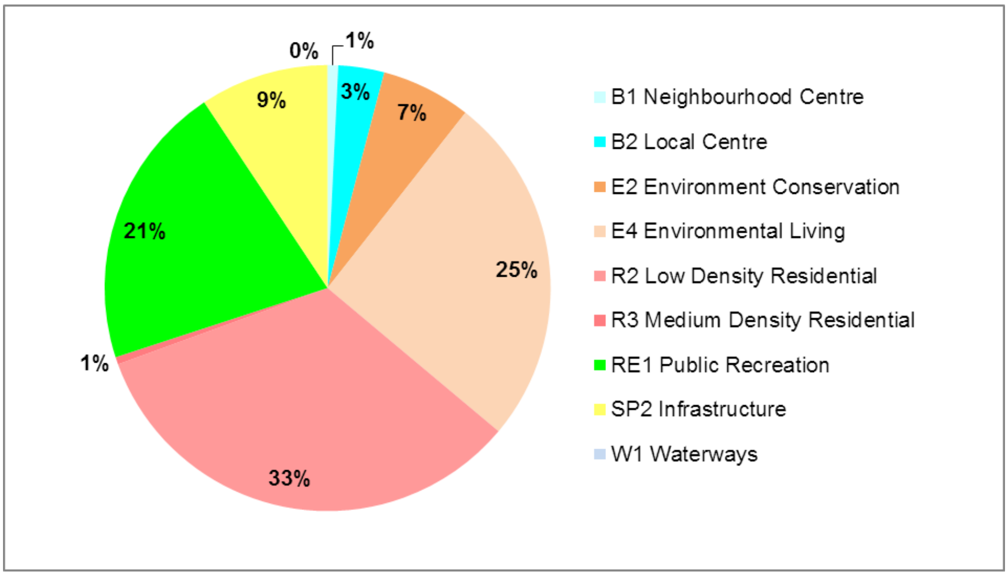
- Rear of properties in Central Road;
- Some properties in Ruskin Rowe (rarely intersecting with building footprints);
- Internal roads in Pittwater Palms retirement village;
- Rear of properties in Elaine Avenue and Catalina Crescent;
- Properties along the Albert Road to Burrawong Road to Barrenjoey Road flow path;
- Some properties in Therry Street;
- Some properties in Bilgola;
- Some properties in Hudson Parade, Clareville

Ideally residential areas within the high flood risk precinct (or within H5-H6 Flood Life Hazard categories) could be gradually converted to environmental conservation or recreational uses.



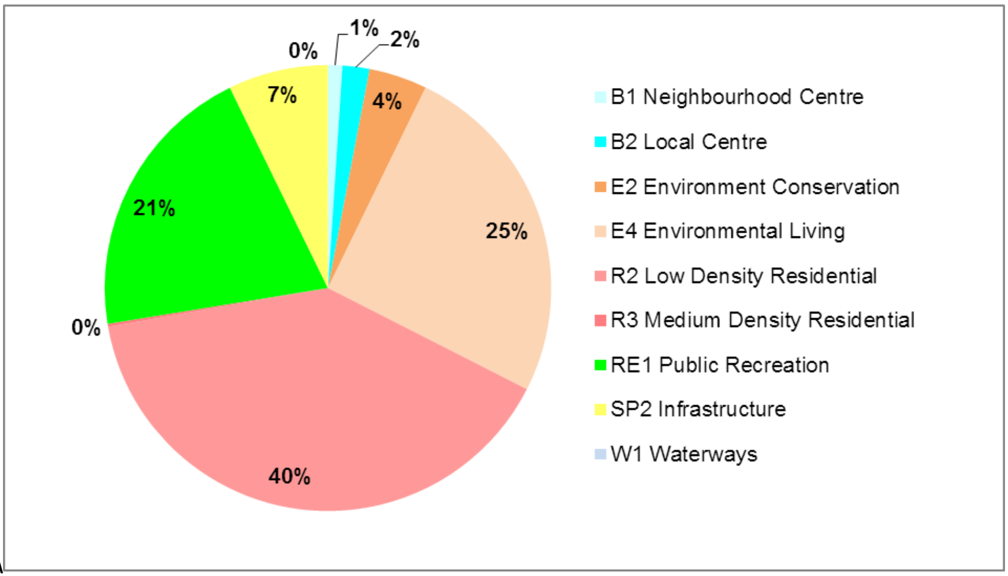
High flood risk precinct

(total area 260,334 m^2)



Medium flood risk precinct

(total area 941,851 m^2)



Low flood risk precinct

(total area 557,655 m^2)

Figure 12.1 – Comparison of flood risk precincts and land use zoning

12.4.2 Pittwater 21 DCP

Pittwater 21 DCP is described in Section 3.5. In parallel to this study, PolisPlan was commissioned to review and draft a revised flood risk management chapter for inclusion in Pittwater 21 DCP. Reasons for this revision included:

- Align with best practice flood risk management;
- Align with ever evolving State Government policies;
- Desire for a simpler matrix approach used by many Councils, which is more easily understood;
- Desire for a simpler method of classifying different categories of flood affectation; the proposed draft policy replaces the five-fold classification currently used on Council's floodplain maps[13] with a three-fold classification of High, Medium or Low Flood Risk Precincts, defined below.

  Flood Risk Precinct (FRP) refers to the division of the floodplain on the basis of the level of expected risk to persons and property due to flooding. In this plan the floodplain is divided into the Low, Medium and High flood risk precincts.

  > ***Low Flood Risk Precinct*** means all *flood prone land* (i.e. subject to inundation by the PMF) not identified within the High or Medium flood risk precincts.
  >
  > ***Medium Flood Risk Precinct*** means all *flood prone land* that is (a) within the 1% AEP Flood Planning Area; and (b) is not within the high flood risk precinct.
  >
  > ***High Flood Risk Precinct*** means all *flood prone land* (a) within the 1% AEP Flood Planning Area; and (b) is either subject to a high hydraulic hazard or is within the floodway.

The definition of the Flood Planning Area has been carefully crafted to incorporate both mainstream and overland flooding:

> ***Flood Planning Area (FPA):*** *The 1% AEP Flood Planning Area* is that area (a) below the 1% AEP mainstream flood level + adopted freeboard[14], extended to intersect the surrounding topography; or (b) inundated by overland flooding of greater than 0.05 m depth during the 1% AEP; or (c) within 5 m horizontal distance of an area inundated by overland flooding of greater than 0.3 m depth during the 1% AEP.

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[13] (1) High hazard – affected by FPL and PMF, (2) Low hazard – affected by FPL and PMF, (3) Property affected by PMF only, (4) Overland flow (major), (5) Overland flow (minor)

[14] For the purposes of mapping, the adopted freeboard is set at 0.5m.

Various freeboards are proposed to be incorporated into the flood planning levels as set out below:

Flood Planning Levels (FPL) has the same meaning as provided in the Pittwater LEP 2014 as extracted and varied below:

> ***flood planning level*** means the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metres freeboard, or other freeboard determined by an adopted floodplain risk management plan.

Pursuant to the definition above, the Avalon to Palm Beach Floodplain Risk Management Plan has adopted other freeboards, which vary according to the type of development as follows:

ADOPTED FREEBOARDS

Critical and Vulnerable Uses: 0.5 metres minimum or such higher dimension as to extend the flood planning level to the level of the Probable Maximum Flood, whichever is the greater

Subdivision and all Residential Uses: 0.5 metres

Business and Industrial Uses: 0.5 metres, except that this may be reduced to 0.0metres for driveways, loading docks and other equivalent trafficked areas.

Recreational and Environmental Uses: 0.0metres

Concessional Uses: the freeboard applicable to the relevant land use type but may be varied by Council so as to allow for the appropriate integration with the existing dwelling/building on site.

Following public exhibition and review of feedback, it is recommended that Council adopt the revised DCP.

Recommendation:

Review and adopt the revised flood risk management provisions of Pittwater 21 DCP including the particular freeboards for the Avalon to Palm Beach study area (Council).

13. Response Modification Options

Response modification measures aim to reduce risks to life and property in the event of flooding through improvements to flood prediction and warning, through improvements to emergency management capabilities and planning, and through better flood-educated communities.

13.1 Flood Warning Systems

13.1.1 General

Flood warning systems aim to provide advice on impending flooding so people can take action to minimise its negative impacts. Where effective flood warnings are provided, risk to life and property can be significantly reduced. Studies have shown that flood warning systems generally have high BCRs if sufficient warning time is provided and if the population at risk is aware of the threat and prepared to respond appropriately.

Due to the small size and steep terrain, inundation in the Avalon to Palm Beach study area is typically 'flash flooding', occurring within minutes of heavy rain. Design flood hydrographs and pluviographs for the Avalon commercial district are presented in Figure 13.1. It shows that the 20% AEP and 1% AEP floods peak within one hour of the commencement of rain. The PMF is even faster to rise.

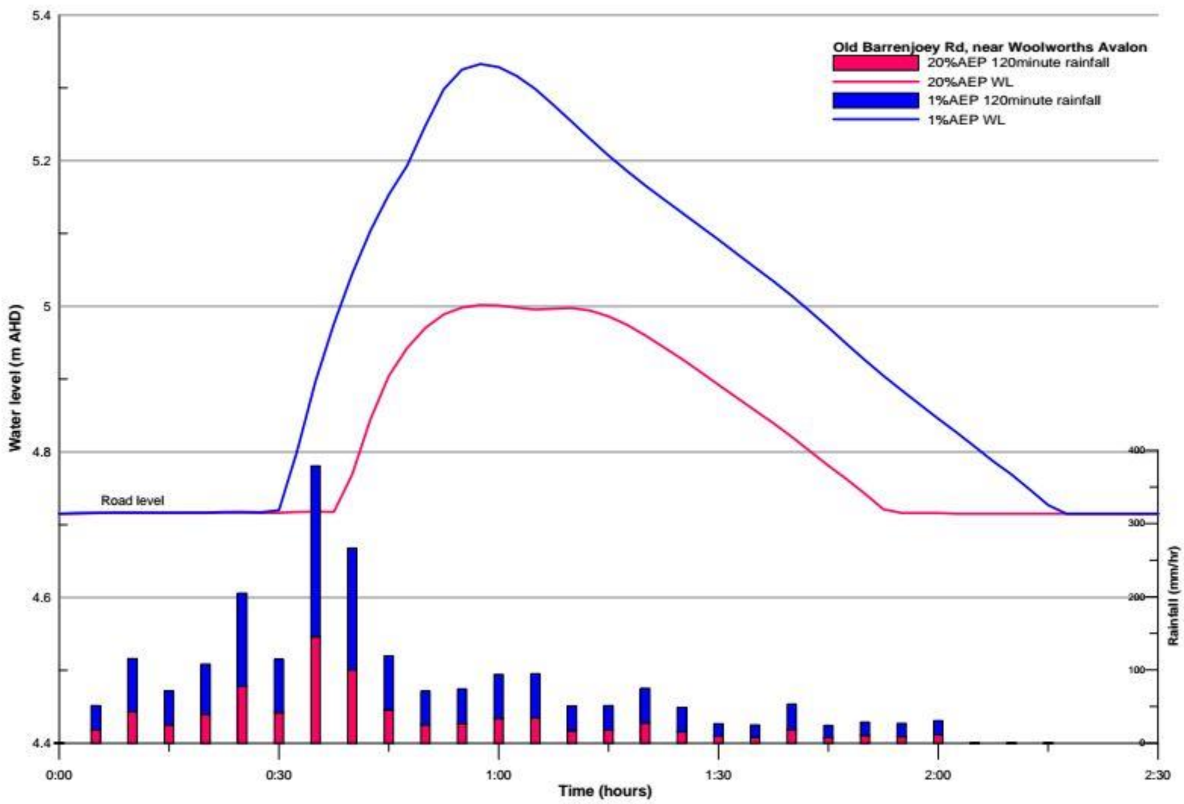

Figure 13.1 – Pluviograph and stage hydrograph for 20% AEP and 1% AEP events at Old Barrenjoey Road

For flash flood catchments like these, the provision of an effective flood warning service is problematic. The 'total flood warning system' has five components that need to be completed during a flood emergency – prediction, interpretation, message construction, communication and appropriate response (Commonwealth of Australia, 2009). But several challenges to the effective operation of such a system have been identified for flash flood catchments (McKay, 2004, 2008):

- Flash floods are less predictable than larger scale flooding. Rainfall over small catchments is usually not well predicted by numerical weather prediction models.
- For flash floods, there is insufficient time to develop reliable flood warnings and for effective dissemination and response to the flood warnings. More rapid user response is required, which necessitates specialised communication systems and a high level of public flood awareness.
- A reliance on rainfall triggers increases the frequency of false alarms.
- The use of water level triggers does not allow sufficient time for response.

For these reasons, the Bureau of Meteorology traditionally has not issued specific flood predictions for flash flood catchments. The Bureau does offer more general services that may be of some benefit in alerting the emergency services and community to the threat of flooding (Table 13.1).

Table 13.1 – Bureau of Meteorology warning services of potential benefit in flash flood catchments

Sources: McKay, 2004, p.3; www.bom.gov.au

General Weather forecast
General weather forecasts may indicate the likelihood of heavy rain from synoptic scale events, typically with more than 24 hours' notice.

Flood Watch
A Flood Watch is issued by the NSW Flood Warning Centre, typically providing 24 to 48 hours' notice that flooding is *possible* based upon current catchment conditions and future rainfall, which is predicted by computer models of the atmosphere.

Severe Weather Warning
A Severe Weather Warning is issued for synoptic scale events when one or more of the following hazardous phenomena are forecast:

- Gale force winds (average 10-minute wind speed exceeding 62 km/hr)
- Damaging winds (peak wind gusts exceeding 89 km/hr)
- Destructive winds (peak wind gusts exceeding 124 km/hr)
- Torrential rain and/or flash flooding
- Damaging surf conditions leading to significant beach erosion

Severe Thunderstorm Warning
A Severe Thunderstorm Warning is issued by the Severe Weather Team, typically providing 0.5 to 2 hours' notice of impending severe storms. These forecasts are based upon radar and, if available, data from field stations, reports from storm spotters, as well as an analysis of the synoptic situation. For the Greater Sydney region the Bureau issues more detailed graphical Severe Thunderstorm Warnings when actual thunderstorms have been detected.

Pittwater Council has partnered with Warringah and Manly Councils to establish the *Northern Beaches Flood Information Network*. This makes real-time rain and water level information available at http://www.mhl.nsw.gov.au/users/NBFloodInfo/ (see Figure 13.2). At the current time, two rain gauges in the network are located within the Avalon to Palm Beach study area, at Avalon Golf Course (566145) and at Palm Beach Golf Club (566154). No water level recorders are located within the study area. In addition to data being available online, six rain gauges are alarmed so that when pre-determined triggers are reached, emails or SMS are issued to trained personnel from the Councils, NSW SES and RMS (Milliner et al., 2013). The following triggers have been adopted:

- 20mm in 1 hour
- 70mm in 3 hours
- 150mm in 24 hours.

The two rain gauges located within the study area are not alarmed at the current time.

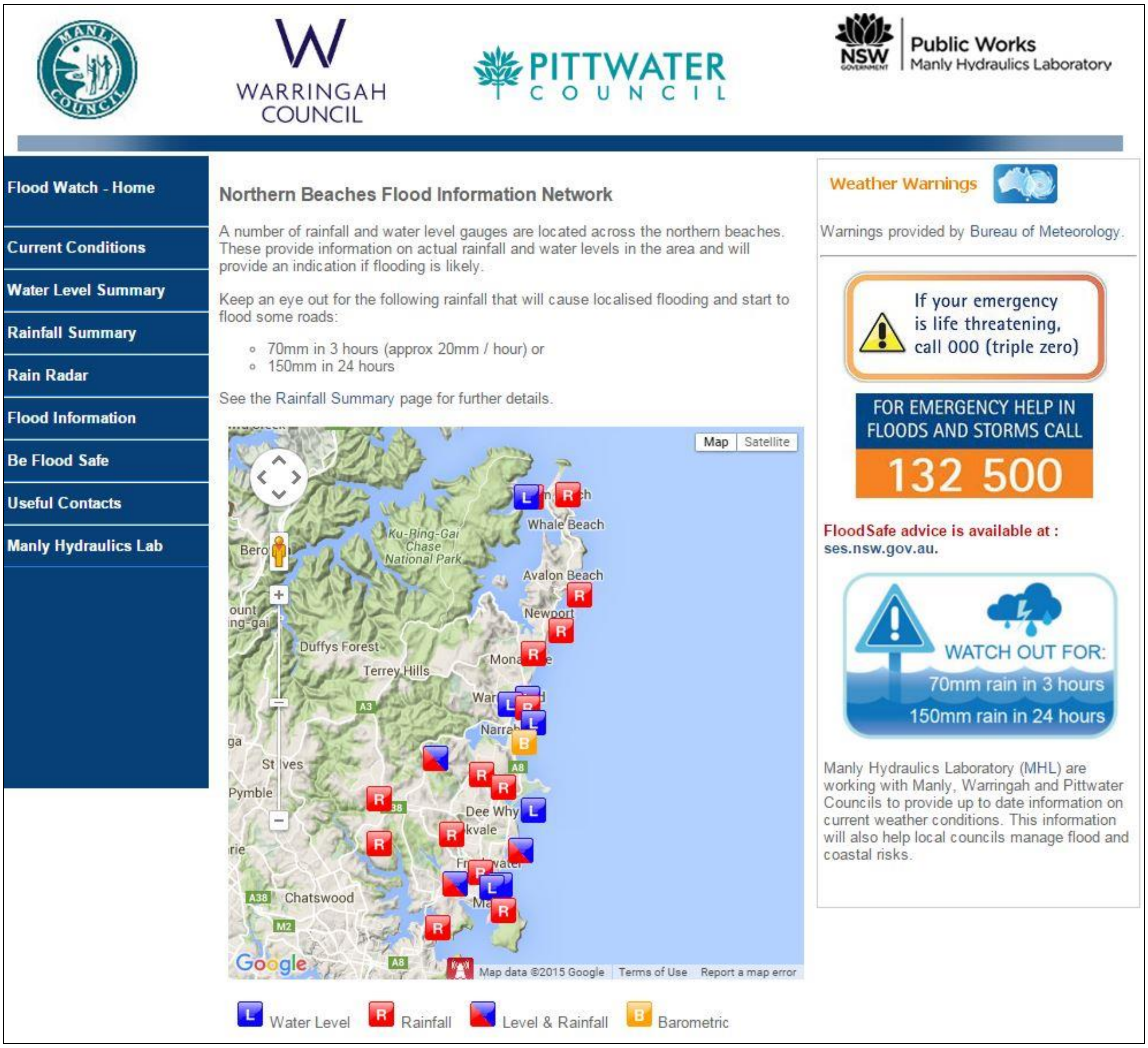

Figure 13.2 – Web interface, Northern Beaches Flood Information Network

13.1.2 Evaluation

Consideration has been given to the need and practicality of enhancing the flood warning system in the Avalon to Palm Beach study area.

In terms of the need, there are a few areas within the floodplain where, given the current style of houses, evacuation off site would be of high priority for saving lives. One of these is in the southern part of Elaine Avenue in extreme floods. Other areas may also require evacuation to a higher storey, which may not be straightforward given the lack of internal access and vulnerable populations (e.g. Pittwater Palms retirement village; Avalon commercial district). These exposures could benefit from enhanced flood warnings to reduce the risk to life. Business proprietors could also benefit from enhanced warnings that provide time to raise stock.

But oftentimes the safest course of action in a flood will be for people to shelter in place and to avoid entering floodwaters. One of the risks of providing flood warnings for the Avalon commercial district could be for patrons to rush outside when an alarm is sounded in attempt to relocate their vehicles from low-lying carparks or to reach their homes. If the carparks and local roads have begun to flood, a warning without appropriate interpretation could lead to unsafe behaviours and actually increase the risk to life.

In terms of the practicality, it is clear from Figure 13.1 that available warning times are very short. The rate of rise in a PMF would be faster still, allowing negligible time to respond. As recognised by the Bureau of Meteorology, relying on rainfall triggers will lead to a higher proportion of false alarms, which may over time erode confidence in the warning system causing people to disregard future alerts. But relying on water level recorders would reduce the time available to respond to just a few minutes. Maintaining a water level recorder in a channel or depression that is dry most of the time is also technically demanding. Selecting a secure location for a water level recorder could also be difficult.

Recommendations:

Considering the existing warning infrastructure and marginal opportunities to improve the flood warning system in a way that enhances protective behaviours, the following measures are recommended:

- Continue to promote the Northern Beaches Flood Information Network website;
- Alarm the Avalon Golf Course rain gauge so that it issues email/SMS when rain triggers are reached. This is justified on the basis of the significant flood risks downstream at Avalon commercial district and Elaine Avenue;
- Consider installing a second real-time rain gauge in the vicinity of Bilgola Plateau Public School, to provide more comprehensive coverage of the Careel Creek catchment. Whilst this site is only 1.6km from the Avalon Golf Course rain gauge, it is located at a much higher elevation (~150m) near the top of the Careel Creek catchment and may capture rain from storm cells approaching from the southwest. The high spatial variability of rainfall in the Northern Beaches (MHL, 2013) and the significant flood risks in the Careel Creek floodplain including Pittwater Palms retirement village also commend this additional investment.
- Include Avalon Palm Beach Business Chamber Inc. on the recipient list for alerts when rainfall triggers at Avalon are reached. The Chamber may elect to disseminate this information to their members;
- Transition towards a system where people living or working in the floodplain can opt in for receiving emails/SMS. People have previously indicated that this is their preferred means of receiving advice (Milliner et al., 2013). This is justified because every additional chain in a flood warning dissemination system (even having NSW SES personnel interpret or 'add value to' the rain gauge information) tends to delay the process when for flash flood situations time is invariably short. It is understood that a direct gauge-to-user dissemination system may be developed at the conclusion of the current contract (Milliner et al., 2013);
- Devise appropriate messages to accompany the rainfall alerts, making clear to users that rainfall is a 'heads up' of *possible* flooding and that residents/proprietors should not drive/ride/walk through floodwater.

13.2 Emergency Response Planning

13.2.1 Prepare Local Flood Sub-Plan

Effective planning for emergency response is a vital way of reducing risks to life and property. The NSW State Emergency Service (SES) is the legislated combat agency for floods in NSW and is responsible for the control of flood operations. This role is undergirded by detailed flood planning.

At the current time, the only plan giving some attention to flooding in the Avalon to Palm Beach study area is the Local Disaster Plan (DISPLAN) for Manly, Warringah and Pittwater dated August 2005. The Local Emergency Management Committee (LEMC) is in the process of updating the DISPLAN to an Emergency Management Plan (EMPLAN), which contains somewhat different content and formatting to the DISPLAN. Notwithstanding these differences in content and format, it is recommended that the following comments on the current DISPLAN – and more broadly, the flood risk information in this FRMS&P – be considered in the preparation of the EMPLAN:

- Section 1.7 describes the flooding hazard for coastal lagoons and the flash flooding hazard around Forestville, Davidson and Belrose. This section should also acknowledge the flood hazard from Careel Creek in Avalon and the flash flooding hazard that can occur anywhere near steep terrain. It could draw upon the summary of flooding types contained in the *Northern Beaches Flood & Coastal Storm Education Strategy 2012-2016*.
- Section 1.8.1 describes ambulance stations within the three LGAs. There is an additional station in Avalon (corner Barrenjoey and Central Roads).
- Section 6.6 describes the response of evacuation. The common sense wording of clause 'd' (below) is noted:

  Evacuation of persons or animals from an area of danger or potential danger is a possible strategy in combating any particular hazard. The decision to evacuate is one which should not be taken lightly. In some circumstances, it may be more appropriate for people to remain in their homes and to take other measures to ensure their safety.
- Section 6.7 describes protocols, means and messages for evacuation warnings. This may need to be fine-tuned to better reflect the challenges for effective flood warning systems in flash flood settings, which may require rapid dissemination methods. Also, in some cases the appropriate message may be *not* to attempt to evacuate (e.g. if a car park at Avalon has begun to flood).
- The DISPLAN does not nominate any assembly or evacuation centres. This may reflect an understanding that evacuation outside buildings or through flooded roads is not necessarily the most appropriate strategy where flooding has already commenced. But it may still be prudent to consider some assembly areas proximate to concentrated risk exposures. For example, if Pittwater Palms retirement village begins to flood and egress is cut off, the 2-storey buildings to which residents could evacuate could be listed. Similarly, if the Avalon commercial district has begun to flood during business hours, buildings that could potentially serve as a place of assembly until floodwaters recede could be listed.
- Appendix C of the DISPLAN lists vulnerable communities including childcare centres, hospitals, nursing homes, retirement communities, retired and disabled persons accommodation, and schools. It needs to be completed (including addresses) and updated (e.g. Barrenjoey Montessori School should be included). The Avalon to Palm Beach FRMS details how these vulnerable communities are affected. Consideration could be given to adding locations of critical infrastructure.

No Local Flood Sub-Plan has been prepared for Pittwater LGA. It is recommended that the NSW SES prepare a Pittwater Local Flood Sub-Plan drawing on the flood intelligence in this FRMS&P.

Volume 1 of the NSW SES Local Flood Plan template describes responsibilities for managing flood operations including for the SES and Council, and arrangements for preparing for, responding to and recovering from floods. Although evacuation from a flood affected area before flooding is preferred, in many cases in the Avalon to Palm Beach study area, this may not be feasible given the rapid rise of water, low-set roads, limited warning times and limited numbers of emergency services personnel (see Section 5.3). The application of Council's DCP will gradually transform the built environment in the floodplain to provide places of shelter above the PMF in resilient dwellings. Isolation is likely to be of relatively short duration for this study area. For these reasons, it is recommended that the Local Flood Sub-Plan preserve the spirit of clause 'd' of Section 6.6 of the DISPLAN for Manly, Warringah and Pittwater dated August 2005 (cited above), which allows that sheltering in place may be the most appropriate strategy.

It is, nonetheless, advisable to consider and document appropriate evacuation shelters that people could access at short notice. This is particularly so for the Avalon commercial district, where numbers of people could potentially be caught by flash flooding. It is recommended that the SES identify and list in the Local Flood Sub-Plan accessible two-storey buildings within each major shopping block that people should be able to access without having to cross generally lower-set roads. This could include the Avalon Library/Recreation Centre building (Figure 13.3) in the block bounded by Old Barrenjoey Road, Avalon Parade, a laneway and Dunbar Park. An indication on a sign outside the Woolworths supermarket that people should make their way to the Avalon Surf Club via Avalon Parade (Figure 13.5) may be unwise, since this may direct people through floodwaters. If open (if currently not, keys should be supplied to the Woolworths manager), the upper storey of the Woolworths building is likely to represent a more accessible, safer area of short-term shelter.

Volume 2 of the NSW SES Local Flood Plan template describes the flood threat and the effects of flooding on the community. The Avalon to Palm Beach FRMS&P includes much flood intelligence that could be incorporated into this Volume when it is drafted, including:

- Flood history;
- Characteristics of flooding (extents, depths, velocities, hazard, rate-of-rise and duration) for six design events including the PMF;
- Maps showing the distribution of buildings flooded above floor;
- A property database including ground levels, estimated floor levels and design flood levels for every building with the floodplain;
- A map and description of evacuation-constrained areas;
- A list of vulnerable uses and critical infrastructure exposed to flooding;
- A list of roads subject to flooding.

Volume 3 of the NSW SES Local Flood Plan template describes response arrangements for areas within each LGA. As described above, on many occasions, the rapid onset and short duration of flooding in the Avalon to Palm Beach study area suggest that shelter-in-place may be a safer course of action than evacuating. However, in some extreme floods, the flood hazard and current housing styles suggest that early evacuation is imperative (e.g. east Central Road and south Elaine Avenue). Given that an extreme flood may not manifest itself until it has occurred, the emergency services will need to pay special attention to these areas, which could be documented in this volume. It is also noted that Dunbar Park is regularly used for community events (e.g. Avalon Beach Market Day), which because of the volume of people represents a heightened risk. A plan of response should a flood threat occur during one of these events should be formulated.

Figure 13.3 – One potential evacuation shelter for Avalon

13.2.2 Prepare and update private flood plans

As well as preparing a Local Flood Sub-Plan, there would be benefit in NSW SES and Council encouraging and helping key floodplain exposures to prepare and update their own flood emergency response plans. The process of preparing plans would in itself be an important process of raising awareness and preparedness.

Among the higher priorities for flood plans are:

- Pittwater Palms retirement village;
- Schools and pre-schools.

Recommendations:

- Consider the information in the Avalon FRMS&P in completing the EMPLAN (LEMC)
- Prepare a Pittwater Local Flood Sub-Plan, recognising the limits to evacuation in the Avalon to Palm Beach study area, identifying evacuation shelters that people in the Avalon commercial district could access at short notice, using the flood intelligence contained in this study and identifying hotspots requiring attention (NSW SES)
- Encourage and assist key floodplain exposures to prepare and update their own flood emergency plans (NSW SES, Council)

13.3 Flood Education

13.3.1 General

Actual flood damages can be reduced, and safety increased, where communities are flood-ready:

> *'People who understand the environmental threats they face and have considered how they will manage them when they arise will cope better than people who lack such comprehension… Many people who live and work in flood liable areas have little idea of what flooding could mean to them – especially in the case of large floods of severities well beyond their experience or if a long period has elapsed since flooding last occurred. It falls to the [SES], with assistance from councils and other agencies, to raise the level of flood consciousness and to ensure that people are made ready for flooding. In other words, flood-ready communities must be purposefully created. Once created, their flood-readiness must be purposefully maintained and enhanced'* (Keys, 2002, p.52).

Although a number of flood and property modification measures are available to manage flood risk, communities living and working in floodplains in the Avalon to Palm Beach study area will never be totally protected from the impacts of flooding. Nor can emergency authorities such as the NSW SES ensure the safety of all residents. Therefore, it is critical that through community education the flood-affected communities are aware of the flood risk, are prepared for floods, know how to respond appropriately and are able to recover as quickly as possible.

Based on learnings from recent disasters, the focus of community disaster education has now turned from a concentration on raising awareness and preparedness to *building community resilience through learning*. Simply disseminating information to the community does not necessarily trigger changed attitudes and behaviours. Flood education programs are most effective when they:

- Are participatory i.e. not consisting only of top-down provision of information but where the community has input to the development, implementation and evaluation of education activities;
- Involve a range of learning styles including experiential learning (e.g. field trips, flood commemorations), information provision (e.g. via pamphlets, DVDs, the media), collaborative group learning (e.g. scenario role plays with community groups) and community discourse (e.g. forums, post-event de-briefs);
- Are aligned with structural and other non-structural methods used in floodplain risk management and with emergency management measures such as operations and planning; and
- Are ongoing programs rather than one-off, unintegrated 'campaigns', with activities varied for the learner.

Pittwater, Warringah and Manly Councils partnered with NSW SES to develop the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16*. The Strategy drew upon a baseline quantitative social survey conducted by Micromex Research (2012). Among the key findings were:

- The Northern Beaches community has a very low level of concern about the risk of flooding.[15] This finding is also suggested by the low participation rate in the community questionnaire prepared for the current study.
- The Northern Beaches community generally has a low level of preparedness as measured by existence of home emergency kits and evacuation plans, and very few people are aware of the national SES hotline number.
- Although only 11% of respondents indicated they would drive across a familiar road that had fast flowing or deep water crossing it, the reasons provided by those who would 'give it a go' are informative:
  - 'It would depend on my vehicle, if I was in a 4WD, I would proceed' (26%);
  - 'I have done it before, know the roads very well or am a very experienced driver' (18%);
  - 'I would assess the situation/depth myself and act accordingly' (18%).

Based on this research, the Strategy aims '*to build community resilience to flood and coastal storms by improving the capacity of the Northern Beaches community to prepare, respond and recover from major flood and storm events…*' The Strategy sets out the following four outcomes, together with key messages and prioritised actions to achieve those outcomes:

- Increased community concern for the potential risk and impact of flooding and coastal storm hazards on the Northern Beaches
- Increased community preparedness for flood and coastal storm hazards evidenced by owning a home emergency kit and establishing an evacuation plan
- Increased community understanding of, and willingness to engage in, appropriate emergency response behaviour
- Strengthened regional networks with stakeholders for ongoing support and adaptive capacity within the community

Building on the Strategy, consideration is given to the flood education messages and methods that may be of particular benefit for the Avalon to Palm Beach study area.

13.3.2 Messages

A basic message to continue to communicate is that floods are a genuine hazard within the study area and that effort should be made to prepare for flooding. Historical flood photos depicting people swimming or paddling in Avalon streets suggests lackadaisical attitudes towards flooding (Figure 13.4). But the flood history reported in Section 2.3 indicated that damaging floods have been experienced, including in 1973 and 1977 when businesses and houses were inundated. People also need to understand that bigger and faster-rising floods than have been experienced previously will one day occur, which may pose significant risk to life and property.

[15] This result could reflect the sampling method employed. Because this research was not confined to flooding, the random sample was evidently not confined to floodplains, so some people's low levels of concern about the risk of flooding could be accurate for their properties.

THE Manly Daily

TUESDAY, FEBRUARY 5, 2008 YOUR LOCAL CUMBERLAND NEWSPAPER PHONE 9977 3333 80c incl. GST

When traffic slows to a crawl in the rain

Chelsea White

AVALON residents have always done things that little bit differently, but even locals were stopped in their tracks as roads were turned into lap pools by brave swimmers over the weekend.

Despite being hit by some of the highest rainfalls in the state, locals and travellers were making the most out of localised flooding with body boarders and swimmers taking to Avalon's streets and parks.

Slovenian traveller Franci Legen caught the action on his camera, saying even though he had travelled around the world, swimming in the street was something new.

Full story – Page 5

This swimmer found a novel way to get around a flooded Avalon street on Sunday. Picture: FRANCI LEGEN

Figure 13.4 – Swimming in a flooded Avalon street

Business proprietors in Avalon are a community who may need special effort to persuade that planning for floods is a worthy investment, in line with the NSW SES's 'Don't let your business go under'. Low levels of interest in flooding are suggested by the very low response rate to the business questionnaire prepared for this study.

Some roads, including Barrenjoey Road at several locations north of Careel Head Road, may be flooded to dangerous depths and velocities even in relatively frequent events. This suggests that messages such as the NSW SES's 'Never drive, ride or walk through floodwater' are especially pertinent. But there is also a need for messages to confront the reasons people may reject that guidance. For example, that cars float in just 30cm of still water, that even 4WDs float and may wash downstream, and that every flood is different.

Messages to combat people playing in floodwaters include the danger of doing so since children have drowned playing in drains and that floodwaters can carry harmful bacteria.

13.3.3 Methods

General methods

Avalon Historical Society has a good collection of historical flood photos that could be drawn upon for flood education. The flood history reported in Section 2.3 could also be extended by further research of local newspapers. This historical material could be developed into a library or mobile display, which could be accompanied by maps showing the extent and depth of design floods and relevant educational messages. Where needed, surrogates (e.g. Dungog) could be used to make the case that extreme floods happen.

A FloodSafe guide has been prepared for Pittwater LGA. This sets out the different styles of flooding in the LGA, how people may be advised of flooding and what people can do to prepare their family and property for floods. Having an additional FloodSafe guide specific to Careel Creek or the Avalon village centre would enable a particular focus on the flood behaviour and responses appropriate for this catchment, but the benefits of this are considered marginal.

Business

One of the actions of the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16* is the distribution of Business FloodSafe toolkits and guides. The *Flash Flood Business FloodSafe* toolkit and guide aim to persuade businesses of the importance of planning for floods and to help proprietors prepare an action plan. It is a comprehensive 38-page document that if completed and maintained would significantly increase businesses' awareness and readiness for floods. But existing levels of interest in flooding in Avalon are so low that proprietors may be unlikely to take the effort to complete this lengthy plan. For this reason there would be benefit in developing a more accessible, condensed version of the Business FloodSafe toolkit. This exercise was undertaken for the Eastwood commercial district, which also has a significant flash flood risk, resulting in a 5 page template (Bewsher Consulting, 2010a). Ryde Council requires that this template be completed whenever there is a change of business use in the Eastwood commercial district's floodplain.

NSW SES holds Business Breakfasts to present the Business FloodSafe toolkit and to discuss local flood risks and responses. These are usually held in conjunction with a local Chamber of Commerce and provide a free breakfast for attending business managers and owners. Because the Avalon commercial district represents such a distinct and significant flood risk in the study area, a Business Breakfast is considered to be a good forum for encouraging businesses to become more flood-resilient.

Residents

One option to directly engage residents is via 'meet-the-street' events, which involves NSW SES and Council setting up a 'stall' at an appropriate and visible location at a time that people will be at home. The 'meet-the-street' should be advertised through a specific letter box drop to the targeted neighbourhood or vulnerable site. The stall could consist of flood maps on boards, NSW SES banners and NSW SES materials (Pittwater FloodSafe guide) to hand out. These materials are used to engage with people and make them aware of flood risk, encourage preparedness behaviours (e.g. develop emergency plans) and help them understand what to do during and after a flood. A meeting could also encourage property owners to develop self-help networks and particularly people checking on neighbours if a flood is imminent. Longer-term residents with flood experience could be used to help other residents understand flooding. Considering the existing flood risk, at least the following two sites would benefit from this approach:

- Pittwater Palms retirement village, Avalon Parade;
- south Elaine Avenue/east Central Road.

One point of caution for meet-the-street events relates to the potential for conflicting advice in relation to whether to attempt to evacuate or to shelter-in-place. Council and NSW SES will need to ensure that they are presenting a clear and consistent message for each location, so that residents know how they need to respond in a flood emergency.

Schools

Another action in the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16* is for presentations in schools. Given the age range of its students and its proximity to Careel Creek, Barrenjoey High School should be a high priority. Innovative approaches to communicating the dangers of playing in floodwater would be beneficial.

Signage

Permanent signage can be of value in a variety of contexts, showing:

- that an area or road is subject to flooding;
- the potential depths of flooding;
- evacuation routes;
- safety messages (e.g. don't enter floodwater).

Several of these features are included on the sign located near the entrance to the Woolworths supermarket in Avalon Beach (Figure 13.5), which is a well-chosen site for its volume of pedestrian usage, though one wonders whether over time the community may tend to forget the sign. If flooding has already commenced, it is doubtful that safe access to the Surf Club via Avalon Parade would be possible. Since the safest course of action in likely to be 'upstairs', appropriate signage at the entrance to each flood evacuation shelter identified in the commercial district would be beneficial.

It is also advisable to install signage in flood prone carparks servicing Avalon, such as near the RSL Club and the Woolworths supermarket. This could indicate that the areas are subject to flooding but also include safety advice to discourage people from attempting to relocate their vehicles if flooding has commenced. Signage is also recommended for the carpark leading to Bilgola Beach, where high velocity flows could mobilise vehicles.

Flood depth indicators up to 1m high could be of value where flood modelling shows important roads to be inundated to serious levels in relatively frequent events. The analysis of road inundation identified four sites flooded to >0.5m in the 20% AEP flood:

- Barrenjoey Road near Palm Beach ferry;
- Barrenjoey Road opp. No. 746;
- Barrenjoey Road/Careel Head Road intersection;
- Barrenjoey Road opp. No. 712A.

Consultation may need to be conducted to gain the acceptance of nearby residents, given fears of adverse impacts of signage on property values.

Detention basins may also require signage to warn of potentially deep flooding.

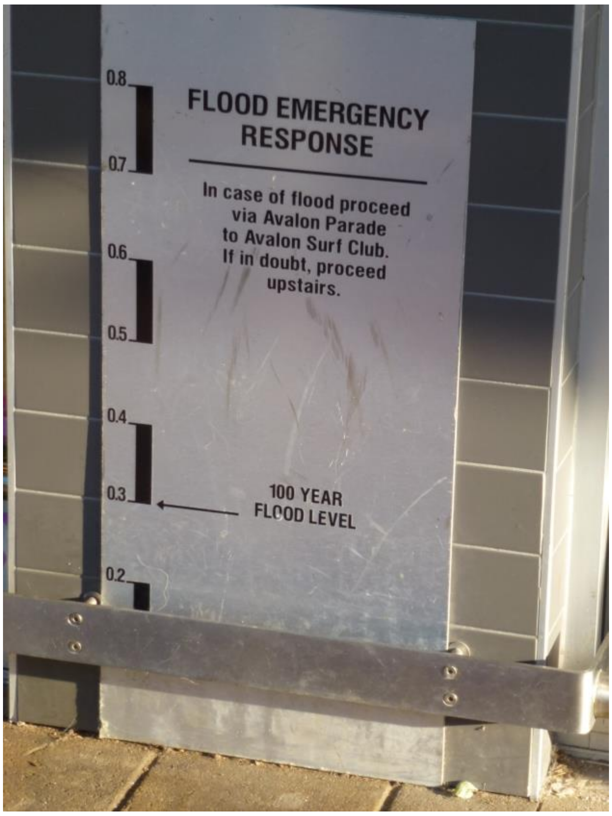

Figure 13.5 – Signage outside Woolworths supermarket, Avalon

Recommendations:

- Develop a library or mobile display using historical flood photos, modelled flood extents and appropriate messaging;
- Develop an accessible flood emergency plan template suitable for use by Avalon Beach businesses, in conjunction with Avalon Palm Beach Business Chamber Inc.;
- Hold a Business FloodSafe Breakfast in conjunction with Avalon Palm Beach Business Chamber Inc. (NSW SES);
- Conduct ‘meet-the-street’ type events for residents at Pittwater Palms retirement village and at south Elaine Ave/east Central Road (NSW SES);
- Engage with students at Barrenjoey High School to help them understand flood behaviour near the school and to promote safe responses, including not to play in flooded creeks and drains (Council in collaboration with NSW SES);
- Install signage indicating entrances to evacuation shelters in Avalon commercial district;
- Install signage in flood prone carparks in Avalon commercial centre and Bilgola Beach;
- Install flood depth indicators at ~4 low-points on Barrenjoey Road;
- Install signage in any detention basins where flooding could pond to dangerous depths.

14. Implications of Climate Change

14.1 Climate Change Impacts Relevant to Flood Risk

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014) confirms that human influence on the climate system is clear and growing, with impacts observed across all continents and oceans. Projected changes in climate that would have implications on flood risk are sea level rise and changes in the hydrologic cycle, namely an anticipated increase in the frequency and intensity of heavy rainfall events.

14.1.1 Sea Level Rise

According to the IPCC Fifth Assessment Report (IPCC 2014) global mean sea level rose by 0.19 m over the period 1901–2010, with the mean rate of global averaged sea level rise of 3.2 mm/yr between 1993 and 2010 being significantly larger than the mean rate during the previous two millennia. This process is driven primarily by thermal expansion of the ocean due to warming, and the melting of glaciers and ice sheets.

It is notable that rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades due to fluctuations in ocean circulation and, since 1993, the regional rates for the Western Pacific are up to three times larger than the global mean (IPCC 2014).

While there is a consensus among many scientists on the occurrence of sea level rise, projected increases vary considerably. The IPCC Fifth Assessment Report states that future sea level rise is expected to proceed at rates exceeding those observed to 2010, with climate modelling estimating a rate of rise of 8 to 16 mm/yr during the period 2081–2100 (IPCC 2014). The Floodplain Risk Management Guideline on Practical Consideration of Climate Change (DECC 2007) identifies, from relevant IPCC and CSIRO research, that sea level rise on the NSW coast is expected to be in the range of 0.18 m to 0.91 m by between 2090 and 2100.

14.1.2 Frequency and Intensity of Heavy Rainfall Events

The IPCC Fifth Assessment Report (IPCC 2014) found that the frequency and intensity of heavy precipitation events has likely increased over the second half of the 20th century.

The observation and prediction of this phenomenon presents difficulties due to factors such as natural seasonal and longer-term variations, limited observational coverage, and the non-uniformity of changes across the globe. There is therefore significant variation in projected increases in the intensity of heavy rainfall events.

Australian rainfall is particularly variable, making it difficult to identify significant trends over time, and understanding changes to rainfall intensity is an area of ongoing research. The Floodplain Risk Management Guideline on Practical Consideration of Climate Change (DECC 2007) identifies that changes in extreme rainfall intensity for Sydney Metropolitan Catchments may be in the order of -3% to +12% based upon previous CSIRO studies.

14.1.3 NSW and Pittwater Council Approaches

Climate change sensitivity analyses undertaken in floodplain risk management studies under the OEH Floodplain Management Program typically adopt sea level rise (SLR) values of between 0.4 m and 0.9 m and increases in rainfall intensity of between 10% and 30% as per the Floodplain Risk Management Guidelines Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW 2010) and Practical Consideration of Climate Change (DECC 2007). The ranges of values recommended in these documents were based upon studies from the IPCC and CSIRO for the period to 2100.

In 2012 the NSW Government announced its Stage One Coastal Management Reforms, a result of which is that the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils. The NSW Chief Scientist and Engineer's report titled *Assessment of the Science behind the NSW Government's Sea Level Rise Planning Benchmarks* (2012) however identified that the science behind sea level rise benchmarks from the 2009 NSW Sea Level Rise Policy Statement was adequate.

Pittwater Council has adopted a climate change scenario including 0.9 m sea level rise and a 30% increase in design rainfall intensity for considering the possible implications of climate change on floodplain risk management activities. While these values lie at the upper end of projections for the period to 2100, it is noted that climate change and sea level rise are likely to continue for many centuries beyond 2100 (e.g. IPCC 2014).

14.2 Impact of Climate Change on Local Flood Behaviour and Impacts

The sensitivity of flood behaviour in the Avalon to Palm Beach study area to potential climate change was investigated by simulating Pittwater Council's adopted climate change scenario of 0.9 m sea level rise and 30% increase in design rainfall intensity for the 1% AEP design flood event.

Changes in 1% AEP peak flood levels and extents associated with the simulated climate change scenario are presented in Figure 14.1 and Figure 14.2 respectively.

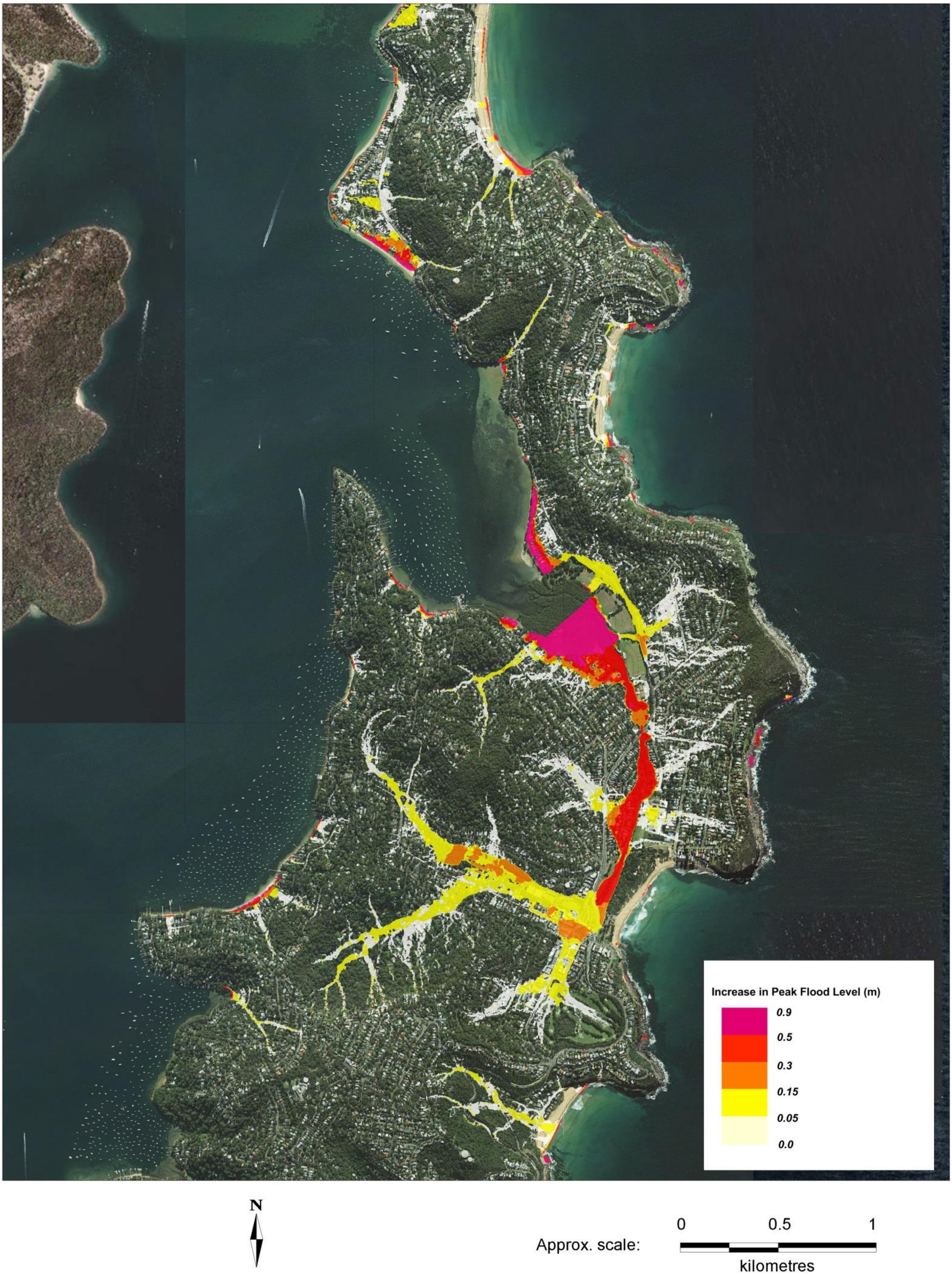

Figure 14.1 – Simulated changes in 1% AEP peak flood levels due to climate change

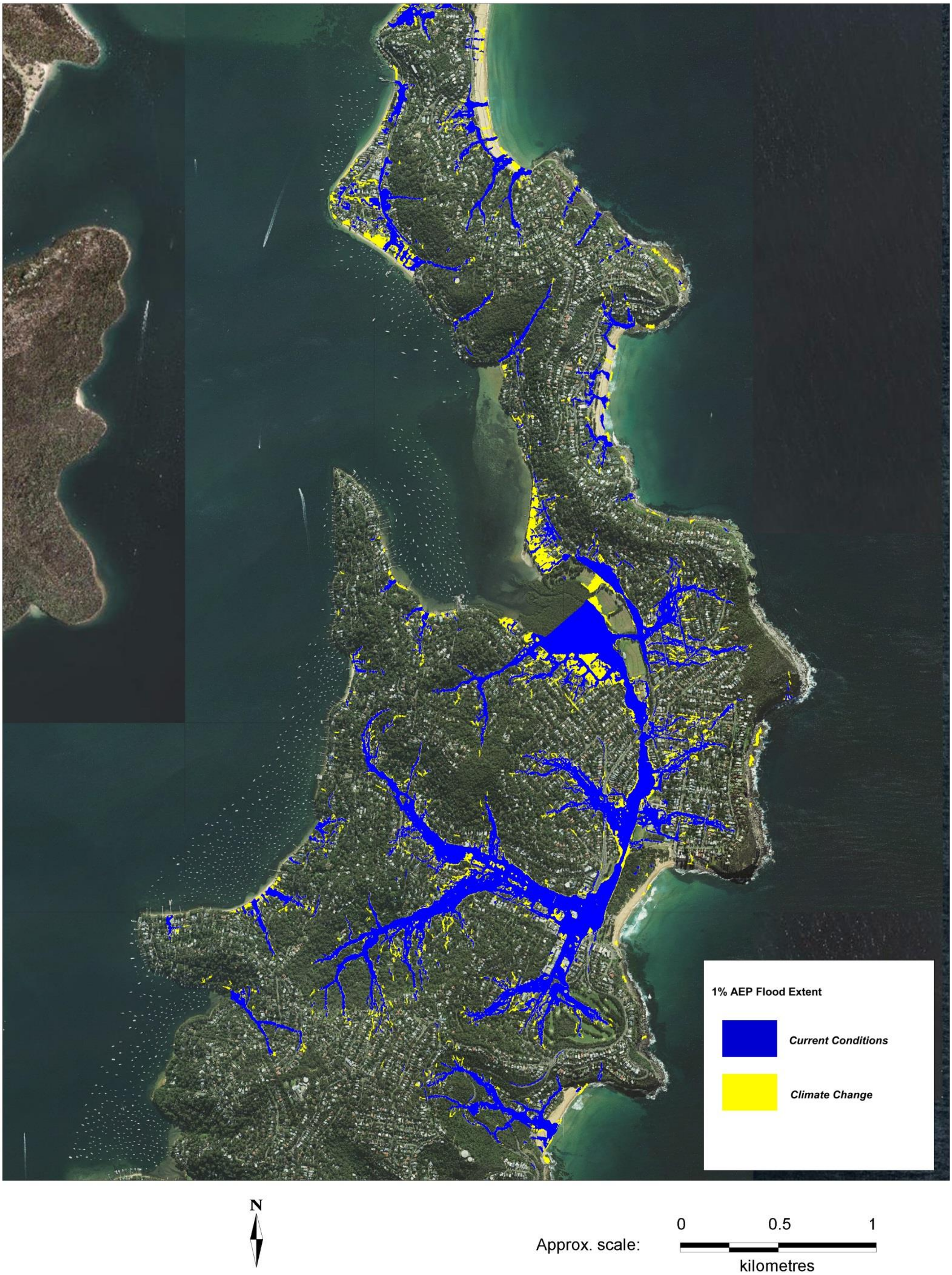

Figure 14.2 – Simulated changes in 1% AEP flood extent due to climate change

In comparison with current design conditions, simulation of sea level rise of 0.9 m and a 30% increase in rainfall intensity has the following impacts on 1% AEP design flood conditions:

- peak flood levels were increased by 0.05 m or more over approximately 48% of the floodplain
- peak flood level increases of the order of 0.3 to 0.4 m were observed throughout much of Careel Creek, with larger increases toward Careel Bay where the influence of sea level rise is greater
- peak flood levels increased by over 0.5 m along the western side of Currawong Avenue and Barrenjoey Road immediately to the north, with similar increases observed toward the southern end of Iluka Road
- significant increases in flood extent were observed at Iluka Road, Currawong Avenue, and in Careel Creek particularly in the John Street area approaching Careel Bay
- changes in peak flood levels and extents in higher areas (i.e. areas affected only by the increase in rainfall intensity) were less marked, with increases of the order of 0.15 to 0.25 m observed in Toongarri Reserve, in the vicinity of Pittwater Palms, and in the Avalon CBD around the intersection of Old Barrenjoey Road and Avalon Parade.

The most significant changes in flood level and extent noted above generally occurred in low-lying areas of the Pittwater foreshore including Iluka Road, Currawong Avenue, and in the John Street area adjacent to Careel Creek. These increases can be attributed primarily to sea level rise and, outside of Careel Creek, appear to be largely a result of inundation from elevated levels in Pittwater itself. It is likely that the occurrence of ocean storm-driven estuarine flooding in combination with sea level rise would have greater impacts in these areas than catchment-driven flooding of the same probability.

Figure 14.3 shows the distribution of buildings estimated to be flooded over floor by the 1% AEP event under existing conditions and additional buildings inundated under the simulated climate change scenario. Consistent with the above analysis of increases in flood levels and extents, a significant number of additional dwellings would be flooded over floor in:

- Iluka Road, Palm Beach
- Currawong Avenue, Careel Bay
- John Street area, Avalon
- Elaine Avenue, Avalon.

Table 14.1 shows the number and depths of over floor flood affectation by the 1% AEP event under existing conditions and the climate change scenario, with this data presented graphically for the residential sector in Figure 14.4 and the non-residential sector in Figure 14.5.

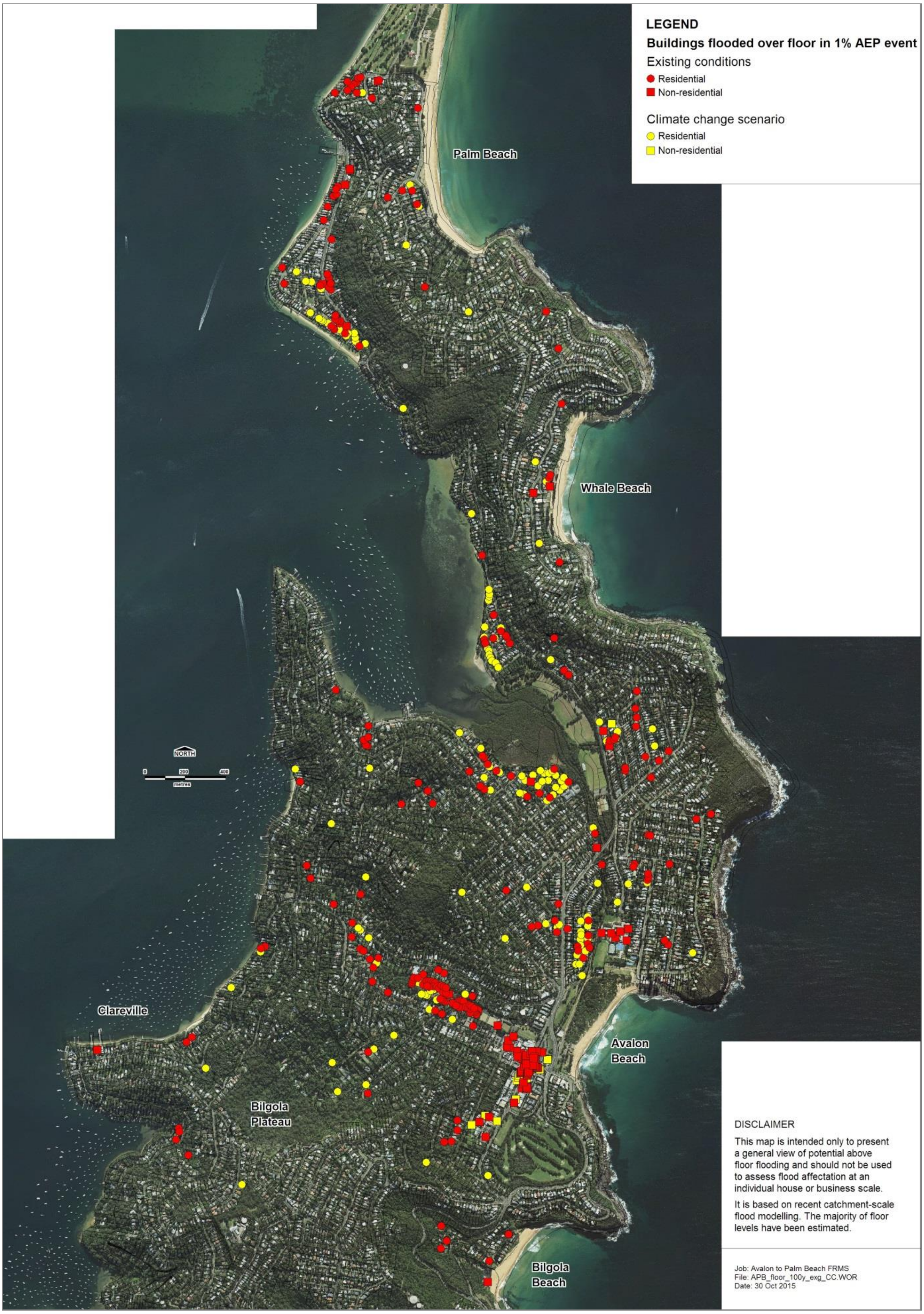

Figure 14.3 – Simulated changes in over floor flood affectation due to climate change

Table 14.1 – Number of dwellings and business premises/public sector buildings by above floor depth in 1% AEP event

	Existing Conditions		Climate Change	
Depth over (below) floor in 1% AEP event	Residential	Non-residential	Residential	Non-residential
0.0-0.1m	115	27	136	20
0.1-0.3m	84	53	146	39
0.3-0.5m	18	17	58	51
0.5-1.0m	2	4	20	8
>1.0m	0	0	2	0
TOTAL flooded over floor	**219**	**101**	**362**	**118**

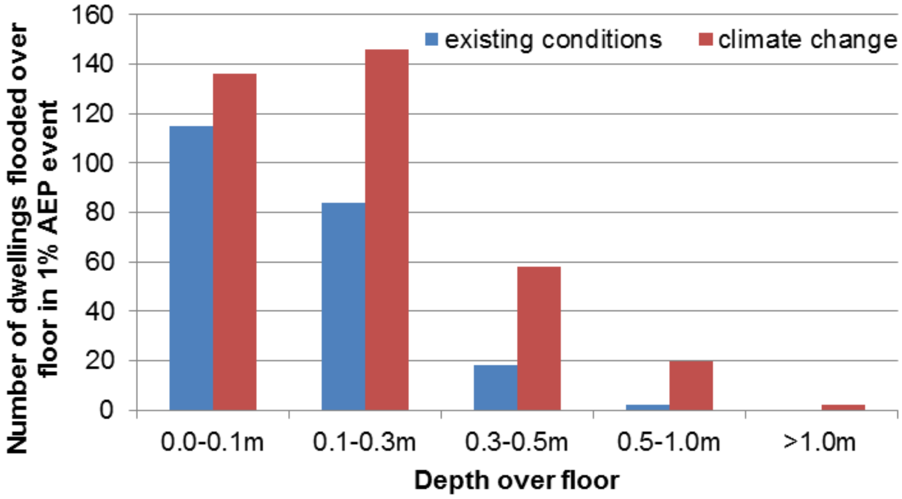

Figure 14.4 – Depths of above floor inundation in 1% AEP event, residential sector

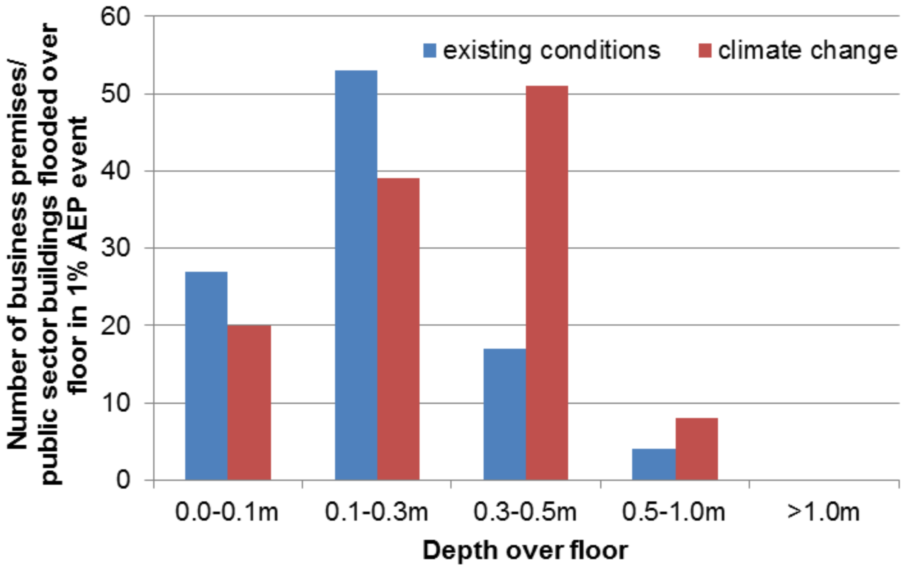

Figure 14.5 – Depths of above floor inundation in 1% AEP event, non-residential sector

Under the simulated climate change scenario, the number of residential dwellings flooded above floor in the 1% AEP event would increase from 219 to 362, and the number of non-residential premises from 101 to 118. Depths of over floor flooding also increased markedly. Under existing conditions over 50% of affected residential dwellings were estimated to be flooded over floor to a depth of less than 0.1 m, while under the climate change scenario this proportion reduced to 38%. Under existing conditions the proportion of affected dwellings flooded over floor by depths of 0.3 m or more was less than 10%, with this proportion increasing to 22% under the climate change scenario. The number of residential dwellings with over floor flooding depths of 0.5-1.0 m increased tenfold while two properties became affected by over 1.0 m of over floor flooding. For the non-residential sector the number of properties in the 0.0-0.3 m range actually decreased while numbers in the 0.3-0.5 m and 0.5-1.0 m ranges tripled and doubled respectively.

Direct residential damages for the 1% AEP event would increase by around 60% from $15.2M to $24.3M, direct non-residential by around 32% from $3.7M to $4.9M, and total damages by over 50% from $29M to $44.5M (Table 14.2).

In summary, the implications of climate change on flood impacts within the Avalon to Palm Beach area could be significant. Under the investigated climate change scenario of 0.9 m sea level rise and 30% increase in rainfall intensity, significant increases in peak flood depths, inundation extent, number of buildings flooded over floor and flood damages were simulated for the 1% AEP event. The greatest impacts were observed in low-lying areas along the Pittwater and Careel Bay foreshore including properties in the Iluka Road, Currawong Avenue and John Street areas, and are predominantly associated with sea level rise. Significant impacts were also observed along Careel Creek in the vicinity of Elaine Avenue with increased rainfall and sea level rise both contributing to this impact.

It is noted that a 1% AEP ocean water level boundary of 1.45 m AHD was adopted for modelling of the 1% AEP flood event in this study, representing quite severe conditions in Pittwater in itself. Together with 0.9 m sea level rise this ocean water level condition would produce significant inundation of the Pittwater foreshore, and much of the climate change impact observed in this analysis can be attributed to ocean storm-driven inundation rather than catchment-driven flooding.

14.3 Influence on Flood Modification Options

The impact of climate change on the performance of proposed flood modification options was investigated including the Catalpa Reserve and Toongarri Reserve detention basins alone and in combination. The results of an analysis of 1% AEP flood damages and over floor flooding are presented in Table 14.2, comparing the benefits of the proposed options under existing conditions and the climate change scenario. The driver for changes in flood benefits associated with these options is the 30% increase in rainfall intensity rather than sea level rise.

Table 14.2 – Influence of climate change on flood modification benefits

	Base Case		Catalpa Reserve Detention Basin		Toongarri Reserve Detention Basin		Catalpa & Toongarri Reserve Detention Basins	
	Existing Conditions	Climate Change	Existing Conditions	Climate Change	Existing Conditions	Climate Change	Existing Conditions	Climate Change
Residential								
Reduction in no. houses flooded over floor in 1% AEP	*219**	*362**	6	1	5	2	11	5
Direct residential damages in 1% AEP	$15,211,941	$24,279,846	$14,982,835	$24,166,625	$14,924,933	$24,150,968	$14,715,194	$24,040,356
Reduction in 1% AEP direct residential damages	-	-	$229,106	$113,221	$287,008	$128,877	$496,747	$239,490
Non-residential								
Reduction in no. houses flooded over floor in 1% AEP	*101**	*118**	4	2	4	2	4	2
Direct non-residential damages in 1% AEP	$3,673,760	$4,882,582	$3,483,745	$4,838,265	$3,369,711	$4,771,504	$3,335,386	$4,731,915
Reduction in 1% AEP direct non-residential damages	-	-	$190,015	$44,317	$304,049	$111,078	$338,374	$150,667
Total (including direct residential and non-residential, indirect residential and non-residential, infrastructure and social)								
Total 1% AEP Damages	$29,037,459	$44,482,682	$28,344,227	$44,234,310	$28,043,605	$44,084,762	$27,674,264	$43,849,154
Reduction in Total 1% AEP Damages	-	-	$693,233	$248,372	$993,854	$397,920	$1,363,195	$633,528

**Total number of houses/premises flooded over floor for base case*

The results presented in Table 14.2 can be summarised as follows:

- flood benefits in terms of reduction in the number of buildings flooded over floor in the 1% AEP event were reduced under climate change for all options, with the Toongarri Reserve and combined options proving more resilient
- flood benefits in terms of reduction in total 1% AEP event flood damages were reduced under climate change by approximately 60% for all options
- all options continue to provide flood benefits under climate change in terms of reduction in the number of buildings flooded over floor in the 1% AEP event and reduction in 1% AEP event flood damages.

While the potential impacts of climate change on proposed flood modification options as simulated in this study are significant, there are various reasons why this does not negate the present value of these options. These include the following considerations:

- the simulated reductions in flood benefits are in the context of a 30% increase in rainfall intensity for the 1% AEP design event
    - projections of increase in rainfall intensity for heavy rainfall events are highly uncertain, and actual increases may be considerably lower than 30%
    - the timeframe over which such increases in rainfall intensity may occur is likely to be considerable, during which time the basins would continue to provide a high level of flood benefit and indeed would continue to provide a lower level of benefit thereafter
- while reductions in 1% AEP flood damages under the climate change scenario would be in the order of 60%, this may not be representative of changes in AAD and NPV
- in the case of the Catalpa Reserve detention basin additional flood benefits under climate change may be achievable by an increase in embankment height.

It is therefore considered that, despite the potential for climate change to result in significant reductions in flood benefits provided by the proposed Catalpa and Toongarri Reserve basins, the long-term performance of these options remains viable and the recommendation for their further investigation and adoption remains warranted.

14.4 Influence on Property Modification Options

The impact of climate change on the performance of proposed property modification options was also investigated.

Increased depths of above floor flooding with climate change – particularly driven by sea level rise close to Careel Bay – suggest that a voluntary house raising or redevelopment scheme, or flood-proofing scheme may become more pressing. Table 14.1 and Figure 14.4 indicate that 22 houses could be flooded to depths of more than 0.5m over floor under a warmer climate compared to just two under existing conditions. Currawong Avenue is the most represented street in this category, and Elaine Avenue is also prominent. This count of properties is beset by the same issues that were evident for the assessment of property modification measures to address existing risk, particularly estimated and unsighted floor levels. It is considered that the recommendation for a scoping study to further assess the feasibility of a small scheme remains appropriate. When the effects of climate change begin to manifest themselves, this scheme may need to be expanded and would then benefit from lessons learned via implementation of the 'pilot' program that has been considered for the treatment of existing risk.

If subsidies for house raising or 'knock down and rebuild' development are offered through State/Council funding, it is recommended that consideration be given to incorporating into the new floor levels an allowance for climate change, since this would be cost effective, practical and in keeping with the precautionary principle. This allowance would not necessarily need to be for the 0.9 m SLR and 30% increase in rainfall intensity scenario that was modelled for the climate change simulation described in this chapter. For houses subject to overland flows where the flood height range is typically small, it could be cost effective to raise floors to the PMF level. For houses subject to sea level rise or creek flooding, consideration could be given to the average lifespan of a house and the floor level could be set at the projected 1% AEP + freeboard level at the *midway point* of that lifespan (after Bewsher, 2010b, pp.100-102). A more conservative approach would be to set the floor level at the projected FPL at the *conclusion* of the lifespan.

At the present time, in relation to flooding, Council requires an assessment of climate change only where 'intensification of development' is proposed. This includes an increase in the number of dwellings (excluding dual occupancies and secondary dwellings) and an increase in commercial or retail floor space. Section B3.23 of Pittwater 21 DCP 2014 requires the following:

> *For land identified on Council's Flood Hazard Maps involving development to which this control applies, a Flood Risk Management Report shall be prepared in accordance with Appendix 8 - Flood Risk Management Policy for Development in Pittwater, which includes an assessment of climate change. This assessment shall include the impacts of climate change on the property over the life of the development and the* <u>*adaptive measures to be incorporated in the design*</u> *of the project.* (emphasis added)

Council does not propose to vary this control or to expand the types of development to which it would apply. Such a change would likely be unacceptable to the community and would also require amendment of S149 Certificates, so is not recommended.

14.5 Influence on Response Modification Options

A heightened flood problem with climate change would add weight to the recommendations proposed to improve flood warning systems, emergency response planning and flood education. Since Local Flood Plans are intended to be reviewed and updated at regular intervals, it is not considered necessary to document projected changes to flood behaviour and impacts as a result of climate change.

15. Floodplain Risk Management Plan

15.1 Objective

The overall objective of the Avalon to Palm Beach Floodplain Risk Management Plan (FRMP) is to develop a long-term approach to flood and floodplain management in the Avalon to Palm Beach study area that addresses the existing and future flood risks in accordance with the general desires of the community and in line with the principles and guidelines laid out in the NSW Government's *Floodplain Development Manual*.

This will ensure that the following broad needs are met:

- Manage the flood hazard and the flood risk to people and property, now and in the future; and
- Ensure floodplain risk management decisions integrate economic, environmental and social considerations.

15.2 Recommended Measures

The recommended measures for the FRMP have been selected from the suite of options identified in Chapter 10 and evaluated in Chapters 11 to 13, after an assessment of each measure's impact on flood risk, as well as consideration of economic, environmental and social factors. The recommended measures are listed in Table 15.1 and presented in Figure 15.1.

15.3 Plan Implementation

15.3.1 Costs

The total capital cost of implementing the Plan is about $2.0M, comprised mainly of the Catalpa Reserve detention basin ($660K) and the Toongarri Reserve detention basin ($1250K). The basins alone would produce benefits (damage savings) of $2.8M, yielding a benefit-cost ratio (BCR) of ~1.5. The number of houses flooded above floor level in the 1% AEP flood would be reduced by 11 and the number of non-residential buildings by four. Preliminary investigation points to high BCRs for measures that modify other properties currently flooded over floor even in the 20% AEP event, either through redevelopment or flood-proofing to keep water out of houses. This requires a scoping study ($15K) to confirm floor levels, consult with landowners and to conduct site inspections to devise viable approaches to flood-proofing for six houses as part of a pilot study. Minor amendments to Council's Flood Proofing Guidelines are recommended, including commissioning a one-page, graphic summary of the Guidelines in attempt to increase circulation ($10K). Other recommendations to revise the DCP require staff time but no capital expenditure. Flash flood warning systems are difficult but marginal improvements are recommended at an initial cost of about $20K. There is an urgent need for a Pittwater Local Flood Sub-Plan, prepared by

NSW SES. Measures to build on the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16* are recommended at a cost of about $80K, including development of a more accessible emergency management plan template for businesses, a Business FloodSafe breakfast, two 'meet-the-street' events and signage. The measures to modify people's response have significant intangible benefits through improved management of risk to life.

15.3.2 Priorities and Timing

Each measure in Table 15.1 includes a priority and a timeframe. The priority reflects the urgency of the option from a purely flood risk reducing perspective, particularly to reduce the risk to life. The estimated timing reflects what is likely to be practical given the required capital expenditure, or need for further investigation, or need for stakeholder and community consultation.

15.3.3 Resourcing

Plan implementation will be dependent on adequate resourcing of its implementation and maintenance. Resources may include financial and human resource and come from a number of sources. Potential contributors of resources include:

- Pittwater Council – financial resources from capital and operating budgets, staff time;
- NSW State Government – financial grants for investigations, mitigations works and programs, SES staff time;
- Commonwealth Government – financial grants for investigations, mitigations works and programs;
- Developers – OSD construction and maintenance, Section 94 contributions for open space;
- Community – volunteer time.

15.4 Plan Maintenance

A FRMP plan is never truly finished. The Avalon to Palm Beach FRMP should be regarded as a dynamic instrument requiring review and modification over time. Catalysts for change could include flood events, revised flood modelling, better information about potential climate change flood impacts, social changes, legislative and planning changes or variations to the availability of funding. In any event, a thorough review every five years is warranted to ensure the ongoing relevance of the Plan.

It is envisaged that the Plan will be implemented progressively over a 5 to 10 year timeframe. The timing of the proposed works and measures will depend on the overall budgetary commitments of Council and the availability of funds from other sources.

Table 15.1 – Draft Avalon to Palm Beach Floodplain Risk Management Plan

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
	FLOOD MODIFICATION MEASURES							
11.2.1	Catalpa Reserve detention basin	Pittwater Council	$660K	$5K p.a.	Medium	> 2 yrs	OEH, PC	
11.2.2	Toongarri Reserve detention basin	Pittwater Council	$1250K	$0K*	Medium	> 2 yrs	OEH, PC	Subject to environmental issues being satisfactorily addressed
	PROPERTY MODIFICATION MEASURES							
12.2, 12.3	Prepare a scoping study including floor level survey, consultation and site inspections to further assess feasibility of establishing a small voluntary house redevelopment/flood proofing scheme	Pittwater Council	$15K	$0K	Low	> 2 yrs	OEH, PC	
12.3	Amend Council's Flood Compatible Building Guidelines as suggested; prepare a one-page, graphic summary of the Guidelines	Pittwater Council	$10K	$0K	Medium	1-2 yrs	OEH, PC	
12.4	Review and adopt the revised flood risk management provisions of Pittwater 21 DCP including freeboards for the study area	Pittwater Council	Staff costs	$0K	High	0-1 yr	PC	

* No increment to existing maintenance costs expected

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
	RESPONSE MODIFICATION MEASURES							
13.1	Improve flood warning system: • Continue to promote the Northern Beaches Flood Information Network website; • Alarm the Avalon Golf Course rain gauge so that it issues email/SMS when rain triggers are reached; • Consider installing a second real-time rain gauge in the vicinity of Bilgola Plateau Public School; • Include Avalon Palm Beach Business Chamber Inc. on the recipient list for alerts when rainfall triggers reached; • Transition towards a system where people living or working in the floodplain can opt in for receiving emails/SMS; • Devise appropriate messages to accompany the rainfall alerts	Pittwater Council, NSW SES	$20K	$6K p.a.	Medium	1-2 yrs	OEH, PC, NSW SES	
13.2	Improve emergency response planning: • Complete the Manly-Warringah-Pittwater EMPLAN in view of the flood risk information in the Avalon to Palm Beach FRMS&P; • Prepare Pittwater Local Flood Sub-Plan; • Encourage and assist key floodplain exposures to prepare and update their own flood emergency plans	NSW SES, Local Emergency Management Committee (LEMC)	Staff costs	$0K	High	0-1 yrs	NSW SES, Local Emergency Management Officers (LEMOs)	

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
13.3	Build upon the *Northern Beaches Flood and Coastal Storm Education Strategy 2012–16*: • Develop a library or mobile **display** using historical flood photos, modelled flood extents and appropriate messaging; • Develop an accessible flood emergency plan **template** suitable for use by Avalon Beach businesses, in conjunction with Avalon Palm Beach Business Chamber Inc.; • Hold a Business FloodSafe **Breakfast** in conjunction with Avalon Palm Beach Business Chamber Inc.; • Conduct '**meet-the-street**' type events for residents at Pittwater Palms retirement village and at south Elaine Ave/east Central Road; • Engage with **students** at Barrenjoey High School to help them understand flood behaviour near the school and to promote safe responses; • Install **signage** indicating entrances to evacuation shelters in Avalon commercial district; • Install signage in flood prone carparks in Avalon commercial centre and Bilgola Beach; • Install flood depth indicators at ~4 low-points on Barrenjoey Road; • Install signage in any detention basins where flooding could pond	NSW SES, Pittwater Council	$80K ($5K display, $5K template, $20K breakfast, $20K two meet-the-street events, $20K for ~15 signs)	$0K	High	1-2 yrs	OEH, NSW SES, PC	Signage may require community concurrence at each location
TOTAL			$2035K	$11K p.a.				

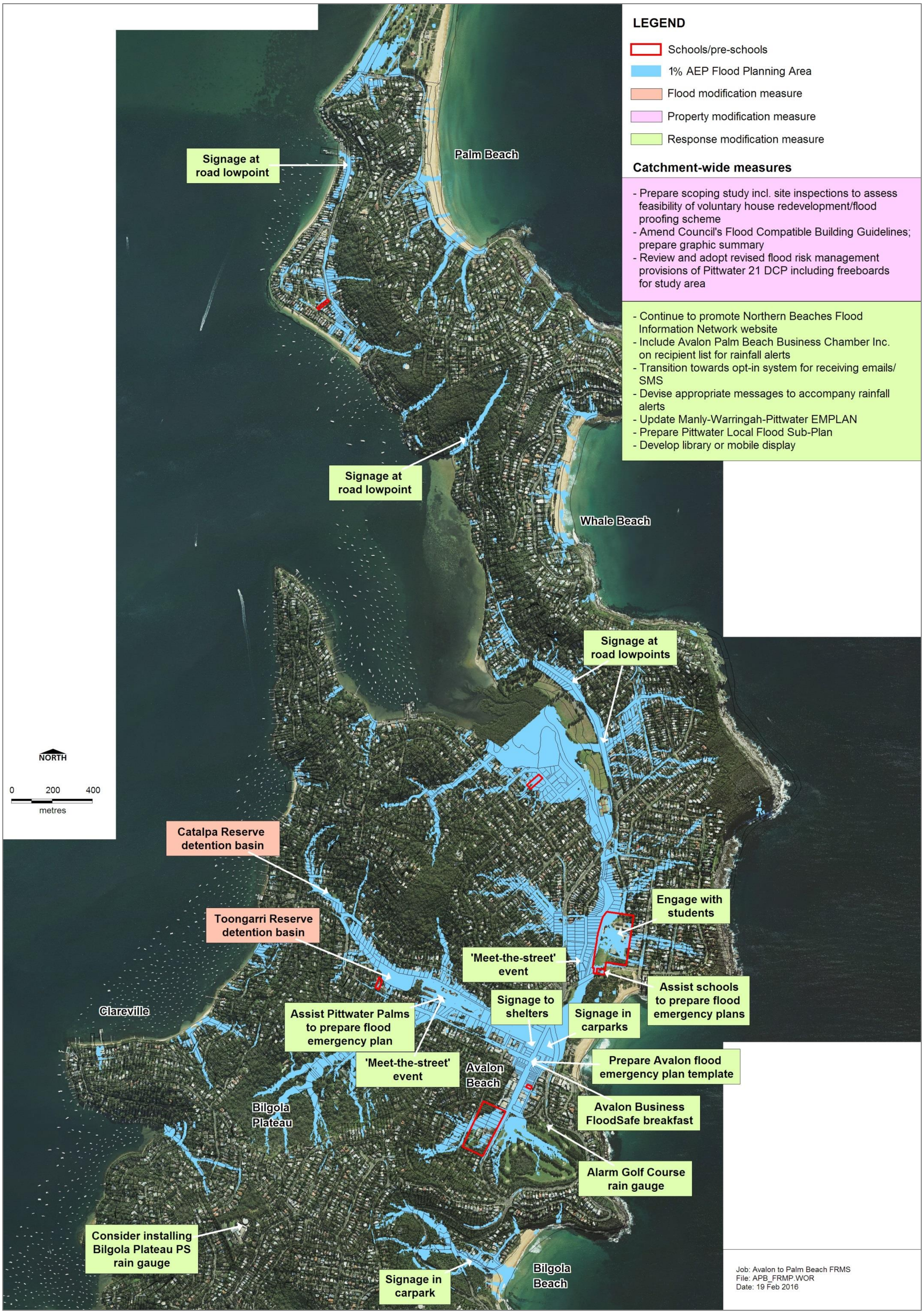

Figure 15.1 – Recommended measures

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17. Glossary

The following glossary has been adapted from the *Floodplain Development Manual: the management of flood liable land* (New South Wales Government 2005).

acid sulfate soils	are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	the long-term average number of years between the occurrence of a flood as large as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. Relates to an area above a specific location.
consent authority	the council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the council, however legislation or an EPI may specify a Minister or public authority (other than a council), or the Director General of DIPNR, as having the function to determine an application.
critical rainfall duration	the design rainfall duration that leads to critical flood conditions (typically maximum flood levels) throughout a given catchment. The critical duration of a particular catchment may be dependent on many factors, primarily catchment size.
design flood	flood conditions estimated from hypothetical design rainfall events that have a specific statistical probability of occurrence. The probability of a design event occurring can be expressed in terms of percentage AEP or ARI, and provides a measure of the relative frequency and magnitude of the flood event.
design rainfall	hypothetical rainfall events that have a specific statistical probability of occurrence. In Australia design rainfall hyetographs are determined from temporally varying intensity-frequency-duration (IFD) data and temporal patterns defined in *Australian Rainfall and Runoff* (Engineers Australia 1987).

development is defined in Part 4 of the EP&A Act

infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development

new development: refers to development of a completely different nature to that associated with the former land use. Eg, the urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. Eg, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.

disaster plan (DISPLAN) a step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

Ecologically Sustainable Development (ESD) using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act, 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time the time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management a range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage (refer Section C6) before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood affected properties properties on land susceptible to overland flooding or mainstream flooding up to the PMF.

flood awareness awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education — flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas — the remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land — is synonymous with flood prone land - land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).

flood mitigation standard — the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain — area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

floodplain risk management options — the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.

floodplain risk management plan — a management plan developed in accordance with the principles and guidelines in the *NSW Floodplain Development Manual*. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

flood plan (local) — a sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.

flood planning area — the area of land below the FPL and thus subject to flood related development controls.

flood planning levels (FPLs) — are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.

flood proofing — a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.

flood prone land — land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.

flood readiness — Readiness is an ability to react within the effective warning time.

flood risk — potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.

<u>existing flood risk:</u> the risk a community is exposed to as a result of its location on

the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood Risk Precinct (FRP)

refers to the division of the floodplain on the basis of the level of expected risk to persons and property due to flooding. In this plan the floodplain is divided into the Low, Medium and High flood risk precincts.

Low Flood Risk precinct means all flood prone land not identified within the High or Medium flood risk precincts.

Medium Flood Risk precinct means all flood prone land that is (a) within the 1% AEP Flood Planning Area; and (b) is not within the high flood risk precinct.

High Flood Risk precinct means all flood prone land (a) within the 1% AEP Flood Planning Area; and (b) is either subject to a high hydraulic hazard, within the floodway or subject to significant evacuation difficulties (H5 and or H6 Life Hazard Classification).

Note: For the purposes of this study the 1% AEP Flood Planning Area is that area (a) below the 1% AEP mainstream flood level + 0.5m freeboard, extended to intersect the surrounding topography; or (b) inundated by overland flooding of greater than 0.05 m depth during the 1% AEP; or (c) within 5 m horizontal distance of an area inundated by overland flooding of greater than 0.3 m depth during the 1% AEP

flood storage areas

those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas

those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

freeboard

provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc.. Freeboard is included in the flood planning level.

habitable room

in a residential situation: a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. In an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.

hazard

a source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in Appendix L of the *NSW Floodplain Development Manual*.

hydraulics term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of the *NSW Floodplain Development Manual* major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
- water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
- major overland flowpaths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

mathematical / numerical / computer models the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach the merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well-being of the State's rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into council plans, policy, and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local flood risk management policy and EPIs.

minor, moderate and major flooding

both the SES and the BoM use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures

measures that modify either the flood, the property or the response to flooding.

overland flow flooding

see 'local overland flooding'

peak discharge

the maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF)

the PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP)

the PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability

a statistical measure of the expected chance of flooding (see AEP).

risk

chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

runoff

the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.

stage

equivalent to water level (both measured with reference to a specified datum).

stage hydrograph

a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.

survey plan

a plan prepared by a registered surveyor.

TUFLOW

a numerical modelling software that provides one-dimensional (1D) and two-dimensional (2D) solutions of the free-surface flow equations to simulate flood behaviour. Used to derive information on flood levels, depths and velocities.

water surface profile a graph showing the flood stage at any given location along a watercourse at a particular time.

wind fetch the horizontal distance in the direction of wind over which wind waves are generated.

Appendix A

Community Consultation Materials

30 June 2014

Mailing Address

Dear Sir/Madam

Re: AVALON TO PALM BEACH FLOOD RISK MANAGEMENT STUDY & PLAN

Pittwater Council is carrying out a Floodplain Risk Management Study and Plan to identify possible flood mitigation and management options. With financial assistance from the NSW Government, Council has engaged consultants, NSW Public Works, to undertake the Avalon to Palm Beach Floodplain Risk Management Study and Plan.

The study will identify floodplain management activities to improve flood planning. These activities include setting design flood levels for development controls and investigating possible mitigation options.

Pittwater Council is seeking your input and ideas about how to manage flooding within the study area and where to focus Council's efforts. The study area covers the suburbs of Bilgola Beach, Bilgola Plateau, Clareville, Avalon Beach, Whale Beach and Palm Beach.

An online survey is available for you to complete at www.pittwater.nsw.gov.au/flooding. All information provided is confidential and used only for the purpose of the study. Further information about the study can also be viewed online.

We are also seeking community representatives to be part of the Avalon to Palm Beach Floodplain Risk Management Study and Plan Community Working Group. The working group will act as a forum for the discussion of technical, social, economic and environmental issues in an advisory role to Council. The group is anticipated to meet at least four times between August 2014 and September 2015. Expression of Interest forms to nominate yourself to be part of the committee can be obtained by emailing floodplain@pittwater.nsw.gov.au.

Your help is most appreciated. For further enquiries please contact Council at floodplain@pittwater.nsw.gov.au or phone 02 9970 1111.

Yours sincerely

Melanie Schwecke
Acting Principal Officer, Floodplain Management

Avalon to Palm Beach Floodplain Risk Management Study
Questionnaire for Residents and Business Proprietors

The information provided from this questionnaire will help us to identify any flooding or overland flow problems within the study area, and to consider measures to manage these problems. It will also help us to determine which issues are important to you.

Suburbs included in study area: Bilgola Beach, Bilgola Plateau, Avalon, Avalon Beach, Clareville, Whale Beach and Palm Beach

All information provided is confidential and used only for the purpose of the study.

---

1. What is the address of your property within the study area?

   ____

2. Is this property:
   - ❑ A residential house
   - ❑ A residential unit or apartment
   - ❑ A business premises
   - ❑ Other

3. Since what year have you owned/occupied this property? __________

4. Has your property previously flooded? In what year did this happen? ___________
   - ❑ Yes, above main building floor level Depth above floor? __________m.
   - ❑ Yes, above the garage or shed floor level Depth above floor? __________m.
   - ❑ Minor flooding within yard only
   - ❑ No flooding within this property

5. Whereabouts beyond your property, within the Avalon to Palm Beach study area, have you observed flood/overland flow problems, if at all?

   ____

   ____

   ____

6. Please describe any adverse impacts that floods/overland flows have had on your house, business or the environment (e.g. damaged assets, loss of trade, health effects, stream erosion)

   ____

   ____

   ____

7. What solutions for managing flood/overland flow problems do you think deserve most consideration?

   ____

   ____

   ____

8. Have you ever referred to the estuarine or flood hazard controls in Council's DCP 21?

- ❒ Yes
- ❒ No
- ❒ Not sure what this is

9. If yes, how readable/understandable did you find the estuarine and flood hazard controls?

- ❒ Very easy
- ❒ Easy
- ❒ Difficult
- ❒ Very difficult
- ❒ Not applicable

10. Council's DCP currently distinguishes between Flood Category 1, Category 2 and Category 3 Areas. Do you understand what these categories mean?

- ❒ Yes
- ❒ No
- ❒ A little

11. One view is that a higher degree of flood risk exposure might be tolerated for commercial land uses compared to residential land uses. Would you support somewhat lower minimum floor level controls for new commercial developments or redevelopments?

- ❒ Yes
- ❒ No
- ❒ Not sure

12. Have you ever used Council's online property information page to look up flood hazard mapping for your property?

- ❒ Yes
- ❒ No
- ❒ Not sure what this is

13. If yes, how user-friendly did you find the process?

- ❒ Very easy
- ❒ Easy
- ❒ Difficult
- ❒ Very difficult
- ❒ Not applicable

14. Have you ever used Council's online property enquiry page to look up the flood hazard for your property?

- ❒ Yes
- ❒ No
- ❒ Not sure what this is

15. If yes, how user-friendly did you find the process?

- ❐ Very easy
- ❐ Easy
- ❐ Difficult
- ❐ Very difficult
- ❐ Not applicable

16. Are you aware Pittwater Council offers a Flood Information Request service?

- ❐ Yes
- ❐ No
- ❐ A little

17. Other comments you'd like to make:

____

____

____

18. Your contact details (in case we need to ask you anything further)

Name: ________________________________

Email: ________________________________

Phone: ________________________________

Please submit your completed questionnaire by 31ST JULY 2014. Thank you for your help.

Avalon Beach Village
Chamber of Commerce Inc

11 November 2014

Dear Sir/Madam

Re: AVALON TO PALM BEACH FLOOD RISK MANAGEMENT STUDY & PLAN

Flooding has the potential to seriously damage business premises and to disrupt trade in Pittwater LGA. It has happened it the past (see extracts below) and will happen again.

> *Stormwater, in places three feet deep, raced through the shopping centre, flooding shops and homes. One of the shops which suffered most damage was Le Clercq's general merchandise store in Avalon Parade. Two feet of water damaged goods. The rush of water through Avalon Parade was so great at one stage that several cars were almost submerged.*
>
> 'Freak storm hits Avalon', *The Sydney Morning Herald*, Thu 7 May 1953 p.1

> *Torrential rain caused havoc in Avalon today when a flash flood trapped scores of people inside stores in the shopping centre. Water flowed a metre deep in Barrenjoey Road, Avalon, trapping many motorists in their cars. The water flowed into stores up to ankle height and proprietors were forced to close their shops.*
>
> 'Sydney floods', *The Canberra Times*, Wed 2 Mar 1977, p.20

Pittwater Council is carrying out a Floodplain Risk Management Study and Plan to identify possible flood mitigation and management options. With financial assistance from the NSW Government, Council has engaged consultants, NSW Public Works, to undertake the Avalon to Palm Beach Floodplain Risk Management Study and Plan.

The study will identify floodplain management activities to improve flood planning. These activities include setting design flood levels for development controls and investigating possible mitigation options.

Pittwater Council is keen to engage with the business sector to learn how businesses are already managing their flood risk and to gather ideas about how Council can better assist in this task. The study area covers the suburbs of Avalon Beach, Bilgola Beach, Bilgola Plateau, Clareville, Palm Beach and Whale Beach.

The Avalon Beach Village Chamber of Commerce encourages its members and other businesses to participate in this study by completing a questionnaire and returning to Council. The questionnaire is attached or may be completed at the following website:
https://www.surveymonkey.com/s/Avalon-PalmBeachFloodRiskBusiness
If you elect to complete the attached questionnaire, please scan and email the completed questionnaire to Council at floodplain@pittwater.nsw.gov.au or post to Council at:
PO Box 882 Mona Vale 1660 (attention: Melanie Schwecke).

If any of your neighbouring businesses are not members of the Chamber, we would appreciate it if you could forward this letter and the questionnaire to them, so that as many businesses as possible have the opportunity of contributing to the study.

Your help is most appreciated. For further enquiries please contact Council at floodplain@pittwater.nsw.gov.au or phone 02 9970 1111.

Yours sincerely

Ros Marsh
President
Avalon Beach Village Chamber of Commerce

Avalon Beach Village Chamber of Commerce Inc.
ABN: 91 422 049 880 Incorporated: Y2119244
PO Box 404, Avalon, NSW, 2107
info@avalonchamberofcommerce.com.au 9918 9950
www.avalonchamberofcommerce.com.au

Avalon to Palm Beach Floodplain Risk Management Study

Questionnaire for Businesses

All information provided is confidential and used only for the purpose of the study.

Name of your business: ____________________

Street address of your business: ____________________

Your name: ____________________

Your role/title in the business (e.g. owner): ____________________

Email: ____________________ Phone: ____________________

1) What is the mapped flood hazard at your business premises? *(tick one)*

- ❐ Don't know
- ❐ None
- ❐ FPL* - high hazard
- ❐ FPL* - low hazard
- ❐ PMF** only
- ❐ Major overland flow
- ❐ Minor overland flow

* FPL = Flood planning level, which corresponds to the 1% AEP flood level plus 500mm freeboard for creek flooding
** PMF = Probable maximum flood

2) How damaging do you think flooding could be at your premises? *(tick one)*

- ❐ Don't know
- ❐ Not applicable (no flood risk)
- ❐ Not at all damaging
- ❐ Minor inconvenience
- ❐ Moderate damage/disruption
- ❐ Major damage/disruption

3) What measures, if any, have you taken to prepare your business for flooding? *(tick all that apply)*

- ❐ Written a flood emergency plan
- ❐ Raised the floor level
- ❐ Installed flood-compatible floor coverings and/or furnishings
- ❐ Flood gates/sandbags etc stored on site to keep water out
- ❐ Purchased insurance to cover the risk of inundation
- ❐ Other (please describe) ____________________

4) Would you have any interest in Council developing a **template flood emergency plan** to help you assess and prepare for flooding at your business premises? *(tick one)*

- ❐ Strong interest
- ❐ Some interest
- ❐ No interest

5) Would you have any interest in attending a **business FloodSafe breakfast** (with SES input) to help you be ready for flooding at your business premises? *(tick one)*

- ❐ Strong interest
- ❐ Some interest
- ❐ No interest

6) How do you think Council could better manage the flood/overland flow risk?

____

____

7) Have you previously referred to the estuarine or flood hazard controls for businesses in Council's DCP 21? *(tick one)*

- ❒ Yes
- ❒ No
- ❒ Not sure what this is

8) Below is an extract from Section B3.18 of the DCP, which is relevant for businesses affected by high hazard flooding in the Pittwater LGA.

> Floor Levels - Change of Use to Existing Premises and Additions up to 30 square metres Gross Floor Area - High Hazard Storage Area only
>
> Where the existing floor level of a building is below the Flood Planning Level and raising the floor level of existing development to the Flood Planning Level may be difficult to achieve due to site and access constraints and /or an addition up to 30m2 gross floor area (GFA) is proposed, consideration may be given to retaining the existing floor levels and satisfactory flood proofing (wet and/or dry) to the Flood Planning Level, subject to demonstration through a Flood Risk Management Report that all precautions have been taken to minimise flood risk.
> (The additional gross floor area of the development, at any point in time from 13 December 2002 (adoption of DCP 30), can only be increased to a maximum total area not exceeding 30m2 if any part of the existing gross floor area (GFA) of the development is below the Flood Planning Level).
>
> Floor Levels - New development within Shopping Precincts of Avalon, Newport and North Narrabeen
>
> Where constructing or raising the total area of the Ground Floor to the level of the Flood Planning Level may be difficult to achieve due to site and access constraints, consideration on merit may be given to a floor level below the Flood Planning Level for the internal front 5m of the development to accommodate window displays, pedestrian stairs and/or ramp(s) that lead up to the remainder of the development (subject to demonstration through a Flood Risk Management Report) provided that:
>
> - the proposed development is within the Shopping Precincts of Avalon, Newport and North Narrabeen; and
> - the ground floor is for business purposes only; and
> - the proposed Ground Floor Level for the internal front 5m is no lower than the existing floor level; and
> - the proposed Ground Floor Level of the remainder of the Ground Floor is at or above the Flood Planning Level; and
> - no electrical equipment or electrical motors are located below the Flood Planning Level.

a) Would you like to see any changes to these conditions? *(tick one)*

- ❒ Yes
- ❒ No
- ❒ Not sure

b) If yes, please provide comment here:

____

____

____

____

Please submit your completed questionnaire by 30TH NOVEMBER 2014. Thank you for your help.

Appendix B

Report on Flood Model Extension

Public Works
Manly Hydraulics Laboratory

AVALON TO PALM BEACH FLOODPLAIN RISK MANAGEMENT STUDY AND DRAFT PLAN

APPENDIX B - FLOOD MODEL EXTENSION

June 2017

PITTWATER COUNCIL

A division of the Office of Finance and Services

B1. Background

Update of Existing Flood Models

As part of the current Floodplain Risk Management Study it was determined that it would be preferable to update previous modelling, essentially through extension of the existing Careel Creek TUFLOW model to include those parts of the Avalon to Palm Beach study area previously modelled using SOBEK. Benefits of the model update include:

- Apparent model boundary effects evident in previous flood mapping have been addressed.
- Impacts of the pit and pipe drainage network of flood behaviour have been specifically modelled throughout the entire study area. This improves confidence in overland flow model results and negates confusion over the approach adopted in the *Pittwater Overland Flow and Mapping Study* to approximate the impact of pits and pipes on flood levels for the 100 year ARI design event.
- The entire study area has been modelled using a single model platform. Model results are therefore directly comparable throughout the study area and assessment of the impact of any proposed mitigation works can be undertaken in a consistent manner.

Review of Previous Flood Modelling

Careel Creek Catchment Flood Study

The *Careel Creek Catchment Flood Study* (WMA Water 2013) encompasses the 4.3 square kilometre Careel Creek catchment in the south-central portion of the Avalon to Palm Beach study area. The study provides an assessment of flood behaviour under existing conditions at the time of the study. No significant changes to the catchment appear to have occurred since from a flooding perspective.

The study outputs included design flood information such as peak flood levels and velocities, provisional flood hazard, preliminary hydraulic categorisation, preliminary flood planning extents, assessment of potential climate change impacts and property classifications according to Pittwater Council's Development Control Plan (DCP). An initial assessment of over floor flooding and inundation of roads was also undertaken.

Problem areas were identified throughout Avalon, with floodways defined along Old Barrenjoey Road, north of Avalon Golf Course; along Ruskin Rowe; between properties located on Central Road and Avalon Parade, along Elba Lane and through Avalon Bowling Greens; as well as through the open channel sections of Careel Creek.

Results of the study found that up to 920 residential, commercial and industrial properties would be affected by flooding during a 1% AEP flood event, with 502 of these affected by depths of 0.3 m or more. It was estimated that up to 266 properties would potentially be affected by over-floor flooding in a 1% AEP design event.

Flood models established to define flood behaviour in the study comprised of a Watershed Bounded Network Model (WBNM) hydrologic model and a TUFLOW hydraulic model. The hydrologic model determines flow hydrographs at various locations within the floodplain resulting from runoff from a particular rainfall event. These flow hydrographs are then input to the hydraulic model which simulates the movement and storage of floodwaters through the floodplain to determine flood levels, velocities and flow patterns. The TUFLOW hydraulic model includes representation of catchment topography, open channel geometry, drainage system elements, surface roughness and key hydraulic structures including culverts and bridges.

Model calibration was undertaken to three historical flood events; the 3 February 2008, 10 April 1998 and 24 October 1987 events. The 2008 event incorporated catchment changes that occurred since the 1998 and 1987 flood events, including the addition of the Avalon Golf Course detention basin, the culvert enlargement underneath Barrenjoey Road (North) and the gross pollutant trap in Careel Creek near Central Road. A satisfactory calibration was achieved to surveyed and derived flood levels and extents.

The design flood events modelled were the 20%, 5%, 1%, 0.5% and 0.2% AEP design events and the Probable Maximum Flood (PMF). A critical duration of 2 hours was determined for the 1% AEP event, while a 1 hour duration was found to be critical for the PMF.

Pittwater Overland Flow Mapping and Flood Study

The *Pittwater Overland Flow Mapping and Flood Study* (Cardno 2013) aimed to identify properties and areas potentially affected by overland flow rather than "mainstream" flooding. The study encompasses the entire Pittwater LGA excluding undeveloped areas of the Ku-Ring-Gai Chase National Park.

Key outcomes from the study were:

- Mapping of flood extents, flood depths, flood hazard, velocities and floodways for the 5 year ARI, 20 year ARI, 100 year ARI and PMF events
- Mapping on a property basis of land potentially affected by overland flow to inform the Pittwater LEP and Pittwater 21 DCP
- Prioritisation of catchments for future detailed flood studies.

Flood behaviour under existing conditions was defined by means of a two-dimensional SOBEK hydraulic model utilising the 'direct rainfall' method to simulate hydrological processes. The 'direct rainfall' method applies rainfall directly to the hydraulic model such that run-off and flood flows are automatically routed according to the model terrain (and other hydraulic influences), negating the need to pre-determine the location of often complex overland flowpaths. The Pittwater LGA was divided into seven model zones, with the current Avalon to Palm Beach study area comprising 'Model Zone A (Avalon)' and the most northerly sub-catchments of 'Model Zone B (Newport Beach)'. In-lieu-of sufficient historical overland flow flooding information to undertake model calibration, the SOBEK model was validated through inter-model comparisons of flow hydrographs generated by SOBEK and a RAFTS hydrological model.

Flood modelling did not include representation of the pit and pipe network. A sensitivity analysis undertaken on a pilot section of the LGA for the 100 year ARI event indicated that "*the conveyance capacity of the pit and pipe network is approximately equal to the difference in flow between the 20 year and 100 year ARI events*" (Cardno 2013). The 'blocked' 20 year ARI event (i.e. without representation of the pit and pipe network) was deemed to be representative of the 'unblocked' 100 year ARI event (i.e. with representation of the pit and pipe network) within the pilot area and this premise was subsequently extrapolated throughout the LGA for planning purposes.

For planning purposes, overland flow was categorised into:

- Overland Flow Path – Major: land that has a depth of overland flow greater than 0.3m.
- Overland Flow Path – Minor: land that has a depth of overland flow greater than 0.15m and less than 0.3m.

Flood Planning Level (FPL) mapping undertaken as part of the study was based on the above two overland flow categories for the 'unblocked' 100 year ARI event, as represented by the 'blocked' 20 year ARI event. A 5 m horizontal (lateral) buffer was applied to areas with 'major' overland flow major affectation, while no buffer was applied to areas of 'minor' affectation.

B2. Numerical Model Development

Modelling Approach

Numerical computer models have been adopted as the primary means of investigating flood behaviour throughout the Avalon to Palm Beach study area. When used carefully, modern computer models allow simulation of flood behaviour over large areas in a cost efficient and reliable manner.

For this study, the TUFLOW 2D/1D hydraulic modelling software package was selected. TUFLOW was considered suitable to replicate the complex 2D nature of overland flow patterns in the study catchments due to its ability to allow:

- accurate representation of overland flow paths in 2D
- integrated investigation and interaction of overland, mainstream and tidal components
- accurate representation of stormwater drainage components in 1D with dynamic linkage to the 2D model domain
- direct application of rainfall over the study area to simulate development of overland flows (as opposed to applying mainstream flows only)
- production of high quality, GIS compatible flood mapping outputs.

While hydrologic rainfall-runoff processes have been represented within TUFLOW using the direct rainfall approach, a previous model developed using the WBNM software for hydrologic model inputs has been used to provide verification of the TUFLOW flood model operation.

Hydraulic Model Development

Model Extent and Layout

The 2D/1D hydraulic TUFLOW model developed covers all areas of the Avalon to Palm Beach study area plus parts of sub-catchments adjoining the southern study area boundary that may influence flood behaviour within the study area (see Figure B1). The selected model extent and boundary locations ensure that there are no unrealistic boundary condition effects influencing flood behaviour within the study area.

The model consists of both a 2D domain and a dynamically linked 1D domain. The 2D domain model flows over the catchment topography using a square grid, while the 1D domain has been used to model drainage pits, pipes and culverts, and open channels including the main Careel Creek channel and the open channel along Ruskin Rowe. Representation of the 1D open channels has been directly maintained from the *Careel Creek Catchment Flood Study* (WMA Water 2013) model setup.

2D Model Domain and Topography

The 2D hydraulic model domain covers an area of 9.853 km^2 with a 3 m square grid size, resulting in approximately 1,094,800 computational grid cells.

Each square grid cell contains information on ground surface elevation, hydraulic roughness and rainfall loss rates. The ground surface elevation is sampled at the centre, mid-sides and corners of each cell from a specified DEM. For a 3 m grid this results in DEM elevations being sampled every 1.5 m. This resolution was selected in order to accurately represent overland flow paths and open channels in 2D.

The DEM used to sample model ground surface topography was created by combining those used in the previous TUFLOW (WMA Water 2013) and SOBEK (Cardno 2013) models. While these were derived from high quality ALS data, a lower data point density is achieved in heavily vegetated areas. In such areas DEM values may be interpolated across distances in excess of the TUFLOW sampling distance, potentially resulting in less accurate representation of smaller scale topographic features.

Boundary Conditions

The model boundary conditions consist of the following:

- direct rainfall application over the 2D model domain
- a downstream tidal boundary at Pittwater and the ocean
- a normal flow boundary allowing flow to occur out of a sub-catchment to the south of the study area.

The location of these boundary conditions is shown in Figure 2.1. The normal flow boundary has been applied sufficiently down slope of the study area such that it has no influence on model results within the study area.

Pit and Pipe Drainage Network

Council provided a GIS database of the pit and pipe network including details of the majority of pits and pipes within the study area. This pit and pipe data was used to create a 1D drainage network in the TUFLOW model using an approach similar to that adopted in the *Careel Creek Catchment Flood Study* (WMA Water 2013). The pipe network layout is shown in Figure 2.1.

Where pit and pipe details were not available from Council's database, estimates and logical assumptions were made based on existing data. While due effort was made to realistically estimate missing information, the quality of the model representation of the pit and pipe drainage network is commensurate with the quality of the GIS layers provided by Council.

For the purpose of design event simulations, pipes and pits were modelled as unblocked.

Hydraulic Roughness

Hydraulic roughness coefficients (Manning's 'n') are used to represent the resistance to flow of different surface materials. Hydraulic roughness has a major influence on flow behaviour and is one of the primary parameters in hydraulic model calibration.

Spatial variation in hydraulic roughness is represented in TUFLOW by delineating the catchment into zones of similar hydraulic properties. The hydraulic roughness zones adopted in this study have been delineated based on consideration of Council LEP zoning, cadastral data, aerial photography and site observations. Factors affecting resistance to flow were of primary importance including surface material, vegetation type and density, and the presence and density of flow obstructions such as buildings, fences and garden beds. Manning's 'n' values assigned to each zone were determined based on site observations, with reference to standard values recommended by Chow (1959). As resistance to flow due to surface and form roughness varies with depth (e.g. Chow 1959, Institution of Engineers Australia 1987), variable depth-dependent hydraulic roughness values have been adopted for this study.

Manning's 'n' roughness coefficients applied in the TUFLOW are provided in Table B1, with delineation of hydraulic roughness zones shown in Figure B2. The highest Manning's values are applied at shallow depths below the specified range of depth variable roughness, while the lowest Manning's values are applied at depths above the specified depth range. At depths within the range of depth variable roughness, applied Manning's values are determined by linear interpolation.

Table B1 - Adopted Manning's 'n' Hydraulic Roughness Coefficients

Material	Range of depth variable roughness (m)	Manning's 'n'
Harbour	0.1–0.5	0.03–0.013
Beach / Foreshore	0.2–1.0	0.1-0.06
Medium density development	0.1–0.5	0.15–0.075
High density development	0.2–1.0	0.3–0.15
Open Space	0.1–0.5	0.075–0.03
Vegetation – medium density	0.2–1.0	0.1–0.06
Vegetation – high density	0.4–2.0	0.1–0.08
Roads / Pavement	0.04–0.2	0.03–0.02

Manning's values for pipes and channels modelled in 1D remained as per those used in *Careel Creek Catchment Flood Study* (WMA Water 2013).

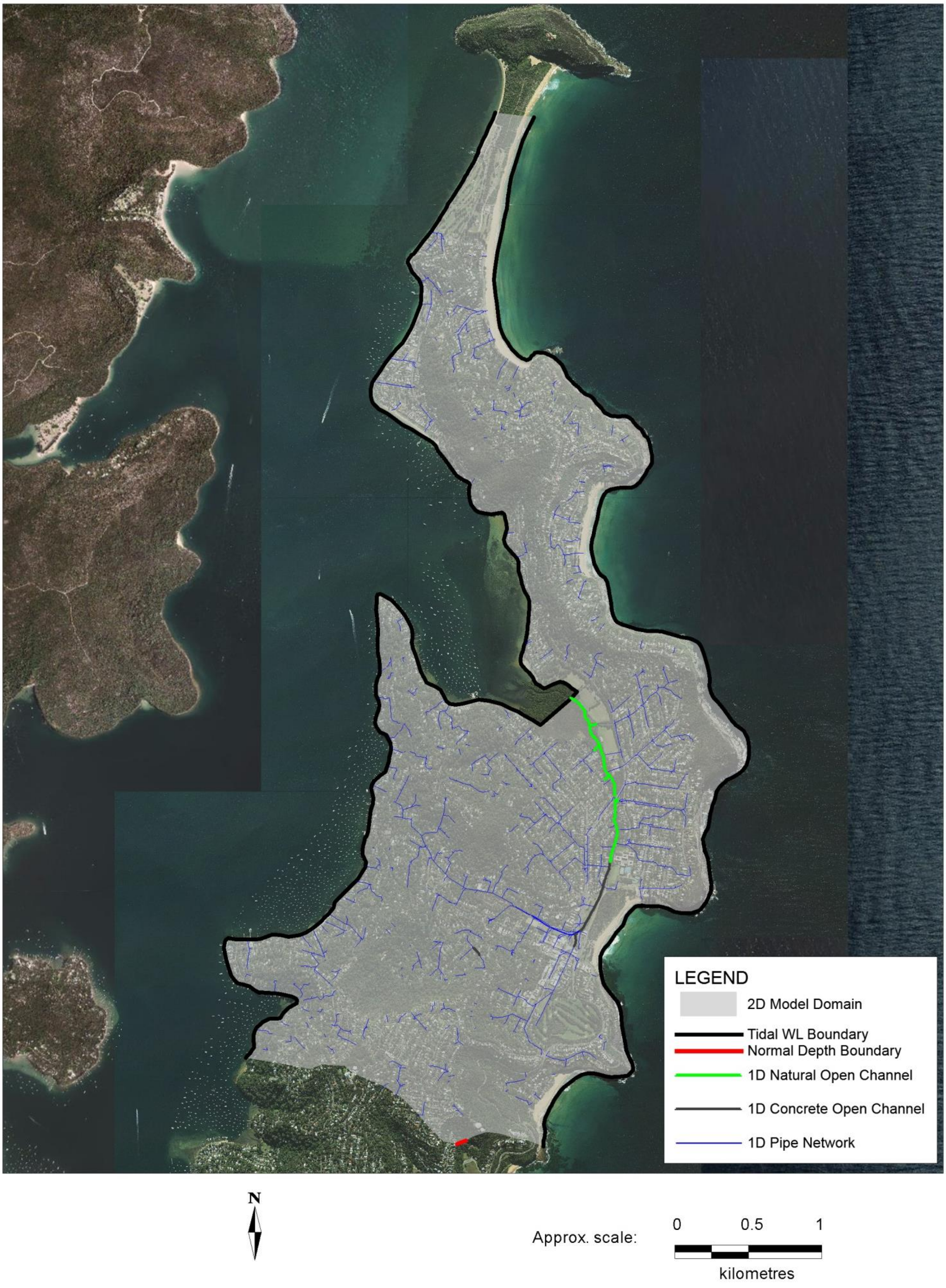


Figure B1 TUFLOW Model Extent and Layout

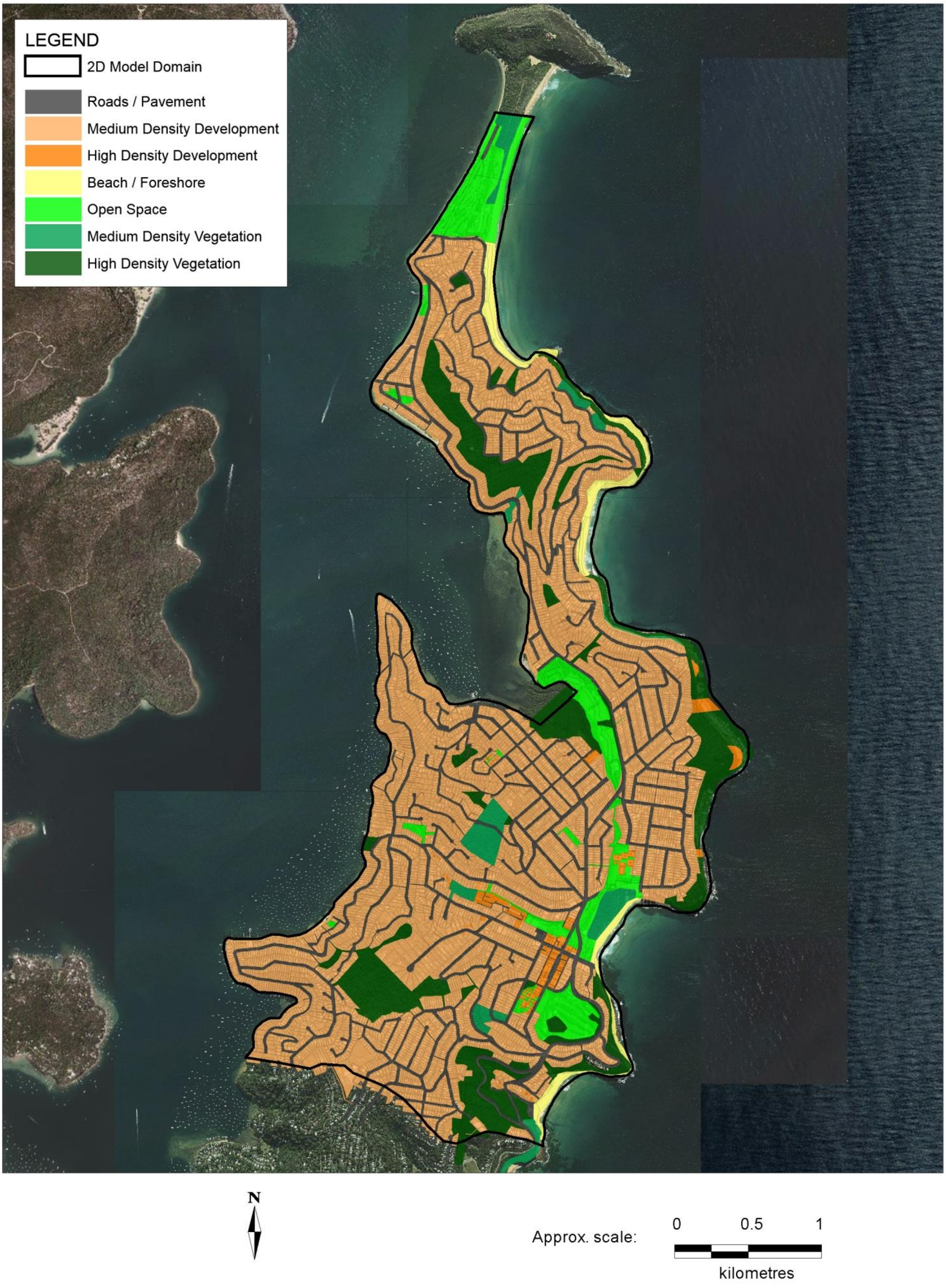


Figure B2 Hydraulic Roughness Zones

B3. Model Calibration and Verification

Summary of Model Calibration and Verification

Model calibration and verification is an essential step in the flood modelling process to confirm that the model can adequately simulate historical flood events. The approach in the current study was to provide model calibration against one recent flood event with additional model verification carried out against the existing *Careel Creek Catchment Flood Study* model which has been calibrated to an additional two historic events.

The results of the model calibration event along with the good correlation between these two relatively different models provides substantial confidence in the ability of the current TUFLOW model to realistically simulate design discharges and flood behaviour across the study area.

Model Calibration – 3 February 2008 Event

The February 2008 flood event was the most recent event for which model calibration was undertaken in the *Careel Creek Catchment Flood Study* (WMA 2013). Other recorded flood events in 1987 and 1998 occurred prior to a number of significant changes within the catchment and hence have not been simulated with the current model. Based upon a one hour duration burst of rainfall, the February 2008 event was approximately equal to a 20% AEP design event.

Calibration results to a number of recorded flood levels are provided in Table B2 below, along with comparison to model results obtained by WMA (2013). All presented flood levels were recorded at locations on the banks of Careel Creek in the vicinity of Barrenjoey High School.

Generally, modelled results were slightly above those recorded, by an average of 0.06 m. Current model results were also higher than previous modelling by WMA by an average of 0.11 m. This represents an acceptable calibration result however, given the limited availability of calibration data, model verification against previous modelling has been undertaken for the 1% AEP and PMF design events.

It was found that calibration results for the February 2008 event could be improved by modification of Mannings 'n' roughness values, however these changes resulted in a poorer verification of the 1% AEP design event against previous modelling and were not considered warranted.

Table B2 Calibration Results February 2008

Location ID	Surveyed or Derived Data	Current Model Calibration		Verification to Previous WMA Model	
	Peak Flood Level (m AHD)	Peak Flood Level (m AHD)	Difference to Recorded (m)	WMA Peak Flood Level (m AHD)	Difference Current-WMA (m)
16	2.76	2.90	0.14	2.76	0.14
17	2.21	2.22	0.01	2.14	0.08
18	2.32	2.21	-0.11	2.13	0.08
19	2.93	2.83	-0.10	2.7	0.13
20	2.72	2.83	0.11	2.7	0.13
21	2.77	2.86	0.09	2.74	0.12
22	2.77	2.86	0.09	2.73	0.13
23	2.81	2.87	0.06	2.74	0.13
24	2.82	2.87	0.05	2.75	0.12
25	2.91	2.98	0.07	2.89	0.09
26	2.84	3.05	0.21	2.98	0.07
27	2.79	2.89	0.10	2.76	0.13

Model Verification

In the absence of extensive recorded data, model verification through comparison with alternative models is recommended (e.g. Institution of Engineers Australia, 2012). Model verification has been undertaken through comparison of 1% AEP and PMF design results simulated by the current extended TUFLOW model and the TUFLOW model developed in the *Careel Creek Catchment Flood Study* (WMA Water 2013).

While the two models have utilised the same hydraulic modelling software (TUFLOW) they have a number of fundamental differences, particularly in their hydrologic approach. A good correlation between the two models would indicate that the different principles of operation in each model are converging on a common result, providing additional confidence in model results.

1% AEP Design Event

A comparison between the current TUFLOW model and that used in the *Careel Creek Catchment Flood Study* has been undertaken for the 1% AEP 120 minute duration design event in terms of both peak flood levels (see Figure B3) and simulated flow hydrographs (see Figures B4 to B6).

The results of model verification for the 1% AEP 120 minute duration design event can be summarised as follows:

- Differences in peak flood levels are generally less than 0.1 m
- The current model often simulated slightly higher flood peaks along overland flow paths, while lower levels were simulated toward the upstream end of Careel Creek
- Differences in peak flood level of greater than 0.2 m are localised to the Golf Course detention basin and the downstream end of Ruskin Rowe
- The timing, hydrograph shape and total flow simulated by the two models are highly similar
- There are some differences in peak flows which may be attributable to various factors (e.g. interpretation of sub-catchment areas in WBNM and, application of WBNM simulated flows into TUFLOW).
- Results indicate that the different principles of operation in each model are converging on a common result.

PMF Design Event

A comparison of peak flood levels for the PMF 60 minute duration design event is presented in Figure B7. The results can be summarised as follows:

- Differences in peak flood levels are accentuated for the PMF event
- Differences in peak flood level of greater than 0.2 m occur at the Golf Course detention basin, Elba Lane in the vicinity of the retirement village, and the upstream end of Careel Creek including parts of the Avalon Town Centre
- The current model often simulated slightly higher flood peaks along overland flow paths, while lower levels were simulated toward the upstream end of Careel Creek
- Results generally indicate that the different principles of operation in each model are converging on a common result.

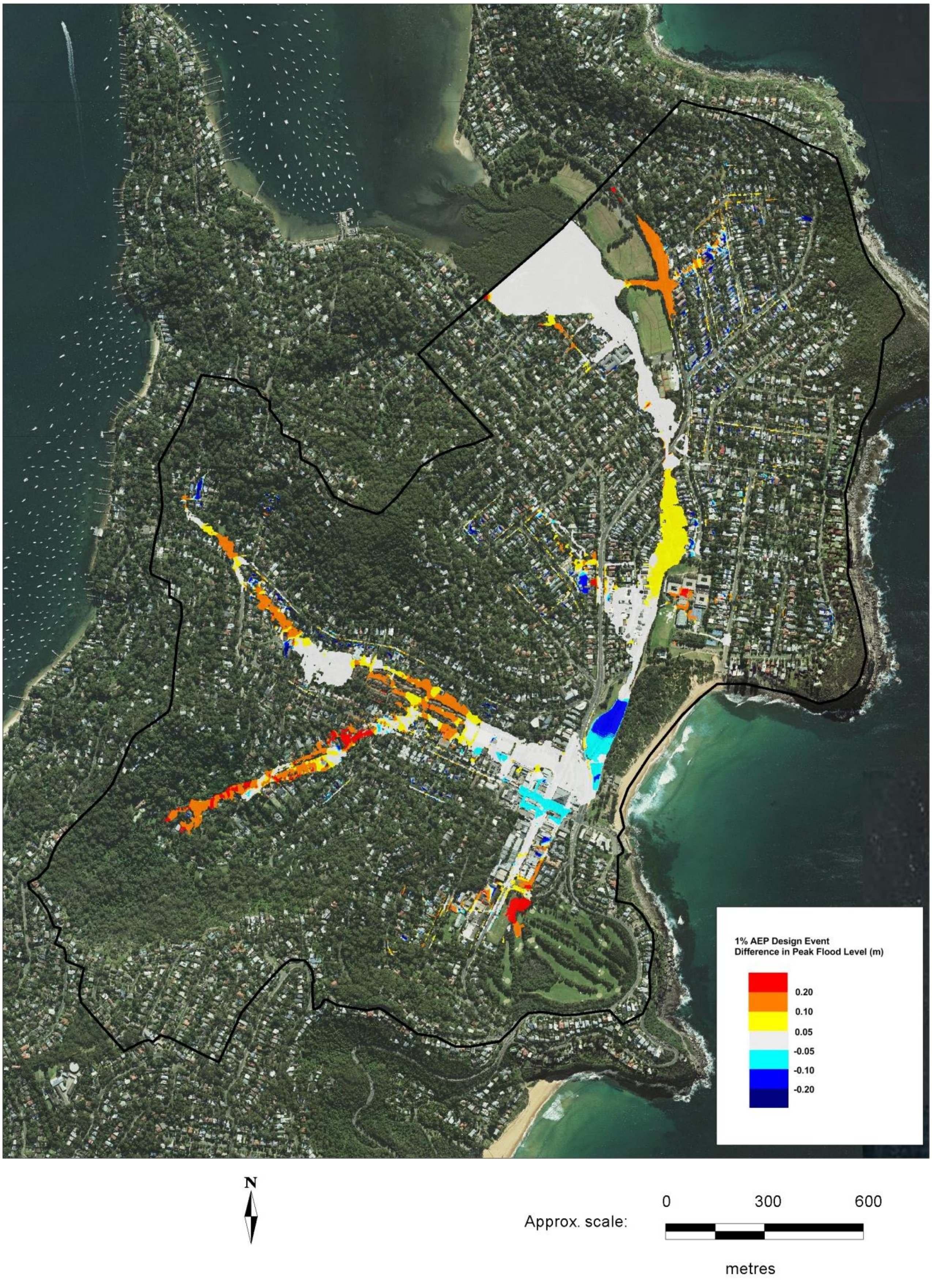


Figure B3 1% AEP Event Flood Level Verification

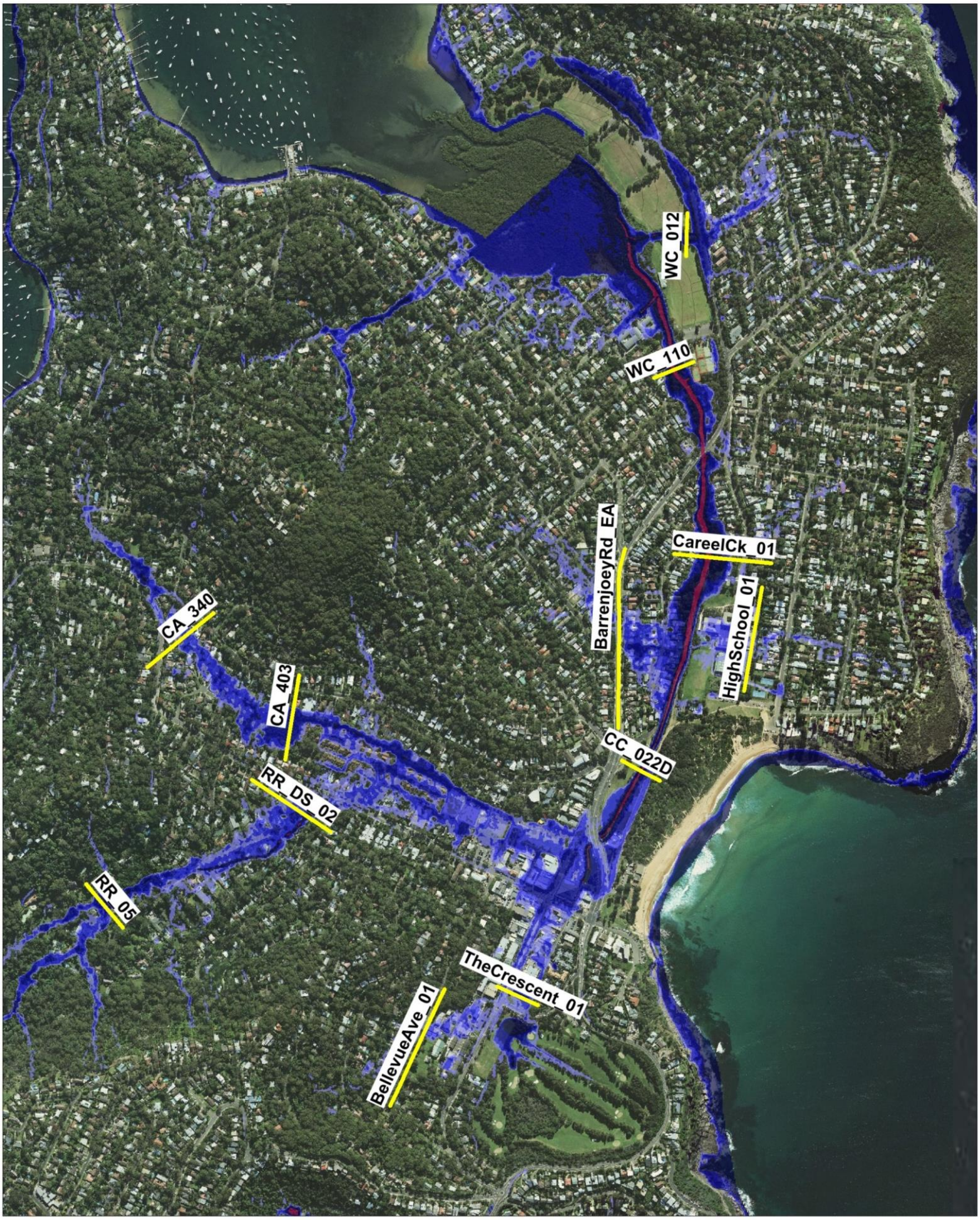


Figure B4 Flow Verification Locations

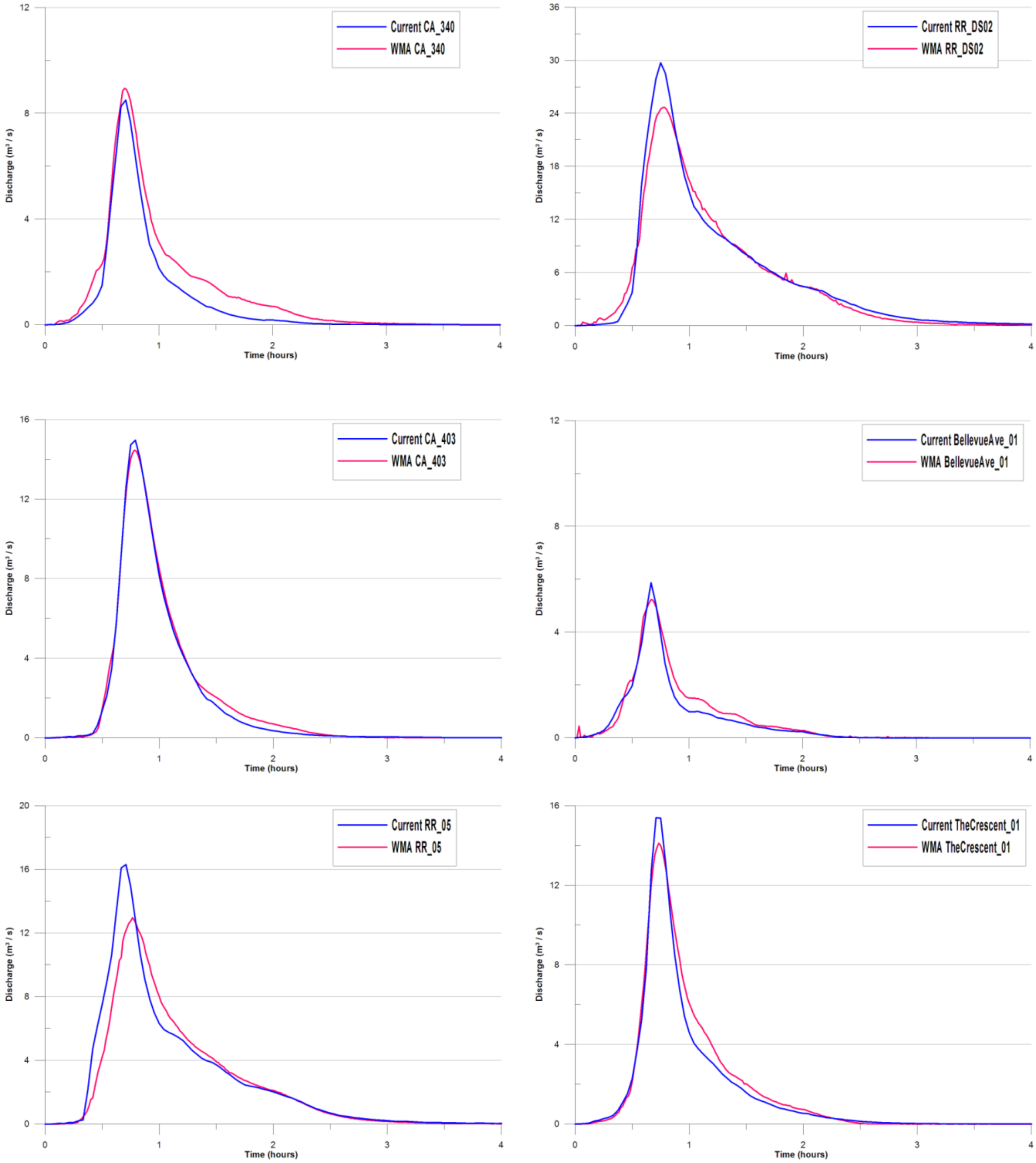


Figure B5 1% AEP 120-minute Event Flow Verification Results

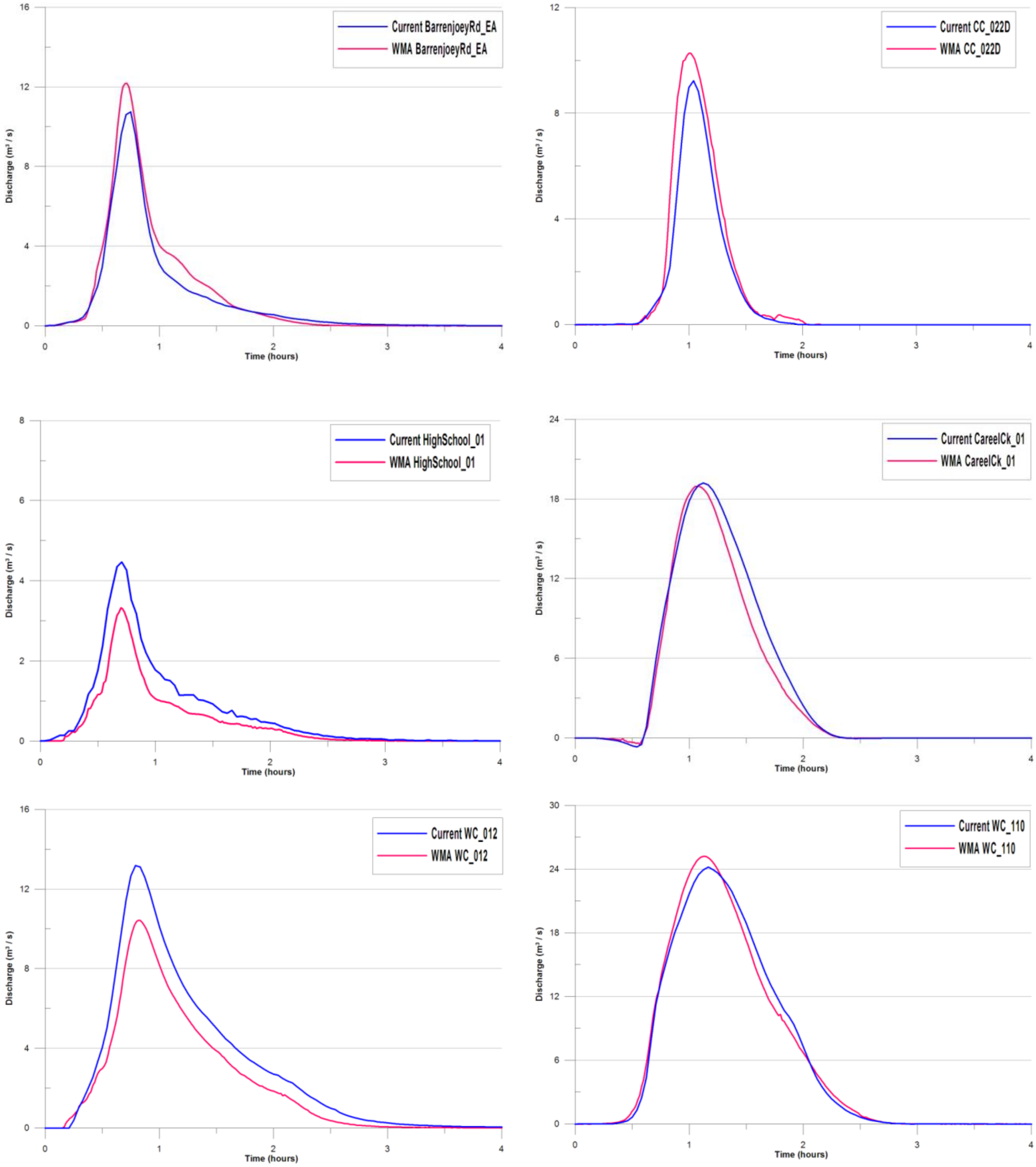


Figure B6 1% AEP 120-minute Event Flow Verification Results

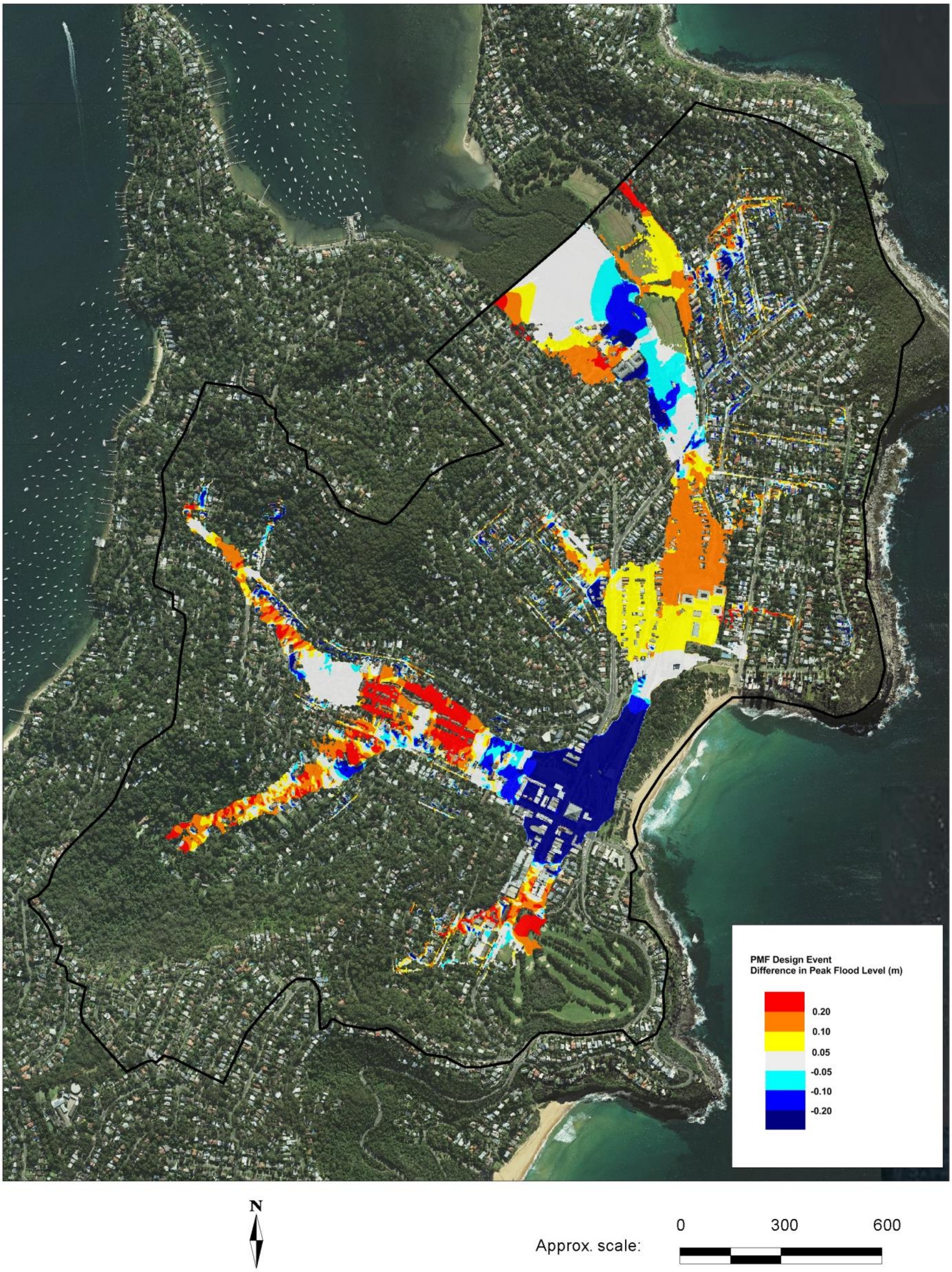


Figure B7 PMF Event Flood Level Verification

B4. Design Flood Estimation

Design Flood Events

Design flood conditions are estimated from hypothetical design rainfall events that have a given statistical probability of occurrence. The probability of a design event occurring can be expressed in terms of percentage Annual Exceedance Probability (AEP), and provides a measure of the relative frequency and magnitude of the flood event.

Flood conditions for the PMF, 0.2%, 0.5%, 1%, 5% and 20% AEP design events have been investigated in this study.

Design Rainfall

Design Rainfall Hyetographs

Design rainfall hyetographs from *Careel Creek Catchment Flood Study* (WMA Water 2013), which were derived from standard procedures defined in AR&R (1987) and the Generalised Short Duration Method (GSDM) as defined by BoM (2003), were adopted for use in the current study.

Critical durations were adopted as per the *Careel Creek Catchment Flood Study* (WMA Water 2013) and comprise a 120 minute duration for the 0.2%, 0.5%, 1%, 5% and 20% AEP events, and a 60 minute duration for the PMF.

Design Rainfall Losses

The initial loss-continuing loss approach was adopted in this study to represent losses in the rainfall-runoff process.

Zero initial losses have been applied in design modelling. This value has been determined in consideration of the following:

- Traditionally adopted initial loss values incorporate losses due to infiltration, initial storage and other processes. When using the direct rainfall approach with a high resolution DEM, as adopted in this study, losses associated with initial storage are well represented in the 2D domain. Research has shown that such losses can be of the same order as traditionally adopted initial loss values (Taaffe et al. 2011). Initial losses should therefore be lower in a direct rainfall model when compared with a traditional hydrologic model (Institution of Engineers Australia 2012).
- The design rainfalls applied are representative of intense bursts of rainfall. Such bursts generally occur within longer storm events (Institution of Engineers Australia, 1987) and therefore it is likely that initial losses will have occurred prior to the start of the design storm burst.

Adopted continuing loss values of between 0 and 2.5 mm/hr have been applied in design modelling depending on the imperviousness of delineated TUFLOW hydraulic roughness zones. These values are consistent with standard recommended values for eastern NSW in AR&R (Institution of Engineers Australia 1987). The continuing loss is directly subtracted from applied model rainfall in TUFLOW.

Design Ocean Boundary Condition

Flood levels in low lying foreshore areas of the study area as well as discharge from Careel Creek are influenced by the coinciding water level in Pittwater and the ocean. Water levels in Pittwater are largely consistent with open ocean levels and consist of astronomical tide plus tidal anomalies, most notably storm surge (changes in ocean level driven by the combined effects of variations in air pressure and wind stress during storms).

Pending the release of the draft OEH Guideline *Modelling of the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways*, the latest advice on appropriate tailwater levels for use in studies under the NSW Floodplain Management Program is discussed in *Development of Practical Guidance for Coincidence of Catchment Flooding and Oceanic Inundation* (Toniato et. al 2014).

Following the 'Simplistic Approach' described in this paper for a 'Type A' waterway entrance south of Crowdy Head it is recommended to adopt an envelope approach to determine peak 1% AEP design levels and velocities from:

- 1% AEP design flood event with a 5% AEP ocean water level boundary (1.4 m AHD)
- 5% AEP design flood event with a 1% AEP ocean water level boundary (1.45 m AHD).

Given the difference between the recommended tailwater values is only 0.05 m, and that results of climate change analysis undertaken for the *Careel Creek Catchment Flood Study* (WMA Water 2013) showed that results were not sensitive even to a 0.2 m increase in ocean boundary level, NSW Public Works has adopted a design tailwater level of 1.45 m AHD for the 1% AEP, negating the need to use an enveloped approach. This tailwater has also been adopted for the PMF, 0.2% and 0.5% AEP events, while for the smaller AEP events a tailwater of 0.95 m has been adopted equivalent to the mean Highest High Water Solstice Springs (HHWSS) for Sydney.

B5. Design Flood Results and Mapping

Flood Mapping Approach

The use of the direct rainfall method in TUFLOW results in all active model cells being 'wet' or inundated. Directly mapping all flood model results therefore produces a flood extent covering the entire model domain, an outcome that would be very difficult to interpret and would not be suitable to meet the objectives of the Avalon to Palm Beach Floodplain Risk Management Study.

In order to improve the presentation and interpretability of results, and distinguish 'flooding' from catchment runoff and minor ponding, filtering of model results is required. Development of a filtering methodology requires application of engineering judgement in consideration of the catchment flood behaviour and the objectives of the study.

To meet the objectives of the study a filtering methodology was devised with the aim to identify and map:

- Mainstream flood flows
- Overland flood flows
- Flooding caused by overflows from mainstream and overland flow path
- Important features of flood flow behaviour such as continuity of flow paths and linkages between inundation and its source.

The methodology has been developed with consideration to advice provided in *Australian Rainfall and Runoff Revision Project 15: Two Dimensional Modelling in Urban and Rural Flood Plains* (Institution of Engineers Australia, 2012).

Mapped flood extents for the design events were determined by applying the methodology described in Table B3 as follows:

Step 1: Identify initial flood extent satisfying: (1 OR 2) AND 3

Step 2: Remove discrete ponds of inundation that do not satisfy criteria number 4.

Table B3 Flood Mapping Criteria

	Flood Mapping Criteria	Comments
Criteria for 1% AEP Flood Planning Level Mapping		
1	Depth ≥ 0.15 m	NSW Public Works considers this an appropriate depth threshold as: − The National Flood Risk Advisory Group (NFRAG) describes flood depths of <0.15 m as “relatively benign”, posing little hazard to the stability of children, stability of small vehicles or stability of light structures, except where velocities exceed 2 m/s (NFRAG 2014) − Flooding ≥0.15 m has greater potential to cause disruption and economic loss as it exceeds the typical height of guttering or single front step of a dwelling
2	Depth < 0.15 m AND Velocity x Depth (VxD) ≥ 0.30 m^2/s	NSW Public Works’ experience has found these criteria appropriate for identifying shallower flows <0.15 m deep with some conveyance which may: − Form part of overland flood flow paths − Occur near-bank in mainstream areas − Form important linkages between deeper areas of flooding and their source flow paths. Mapping of such flood conditions is important as: − It provides a more complete understanding of flood behaviour, particularly for overland flood flows − Shallow flowing water has greater potential to cause disruption and economic loss than stagnant or slow moving water of the same depth − Obstruction of such flows may have adverse flood impacts − Provides confidence that resulting small discrete ‘ponds’ of inundation are not associated with overland flow paths.
3	Difference of PMF peak level and 1% AEP peak level > 0.02 m	Upon investigation of depths along cliffs within the catchment, this criteria was found to reduce the inclusion of erroneous model flood depths that can occur at very steep drops or small ‘pits’ in the DEM (topography). It essentially differentiates between areas where high depths are the result of DEM artefacts and those where depths result from a significant contributing sub-catchment area. It also removes mapping along most of the ocean.
4	Area of flooding ≥ 100 m^2	Discrete ‘ponds’ of inundation that did not meet this criterion were removed from flood mapping. This area threshold was selected based upon the assessment presented in Section 5.1.1.

5	Extent less than 1m inside the properties	Properties will not be tagged in this circumstance to take into consideration the hydraulic model accuracy with a 3m grid cell size.
6	Depth <0.15m AND $0.025\ m^2/s < VxD < 0.30 m^2/s$	Areas of lower flood depth and hazard (VxD) will be marked as “Local Stormwater” to separate from flooding
Criteria for PMF Mappping		
1	Depth > 0.15m	As per 1% AEP mapping above
2	Area of flooding $\geq 200\ m^2$	Discrete ‘ponds’ of inundation that did not meet this criterion were removed from flood mapping.
3	Extent less than 1m inside the properties	As per 1% AEP mapping above

Assessment of Discrete Pond Removal

A ‘small pond filter’ is often applied, in conjunction with other filtering techniques, whereby discrete ‘ponds’ of inundation below a selected area threshold are removed from mapping (e.g. Institution of Engineers Australia 2012). Pond size distribution for 1% AEP design event following identification of the initial flood extent is presented in Figure B8.

Review of the information presented in Figure B8 along with interrogation of the DEM and velocity vectors informed the assessment of an appropriate area threshold for removal of discrete ponds of inundation, as presented in Table B4.

Table B4 Review of Discrete Pond Sizes

<table>
<tr><th>Pond Size (m^2)</th><th>Number of Ponds</th><th>Comments</th></tr>
<tr><td>0-20</td><td>6060</td><td rowspan="2">– Generally discrete ponds that are isolated from major flow paths and are likely to be associated with small depressions in the DEM
– Often occur high in the catchment before runoff becomes concentrated into overland flow paths
– Inclusion in mapping would rarely improve depiction of key features of flow behaviour and continuity
– It is considered that flood risk from such pond sizes is minor, that their potential impact on development and the potential adverse impact of development within them are negligible and that they should not be included in flood mapping.</td></tr>
<tr><td>20-50</td><td>911</td></tr>
<tr><td>50-100</td><td>371</td><td>– Often discrete ponds that are isolated from major flow paths and are potentially associated with depressions in the DEM
– Often occur higher in the catchment as runoff begins to concentrate into overland flow paths, or where there are discontinuities in flow paths due to obstructions, piping or spreading of flow
– Inclusion in mapping may improve representation of key features of flow behaviour and continuity in some cases, but this is counteracted by the occurrence of numerous isolated ponds of such size</td></tr>
</table>

		− It is considered that flood risk from such pond sizes is minor, that their potential impact on development and the potential adverse impact of development within them are low and that they should not be included in flood mapping.
100-200	195	− Inclusion in mapping generally improves representation of key features of flow behaviour and continuity − Ponds of this size are rarely isolated from major flow paths or associated with local depressions in the DEM − Generally occur where there are discontinuities in overland flow paths due to obstructions, piping of flows or spreading of flow − It is considered that the level of flood risk associated with such pond sizes, their potential impact on development and the potential adverse impact of development within them is sufficient to warrant inclusion in flood mapping − A small number of these ponds were manually removed based upon their isolation from other flooding and/or interrogation of the DEM.

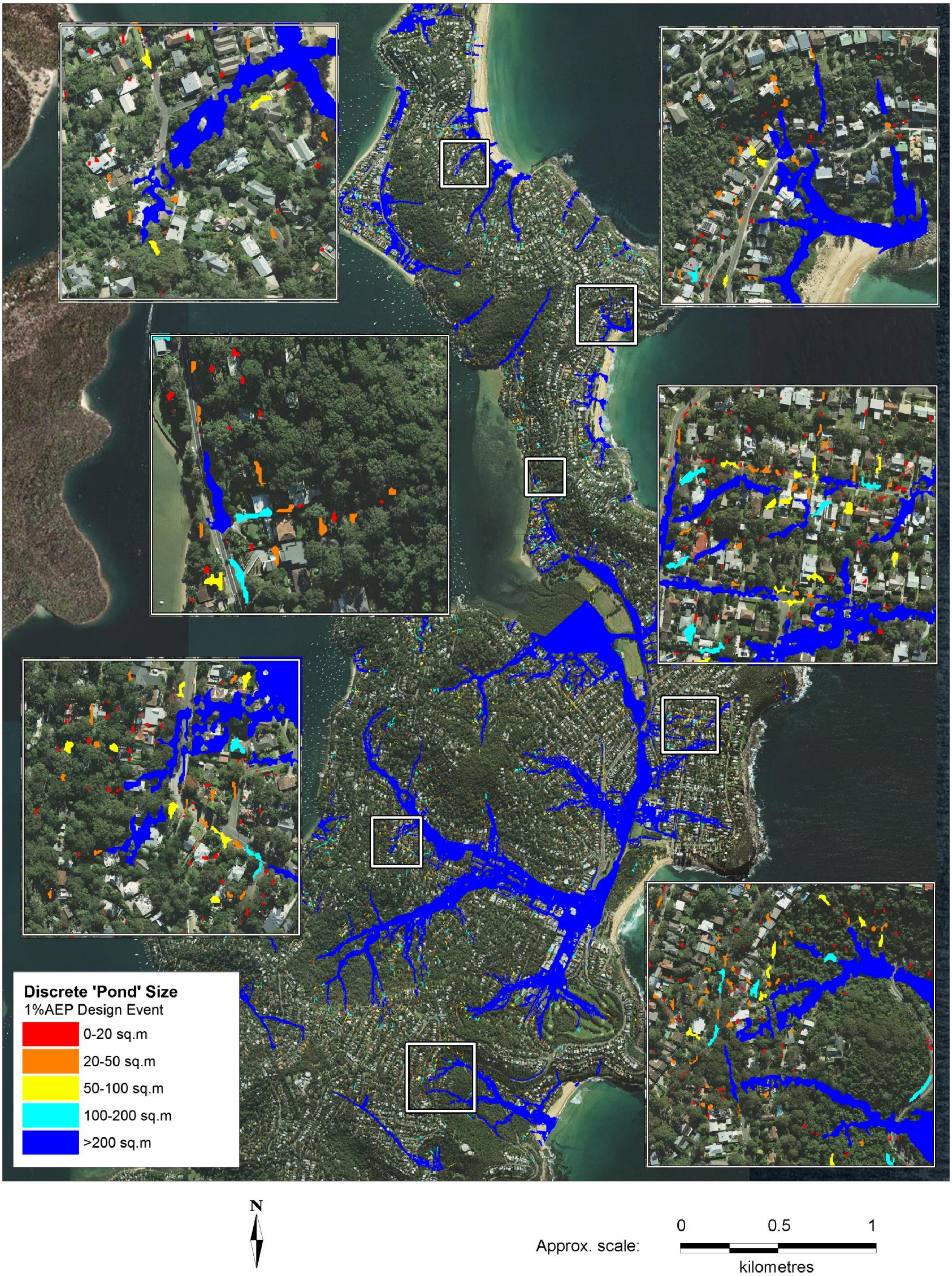


Figure B8 1% AEP Design Event Pond Size Distribution

Design Flood Peaks

Results of design flood modelling are presented in a series of flood maps in Appendix C. This includes maps of peak flood depth, level and velocity as well as provisional flood hazard and hydraulic categories as described in the following sections.

Flood Hazard Categories

Provisional Flood Hazard Categories

Flood hazard is a measure of the potential risk to life, limb and property posed by a flood. Flood hazard categories are defined in the Floodplain Development Manual (NSW Government 2005) as follows:

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

Provisional flood hazard categories for flood-prone land are generally determined based on relationships between simulated flood depths and velocities. These relationships are defined in Figures L1 and L2 in the Floodplain Development Manual (NSW Government 2005), as presented in Figure B9.

Provisional hazard categories have been determined for the 20% AEP, 5% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF design events and are presented in Appendix C. The ‘transition zone’ between high and low hazard is often assigned a high hazard category, as has been done in this study in accordance with Pittwater 21 DCP Appendix 8 Flood Policy.

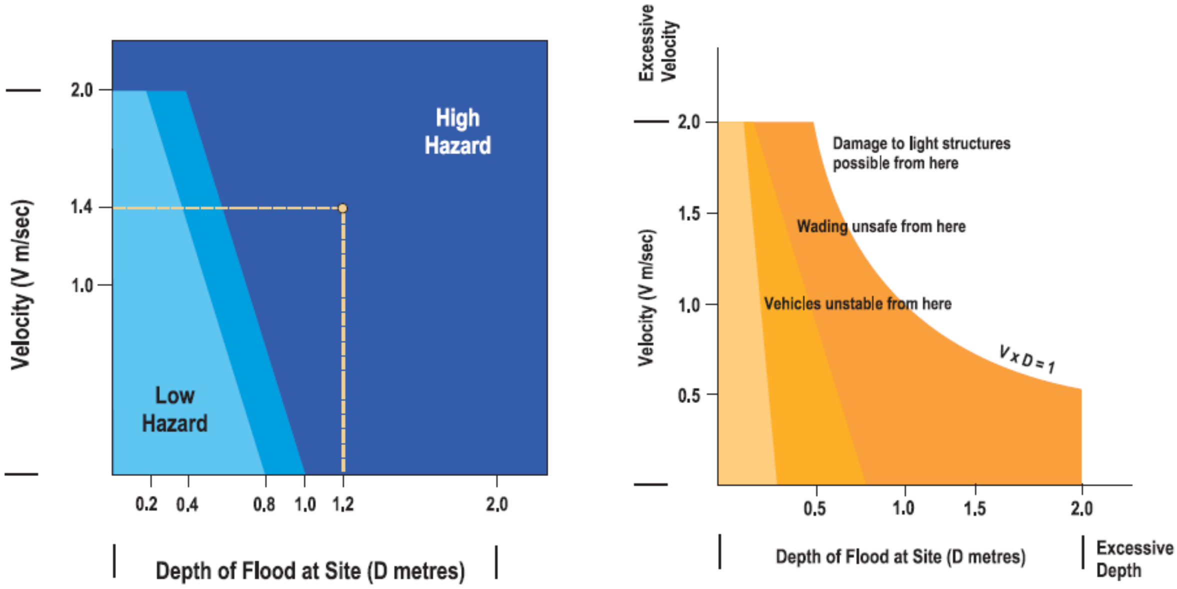


Figure B9 Velocity-Depth Relationships for Provisional Hazard Categories

(Source: NSW Government, 2005)

5.1.1 True Flood Hazard Categories

True hazard categorisation requires the consideration of various factors in addition to provisional hazard categories including:

- effective warning time
- flood readiness
- rate of rise of floodwaters
- duration of flooding
- evacuation problems
- effective flood access, and
- type of development.

Mapping of true flood hazard was not undertaken in this study. Rather, during the mapping of flood risk precincts (FRP) consideration was given to upgrading areas of Medium FRP to High FRP to account for the true flood hazard (see Section 7.5 of this report). It was found that in light of the particular policy context that applies in the study area that the need for upgrading areas to High FRP on the basis of evacuation constraints is less pronounced than for other LGAs. Nonetheless, it was considered appropriate to upgrade small areas (<1000 m^2) of Medium FRP entirely surrounded by High FRP to the higher FRP.

Hydraulic Categories

Hydraulic categorisation is a useful tool in assessing the suitability of land use and development in flood-prone areas. The Floodplain Development Manual (NSW Government, 2005) describes the following three hydraulic categories of flood-prone land:

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

These qualitative descriptions do not prescribe specific thresholds for determining the hydraulic categories in terms of model outputs, and such definitions may vary between floodplains depending on flood behaviour and associated impacts.

For the purposes of the Avalon to Palm Beach Floodplain Risk Management Study and Plan, hydraulic categories have been defined as per the criteria in Table B5. These criteria were defined in the *Careel Creek Catchment Flood Study* (WMA 2013). NSW Public Works have reviewed these criteria, particularly the definition of floodway with respect to simulated flow behaviour, and found them to be appropriate and in-line with industry practice (e.g. Howell et al. 2003).

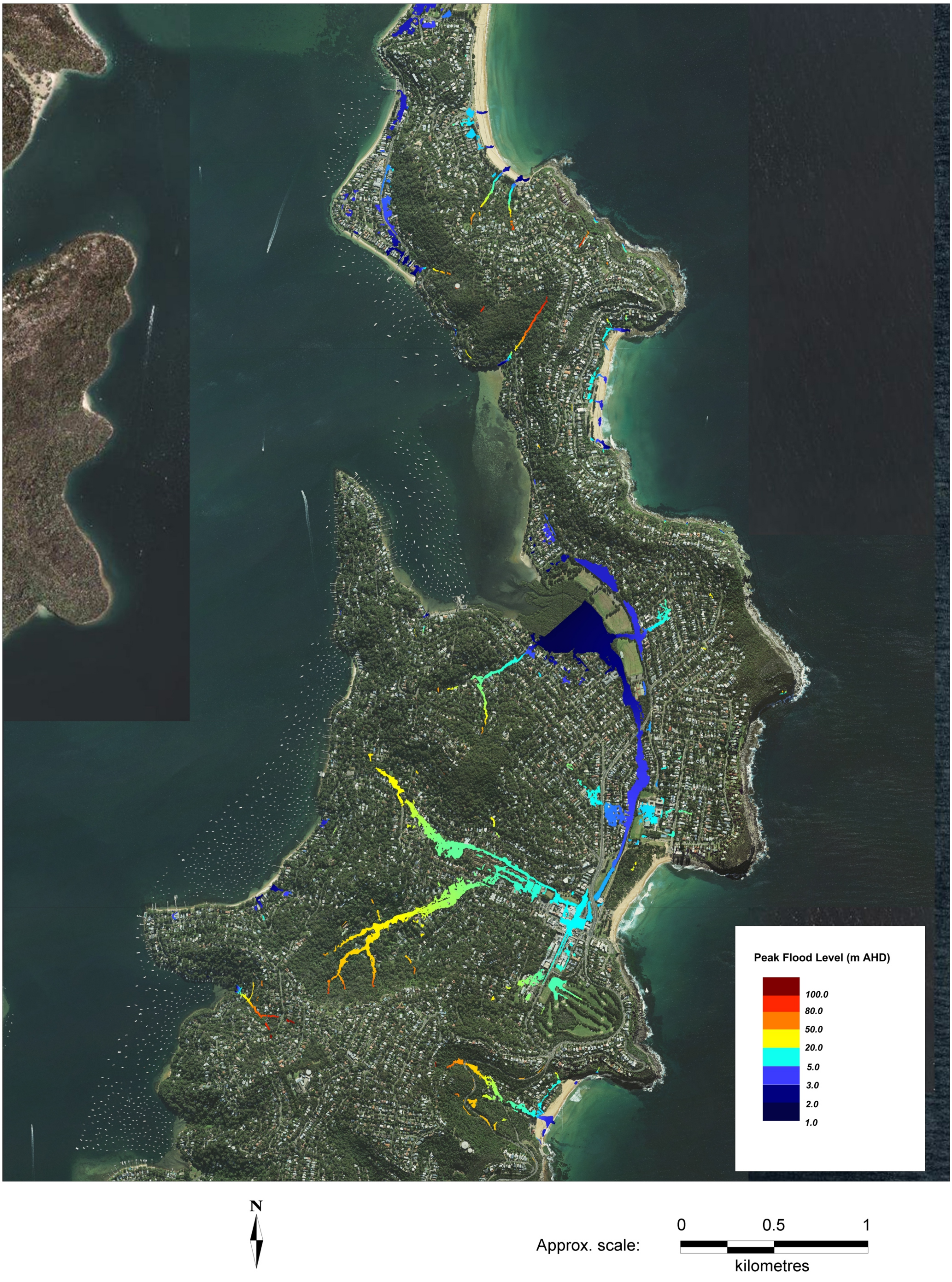
Table B5 Hydraulic Category Criteria

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s AND Velocity > 0.25 m/s OR Velocity > 1.0 m/s AND Depth > 0.15 m	Flowpaths and channels where a significant proportion of flood flows are conveyed
Flood Storage	Depth > 0.5 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows
Flood Fringe	Depth < 0.5 m, Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

Hydraulic category mapping for the PMF, 1% and 20% AEP design events is presented in Appendix C. Areas defined as floodway for the 1% AEP design event have been incorporated into the definition of High FRP in this study.

Appendix C

Floodplain Mapping



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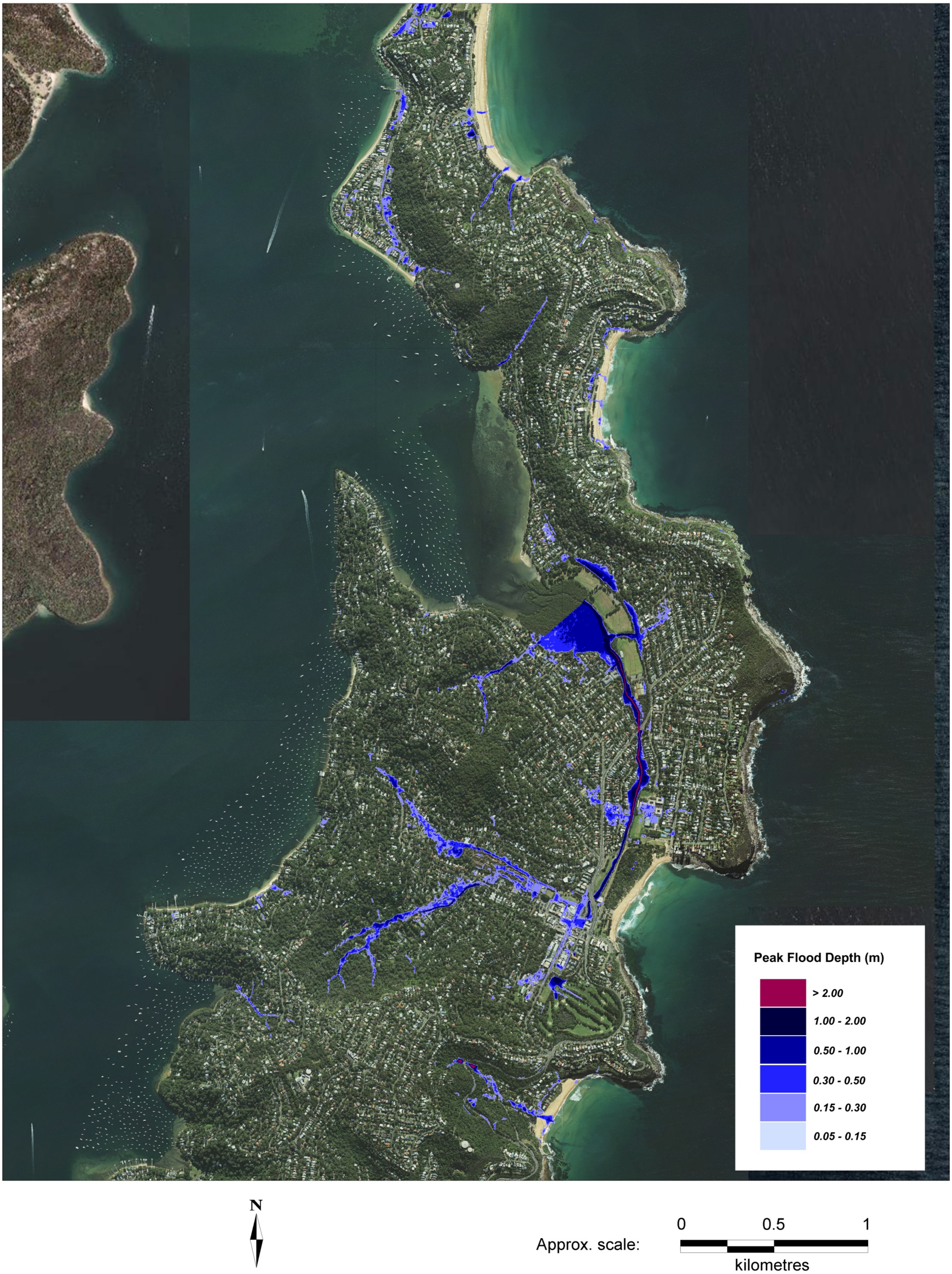
AVALON TO PALM BEACH FRMS&P
20% AEP PEAK FLOOD LEVEL

MHL Report 2321

Figure C1

AvalonPB_FigureC1.cdr



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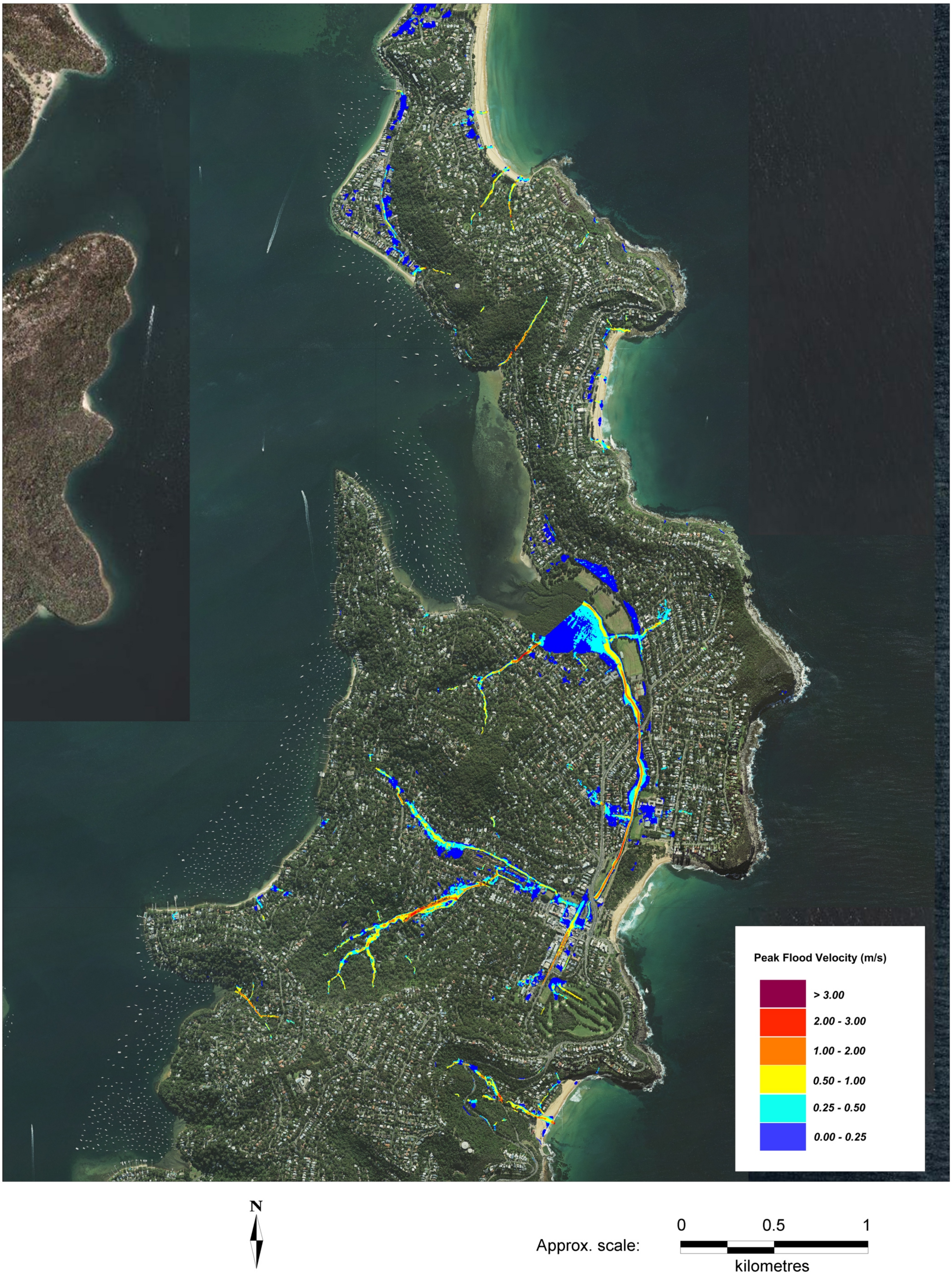
AVALON TO PALM BEACH FRMS&P
20% AEP PEAK FLOOD DEPTH

MHL Report 2321

Figure C2

AvalonPB_FigureC2.cdr



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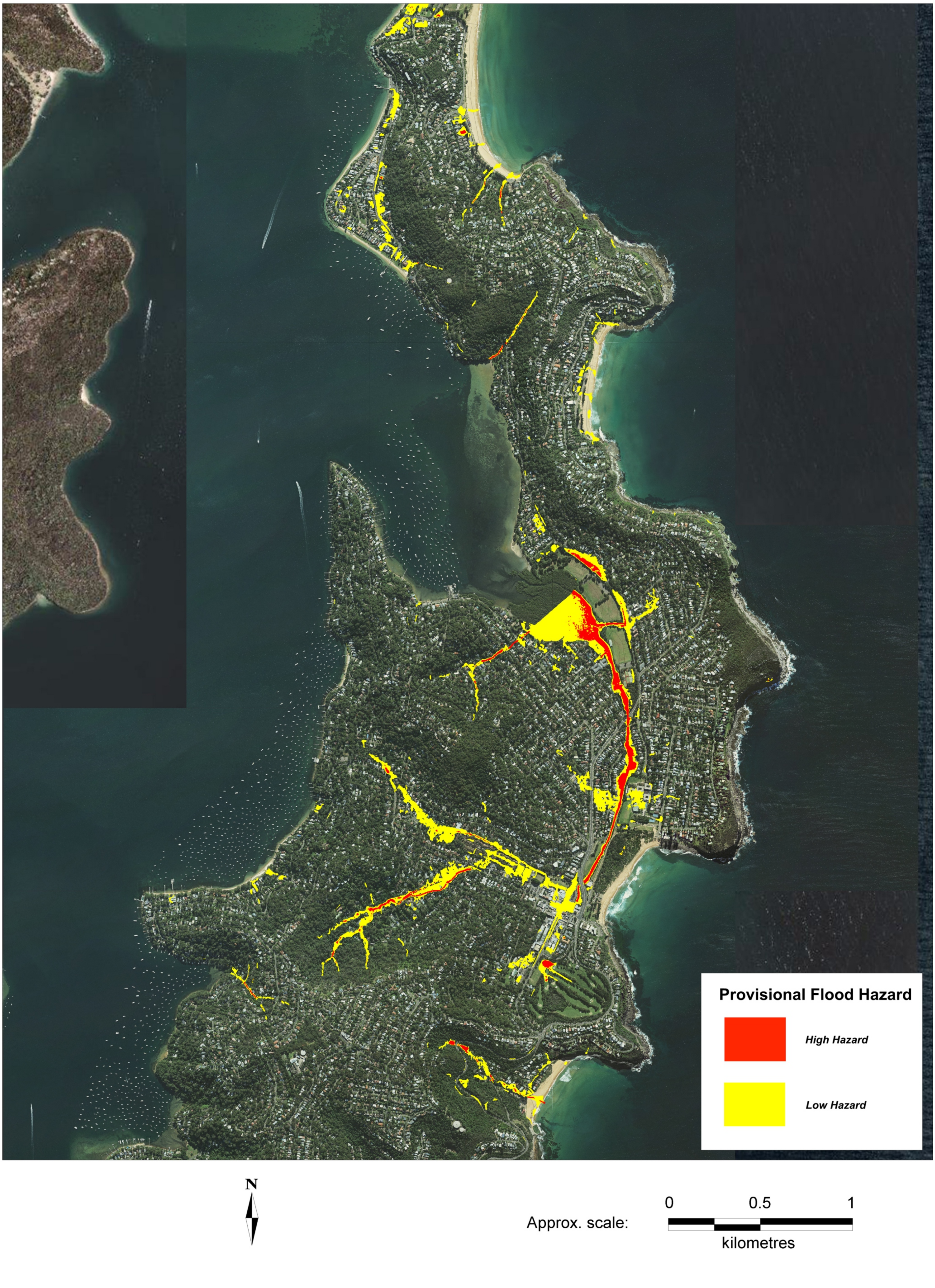
AVALON TO PALM BEACH FRMS&P
20% AEP PEAK FLOOD VELOCITY

MHL Report 2321

Figure C3

AvalonPB_FigureC3.cdr



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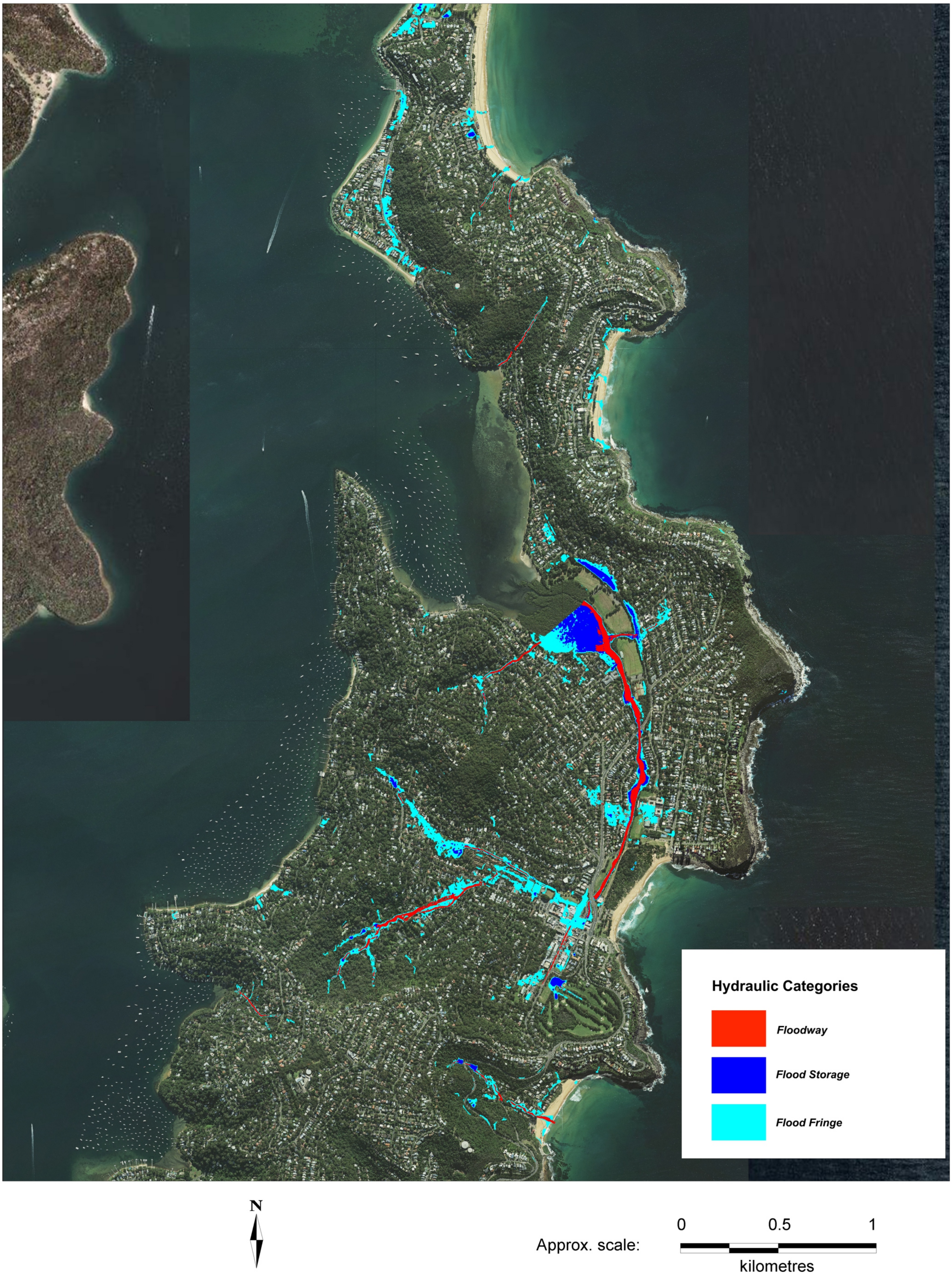
AVALON TO PALM BEACH FRMS&P
20% AEP PROVISIONAL FLOOD HAZARD

MHL Report 2321

Figure C4

AvalonPB_FigureC4.cdr



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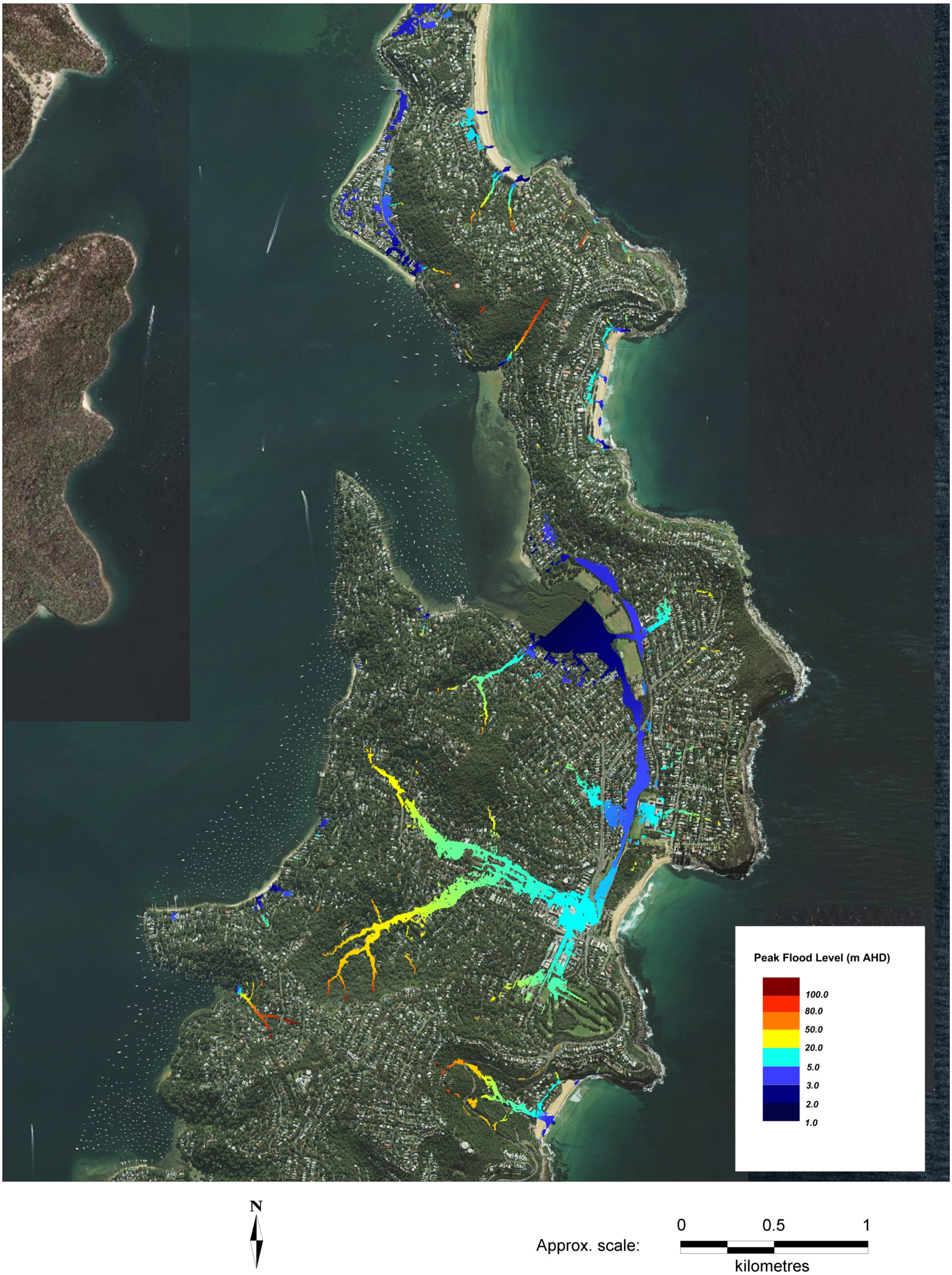
AVALON TO PALM BEACH FRMS&P
20% AEP HYDRAULIC CATEGORIES

MHL Report 2321

Figure C5

AvalonPB_FigureC5.cdr



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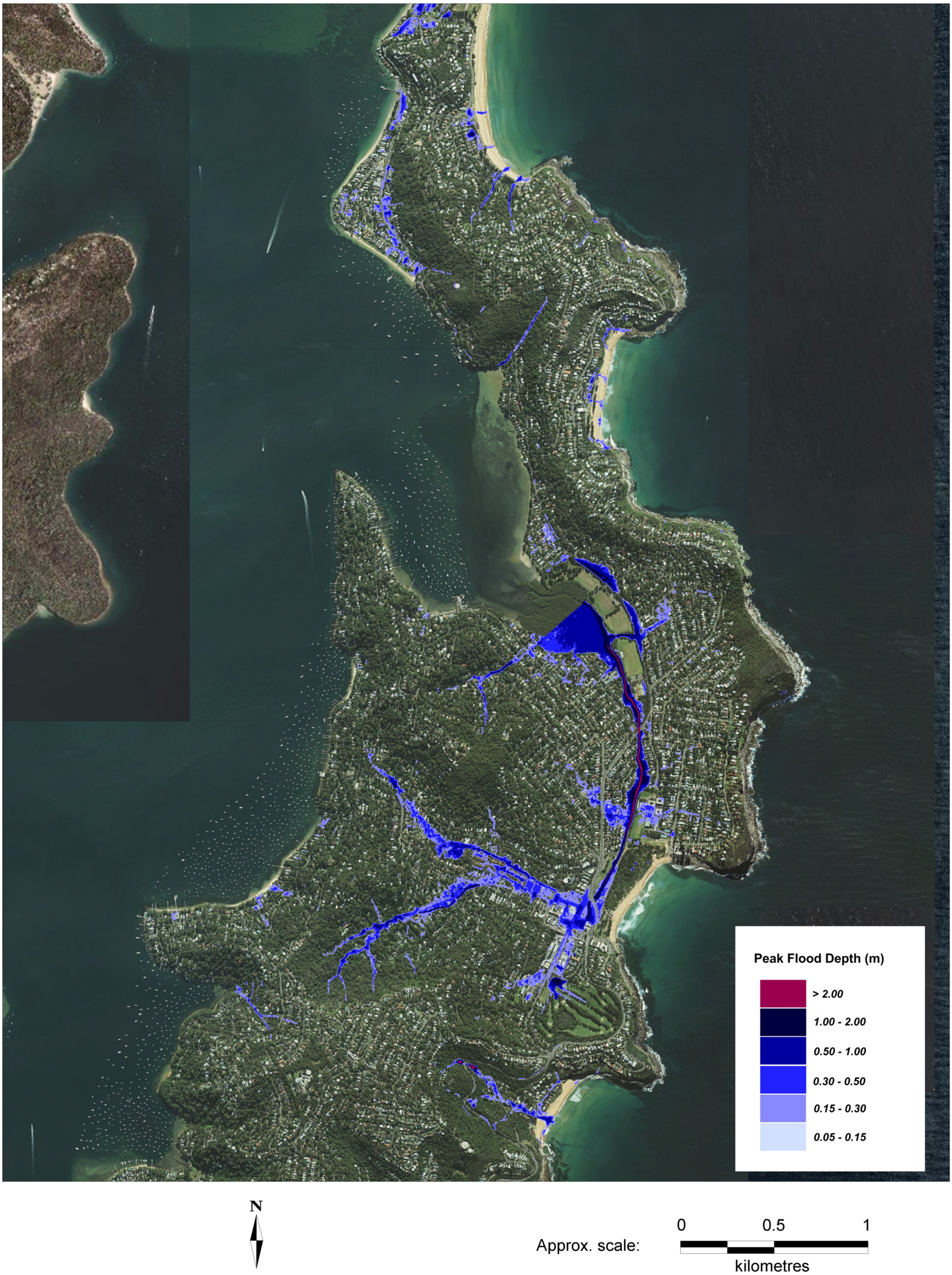
AVALON TO PALM BEACH FRMS&P
5% AEP PEAK FLOOD LEVEL

MHL Report 2321

Figure C6

AvalonPB_FigureC6.cdr



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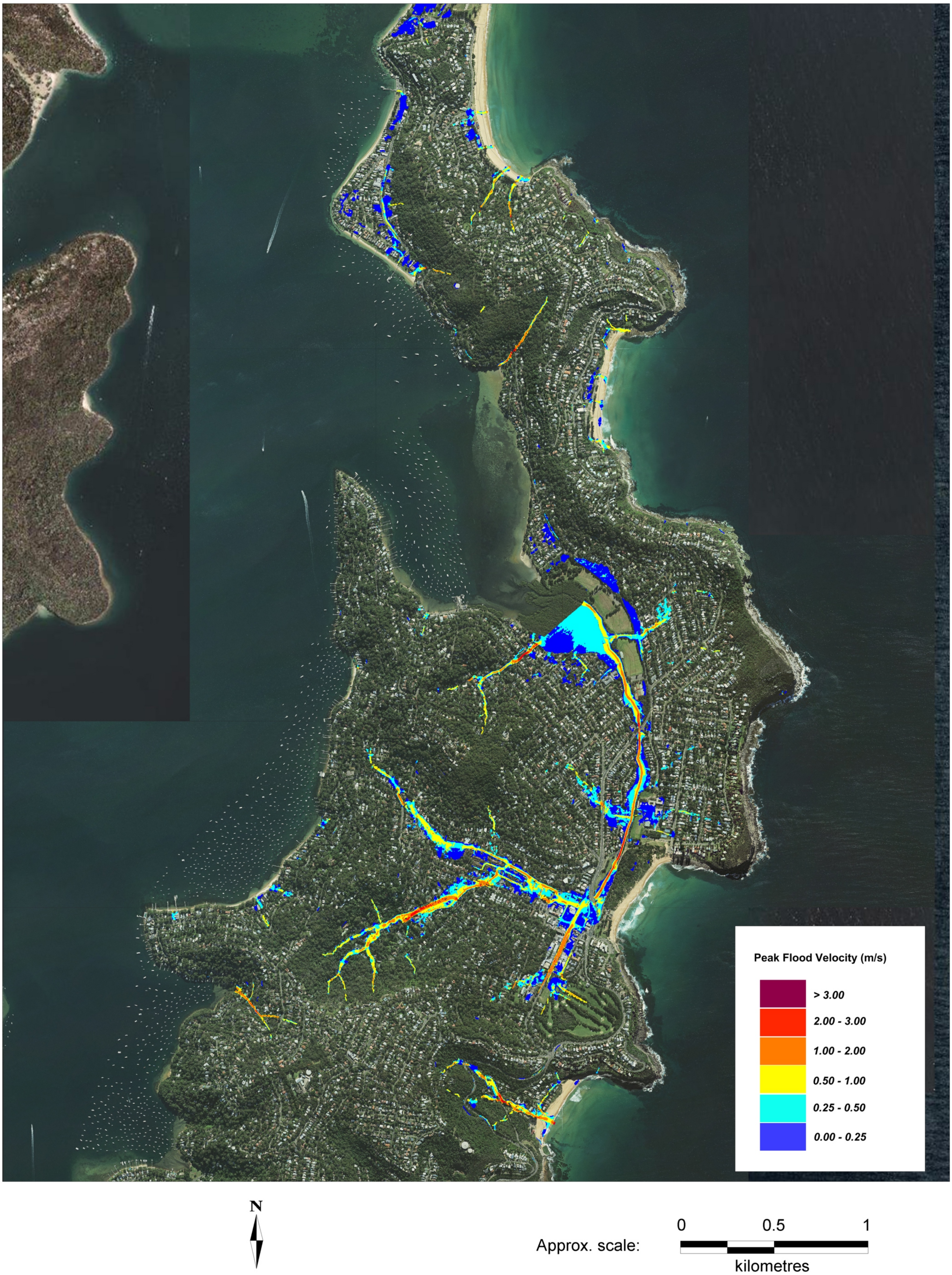
AVALON TO PALM BEACH FRMS&P
5% AEP PEAK FLOOD DEPTH

MHL Report 2321

Figure C7

AvalonPB_FigureC7.cdr



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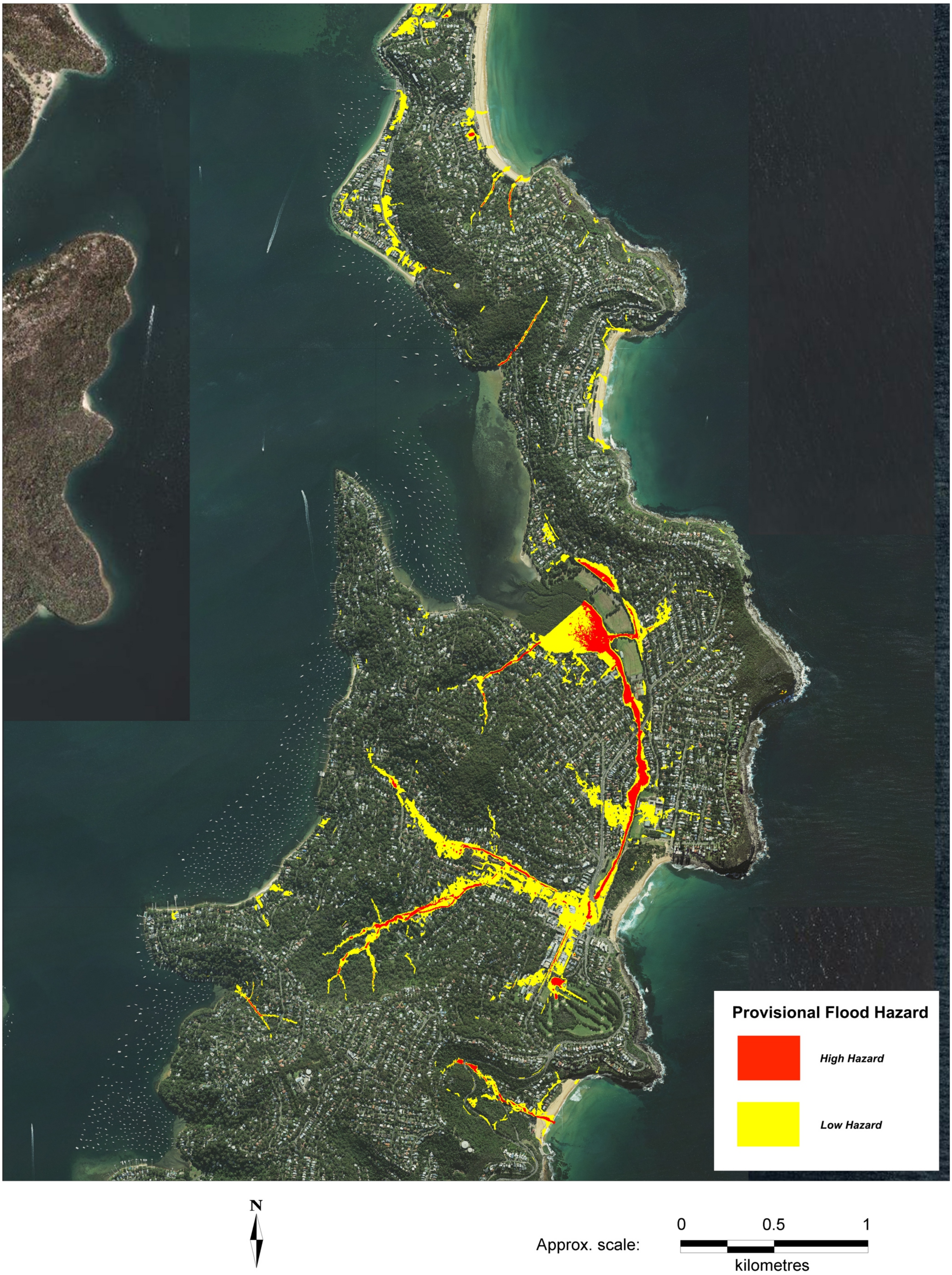
AVALON TO PALM BEACH FRMS&P
5% AEP PEAK FLOOD VELOCITY

MHL Report 2321

Figure C8

AvalonPB_FigureC8.cdr



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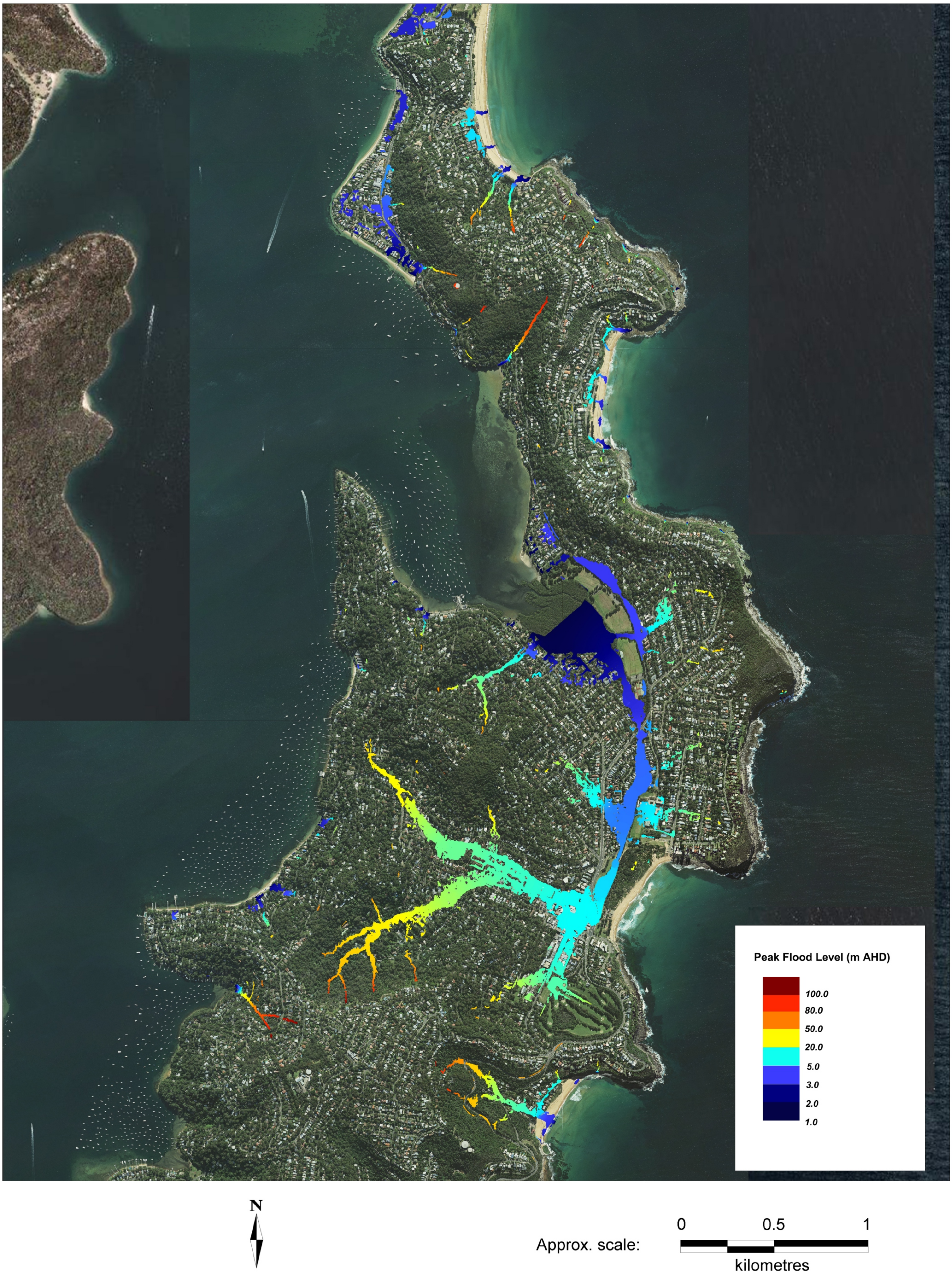
AVALON TO PALM BEACH FRMS&P
5% AEP PROVISIONAL FLOOD HAZARD

MHL Report 2321
Figure C9

AvalonPB_FigureC9.cdr



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AVALON TO PALM BEACH FRMS&P
1% AEP PEAK FLOOD LEVEL

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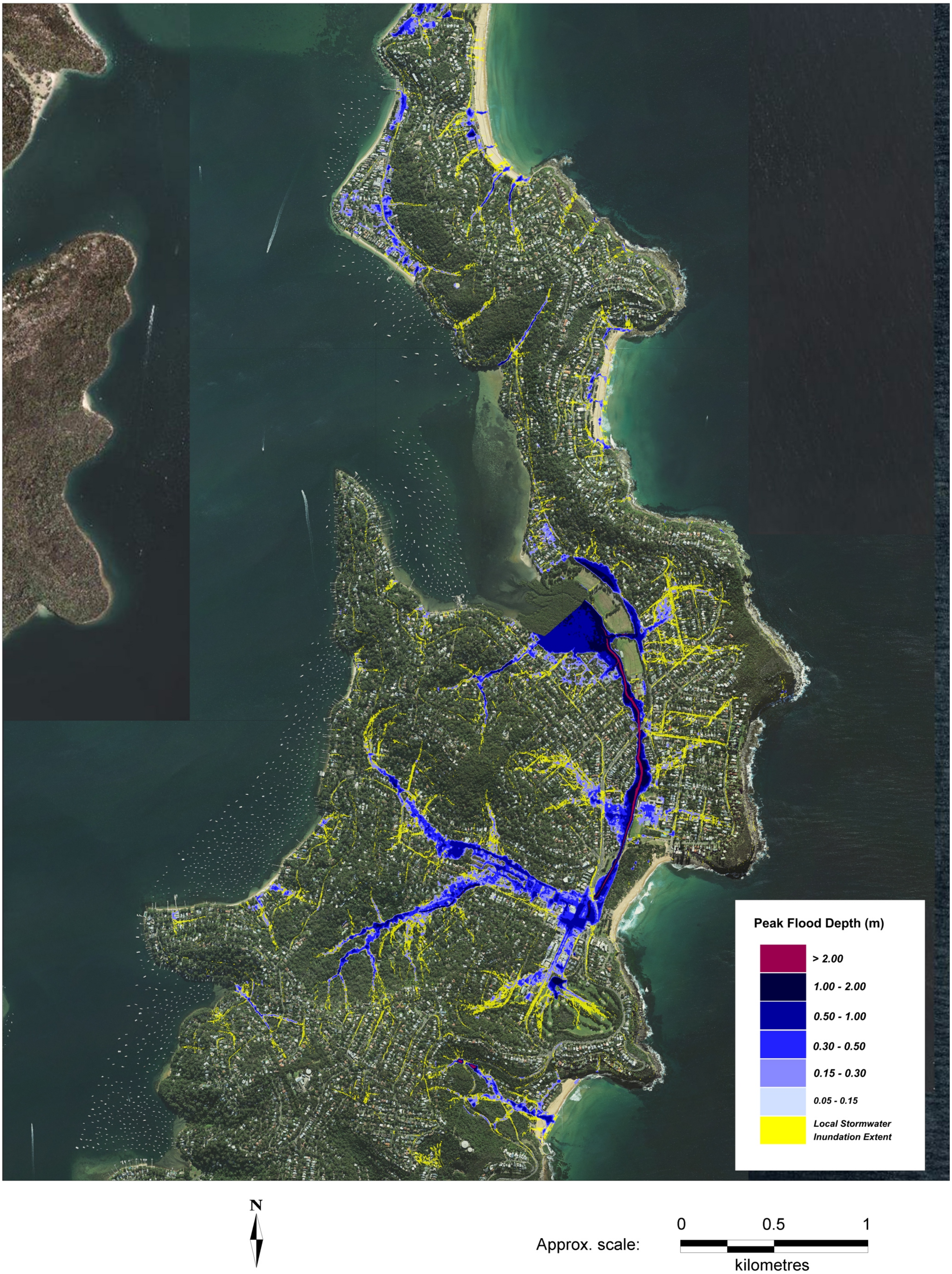
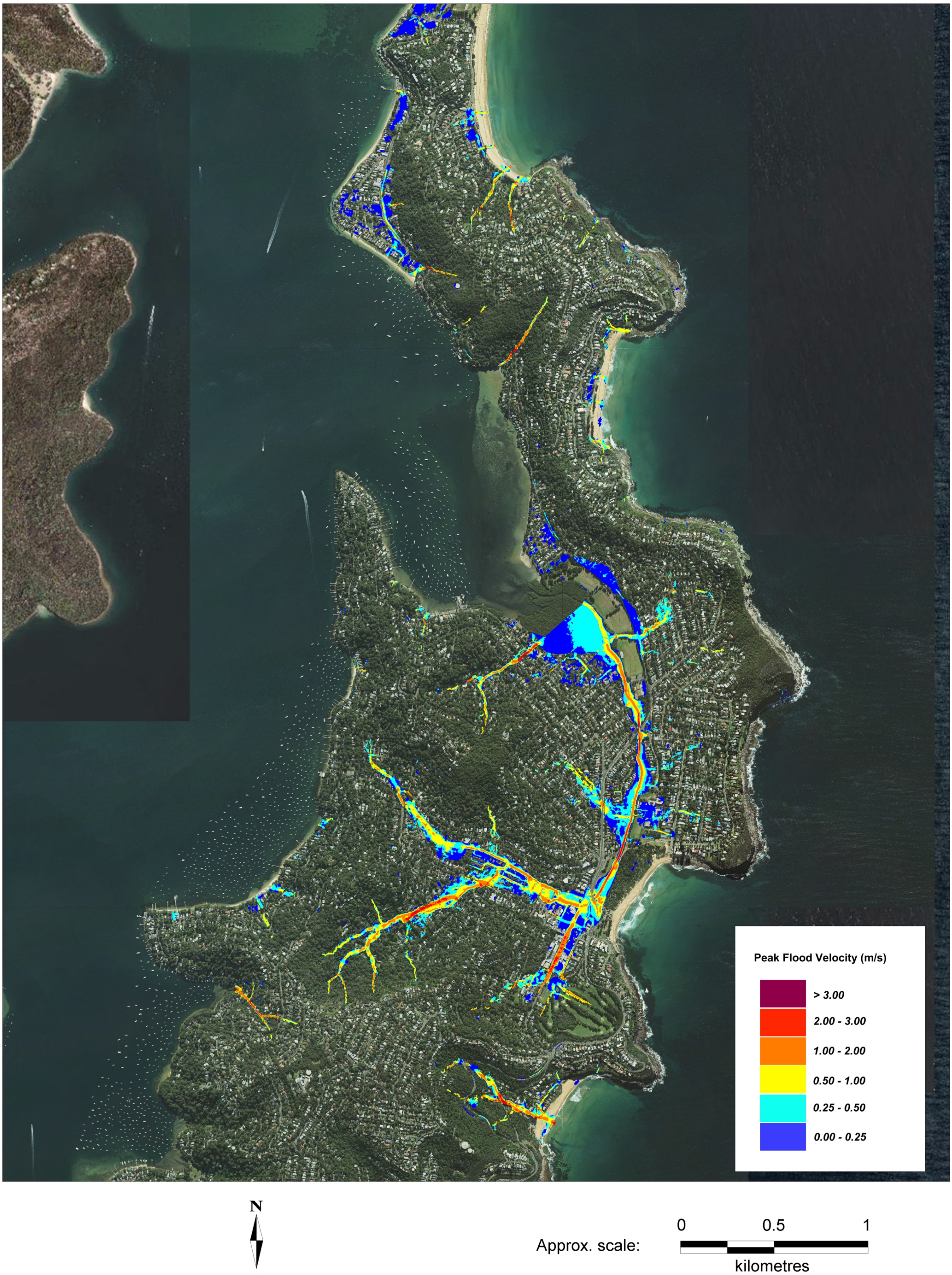
Figure C10

AvalonPB_FigureC10.cdr



NSW GOVERNMENT Public Works Manly Hydraulics Laboratory	AVALON TO PALM BEACH FRMS&P 1% AEP PEAK FLOOD DEPTH	MHL Report 2321 Figure C11 AvalonPB_FigureC11.cdr



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AVALON TO PALM BEACH FRMS&P
1% AEP PEAK FLOOD VELOCITY

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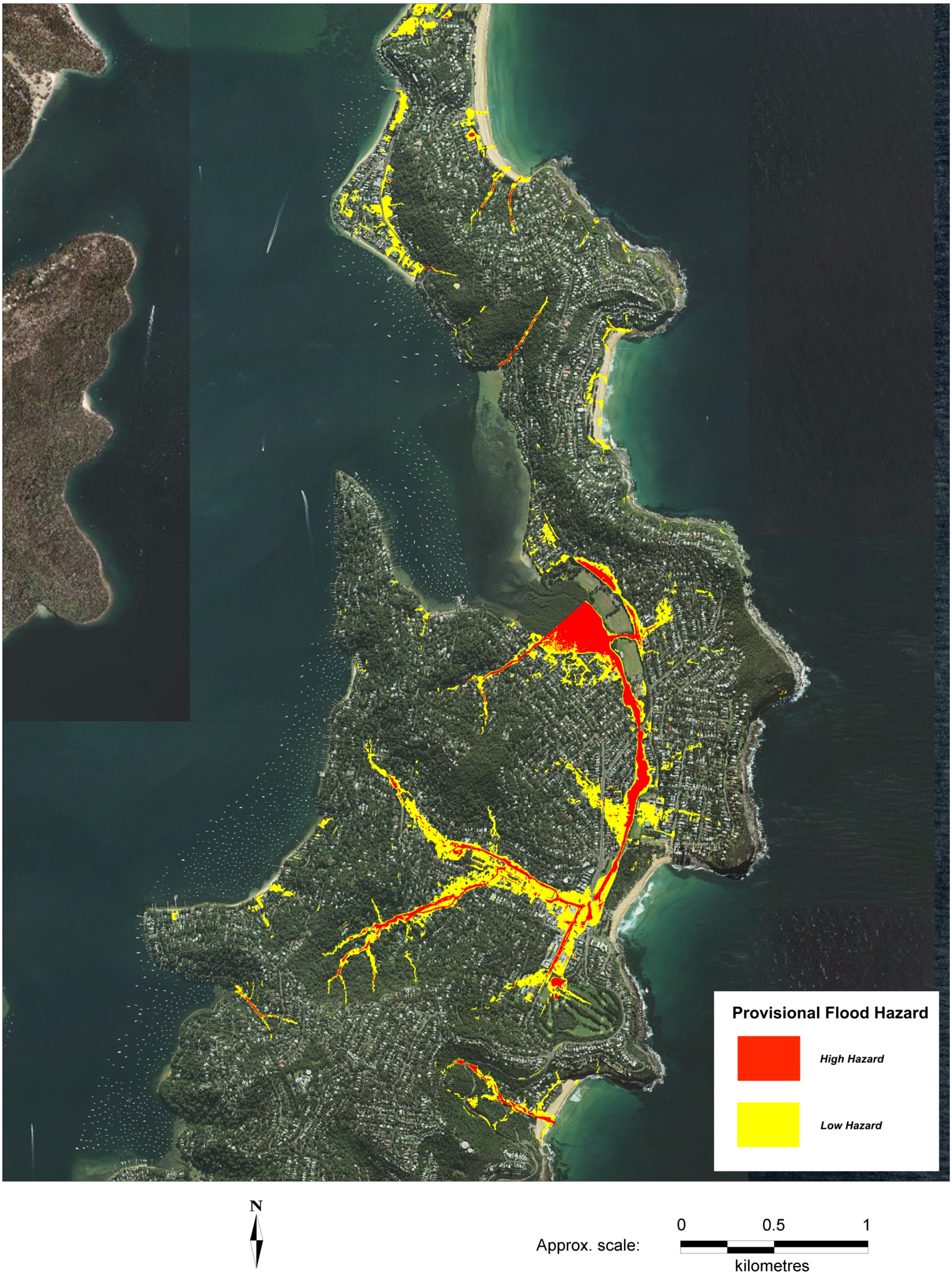
Figure C12

AvalonPB_FigureC12.cdr



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AVALON TO PALM BEACH FRMS&P
1% AEP PROVISIONAL FLOOD HAZARD

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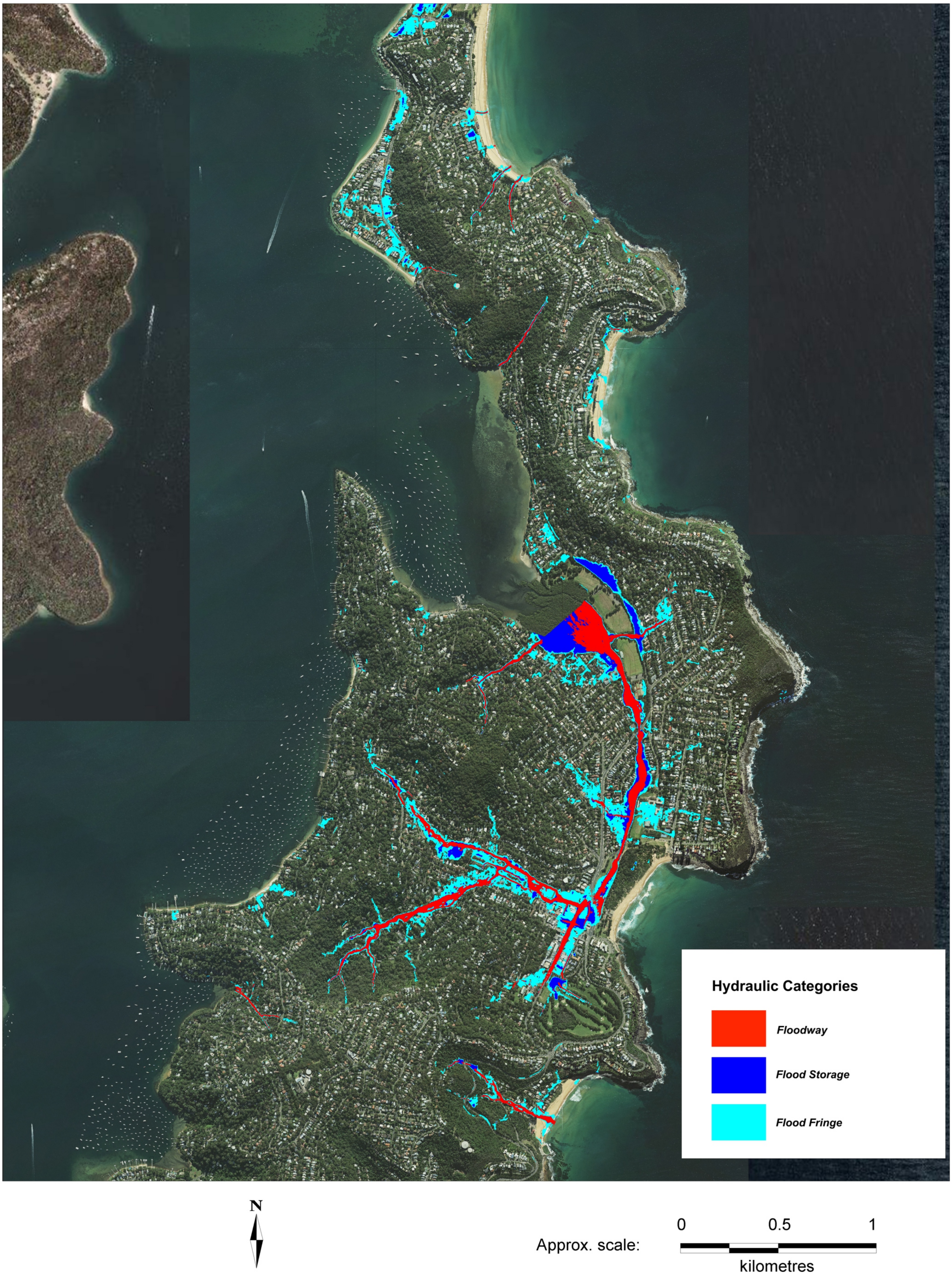
Figure C13

AvalonPB_FigureC13.cdr



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AVALON TO PALM BEACH FRMS&P
1% AEP HYDRAULIC CATEGORIES

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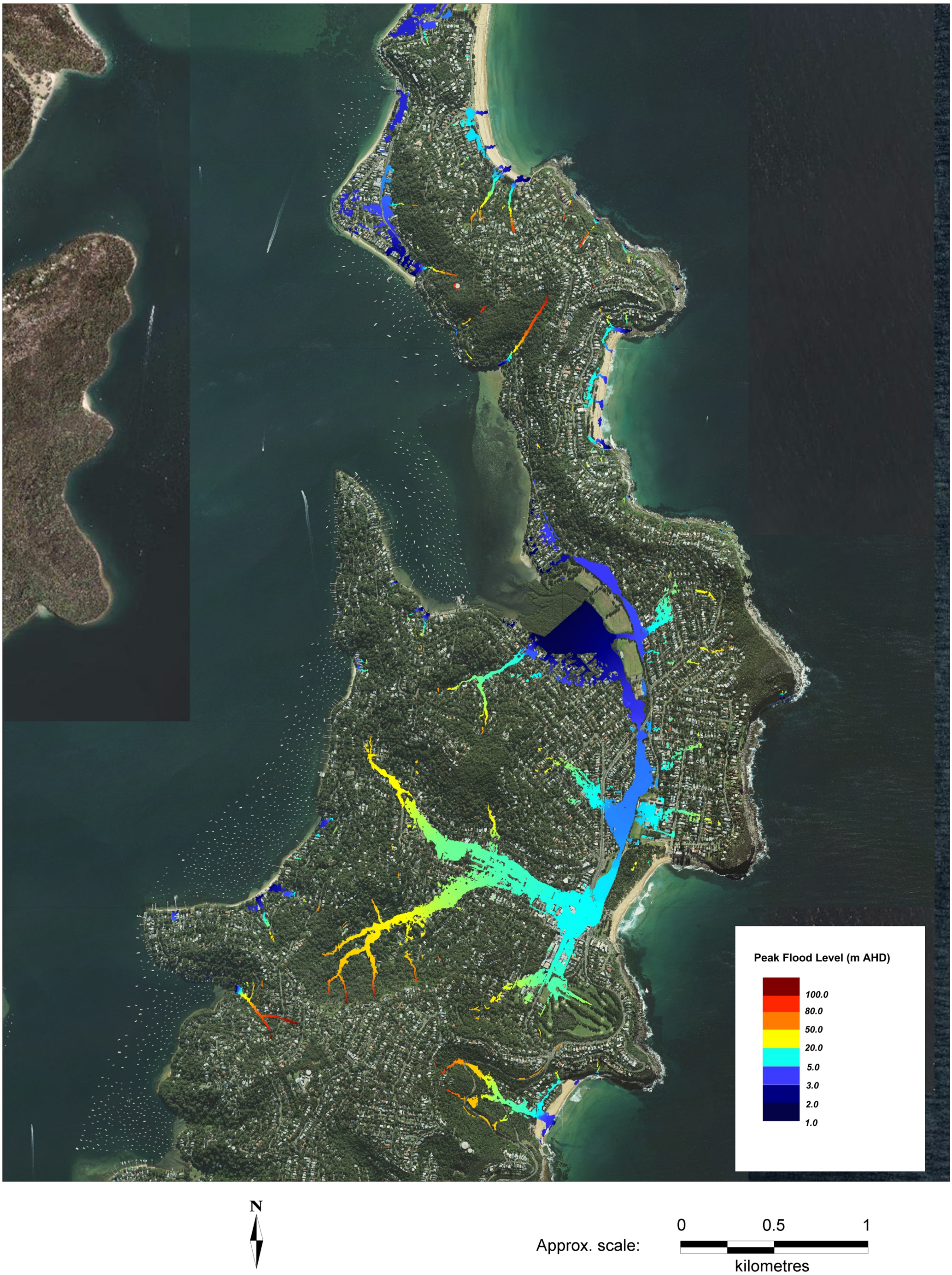
Figure C14

AvalonPB_FigureC14.cdr



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AVALON TO PALM BEACH FRMS&P
0.5% AEP PEAK FLOOD LEVEL

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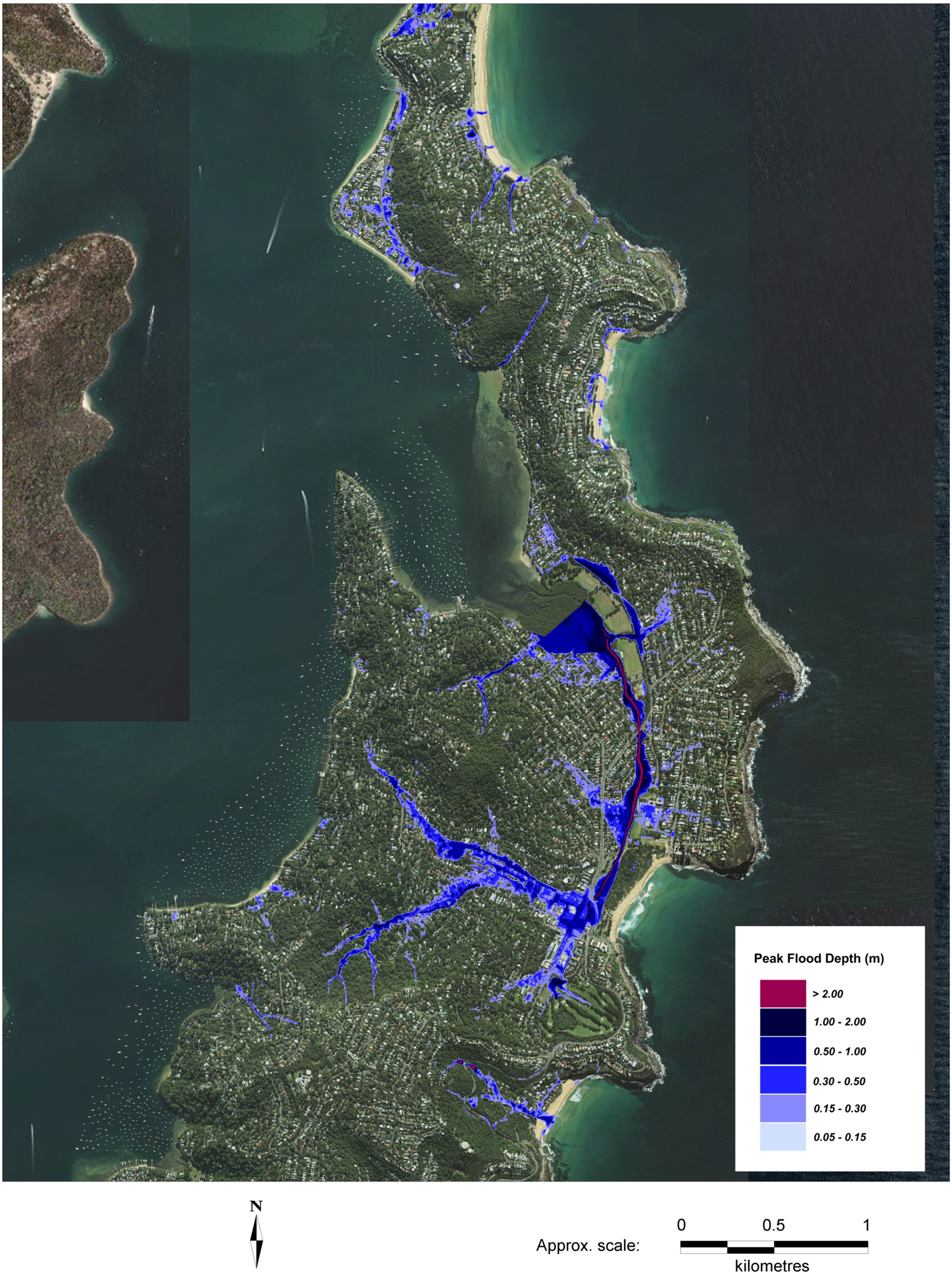
Figure C15

AvalonPB_FigureC15.cdr



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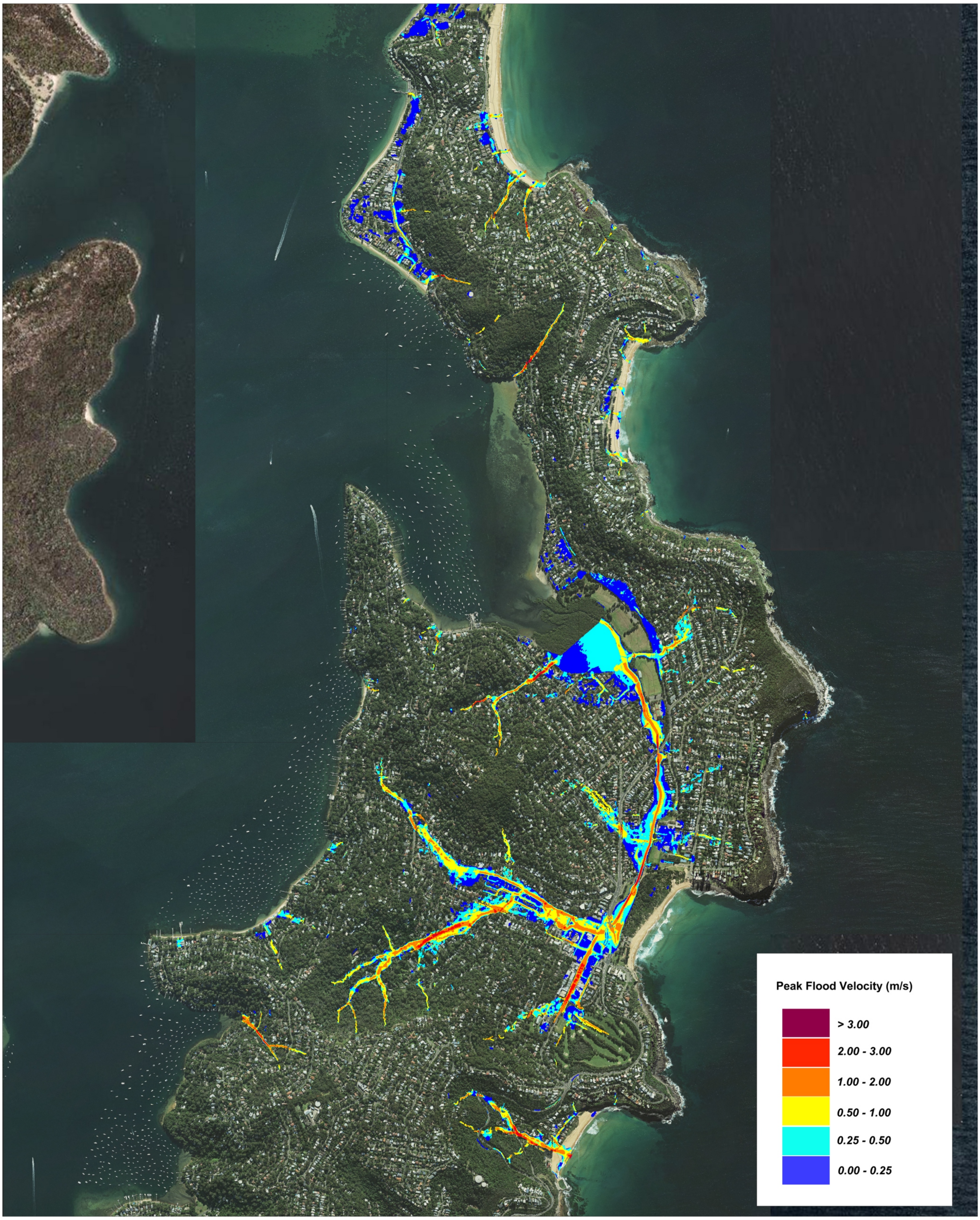
AVALON TO PALM BEACH FRMS&P
0.5% AEP PEAK FLOOD DEPTH

MHL Report 2321

Figure C16

AvalonPB_FigureC16.cdr



N

Approx. scale: 0 0.5 1 kilometres

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AVALON TO PALM BEACH FRMS&P
0.5% AEP PEAK FLOOD VELOCITY

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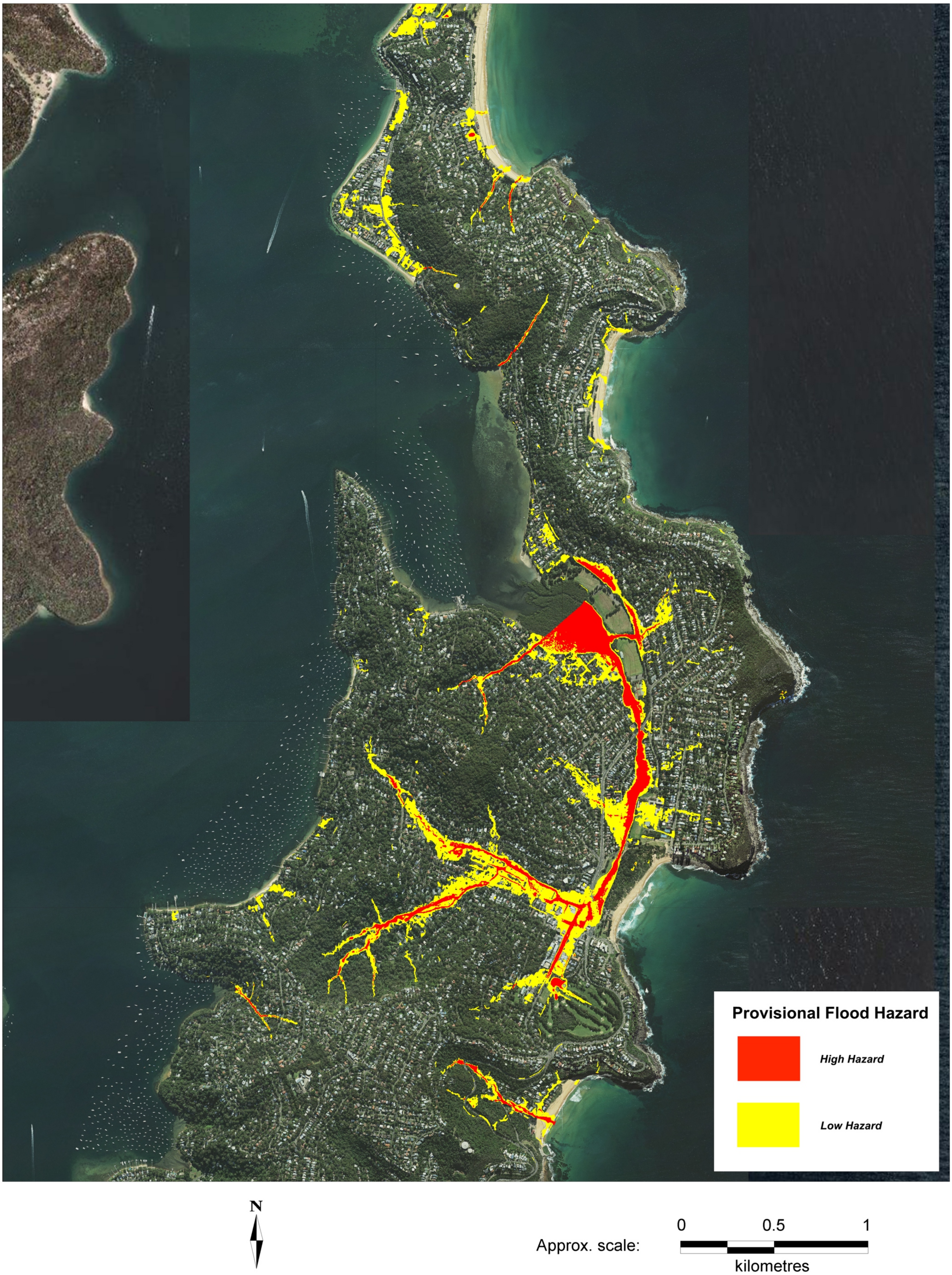
Figure C17

AvalonPB_FigureC17.cdr



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AVALON TO PALM BEACH FRMS&P
0.5% AEP PROVISIONAL FLOOD HAZARD

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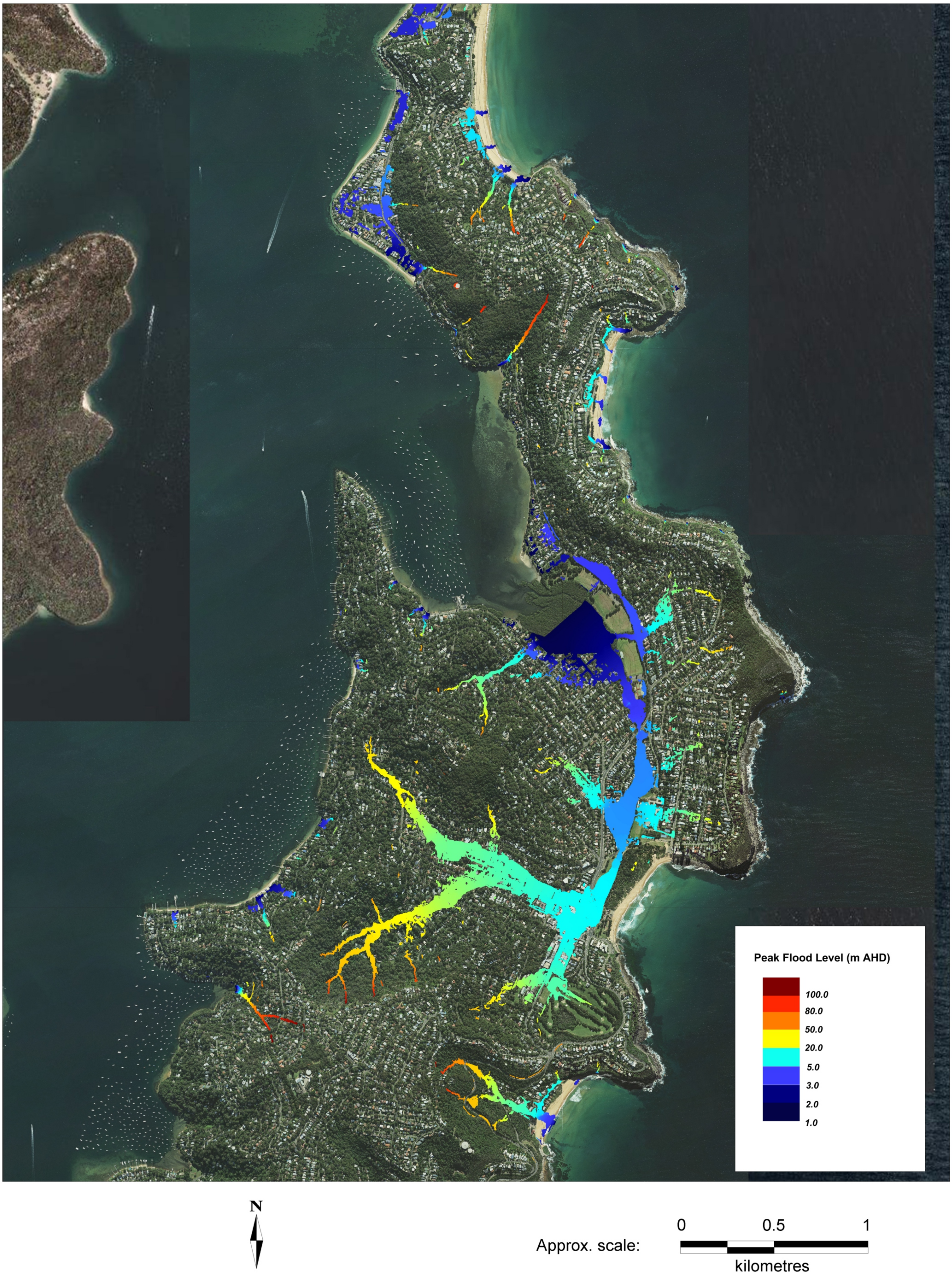
Figure C18

AvalonPB_FigureC18.cdr



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AVALON TO PALM BEACH FRMS&P
0.2% AEP PEAK FLOOD LEVEL

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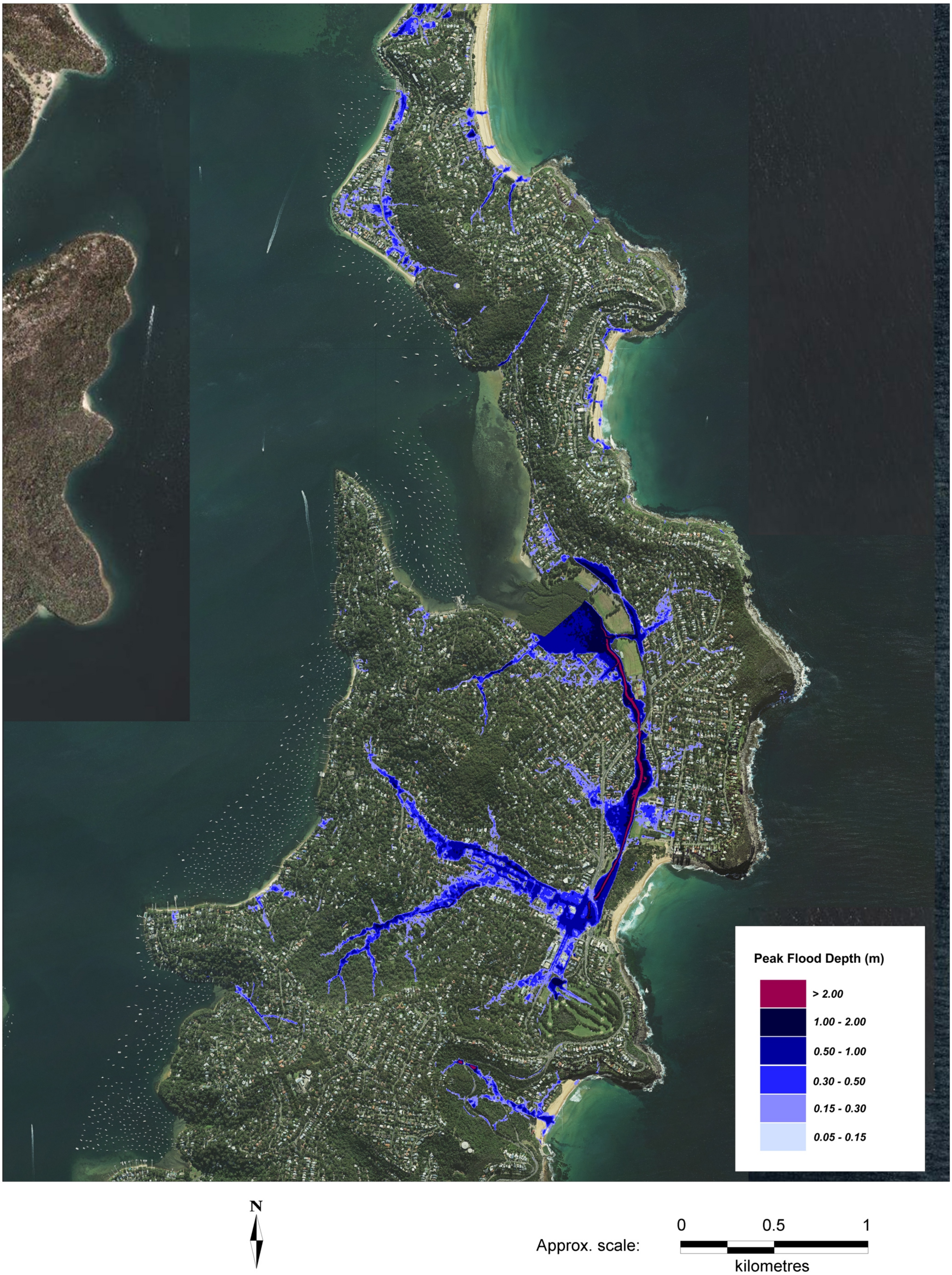
Figure C19

AvalonPB_FigureC19.cdr



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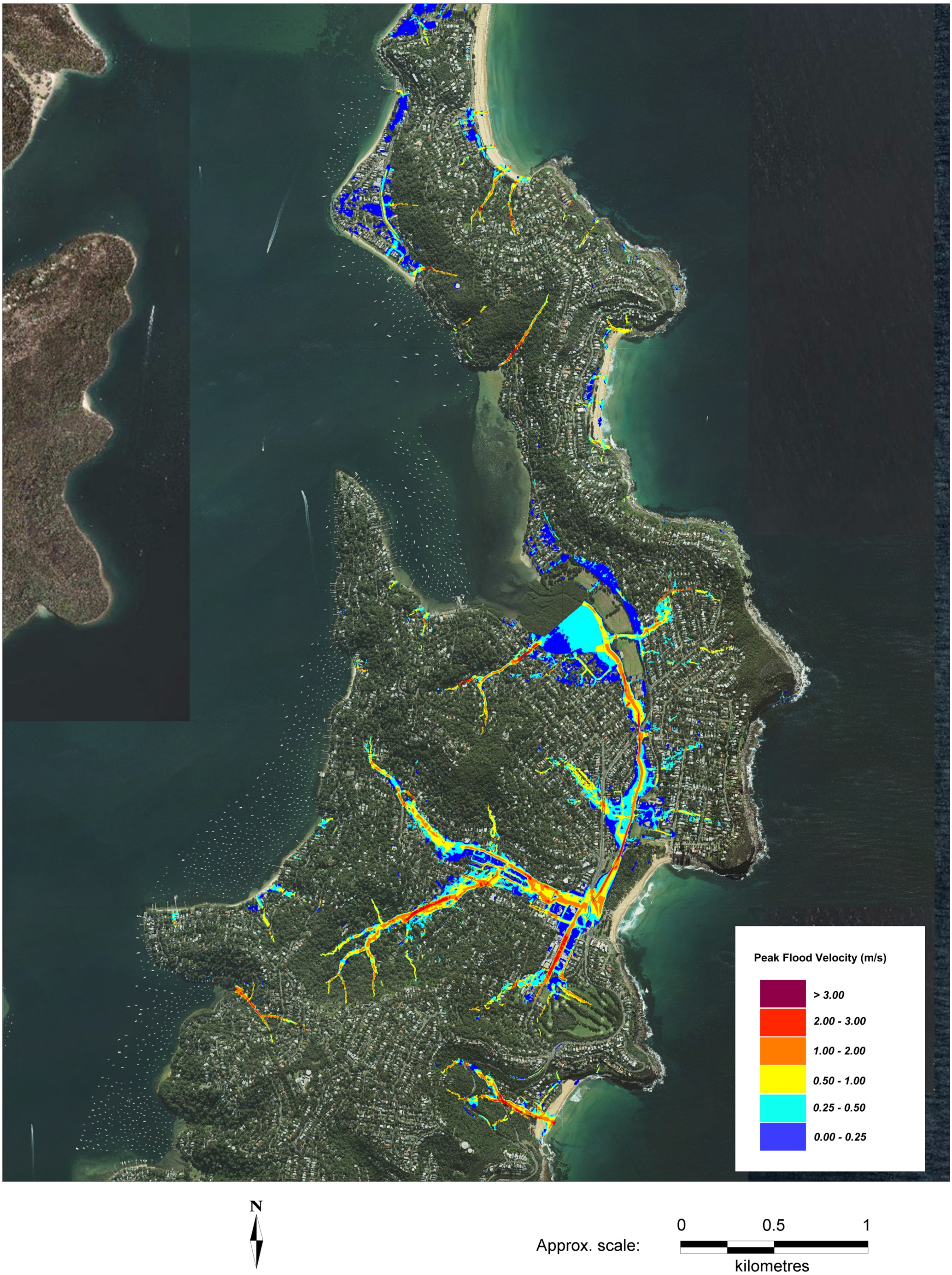
Manly Hydraulics Laboratory

AVALON TO PALM BEACH FRMS&P
0.2% AEP PEAK FLOOD DEPTH

MHL Report 2321
Figure C20
AvalonPB_FigureC20.cdr



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AVALON TO PALM BEACH FRMS&P
0.2% AEP PEAK FLOOD VELOCITY

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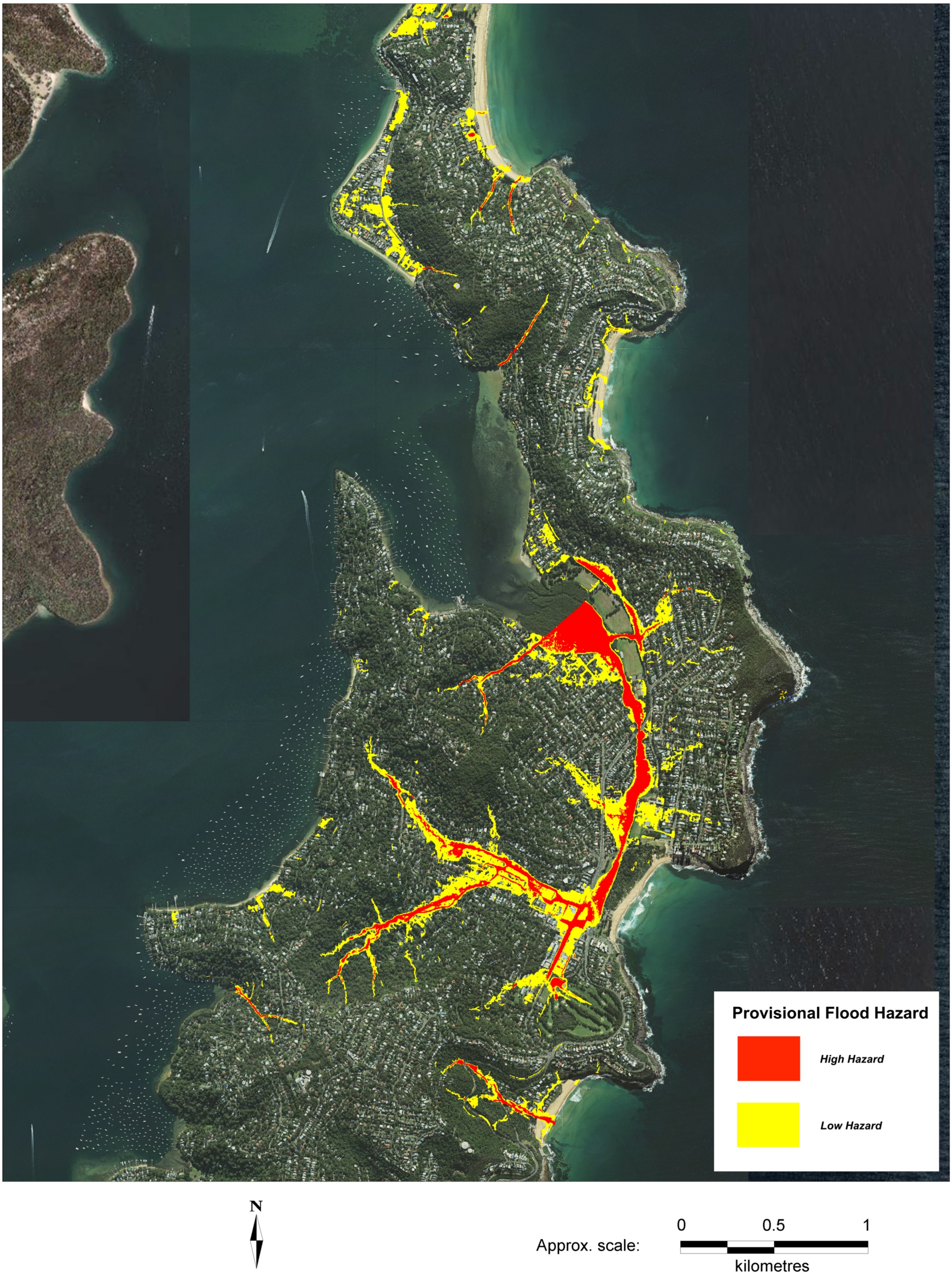
Figure C21

AvalonPB_FigureC21.cdr



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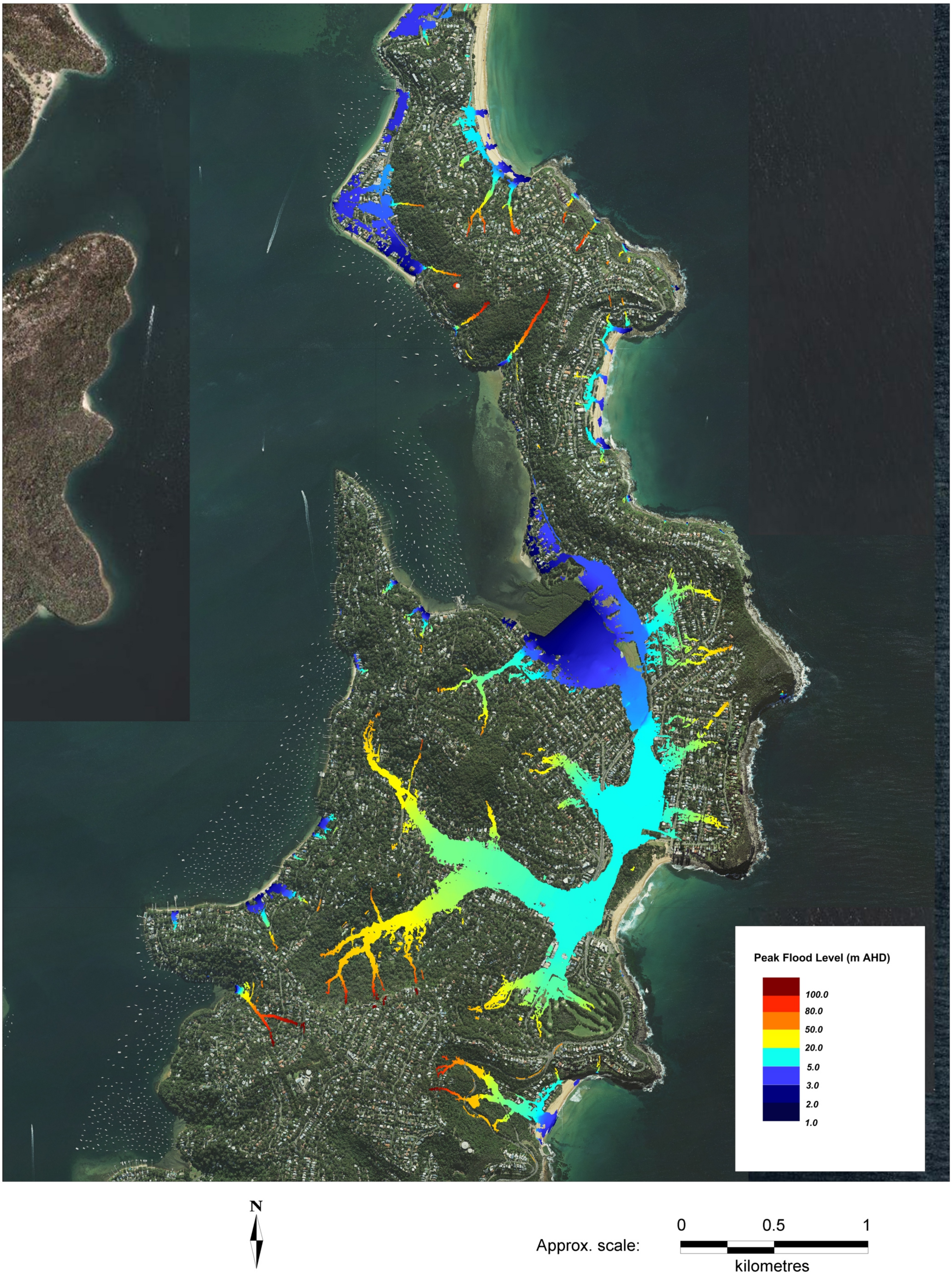
AVALON TO PALM BEACH FRMS&P
0.2% AEP PROVISIONAL FLOOD HAZARD

MHL Report 2321

Figure C22

AvalonPB_FigureC22.cdr



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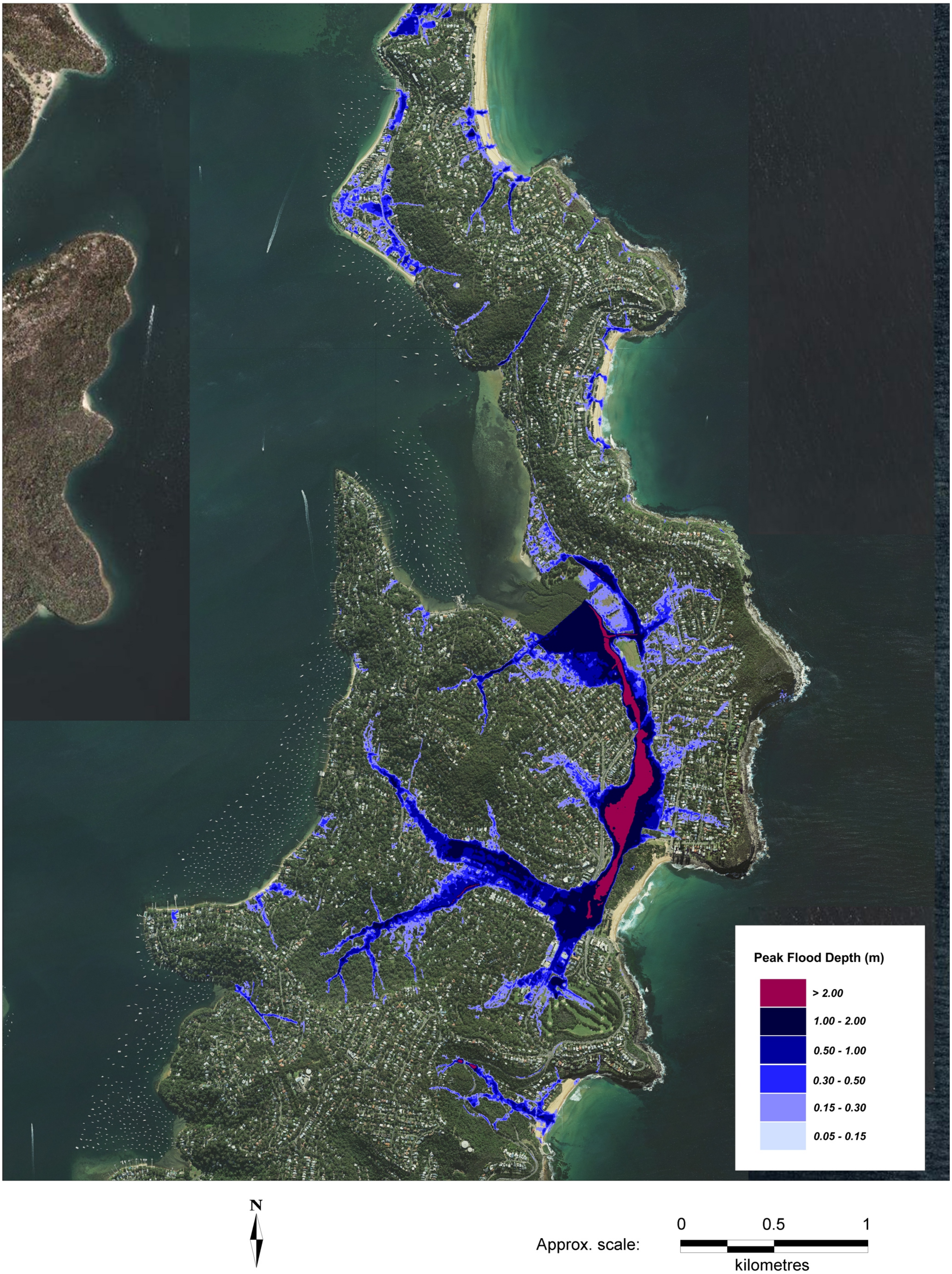
AVALON TO PALM BEACH FRMS&P
PMF PEAK FLOOD LEVEL

MHL Report 2321

Figure C23

AvalonPB_FigureC23.cdr



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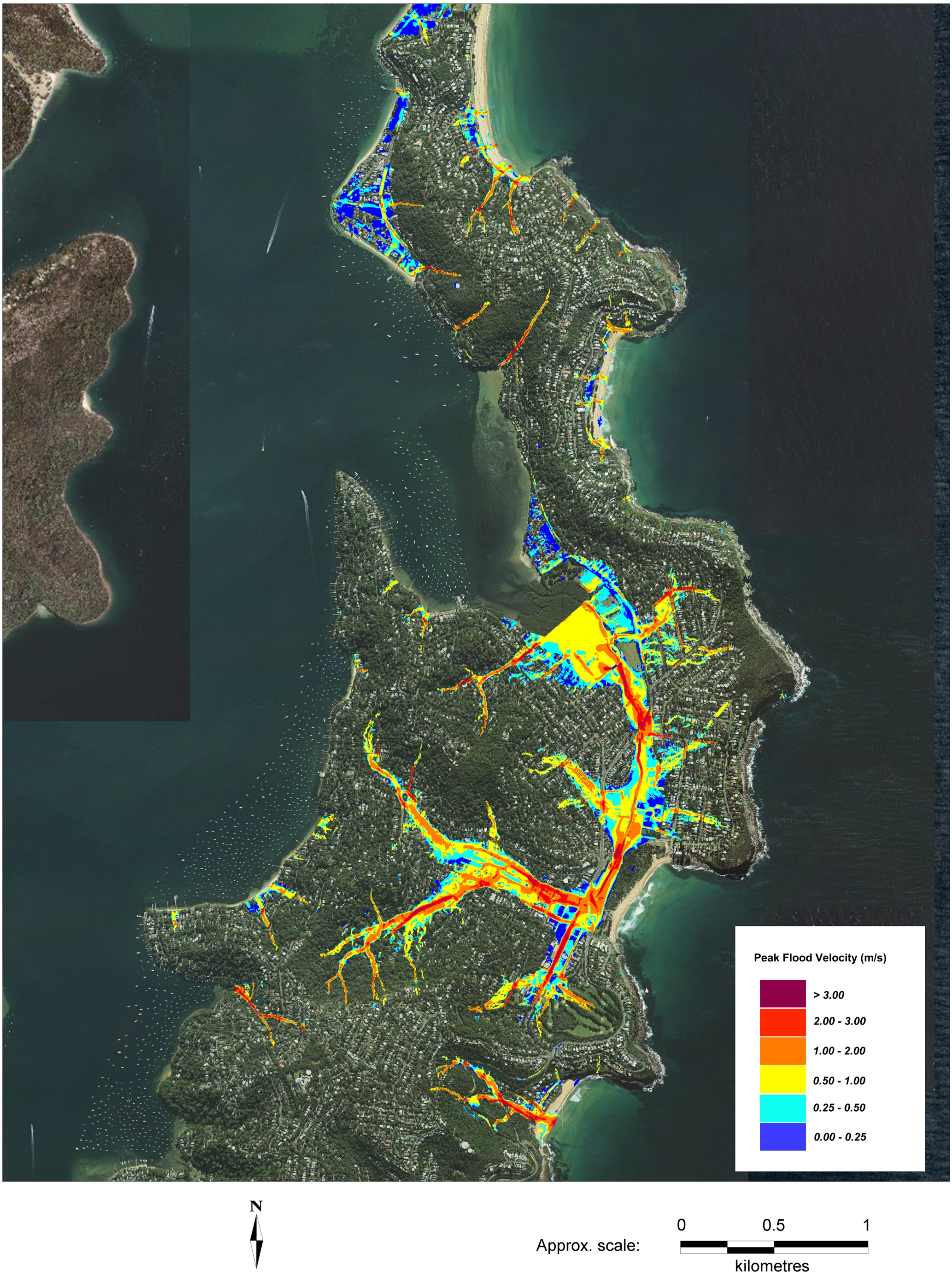
AVALON TO PALM BEACH FRMS&P
PMF PEAK FLOOD DEPTH

MHL Report 2321

Figure C24

AvalonPB_FigureC24.cdr



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AVALON TO PALM BEACH FRMS&P
PMF PEAK FLOOD VELOCITY

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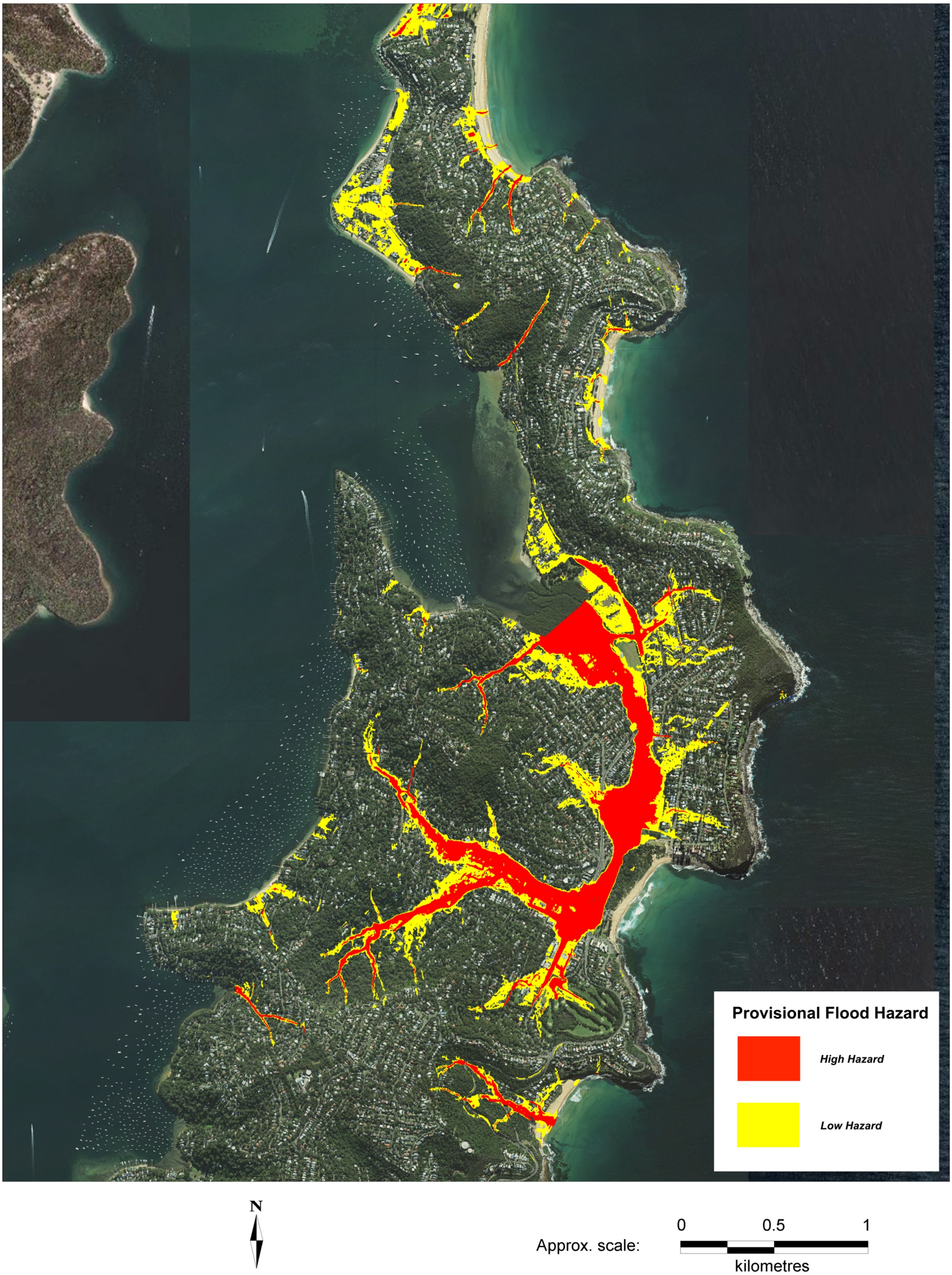
Figure C25

AvalonPB_FigureC25.cdr



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AVALON TO PALM BEACH FRMS&P
PMF PROVISIONAL FLOOD HAZARD

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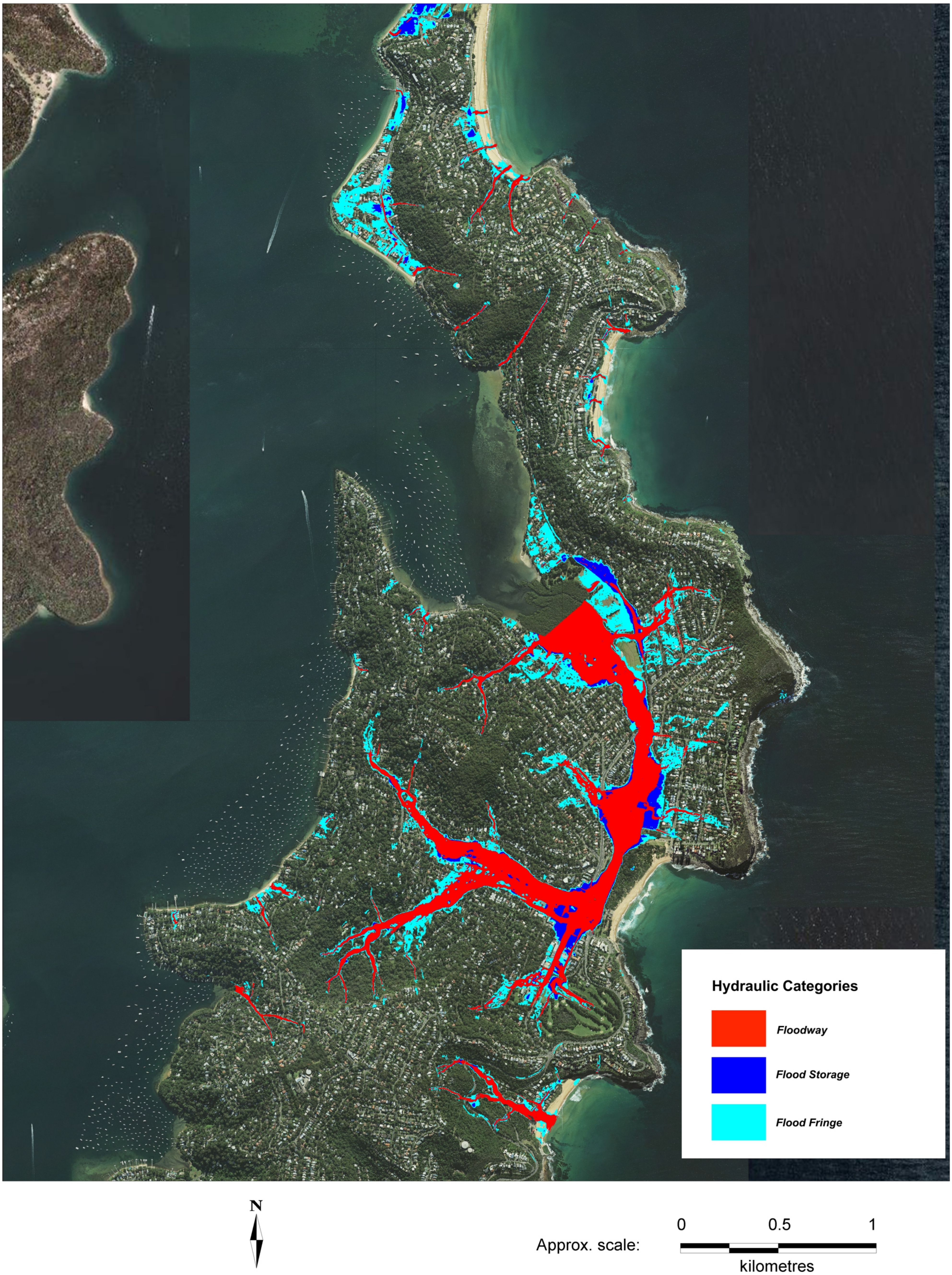
Figure C26

AvalonPB_FigureC26.cdr



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AVALON TO PALM BEACH FRMS&P
PMF HYDRAULIC CATEGORIES

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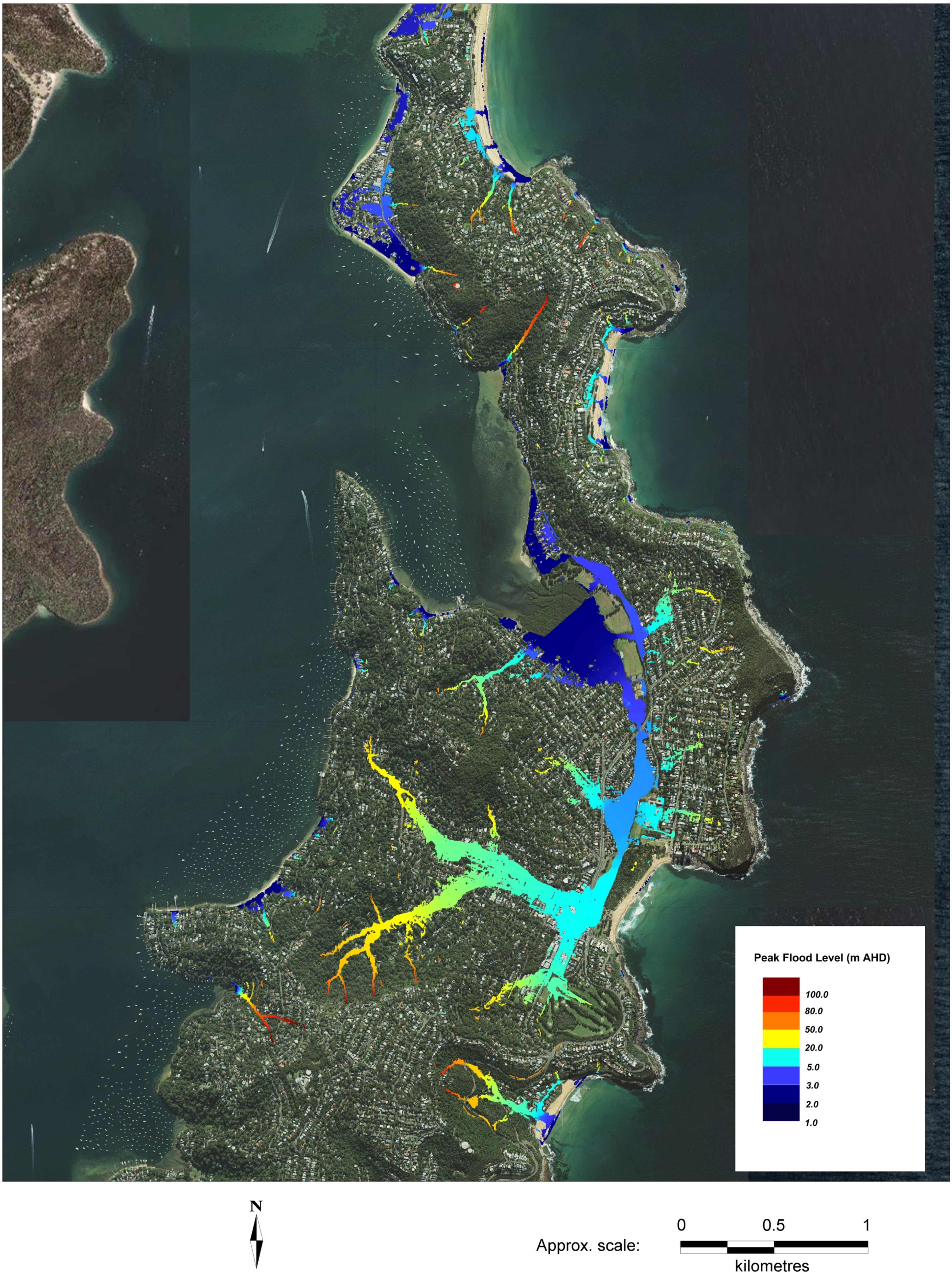
Figure C27

AvalonPB_FigureC27.cdr



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AVALON TO PALM BEACH FRMS&P
1% AEP CLIMATE CHANGE SCENARIO
PEAK FLOOD LEVEL

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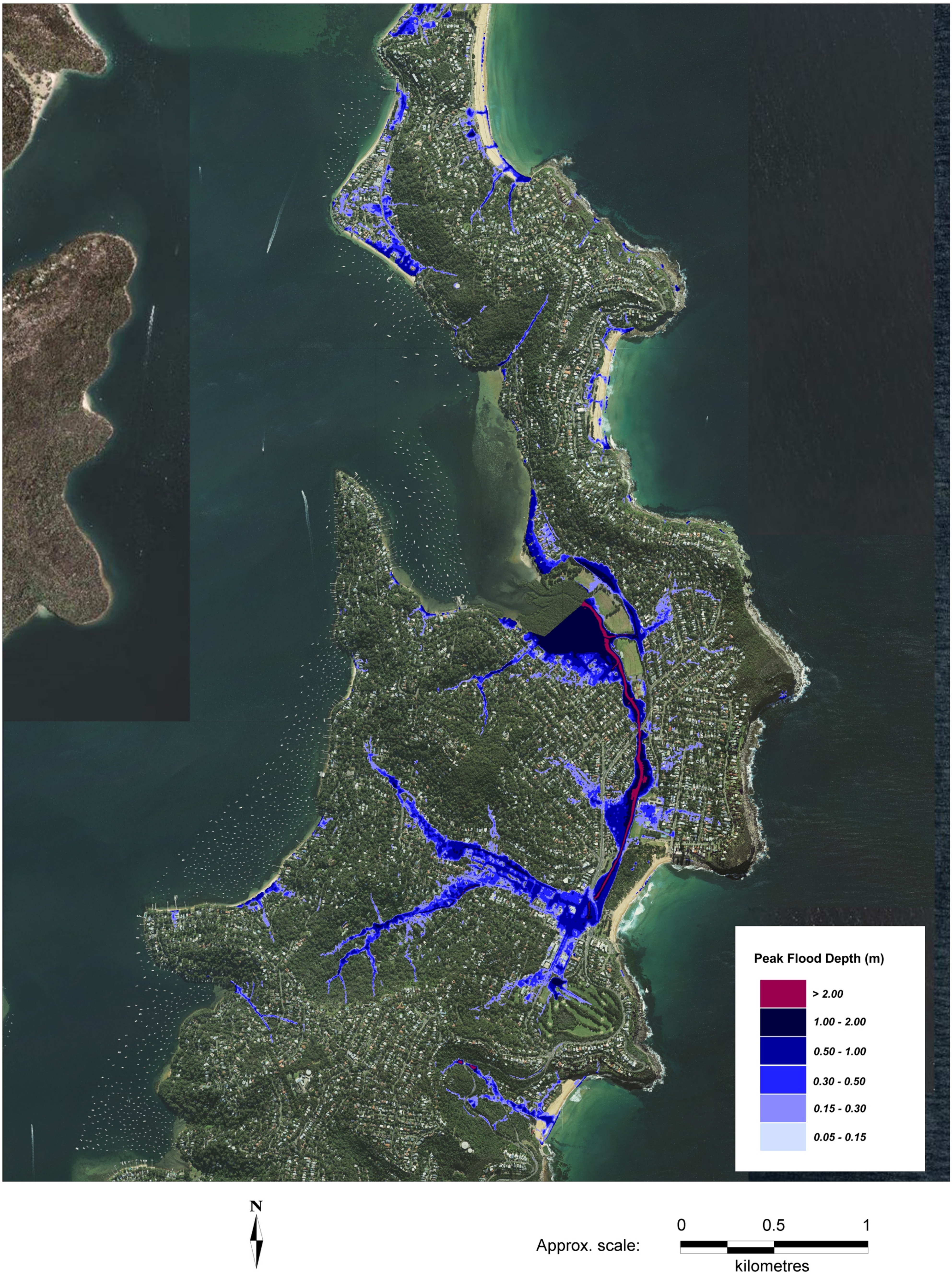
Figure C28
AvalonPB_FigureC28.cdr



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AVALON TO PALM BEACH FRMS&P
1% AEP CLIMATE CHANGE SCENARIO
PEAK FLOOD DEPTH

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Figure C29

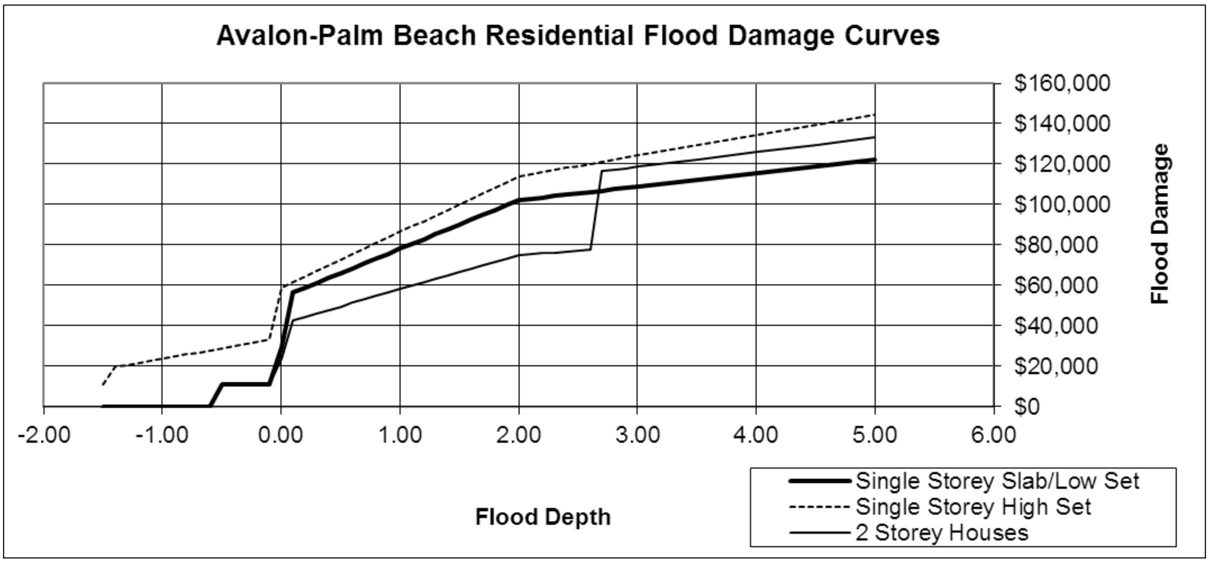
AvalonPB_FigureC29.cdr

Appendix D

Damages Assessment Stage-Damage Data

Residential Stage-Damage Data

	Single Storey High Set	Single Storey Slab/Low Set	2 Storey Houses
Code	1	2	3
Above floor depth	Damage	Damage	Damage
-5.00	$0	$0	$0
-1.50	$11,256	$0	$0
-1.40	$19,710	$0	$0
-1.30	$20,734	$0	$0
-1.20	$21,759	$0	$0
-1.10	$22,783	$0	$0
-1.00	$23,808	$0	$0
-0.90	$24,832	$0	$0
-0.80	$25,857	$0	$0
-0.70	$26,881	$0	$0
-0.60	$27,906	$0	$0
-0.50	$28,930	$11,256	$11,256
-0.40	$29,955	$11,256	$11,256
-0.30	$30,979	$11,256	$11,256
-0.20	$32,003	$11,256	$11,256
-0.10	$33,028	$11,256	$11,256
0.00	$58,837	$29,349	$23,921
0.10	$61,594	$56,535	$42,951
0.20	$64,350	$58,937	$44,633
0.30	$67,107	$61,339	$46,314
0.40	$69,864	$63,741	$47,995
0.50	$72,621	$66,143	$49,677
0.60	$75,378	$68,545	$51,358
0.70	$78,135	$70,947	$53,040
0.80	$80,892	$73,349	$54,721
0.90	$83,649	$75,751	$56,402
1.00	$86,406	$78,153	$58,084
1.10	$89,163	$80,555	$59,765
1.20	$91,920	$82,957	$61,446
1.30	$94,677	$85,359	$63,128
1.40	$97,434	$87,761	$64,809
1.50	$100,191	$90,163	$66,491
1.60	$102,948	$92,565	$68,172
1.70	$105,705	$94,966	$69,853
1.80	$108,462	$97,368	$71,535
1.90	$111,219	$99,770	$73,216
2.00	$113,976	$102,172	$74,897
2.10	$115,000	$102,842	$75,366
2.20	$116,025	$103,511	$75,835
2.30	$117,049	$104,181	$76,303
2.40	$118,074	$104,850	$76,772
2.50	$119,098	$105,520	$77,241
2.60	$120,123	$106,189	$77,709
2.70	$121,147	$106,859	$116,419
2.80	$122,171	$107,528	$117,155
2.90	$123,196	$108,198	$117,892
3.00	$124,220	$108,867	$118,628
3.50	$129,343	$112,214	$122,310
4.00	$134,465	$115,562	$125,992
4.50	$139,587	$118,909	$129,674
5.00	$144,710	$122,256	$133,356



Commercial-Industrial Damages

Damage per square metre in Nov 2014 dollars

Depth (m)	Commercial Low WS-C-low	Commercial Medium WS-C-med	Commercial High WS-C-high	Industrial Low WS-I-low	Industrial Medium WS-I-med	Industrial High WS-I-high
-999	0	0	0	0	0	0
0.1	$106	$187	$399	$106	$187	$852
0.2	$106	$187	$399	$106	$187	$852
0.3	$125	$248	$533	$138	$257	$941
0.5	$159	$373	$799	$200	$399	$1,118
0.6	$171	$404	$885	$216	$458	$1,193
0.75	$187	$453	$1,012	$240	$546	$1,305
1	$213	$492	$1,132	$267	$653	$1,491
1.5	$253	$519	$1,293	$293	$746	$1,811
2	$267	$546	$1,438	$320	$825	$2,104