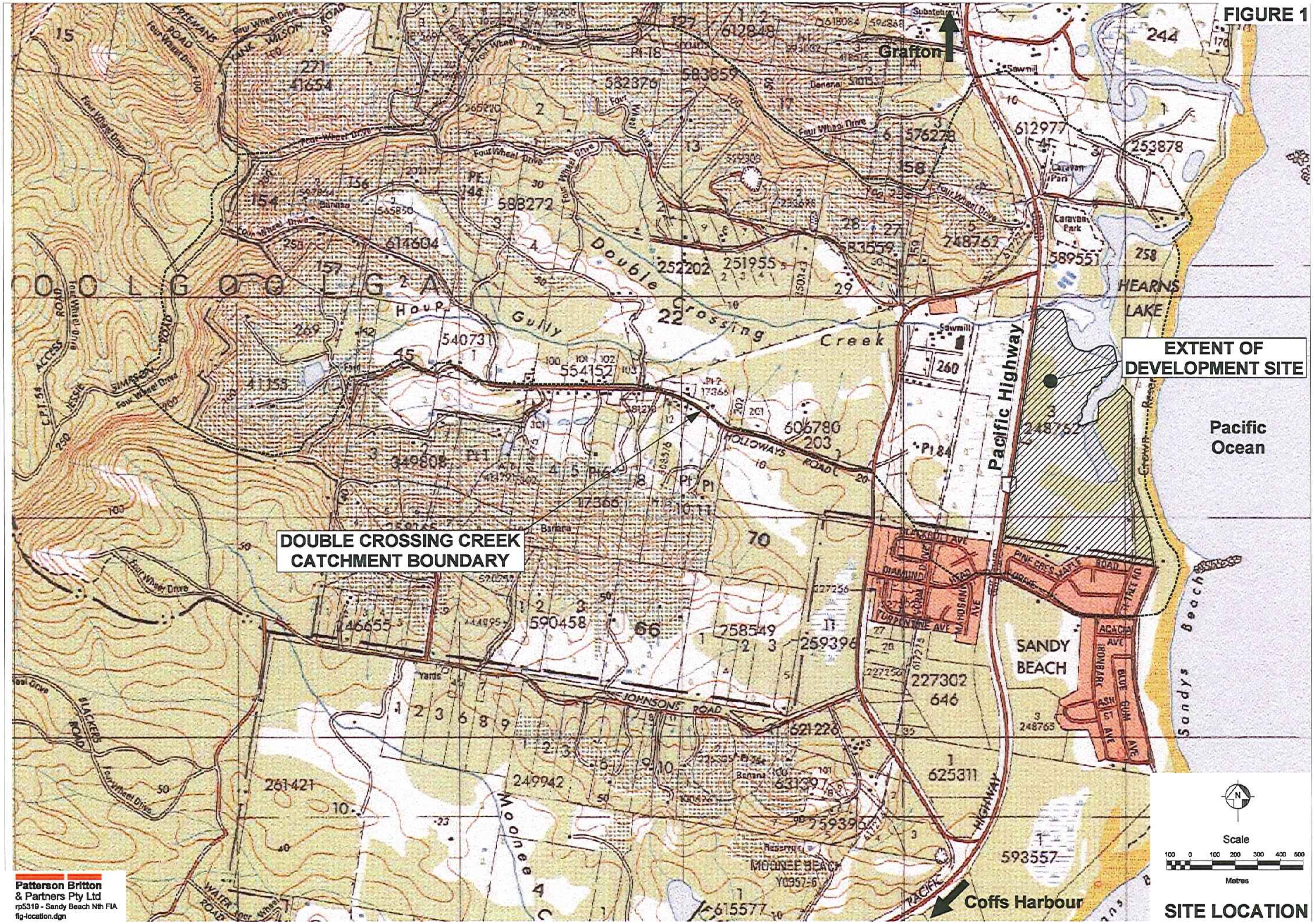
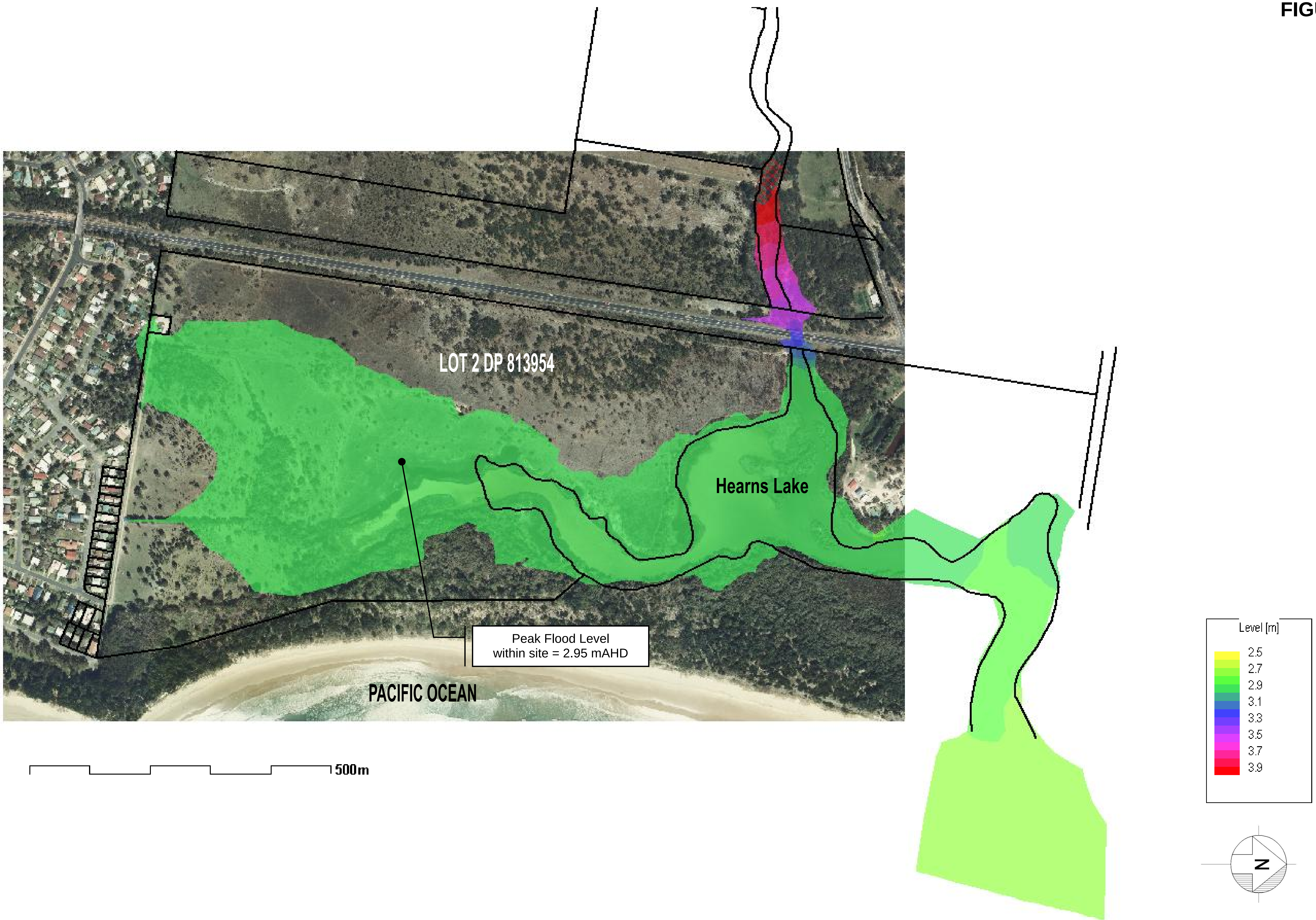


FIGURE 1
Grafton
EXTENT OF DEVELOPMENT SITE
Pacific Ocean
HEARNS LAKE
Pacific Highway
Double Crossing Creek
DOUBLE CROSSING CREEK CATCHMENT BOUNDARY
SANDY BEACH
Sandys Beach
JOHNSONS ROAD
HOLLOWAYS ROAD
MOONEE BEACH
Coffs Harbour
PACIFIC HIGHWAY
Scale
100 0 100 200 300 400 500
Metres
SITE LOCATION
Patterson Britton & Partners Pty Ltd
rp5319 - Sandy Beach Nth FIA
fig-location.dgn



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Rp5319 - Sandy Beach North FIA
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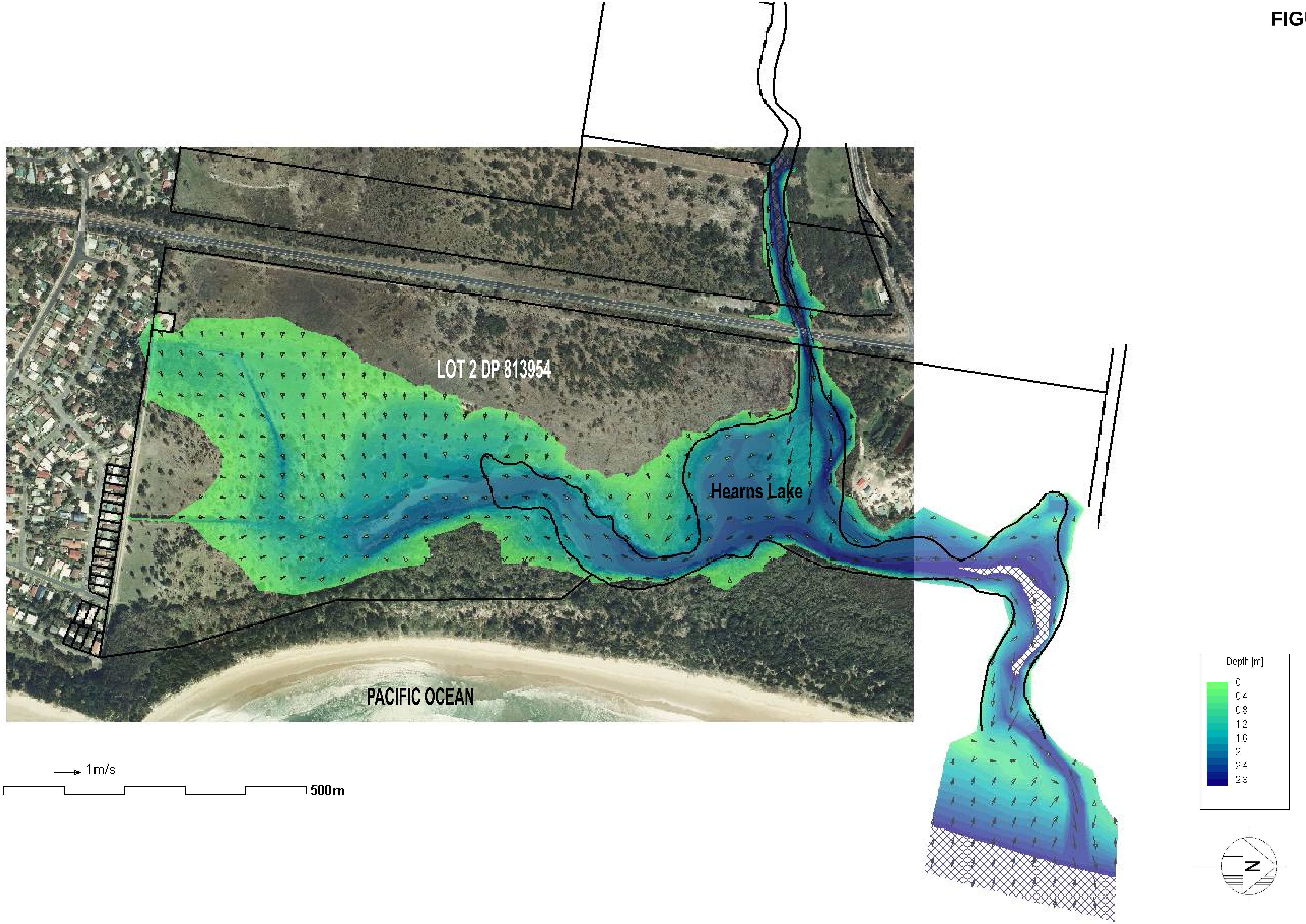
PREDICTED FLOOD LEVEL AT THE PEAK OF THE 100 YEAR RECURRENCE FLOOD WITH PROVISION FOR CLIMATE CHANGE



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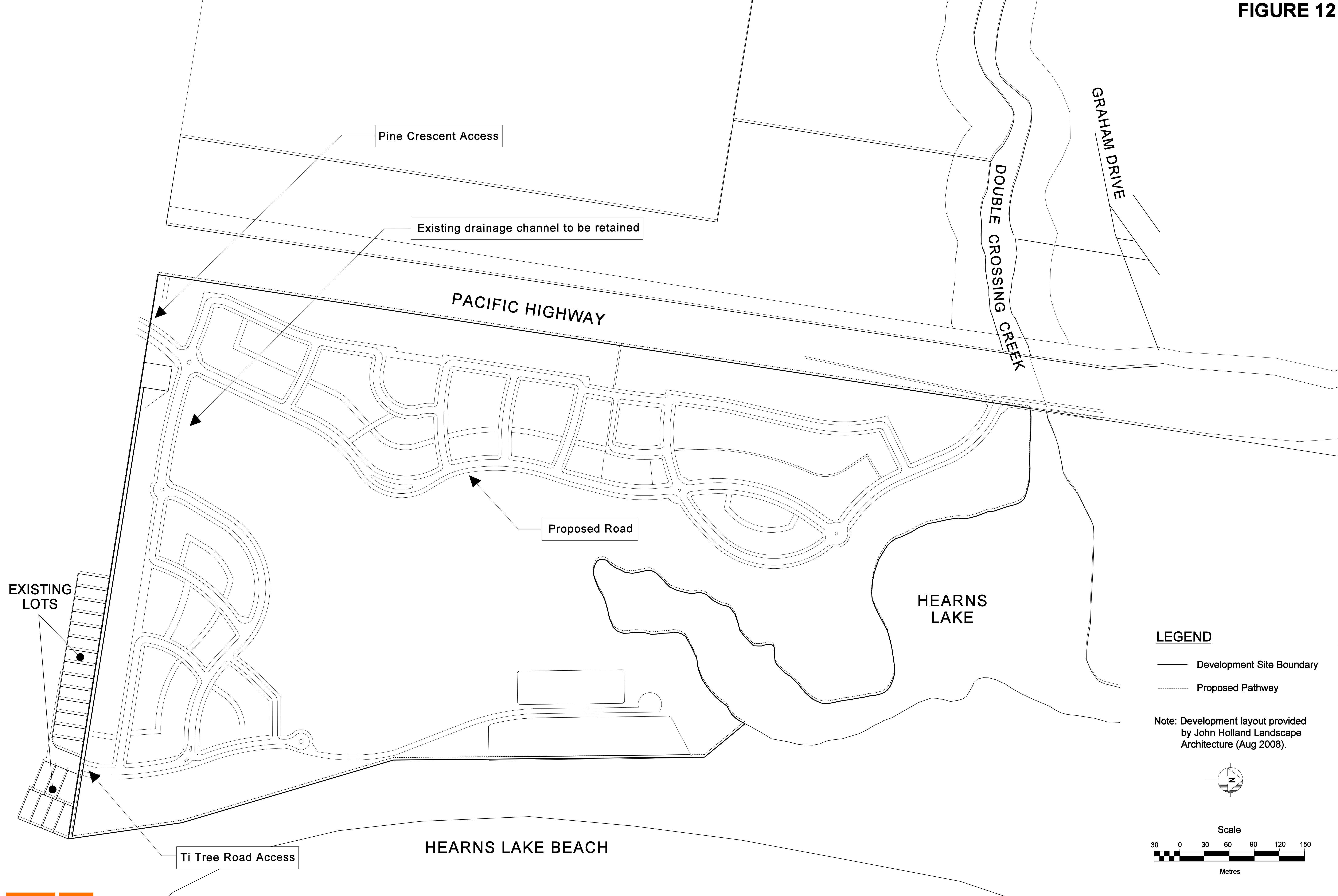
Rp5319 - Sandy Beach North FIA
Fg5319.00rg080909_fig11-Depth&VelocityClimCh.doc

VARIATION IN DEPTH AND VELOCITY OF FLOODWATERS AT THE PEAK OF THE 100 YEAR RECURRENCE FLOOD WITH PROVISION FOR CLIMATE CHANGE

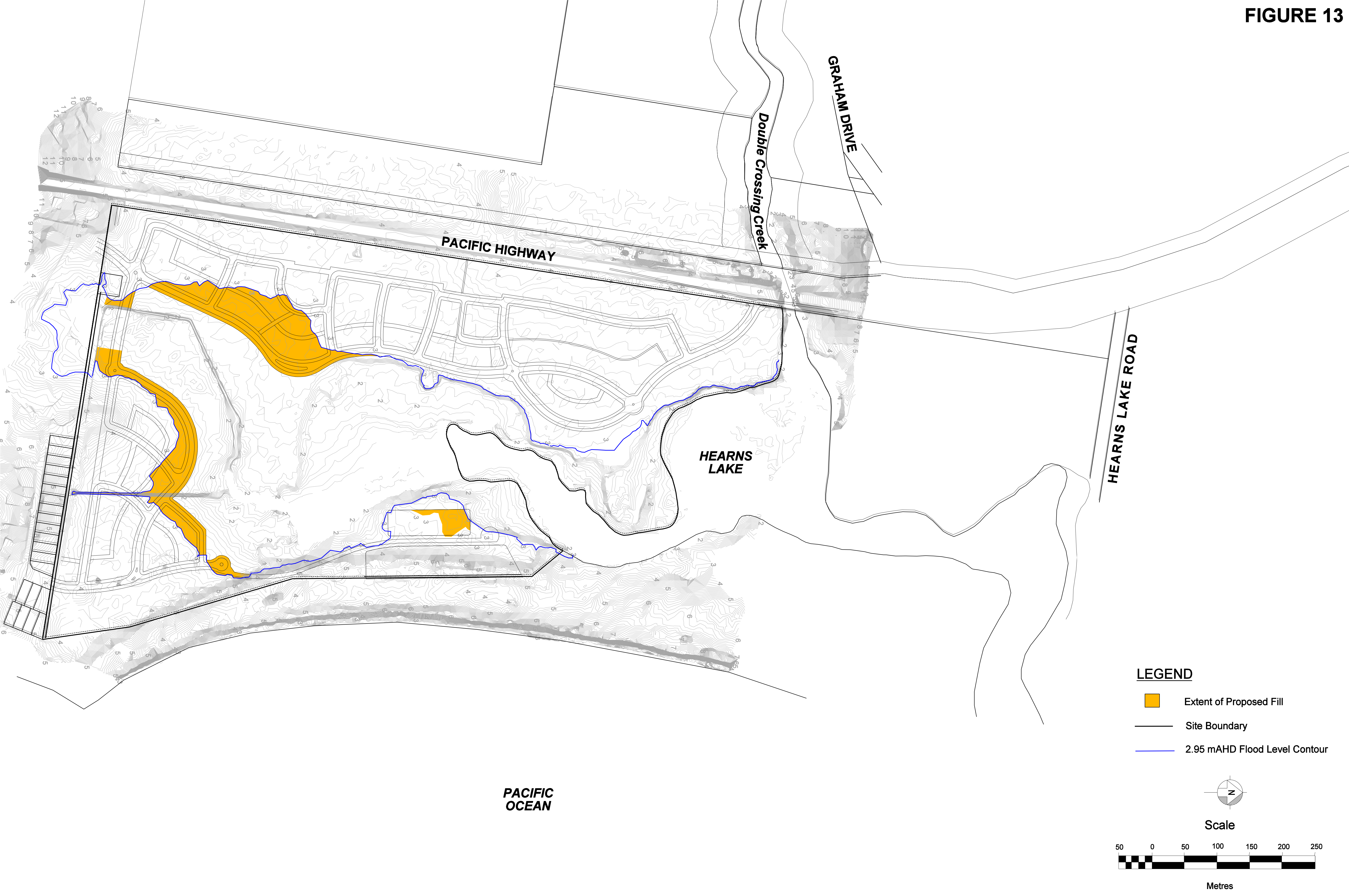
FIGURE 12



Patterson Britton & Partners Pty Ltd
rp5319_00 - Sandy Beach North FIA
fig12-site_layout_latest_rg.dgn

LAYOUT OF THE PROPOSED DEVELOPMENT

FIGURE 13



Patterson Britton & Partners Pty Ltd
rp5319_00 - Sandy Beach North FIA
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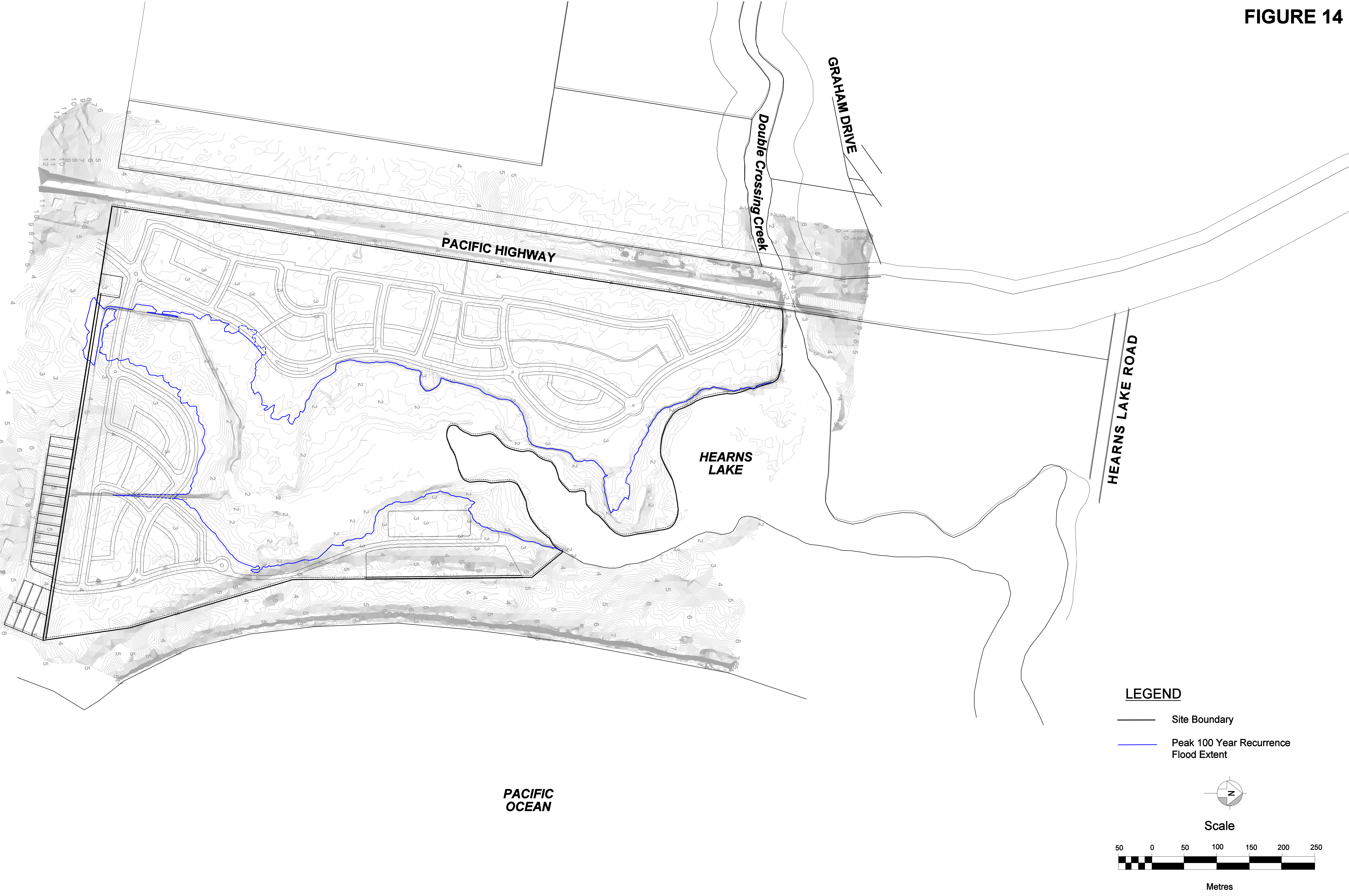
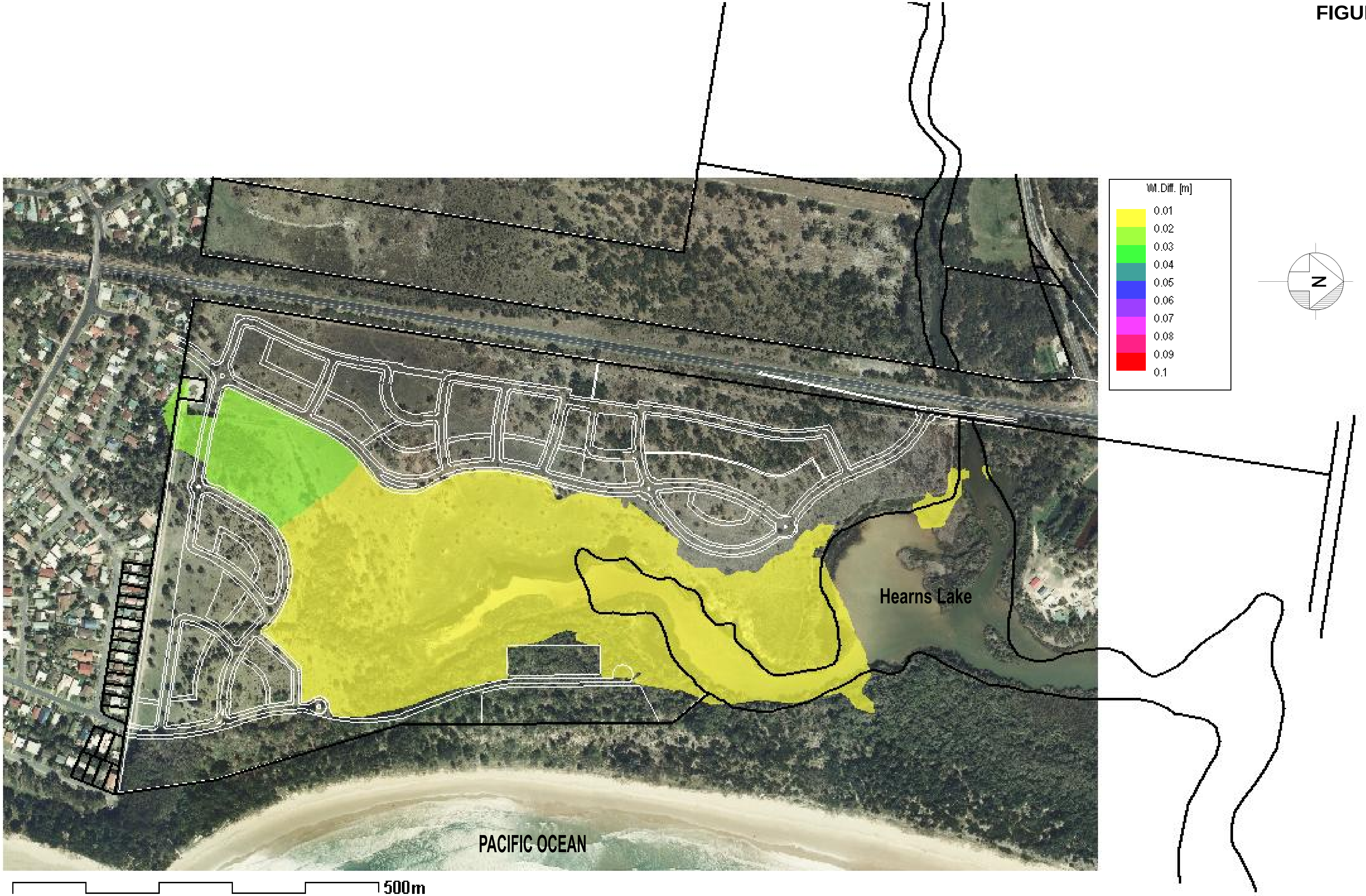
APPROXIMATE EXTENT OF PROPOSED FILLING

FIGURE 14



Patterson Britton & Partners Pty Ltd
rp5319_00 - Sandy Beach North FIA
fig14-100yr_fill_reqd.dgn

PEAK 100 YEAR RECURRENCE FLOOD EXTENT WITH PROPOSED DEVELOPMENT



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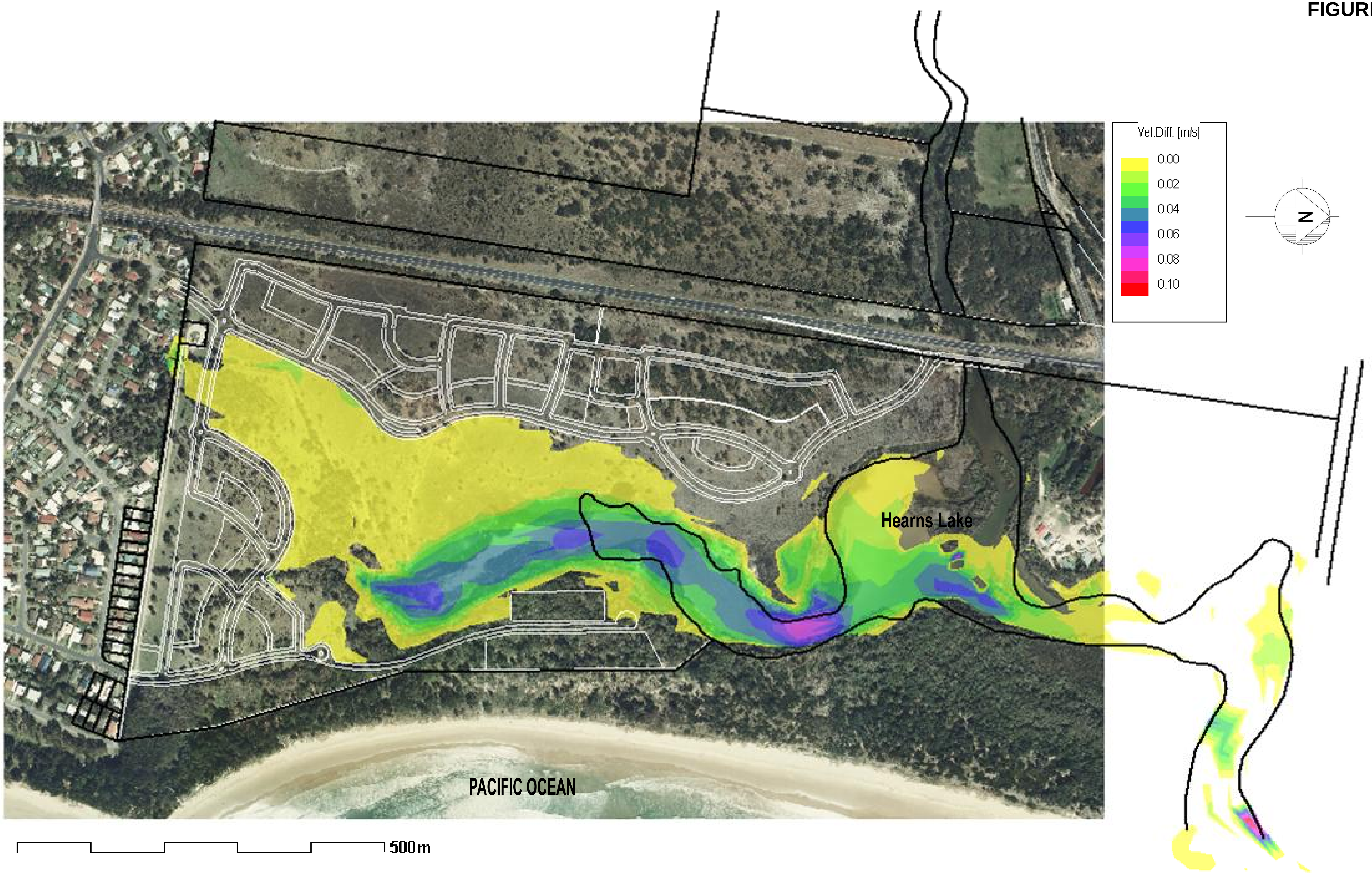
PREDICTED INCREASE IN PEAK "YEAR 2100" DESIGN 100 YEAR RECURRENCE FLOOD LEVELS AFTER FILLING



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Rp5319 - Sandy Beach North FIA
Fg5319.00rg080903_fig16_ClimCh Velocity Diff.doc

PREDICTED INCREASE IN PEAK "YEAR 2100"
DESIGN 100 YEAR RECURRENCE FLOOD
FLOW VELOCITIES AFTER FILLING

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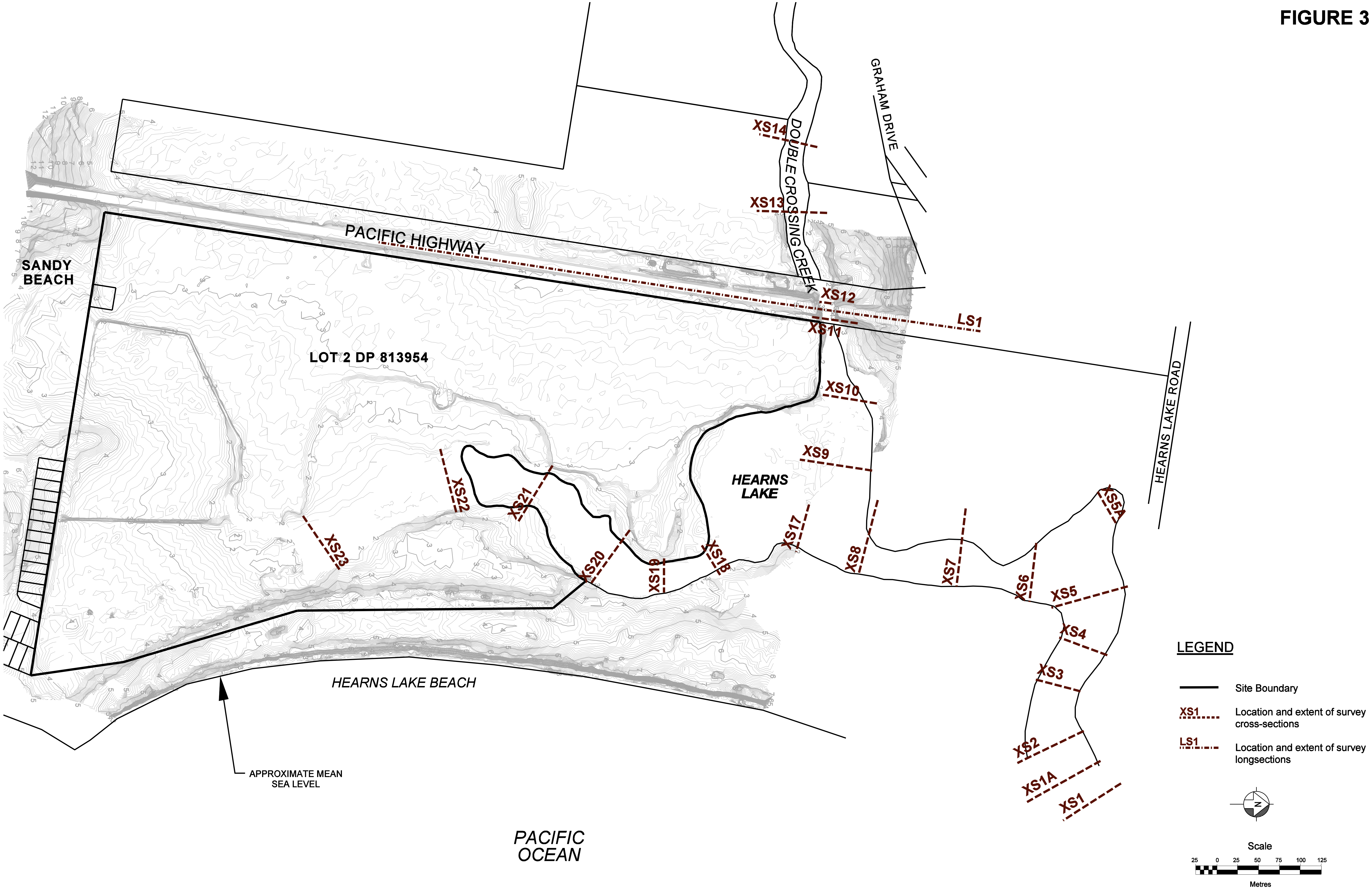
fig2-site_topography.dgn

EXISTING SITE TOPOGRAPHY

FIGURE 3



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rp5319 - Sandy Beach Nth FIA
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LOCATION AND EXTENT OF SURVEY CROSS-SECTIONS

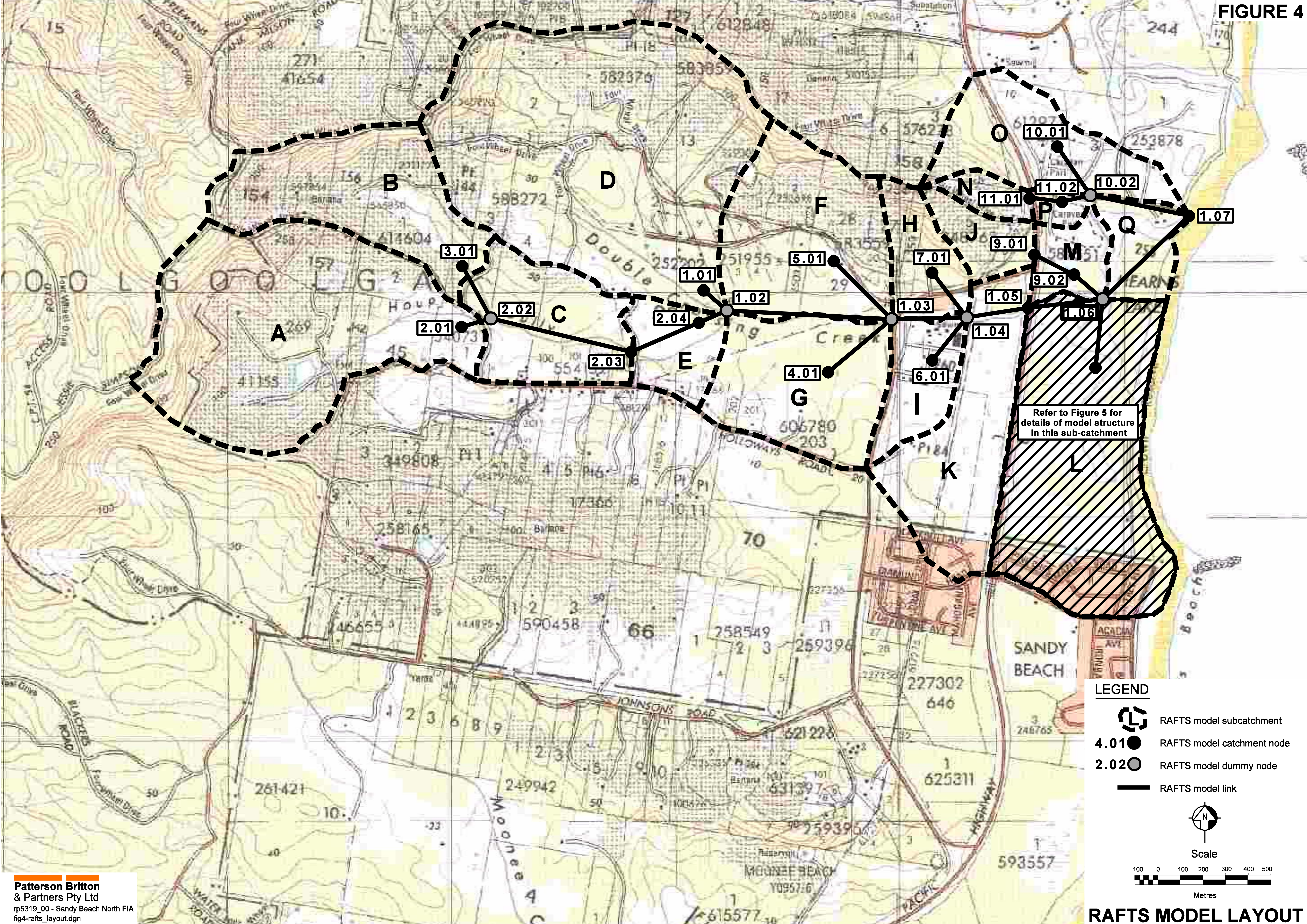

FIGURE 4

RAFTS MODEL LAYOUT

FIGURE 5

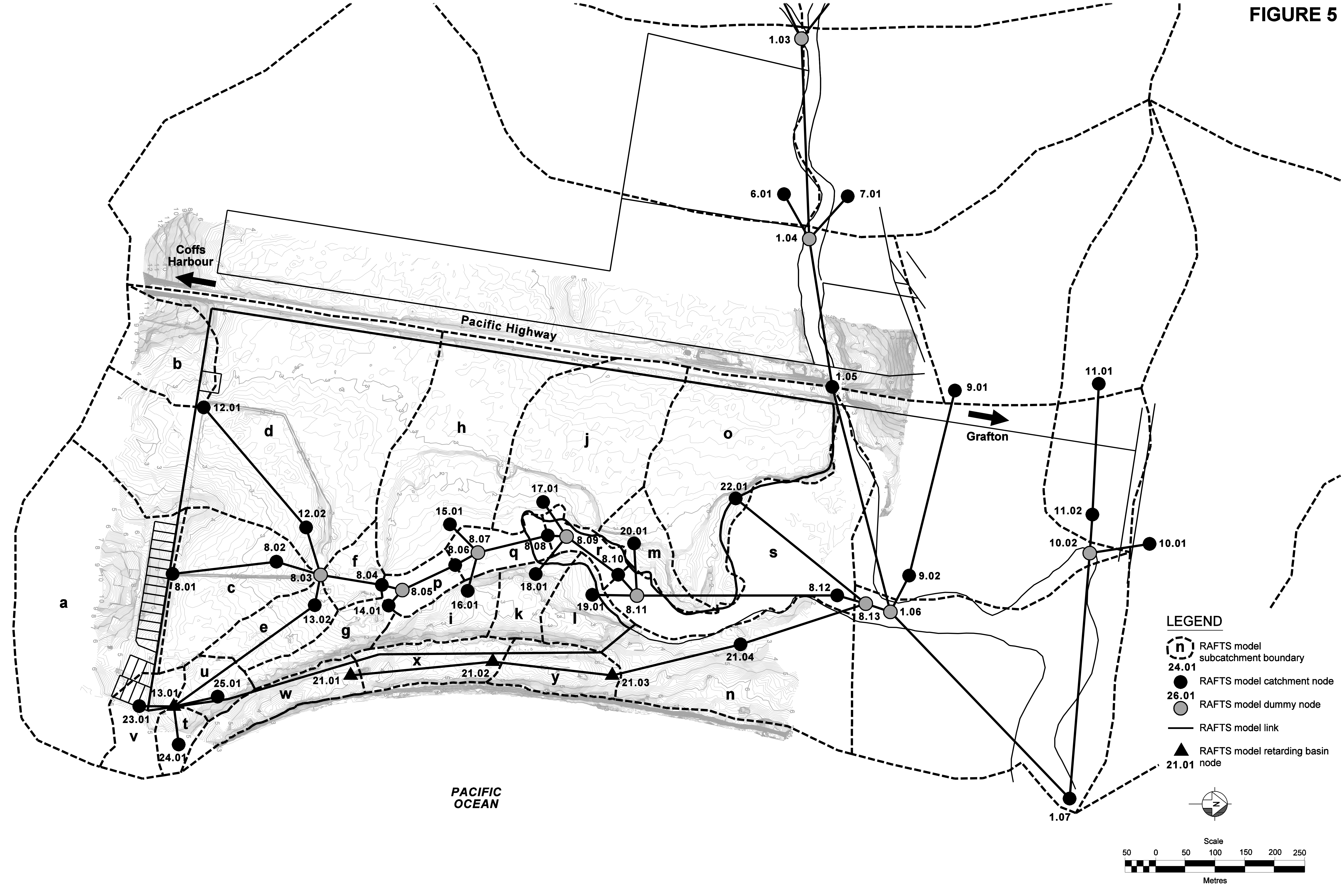

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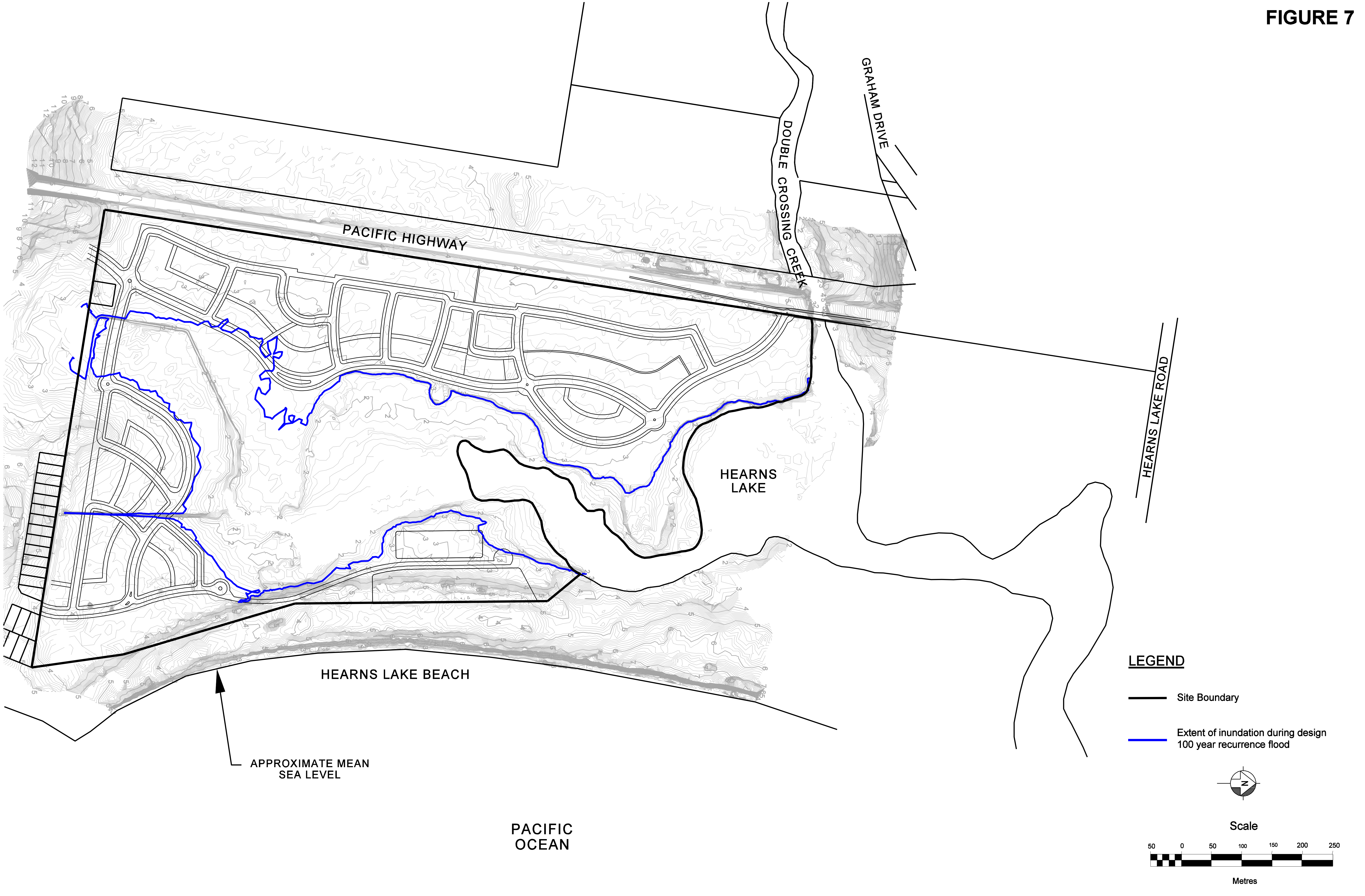
fig5-site_rafts.dgn

RAFTS MODEL LAYOUT IN THE VICNITY OF THE DEVELOPMENT SITE

FIGURE 6

Patterson Britton & Partners Pty Ltd
rp5319_00 - Sandy Beach North FIA
fig6-network_rg.dgn

RMA-2 MODEL NETWORK



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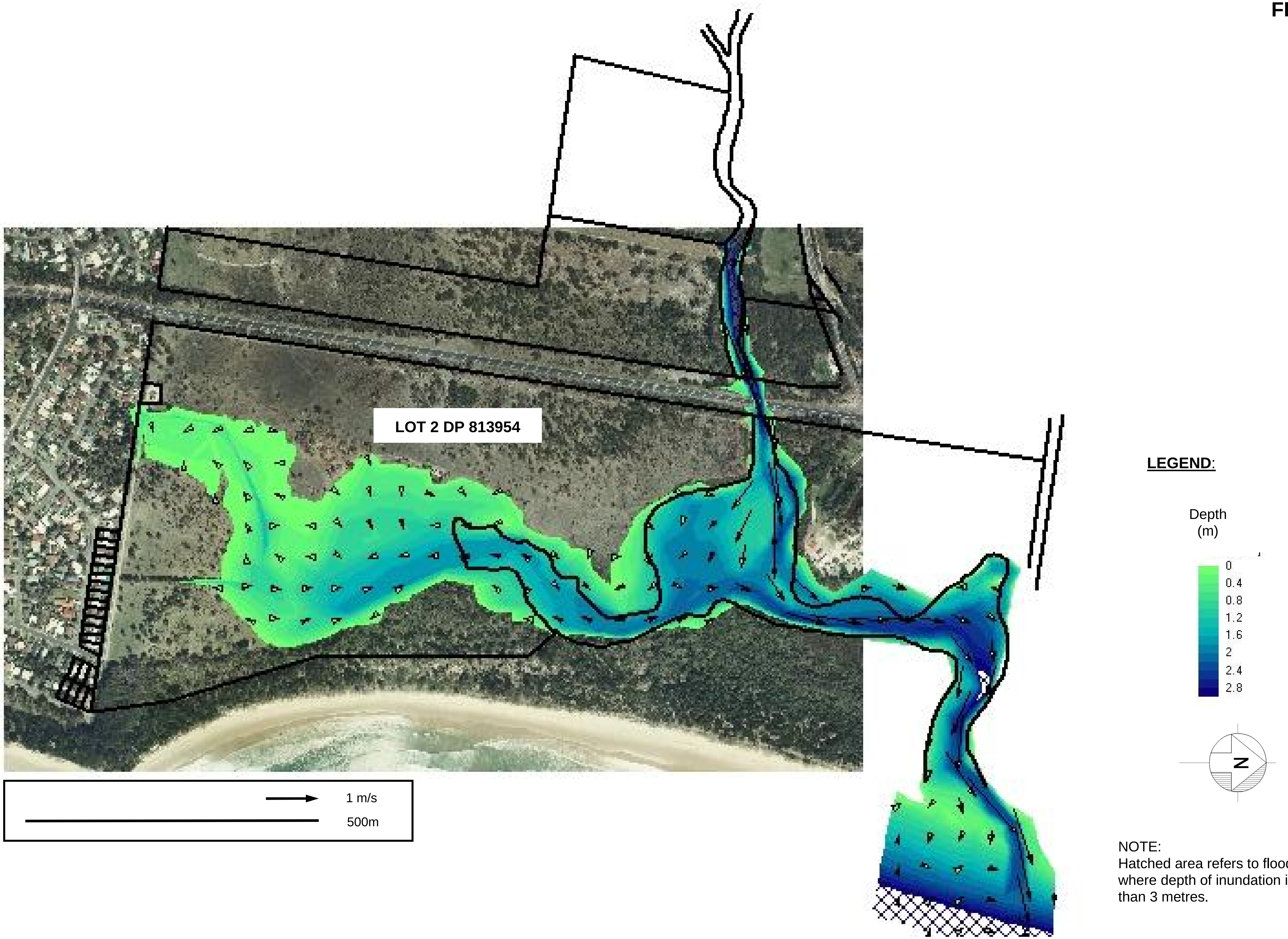
rp5319_00 - Sandy Beach North FIA
fig7-extent_rg.dgn

EXTENT OF INUNDATION DURING DESIGN 100 YEAR RECURRENCE FLOOD

FIGURE 8



NOTE:
Hatched area refers to flooded areas where depth of inundation is greater than 3 metres.

VARIATION IN DEPTH AND VELOCITY OF FLOODWATERS AT THE PEAK OF THE DESIGN 100 YEAR RECURRENCE FLOOD

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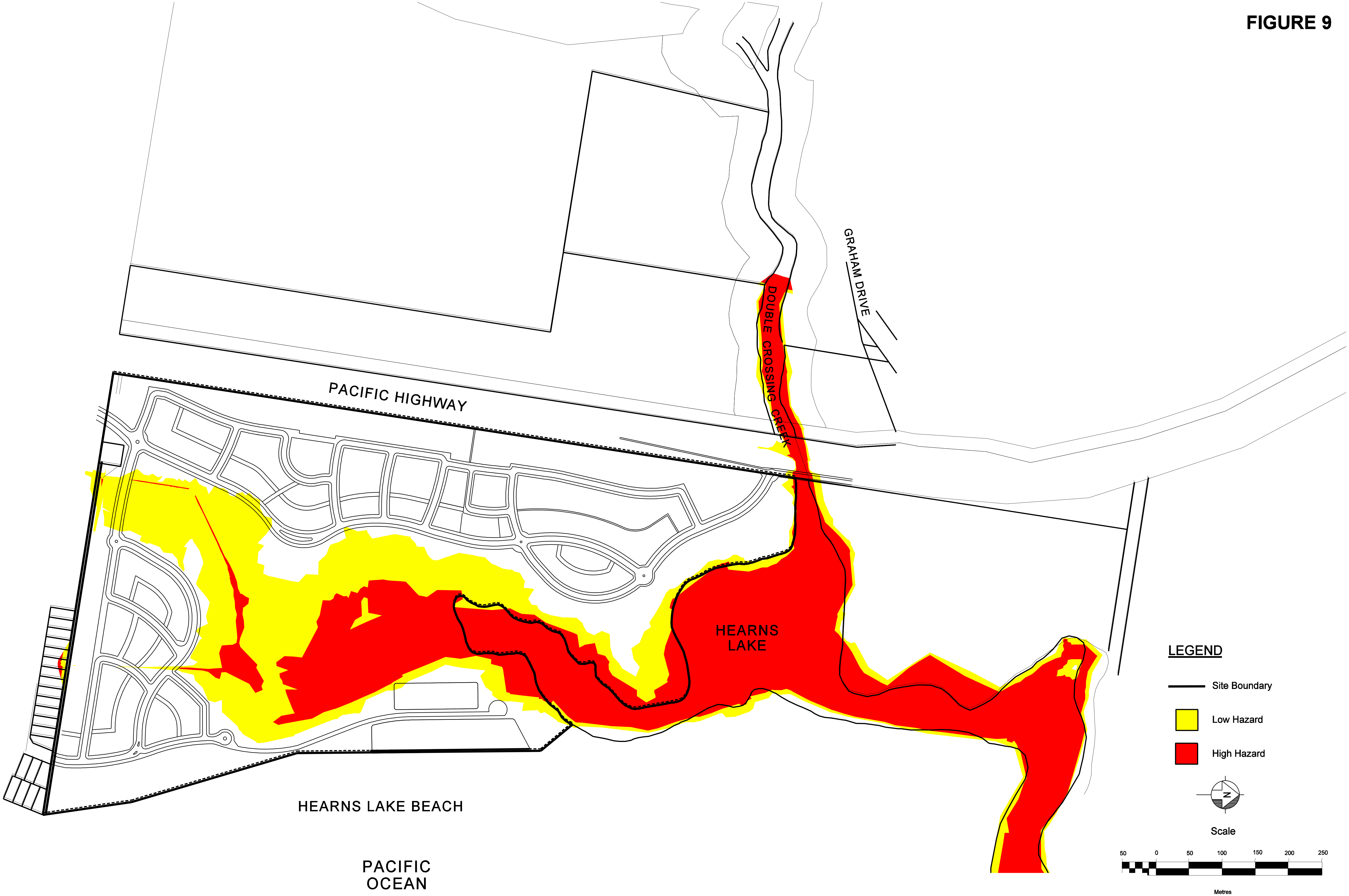
rp5319_00 - Sandy Beach North FIA
fig8-depth.dgn



PROVISIONAL FLOOD HAZARD CALSSIFICATION FOR THE DESIGN 100 YEAR RECURRENCE FLOOD

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rp5319_00 - Sandy Beach North FIA
fig9-hazard_rg.dgn

SANDY SHORES DEVELOPMENT PTY LTD

SANDY BEACH NORTH RESIDENTIAL DEVELOPMENT

FLOOD IMPACT ASSESSMENT

Issue No. 5
FEBRUARY 2009

WorleyParsons
resources & energy

Patterson Britton
& Partners Pty Ltd
consulting engineers

SANDY SHORES DEVELOPMENT PTY LTD

SANDY BEACH NORTH RESIDENTIAL DEVELOPMENT

FLOOD IMPACT ASSESSMENT

Issue No. 5
FEBRUARY 2009

Document Amendment and Approval Record

Issue	Description of Amendment	Prepared by [date]	Verified by [date]	Approved by [date]
1	Draft Report - Issued for Client Review	JMH (*21/4/04*))		
2	Final Draft Report	JMH/CRT (*24/1/05*)	CRT (*31/1/05*)	
3	Final Report	CRT (*18/10/05*)	BMD [*20/10/05*]	CRT [*2/11/05*]
4	Amended to incorporate revised development layout and to address climate change issues	CRT/WJH [10/10/08]		Chris Thomas [31/10/08]
5	Amended Final Report to address editorial comments raised in DoP letter dated 4/2/09	CRT [22/2/09]		Chris Thomas [22/2/09]

Note: This document is preliminary unless it is approved by a principal of Patterson Britton & Partners.

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TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Sandy Shores Development Pty Ltd (*Sandy Shores*) plans to develop a 49 hectare (*ha*) parcel of land near Sandy Beach on the North Coast of New South Wales. The site is located adjacent to the Pacific Highway, about 20 kilometres north of Coffs Harbour. It is referred to as Lot 22 in DP 1070182 and adjoins the northern boundary of the existing residential area of Sandy Beach. As shown in **Figure 1**, the site also adjoins the southern shoreline of Hearns Lake and extends to the rear of the back beach dune along Hearns Lake Beach.

Hearns Lake is an Intermittently Closed and Open Lake or Lagoon (*ICOLL*) which drains to the ocean at the northern end of Hearns Lake Beach. An oblique aerial view of the lake showing the ocean entrance in its partially 'closed' state is shown overleaf in **Plate 1**. The lake has a surface area of about 15 hectares and is fed by catchment runoff that is discharged to the lake via Double Crossing Creek (*refer* **Figure 1**). The lake is usually closed to the ocean but opens following significant rainfall in the catchment.

The development site extends around the southern shoreline of Hearns Lake and comprises coastal heath that is currently used for grazing and which has previously been mined for rutile. Sandy Shores plans to develop the land and create up to 280 residential lots within an integrated landscape comprising a balanced mix of open space, leafy streetscapes and gardens, and set within a restored coastal landscape.

As shown in **Figure 2**, Double Crossing Creek and Hearns Lake form the northern boundary of the site. Double Crossing Creek drains a 526 ha catchment that extends to the west of the Pacific Highway and discharges into Hearns Lake.

During major storms, there is potential for floodwaters to overtop the banks of Double Crossing Creek and Hearns Lake, and inundate low lying areas of the development site. The potential for inundation varies as a function of one or a combination of the following:

- the frequency of the storm that causes flooding of Double Crossing Creek;
- the entrance conditions at the mouth of Hearns Lake; and,
- the ocean water level at the time of catchment flooding.

Coffs Harbour City Council's *Flood Policy* is outlined in a document titled, *'Potentially Flood Prone Land Information Sheet'* (*October 2002*). This is available from Council's website and indicates that each of the floodplains within the local government area can be divided based on differing levels of flood hazard. Low, medium and high Flood Risk Precincts have been determined for the floodplain of Coffs Creek. However, Flood Risk Precincts have not been defined for other areas within the LGA.

Notwithstanding, the Information Sheet indicates that, in the interim, the controls specified for the Coffs Creek floodplain should be applied elsewhere within the LGA.

Plate 1 OBLIQUE AERIAL VIEW OF HEARNS LAKE SHOWING THE PARTIALLY CLOSED OCEAN ENTRANCE AND EXTENT OF THE DEVELOPMENT SITE.

Therefore, based on the Policy, residential dwellings can only be constructed on land that has a low or medium flood risk. In addition, all habitable rooms must be constructed with floor levels that are a minimum of 500 mm above the predicted peak 100 year recurrence flood level.

Accordingly, Sandy Shores engaged Patterson Britton & Partners (*now WorleyParsons*) to undertake the necessary investigations required to determine the 100 year recurrence flood level at the site and to identify the associated flood extent.

Sandy Shores also plans to fill selected areas of the development site that are subject to Low Flood Risk and thereby increase the area of land that is available for dwelling construction. Filling of the site will effectively eliminate the potential for inundation from floodwaters that would currently overtop the banks of Hearns Lake and Double Crossing Creek. It would therefore reduce the flood risk and allow development in accordance with Council's *Flood Policy*.

However, the proposed filling will also remove a proportion of the flood storage currently afforded by the low lying areas that adjoin the lake. Therefore, the proposed development has the potential to increase peak flood levels and could adversely impact on adjacent properties.

Accordingly, Sandy Shores requested that Patterson Britton & Partners investigate the potential for the proposed filling to adversely impact on flood behaviour and to determine the optimal fill for areas of the site proposed for development.

The results of these investigations were documented in an earlier version of this report (*Issue No.3, November 2005*). The previous report was incorporated into an Environmental Assessment Report (*EA*) for the residential development that is proposed for the site. The EA was prepared to address the requirements of the Director General of the NSW Department of Planning which were issued on 20th October 2006.

In March 2008, the Department of Planning issued a Supplementary Director-General's Requirement. The supplementary DGR is referred to as Item 7.7 and states that:

> A risk management assessment of climate change impacts to the year 2100 is to be undertaken using the latest available information from the International Panel on Climate Change (*IPCC*), the Department of Environment and Climate Change (*DECC*) and the CSIRO. This should include sensitivity analyses for low level, mid range and high level ocean impacts as set out in the DECC Floodplain Risk Management Guideline titled *'Practical Consideration of Climate Change'*.

In recognition of this, Sandy Shores requested that additional investigations be undertaken to address the Supplementary DGR. The results of these additional investigations are documented in a report prepared by Patterson Britton & Partners (*now a part of WorleyParsons*) titled, *'Climate Change Assessment for Proposed Development at Sandy Beach North'* (*Issue No.3, February 2009*).

The key findings from that report are documented in **Section 4**. They indicate that the peak 100 year recurrence flood level at Hearns Lake could increase by up to 350 mm by the Year 2100 due to climate change impacts.

Accordingly, the proposed Sandy Shores development has been modified to incorporate a design layout and fill scenario based on the adoption of a Year 2100 design 100 year recurrence flood level that incorporates the projected increase in peak flood level due to climate change.

The following report is based on the Flood Impact Assessment that was prepared in 2005, but incorporates the findings of additional modelling to assess the potential for the revised development layout and site filling to adversely impact on flood behaviour.

2 PREVIOUS INVESTIGATIONS

A previous investigation into the potential for flooding of Hearns Lake and Double Crossing Creek was undertaken in 1982 by Antony Tod & Partners (Mid North Coast) Pty Ltd. The investigation led to the production of a flood study which was incorporated within a local environmental study for the area. The flood study is documented in a report titled, *'Hearns Lake / Double Crossing Creek Local Environment Study – Flood Investigation and Report on Water Supply, Sewerage and Water Pollution'* (*1982*).

The study area for the investigation was bound by the village of Sandy Beach to the south, the sand dunes to the east, Graham Drive (*referred to in the report as the 'Old Pacific Highway'*) and Flat Top Point. This area includes the Sandy Beach North development site.

A hydrologic analysis was undertaken as part of the investigation to determine peak design flows for the Double Crossing Creek / Hearns Lake system for the 20 and 100 year recurrence design storm events. The analysis was based on the Cordery Webb Method which was used to derive unit hydrographs and subsequent design flood hydrographs at the Graham Drive and Pacific Highway crossings of Double Crossing Creek. The peak flow at the Pacific Highway Crossing was determined to be 67 m^3/s and 92 m^3/s for the 20 and 100 year recurrence floods, respectively.

A hydraulic model of Double Crossing Creek was also developed using the HEC-2 software package. The model was based on cross-sections of Double Crossing Creek and extended along the lower reaches of the creek from the Graham Drive crossing to the ocean entrance. Ocean levels at the mouth of Hearns Lake were adopted as the downstream boundary conditions for the hydraulic model. Ocean levels of 1.8 and 2.4 mAHD were used for the 20 and 100 year recurrence catchment events, respectively.

The hydrologic and hydraulic models were used to estimate peak flood levels within Hearns Lake. The 20 and 100 year recurrence flood levels were determined to be 2.2 and 2.6 mAHD, respectively.

The results of the modelling indicated that flooding due to a design 100 year recurrence storm over the catchment would generally be limited to the creek channel. Notwithstanding, some minor inundation was predicted in low lying overbank areas around Hearns Lake.

However, the hydrologic analysis was based on rainfall data that pre-dates the 2nd edition of *'Australian Rainfall & Runoff – A Guide to Flood Estimation'*. This document was published in 1987 and outlines procedures for flood estimation and defines design rainfall intensities across Australia. It replaced the 1st edition which was published in 1977.

The design rainfall intensities published in *Australian Rainfall & Runoff* are based on extensive recorded rainfall data. The additional data gathered over the 10 years between the 1st and 2nd editions indicated a general trend for design rainfall intensities across eastern Australia to be higher than those published in 1977. As a result, the application of procedures outlined in the 2nd edition typically results in higher design rainfall intensities than for the 1st edition.

Therefore, the Antony Tod & Partners report is based on hydrologic analysis that used design rainfall intensity data that is outdated.

More importantly, as design rainfall intensities have increased, it was considered that the Antony Tod & Partners Report is likely to underestimate peak flood discharges entering Hearns Lake. Accordingly, it is considered appropriate to revisit the catchment hydrology to establish peak design flood levels for the lake.

3 ASSESSMENT OF EXISTING FLOOD BEHAVIOUR

3.1 DESCRIPTION OF THE EXISTING DEVELOPMENT SITE

The development site is located on the eastern side of the Pacific Highway about 3 kilometres south of the North Coast town of Woolgoolga (*refer* **Figure 1**). It is situated immediately north of the village of Sandy Beach and covers all of the land between the Pacific Highway and Hearns Lake Beach. As shown in **Figure 2**, the southern shoreline of Hearns Lake effectively forms the northern boundary of the site.

Hearns Lake is an Intermittently Closed and Open Lake or Lagoon (*ICOLL*) which drains to the ocean at the northern end of Hearns Lake Beach (*refer* **Plate 1** *on page 2*). The lake has a surface area of about 15 hectares and is fed by catchment runoff that is discharged to the lake via Double Crossing Creek (*refer* **Figure 1**).

The development site has a total area of 49 ha. It's current zoning varies and includes areas zoned 2A Residential (*low density*), 2E Tourist, 7A Environmental Protection Habitat and Catchments, and 7B Environmental Protection / Scenic Buffer.

The existing vegetation across the site varies from open pasture to more densely vegetated creek and lake shorelines. There is also a corridor of dense vegetation that extends along the back of the dune system that adjoins Hearns Lake Beach.

Consulting Surveyors, Asquith & de Witt Pty Ltd, have developed a contour plan of the site based on detailed photogrammetric survey. The contour plan is presented as **Figure 2** and shows contours of natural surface at 0.1 metre intervals. Interpretation of these contours indicates that the existing surface elevation across the development site varies between 0.8 mAHD near the Hearns Lake shoreline to 6 mAHD along the rear of the dunes that adjoin the eastern boundary of the site (*refer* **Figure 2**).

The western portion of the site can be characterised as a sparsely vegetated coastal plain. The land in this area has a typical grade of less than 1% and generally slopes from the Pacific Highway toward Hearns Lake.

The southern area of the site is steeper but only rises to an elevation of about 5.5 mAHD. This area drains to two open channels that flow in a northerly direction and discharge runoff to Hearns Lake. These channels are man made and are understood to have been constructed in the 1980s.

Hydrographic survey of Hearns Lake and Double Crossing Creek was also undertaken by Asquith & de Witt. The location and extent of the surveyed cross-sections are shown in **Figure 3**. Based on this survey, the top-of-bank elevation of Hearns Lake is estimated to be 1.3 mAHD. The data shows that at the time of the survey in June 2004, the lake had a water level of 1.35 mAHD.

3.2 HYDROLOGIC ANALYSIS

3.2.1 Catchment Description

The catchment draining to Hearns Lake is shown in **Figure 1**. It has an area of 650 ha and extends about 6 kilometres west from the coast to Jessie Simpson Drive. The catchment rises to an elevation of over 230 metres above sea level and is characterised by steeply sloping valley walls in the upper half which give way to a flat valley floor that extends to an estuarine floodplain. The steeper western half of the catchment comprises extensive areas of banana plantations. These areas are typically at grades of 1 (V) in 3 (H).

The catchment is drained by two major watercourses that join approximately midway through the catchment near the 10 metre contour. Houp Gully is the smaller of these tributaries and drains the southern half of the catchment. It flows in an easterly direction from the downstream side of a farm dam that services one of the banana plantations.

Houp Gully is joined by a smaller creek that drains a small sub catchment that extends to the north-western corner of the valley.

Double Crossing Creek is the major tributary in the catchment. It primarily drains the northern section, but as discussed above is joined midway through the catchment by Houp Gully. Below its confluence with Houp Gully, Double Crossing Creek runs across a flat coastal plain before discharging into Hearns Lake just below the Pacific Highway. Between the Houp Gully confluence and Hearns Lake, Double Crossing Creek is crossed by Graham Drive and the Pacific Highway.

Hearns Lake is situated behind the coastal dunes along Hearns Lake Beach. It is orientated approximately north-south and receives runoff from a number of minor tributaries in addition to the larger catchment flows from Double Crossing Creek. Under normal conditions, the entrance to Hearns Lake is closed, being effectively “blocked” by the beach berm.

As shown in **Figure 1**, the development site is situated east of the Pacific Highway and adjoins the southern shoreline of Hearns Lake.

3.2.2 Hydrologic Model Development

The Runoff Analysis and Flow Training Simulation (*RAFTS-XP*) software was employed to develop a hydrologic model of the Double Crossing Creek catchment. The RAFTS model was used to analyse runoff processes and determine an estimate of the peak flow at the development site for the 20 and 100 year recurrence floods.

RAFTS-XP is a deterministic runoff routing model that simulates catchment runoff processes. It is recognised in *‘Australian Rainfall and Runoff – A Guideline to Flood Estimation’* (*1987*) as one of the available tools for use in flood routing within Australian catchments. Importantly, it can account for the impact of urban development and therefore provides a more reliable estimate of peak discharge than does the more empirical Probabilistic Rational Method.

The RAFTS model was developed using the physical characteristics of the catchment including catchment area, slope, percentage impervious area and extent of vegetation cover.

The catchment was delineated using contours provided in 1:25000 series topographic mapping and the available 1:4000 series orthophoto mapping covering the lower reaches of the catchment. Sub catchment boundaries were determined based on the local topography, alignment of roads and four wheel drive tracks, the position of hydraulic controls such as bridges, and the locations of major creek confluences.

Seventeen sub catchments were identified as contributing inflow into Hearns Lake. These sub catchments and the adopted node and link arrangement for the RAFTS model are shown in **Figure 4**.

Catchment L was further subdivided into 25 smaller sub catchments to enable a detailed assessment of drainage behaviour through the development site. Sub catchments across the site were defined using 0.1 metre contours obtained from the detailed photogrammetric survey undertaken over the site area.

The sub catchments and the RAFTS model layout in the vicinity of the development site are shown in **Figure 5**. A summary of adopted sub catchment parameters is enclosed in **Appendix A**.

Storm rainfall data for design events was generated by applying the principles of rainfall intensity estimation and design temporal distributions outlined in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (*1987*). These procedures were used to determine intensity-frequency-duration (*IFD*) data for the Hearns Lake catchment. A summary of the adopted IFD data is enclosed in **Appendix B**.

All standard storm events were analysed to determine the critical duration storm for the catchment. The critical storm duration was assumed to corresponds to the storm that results in the largest peak discharge at the ocean entrance.

The critical storm duration for all design events was determined to be 120 minutes.

3.2.3 Predicted Peak Discharges

The RAFTS model was used to simulate design 20 and 100 year recurrence storms across the catchment. Selected peak discharges generated from the RAFTS modelling are listed in **Table 1**. These correspond to model nodes located at or near the site (*refer* **Figures 4** *and* **5**). Output files from the RAFTS modelling are enclosed in **Appendix C**.

The Graham Drive and Pacific Highway bridge crossings correspond to RAFTS model nodes 1.03 and 1.05, respectively. The peak flows determined at these locations and the flows determined by Antony Tod & Partners (Mid North Coast) Pty Ltd for 1982 Flood Study are compared in **Table 2**.

Table 1 PEAK DISCHARGES IN THE VICINITY OF THE DEVELOPMENT SITE

RAFTS MODEL NODE (*refer Figures 4 and 5*)	PEAK DISCHARGE	
	20 Year Recurrence Flood (*m³/s*)	100 Year Recurrence Flood (*m³/s*)
1.03	92.7	123.1
1.04	93.9	124.9
1.05	97.0	129.4
8.13	15.9	21.5
1.06	102.2	136.6
1.07	103.5	138.4

Table 2 PEAK DISCHARGES AT GRAHAM DRIVE AND THE PACIFIC HIGHWAY

LOCATION	ANTONY TOD & PARTNERS		ADOPTED FOR THIS INVESTIGATION	
	20 Year Recurrence Flood (*m³/s*)	20 Year Recurrence Flood (*m³/s*)	20 Year Recurrence Flood (*m³/s*)	100 Year Recurrence Flood (*m³/s*)
Graham Drive	48	66	92.7	123.1
Pacific Highway	67	92	97.0	129.4

The comparison shows that the peak flows calculated for this study are significantly higher than those determined by Antony Tod & Partners.

As expected (*refer* **Section 2**), these differences can be attributed to the fact that the flows determined for the 1982 Flood Study were based on the data and methodologies outlined in 1977 edition of *Australian Rainfall & Runoff* (*i.e., the 1st edition*). Additional data was obtained over the following 10 years and has resulted in revised procedures and higher estimates of design rainfall intensities.

These procedures are presented in the 1987 and 1998 editions of *Australian Rainfall & Runoff* and have been adopted in the hydrologic analysis for this investigation.

3.3 HYDRAULIC ANALYSIS

3.3.1 Model Development

A two-dimensional hydrodynamic model was developed to define flood behaviour in the vicinity of the development site. The model was created using the RMA suite of software, and specifically using RMA-2.

RMA-2 is a finite element software package that employs a variable grid geometry in which elements with irregular and curved boundaries can be modified as required without the need for regeneration of the entire grid. This is particularly advantageous for assessing the impact of a development proposal involving filling, as the model can be easily modified to incorporate changes in model node elevations, thereby allowing the impact of the filling to be quantified.

The RMA-2 model that was developed for this investigation extends over all of the body of the Hearns Lake downstream to the ocean entrance at Hearns Lake Beach. It covers the entire development site and extends upstream along Double Crossing Creek to about 300 metres upstream of the Pacific Highway bridge crossing.

The final adopted RMA-2 model network is shown in **Figure 6**. This shows the density and location of finite elements that have been used to develop the model. Each element (*triangle or rectangle*) represents a lake bed or floodplain surface. As also shown in **Figure 6**, the finite element grid was aligned with the surveyed cross-sections of the lake bed.

The size and location of floodplain elements were determined based on the detail required to reliably represent critical hydraulic controls and the definition required in areas where filling is likely to be proposed within the development site. Ground surface elevations were assigned to corners of individual elements based on a digital terrain model derived from the detailed photogrammetric survey undertaken by Asquith & de Witt. The hydrographic survey was used to define the bathymetry of the bed of Hearns Lake, the ocean entrance and Double Crossing Creek.

3.3.2 Channel and Floodplain Roughness

Main channel and overbank roughness values were determined for the study area based on an analysis of aerial photography of the area and from field observations. The adopted roughness parameters were determined by comparing vegetation density and site characteristics with standard values for stream and floodplain conditions for which Manning's "n" values are documented in the literature.

Most of the development site has been cleared for grazing, although there are some areas of light scrub. There are also some small areas of dense vegetation in the southern section of the site and along the rear of the dune located along the eastern site boundary.

The roughness parameters adopted for the RMA-2 model of Hearns Lake are listed in **Table 3**.

Table 3 RMA-2 MODEL ROUGHNESS PARAMETERS

ELEMENT TYPE	DESCRIPTION	ROUGHNESS VALUE
1	Creek channel and lake bed	0.035
2	Grassed overbank areas with pockets of light scrub	0.040
3	Channel and lake banks with dense vegetation	0.100
4	Existing roadway areas	0.012
5	Bed of lake entrance and back beach berm (*sand*)	0.025

3.3.3 Hydraulic Model Boundary Conditions

Boundary conditions simulate the physical boundaries of the model area as well as model inflows and outflows throughout the duration of the flood simulation.

For a flood model, the upstream boundary conditions are typically defined by the catchment runoff that enters the area of interest for flood level estimation. Upstream boundary conditions are typically represented by flood hydrographs which are specified at the upstream end of the hydraulic model.

Downstream boundary conditions are typically defined by a time varying water level. In the case of an ocean entrance, this time varying water level reflects ocean water levels and accounts for tidal variation, storm surge (***barometric setup and wind setup***) and wave setup.

Adopted Upstream Boundary Conditions

Upstream boundary conditions for the RMA-2 model of Hearns Lake and Double Crossing Creek were based on flood discharge hydrographs generated from the RAFTS hydrologic modelling discussed in **Section 3**. Positive element inflows were also used to simulate runoff generated across the development site at points within the network.

The RAFTS model nodes that correspond to the adopted upstream limits of the model are shown in **Figures 4** and **5**. The peak discharges for the 20 and 100 year recurrence events at these nodes / points of inflow are listed in **Table 4**. These flows and the associated discharge hydrographs were adopted as the upstream boundary conditions for the hydraulic model.

Adopted Downstream Boundary Conditions

As discussed, Hearns Lake is an ICOLL, but would typically be open and discharge to the Pacific Ocean during or following flood conditions. Accordingly, peak flood levels within the development site could be influenced by ocean water levels, or alternatively, by the capacity for floodwaters to discharge through the entrance to the ocean.

Therefore, it is necessary to develop an understanding of the variation in ocean water levels that could arise at the time of a flood.

Table 4 UPSTREAM BOUNDARY CONDITIONS FOR RMA-2 MODEL

LOCATION	RAFTS MODEL NODE	PEAK DISCHARGE (m^3/s)	
		20 Year Recurrence Event	100 Year Recurrence Event
Double Crossing Creek about 300 m upstream of the Pacific Highway	1.05	97.1	129.4
Eastern Drainage Easement at Southern Boundary of the Development Site	12.01	1.1	1.4
Western Drainage Easement at Southern Boundary of the Development Site	8.01	4.7	6.0
Inflow at Depression at South-Eastern Corner of the Site	13.01	0.7	1.0
Inflow at Hearns Lake	8.09	7.8	11.0
Inflow at Hearns Lake	8.13	4.2	5.8
Inflow at Hearns Lake	9.02	8.1	10.7
Inflow approx. 400 metres Upstream of Ocean Entrance	10.02	9.9	13.8

Flood producing storm cells generally produce increases in ocean levels, which are associated with a drop in atmospheric pressure. These storm cells can cause further increases in ocean levels through the combined impacts of wind and wave setup. Accordingly, the downstream boundary condition for the model has been defined by a sinusoidal tide curve that is representative of the combined effects of astronomical tide, storm surge and wave setup.

The peak ocean water levels used to develop the downstream boundary conditions for the design events were extracted from a coastal processes report prepared in 1987 for Park Beach at Coffs Harbour. The report was prepared by the then NSW Public Works Department, and is titled, *'An Assessment of Coastal Processes Affecting Park Beach, Coffs Harbour'*. Peak ocean water levels were extracted from this report for the design 20 and 100 year recurrence ocean storms. These are listed in **Table 5** and were adopted as defining the amplitude of the sinusoidal curve that was generated as the downstream boundary condition for the hydraulic model.

Table 5 PEAK DESIGN STORM OCEAN WATER LEVELS

DESIGN OCEAN STORM EVENT	PREDICTED PEAK WATER LEVEL AT PARK BEACH (*m AHD*)
20 year	2.2
100 year	2.6

Source: NSW Public Works Department (1987)

3.3.4 Design Flood Simulations

Combination of Ocean and Catchment Storm Conditions

The 2D hydrodynamic model of Hearns Lake and the lower reaches of Double Crossing Creek was used to simulate a number of design flood scenarios. These scenarios include combined catchment and ocean storm events, and various entrance blockage conditions.

It is difficult to establish a 'typical' design 100 year recurrence flood due to the various combinations of ocean level and catchment runoff conditions that could potentially occur in isolation or concurrently. For this investigation, two base scenarios were modelled. These are described as:

§ the coincidence of a 20 year recurrence catchment storm event and a 100 year ocean storm event; and,

§ the coincidence of a 100 year recurrence catchment storm event and 20 year ocean storm event.

Adopted Entrance Conditions

As outlined previously, Hearns Lake is an Intermittently Closed and Open Lake or Lagoon (*ICOLL*) which is typically closed at the ocean entrance at the northern end of Hearns Lake Beach.

The entrance is effectively closed by wave action along Hearns Lake Beach which deposits marine sand within the mouth of the entrance and creates a berm that "closes off" the entrance. Therefore, lake water levels would rise during and following catchment rainfall, until such time as the build-up of floodwaters led to the formation of a pilot channel through the mouth of the lake entrance. Lake water levels would then recede as floodwaters are discharged to the ocean.

In order to determine the worst flood conditions that could apply at the development site, both open and closed conditions were considered and modelled. In the case of the closed entrance condition, a number of additional simulations were undertaken to assess the potential impact of an entrance "breakout".

The "blocked" entrance condition was based on the adoption of a beach berm extending across the mouth of the lake entrance with a minimum crest elevation of 1.6 mAHD. This was based on topographic survey of the beach and entrance bathymetry undertaken by Asquith & deWitt Pty Ltd in June 2004 (*refer cross-sections XS 1, XS 1A and XS 2 shown in* **Figure 3**).

Several open entrance conditions were also modelled to analyse the sensitivity of the peak flood level at the site to a change in minimum bed elevation and channel width for entrance breakout. These conditions included minimum channel bed elevations 0 mAHD and -1 mAHD, and pilot channel widths of 20, 30 and 40 metres.

The full range of scenarios that were modelled are listed in the first column of **Table 6**.

3.3.5 Hydraulic Modelling Results

Peak Flood Levels

Predicted peak flood levels at the development site were extracted from the model results for each scenario and are listed in **Table 6**.

The hydraulic modelling results confirm that the entrance condition at the mouth of Hearns Lake will influence peak flood levels at the development site (*refer* **Table 6**). When the ocean entrance is blocked, the peak flood level is dominated by the discharge from catchment storm event.

However, when the entrance is open, the floodwaters from the catchment storm event are released through the ocean entrance, thereby lowering the flood level at the site. For example, for the scenario where there is a 20 year recurrence catchment storm event and a 100 year recurrence ocean storm event, and in which breakout occurs at the entrance creating a 20 metre wide pilot channel with a minimum bed elevation of 0 mAHD, it is predicted that the breakout will effectively reduce lake flood levels by about 150 mm.

The results of the modelling also show that the width and minimum bed elevation of the pilot channel under an entrance breakout condition, do not significantly alter the peak flood level across the site. That is, there is an optimum pilot channel width and scour depth that provides for efficient discharge of lake waters to the ocean. This suggests that the hydraulic control is probably the berm crest elevation which has been fixed for this analysis.

Table 6 PEAK FLOOD LEVELS ACROSS THE DEVELOPMENT SITE

CATCHMENT STORM EVENT (*years*)	OCEAN STORM EVENT (*years*)	ENTRANCE CONDITION	CHANNEL WIDTH (*m AHD*)	PEAK WATER LEVEL (*m AHD*)
20 year	100 year	Blocked	-	2.80
100 year	20 year	Blocked	-	2.73
20 year	100 year	Open (*Minimum bed elevation 0 mAHD*)	20m	2.76
			30m	2.75
			40m	2.74
20 year	100 year	Open (*Minimum bed elevation -1 mAHD*)	20m	2.74
			40m	2.73
100 year	20 year	Open (*Minimum bed elevation 0 mAHD*)	20m	2.60
			30m	2.58
			40m	2.56
100 year	20 year	Open (*Minimum bed elevation -1 mAHD*)	20m	2.54
			40m	2.52

Adopted Peak Flood Level for the Design 100 year Recurrence Flood

Based on an analysis of the results presented in **Table 6**, it is recommended that a peak design 100 year recurrence flood level of 2.6 mAHD be adopted for the development site. This level corresponds to the peak flood level that would arise should the design 100 year recurrence catchment storm event coincide with a 20 year recurrence ocean storm event, and result in a modest sized pilot channel being formed at the lake entrance (***i.e.,*** *the formation of a 20 metre wide pilot channel scoured to a minimum bed elevation of 0 mAHD*).

It is recognised that this scenario would not occur instantaneously during a flood and would occur as a dynamic response to elevated water levels within the lake and the associated hydrostatic head formed against the beach berm. Hence, it would take some time to achieve the modelled channel width of 20 metres.

Notwithstanding, it is considered that the size of the lake would sufficiently "damp" the impact of the progressive increase in pilot channel width and depth to result in there being no impact on the adopted peak 100 year recurrence flood level of 2.6 mAHD.

It should also be noted that the adopted peak 100 year recurrence flood level of 2.6 mAHD is equal to the peak ocean level for a 100 year recurrence ocean storm event determined in 1987 by the NSW Public Works Department for Park Beach. Therefore, it is considered that the adopted peak flood level is consistent with design 100 year recurrence storm conditions for both ocean and catchment dominated events.

Flood Extent and Peak Flood Depth

The flood extent for the design 100 year recurrence flood is shown in **Figure** 7. This is based on the results of modelling of the adopted design flood scenario referred to above which generated a uniform lake flood level of 2.6 mAHD.

The results indicated that at the peak of the design 100 year recurrence flood, about 27% of the Sandy Beach North development site would be inundated. As shown in **Figure** 7, the area that would be inundated is generally limited to the low lying overbank areas that adjoin the shoreline of Hearns Lake and the two drainage channels in the southern section of the development site.

Figure 8 shows the predicted depth of inundation across the development site at the peak of a design 100 year recurrence flood. Depths of inundation across the development site are predicted to vary between 0.1 and 1.8 metres. However, the deeper areas correspond to sections of the site that fall within the lake.

As discussed previously, the top of bank elevation of Hearns Lake within the development site is approximately 1.3 mAHD. As the peak flood level at the site is 2.6 mAHD, the peak floodwater depth outside Hearns Lake during the design 100 year recurrence flood is 1.3 mAHD. Floodwater depths across areas of the site that immediately adjoin the lake shoreline are typically 0.7 metres. However, floodwater depths are only 0.2 metres in areas that adjoin the open channels in the southern section of the site (*refer* **Figure 8**).

Peak Flood Velocity

As shown in **Figure 8**, predicted peak flow velocities across the development site during the design 100 year recurrence flood are relatively low. The peak design 100 year recurrence flow velocity is only 0.28 m/s, and is predicted to occur in a small area on the western floodplain of Hearns Lake, at the southern extent of the northern site boundary.

Generally, the peak flow velocity across the site is less than 0.15 m/s and reflects the impact of the lake in "damping" the velocity of floodwaters as they enter it.

Provisional Flood Hazard

Flood hazard is a measure of the degree of difficulty that pedestrians, cars and other vehicles will have in egressing flooded areas, and the likely damage to property and infrastructure. The NSW Government's ***'Floodplain Management Manual'*** (*2001*), characterises hazards associated with flooding into a combination of two hazard categories. These hazard categories are defined in **Table 7**.

Table 7 DEFINITIONS FOR HAZARD CATEGORIES

HAZARD CATEGORY	DEFINITION
HIGH	• possible danger to life and limb • evacuation by trucks difficult • potential for structural damage • social disruption • potentially high financial losses • velocity > 2 m/s, depth > 0.8 m and velocity x depth > 0.5 m^2/s^*
LOW	• should it be necessary, people and their possessions could be evacuated by trucks • able-bodied adults would have little difficulty wading • velocity < 2 m/s, depth < 0.8 m and velocity x depth < 0.5 m^2/s^*

* *Based on interpretation of Figure G2 from the 'Floodplain Management Manual' (2001).*

The flood hazard across the site varies as a function of the depth and velocity of floodwaters, and their product. As discussed, peak floodwater depths across areas of the site are predicted to vary up to a maximum depth of 1.8 metres and peak flow velocities are predicted to range up to 0.28 m/s.

The *'Floodplain Management Manual'* (*2001*) indicates that areas subject to floodwater depths of greater than 0.8 metres and/or flow velocities greater than 2 m/s should be classified as high hazard areas (*based on Figure G2 in the Manual*). As the flow velocities at the site only range up to 0.28 m/s, the floodwater depths will govern the hazard classification across the development site.

As the peak flood level for the design 100 year recurrence flood is 2.6 mAHD, any part of the site with an existing ground surface elevation less than or equal to 1.8 mAHD will have a depth of inundation greater than 0.8 metres and therefore be classified as high flood hazard areas.

Alternatively, areas of the site which have an existing ground surface elevation greater than 1.8 mAHD will have a low hazard classification. The provisional hazard categories for the site are shown in **Figure 9**.

4 CLIMATE CHANGE CONSIDERATIONS

Due to the proximity of the development site to Hearns Lake and the proximity of the lake to the ocean, there is potential for increased frequency of inundation due to the predicted impacts of climate change.

Climate change also has the potential to impact on existing flood characteristics, potentially leading to increased peak levels for floods of a specified frequency of occurrence or average recurrence interval. Increased peak flood levels could in turn result in a requirement for the minimum fill elevation to be raised by an amount commensurate with the projected increase in predicted peak flood level due to climate change.

In summary, climate change predictions could impact on design constraints such as the development footprint extent and minimum floor levels for dwellings. These constraints could be imposed due to either of the following mechanisms:

(i) increased peak flood levels within Hearns Lake due to an increase in predicted rainfall intensity for catchment storms combined with increased ocean water levels in storm events that lead to flooding; or,

(ii) an increase in the typical elevation of the entrance berm coincident with the projected increase in ocean water levels and the associated redefinition of the ICOLL extent upslope from the extent that is currently adopted and defined in the Patterson Britton & Partners Report titled, *'Scientific Assessment of Entrance Berm Elevation for Hearns Lake, Sandy Beach North'* (*January, 2007*).

In effect, climate change could result in:

(a) a reduction in the area of the site that can be developed, and;

(b) an increased depth of filling to achieve minimum floor level requirements for development on or adjacent to floodplain lands.

A discussion of additional investigations that have been undertaken to assess these issues is outlined in the following sections.

4.1 IMPACT OF CLIMATE CHANGE ON FLOOD CHARACTERISTICS

An assessment of the impact of climate change on flood characteristics in the vicinity of the Sandy Beach North Site was undertaken to establish the extent to which fill elevations and minimum floor levels may need to be raised to accommodate the projected impact of climate change to the year 2100.

This involved additional hydrologic and hydraulic flood modelling to investigate the impact of projected estimates for sea level rise and projected increases in storm rainfall intensity.

Specifically, the impact of climate change on peak flood level estimates was based on consideration of the following for a 100 year recurrence flood scenario:

- An averaged 12% increase in peak flows for the 100 year recurrence design storm event which reflected a 10% increase in peak rainfall intensity over the entire Double Crossing Creek catchment. The adoption of a 10% increase in rainfall intensity was based on application of the guidelines documented in the DECC's Floodplain Risk Management Guideline titled, *'Practical Consideration of Climate Change'* (*October 2007*).
- Increased tidal boundary conditions reflecting each of the lower, median, and upper bound scenarios of sea level rise predictions for Year 2100 as detailed in the DECC's Floodplain Risk Management Guideline titled, *'Practical Consideration of Climate Change'* (*October 2007*). The IPCC has set values of 0.18, 0.55 and 0.91 metres as the lower, median and upper bound values for sea level rise on the North Coast of NSW to Year 2100.

4.1.1 Flood Modelling

The RAFTS hydrologic model used for the prediction of flows for the 20 and 100 year recurrence storms was used to simulate the impact of the projected increase in peak rainfall on flood flows that would be discharged to Hearns Lake in a design 100 year recurrence storm event. As outlined above, the increase in peak flows is predicted to result in a 12% increase in discharge from the Double Crossing Creek catchment.

The RMA-2 flood model that was then used to simulate flooding for existing conditions at the site was modified to incorporate boundary conditions representing the adopted climate change scenarios described above. The analysis was undertaken in accordance with recommendations outlined in the Department of Environment & Climate Change (*DECC*) guideline titled, *'Floodplain Risk Management Guideline No 5 – Ocean Boundary Conditions'*.

Separate simulations were undertaken for each of the lower, median and upper bound ocean level increase projections, for each of the 20, 30 and 40 metre wide pilot channel configurations (*refer* **Table 6**). In addition, pilot channel invert levels of 0 mAHD and -1 mAHD were considered to assess the sensitivity of flood level estimates to entrance condition. All other parameters were assumed to be the same as adopted for simulations for existing conditions, as outlined in **Section 3**.

4.1.2 Impact of Climate Change Scenarios on Peak Flood Levels

The results of modelling show that the adopted climate change scenario will act to increase peak 100 year recurrence flood levels for Hearns Lake. Predicted peak flood levels at the development site were extracted from the model results for each scenario and are listed in **Tables 8** and **9**. For comparison purposes, predicted peak 100 year recurrence flood levels for each entrance configuration are highlighted in yellow for existing conditions.

The results from the analysis indicate that peak 100 year recurrence flood levels for Hearns Lake are insensitive to the width of the pilot channel that would form during a flood that led to draining of the lake. The results also show that peak lake flood levels are also insensitive to the minimum elevation to which the pilot channel would scour.

Table 8 PREDICTED PEAK FLOOD LEVELS ALLOWING FOR CLIMATE CHANGE IMPACTS AND ADOPTION OF A 0 mAHD MINIMUM PILOT CHANNEL ELEVATION

CATCHMENT STORM EVENT	OCEAN STORM EVENT	CHANNEL WIDTH (*metres*)	CLIMATE CHANGE SCENARIO	PEAK WATER LEVEL (*mAHD*)
100 year	20 year	20 m	No Consideration	2.60
			Lower	2.72
			Median	2.97
			Higher	3.25
		30 m	No Consideration	2.58
			Lower	2.71
			Median	2.96
			Higher	3.25
		40 m	No Consideration	2.56
			Lower	2.69
			Median	2.95
			Higher	3.24

Table 9 PREDICTED PEAK FLOOD LEVELS ALLOWING FOR CLIMATE CHANGE IMPACTS AND ADOPTION OF -1 mAHD MINIMUM PILOT CHANNEL ELEVATION

CATCHMENT STORM EVENT	OCEAN STORM EVENT	CHANNEL WIDTH (*metres*)	CLIMATE CHANGE SCENARIO	PEAK WATER LEVEL (*mAHD*)
100 year	20 year	20	No Consideration	2.54
			Lower	2.68
			Median	2.94
			Higher	3.24
		40	No Consideration	2.52
			Lower	2.66
			Median	2.93
			Higher	3.23

As shown in **Tables 8** and **9**, the median Year 2100 climate change scenario generates peak 100 year recurrence levels that range from 2.93 to 2.97 mAHD.

Accordingly, it is considered appropriate to adopt an elevation of 2.95 mAHD as the Year 2100 estimate of the 100 year recurrence flood level for Hearns Lake.

The 100 year recurrence flood extent for the adopted Year 2100 climate change scenario is shown in **Figure 10**. The depth of flooding and peak flow velocity vectors are provided in **Figure 11**.

5 IMPACT OF THE PROPOSED DEVELOPMENT

5.1 PROPOSED SITE CHANGES

It is proposed that the site be developed to create up to 280 residential lots set within a restored coastal landscape. The proposed layout for the subdivision is shown in **Figure 12**.

As shown, the lots are to be concentrated along the western and southern site boundaries within what is referred to as the Southern and South-western Precincts. However, several lots are also proposed along the rear of the dune at the eastern site boundary in what is being termed as the "Beach Precinct".

An internal road network is proposed to provide access to individual lots and will be linked to the Pacific Highway midway along the western boundary of the site. The road network will also connect the site to the existing village of Sandy Beach via Pine Crescent and Ti Tree Road at the southern boundary of the site (*refer* **Figure 12**).

All lots and roadways are set back at least 70 metres from the edge of Hearns Lake and Double Crossing Creek. Provision has also been made in the development layout to retain an existing drainage channel that runs through the southern section of the site and discharge surface runoff from Sandy Beach to the southern shoreline of Hearns Lake.

In order to comply with Council's current *Flood Policy*, the floor level of all habitable dwellings must be located at least 500 mm above the design 100 year recurrence flood level. However, it is considered appropriate to set the minimum floor level at 500 mm above the Year 2100 design 100 year recurrence flood level that incorporates an allowance for climate change. Therefore, based on an adopted Year 2100 design 100 year recurrence flood level of 2.95 mAHD, the floor level of all proposed dwellings will need to be set at or above 3.45 mAHD (*i.e., 2.95 mAHD plus 500 mm*).

It is understood that slab-on-ground dwelling construction is proposed for the site. Assuming a minimum slab thickness of 200 mm, low lying areas of the site that are proposed for development will need to be filled to an elevation of at least 3.25 mAHD. This would provide dwelling sites that would be 300 mm above the Year 2100 peak 100 year recurrence flood level and would allow easy construction of slabs for individual dwellings without significantly affecting the visual character of the development.

It is also proposed that the roads within the development be constructed to at least the peak level of the Year 2100 design 100 year recurrence flood level. Therefore, all roadways will have low points set at a minimum level of 2.95 mAHD. This will ensure that no flooding of the roadways would occur in the rare occurrence of coincident ocean and catchment storms of the magnitude of the adopted 100 year recurrence flood with provision for climate change impacts.

Accordingly, filling is proposed in some areas of the site to raise the level of the land surface so that roads and lots can be constructed to meet the above objectives.

Figure 13 shows the approximate extent of filling required to raise levels to above 2.95 mAHD across areas where lots and roadways are proposed.

5.2 POTENTIAL IMPACT OF PROPOSED FILLING ON EXISTING FLOODING

5.2.1 Hydraulic Model Modifications

The proposed development will involve modification to the existing natural surface of the site and the construction of residential dwellings. The proposed filling will remove a portion of the flood storage area provided across areas that adjoin Hearns Lake and therefore, has the potential to cause localised increases in peak flood level.

Accordingly, the existing RMA-2 flood model was used to quantify any impacts and assess the potential for the proposed development to adversely impact flood behaviour on adjoining properties.

In order to quantify the potential impact (*i.e., in terms of altered flood level or velocity*), the model was updated to reflect the fill proposal. This was achieved by modifying the hydraulic model to reflect the proposed ground surface topography. The alterations involved adjusting the elevations assigned to nodes where the filling is proposed to an elevation of 2.95 mAHD or higher (*i.e., to above the Year 2100 peak 100 year recurrence flood level*). Land surfaces outside of the proposed extent of fill were not altered.

5.2.2 Hydraulic Modelling Results

The modified model was used to simulate the 100 year recurrence flood and to define flood behaviour under post-development conditions (*i.e., with the proposed filling and buildings in place*). The magnitude of any changes in flood behaviour arising from the proposed filling can be established by comparing flood modelling results for pre and post-development scenarios.

Impact on Peak Flood Level

The results of the simulation were extracted and compared with results generated from simulations for the existing scenario (*i.e., those shown in* **Figures 7** *and* **8**).

As shown in **Figure 14**, the proposed development will not cause a significant encroachment into the existing 100 year recurrence flood extent. This is to be expected, as the development layout and associated fill platforms have been designed according to a higher peak flood level that incorporates an allowance for climate change.

As expected, the flood model results for the post-development scenario confirm that the proposed development will not impact on the existing peak level of flooding in the lake during the 100 year recurrence event.

Impact on Peak Flow Velocity

Peak flow velocities were extracted from the *'post-development'* model results and compared with peak flow velocities from the pre-development scenario.

As is the case for predicted flood levels, peak flow velocities during the 100 year recurrence flood are not expected to be impacted by the proposed development. This is a direct reflection of the negligible encroachment of the proposed filling into the existing 100 year recurrence flood extent (*refer* **Figure 14**).

Impact on Flood Hazard

As discussed, the proposed site filling is not expected to impact on peak flood levels and flow velocities during the 100 year recurrence flood. As a result, the velocity-depth product of flooding in the vicinity of the site is not expected to increase.

Hence, the impacts of the proposed filling on flood behaviour during the existing 100 year recurrence event are considered to be negligible and the development will not worsen flood conditions on adjoining properties.

5.3 POTENTIAL IMPACT OF PROPOSED FILLING ON “YEAR 2100” FLOODING

5.3.1 Hydraulic Modelling Results

As discussed above, the RMA-2 flood model was modified to incorporate the proposed filling at the site according to the extent shown in **Figure 13**.

The modified model was also used to simulate the 100 year recurrence flood that incorporates an allowance for Year 2100 climate change predictions, to define flood behaviour under post-development conditions (*i.e., with the proposed filling and buildings in place*). The magnitude of any changes in flood behaviour arising from the proposed filling were established by comparing model results for pre and post-development scenarios that incorporate climate change predictions.

Impact on Peak Flood Level

The results of the simulation were extracted and combined with results generated from simulations for the existing scenario (*i.e., those shown in* **Figures 7** *and* **8**) to generate a flood level difference map. This map presents a graphical representation of the magnitude and location of changes in flood levels by comparing the water levels for both the pre and post-development scenarios at each node in the hydraulic model. This effectively creates a contour map of predicted post-development “affluxes” and allows easy determination of the impact of the proposed development on flood levels.

The flood level difference map for the Year 2100 design 100 year recurrence flood, which shows the location and magnitude of increases in peak flood level, is presented in **Figure 15**.

Figure 15 indicates that the proposed filling will result in increases in peak flood level in some areas across the floodplain of the Hearns Lake / Double Crossing Creek system. However, the maximum increase in peak flood level is predicted to be less than 20 mm, within and outside of the development site. This change is considered to be negligible.

Therefore, the peak Year 2100 design 100 year recurrence flood level for the post-development scenario is estimated to be a maximum of 2.98 mAHD.

Impact on Peak Flow Velocity

Peak flow velocities were extracted from the *'post-development'* model results and compared with peak flow velocities from the pre-development scenario. A difference map was created to quantify any increases in peak flow velocities associated with the proposed filling.

The velocity difference map created for the Year 2100 design 100 year recurrence flood is presented in **Figure 16**. As shown, the proposed filling of part of the development site will result in localised increases in peak flow velocity both within and outside the site.

However, the increases in peak flow velocity outside the development site are predicted to be less than 0.1 m/s and primarily occur within Hearns Lake and near the entrance to the ocean. At this location, the peak flow velocity is predicted to increase from 0.5 m/s to 0.6 m/s, which is not considered to be a significant change and would therefore have no discernable impact on flood behaviour.

Typically, increases in peak flow velocity during the Year 2100 design 100 year recurrence flood are predicted to be less than 0.05 m/s (*refer* **Figure 16**).

Impact on Flood Hazard

As discussed, the proposed filling will prevent inundation of part of the development site in events up to and including the Year 2100 design 100 year recurrence flood. Therefore, the hydraulic flood hazard across those areas that are proposed to be filled, as shown in **Figure 9**, will be effectively eliminated in events of this magnitude.

As shown in **Figures 15** and **16**, the filling is predicted to cause an increase in peak Year 2100 design 100 year recurrence flood levels and flow velocities of typically less than 20 mm and 0.1 m/s, respectively.

The maximum change in velocity-depth product would occur over the small area where the maximum increase in flow velocity is predicted. However, in this area the increase in velocity-depth product would only be 2.0×10^{-3} m^2/s (*i.e., 0.1 m/s x 0.02m*). Accordingly, the provisional flood hazard classification in this area would effectively remain the same.

Therefore, while the proposed filling will increase the peak velocity-depth product at some locations across the southern floodplain of the Hearns Lake / Double Crossing Creek system, the increases are not sufficient to alter the hazard classification that would apply at any location across the floodplain.

Hence, the proposed filling is considered to have a no measurable impact on flooding during the Year 2100 design 100 year recurrence event and the development is not expected to worsen flood conditions on adjoining properties.

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6 CONCLUSIONS

Sandy Shores Development Pty Ltd plans to develop a residential subdivision on a 49 hectare parcel of land that adjoins Hearns Lake immediately north of the village of Sandy Beach. The proposed development is to involve the creation of up to 280 residential lots and the construction of an internal road network to provide access to the site from Sandy Beach and the Pacific Highway.

Due to its proximity to Hearns Lake, it is recognised that there is potential for inundation of low lying areas of the site during flooding of Double Crossing Creek or when elevated ocean water levels occur. Furthermore, "closed" lake entrance conditions occur for most of the time and are likely to influence peak flood levels in the lake when storms occur across the catchment.

Investigations undertaken for this report have determined that flooding could occur as a result of a range of ocean and catchment storm scenarios. The investigations have also determined that peak flood levels in the lake are critically controlled by lake entrance conditions and the potential for elevated water levels to cause a "breakout" at the entrance. Computer modelling of the lake and Double Crossing Creek system for a range of breakout scenarios has determined that the critical factor affecting flood behaviour in the lake is the relative differential between lake and ocean water levels. Recent survey of the berm that effectively blocks the entrance indicates that it has typical crest elevations of between 1.6 and 2.0 mAHD. Therefore, depending on ocean water levels, it is likely that a pilot channel will begin to be cut through the berm once flood levels in the lake exceed 1.6 mAHD.

The following conclusions can be drawn from the results of the modelling undertaken for the investigation:

§ A peak design 100 year recurrence flood level of 2.6 mAHD can be adopted for the development site. This is based on consideration of the potential for coincident ocean and catchment storms, and assumes that the coincidence of a 100 year recurrence catchment storm with a 20 year recurrence ocean storm, is representative of a 'design 100 year recurrence event' scenario. This design 100 year recurrence flood level is based on a 20 metre wide pilot channel being formed at the lake entrance during the flood and scouring to a minimum elevation of 0 mAHD.

§ The maximum design 100 year recurrence flow velocity across the development site is predicted to be 0.3 m/s and will occur in a small area on the western floodplain of Hearns Lake, at the southern extent of the northern site boundary. Generally, the peak flow velocity across the site is less than 0.15 m/s and reflects the impact of the lake in "damping" the velocity of floodwaters as they enter it.

Additional investigations have established that climate change considerations to the Year 2100 could impact on the development site by increasing the peak level of the design 100 year recurrence flood for Hearns Lake from the current estimate of 2.60 mAHD to an elevation of 2.95 mAHD.

On this basis, it is considered that the adoption of a peak 100 year recurrence flood level of 2.95 mAHD will provide sufficient redundancy over the design life of the project. Accordingly, it is recommended that an elevation of 2.95 mAHD be adopted as the "Year 2100" design 100 year recurrence flood level and that building controls for development be based on this. Accordingly, minimum habitable floor levels should be set at 3.45 mAHD.

The results of the flood modelling investigations indicate that inundation of some areas of the site that are proposed for development would occur. Accordingly, Sandy Shores plans to fill some low lying areas of the site to raise the ground surface to acceptable levels for development. It is proposed that currently inundated areas that are to be dedicated for residential lots will be filled to an elevation of 3.25 mAHD.

This allows for construction of a 200 mm thick concrete slab on these lots so that dwellings can be constructed to a floor level that is 500 mm above the predicted peak Year 2100 design 100 year recurrence flood level.

It is also proposed that the roads within the development be constructed to a level above the peak Year 2100 design 100 year recurrence flood level of 2.95 mAHD. This will provide "flood-free" evacuation routes within the site during events up to and including the 100 year recurrence flood with provision for climate change impacts.

The extent of the proposed filling is shown in **Figure 13**.

In order to assess the potential impact of the proposed filling, the RMA-2 flood model was modified to reflect the filling shown and **Figure 13**, and was used to simulate flood behaviour under post development conditions. The following conclusions can be drawn from the results of simulations undertaken to assess post development conditions:

- The proposed filling is <u>not</u> expected to impact on peak flood levels or flow velocities during the existing 100 year recurrence flood.
- The proposed filling will result in some increases in peak "Year 2100" design 100 year recurrence flood level, but these are predicted to be typically <u>less than 20 mm</u> (*refer* **Figure 15**).
- The proposed filling will result in increases in peak flow velocity during the "Year 2100" design 100 year recurrence flood. However, these increases are predicted to range between 0.01 m/s and 0.1 m/s and combined with the minor change in peak floodwater depth, will result in no change to the hazard classification that currently applies to flood affected areas of the site (*refer* **Figure 9**).
- The proposed filling will result in no significant change in flood characteristics (*i.e., flood level or velocity*) across properties that adjoin the development site.

Therefore, it can be concluded that the filling proposed as part of the development will not have a significant impact on flood behaviour in either the existing 100 year recurrence flood scenario or the "Year 2100" design 100 year recurrence flood scenario. It can also be concluded that the majority of the site area to be developed for residential purposes is above the Year 2100 design 100 year recurrence flood level. The remainder of the area that will be developed for residential purposes is able to be modified (*by relatively shallow filling*) to allow residential development to proceed.

7 REFERENCES

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(2) Department of Environment & Climate Change (*October 2007*); *'Floodplain Risk Management Guideline – Practical Consideration of Climate Change'*

(3) Chow VT (*1959*), *'Open Channel Hydraulics'*; McGraw Hill Book Company, Inc.; Reissued 1988; ISBN 07 010776 9.

(4) Coffs Harbour City Council (*2002*), *'Potentially Flood Prone Land Information Sheet'*.

(5) Griffin AG (*1983*), *'The Effects of Storm Tides on Flooding'*; paper presented to the 23rd Flood Mitigation Conference, Kempsey.

(6) Haines PE (*2005*), *'Determining Appropriate Setbacks for Future Development Around ICOLLs'*; presented at the 14th NSW Coastal Conference, Narooma, 8-11th November 2005.

(7) Institution of Engineers (*1987*), *'Australian Rainfall and Runoff – A Guide to Flood Estimation'*; edited by DH Pilgrim.

(8) NSW Department of Infrastructure Planning & Natural Resources (*May 2005*); *'Draft Floodplain Risk Management Guideline No 5 – Ocean Boundary Conditions'*.

(9) New South Wales Government (*April 2005*), *'Floodplain Development Manual: the management of flood liable land'*; ISBN 0 7347 5476 0, DIPNR 05_020.

(10) NSW Public Works Department (*February, 1987*), *'An Assessment of Coastal Processes Affecting Park Beach, Coffs Harbour'*.

(11) Sainty & Associates (*September 2006*), *'Environmental Constraints Analysis - Lot 22 DP 1070182, Pacific Highway, Sandy Beach North'*; prepared for the NSW Department of Planning.

(12) Willing & Partners Pty Ltd (*1996*), *'RAFTS-XP User Manual'*.

(13) WorleyParsons (*incorporating Patterson Britton & Partners*) (*2009*), *'Climate Change Assessment for Proposed Development at Sandy Beach North'* (*Issue No.3, February 2009*); prepared for Sandy Shores Development Pty Ltd.

APPENDIX A

ADOPTED SUB-CATCHMENT PARAMETERS

TABLE A1: RAFTS SUB-CATCHMENT PARAMETERS

RAFTS MODEL SUB CATCHMENT	AREA (*ha*)	IMP. AREA (%)	MANNINGS 'n'	INITIAL LOSS (*mm*)	CONTINUING LOSS (*mm/hr*)
A	104.4	5	0.035	10	2.5
B	50.5	5	0.035	10	2.5
C	35.3	5	0.035	10	2.5
D	141.9	5	0.035	10	2.5
E	16.1	5	0.035	10	2.5
F	52.7	5	0.035	10	2.5
G	44.1	5	0.035	10	2.5
H	16.8	20	0.035	10	2.5
I	17.5	25	0.035	10	2.5
J	11.3	5	0.035	10	2.5
K	46.9	5	0.035	10	2.5
L	88.5	10	0.035	10	2.5
M	11.5	50	0.025	10	2.5
N	6.1	5	0.035	10	2.5
O	34.4	5	0.035	10	2.5
P	3.7	70	0.025	10	2.5
Q	13.9	25	0.035	10	2.5

TABLE A2: ADOPTED SITE SUB-CATCHMENT PARAMETERS FOR RAFTS HYDROLOGIC MODEL

CATCHMENT	AREA (*ha*)	IMP. AREA (*%*)	MANNINGS 'n'	INITIAL LOSS (*mm*)	CONTINUING LOSS (*mm/hr*)
a	10.6	5	0.025	10	2.5
b	2.5	5	0.025	10	2.5
c	4.1	5	0.035	10	2.5
d	16.6	5	0.035	10	2.5
e	1.7	5	0.035	10	2.5
f	0.9	5	0.035	10	2.5
g	1.3	5	0.06	10	2.5
h	7.2	5	0.035	10	2.5
i	1.5	5	0.06	10	2.5
j	6.2	5	0.035	10	2.5
k	1.2	5	0.06	10	2.5
l	1.5	5	0.06	10	2.5
m	1.4	5	0.035	10	2.5
n	6.7	5	0.06	10	2.5
o	7.4	5	0.035	10	2.5
p	0.8	100	0.035	10	2.5
q	1.2	100	0.035	10	2.5
r	0.8	100	0.035	10	2.5
s	6.2	100	0.035	10	2.5
t	0.7	5	0.06	10	2.5
u	0.9	5	0.06	10	2.5
v	1.5	5	0.06	10	2.5
w	1.6	5	0.06	10	2.5
x	1.7	5	0.06	10	2.5
y	1.6	5	0.06	10	2.5

APPENDIX B
INTENSITY-FREQUENCY-DURATION DATA

IFD ANALYSIS BASED ON AUSTRALIAN RAINFALL & RUNOFF 1987

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Site Location: Hearns Lake

Geographical factor for 6 min 2 yr storm = 4.375
Geographical factor for 6 min 50 yr storm = 16.6
Skewness = 0.04

2 Year ARI:
1 hour intensity = 46 mm/hr
12 hour intensity = 9.55 mm/hr
72 hour intensity = 3.26 mm/hr

50 Year ARI:
1 hour intensity = 90 mm/hr
12 hour intensity = 19.4 mm/hr
72 hour intensity = 7.75 mm/hr

IFD Table for Various ARIs and Duration

Duration	1 yr (*mm/hr*)	2 yr (*mm/hr*)	5 yr (*mm/hr*)	10 yr (*mm/hr*)	20 yr (*mm/hr*)	50 yr (*mm/hr*)	100 yr (*mm/hr*)
5 mins	115	146	181	201	228	264	290
6	108	137	170	189	215	249	274
10	88	112	141	157	179	207	229
15	74	94	119	133	151	176	195
20	64	82	104	116	133	155	172
30	52	67	85	96	110	129	143
45	41.9	53.9	69.1	78	90	105	117
1 hour	35.6	45.9	59.1	67	77	91	101
1.5	27.7	35.7	46.2	52	60	71	79
2	23.1	29.8	38.6	43.8	51	60	67
3	17.8	23.0	29.9	34.0	39.3	46	52
4.5	13.7	17.8	23.1	26.3	30.5	36.0	40.2
6	11.4	14.8	19.3	21.9	25.4	30.1	33.6
9	8.82	11.4	14.9	17.0	19.8	23.4	26.2
12	7.34	9.52	12.5	14.2	16.5	19.6	21.9
18	5.81	7.57	10.05	11.6	13.5	16.1	18.1
24	4.92	6.43	8.62	9.96	11.7	14.0	15.8
30	4.30	5.65	7.63	8.85	10.42	12.5	14.2
36	3.85	5.07	6.89	8.02	9.47	11.4	13.0
48	3.22	4.25	5.84	6.83	8.10	9.84	11.20
72	2.45	3.25	4.54	5.36	6.40	7.83	8.96

APPENDIX C
RAFTS MODEL RESULTS

```
Max. no. of links allowed =  2000
Max. no. of routing increments allowed = 30000
Max. no. of rating curve points = 30000
Max. no. of storm temporal points = 30000
Max. no. of channel subreaches =    25
Max link stack level =    25
Input Version number =          600
```

Modelling Results for 20 Year Recurrence Storm

```
ROUTING INCREMENT (MINS) =       1.00
STORM DURATION (MINS)    =       120.
RETURN PERIOD (YRS)      =        20.
BX                       =     1.0000
TOTAL OF FIRST SUB-AREAS  (ha) =     694.90
TOTAL OF SECOND SUB-AREAS (ha) =       0.00
TOTAL OF ALL SUB-AREAS (ha)    =     694.90
```

SUMMARY OF CATCHMENT AND RAINFALL DATA

Link Label	Catch. Area #1 (ha)	Catch. Area #2	Slope #1 (%)	Slope #2	% Impervious #1 (%)	% Impervious #2	Pern #1	Pern #2	B #1	B #2	Link No.
3.01	50.500	0.000	8.200	0.000	5.000	0.000	.035	0.00	.0712	0.000	1.000
2.01	104.40	0.000	8.500	0.000	5.000	0.000	.035	0.00	.1021	0.000	2.000
2.02	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.001
2.03	35.300	0.000	5.500	0.000	5.000	0.000	.035	0.00	.0722	0.000	1.002
2.04	16.100	0.000	3.600	0.000	5.000	0.000	.035	0.00	.0593	0.000	1.003
1.01	141.90	0.000	2.700	0.000	5.000	0.000	.035	0.00	.2122	0.000	3.000
1.02	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.004
5.01	52.700	0.000	11.30	0.000	5.000	0.000	.035	0.00	.0621	0.000	4.000
4.01	44.100	0.000	1.500	0.000	5.000	0.000	.035	0.00	.1550	0.000	5.000
1.03	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.005
7.01	16.800	0.000	9.100	0.000	20.00	0.000	.035	0.00	.0223	0.000	6.000
6.01	17.500	0.000	14.80	0.000	25.00	0.000	.035	0.00	.0154	0.000	7.000
1.04	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.006
1.05	46.900	0.000	.2000	0.000	5.000	0.000	.035	0.00	.4373	0.000	1.007
9.01	11.300	0.000	12.20	0.000	5.000	0.000	.035	0.00	.0268	0.000	8.000
9.02	11.500	0.000	4.900	0.000	50.00	0.000	.025	0.00	.0107	0.000	8.001
8.01	10.600	0.000	6.300	0.000	5.000	0.000	.025	0.00	.0285	0.000	9.000
8.02	4.100	0.000	1.100	0.000	5.000	0.000	.035	0.00	.0526	0.000	9.001
12.01	2.500	0.000	2.800	0.000	5.000	0.000	.025	0.00	.0201	0.000	10.00
12.02	16.600	0.000	1.000	0.000	5.000	0.000	.035	0.00	.1141	0.000	10.00
23.01	1.500	0.000	1.300	0.000	5.000	0.000	.060	0.00	.0438	0.000	11.00
24.01	0.7000	0.000	7.600	0.000	5.000	0.000	.060	0.00	.0122	0.000	12.00
25.01	0.9000	0.000	.2000	0.000	5.000	0.000	.060	0.00	.0854	0.000	13.00
13.01	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	11.00
13.02	1.700	0.000	1.100	0.000	5.000	0.000	.035	0.00	.0333	0.000	11.00

8.03	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.002
8.04	0.9000	0.000	.7000	0.000	5.000	0.000	.035	0.00	.0300	0.000	9.003
14.01	1.300	0.000	1.200	0.000	5.000	0.000	.060	0.00	.0423	0.000	14.00
8.05	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.004
8.06	0.8000	0.000	.0010	0.000	100.0	0.000	.035	0.00	.1055	0.000	9.005
16.01	1.500	0.000	2.100	0.000	5.000	0.000	.060	0.00	.0345	0.000	15.00
15.01	7.200	0.000	.3000	0.000	5.000	0.000	.035	0.00	.1348	0.000	16.00
8.07	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.006
8.08	1.200	0.000	.0010	0.000	100.0	0.000	.035	0.00	.1303	0.000	9.007
18.01	1.200	0.000	2.900	0.000	5.000	0.000	.060	0.00	.0261	0.000	17.00
17.01	6.200	0.000	.4000	0.000	5.000	0.000	.035	0.00	.1080	0.000	18.00
8.09	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.008
8.10	0.8000	0.000	.0010	0.000	100.0	0.000	.035	0.00	.1055	0.000	9.009
19.01	1.500	0.000	2.400	0.000	5.000	0.000	.060	0.00	.0322	0.000	19.00
20.01	1.400	0.000	3.100	0.000	5.000	0.000	.035	0.00	.0179	0.000	20.00
8.11	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.010
8.12	6.200	0.000	.0010	0.000	100.0	0.000	.035	0.00	.3060	0.000	9.011
22.01	7.400	0.000	.5000	0.000	5.000	0.000	.035	0.00	.1060	0.000	21.00
21.01	1.600	0.000	1.500	0.000	5.000	0.000	.060	0.00	.0422	0.000	22.00
21.02	1.700	0.000	1.100	0.000	5.000	0.000	.060	0.00	.0508	0.000	22.00
21.03	1.600	0.000	2.500	0.000	5.000	0.000	.060	0.00	.0327	0.000	22.00
21.04	6.700	0.000	3.400	0.000	5.000	0.000	.060	0.00	.0590	0.000	22.00
8.13	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.012
1.06	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.008
11.01	6.100	0.000	14.10	0.000	5.000	0.000	.035	0.00	.0181	0.000	23.00
11.02	3.700	0.000	4.700	0.000	70.00	0.000	.025	0.00	.0042	0.000	23.00
10.01	34.400	0.000	1.500	0.000	5.000	0.000	.035	0.00	.1362	0.000	24.00
10.02	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	23.00
1.07	13.900	0.000	2.100	0.000	25.00	0.000	.035	0.00	.0361	0.000	1.009

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2	Cont. Loss #1 (mm/h)	Cont. Loss #2	Excess Rain #1 (mm)	Excess Rain #2	Peak Inflow (m^3/s)	Time to Peak	Link Lag mins
3.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	19.025	41.00	0.000
2.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	35.334	41.00	0.000
2.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	54.358	41.00	18.40
2.03	50.699	10.00	0.000	2.500	0.000	86.939	0.000	60.560	59.00	13.70
2.04	50.699	10.00	0.000	2.500	0.000	86.939	0.000	62.390	73.00	0.000
1.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	27.309	60.00	0.000
1.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	85.673	73.00	27.00
5.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	21.333	40.00	0.000
4.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	8.320	60.00	0.000
1.03	50.699	10.00	0.000	2.500	0.000	86.939	0.000	92.721	100.0	18.20
7.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	8.295	37.00	0.000
6.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	9.754	36.00	0.000
1.04	50.699	10.00	0.000	2.500	0.000	86.939	0.000	93.904	118.0	20.50
1.05	50.699	10.00	0.000	2.500	0.000	86.939	0.000	97.074	139.0	0.000
9.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	5.131	40.00	12.00
9.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	8.062	36.00	0.000
8.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	4.744	40.00	8.100
8.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	5.835	48.00	0.000
12.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	1.106	40.00	13.80
12.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	4.198	54.00	0.000
23.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.3497	47.00	0.000
24.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.3165	40.00	0.000
25.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.1052	81.00	0.000

13.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.6726	41.00	5.800
13.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.5415	42.00	0.000
8.03	50.699	10.00	0.000	2.500	0.000	86.939	0.000	10.102	48.00	4.600
8.04	50.699	10.00	0.000	2.500	0.000	86.939	0.000	10.326	53.00	0.000
14.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.3028	48.00	0.000
8.05	50.699	10.00	0.000	2.500	0.000	86.939	0.000	10.622	53.00	4.500
8.06	50.699	0.000	0.000	0.000	0.000	101.40	0.000	10.680	58.00	0.000
16.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.4398	44.00	0.000
15.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.9858	80.00	0.000
8.07	50.699	10.00	0.000	2.500	0.000	86.939	0.000	11.851	58.00	5.000
8.08	50.699	0.000	0.000	0.000	0.000	101.40	0.000	11.954	63.00	0.000
18.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.4169	41.00	0.000
17.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	1.010	66.00	0.000
8.09	50.699	10.00	0.000	2.500	0.000	86.939	0.000	13.141	63.00	4.300
8.10	50.699	0.000	0.000	0.000	0.000	101.40	0.000	13.210	67.00	0.000
19.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.4675	42.00	0.000
20.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.6062	40.00	0.000
8.11	50.699	10.00	0.000	2.500	0.000	86.939	0.000	13.619	67.00	9.500
8.12	50.699	0.000	0.000	0.000	0.000	101.40	0.000	13.936	77.00	0.000
22.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	1.269	65.00	0.000
21.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.3988	46.00	5.900
21.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.3532	52.00	5.600
21.03	50.699	10.00	0.000	2.500	0.000	86.939	0.000	0.5081	41.00	9.800
21.04	50.699	10.00	0.000	2.500	0.000	86.939	0.000	1.871	45.00	0.000
8.13	50.699	10.00	0.000	2.500	0.000	86.939	0.000	15.880	77.00	0.000
1.06	50.699	10.00	0.000	2.500	0.000	86.939	0.000	102.20	139.0	12.90
11.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	2.929	38.00	7.800
11.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	3.652	34.00	0.000
10.01	50.699	10.00	0.000	2.500	0.000	86.939	0.000	6.741	57.00	0.000
10.02	50.699	10.00	0.000	2.500	0.000	86.939	0.000	9.931	46.00	12.90
1.07	50.699	10.00	0.000	2.500	0.000	86.939	0.000	103.53	152.0	0.000

Modelling Results for 100 yr Recurrence Storm

ROUTING INCREMENT (MINS) = 1.00
STORM DURATION (MINS) = 120.
RETURN PERIOD (YRS) = 100.
BX = 1.0000
TOTAL OF FIRST SUB-AREAS (ha) = 694.90
TOTAL OF SECOND SUB-AREAS (ha) = 0.00
TOTAL OF ALL SUB-AREAS (ha) = 694.90

SUMMARY OF CATCHMENT AND RAINFALL DATA

Link Label	Catch. Area #1 (ha)	Catch. Area #2	Slope #1 (%)	Slope #2	% Impervious #1 (%)	% Impervious #2	Pern #1	Pern #2	B #1	B #2	Link No.
3.01	50.500	0.000	8.200	0.000	5.000	0.000	.035	0.00	.0712	0.000	1.000
2.01	104.40	0.000	8.500	0.000	5.000	0.000	.035	0.00	.1021	0.000	2.000
2.02	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.001
2.03	35.300	0.000	5.500	0.000	5.000	0.000	.035	0.00	.0722	0.000	1.002
2.04	16.100	0.000	3.600	0.000	5.000	0.000	.035	0.00	.0593	0.000	1.003
1.01	141.90	0.000	2.700	0.000	5.000	0.000	.035	0.00	.2122	0.000	3.000

1.02	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.004
5.01	52.700	0.000	11.30	0.000	5.000	0.000	.035	0.00	.0621	0.000	4.000
4.01	44.100	0.000	1.500	0.000	5.000	0.000	.035	0.00	.1550	0.000	5.000
1.03	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.005
7.01	16.800	0.000	9.100	0.000	20.00	0.000	.035	0.00	.0223	0.000	6.000
6.01	17.500	0.000	14.80	0.000	25.00	0.000	.035	0.00	.0154	0.000	7.000
1.04	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.006
1.05	46.900	0.000	.2000	0.000	5.000	0.000	.035	0.00	.4373	0.000	1.007
9.01	11.300	0.000	12.20	0.000	5.000	0.000	.035	0.00	.0268	0.000	8.000
9.02	11.500	0.000	4.900	0.000	50.00	0.000	.025	0.00	.0107	0.000	8.001
8.01	10.600	0.000	6.300	0.000	5.000	0.000	.025	0.00	.0285	0.000	9.000
8.02	4.100	0.000	1.100	0.000	5.000	0.000	.035	0.00	.0526	0.000	9.001
12.01	2.500	0.000	2.800	0.000	5.000	0.000	.025	0.00	.0201	0.000	10.00
12.02	16.600	0.000	1.000	0.000	5.000	0.000	.035	0.00	.1141	0.000	10.00
23.01	1.500	0.000	1.300	0.000	5.000	0.000	.060	0.00	.0438	0.000	11.00
24.01	0.7000	0.000	7.600	0.000	5.000	0.000	.060	0.00	.0122	0.000	12.00
25.01	0.9000	0.000	.2000	0.000	5.000	0.000	.060	0.00	.0854	0.000	13.00
13.01	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	11.00
13.02	1.700	0.000	1.100	0.000	5.000	0.000	.035	0.00	.0333	0.000	11.00
8.03	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.002
8.04	0.9000	0.000	.7000	0.000	5.000	0.000	.035	0.00	.0300	0.000	9.003
14.01	1.300	0.000	1.200	0.000	5.000	0.000	.060	0.00	.0423	0.000	14.00
8.05	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.004
8.06	0.8000	0.000	.0010	0.000	100.0	0.000	.035	0.00	.1055	0.000	9.005
16.01	1.500	0.000	2.100	0.000	5.000	0.000	.060	0.00	.0345	0.000	15.00
15.01	7.200	0.000	.3000	0.000	5.000	0.000	.035	0.00	.1348	0.000	16.00
8.07	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.006
8.08	1.200	0.000	.0010	0.000	100.0	0.000	.035	0.00	.1303	0.000	9.007
18.01	1.200	0.000	2.900	0.000	5.000	0.000	.060	0.00	.0261	0.000	17.00
17.01	6.200	0.000	.4000	0.000	5.000	0.000	.035	0.00	.1080	0.000	18.00
8.09	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.008
8.10	0.8000	0.000	.0010	0.000	100.0	0.000	.035	0.00	.1055	0.000	9.009
19.01	1.500	0.000	2.400	0.000	5.000	0.000	.060	0.00	.0322	0.000	19.00
20.01	1.400	0.000	3.100	0.000	5.000	0.000	.035	0.00	.0179	0.000	20.00
8.11	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.010
8.12	6.200	0.000	.0010	0.000	100.0	0.000	.035	0.00	.3060	0.000	9.011
22.01	7.400	0.000	.5000	0.000	5.000	0.000	.035	0.00	.1060	0.000	21.00
21.01	1.600	0.000	1.500	0.000	5.000	0.000	.060	0.00	.0422	0.000	22.00
21.02	1.700	0.000	1.100	0.000	5.000	0.000	.060	0.00	.0508	0.000	22.00
21.03	1.600	0.000	2.500	0.000	5.000	0.000	.060	0.00	.0327	0.000	22.00
21.04	6.700	0.000	3.400	0.000	5.000	0.000	.060	0.00	.0590	0.000	22.00
8.13	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	9.012
1.06	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	1.008
11.01	6.100	0.000	14.10	0.000	5.000	0.000	.035	0.00	.0181	0.000	23.00
11.02	3.700	0.000	4.700	0.000	70.00	0.000	.025	0.00	.0042	0.000	23.00
10.01	34.400	0.000	1.500	0.000	5.000	0.000	.035	0.00	.1362	0.000	24.00
10.02	.00001	0.000	.0010	0.000	0.000	0.000	.025	0.00	.0021	0.000	23.00
1.07	13.900	0.000	2.100	0.000	25.00	0.000	.035	0.00	.0361	0.000	1.009

Link Label	Average Intensity (mm/h)	Init. Loss #1 (mm)	Init. Loss #2 (mm)	Cont. Loss #1 (mm/h)	Cont. Loss #2 (mm/h)	Excess Rain #1 (mm)	Excess Rain #2 (mm)	Peak Inflow (m^3/s)	Time to Peak	Link Lag mins
3.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	24.787	41.00	0.000
2.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	47.513	41.00	0.000
2.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	72.300	41.00	18.40
2.03	66.880	10.00	0.000	2.500	0.000	119.14	0.000	80.092	59.00	13.70

2.04	66.880	10.00	0.000	2.500	0.000	119.14	0.000	82.613	73.00	0.000
1.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	38.213	52.00	0.000
1.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	113.31	72.00	27.00
5.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	27.459	40.00	0.000
4.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	11.620	53.00	0.000
1.03	66.880	10.00	0.000	2.500	0.000	119.14	0.000	123.07	99.00	18.20
7.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	10.482	37.00	0.000
6.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	12.136	36.00	0.000
1.04	66.880	10.00	0.000	2.500	0.000	119.14	0.000	124.86	117.0	20.50
1.05	66.880	10.00	0.000	2.500	0.000	119.14	0.000	129.39	138.0	0.000
9.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	6.512	39.00	12.00
9.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	10.696	36.00	0.000
8.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	6.013	40.00	8.100
8.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	7.490	47.00	0.000
12.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	1.402	40.00	13.80
12.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	5.803	54.00	0.000
23.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.5070	45.00	0.000
24.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.4002	39.00	0.000
25.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.1535	81.00	0.000
13.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.9613	41.00	5.800
13.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.7559	80.00	0.000
8.03	66.880	10.00	0.000	2.500	0.000	119.14	0.000	13.539	48.00	4.600
8.04	66.880	10.00	0.000	2.500	0.000	119.14	0.000	13.821	53.00	0.000
14.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.4284	46.00	0.000
8.05	66.880	10.00	0.000	2.500	0.000	119.14	0.000	14.211	53.00	4.500
8.06	66.880	0.000	0.000	0.000	0.000	133.76	0.000	14.312	58.00	0.000
16.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.6162	41.00	0.000
15.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	1.416	69.00	0.000
8.07	66.880	10.00	0.000	2.500	0.000	119.14	0.000	15.972	58.00	5.000
8.08	66.880	0.000	0.000	0.000	0.000	133.76	0.000	16.112	63.00	0.000
18.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.5669	41.00	0.000
17.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	1.429	65.00	0.000
8.09	66.880	10.00	0.000	2.500	0.000	119.14	0.000	17.776	63.00	4.300
8.10	66.880	0.000	0.000	0.000	0.000	133.76	0.000	17.890	67.00	0.000
19.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.6495	41.00	0.000
20.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.7749	40.00	0.000
8.11	66.880	10.00	0.000	2.500	0.000	119.14	0.000	18.421	67.00	9.500
8.12	66.880	0.000	0.000	0.000	0.000	133.76	0.000	18.925	77.00	0.000
22.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	1.785	63.00	0.000
21.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.5714	45.00	5.900
21.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.5212	46.00	5.600
21.03	66.880	10.00	0.000	2.500	0.000	119.14	0.000	0.6953	41.00	9.800
21.04	66.880	10.00	0.000	2.500	0.000	119.14	0.000	2.551	44.00	0.000
8.13	66.880	10.00	0.000	2.500	0.000	119.14	0.000	21.509	77.00	0.000
1.06	66.880	10.00	0.000	2.500	0.000	119.14	0.000	136.57	138.0	12.90
11.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	3.691	37.00	7.800
11.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	4.761	34.00	0.000
10.01	66.880	10.00	0.000	2.500	0.000	119.14	0.000	9.531	51.00	0.000
10.02	66.880	10.00	0.000	2.500	0.000	119.14	0.000	13.805	46.00	12.90
1.07	66.880	10.00	0.000	2.500	0.000	119.14	0.000	138.40	151.0	0.000