NORTH TUNCURRY
LOWER WALLAMBA RIVER
FLOOD STUDY

APRIL 2014

J:\Storage\Closing\29026\Admin\LetterApril2014.docx

UrbanGrowth NSW
Level 1, 24-30 Wharf Street
Forster
NSW 2428

23 April 2014

Attention: **Mr Michael Pring**
Development Director

Dear Michael,

Re: Clarifications regarding August 2010 Wallamba River Flood Study

In August 2010 WMAwater produced the Final version of a Report titled *North Tuncurry, Lower Wallamba River Flood Study*. This report was produced based on the best available information at the time. However in the period from August 2010 until April 2014 there has been a number of changes to the names of government departments, the study area of the project and to the relevant flood studies. This letter clarifies these changes.

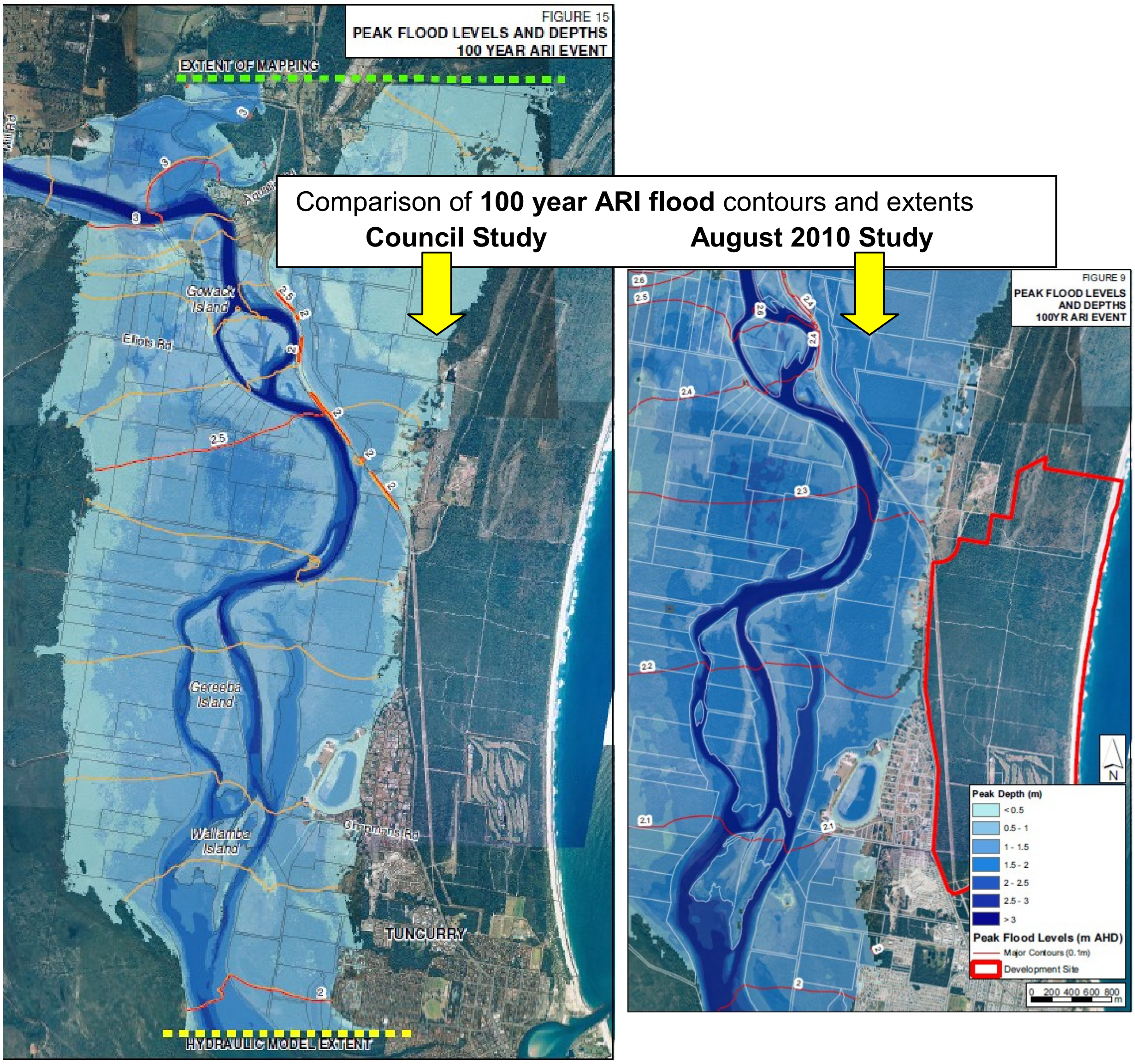
1. The August 2010 report was produced for Landcom which is now known as UrbanGrowth NSW. The report also refers to the Department of lands which is now known as NSW Trade and Investment.

2. The study area referred to in the report has been extended and is referred to as Lot 331 DP 1104340 and Lots 294 and 295 DP 43110 with an area of 615 ha. The area includes the golf course and the foredune extending to the mean high water mark. The figures in the report showing flood extents, velocities and other information cover this entire area.

3. The most significant change that has occurred since August 2010 has been the preparation of the Wallamba River Flood Study for Great Lakes Council. This Council study was undertaken as part of the Nabiac Floodplain Risk Management Study and Plan which was funded jointly by Council and the State Government. This document will go on public exhibition in 2014 with the Wallamba River Flood Study as Appendix B.

   The Council Wallamba River Flood Study extends further upstream than the August 2010 Flood Study and involved calibration of the modelling system to recorded levels at Nabiac. For this reason the Council Wallamba River Flood Study is more comprehensive and its results should be relied upon rather than the August 2010 report. However the differences between the two studies are small with the Council Wallamba River Flood Study producing slightly higher flood levels adjacent to the study area by up to 0.2m. This is exemplified in the Figures shown on the next page. This slight increase in flood level produces only a small lateral increase in flood extent and thus a comparison of the flood extents from the two reports appears to show very little difference.

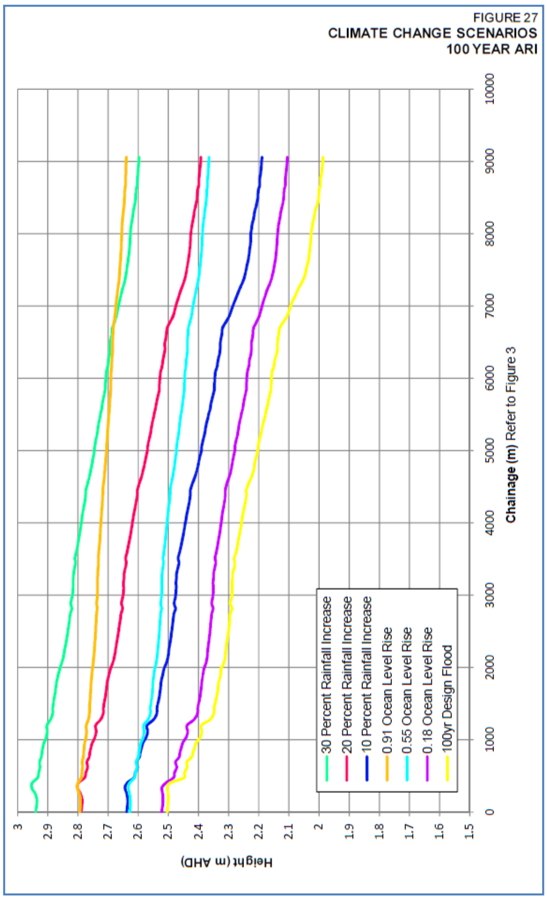
Webb, McKeown & Associates Pty Ltd (trading as WMAwater)
DIRECTORS
M K Babister BE(Hons), MEngSc GradDipMgt, FIEAust
R W Dewar BSc(Hons), MEngSc, MAIG, MIEAust
E J Askew BE(Hons), MIEAust
S D Gray BE, MEng
ASSOCIATES
R Hardwick Jones BE(Hons), MEngSc, MIEAust
ABN 50 366 075 980
Level 2, 160 Clarence St, SYDNEY NSW 2000
Phone: 02 9299 2855 Fax: 02 9262 6208
Email: enquiry@wmawater.com.au
Website: wmawater.com.au

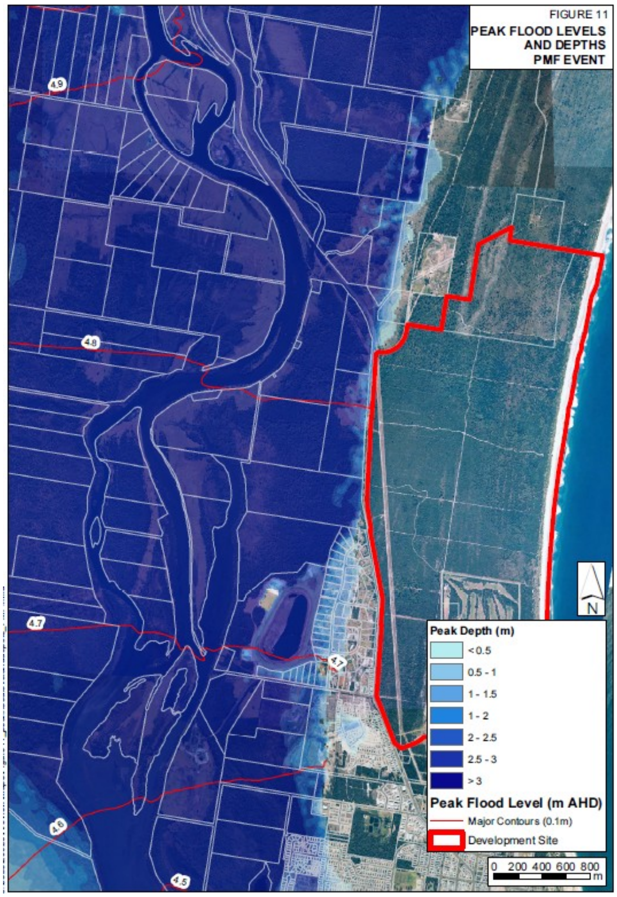


4. The August 2010 report analysed the effects of a 0.18m, 0.55m and 0.91m sea level rise (Section 3.4.2). Since that time the estimates of sea level rise changed to a 0.4m increase by the year 2050 and a 0.9m increase by the year 2100 (Flood Risk Management Guide of August 2010). However whilst these estimates are still reasonable the state government in September 2012 indicated that Councils should make their own estimates of sea level rise and the above mentioned rises are now not mandated by the state government.

5. The analysis on sea level rise in the August 2010 report was undertaken for the 100 year ARI event only. However all design flood events will be affected by sea level rise. The magnitude of the increase in flood level caused by sea level rise diminishes with distance from the ocean (as shown in Figure 27 - copy below). At Chainage 9000 the increase due to a 0.91m sea level rise is approximately 0.65m, at Chainage 6000 (Tuncurry golf course) the increase is 0.55m and at Chainage 0 it is 0.3m. In larger floods than the 100 year ARI the increase due to sea level rise will diminish more rapidly with distance. In a 200 year ARI event the increase in flood level due to a 0.91m sea level rise will still not increase flood levels sufficient to cause flooding within the study area. In the Probable Maximum Flood (PMF) an indicative flood level adjacent to the study area is from 4.6 m to

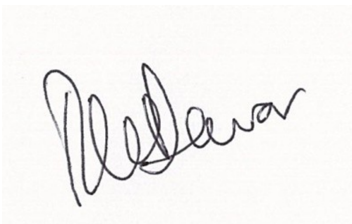
4.8 mAHD (Figure 11 - copy below) and does not cause flooding within the study area. No modelling has been undertaken for a 0.91m sea level rise in the PMF but based on the data available this will still not produce flooding within the study area.





Should you require any further clarification please do not hesitate to contact myself.

Yours faithfully,
WMAwater



R W Dewar
Director
WMAwater

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: 9299 2855
Fax: 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

NORTH TUNCURRY – LOWER WALLAMBA RIVER FLOOD STUDY

FINAL REPORT

AUGUST 2010

Project **North Tuncurry – Lower Wallamba River Flood Study**	**Project Number** **29026**
Client **LANDCOM**	**Client's Representative** John Sorby
Authors **Richard Dewar**	**Prepared by**
Date **2 August 2010**	**Verified by**

Revision	Description	Date
2	Final	2-Aug-10
1	1st Draft	11 May 2010

NORTH TUNCURRY – LOWER WALLAMBA RIVER FLOOD STUDY

TABLE OF CONTENTS

PAGE

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Department of Lands and Landcom have entered into a Project Delivery Agreement for the development of land at North Tuncurry on the NSW Mid North Coast which is nominated as a future urban release area in the Mid North Coast Regional Strategy 2006-31. The site lies between the Wallamba River and the coast and is generally on ground above 3 mAHD with remnant dune systems at 6 mAHD.

Background
Detailed investigations are required to determine the extent and nature of site constraints to allow planning of future development options. Specialist consultants have been engaged to undertake a detailed assessment of coastal processes, flooding, sea level rise, groundwater levels, the interrelationship of these issues and how development on the site may be affected by them. Any mitigation opportunities that are possible to offset to overcome the effects of these issues to enable future development will also be addressed.

This report provides a Flood Study for the Wallamba River and adjacent floodplain within the area of interest.

Literature Review
Initially a comprehensive literature review was undertaken of previous flood studies on the Wallamba River and of Wallis Lake. This indicated that the largest known flood was in April 1927 with peak levels of over 2 mAHD recorded at Tuncurry. An investigation was undertaken to determine the validity of this level as since installation of water level recorders in Wallis Lake in 1985, the highest recorded level is 1 mAHD in July 1999. The study confirmed that a level of approximately 2 to 2.3 m AHD is correct and was most probably due to some form of blockage (sand build up) at the mouth of Wallis Lake (before construction of the entrance breakwaters).

Approach
Design flood levels along the Wallamba River were obtained through construction of a hydrologic model (WBNM) that converts rainfall to runoff and a hydraulic model (TUFLOW) that converts runoff into peak levels and velocities.

Calibration
No calibration of the two models was possible due to the lack of suitable historic flood data. The downstream boundary of the model was obtained from water level hydrographs determined in the Wallis Lake Floodplain Risk Management Study which re defined flood levels in Wallis Lake.

Results
Design flood mapping is provided for the 5, 10, 20, 50, 100 and 200 year ARI design events as well as the Probable Maximum Flood (PMF). The 200 year ARI flood level, adjacent to the site, is a maximum of 2.5 mAHD and as the western boundary is generally above 5 mAHD there is no inundation of the site from floodwaters from the Wallamba River in events up to the 200 year

ARI. Even in a PMF (maximum flood level of 4.9 mAHD) there is no inundation of the site. However it should be noted that ponding of local runoff will produce flooding in low lying areas within the site, even in smaller events, and there may be low lying inlets that are not identified by the survey data which will allow some floodwaters to enter the site in the PMF.

Evacuation

Evacuation from the site to the north along The Lakes Way will be affected by flooding in a 5 year ARI event. However as the road is slightly elevated above the surrounding ground it is possible that access will not be entirely cut and become impassable until a greater magnitude event.

Climate Change

The possible impacts of climate change were also investigated by considering the change in the 100 year ARI flood level for ocean level rises of 0.18m, 0.55m and 0.91m as well as rainfall increases of 10%, 20% and 30%. Combinations of each scenario were also considered. In summary a 10% rainfall increase raises the flood levels by approximately 0.2m and an ocean level increase attenuates to approximately 70% of the increase at the mouth of Wallis Lake compared to the junction with the Wallamba River. At the upstream limit of the site the ocean level rise attenuates to approximately 40% of the increase at the mouth of Wallis Lake.

Even with a 0.91m rise in sea level and a 30% increase in rainfall there will be no inundation of the site in a 100 year ARI event on the Wallamba River.

1. INTRODUCTION

1.1. Background

The Department of Lands and Landcom have entered into a Project Delivery Agreement for the development of land at North Tuncurry on the NSW Mid North Coast (Figures 1 to 3). The agreement authorises the carrying out of site investigations for due diligence purposes to determine the feasibility of the site for residential development.

The site is Crown Land and Landcom, a state owned corporation of the NSW Government that seeks to provide leading edge developments in the areas of residential, commercial and industrial land uses within New South Wales, will manage the development of the site in consultation with the Department of Lands.

Detailed investigations are required to determine the extent and nature of site constraints to allow planning of future development options. The North Tuncurry site is nominated as a future urban release area in the Mid North Coast Regional Strategy 2006-31. The Department of Lands allocates lands on a demonstrated need basis with a strong emphasis on multiple use and the principles of sound asset and conservation management. The site provides a unique opportunity for the Department of Lands to optimise the use of Crown Land for the benefit of the community.

In its development role Landcom will undertake a community building project that promotes sustainable urban form, local economic development and the protection of natural and cultural resources.

Specialist consultants have been engaged to undertake a detailed assessment of coastal processes, flooding, sea level rise, groundwater levels, the interrelationship of these issues and how development on the site may be affected by them. Any mitigation opportunities that are possible to offset the effects of these issues to enable future development will also be addressed.

This report provides an assessment of the flooding and climate change issues for the Wallamba River and adjacent floodplain.

1.2. Site Description

The North Tuncurry project site is situated on the NSW Mid North Coast, approximately160 kilometres north of Newcastle and 320 kilometres from the Sydney CBD (Figure 1) within the local government area of Great Lakes Council. It is within the Wallis Lake catchment area that drains to the Pacific Ocean between the towns of Forster and Tuncurry (Figure 2).

The site of 555.2 hectares has title in Lot 331 in Deposited Plan 1104340 (Figure 3). The land lies east of the Lakes Way (the main road connecting Tuncurry to Taree) and extends approximately 4 kilometres north from the town of Tuncurry and 1.5 kilometres east to the Mean High Water Mark (MHWM) along the Nine Mile Beach.

The potential development site identified in the Great Lakes Council Conservation and Development Strategy 2003 is a smaller area of approximately 430 hectares within Lot 331 (Figure 3). The development site does not include the Forster Tuncurry Golf Course which is comprised in Lot 294 DP 43110 (Figure 3). The site is bordered to the south by the Great Lakes College campus, a combined High School and TAFE facility, and to the north abuts the Great Lakes Council Waste Management Facility.

The site topography varies from remnant sand dunes in the west through to more defined undulating dunes in the east. The development site does not include the area from the fore-dune to the MHWM but this area is included in Lot 331. Figure 3 indicates that the ground is largely above 3m AHD.

The majority of the site is vegetated by a regrowth of a coastal heath land (Banksia) community with some areas of open Blackbutt Forest and stands of remnant pine trees. From approximately 1916 to 1956 the site was cultivated and worked for the production of pine trees in a Prisons Afforestation programme. For a short time during the 1960’s an airstrip operated in the south-western part of the site.

The site is burdened in the south west by an easement for a transmission line and proposed easement for a sewage pipeline. A power transmission line that traverses Lot 331 in the west is apparently not contained in an easement.

1.3. Site Investigation

The future development of the site must be consistent with applicable planning legislation and policies, which may include but are not limited to:

- Environmental Planning and Assessment Act NSW 1979, as amended,
- Mid North Coast Regional Strategy 2006 – 31,
- Great Lakes Council Forster/Tuncurry Conservation & Development Strategy 2003,
- The legislation & policy listed in Table A1.1 of the above Conservation & Development Strategy 2003.

An initial due diligence programme has been conducted for business feasibility purposes. This more detailed site investigation is being undertaken to address major risks to development that may have a severe affect on or limit the potential of the site. The assessment of those risks is fundamental to the forward planning process. The issues identified by the Project Control Group as key project ‘triggers’ are:

- preliminary investigation and advice on the impacts of climate change,
- newly legislated or promulgated climate change policies of Governments,
- coastal geomorphology,
- site ecology, and

- bench marking world's best practice coastal development.

Other issues related to sea level rise that may require comment include flooding, road inundation and evacuation needs and site groundwater levels.

1.4. Objectives

The objective of the present study is to identify the potential for flooding and climate change to impact on the future development of all or part of the site. The interrelationship of flooding, coastal processes and groundwater, together with climate change will be evaluated as part of the assessment but in a separate report.

The present report will also identify any off-site or on-site mitigation works or activities that could be reasonably undertaken to protect against the impact arising from flooding and climate change and how those opportunities might improve or increase the developable potential of the site.

The tasks required by the flood assessment component include:

- Review all relevant legislation and policies related flooding and the latest advice on climate change in regard to sea level rise and rainfall intensities.
- Review all relevant studies related to the site in relation to flood management.
- Based on the above information adopt a range of parameters applicable to the assessment of site constraints.
- Identify the impacts of the nominated hazards on development of the site, under existing and projected climate change scenarios to 2100.
- Identify what mitigation measures can be implemented to optimise the developable area.
- Prepare a report outlining the study investigations and findings.

2. BACKGROUND

2.1. Previous Studies

A summary of previous relevant investigations is provided below.

2.1.1. Wallamba River Flood Study (January 1985) - Reference 1

This Flood Study defined design flood levels along the Wallamba River from approximately 1 kilometre upstream of Nabiac to 1 kilometre downstream of Failford. Major flooding occurred in 1927, 1929 and 1947 but only very limited data are available of the smaller floods. The more recent events of 1978 and 1983 were relatively minor and few peak flood levels are known. The study notes that there is a river gauge approximately 5.5 kilometres upstream of Nabiac but the 1978 flood exceeded the highest flow gauging and thus was of little value for calibration of the hydrologic model. The study produced the most comprehensive record of historical flood levels along the Wallamba River and these are reproduced in Table 1.

Table 1: Historical Flood Data from Reference 1 (Refer Figure 3 for Location)

1927 Flood			
LOCATION No.	**FLOOD LEVEL (m AHD)**	**SOURCE**	**COMMENT**
11	5.56	Mr Elliot McMaster, occupier "Glen Ora"	
12	5.84	Mr Elliot McMaster, occupier "Glen Ora" as told to Mr Hodges, house occupier	
15	5.93	Mr Bob Campbell, Nabiac (former occupier)	Reliability uncertain
17	7.30	Mr Norman Lulham, Nabiac	Local creek level
1929 FLOOD			
LOCATION No.	**FLOOD LEVEL (m AHD)**	**SOURCE**	**COMMENT**
1	1.84	Study by DJ Dwyer in 1978	
2	1.74	Study by DJ Dwyer in 1978	
3	1.92	Study by DJ Dwyer in 1978	
3	1.88	Study by DJ Dwyer in 1978	
17	7.86	Great Lakes Shire Council	Local creek level?
1947 FLOOD			
LOCATION No.	**FLOOD LEVEL (m AHD)**	**SOURCE**	**COMMENT**
7	3.35	Mr W Saxby, Willow Point Rd Failford	
17	7.15	Mr Norman Lulham, Nabiac	
1957 FLOOD			
LOCATION No.	**FLOOD LEVEL (m AHD)**	**SOURCE**	**COMMENT**
11	4.96	Mr Elliot McMaster, occupier "Glen Ora"	
15	5.63	Mr Bob Campbell, Nabiac (former occupier)	Reliability uncertain
16	4.81	Mr Clayton Everingham, Naviac	Considered reliable
1978 FLOOD			
LOCATION No.	**FLOOD LEVEL (m AHD)**	**SOURCE**	**COMMENT**
1	1.04		
3	1.39		
5	1.67	Mr Peter Johnson, resident Wallamba Ski Park	
5	2.69	Proprietor, Shalimar Caravan Park	Considered to be high

6	2.10		
9	2.75	Great Lakes Shire Council	
10	3.15 / 4.24?	Bayley, occupier "Belmont" (Great Lakes Council)	
11	2.50	Mr Elliot McMaster, occupier "Glen Ora"	Considered reliable
12	2.78	Mr David Hodges, occupier	Considered doubtful
13	3.75 / 4.05?	Mr Colman occupier (Great Lakes Shire Council)	
17	5.5	Mr Northam, occupier (Great Lakes Shire Council)	
18	5.8	Mr Abbott, occupier (Great Lakes Shire Council)	
20	13.0 – 13.2	Water Resources Commission gauge (209005) "The Old Sawmill"	
1983 FLOOD			
LOCATION No.	**FLOOD LEVEL (m AHD)**	**SOURCE**	**COMMENT**
1	1.16	Chapmans Road PWD MHR	
3	1.09	Darawank Bridge PWD MHR	
4	1.17	Gowack Island PWD MHR	
5	1.23	Wallamba Ski Park	Considered doubtful
5	2.06	Shalimar Caravan Park	
6	1.37	Bullocky Way PWD MHR	
8	1.68	Willow Point Road PWD MHR	
11	1.79	Mr Elliot McMaster, occupier "Glen Ora"	
14	2.43	Nabiac Street PWD MHR	
17	3.34	Nabiac Bridge PWD MHR	
19	5.49	Dargavilles Crossing PWD MHR	
20	10.94	The Old Sawmill PWD MHR	

Note: Many locations are not within the present study area and thus not shown on Figure 3

2.1.2. Forster/Tuncurry Flood Study (September 1989) - Reference 2

This study established design flood levels within Wallis Lake and its tributaries and indicated historic flood levels around Wallis Lake. A WBNM hydrologic model was established to provide hydrologic inputs. The lack of historical flow data meant this model could not be calibrated. A Wallingford hydraulic model was established and calibrated to recorded levels for the March 1978 flood event. Design ocean levels were determined and in conjunction with design inflows used to determine design flood levels.

2.1.3. Forster/Tuncurry Floodplain Management Study (April 1998) - Reference 3

The Management Study upgraded the Wallingford hydraulic model of Wallis Lake to a MIKE-11 model and included additional branches. The resulting design flood levels did not change.

2.1.4. Wallis Lake Floodplain Management Study – Foreshore Flooding Assessment (August 2001) - Reference 4

This study determined design flood levels as a result of wind wave action on Wallis Lake. The resulting levels were significantly higher than the still water levels derived in Reference 2.

2.1.5. Wallamba River Floodplain Risk Management Study for Nabiac, Failford & Minimbah Areas (June 2004) – Reference 5

This study is primarily a floodplain risk management study that determines the existing flood problem and examines various floodplain management measures. One dimensional hydraulic modelling (Mike-11) was undertaken to update the results from Reference 1. A significant limitation of the hydraulic modelling was the availability of survey data (cross sections) and the study largely used the survey from Reference 1.

2.1.6. Draft Wallis Lake Floodplain Risk Management Study – Flood Study Review (January 2010) - Reference 6

This study undertook a comprehensive review of flooding on the foreshore of Wallis Lake but the results only extended to the mouth of the Wallamba River at Tuncurry. A summary of the outcomes of the study are provided in Section 2.2.3.

2.2. Flood History

2.2.1. Causes

Flooding within Wallis Lake and the lower parts of the tributary rivers (Wallamba, Wallingat, Coolongolook and Wang Wauk) may occur as a result of a combination of factors including:

- an elevated ocean level due to an ocean storm surge, wave setup at the entrance and/or a high astronomic tide,
- rainfall over the lake and the tributary rivers entering Wallis Lake.

Flooding as a result of wind wave action within the lake and along the tributaries may also occur. This was analysed in the Wallis Lake Floodplain Management Study – Foreshore Flooding Assessment (Reference 4) but no results were provided along the Wallamba River. This is to be expected as the fetch (open stretch of water where waves can generate) along the Wallamba River is too short to produce a significant wave height, thus flooding due to wind wave action can be ignored at this locality.

One of the key considerations in modelling coastal systems is the probability of occurrence of a combined ocean and rainfall event and the relative magnitude of both. It is considered to be overly conservative to assume a 100 year ARI ocean event will occur concurrently with a 100 year ARI rainfall event. However there is no data available to accurately define a suitable approach. For this reason a number of scenarios were modelled in Reference 6 to determine the impacts on the peak lake level.

2.2.2. Review of Historical Flood Data

The accuracy of the approach used to determine design flood levels in a Flood Study is largely determined by the quality and quantity of available historical flood height data. All available historical data for the Wallamba River is provided in Section 2.1.1. However flood levels in the lower part of the along the Wallamba River are strongly influenced by levels in Wallis Lake.

Unfortunately historical flood data for locations around Wallis Lake are limited and only available for six events, as given in Table 1 (data taken from the 1989 Forster/Tuncurry Flood Study – Reference 2).

Table 2: Historical Flood Levels around Wallis Lake

Event	Number
16th April 1927	7 levels
2nd March 1956	1 level
28th April 1963	2 levels
13th March 1974	3 levels
18th May 1977	1 level (possibly may be 4th March)
20th March 1978	2 levels

This lack of data is surprising as it is known that other floods occurred as listed in Table 3.

Table 3: Known Flood Events on Wallis Lake for which no Level Data are Available

Event
8th February 1929
21st May 1943
18th June 1949
25th February 1955
19th February 1957
4th March 1976
4th March 1977 (possibly may be 18th May)
22nd March 1983

There is also a significant difference between the peak levels recorded at Tuncurry for the April 1927 event (up to 2.3 mAHD) and the peak recorded levels in all other historical events (maximum level of 1.1 mAHD). Whilst the peak level may have been missed in the past, since installation of an automatic water level recorder in the lake in July 1986, the lake level has never exceeded 1.1 mAHD.

The 1989 Flood Study (Reference 2) derived a peak 100 year ARI flood level in Wallis Lake, similar to the recorded 1927 level of 2.3 mAHD. However, this was only achieved through adopting a high ocean level (2.6 mAHD) coincident with the peak river inflows. Recent studies have suggested that a more appropriate peak ocean level (to occur in conjunction with a 100 year ARI rainfall event) is of the order of only 2 mAHD.

2.2.3. Review of Wallis Lake Historical Data – taken from Reference 6

Reference 6 undertook a review of the historical flood data in Wallis Lake, particularly for the April 1927 event, to provide a greater understanding of why the April 1927 flood reached approximately 2.3 mAHD and is over 1 m higher than all other recorded events.

Three theories for the high recorded levels for the April 1927 event were evaluated, namely:

- The flood never reached 2.3 mAHD and there is a datum or transcription error.
- The recorded levels were as a result of wind wave action and did not reflect the general water level of the Wallamba River or Wallis Lake.
- There was some blockage in the entrance channel or elsewhere which caused the floodwaters to back up.

The seven recorded April 1927 levels are shown below (taken from Reference 2) and listed in Table 4.

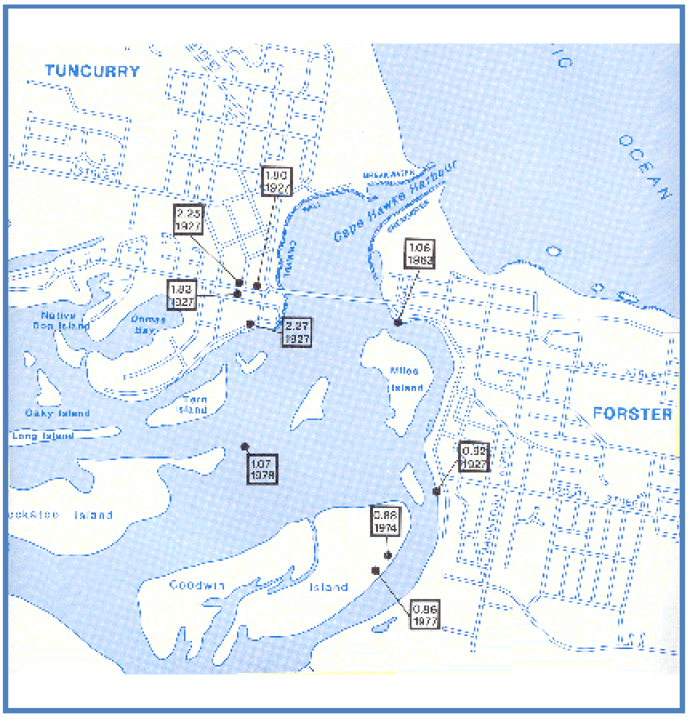


Table 4: April 1927 Recorded Levels around Wallis Lake (Reference 2)

Source	Flood Level (mAHD)	Comments (refer above plan for location)
Great Lakes Shire Council: "Tikki Marina", Forster	0.92	Possibly for the 1929 flood.
Mr M Constable: Old Church, Tuncurry	1.80	
Photo: Tennis Court, Tuncurry	1.83	Uncertain
10 Taree Street, Tuncurry	2.25	Tokelau House
Theatre (Memorial Hall), Tuncurry	2.27	To window sill, >0.76 m above floor.
Great Lakes Council - Broadwater *(not shown on Plan)*	2.45	Estimate of water level
Mrs E Gogerly, Whoota	3.04	Considered too high.

The level at the "Tikki Marina" is rejected as there is doubt whether it is from the 1927 or the 1929 event, so also is the level at Whoota which appears far too high. However, there is very little doubt that the Memorial Hall and 10 Taree Street levels are bona fide. The Northern Champion newspaper report of 23rd April 1927 article implies that:

- The floodwaters were most probably fast flowing (at some stage during the event).
- The level reached up to around to 2.0 mAHD at the Memorial Hall (floor at 1.23 mAHD + 0.76 m), thus disproving the theory that the flood never reached approximately 2.3 mAHD or there was some past datum or transcription error.
- Considerable damage was caused inside the Memorial Hall suggesting the water reached the window sill and the damage was due to inundation rather than wind wave action which would pass as the wave falls away.

The Great Lakes Advocate of 24th May 1984 indicates floodwaters lapping the verandah of Tokelau house (10 Taree Street, Tuncurry, floor level = 2.27 mAHD and indicative ground level at 1.57 mAHD). An article in the 30th April 1927 edition of the Northern Champion indicates that blockage of the entrance occurred. Clearly if blockage did occur this would explain why the April 1927 event reached such a high level (in 1927 there was no entrance rock breakwaters). Council minutes of 26 April 1927 detail the costs to repair damages to roads and bridges, it also mentions dredging. However it is surprising that no mention of blockage is made in the other newspaper articles or reports. One would have thought that Council would have attempted to “unblock” the entrance in the lead up to the peak or that the flood would have eroded a passage itself. Thus whilst this would appear to be the main cause of the high levels there will always be some doubt about why the flood reached the peak level it did.

The January 1985 Wallamba River Flood Study (Reference 1) quotes four levels for the April 1927 flood on the Wallamba River, one at Chapmans Road and three near Darawank Bridge. The levels range from 1.74 mAHD to 1.92 mAHD and appear to contradict the higher levels at Tuncurry.

The April 1927 flood was definitely a significant event on the Wallamba River as there are many reports in the papers, with accompanying photographs. Mention is also made in past reports of a significant flood in 1894 and a lesser one in 1962. Some reports say the 1890 and 1949 floods reached similar levels to 1927. However, the lack of other corroborating recorded data surrounding the lake for April 1927, together with the historical data on the Wallamba River (4 levels) and the two lower levels at Tuncurry (1.8 mAHD and 1.83 mAHD), casts doubt over the two high levels (approximately 2.3 mAHD). It should be noted that the original source of the two lower levels at Tuncurry cannot be substantiated, although the level at the church appears to be from a photograph (not found).

A possible reason for the lack of recorded data around the lake in April 1927 is that few residents would have been affected by the event, except at Tuncurry, as most of Forster is on slightly higher ground.

Notes of flood interviews undertaken in the mid 1980's indicate that there were reports of flooding at the site of the present Forster Keys and at the Coomba boatshed. These reports suggest that flooding occurred over the entire lake.

The available photographs at Tokelau house (10 Taree Street) at Tuncurry and Garrabingbi

Island indicate relatively slow moving water, though this photographic interpretation can be deceptive. This is in contrast to the Northern Champion's report of 23rd April 1927 which describes a *"torrent of raging waters"*. However, there did not appear to be any structural damage to the timber Memorial Hall which might be expected if the floodwaters were over 1 m deep and fast flowing. Also possibly, the fast flowing waters occurred as the entrance opened.

This distinction between the nature of the floodwaters is important. A relatively static water level suggests that the cause is the blockage of the entrance by the dredging works, as reported in the 30th April 1927 edition of the Northern Champion. A simple water balance indicates that with a 3 day average catchment rainfall of 300 mm as occurred in 1927, and assuming 50% losses, the lake level could have risen by some 2.8 m if the entrance was fully blocked.

Thus, even though the lake is 80 km^2 in area, the contributing catchment is large (1300 km^2) which means that a relatively small amount of runoff from the entire catchment can quickly fill the lake if there is a blockage at the entrance.

Reference 6 concluded:

- The rainfall in April 1927 was one of the highest on record.
- The April 1927 event reached approximately 2.0+ mAHD at Tuncurry and most probably across the entire lake.
- It is likely that the elevated level in 1927 was due to some form of blockage (sand bars, dredge or excavated spoil) at the entrance.
- It is likely that some wave set up and storm surge occurred in 1927.

It should be noted that the present entrance to the lake is significantly different to that in 1927, as well there is much less likelihood of wave set up at the entrance due to the relatively deep entrance. Furthermore, Council and DECCW would never allow a temporary or permanent situation to develop (siltation, dredging spoil) that would further restrict the outlet to the ocean.

2.2.4. Flood Record

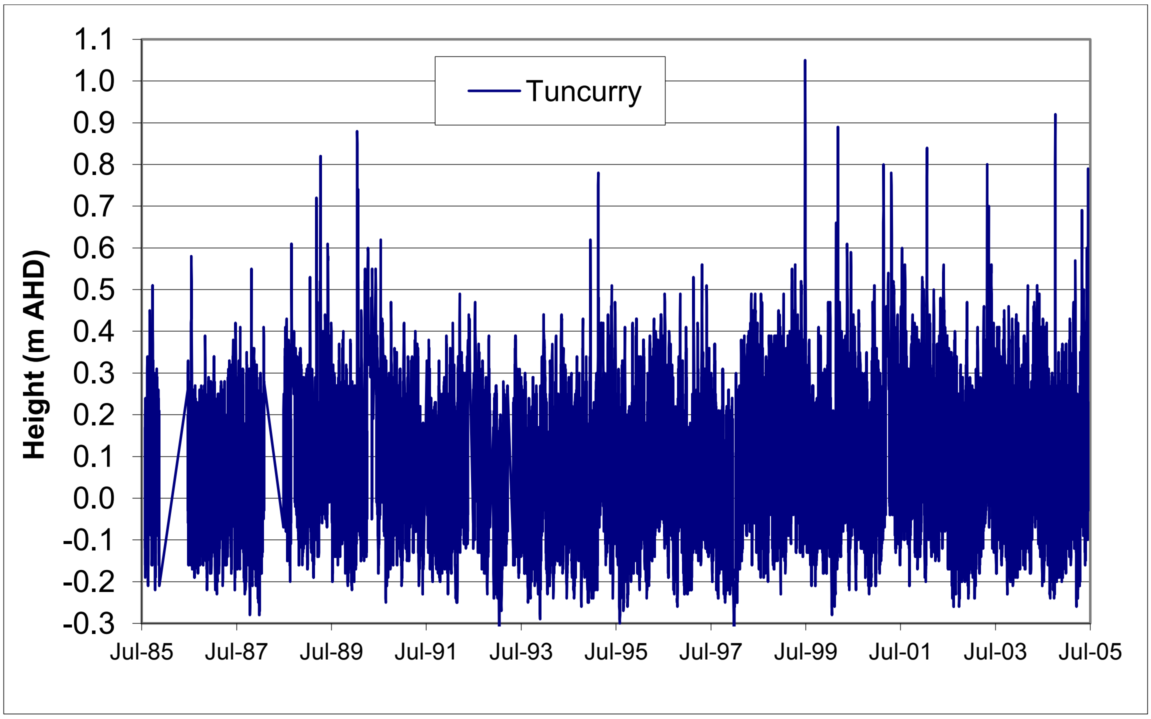
A number of historical flood levels for Wallis Lake are available and an analysis of these was undertaken in Reference 6 and summarised above. By far the largest of these is April 1927 which reached of the order of 2 to 2.3 mAHD. No other event (to the best of our knowledge) has subsequently raised lake levels above say 1.1 mAHD (an exact level is unknown).

A complete listing of the water level records is available from the Tiona and Tuncurry water level recorders (Figure 2). These records indicate that since inception in 1985 the lake level (Tiona) has not exceeded 0.7 mAHD and had only exceeded 0.5 mAHD 10 times (up until 2005), namely:

- 4th - 5th February 1990,
- 10th - 11th February 1990,
- 3rd August 1990,

- 14th - 16th July 1999. The peak level of 0.7 mAHD occurred on 16th July 1999,
- 22nd - 23rd March 2000,
- 3rd June 2000,
- 8th - 17th May 2003,
- 21st October 2004,
- 23rd - 25th March 2005,
- 21st - 22nd June 2005.

As the Tuncurry recorder is on the Wallamba River (Figure 2) it is affected by runoff events in the river and not just the peak water level in Wallis Lake. The record at Tuncurry from 1985 to 2005 is shown below.



A review of the record (20 years) indicates the following:

- Highest record = 14/15 July 1999 of 1.05m AHD,
- Days where water level exceeded 0.9m AHD =3,
- Days where water level exceeded 0.8m AHD =13,
- Days where water level exceeded 0.7m AHD =26.

2.3. Ocean Water Level Assessment

2.3.1. Review of Tidal Data

Tidal data are available from the Forster gauge as well as from Port Stephens. The Forster gauge, though obviously the closest to the outlet of Wallis Lake, is located within the entrance heads and for this reason does not accurately record the ocean tide levels. Port Stephens is the next closest tidal gauge and historical records for this gauge were obtained and analysed in

Reference 6.

The highest level recorded since 1986 at the Forster gauge is 1.0 mAHD in June 2005 (up until 2007) and at Port Stephens is 1.34 mAHD in June 1999.

The Port Stephens record (1985 to 2009) indicates:

- Days exceeded 1.3 mAHD=4,
- Days exceeded 1.2 mAHD=30,
- Days exceeded 1.1 mAHD=142,
- Days exceeded 1.0 mAHD=490.

The design ocean levels at Fort Denison (Sydney Harbour) based on a statistical analysis of the water level record are:

- 100y ARI = 1.50 mAHD,
- 50y ARI = 1.47 mAHD,
- 20y ARI = 1.43 mAHD,
- 10y ARI = 1.39 mAHD,
- 1y ARI = 1.28 mAHD.

No accurate estimates of ocean levels for events greater than the 100y ARI are available. However an indicative estimate for an extreme event is 1.9 mAHD. It should be noted that the highest astronomic tide in a year reaches approximately 1.1 mAHD. These levels are applicable along the NSW coast where there is no wave setup component.

The length of the tidal record for Fort Denison Sydney is over 125 years and although within Sydney Harbour, is considered to be a “deep still water” gauge location. This basically means that the gauge records the ocean astronomic tide plus ocean tidal anomaly components without significant interference from non-ocean effects such as breaking or broken waves, catchment runoff, shallow water effects, local wind shear, etc. Other “deep still water” gauge sites along the NSW coast include Coffs Harbour, Crowdy Head, Port Stephens (Tomaree), Jervis Bay and Batemans Bay.

In addition to the “deep still water” sites, there are also gauges located just inside estuary entrances that respond closely to ocean conditions but are also influenced to some (varying) extent by non-ocean effects. These gauges record the ocean astronomic tide and the tidal anomaly components, but also some wave and/or estuary effects.

2.3.2. Components of Ocean Water Level

The significant water level components affecting the ocean water level at the entrance to Wallis Lake are:

- astronomic tides are caused by the gravitational and centrifical forces between the earth and moon, and to a lesser extent the sun and other planets. They can be predicted with accuracy based on the harmonic movements of these bodies. Along the NSW open coast, astronomic tides are very similar in terms of their levels and timing. There are two high and two low tides per day, with a range of up to around 2.0 m during the summer and winter "King" tides,

- ocean tidal anomaly as a result of :
  - storm surge (barometric and wind stress effects), is the increase in ocean water level that occurs during storms as a result of inverse barometric pressure and wind stress. Barometric pressure causes a localised rise in ocean water levels of about 0.1 m for each 10hPA drop in pressure. Strong onshore winds produce surface currents that cause a build up of water against the coastline,
  - oceanographic effects (shelf waves, ocean currents, temperature variations),
  - wave setup occurs in the surf zone where the shoreward kinetic energy of the breaking and broken waves is converted to gravitational potential energy in the form of increased water levels. Wave setup is largely confined to the nearshore area and is highly dependent on factors such as the wave height, wave length, water depth and embayment slope.

  The ocean anomaly is recorded at a "deep still water" gauge as a variation from the predicted astronomic tide level (Recorded **-** Predicted **=** Residual). Figure 4 provides a summary of ocean anomalies at the Port Stephens gauge, however the record is not long enough for a reliable statistical analysis to determine design ocean levels and for this reason Fort Denison was used. The Fort Denison data indicates that since 1914 the maximum "deep still water" increase is around 0.6 m (May 1974) and that a 0.2 m level occurs for around 5% of the time, but a 0.4 m level occurs for less than 0.1 % of the time.

  A major flood producing storm event is likely to last several days and be associated with very low barometric pressure and strong onshore winds (as well as very heavy rain). Based on the above, it is reasonable to assume that the maximum tidal anomaly (storm surge plus oceanographic) during a flood event would be less than 0.6 m. However, because of the strong correlation between the flood/rainfall event and the conditions likely to produce a high storm surge, an anomaly level of greater than 0.4 m could be expected.

  Wave setup along exposed NSW beaches can be of the order of 1.5 m during very large energy wave climate conditions, but this setup is only maintained if the wave energy remains high for a sustained period of around an hour. "Deep still water" locations not in the breaker zone, such as the Fort Denison and Port Stephens gauge locations have negligible wave setup because there is no significant capacity for the waves to break and convert shoreward kinetic energy into increased water levels.

  Assuming sustained large energy wave breaking occurs across the Wallis Lake entrance during a major storm event, there should be some wave setup at the entrance. Based on the available information, the maximum likely wave setup during a major flood event is unlikely to be greater than 0.4 m.
- climate change. Based on climate modelling, increased Greenhouse gasses are

predicted to cause a rise in ocean levels of between 0.18 m and 0.91 m by the year 2100. These increases would develop progressively over the next 90 years. The increase in Greenhouse gasses is also predicted to change weather patterns. The predictions are preliminary and variable, but generally indicate a likelihood for increased storminess. The possibility of increased storminess could increase the recurrence of storm/flood events. This component is discussed further in Section 3.3.3.

Reference 6 undertook a detailed analysis of design ocean levels and the adopted levels are shown in Table 5.

Table 5: Adopted Design Peak Ocean Levels at Entrance to Wallis Lake

Design Event (ARI)	Fort Denison Design Ocean Level (mAHD)	Wave Setup (m)	Adopted Peak Ocean Level (mAHD) NO Climate Change
Extreme	1.90	0.40	2.30
100y	1.50	0.35	1.85
50y	1.47	0.33	1.80
20y	1.43	0.30	1.73
10y	1.39	0.28	1.67
5y	1.30 (estimate)	0.25	1.55

2.3.3. Ocean Levels in Conjunction with Design Flood Levels

The ocean level at the time of a major flood affect can have a significant impact on the resulting lake level. Thus for design flood analysis in Wallis Lake a coincident ocean level must be determined. The most rigorous approach to determine this is to undertake a probability analysis of the joint coincidence of rainfall and ocean induced flooding. This has been undertaken for some ocean entrances (Narrabeen Lagoon) but unfortunately the lack of a long and accurate oceanic and flood height record makes this approach of limited value. The generally accepted approach is to consider an envelope of two design scenarios:

- The **design ocean** level in conjunction with a more frequent rainfall event. Reference 6 adopted the 5 year ARI rainfall event (termed **Ocean Induced** flooding),
- The **design rainfall** event over Wallis Lake in conjunction with a more frequent ocean event. Reference 6 adopted a “modified normal tide” which was a synthetic tide oscillating between 0 mAHD and 1 mAHD in 12.5 hour cycles. This tide represents a normal tide with a 0.4 m anomaly added uniformly (termed **Rainfall Induced** flooding).

Reference 6 undertook the above analysis and the resulting adopted design peak water levels in Wallis Lake are given in Table 6.

Table 6: Wallis Lake Design Flood Levels (mAHD) assuming **NO** Climate Change

Event (ARI)	Seaward limit of Breakwater to Bridge	Upstream of Bridge to within Wallis Lake
Extreme	2.37*	4.41
200y	1.83*	2.15
100y	1.83*	1.95
50y	1.78*	1.74
20y	1.71*	1.52
10y	1.65*	1.46*
5y	1.54*	1.35*

* Peak level due to design ocean tide in combination with a low inflow

2.4. Survey Data

The establishment of a hydraulic model requires survey of the river channel (bathymetry) as well as the overbank floodplain. This was obtained from a bathymetric survey of Wallis Lake and the Wallamba River that was obtained for use in Reference 6 (it was obtained over several years) from the NSW Public Works as well as ALS (Airborne Laser Survey) provided by Great Lakes Council in 2009. This combination of survey provided a highly accurate definition of the Wallamba River channel and floodplain.

3. MODELLING

3.1. Approach

A diagrammatic representation of the Flood Study process is shown in Diagram 1. As the Wallamba River discharges into Wallis Lake the design water levels in Wallis Lake (as determined in Reference 6) have a significant bearing on the water levels along the Wallamba River. In Reference 6 a hydrologic model (WBNM) was established for the entire catchment and used to convert rainfall into streamflow for input to a 2D hydraulic (SOBEK) model of Wallis Lake. To ensure confidence in the results, the WBNM model used the same calibration parameters as Reference 2 and the SOBEK model was calibrated to two historical events. With the limited amount of rainfall and flood data available and given the lack of any stream gauging, the model calibration process focussed on ensuring the SOBEK model stage hydrographs were compatible with the recorded data. The calibrated SOBEK model was then used to quantify the design flood behaviour for a range of design storm events up to and including the Probable Maximum Flood (PMF).

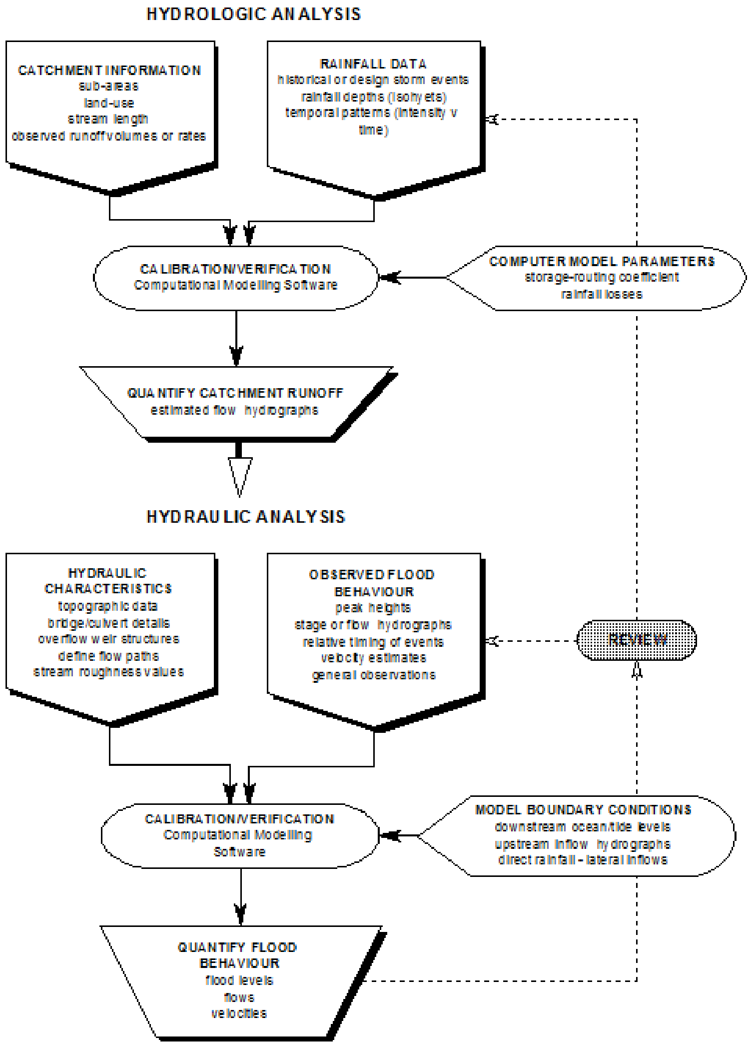


Diagram 1: **Flood Study Process**

For the present Wallamba River Flood Study the same hydrologic model (WBNM) was adopted but a TUFLOW hydraulic model was used instead of SOBEK. The downstream boundary of the TUFLOW model was taken as the upstream boundary of the SOBEK model. This meant that water level hydrographs from the various design events and climate change scenarios from the SOBEK model could be included as the downstream boundary of the TUFLOW model.

Calibration of the hydrologic or hydraulic models was not possible due to the lack of recorded historic water levels for major flood events. The data that is available (April 1927) cannot be used as it is considered that the high levels were due to some form of blockage which would not occur today due to construction of the entrance breakwaters.

3.2. Hydrologic Model

Hydrologic models suitable for design flood estimation are described in AR&R 1987. In current Australian engineering practice, examples of the more commonly used runoff routing models include RORB, RAFTS and the Watershed Boundary Network Model (WBNM). These models allow the rainfall depth to vary both spatially and temporally over the catchment and readily lend themselves to calibration against recorded streamflow data (if available).

Either model is equally suitable and as a WBNM model was used in Reference 2, a WBNM model was established in Reference 6 for determining flows and this same model was used in this present study. The catchment was divided into sub_catchments (Figure 2) within the four major river systems (Wallingat, Wang Wauk, Coolongolook and Wallamba Rivers) as well as the lake itself. Model parameters were set to the same as those used in Reference 2.

‘C’ Lag factor	1.29
Initial loss	21 mm
Continuing loss	2.5 mm/h

The absence of streamflow data meant calibration of these parameters could not be undertaken.

For the present study the sub catchment layout of the WBNM model was slightly modified in the lower part of the Wallamba River adjacent to the study area to more accurately define the locations of the inflows.

3.3. Hydraulic Model

A two Dimensional (2D) SOBEK model was established in Reference 6 for the main body of Wallis Lake. The southern section of the lake was represented with a storage node, and the northern section using two grids. A 100 m cell size grid covered the majority of the area, whilst a finer 10 m cell grid was used in the entrance area to a point approximately midway along Point Road at Tuncurry. Inflow hydrographs for the river tributaries were generated from the hydrologic (WBNM) model. Tidal conditions at the entrance were input at the mouth of the entrance and included both synthetic and historical tidal data.

Calibration of the hydraulic model was limited as there have been no significant floods since 1985 (highest lake level only 0.7 mAHD). Two recent events, May 2003 and March 2005 were chosen for calibration as there was available pluviometer data. Both events were relatively small in size, and predominantly tide dominated events, though May 2003 had significantly more rainfall than March 2005. A reasonable match to the recorded data was obtained but due to the relatively low peak level compared to the design events this calibration/verification is of limited value.

For the current Wallamba River Flood Study a 2D TUFLOW model was established rather than a 2D SOBEK model as TUFLOW is by far the most common 2D hydraulic model used in NSW and is the preferable model if extension of the model was subsequently required further upstream along the Wallamba River

The downstream boundary of the TUFLOW model was a water level hydrograph obtained from the respective SOBEK model run.

3.3.1. Design Parameters

Design rainfall data were calculated in accordance with Australian Rainfall and Runoff (AR&R) in Reference 6. Due to the large size of the Wallis Lake catchment, the effect of areal reduction of the rainfall needs to be accounted for as well as the areal variation in design rainfall across the catchment. A number of approaches are possible to account for these effects. The approach adopted was identical to that adopted in the Reference 2. Rainfall data were calculated from AR&R at five locations distributed across the catchment with the rainfall at the catchment centroid adopted across the entire catchment without any areal reduction fraction. As this centroid rainfall had the second lowest rainfall intensities it was considered that this approach accounted for any areal reduction and areal variability that would occur across the catchment.

The above approach produced identical 100 year ARI design flows to those provided in the Reference 2.

Design flow hydrographs were extracted from the WBNM model and the critical storm duration (the duration producing the highest peak level) was determined by using 100 year ARI inflows of various durations with a 0 mAHD static tide. The 36 hour duration was adopted as the critical duration and this was used for all other design events, except for the PMF where a critical duration of 24 hours was adopted.

Reference 6 describes the approach adopted to determine the starting level, tidal sequence, timing of rainfall inflows and adopted model parameters.

3.3.2. Results

The results of the hydrologic and hydraulic modelling for the 5, 10, 20, 50 100, 200 and 500 year ARI and Probable Maximum Flood design events are provided on Figures 5 to 26. More accurate information is available from the GIS shape files and output grids which have been provided to the client.

3.4. Climate Change

3.4.1. Description

The Greenhouse Effect results from the presence of certain gases in the atmosphere, these allow the sun's rays to penetrate to the earth but reduce the amount of energy being radiated back. It is this trapping of the reflected heat which has enabled life to exist on earth.

Since the early 1980's there have been concerns that increasing amounts of greenhouse gases resulting from human activity may be raising the average earth surface temperature. As a consequence, this may affect the climate and ocean level. The extent of any permanent climatic or ocean level change can only be established through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change evidence is emerging on the likelihood of climate change and ocean level rise as a result of increasing "greenhouse" gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase,
- the balance of evidence suggests human interference has resulted in climate change over the past century,
- the global ocean level has risen about 0.1 m to 0.25 m in the past century,
- many uncertainties limit the accuracy to which future climate change and ocean level rises can be projected and predicted.

The best available estimate of the projected ocean level rise along the NSW coast is from 0.18 m to 0.91 m by the year 2100.

3.4.2. Discussion

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of climate change, as the possible mechanisms are far from clear, and there is no indication that the changes would in fact increase design rainfalls for major storms. Even if an increase in total annual rainfall does occur, the impact on design rainfalls may not be adverse. There is some literature that suggests rainfalls may increase by up to 10%, however this information is not of sufficient accuracy for use as yet.

It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Any change in the ocean level will have an immediate and significant impact. This issue is complicated by other long term influences on mean ocean level changes. The available literature suggests that a gradual increase in ocean level is likely to occur with a rise of perhaps up to 0.5 m within the next 50 years. Results from Reference 6 indicate that any change to the ocean level results in a similar change to the peak lake level.

3.4.3. Analysis

As part of this study an assessment of the effects of a climate change induced ocean level rise and increase in design rainfalls was undertaken. The following scenarios were modelled for the 100 year ARI event with the results shown on Figures 27 to 29.

- **Rainfall Induced** flooding: increase in design rainfall of 10%, 20% and 30%. The results indicate a 10% increase in rainfall increases the peak water level by approximately 0.1m at the 5 year ARI and up to 0.2m at the 100y ARI in Wallis Lake. A 10% increase in design rainfalls exactly represents the increase from a 100 year ARI to a 200 year ARI event. It is also noted that the increase in rainfall from a 50 year ARI to 100 year ARI event is 10%. On the Wallamba River the respective increases in the 100 year ARI flood levels for the 10%, 20% and 30% increases are 0.2m, 0.4m and 0.6m (Figure 27). Recent literature indicates that rainfall increases of up to 30% may occur. This increase in rainfall may increase the 100 year ARI lake level by up to 0.6 m. As yet there is no substantial scientific evidence that an increase of this magnitude will occur.
- **Rainfall Induced** flooding: increase in ocean level of 0.18m, 0.55m and 0.91m. The results indicate that an increase in ocean level produces an increase in peak water level of approximately 70% of the ocean level rise at the junction of the Wallamba River with Wallis Lake with the increase attenuating further to approximately 40% at the upstream limit of the site (Figure 27).
- **Rainfall Induced** flooding: combination of increase in design rainfall and increase in ocean level. This represents approximately a summation of the individual increases however the 30% rainfall increase represents only a 0.1m increase in level (rather than a 0.2m increase) in combination with a 0.91m ocean rise. Figure 28 indicates the change in extent of inundation for the 0.91m ocean rise and the 10%, 20% and 30% rainfall increases. There is only a small change in flood extent as the land rises relatively steeply on the east bank of the Wallamba River.

The effect of a climate change ocean level rise on **Ocean Induced** flooding was not considered as the **Rainfall Induced** flooding is the mechanism producing the greatest 100 year ARI flood levels on the Wallamba River for the given climate change scenarios. However it should be noted that for the smaller design flood events the **Ocean Induced** flooding plus climate induced ocean level rise may produce higher food levels than **Rainfall Induced** flooding. Also for the 100 year ARI event the **Ocean Induced** flooding may produce higher flood levels if an ocean level rise greater than 0.9m is assumed.

3.4.4. Actions to Mitigate Climate Induced Increase in Flood Levels

For new developments there are a range of possible mitigation measures to protect them from increased flood damages due to climate change. The simplest is to increase the Flood Planning Level to take into account climate change and this has already been undertaken by Council in their Draft Climate Change Policy (this policy has now been adopted by Council) which states:

- Council adopt as a matter of policy, a sea level rise of 0.91m to the year 2100 with a linear rise over the intervening period.
- On large subdivisions and rezonings where there is limited impact on adjoining properties, ground levels be raised to a level equivalent to the 100 year ARI flood level with allowance for climate change to the year 2100. Developments on this land be required to have floor levels 500mm higher than the 100 year ARI flood level.
- For infill development floor levels be raised to 500mm above the 100 year ARI flood level with allowance for climate change to the year 2060 unless such house raising will have an adverse impact on access, neighbouring properties or the surrounding streetscape.
- In conjunction with any application involving extensive areas of filling, the applicant be required to submit a flood study to indicate that such filling will not adversely impact on storm flows or flooding in the area. Such studies to be based on full allowance for climate change.
- Applications upstream of the river mouth be required to submit a flood study to indicate flood levels including any impacts from climate change to enable assessment by Council officers.

3.5. Conclusions

Results
Design flood mapping is provided for the 5, 10, 20, 50, 100 and 200 year ARI design events as well as the Probable Maximum Flood (PMF). The 200 year ARI flood level, adjacent to the site, is a maximum of 2.5 mAHD and as the western boundary is generally above 5 mAHD there is no inundation of the site from floodwaters from the Wallamba River in events up to the 200 year ARI. Even in a PMF (maximum flood level of 4.9 mAHD) there is no inundation of the site. However it should be noted that ponding of local runoff will produce flooding in low lying areas within the site, even in smaller events, and there may be low lying inlets that are not identified by the survey data which will allow some floodwaters to enter the site in the PMF.

Evacuation
Evacuation from the site to the north along The Lakes Way will be affected by flooding in a 5 year ARI event. However as the road is slightly elevated above the surrounding ground it is possible that access will not be entirely cut and become impassable until a greater magnitude event.

Climate Change

The possible impacts of climate change were also investigated by considering the change in the 100 year ARI flood level for ocean level rises of 0.18m, 0.55m and 0.91m as well as rainfall increases of 10%, 20% and 30%. Combinations of each scenario were also considered. In summary a 10% rainfall increase raises the flood levels by approximately 0.2m and an ocean level increase attenuates to approximately 70% of the increase at the mouth of Wallis Lake compared to the junction with the Wallamba River. At the upstream limit of the site the ocean level rise attenuates to approximately 40% of the increase at the mouth of Wallis Lake.

Even with a 0.91m rise in sea level and a 30% increase in rainfall there will be no inundation of the site in a 100 year ARI event on the Wallamba River.

4. REFERENCES

1. Public Works Depertment NSW

   Wallamba River Flood Study
   PWD Report No 84021, January 1985

2. Public Works Depertment

   Forster/Tuncurry Flood Study
   PWD Report No 88036, September 1989

3. Great Lakes Council

   Forster/Tuncurry Floodplain Management Study
   NSW Department of Land and Water Conservation, April 1998

3. NSW Department of Land and Water Conservation

   Wallis Lake Floodplain Management Study – Foreshore Flooding Assessment
   Manly Hydraulics Laboratory, August 2001

5. Great Lakes Council

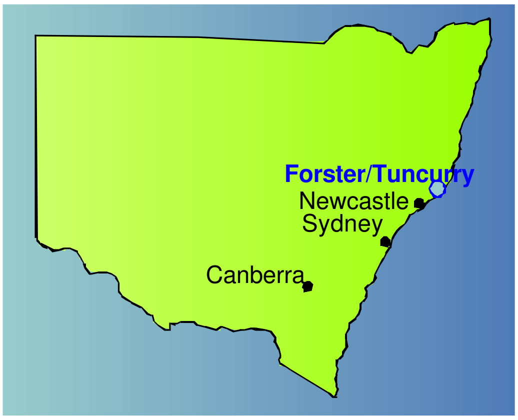
   Wallamba River Floodplain Risk Management Study for Nabiac, Failford & Minimbah Areas
   Department of Infrastructure, Planning and Natural Resources, June 2004

6. Great Lakes Council

   Wallis Lake Floodplain Risk Management Study – Flood Study Review
   WMAwater, Draft Report, January 2010

Figures

FIGURE 1
CATCHMENT MAP



N

5 0 5 10 15 20 25km

SCALE

FIGURE 2
WALLIS LAKE SUB-CATCHMENTS

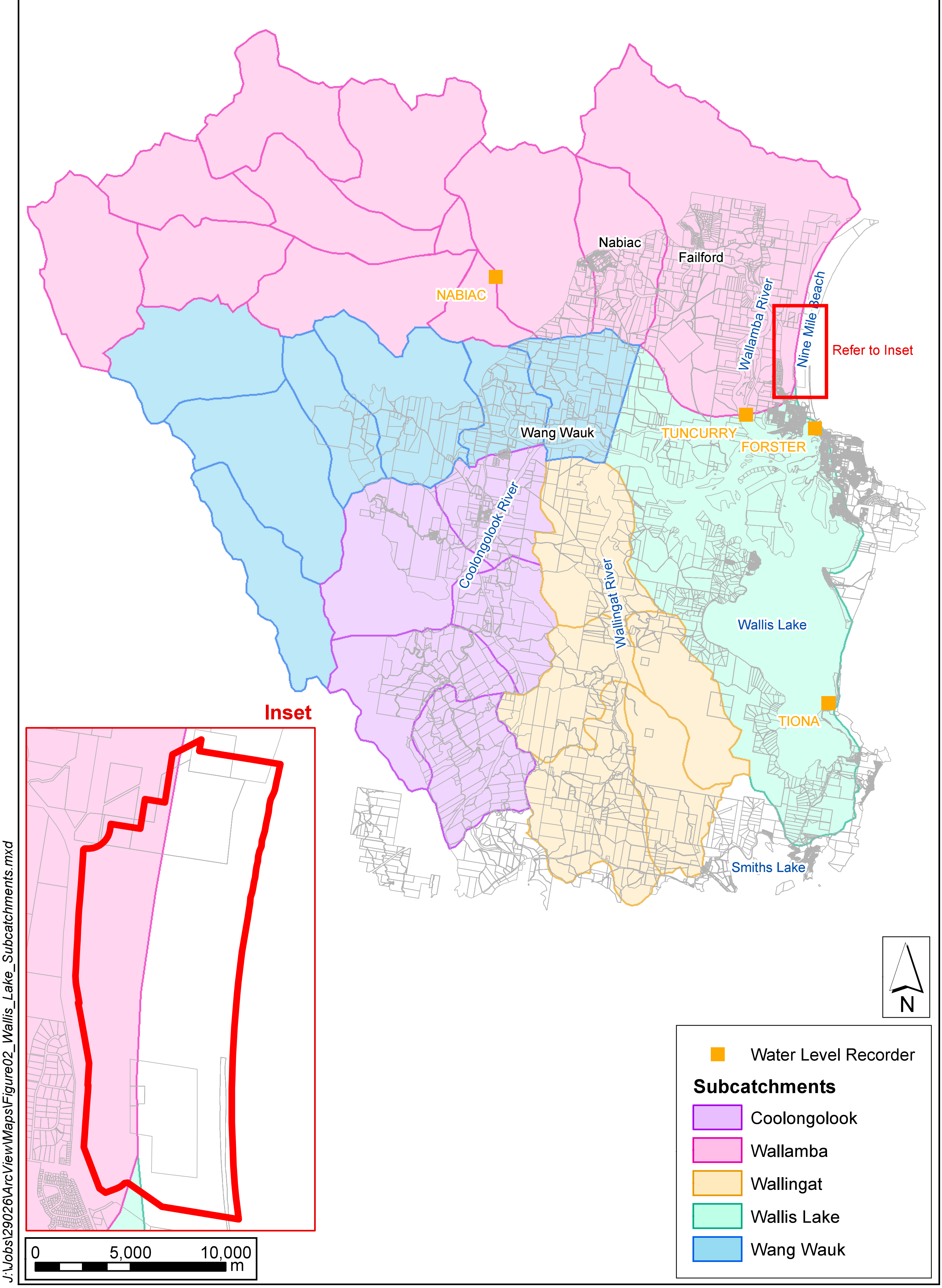


FIGURE 3a
NORTH TUNCURRY DEVELOPMENT SITE

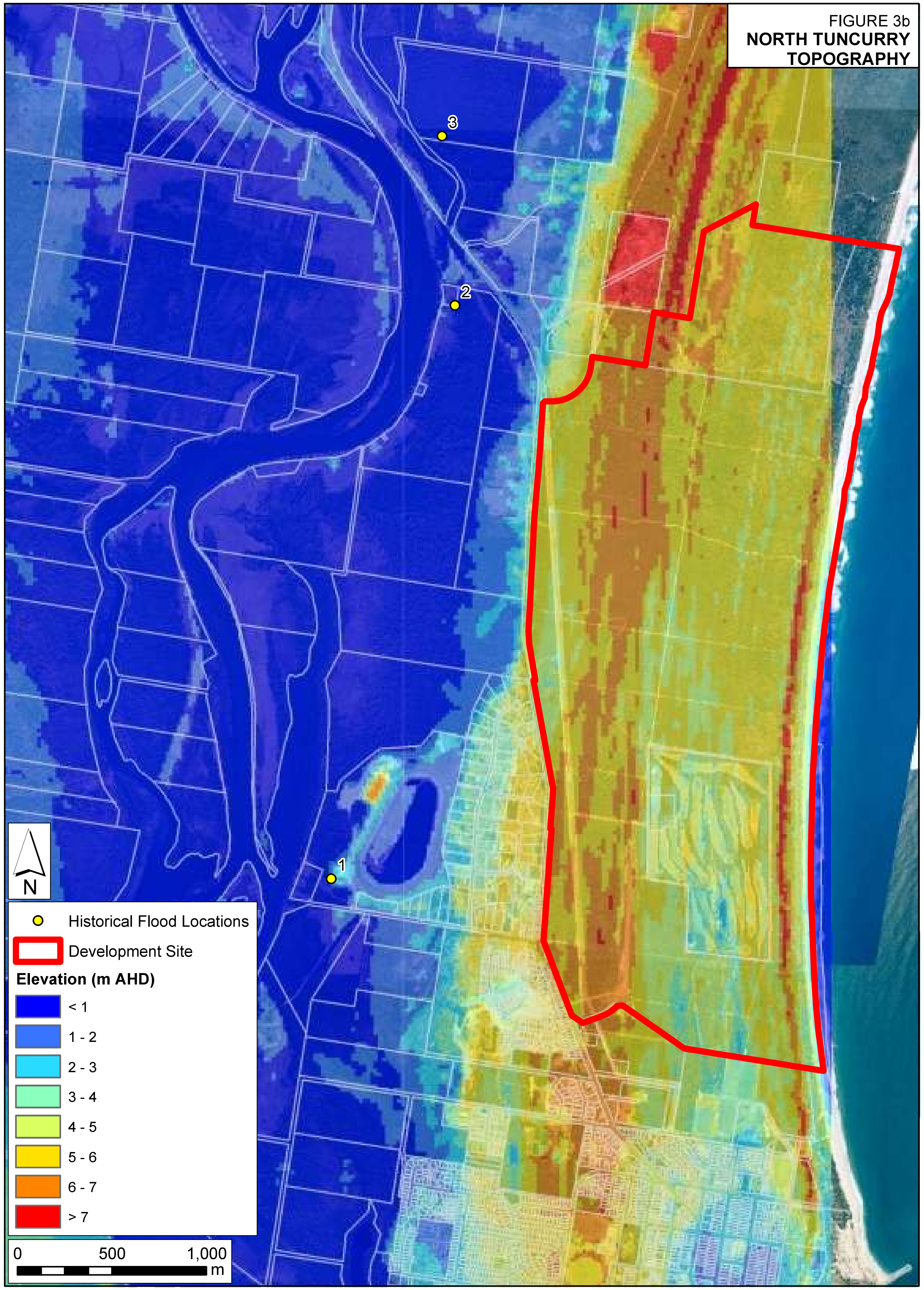
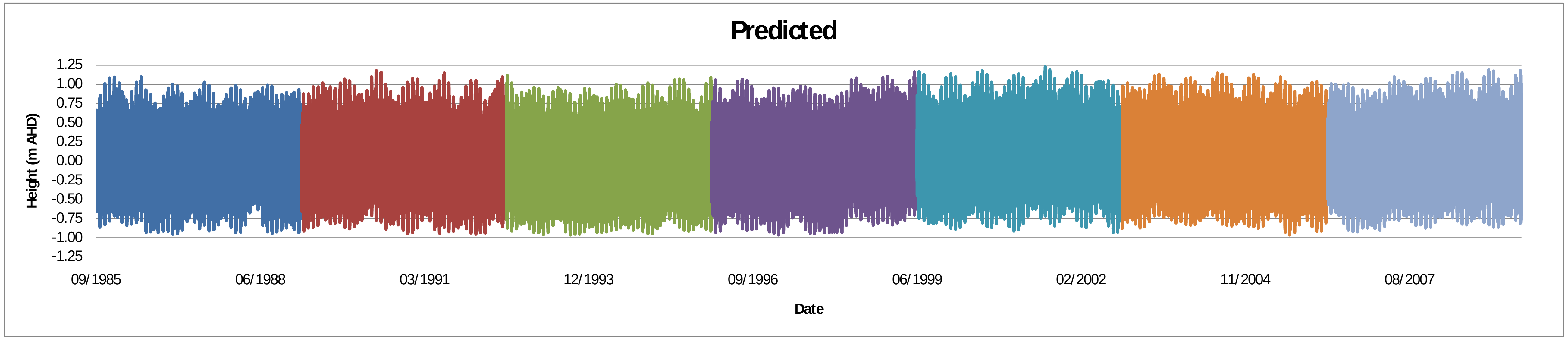
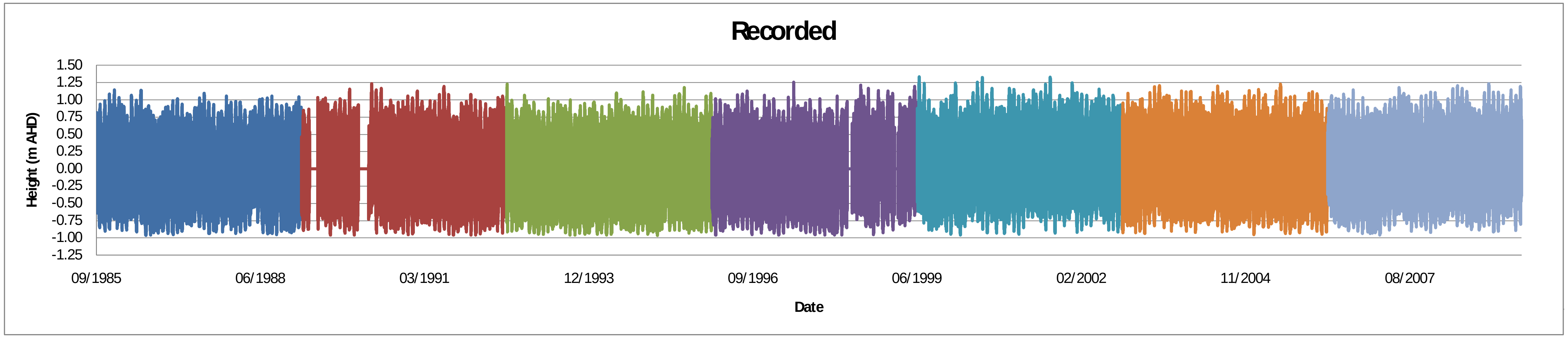
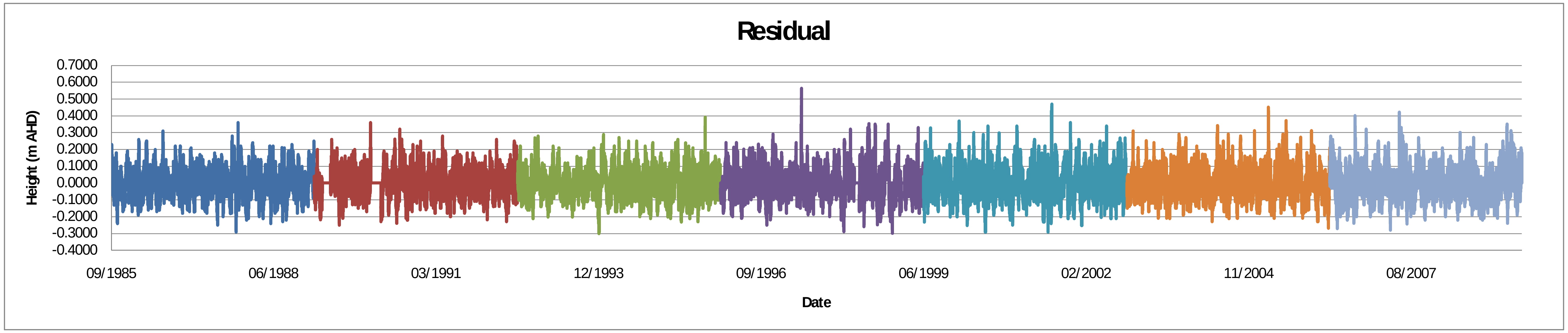


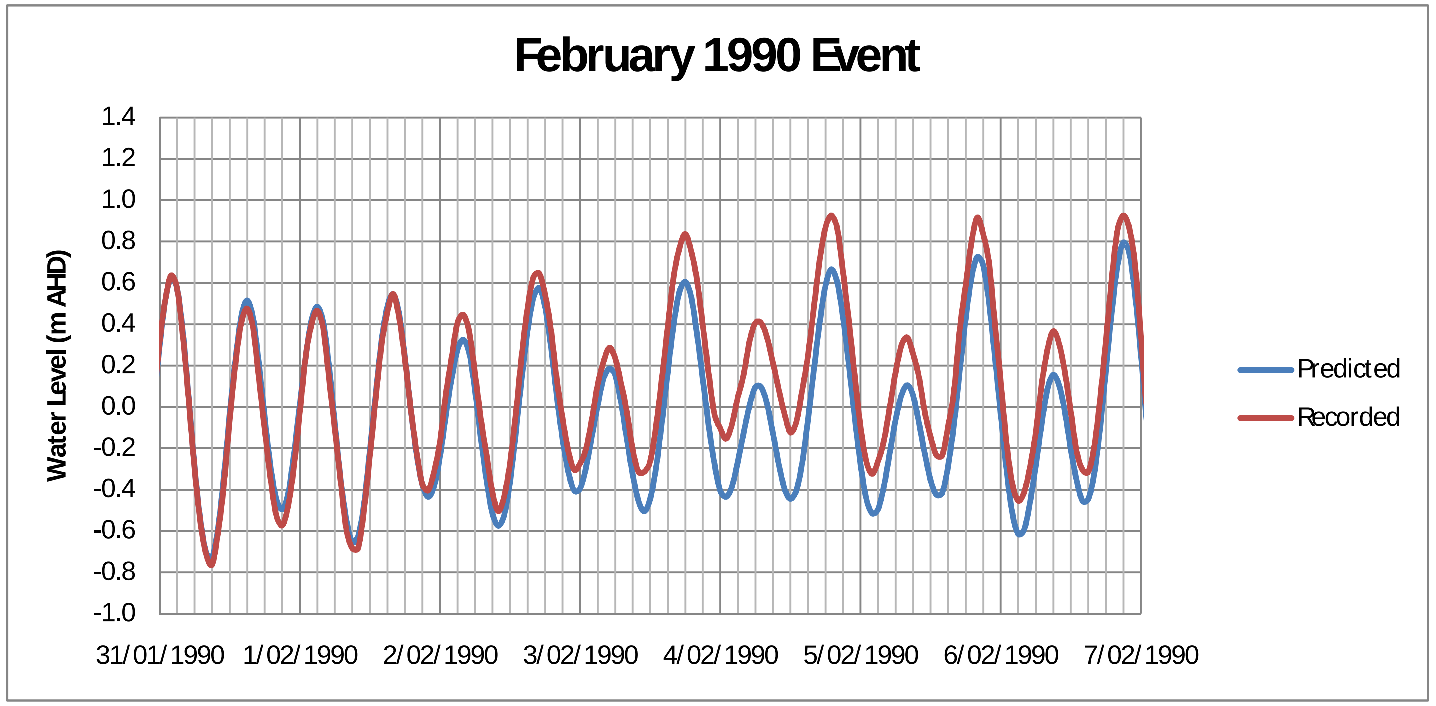
FIGURE 3b
NORTH TUNCURRY TOPOGRAPHY

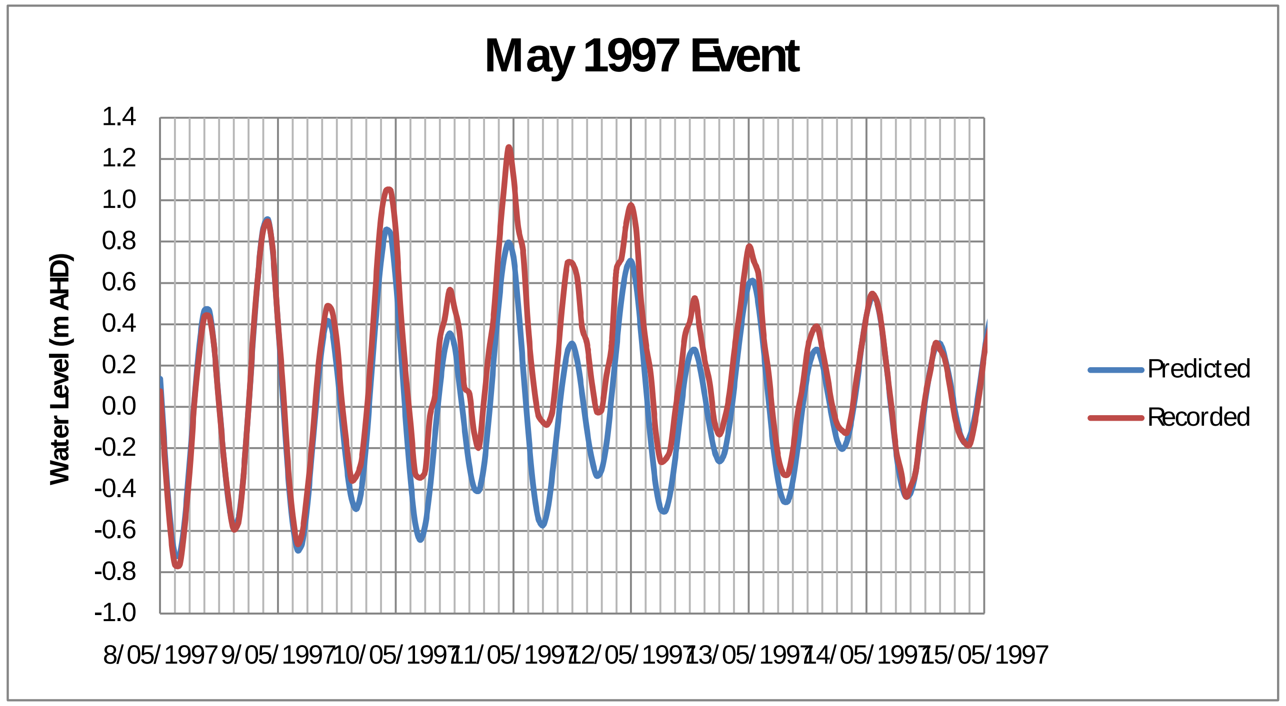


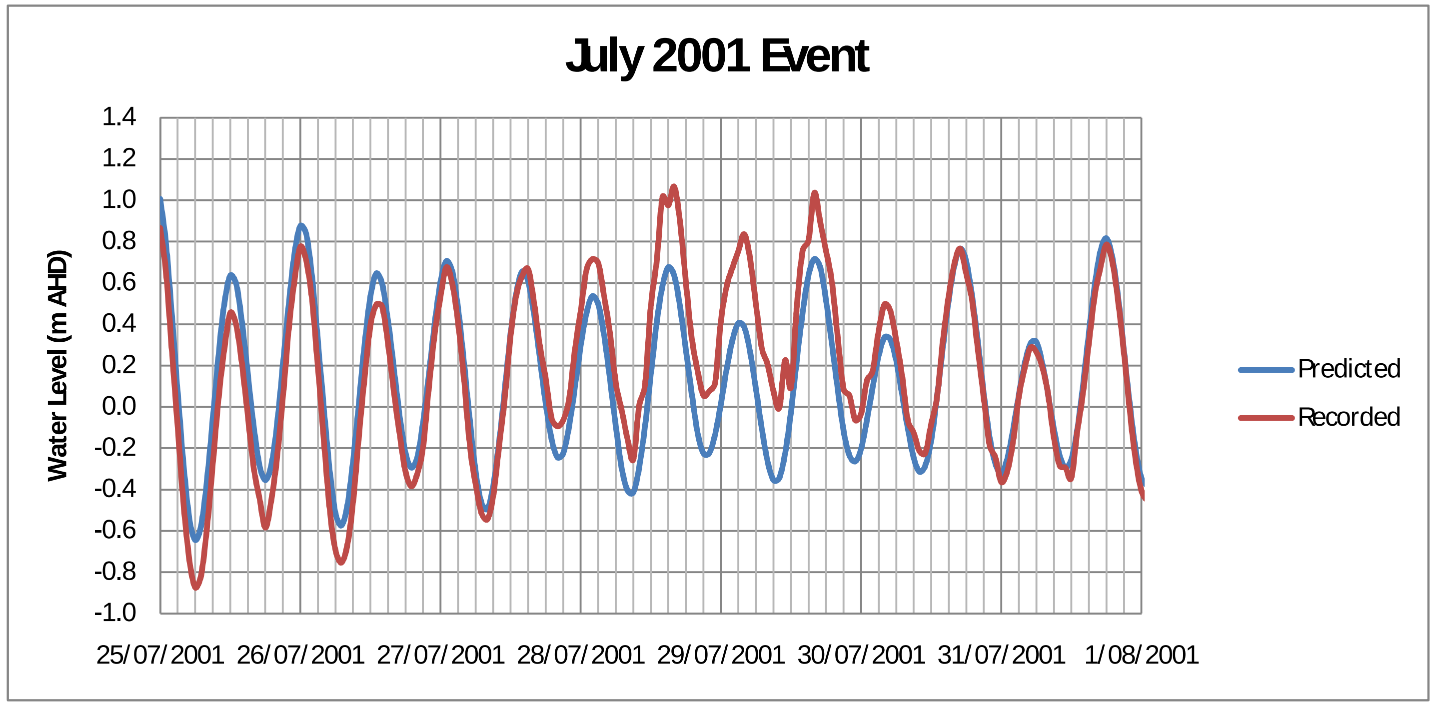


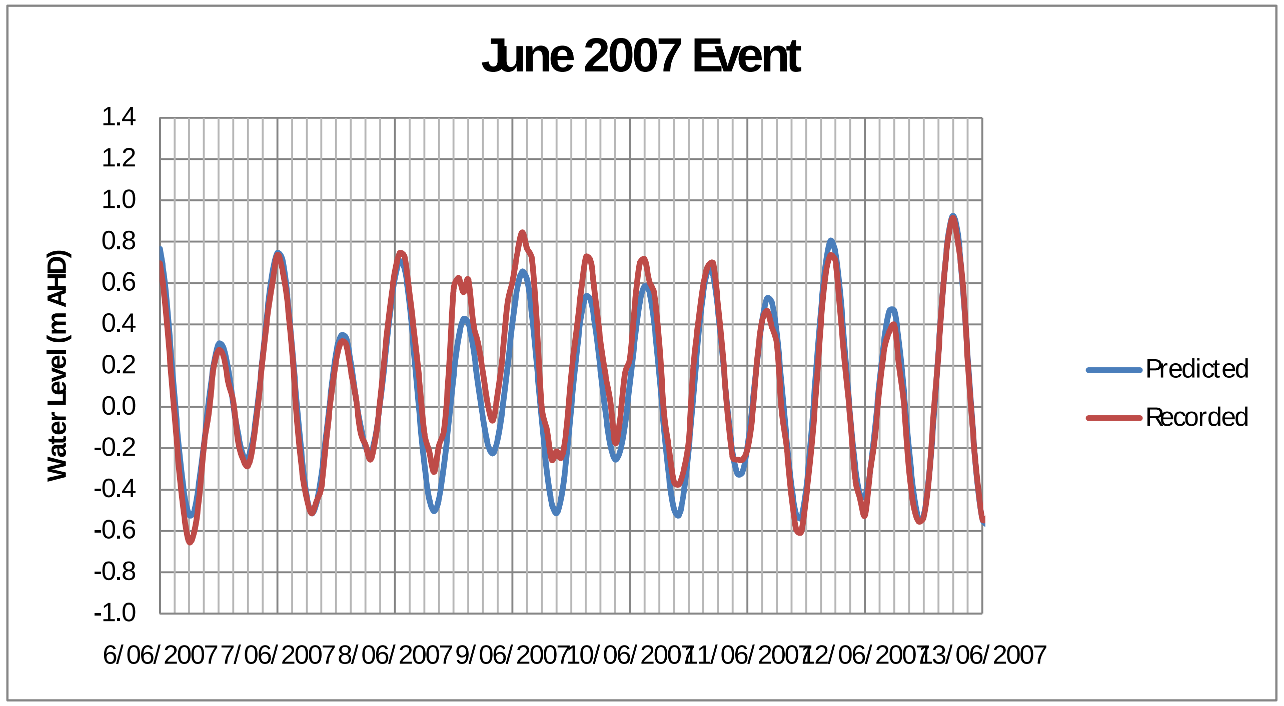


J:\Jobs\29076\Dataconversion\Port_Stephans_Tide_Analysis.xl



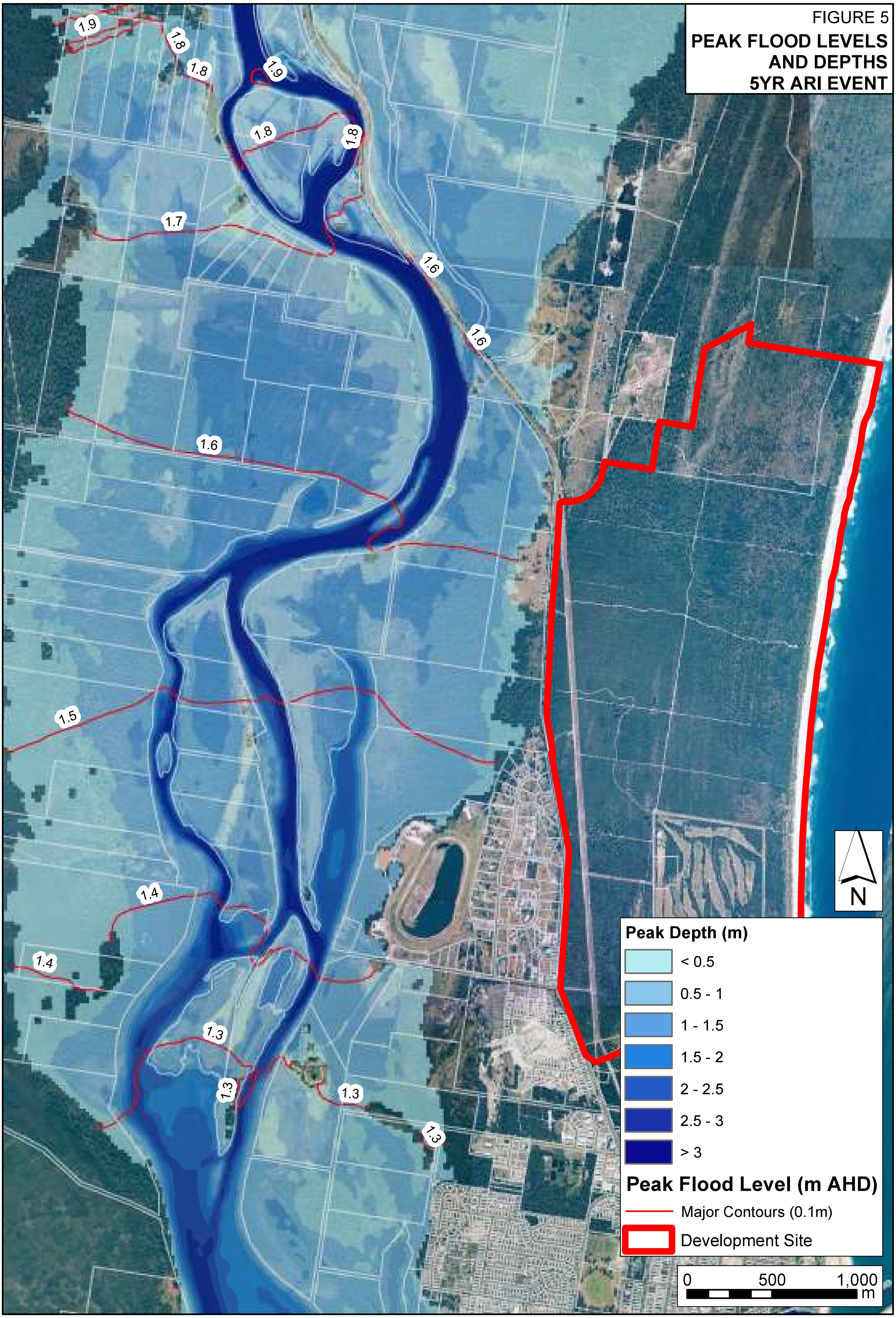






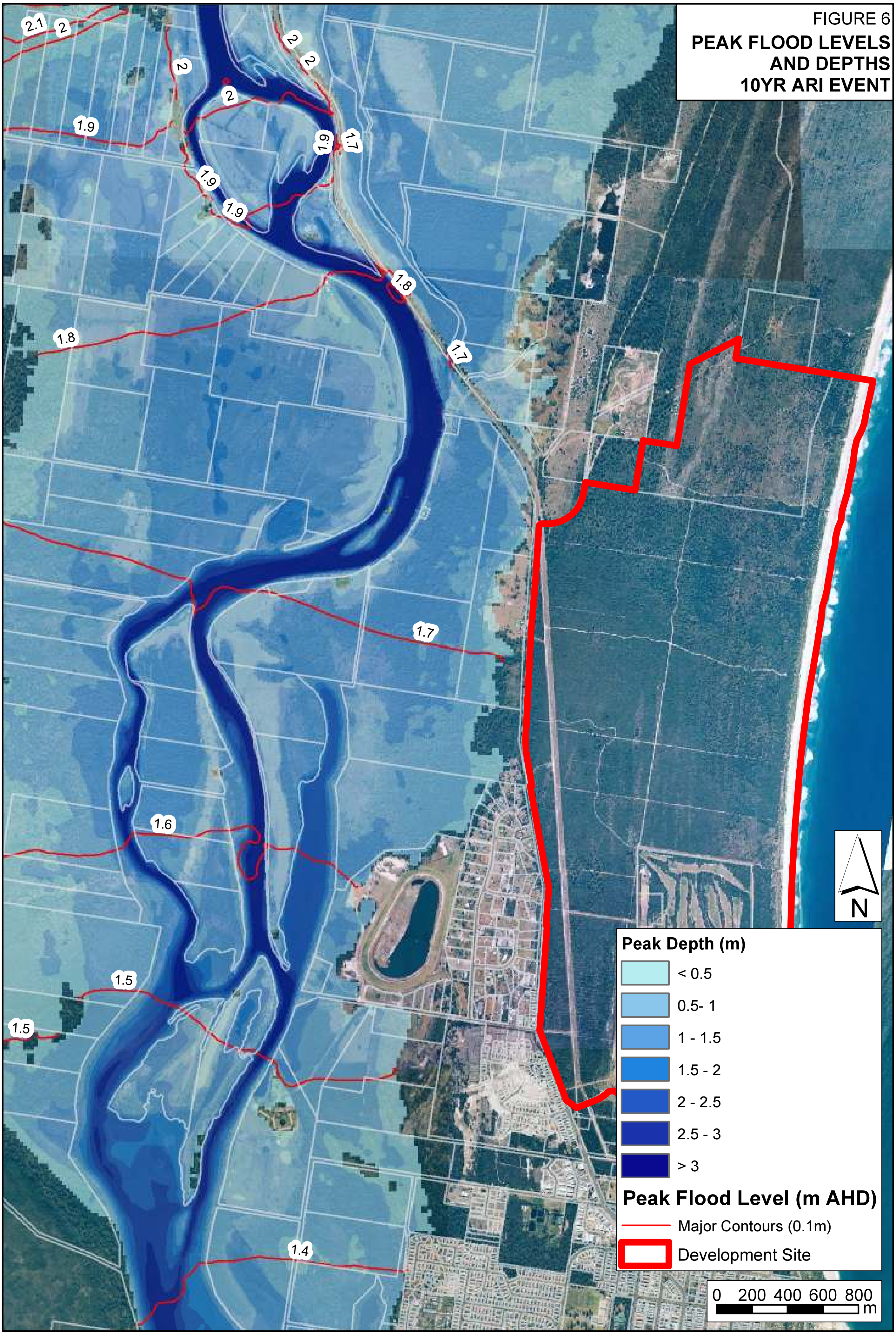
J:\Jobs\29076\Dataconversion\Port_Stephans_Tide_Anomalies.xlsx

FIGURE 5
PEAK FLOOD LEVELS AND DEPTHS 5YR ARI EVENT

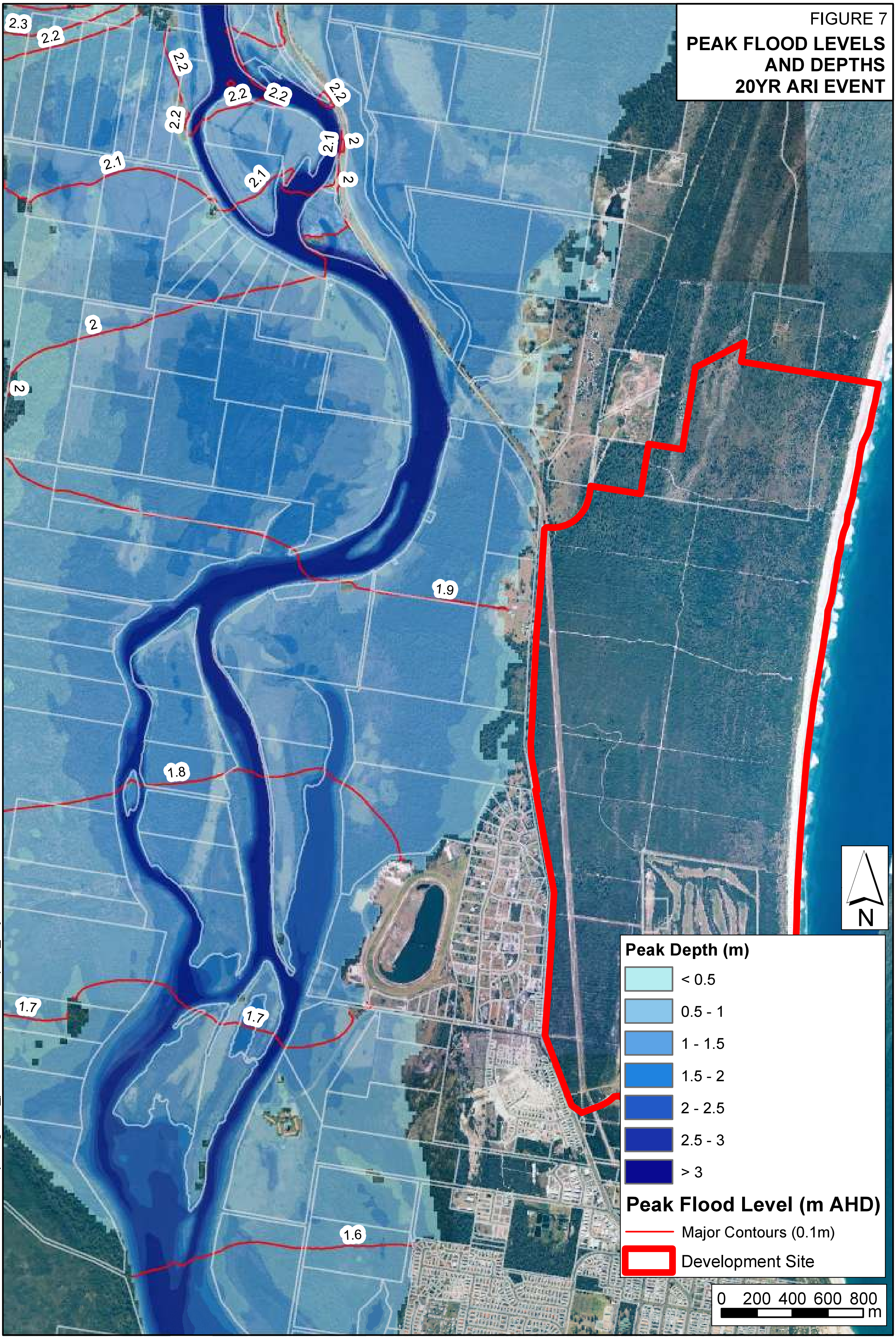


J:\Jobs\29026\ArcViewMaps\Figure05_peakfloodlevelanddepths_5yr.mxd

FIGURE 6
PEAK FLOOD LEVELS AND DEPTHS 10YR ARI EVENT



J:\Jobs\29026\ArcView\Maps\Figure06_peakfloodlevelanddepths_10yr.mxd



J:\Jobs\29026\ArcView\Maps\Figure7_peakfloodlevelanddepths_20yr.mxd

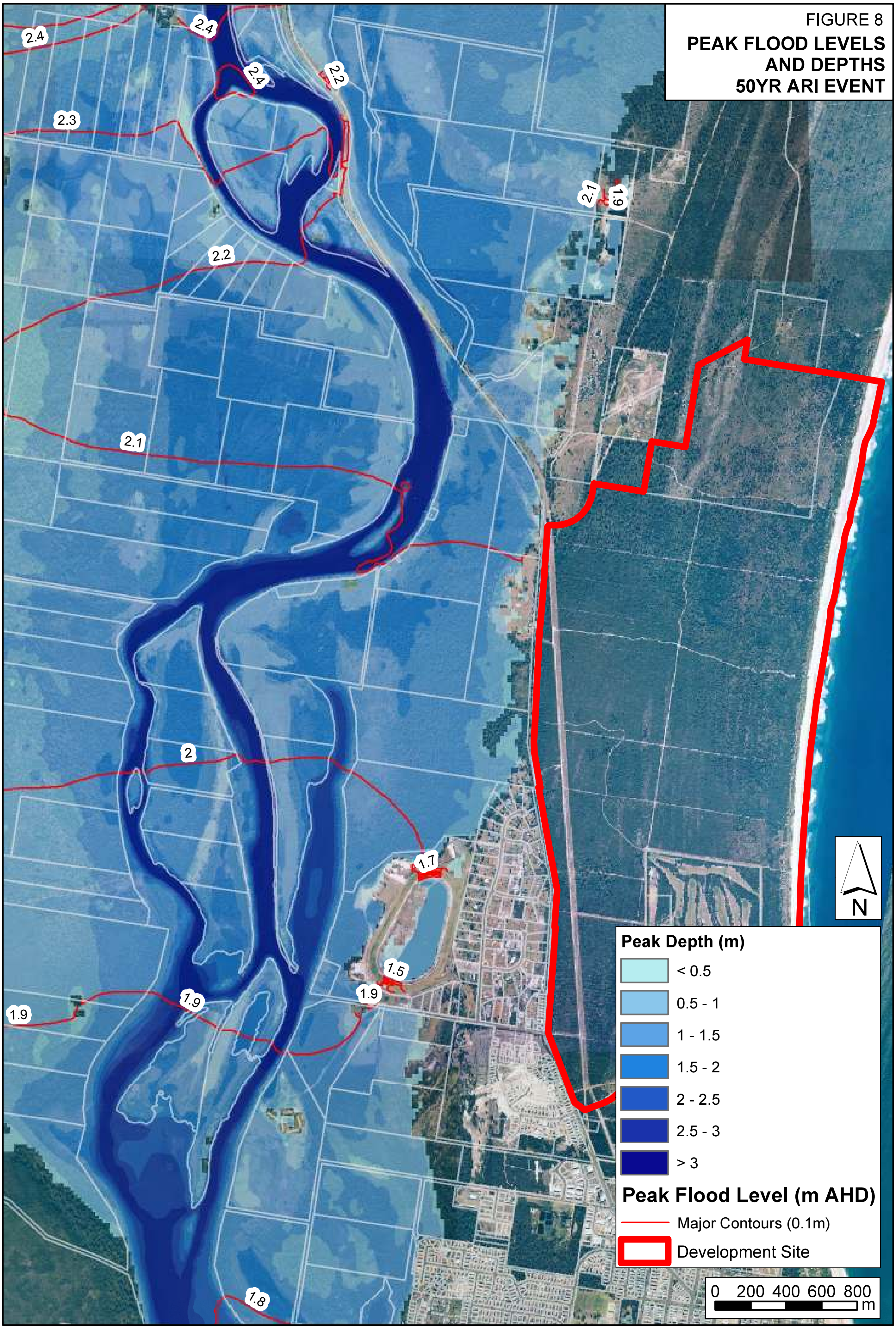
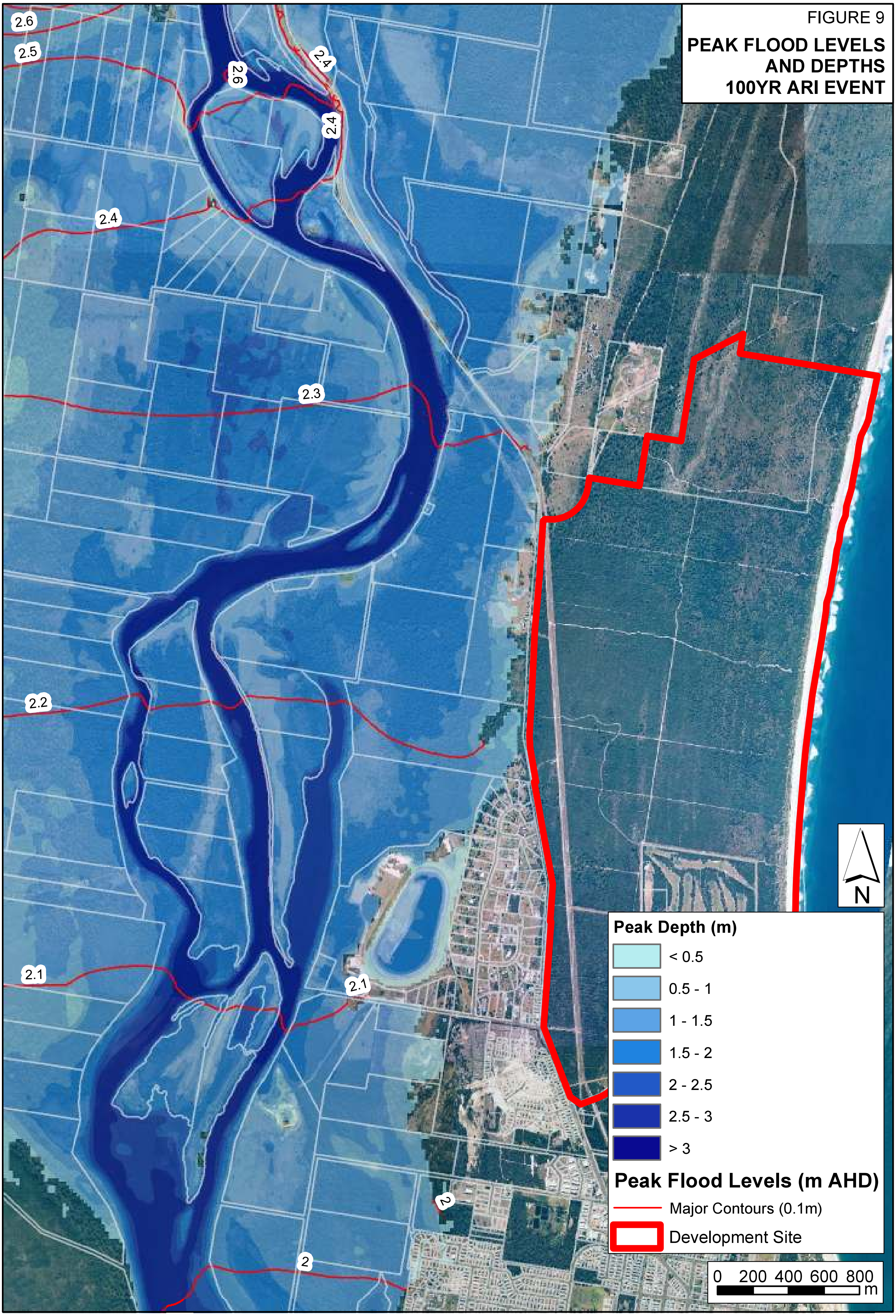
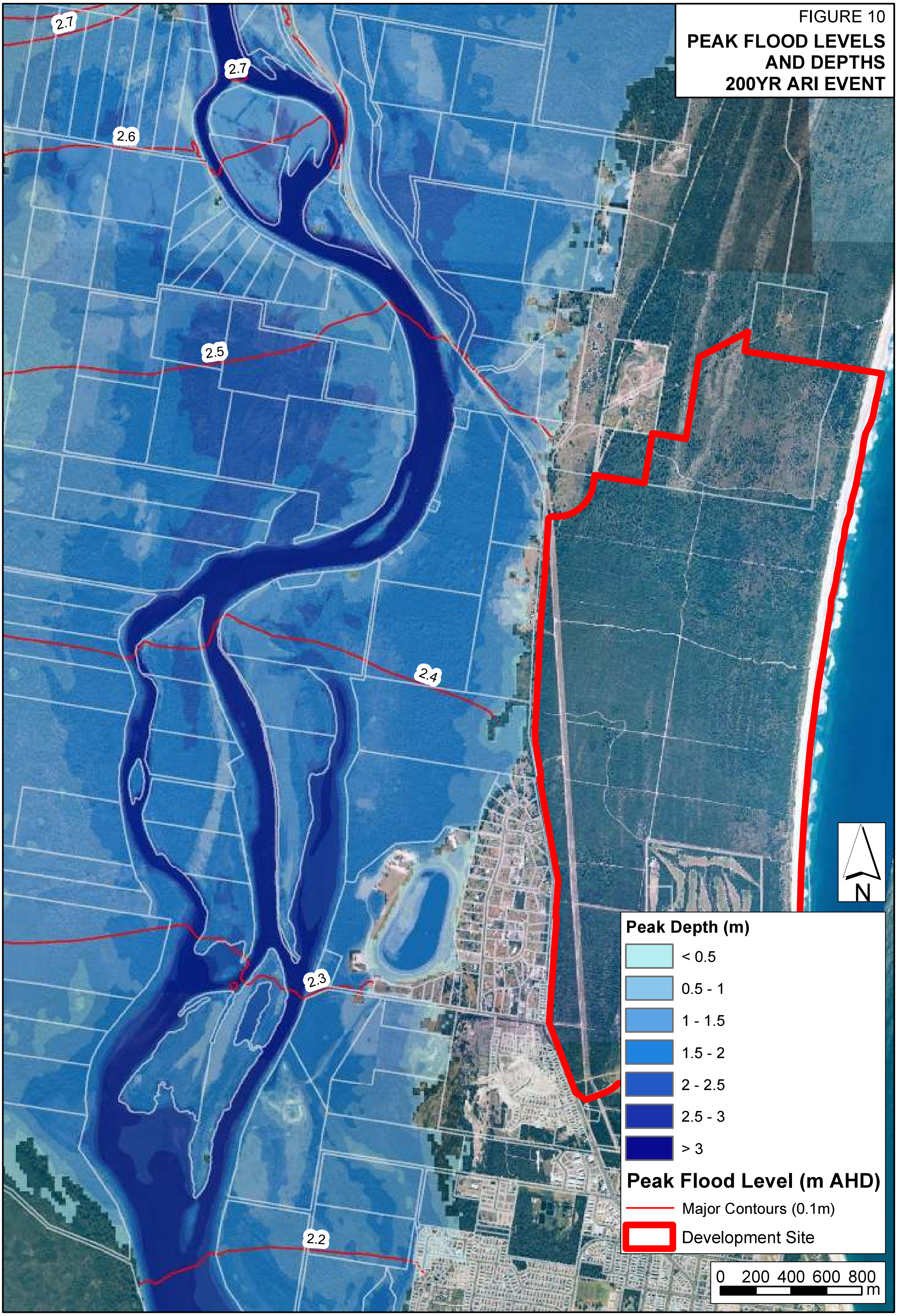


FIGURE 8
PEAK FLOOD LEVELS AND DEPTHS 50YR ARI EVENT

J:\Jobs\29026\ArcView\Maps\Figure8_peakfloodlevelanddepths_50yr.mxd



J:\Jobs\29026\ArcView\Maps\Figure09_peakfloodlevelanddepths_100yr.mxd



J:\Jobs\29026\ArcViewMaps\Figure10_peakfloodlevelanddepths_200yr.mxd

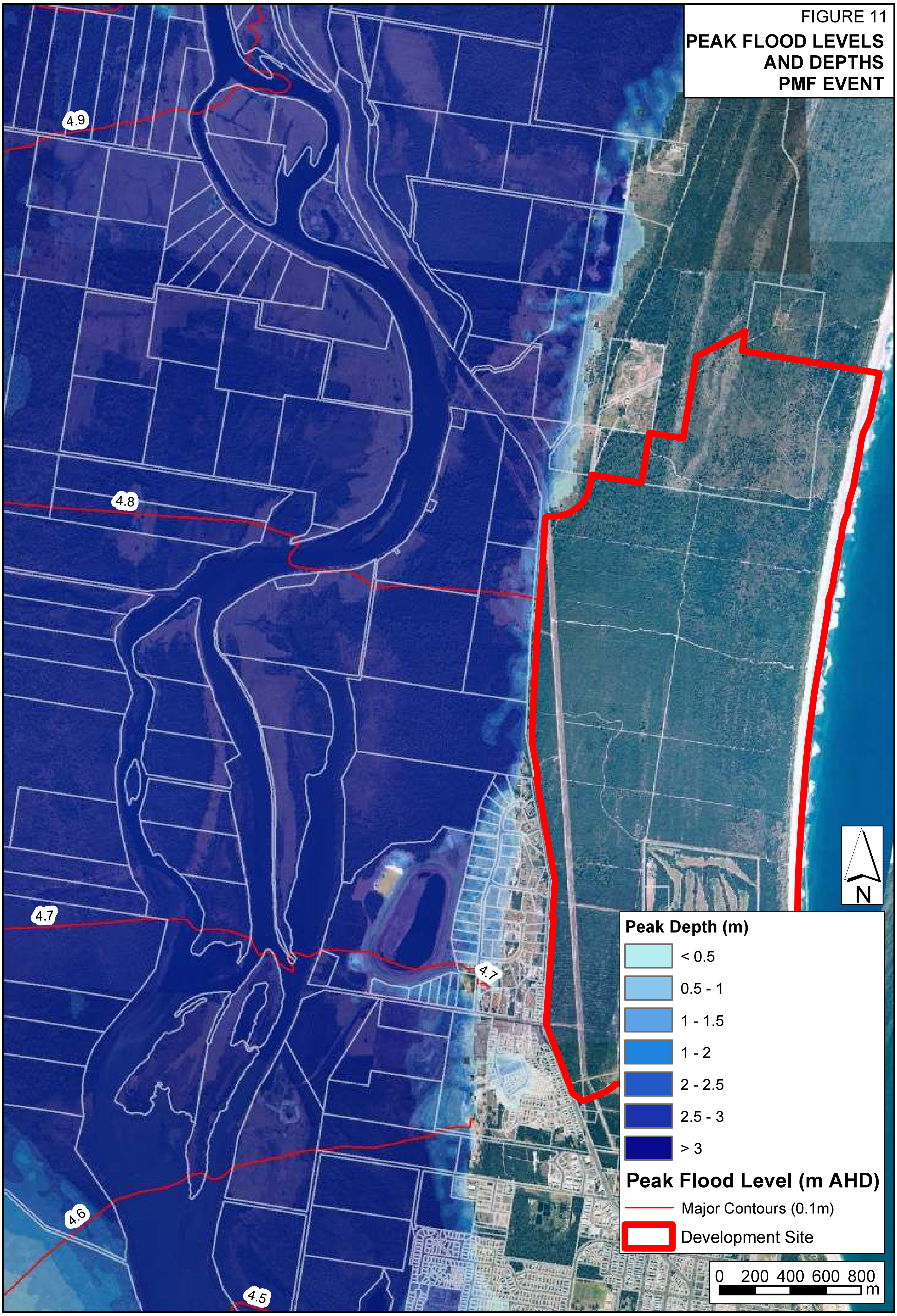


FIGURE 11
PEAK FLOOD LEVELS AND DEPTHS PMF EVENT

J:\Jobs\29026\ArcView\Maps\Figure11_peakfloodlevelanddepths_PMF.mxd

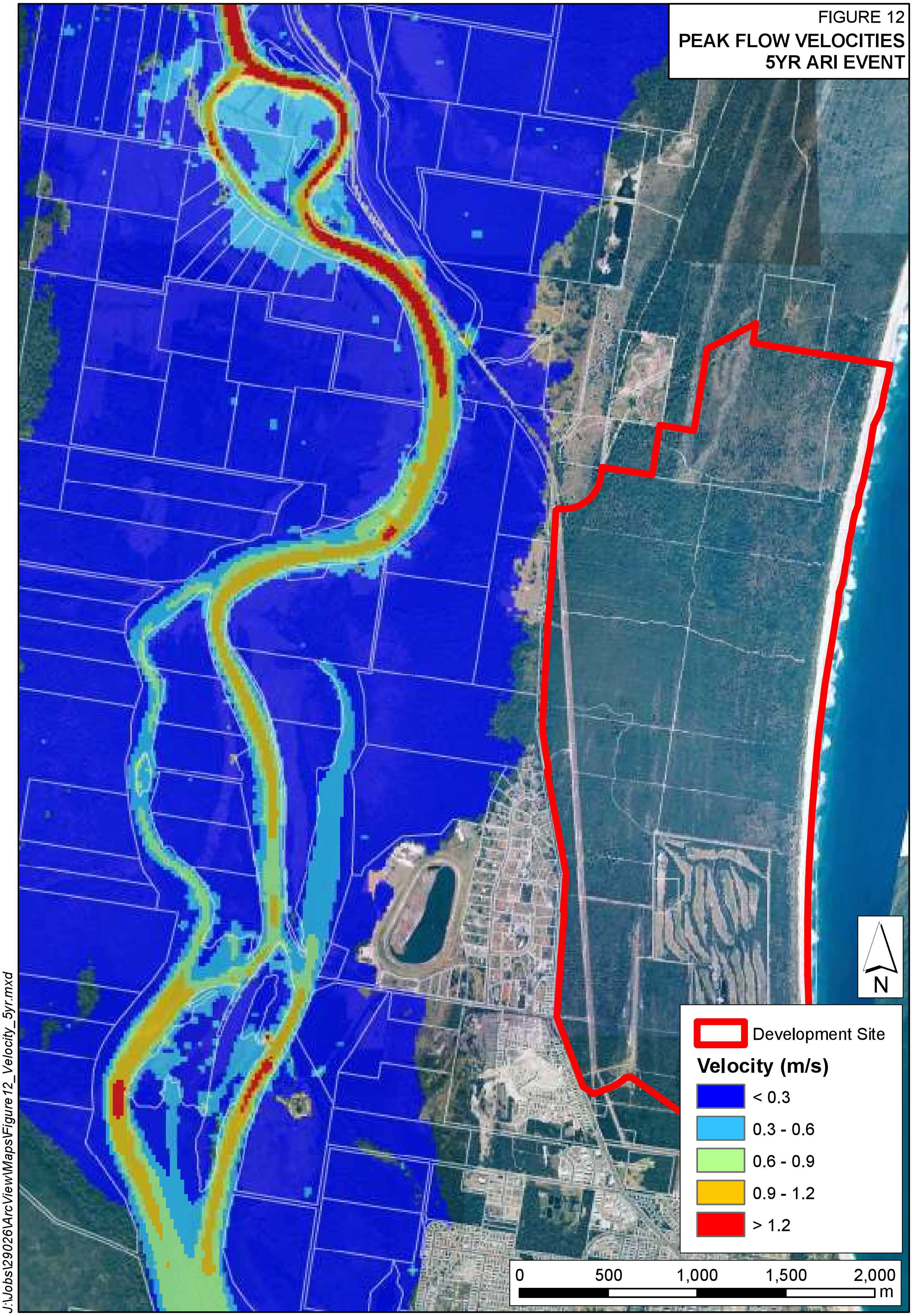


FIGURE 12
PEAK FLOW VELOCITIES
5YR ARI EVENT
N
Development Site
Velocity (m/s)
< 0.3
0.3 - 0.6
0.6 - 0.9
0.9 - 1.2
> 1.2
0
500
1,000
1,500
2,000
m
J:\Jobs\29026\ArcView\Maps\Figure12_Velocity_5yr.mxd

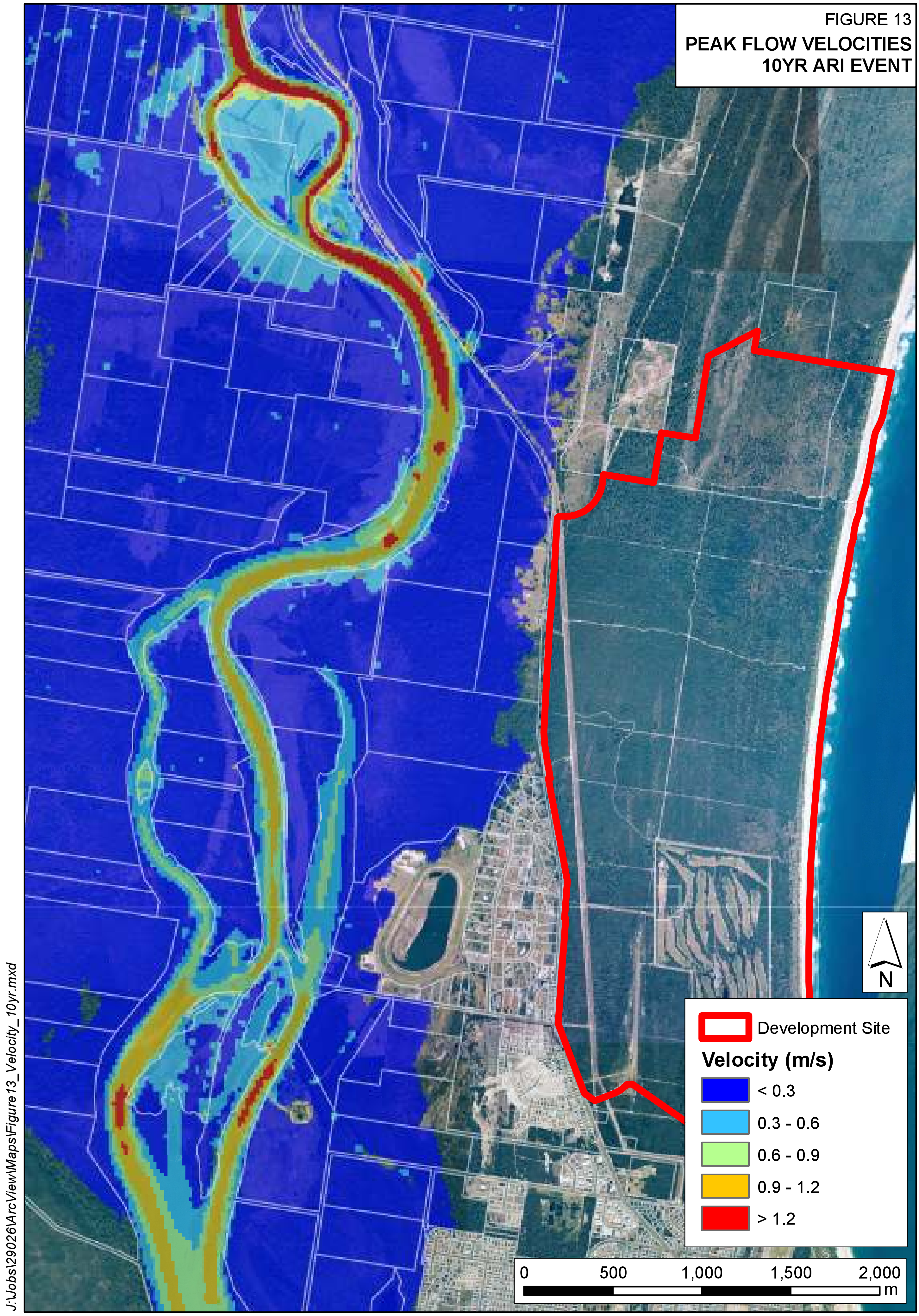
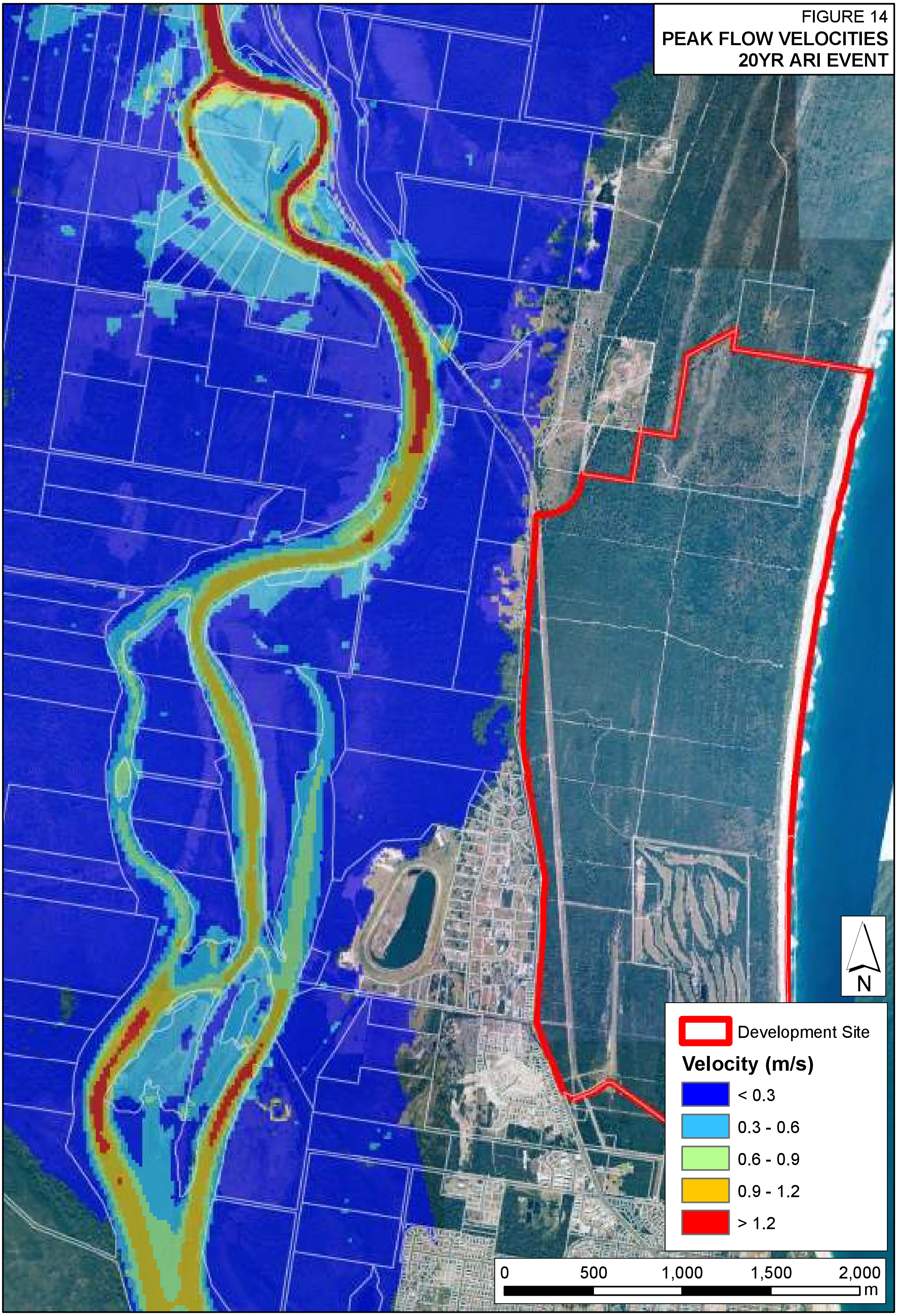


FIGURE 13
PEAK FLOW VELOCITIES
10YR ARI EVENT
Development Site
Velocity (m/s)
< 0.3
0.3 - 0.6
0.6 - 0.9
0.9 - 1.2
> 1.2
N
0
500
1,000
1,500
2,000
m
J:\Jobs\29026\ArcView\Maps\Figure13_Velocity_10yr.mxd



J:\Jobs\29026\ArcView\Maps\Figure14_Velocity_20yr.mxd

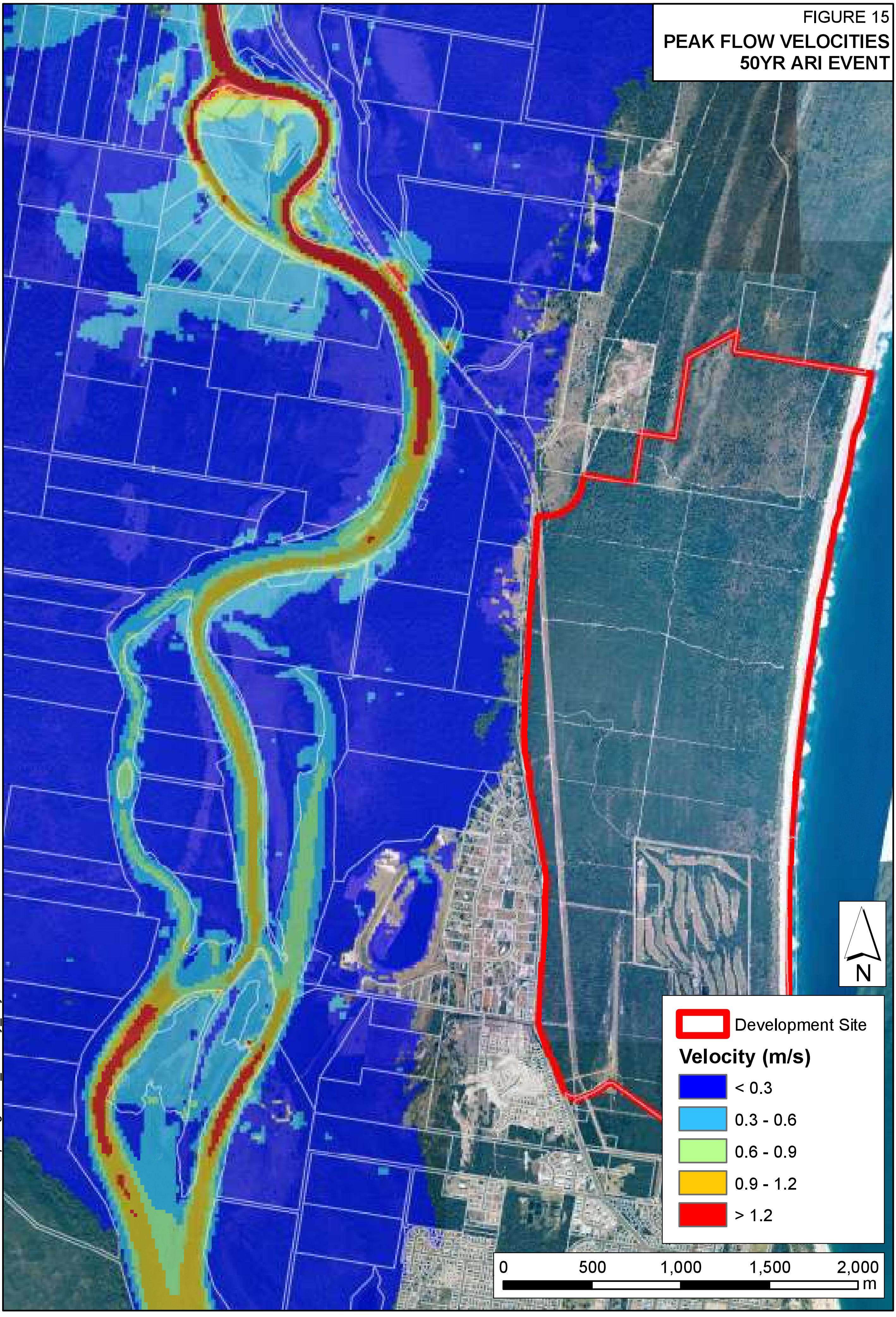
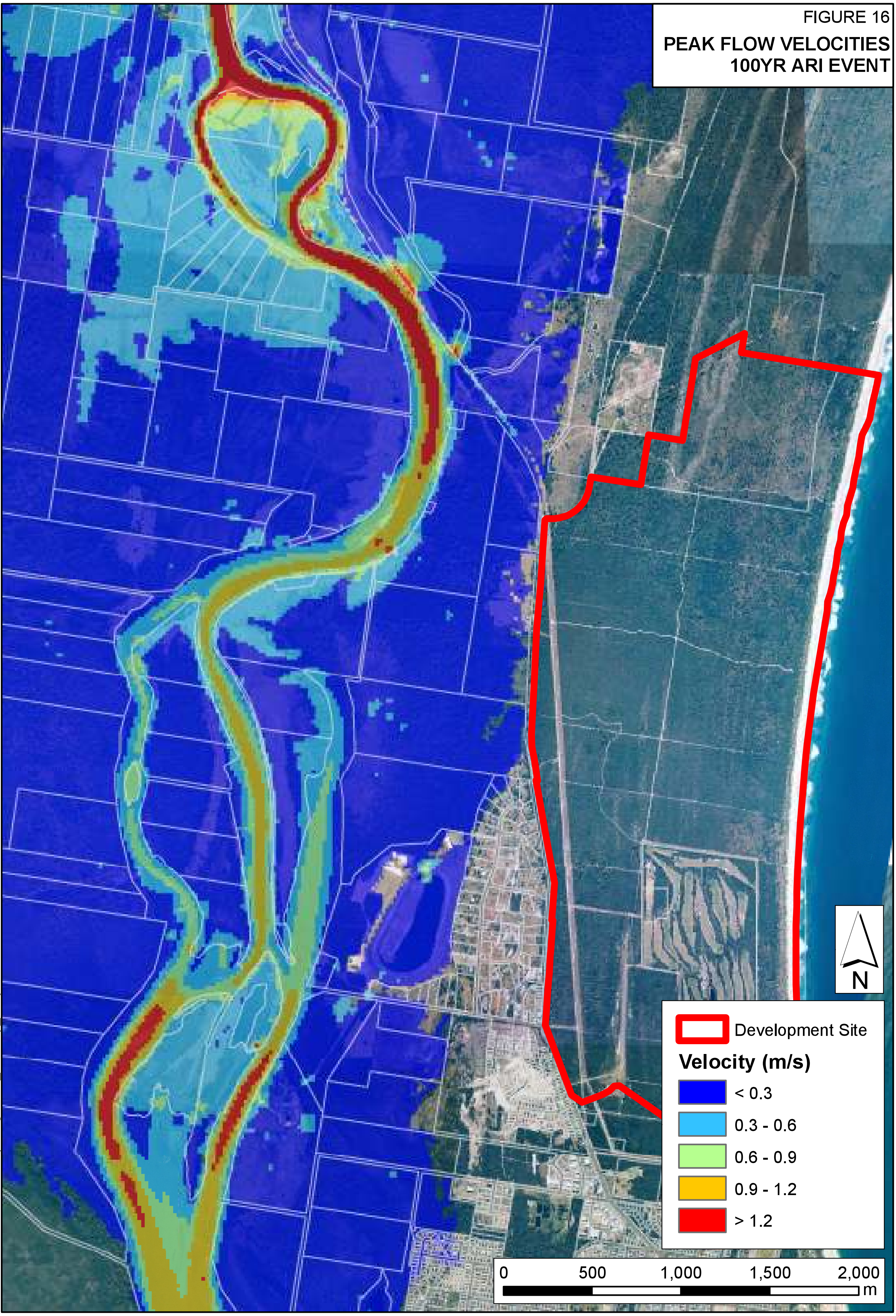


FIGURE 15
PEAK FLOW VELOCITIES
50YR ARI EVENT
N
Development Site
Velocity (m/s)
< 0.3
0.3 - 0.6
0.6 - 0.9
0.9 - 1.2
> 1.2
0
500
1,000
1,500
2,000
m
J:\Jobs\29026\ArcViewMaps\Figure15_Velocity_50yr.mxd

FIGURE 16

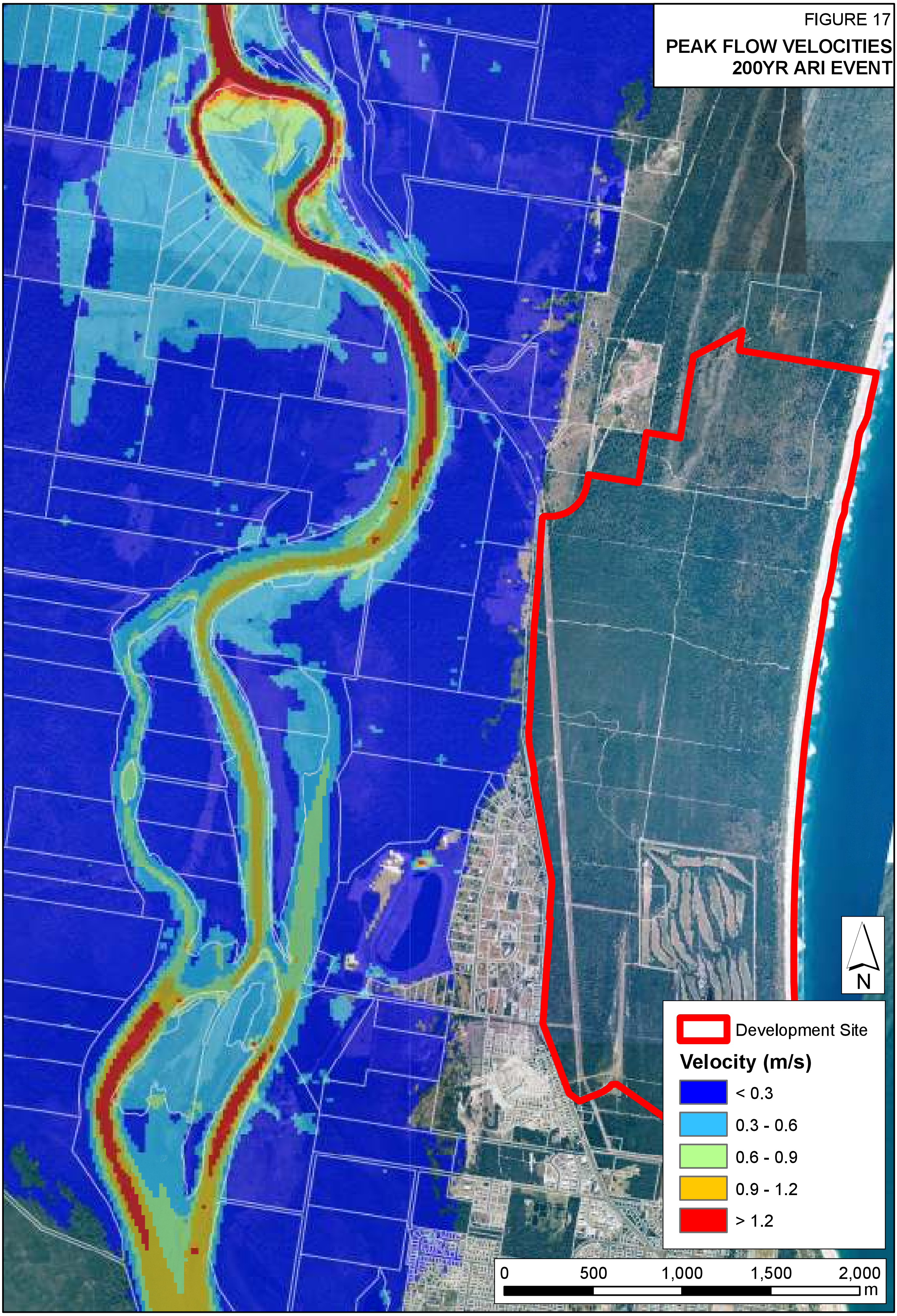
PEAK FLOW VELOCITIES 100YR ARI EVENT



J:\Jobs\29026\ArcViewMaps\Figure16_Velocity_100yr.mxd

FIGURE 17

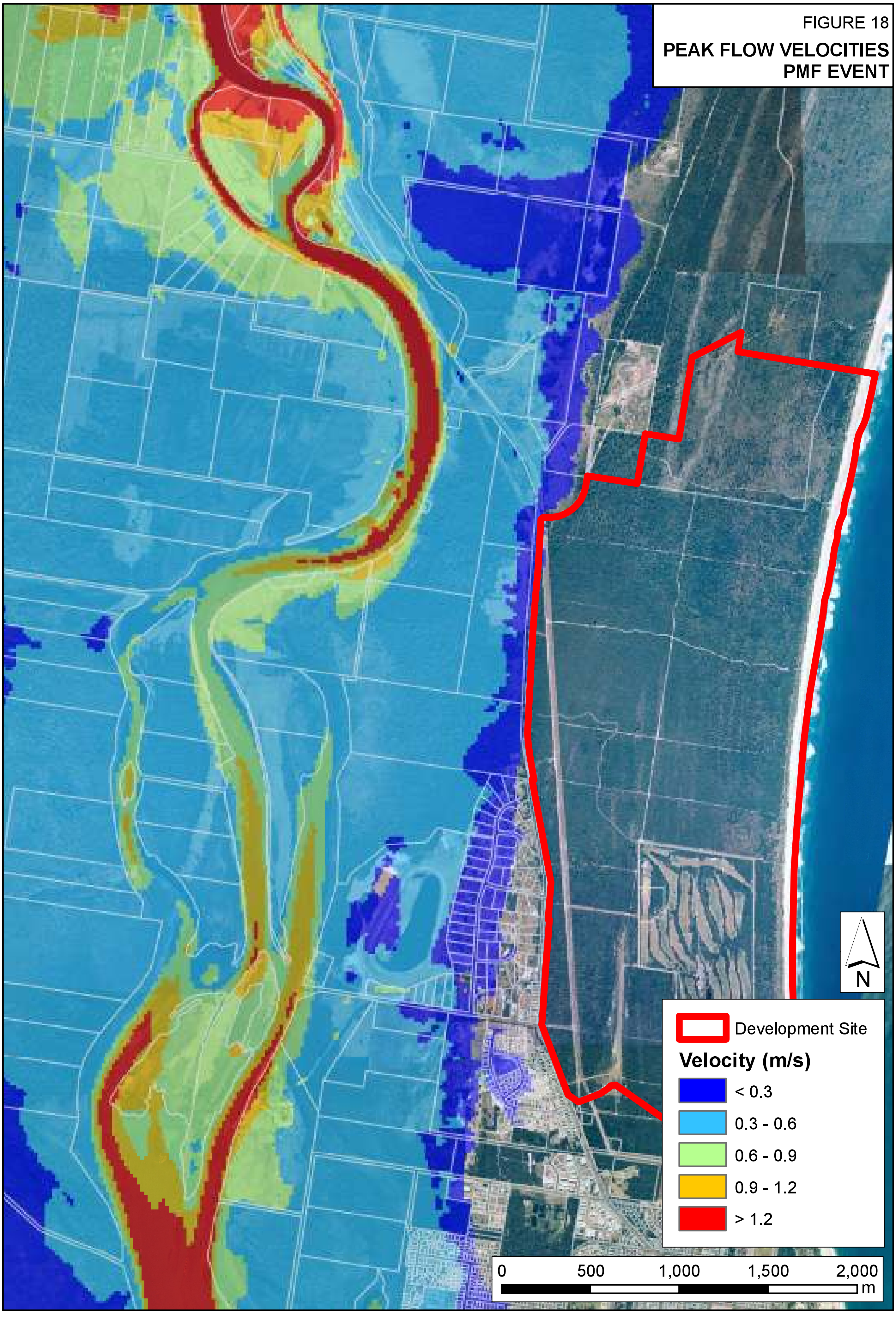
PEAK FLOW VELOCITIES 200YR ARI EVENT



J:\Jobs\29026\ArcView\Maps\Figure17_Velocity_200yr.mxd

FIGURE 18

PEAK FLOW VELOCITIES PMF EVENT



J:\Jobs\29026\ArcView\Maps\Figure18_Velocity_PMF.mxd

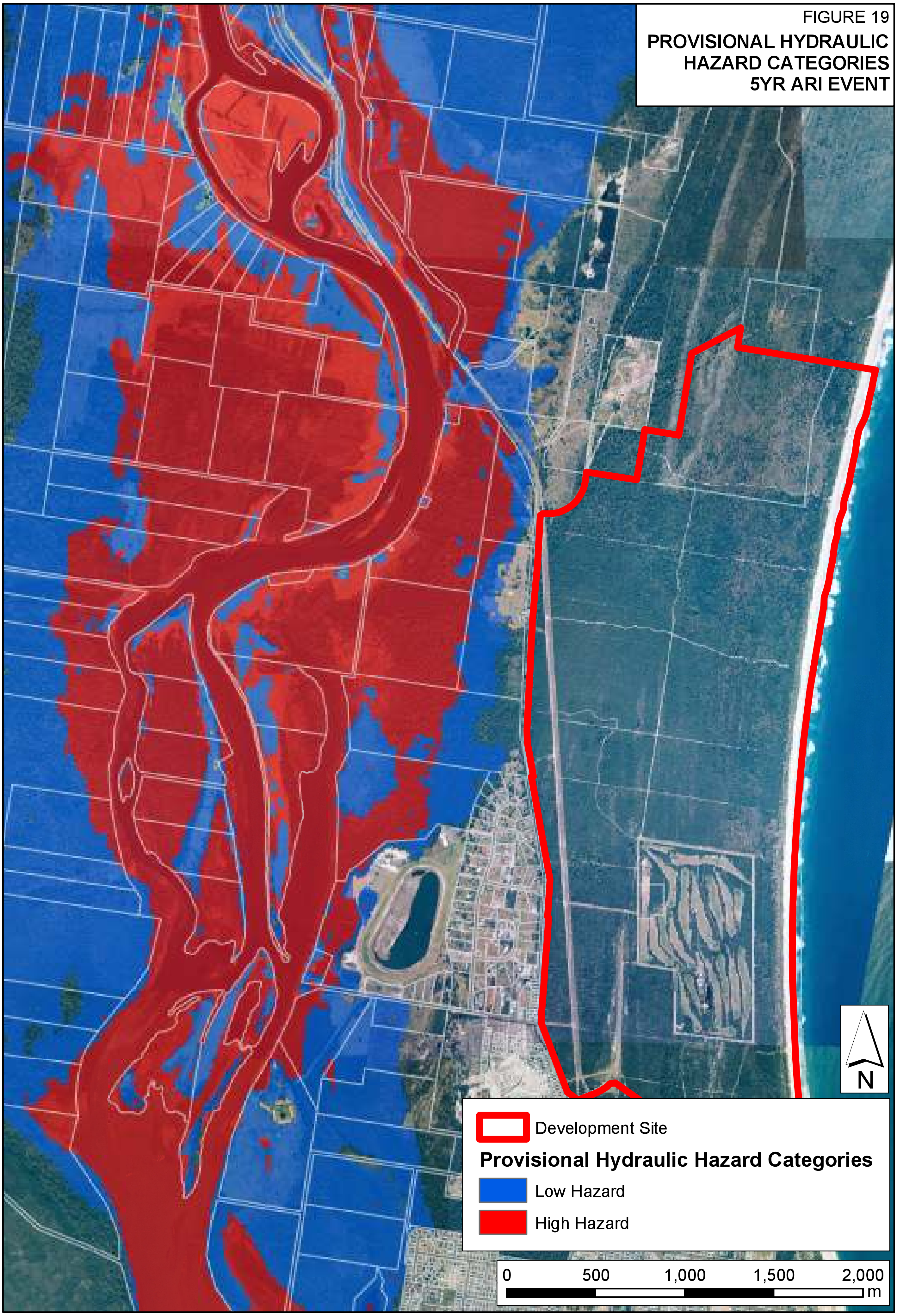


FIGURE 19
PROVISIONAL HYDRAULIC
HAZARD CATEGORIES
5YR ARI EVENT
Development Site
Provisional Hydraulic Hazard Categories
Low Hazard
High Hazard
0
500
1,000
1,500
2,000
m
N
J:\Jobs\29026\ArcView\Maps\Figure19_provisionalhydraulichazardcategories_5yr.mxd

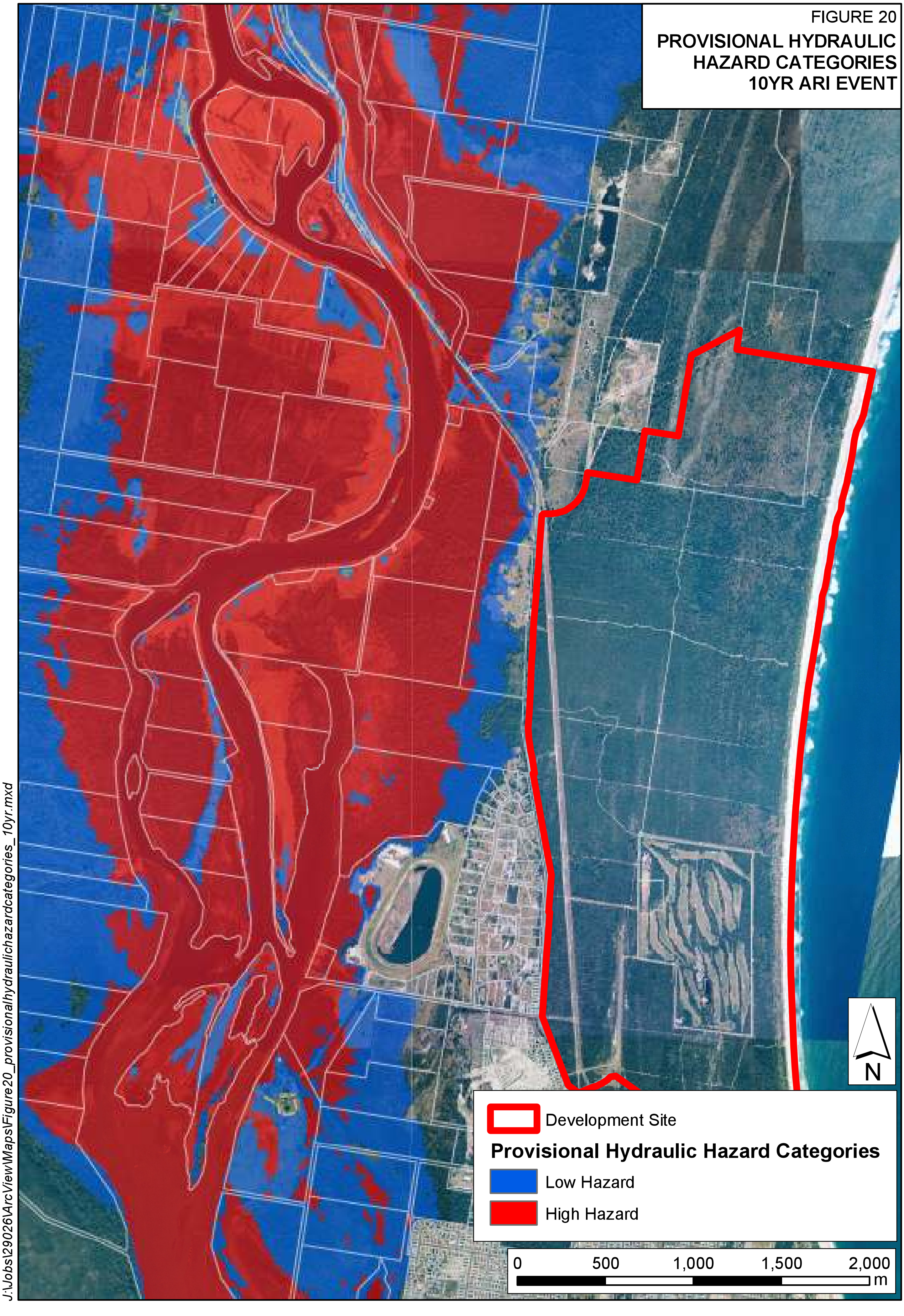
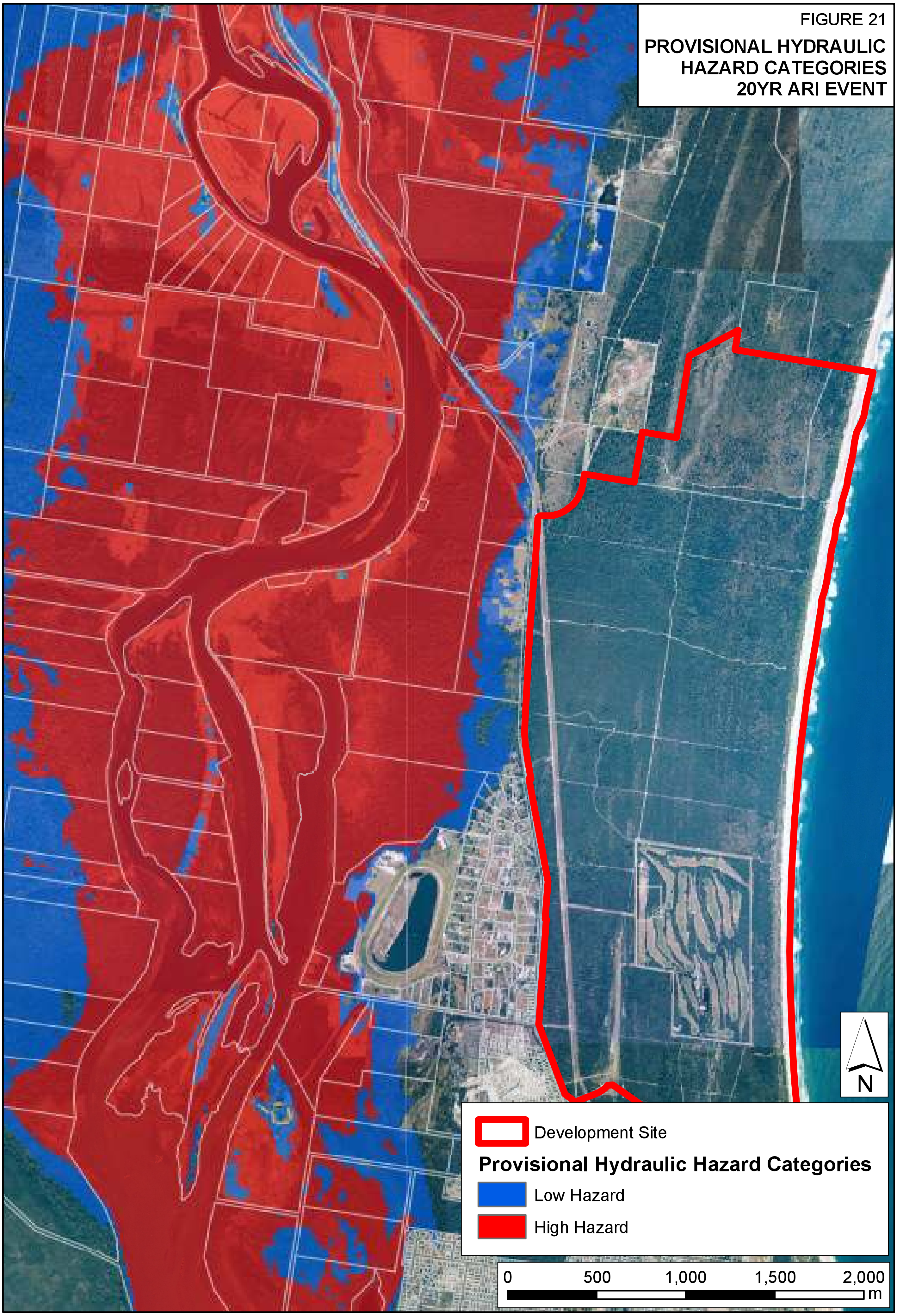
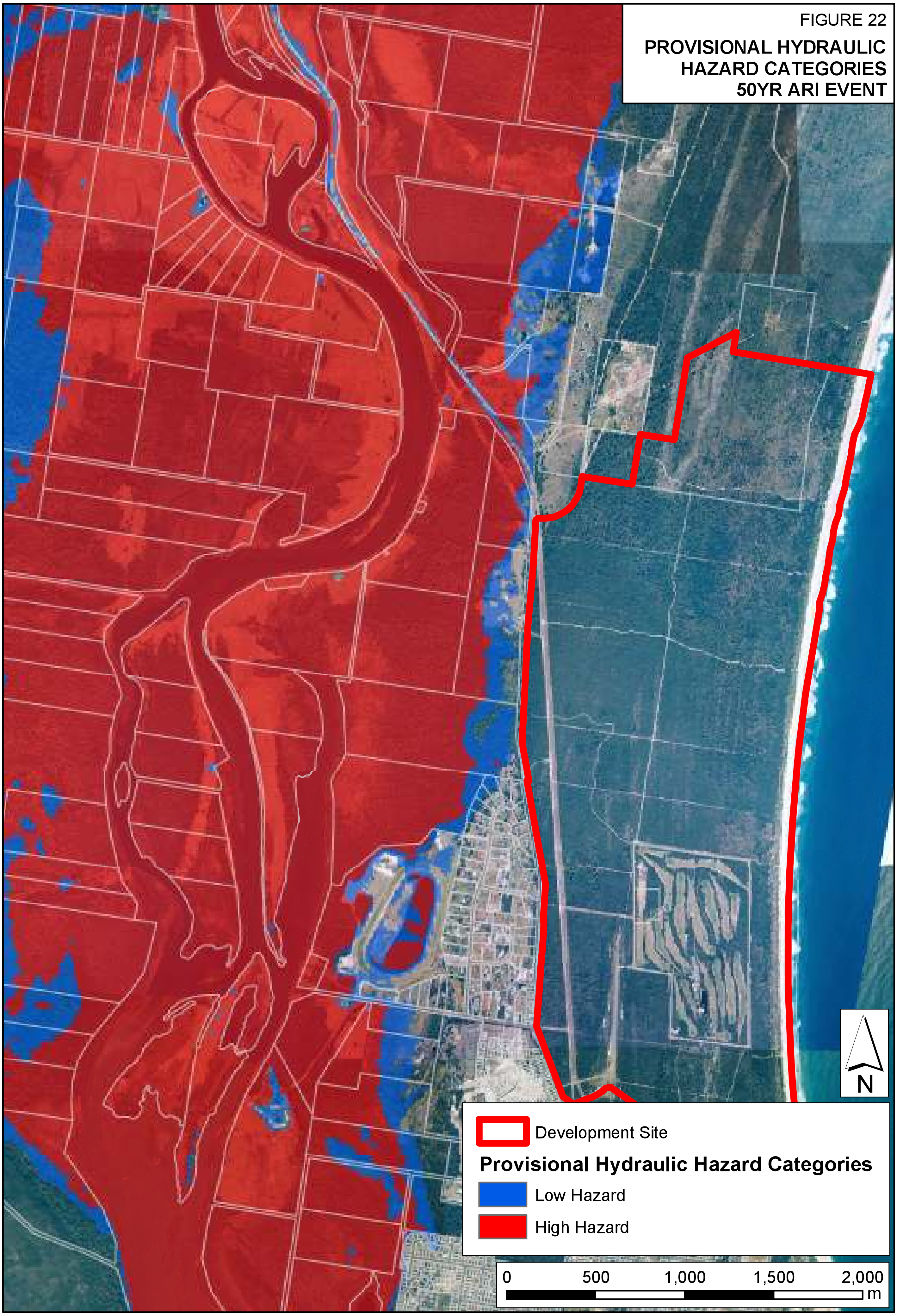


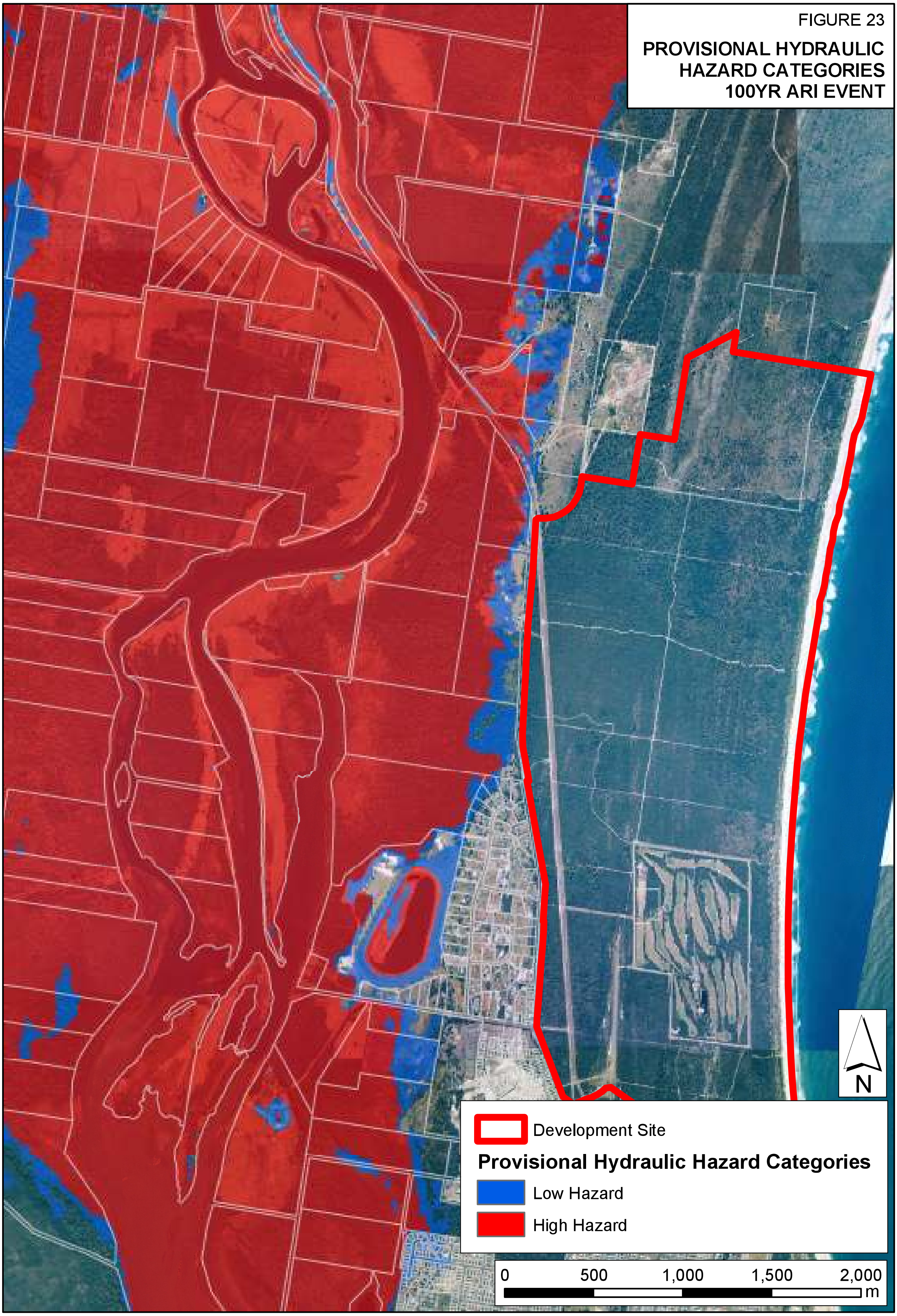
FIGURE 20
PROVISIONAL HYDRAULIC HAZARD CATEGORIES 10YR ARI EVENT
Development Site
Provisional Hydraulic Hazard Categories
Low Hazard
High Hazard
0
500
1,000
1,500
2,000
m
N
J:\Jobs\29026\ArcView\Maps\Figure20_provisionalhydraulichazardcategories_10yr.mxd



J:\Jobs\29026\ArcView\Maps\Figure21_provisionalhydraulichazardcategories_20yr.mxd



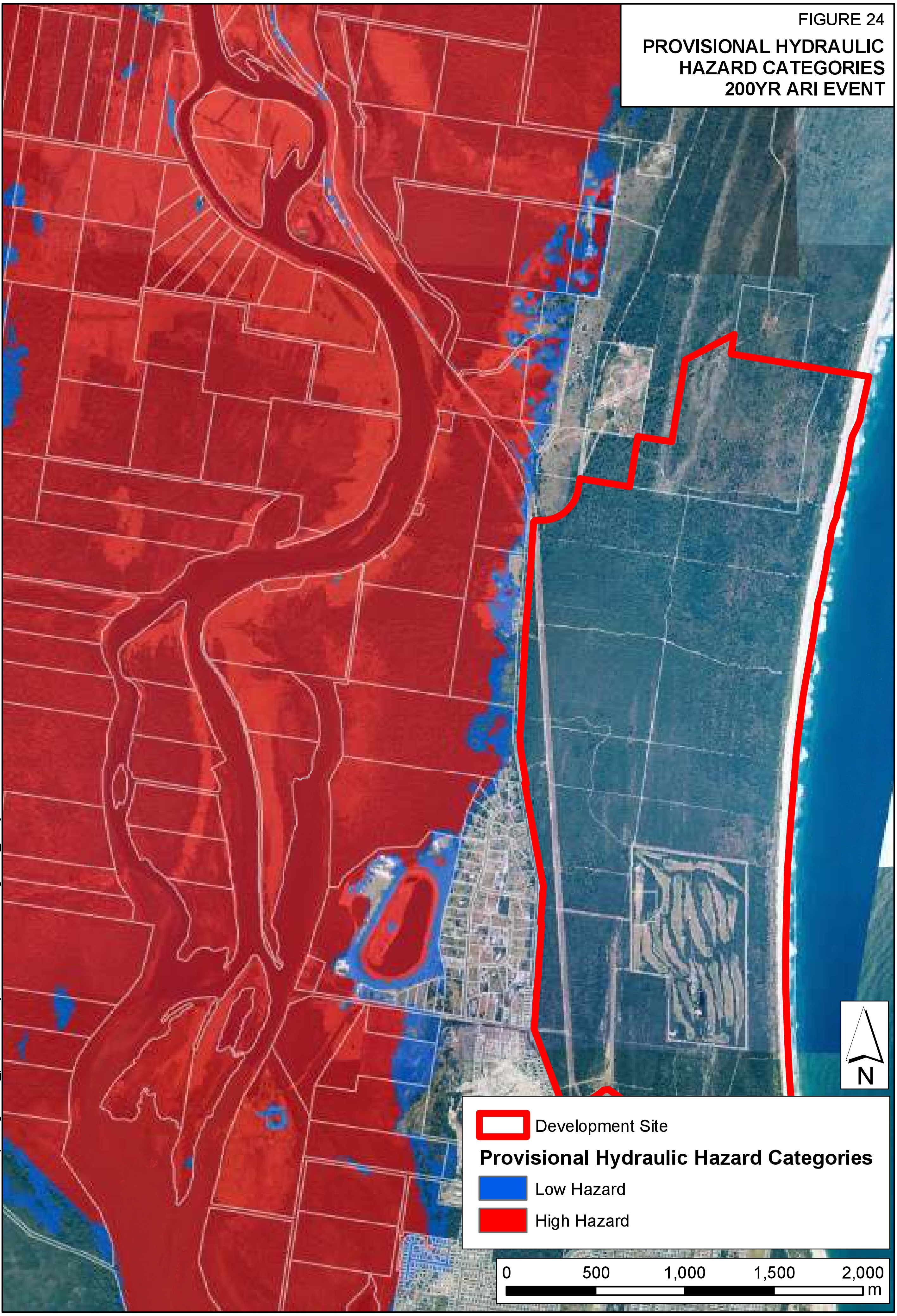
J:\Jobs\29026\ArcView\Maps\Figure22_provisionalhydraulichazardcategories_50yr.mxd



J:\Jobs\29026\ArcView\Maps\Figure23_provisionalhydraulichazardcategories_100yr.mxd

FIGURE 24

PROVISIONAL HYDRAULIC HAZARD CATEGORIES 200YR ARI EVENT



J:\Jobs\29026\ArcViewMaps\Figure24_provisionalhydraulichazardcategories_200yr.mxd

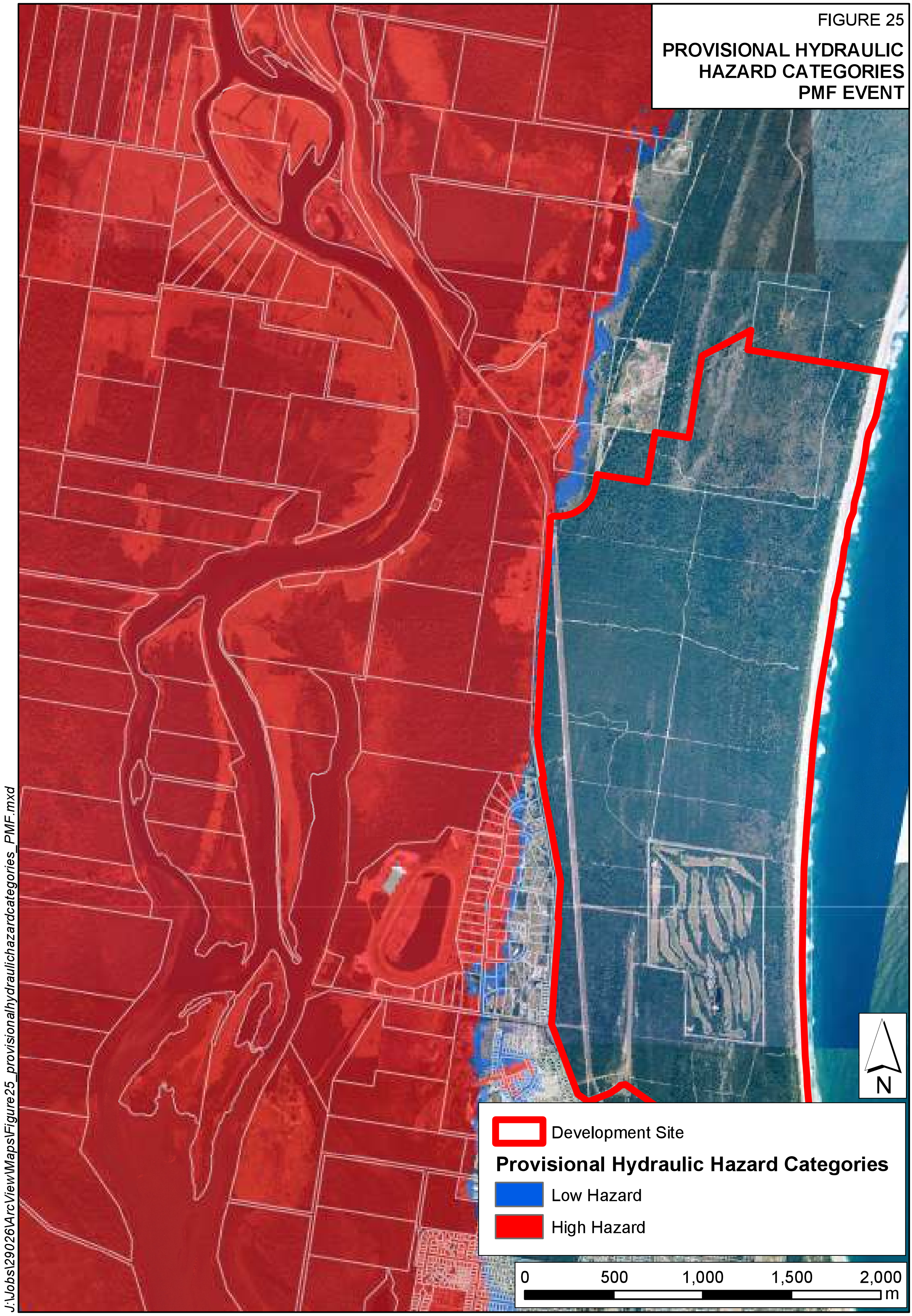


FIGURE 25
PROVISIONAL HYDRAULIC
HAZARD CATEGORIES
PMF EVENT
Development Site
Provisional Hydraulic Hazard Categories
Low Hazard
High Hazard
0
500
1,000
1,500
2,000
m
N
J:\Jobs\29026\ArcView\Maps\Figure25_provisionalhydraulichazardcategories_PMF.mxd

J:\Jobs\29026\TUFLOW\results\Profiles\Profile.xlsx

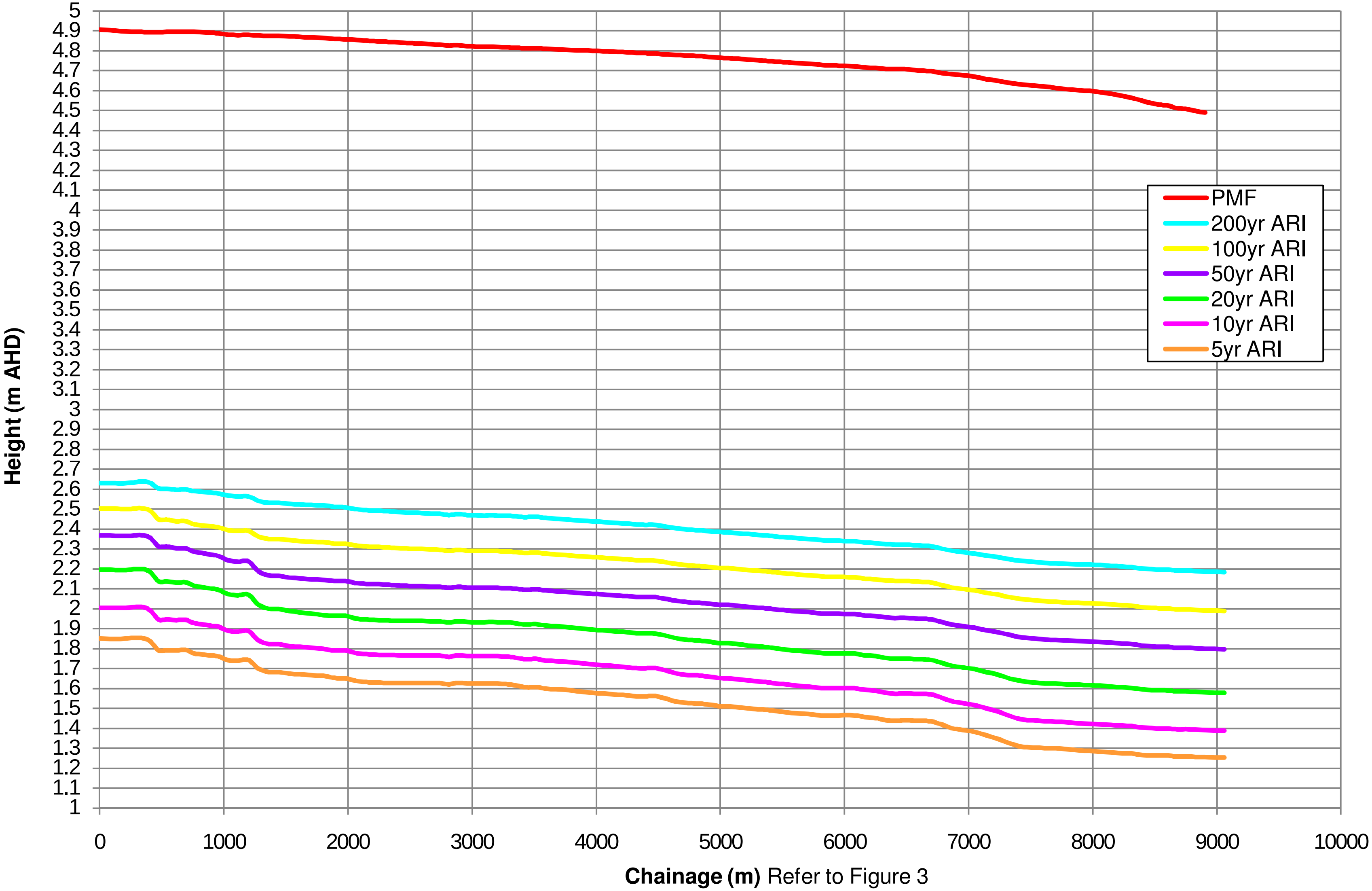


FIGURE 26
DESIGN FLOOD PROFILES

J:\Jobs\29026\TUFLOW\results\Profiles\ClimateChange.xls

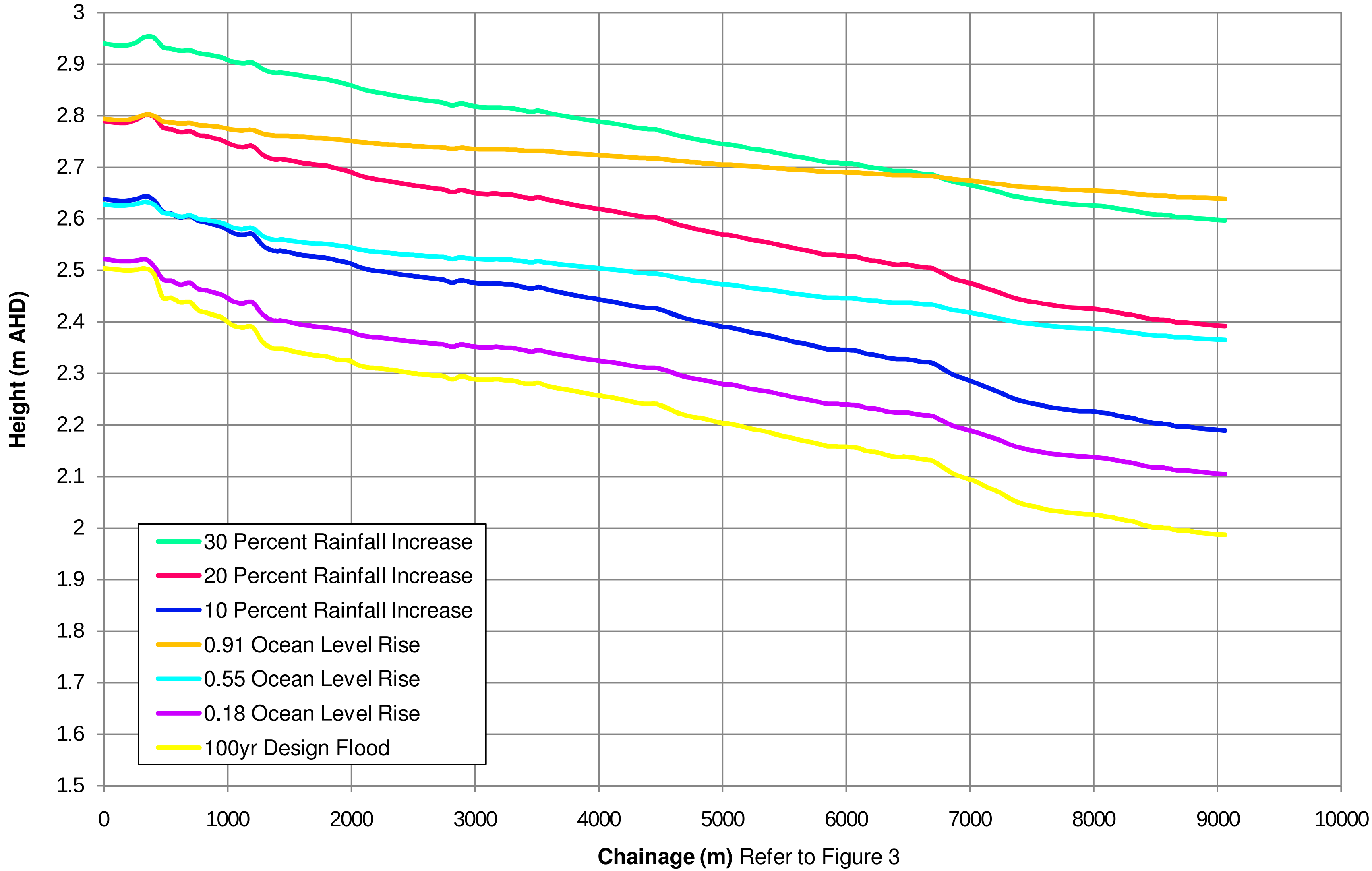


FIGURE 27
CLIMATE CHANGE SCENARIOS
100 YEAR ARI

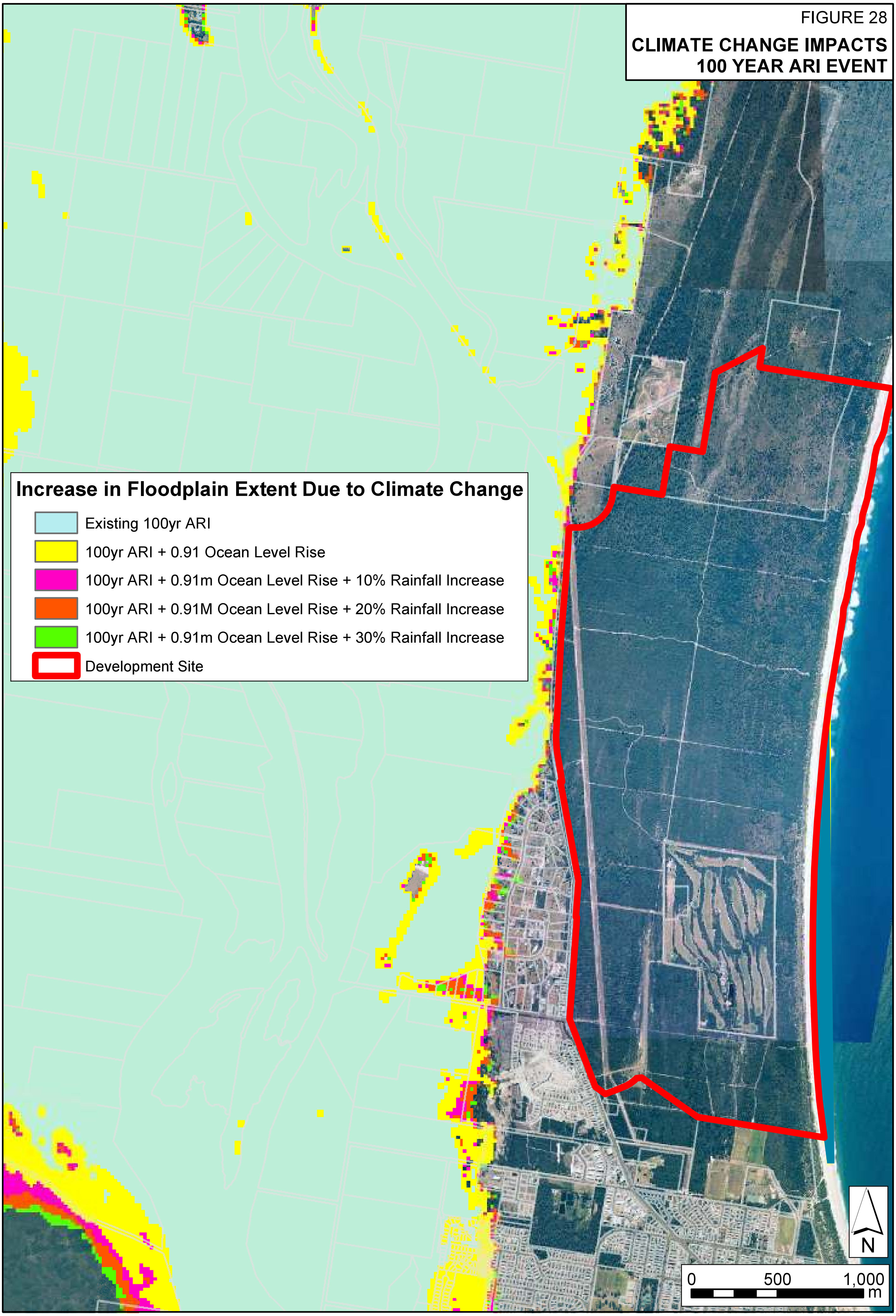


FIGURE 28
CLIMATE CHANGE IMPACTS
100 YEAR ARI EVENT

J:\Jobs\29026\ArcViewMaps\Figure28_ClimateChangeImpacts_100yr.mxd

J:\Jobs\29026\TUFLOW\results\Profiles\ClimateChangecombined.xlsx

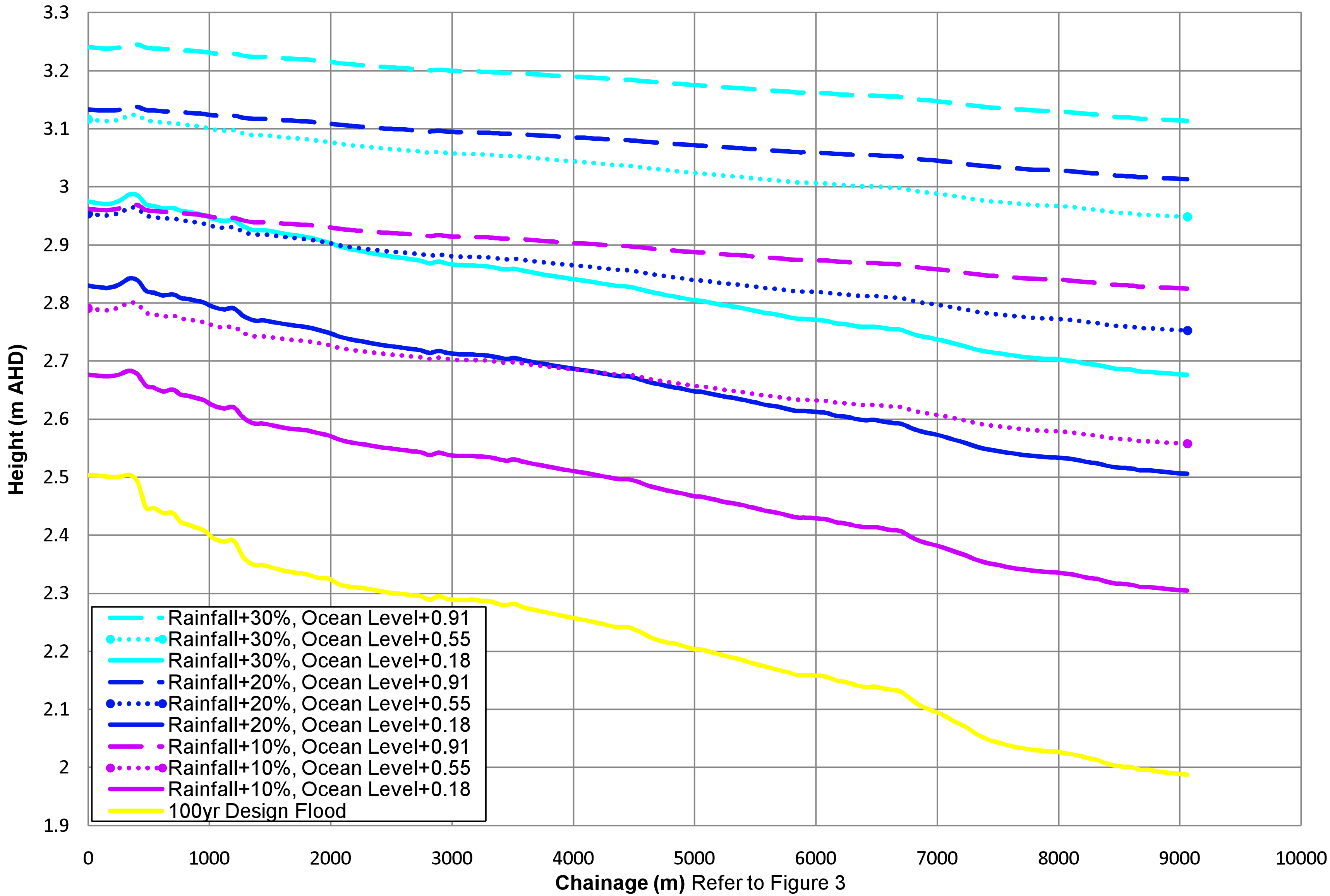


FIGURE 29

ASSESSMENT OF CLIMATE CHANGE

COMBINATION OF OCEAN LEVEL RISE AND RAINFALL INCREASE

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

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 big 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.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always 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.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (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. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning 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. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning 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 (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
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 before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and 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 an 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 (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land

	covers the whole of the floodplain, not just that part below the flood planning level (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 this manual. Usually includes both written and diagrammetic 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 State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s 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. FPLs supersede the Astandard flood event@ in the 1986 manual.
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	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood 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. **existing flood risk:** 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 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 flows, or a significant increase in flood levels.

freeboard 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 the 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 Are 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 purpose of this 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 0.3 m (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 flow paths through developed areas outside of defined drainage reserves; and/or
- $ the potential to affect a number of buildings along the major flow path.

mathematical/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 floodplain risk management policy and EPIs.

minor, moderate and major flooding Both the State Emergency Service and the Bureau of Meteorology 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. Examples are indicated in Table 2.1 with further discussion in the Manual.

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 Awater level@. Both are 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.

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.