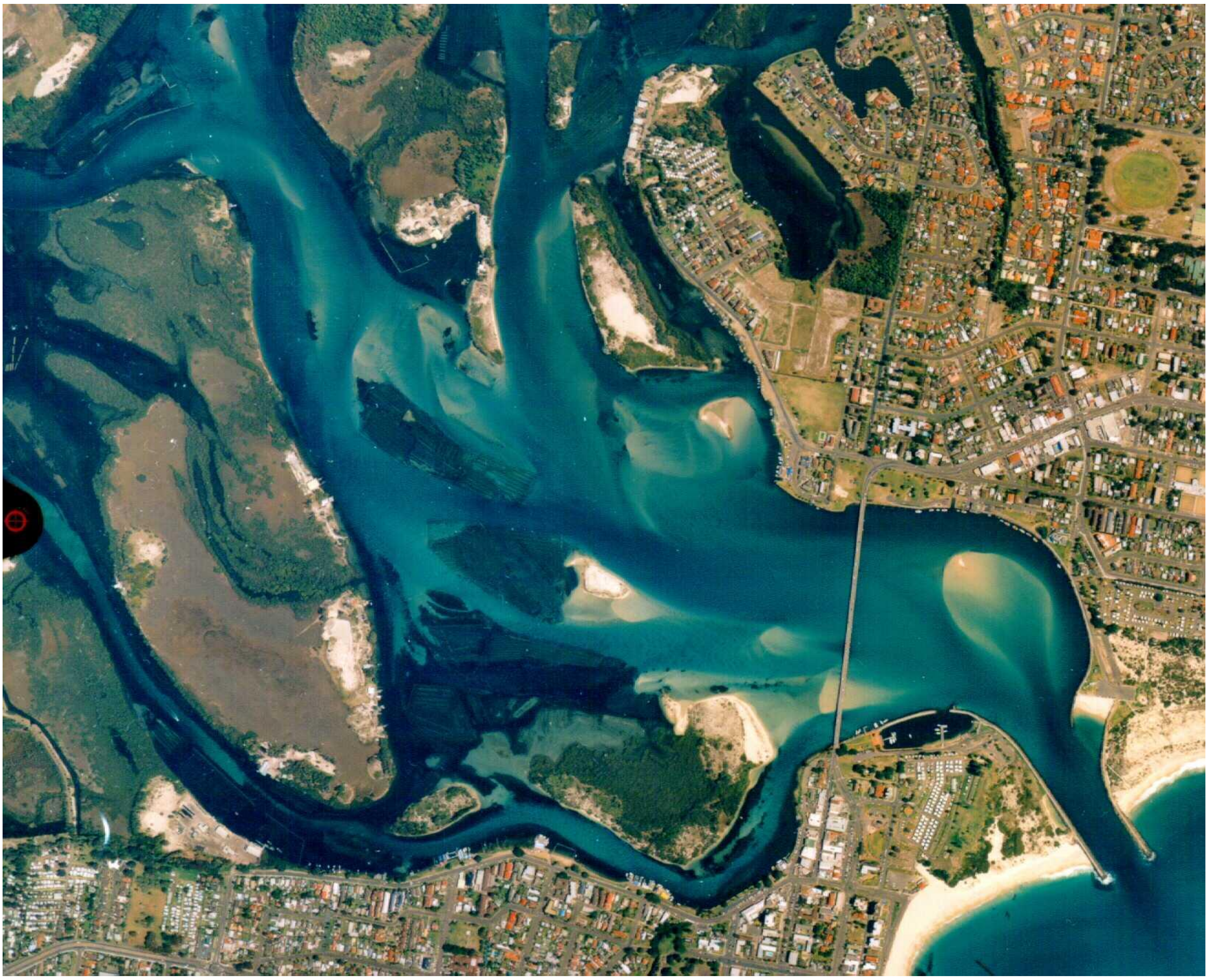
WALLIS LAKE FORESHORE (FLOODPLAIN) RISK MANAGEMENT STUDY

FLOOD STUDY REVIEW



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WALLIS LAKE FORESHORE (FLOODPLAIN) RISK MANAGEMENT STUDY FLOOD STUDY REVIEW

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FOREWORD

The State Government's Flood Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

The Policy provides for technical and financial support by the Government through the following four sequential stages:

1. *Flood Study*
   - determine the nature and extent of the flood problem.
2. *Floodplain Risk Management*
   - evaluates management options for the floodplain in respect of both existing and proposed development.
3. *Floodplain Risk Management Plan*
   - involves formal adoption by Council of a plan of management for the floodplain.
4. *Implementation of the Plan*
   - construction of flood mitigation works to protect existing development,
   - use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Wallis Lake Foreshore (Floodplain) Risk Management Study and Plan constitutes the second and third stages of the management process for Wallis Lake. It builds on the existing Floodplain Management Study and Plan for Forster and Tuncurry and encompasses all of the Wallis Lake foreshore. As part the Wallis Lake Foreshore (Floodplain) Risk Management Study this Flood Study Review was undertaken to ensure that design flood levels are obtained for the Wallis Lake Foreshore using current technology and approaches. This Flood Study Review has been developed by Great Lakes Council and prepared by WMAwater for the future management of flood liable lands surrounding Wallis Lake.

EXECUTIVE SUMMARY

The NSW Governments Flood Policy provides for:

- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of the Policy requires a four stage approach, with the Floodplain Risk Management Study constituting the second stage. The first stage, the Forster/Tuncurry Flood Study, was completed in 1989 and established design flood levels within Wallis Lake. The hydraulic model was later upgraded to a MIKE-11 model and additional branches included.

Due to the significant time since completion of the Flood Study a review was undertaken as part of this Management Study. As a result of this review it was determined that some approaches used in the original modelling of the Wallis Lake catchment are outdated, and coupled with better data available, a more rigorous hydraulic modelling approach is required. However the hydrologic modelling approach using a WBNM model has not been changed.

Reasons for Updating the Hydraulic Modelling Approach

The main reasons for updating the hydraulic modelling approach are as follows:

- the use of a two Dimensional (2D) hydraulic model,
- availability of detailed bathymetric data to better describe the bed of Wallis Lake rather than the use of cross sections,
- availability of Airborne Laser Scanning survey that provides a very accurate definition of the topography of the floodplain,
- a more detailed appraisal of design ocean level conditions,
- the incorporation of an "envelope" approach based on the maximum of an ocean dominated event and a runoff dominated event,
- a rigorous review of the available historical flood level data was undertaken to "explain" the reasons for the relatively high recorded levels for the April 1927 event compared to those recorded in the last 25 years.

Adopted Hydraulic Modelling Approach

The adopted approach was to establish a SOBEK 2D hydraulic model based on the available bathymetric and ALS survey with inflows from a WBNM hydrologic model. A calibration/verification was undertaken to the May 2003 and March 2005 events but is of limited value due to the small magnitude of these events.

Sensitivity analysis was undertaken to assess the impacts of various model parameters and the model was used for design flood estimation.

Coincidence of Ocean Levels and Runoff

Flood levels in Wallis Lake are affected by runoff from the upper catchment into the lake as well as inflows from the Pacific Ocean due to elevated ocean levels. However these two flooding mechanisms, whilst associated with each other, it is incorrect to assume that a (say) 100 year ARI (Average Recurrence Interval) ocean event will occur in conjunction with a 100 year ARI rainfall event. Such an event would have an ARI of greater than 100 year (say 500 year ARI).

Elevated ocean levels occur due to a combination of tides (the high tide varies from approximately 0.5 m to 1.1 mAHD during the year) and what are known as ocean anomalies. The main components of ocean anomalies (difference between the predicted and the recorded tide) are storm surge and wave setup at the entrance to Wallis Lake. The storm surge component 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 and strong onshore winds produce surface currents that cause a build up of water against the coastline.

The oceanographic component of the tidal anomaly covers a range of other factors that can affect ocean water levels. The most important of these are the shelf waves generated by large storms remote from the NSW coast.

Together these components can raise ocean levels by up to 1m. As part of this study ocean anomalies were investigated and two runoff/ocean scenarios were adopted to determine design flood levels in Wallis Lake. A modified normal tide (peak level of 1 mAHD) was adopted in conjunction with the design rainfall event (termed a rainfall dominated event) and the design ocean level in conjunction with a 5 year ARI event (termed an ocean dominated event).

The following conditions were adopted for the design flood analysis:

- 0 mAHD initial water level in Wallis Lake,
- 36 hour critical rainfall storm duration inflows in conjunction with a modified normal tide (peak at 1 mAHD),
- design ocean levels based on the design levels in Fort Denison/Sydney harbour plus a wave setup component of 0.35 m in the 100 year ARI reducing to 0.25 m in the 5 year ARI in conjunction with the 5 year ARI 36 hour critical rainfall storm duration inflows.

Design Flood Approach

An envelope approach was adopted which assumed the maximum of an ocean dominated event (design ocean level combined with a 5 year ARI event) and a runoff dominated event (design rainfall event combined with a "modified normal tide" with a peak at 1 mAHD). The results indicated that downstream of the bridge the ocean dominated event generally produces the higher level but upstream the runoff dominated event produces the higher level. The adopted design flood levels in Wallis Lake are provided in the table below.

Event (ARI)	Year 2010 with NO ocean level rise	Year 2060 with 0.5m ocean level rise	Year 2100 with 0.9m ocean level rise
PMF	4.4	4.5	4.6
200 year	2.2	2.6	2.9
100 year	2.0	2.4	2.7
50 year	1.8	2.2	2.5
20 year	1.5	2.0*	2.4*
10 year	1.5*	1.9*	2.3*
5 year	1.4*	1.8*	2.2*

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

Climate Change

A world wide anthropomorphic climate change is considered to raise ocean levels and increase the design rainfall intensities. A series of climate change scenarios were analysed using the modelling approach and it is concluded that design flood levels will rise if ocean levels or rainfall intensities increase. The results of ocean level rise are shown in the table above. A 10% rainfall increase will raise the 100 year ARI flood level by approximately 0.2m.

1. INTRODUCTION

This Flood Study Review details the updating of the hydraulic modelling approach for Wallis Lake, in accordance with the NSW Floodplain Development Manual (Reference 1), from that undertaken in the 1989 Forster/Tuncurry Flood Study (Reference 2). The hydrologic modelling approach was not updated and uses the same WBNM hydrologic model.

Updating of the hydraulic model for the Wallis Lake catchment (Figure 1) was considered necessary for a number of reasons.

- Since the completion of the Forster/Tuncurry Flood Study in 1989 (Reference 2) there have been significant advances in hydraulic modelling software which now include two-dimensional models (2D). These models have the advantage over the previously used 1D models of calculating direction as well as magnitude. This is particular advantageous for Wallis Lake as more accurate determination of flow paths around the shoals and islands near the entrance can be obtained. They also allow for more accurate representation of floodplain storage.

- 2D models are more data intensive, requiring detailed topographic data. This data has become available since 2000 (Figure 2a and b) with provision of a detailed bathymetric survey and overbank survey (from ALS) provided in 2009. A 2D model provides better utilisation of this information rather than a 1D approach.

- A review was undertaken of the design ocean levels derived in the 1989 Forster/Tuncurry Flood Study (Reference 2). Since 1989, further investigations and long term ocean/entrance water level data collection and analyses have provided a much better understanding of the processes operating at estuary entrances during storms.

- An “envelope” approach based on the maximum of an ocean dominated event and a runoff dominated event has become the accepted approach (Reference 3) rather than combining the design ocean level with the design rainfall event as undertaken previously.

- A review was undertaken of the available historical flood data, in particular the event of April 1927. This was initiated as the water level in Wallis Lake has never exceeded 1.1 mAHD in the last 25 years but reached approximately 2.3 mAHD in April 1927. No other recorded flood level has exceeded 1.1 mAHD.

2. PREVIOUS STUDIES

A summary of previous relevant investigations is provided below.

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

This study established design flood levels within Wallis Lake and its tributaries. 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.

Forster/Tuncurry Floodplain Management Study - April 1998 (Reference 4)

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

Wallis Lake Floodplain Management Study – Foreshore Flooding Assessment - August 2001 (Reference 5)

This study determined design flood levels as a result of wind wave action on the lake. The resulting levels were significantly higher than the still water levels derived in the 1989 Flood Study (Reference 2).

Forster South Breakwater Physical Model - July 2004 (Reference 6)

This study constructed a physical hydraulic model to develop a repair strategy for the head of the Forster southern breakwater. The report states that *...“the contribution of wave setup to the overall water level within a river entrance is minimal....”*. The following water levels were adopted for design:

- 100 year ARI water level of 1.5 mAHD,
- a 1.9 mAHD ocean water level representing the 100 year ARI level plus 0.4 m future ocean level rise,
- an extreme ocean water level of 2.2 mAHD.

3. CAUSES OF FLOODING

Flooding within Wallis Lake 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 rivers entering Wallis Lake,
- wind wave action within the lake itself.

Flooding as a result of wind wave action was not considered as part of this study as it was analysed in the Wallis Lake Floodplain Management Study – Foreshore Flooding Assessment - August 2001 (Reference 5).

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 to determine the impacts on the lake level. This approach is in accordance with Reference 3.

4. REVIEW OF HISTORICAL FLOOD DATA

4.1 Background

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. 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 Forster/Tuncurry Flood Study - 1989 - Reference 2).

Table 1: 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 2 (data taken from the Forster/Tuncurry Data Catalogue - July 1985 -Reference 7).

Table 2: Other 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 maximum 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 April 1927 level of 2.3 mAHD. However, this was only achieved through using a the 100 year ARI design ocean level (2.6 mAHD) in conjunction with the 100 year ARI inflows. Recent studies have suggested that a more appropriate 100 year ARI peak ocean level is of the order of 1.8 mAHD and Reference 3 indicates that this approach of adopting the same design ocean and design rainfall event is outdated.

This review of the historical flood data, particularly for the April 1927 event was initiated to provide greater understanding of why the April 1927 flood reached approximately 2.3 mAHD and is over 1 m higher than all other recorded events.

4.2 Approach

The adopted approach was to review all available data sources (Council, DECCW and historical society) and where possible re-evaluate the recorded historical levels.

Three theories for the high recorded levels for the April 1929 event were evaluated. The theories being:

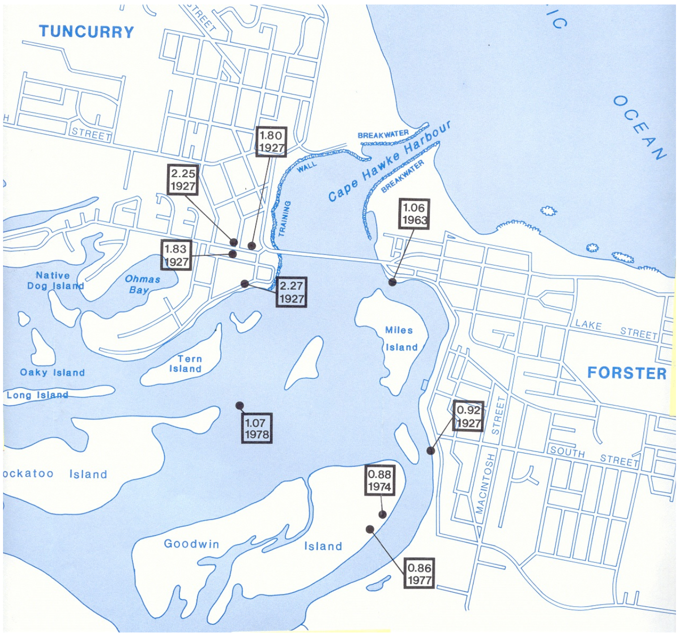
1. The flood never reached 2.3 mAHD and there is a datum or transcription error.
2. The recorded levels were as a result of wind wave action and did not reflect the general water level of the Wallamba River or Wallis Lake.
3. There was some blockage in the entrance channel or elsewhere which caused the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

4.3 Flood Height Data and Newspaper Reports

The seven recorded April 1927 levels are listed in Table 3 and shown on Plan 1.

Table 3: April 1927 Recorded Levels around Wallis Lake (taken from Reference 2)

Source	Flood Level (mAHD)	Comments (refer Plan 1 for location)
Great Lakes Shire Council: "Tikki Marina", Forster	0.92	This is possibly for the 1929 flood.
Mr M Constable : Old Church, Tuncurry	1.80	
Photo : Tennis Court, Tuncurry	1.83	Uncertain
Nov 1983 Wallamba River Flood Study : 10 Taree Street, Tuncurry	2.25	Tokelau house
Nov 1983 Wallamba River Flood Study : Theatre (Memorial Hall), Tuncurry	2.27	To window sill, >0.76 m above floor.
Great Lakes Council - Broadwater *(level not shown on Plan 1)*	2.45	Estimate of water level
Mrs E Gogerly, Whoota	3.04	Considered too high.



Plan 1: Recorded Flood Levels (taken from 1989 Flood Study - Reference 2)

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 states:

> *“However, at Tuncurry, irreparable damage was done. The Memorial Hall was right in the track of the torrent of raging waters and they just flowed through the building as in a tidal channel. At time of writing the actual height of the water in the hall is not ascertainable with any degree of certainty, but our informant says it was not less than two feet six inches. Anyhow, it made an awful mess of the electric lighting plant used in connection with the hall, the engine and the batteries being completely submerged.”*

This article implies that:

1. The floodwaters were most probably fast flowing (at some stage during the event).
2. The level reached up to around to 2.0 mAHD (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.
3. Considerable damage was caused inside the hall suggesting damage by inundation rather than wind wave action which would pass as the wave falls away.

The Memorial Hall in 1921 and today are provided as Photographs 1 and 2. Photograph 3 shows the Memorial Hall following the 1927 flood. Anecdotal information suggests the water level reached the window sill.

Photo 1: Memorial Hall in 1921

Photo 2: Memorial Hall in 2005

Photo 3: Memorial Hall following 1927 flood

Photo 4: Tokelau house, 10 Taree Street - April 1927 flood

Photo 5: Tokelau house (10 Taree Street) in 2005

Photograph 4 from 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). A current photograph of 10 Taree Street is given as Photograph 5.

A subsequent article in the 30th April 1927 edition of the Northern Champion states:

> *"The cause of the floodwaters rising so high was due to the blocking of the various channels by the sand dredge at the entrance, thus preventing the water from getting away. This was proved when the sand bank that stretches east and west along the ferry channel gave way. Then the waters immediately began to recede. It is hoped that all will co-operate in preventing this error of blocking waterways from re-occurring."*

Clearly if the above blockage did occur this would explain why the April 1927 event reached such a high level. Council minutes of 26 April 1927 detail the costs to repair damages to roads and bridges caused by the flood. The minutes also state:

> *"That the Department of Public Works be approached and requested to arrange for the dredging of the Tuncurry and Forster ferry approaches in conjunction with the work of dredging the channel now being carried out."*

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.

Surveys of the entrance to Wallis Lake are available for 1896, 1898, 1912, 1913, 1921, 1937 and 1961. These highlight the progressive changes to the entrance including the construction of the southern (Forster) breakwater around 1900 and the northern breakwater (completed between 1961 and 1971). The surveys of 1912, 1913 and 1921 show the progressive narrowing of the ocean entrance confining the outlet to near the Forster training wall. The 1937 survey indicates that the islands near the mouth appear to have increased in height from ½ foot above Low Water Ordinary Spring Tide in 1921 to 3 ½ feet. However it is important not to draw too many conclusions from comparison between these two surveys as floods in the intervening period could have significantly changed the entrance topography, as could the dredge which was used extensively in this area and upstream.

The January 1985 Wallamba River Flood Study (Reference 8) quotes four levels for the 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 (not mentioned in Table 2). 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 m and 1.83 m), 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).

There are also photographs (Photographs 6 and 7) taken during the April 1927 flood at the Chapman home on Garrabingbi Island, unfortunately the location of these photographs is unknown and a level has not been obtained.

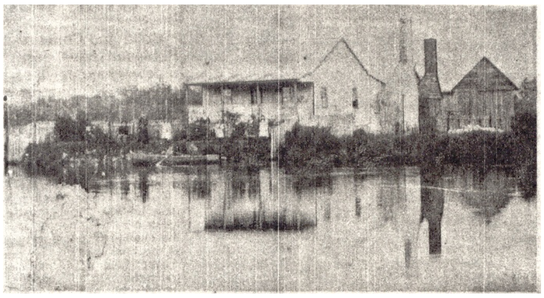


Photo 6: Chapman home Garrabingbi Island

Photo 7: Chapman home 1927 flood

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

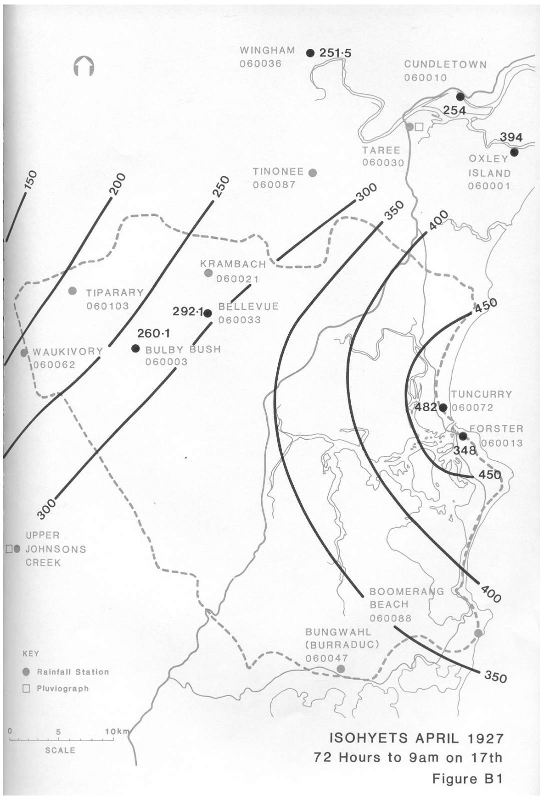
Notes of flood interviews undertaken in the mid 1980's indicate that there was reports of flooding at the site of the present Forster Keys and at the Coomba boatshed. These reports suggest that flooding occurred over the entire lake.

4.4 Rainfall Data

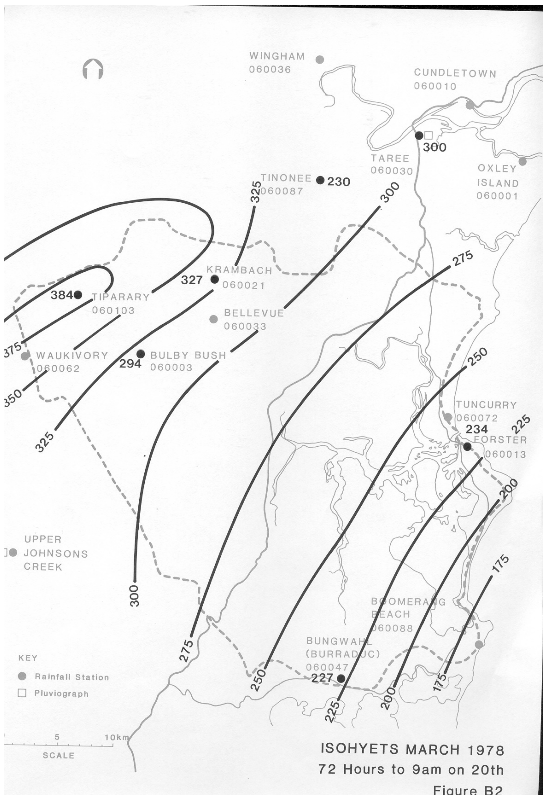
A comparison between the April 1927 and March 1978 rainfalls (see Plans 2 and 3) indicates:

- in the upper catchment the 3 day rainfall totals were greater in 1978 than in 1927,
- at Tuncurry (and probably along the Wallamba River) the 3 day rainfall totals were of the order of 50% greater in 1927. The 1 day totals were also greater in April 1927. Tuncurry recorded 363 mm in 24 hours in 1927, this is significantly greater than the 24h 100 year ARI design rainfall,
- based on the available rainfall data the April 1927 event is likely to have produced greater flood levels than March 1978.

There are no pluviometer data available for either event that would enable a comparison of rainfall intensities.



Plan 2: Isohyets 1927 Flood



Plan 3: Isohyets 1978 Flood

The storm of 15th - 19th April 1927 was identified in previous studies of elevated ocean levels affecting the NSW coast. The peak high tide at Fort Denison was 1.0 mAHD but there is no indication that it was significantly greater than similar such storms, as was the case with the storm of 25th/26th May 1974 (peak of 1.45 mAHD at Fort Denison). Whilst there are no records of storm surge or wave set up in April 1927 it is likely that due to the relatively shallow entrance the wave set up effects are likely to have been more significant than with the present entrance configuration.

4.5 Assessment of whether Floodwaters were Fast Flowing or Relatively Static at Tuncurry

The available photographs of 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 April 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. Photographs 8, 9 and 10 taken during the March 1978 flood indicate that there was no flooding at Point Road, Tuncurry for a similar but smaller 3 day rainfall total.

Photo 8: March 1978 Flood

Photo 9: March 1978 Flood

Photo 10: March 1978 Flood

4.6 Conclusions

- 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 due to the relatively deep entrance. Furthermore Great Lakes Council and DECCW would never allow a situation to develop (siltation, dredging spoil) that would further restrict the outlet to the ocean.

5. AVAILABLE DATA

5.1 Flood Levels

A number of historical flood levels for Wallis Lake were available and an analysis of these was undertaken in Section 4. 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 for the Tiona and Tuncurry water level recorders is provided as Figure 3. 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, 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.

5.2 Rainfall

Rainfall data are available either from daily read gauges or pluviometers. The locations of the gauges are shown on Figure 1 and details of rainfall for the two calibration events are shown in Table 4.

Table 4: Rainfall Stations

Station Name	Station Number	Date Opened	Rainfall (mm) 14 to 17 May 2003	Rainfall (mm) 22 to 25 March 2005
Daily Read				
Bulby Bush - Blue Lookout	60003	1925	109	58
Forster Beach Caravan Park	60013	1896	303	116
Krambach Post Office	60021	1910	95	32
Krambach - Bellevue	60033	1908	108	37
Waukivory (The Ranch)	60062	1961	111	31
Wootton	60065	2002	111	92
Bungwahl	60095	2002	239	75
Cabbage Tree Mountain	60096	2002	163	164
Krambach - Tiparary	60103	1970	86	48
Smiths Lake (Patsys Flat Road)	60144	1980	287	156
Pluviometer				
Tiona		unknown	47	174
Tuncurry		unknown	258	n/a
Nabiac		unknown	129	36

5.3 Survey

The bathymetry of Wallis Lake was recorded by hydrosurvey (Figure 2a and b) and took several years to complete. It did not extend above 0.5 mAHD and thus does not define the floodplain.

Airborne Laser Scanning (ALS) survey was undertaken in 2009 and a validation assessment of this dataset was undertaken as part of this present study (refer Appendix B). In summary this states that a detailed check survey was undertaken which indicated that the ALS dataset should be lowered by 0.1m to correct for the difference between the field surveyed levels and the ALS. This correction was applied for use in this study.

5.4 Tidal

Tidal data were available from the Forster gauge as well as from Port Stephens. The Forster gauge, though obviously the closest to the outlet, 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 used to represent ocean conditions at the entrance to Wallis Lake for historical events. The highest level recorded since 1986 at the Forster gauge is 1.0 mAHD in June 2005 and at Port Stephens is 1.34 mAHD in June 1999. The design ocean levels at Fort Denison based on 80+ years of record (as reported in the Forster South Breakwater Physical Model - July 2004 - Reference 6) are:

- 100 year ARI - 1.50 mAHD,
- 50 year ARI - 1.47 mAHD,
- 20 year ARI - 1.43 mAHD,
- 10 year ARI - 1.39 mAHD,

- 1 year ARI - 1.28 mAHD.

No accurate estimates of ocean levels for events greater than the 100 year 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.

6. OCEAN WATER LEVEL ASSESSMENT

6.1 Background

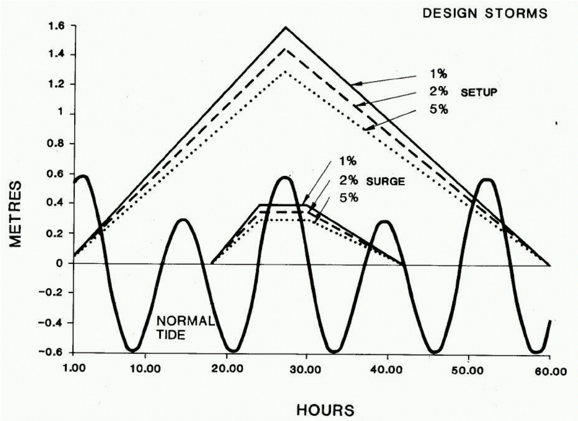
The 1989 Forster/Tuncurry Flood Study (Reference 2) used ocean entrance design hydrographs as downstream boundary conditions for the hydraulic model of the lake. The likely maximum ocean entrance levels during the 100 year, 50 year and 20 year ARI design storm/flood events were determined by examining the ocean level component parts and summing these to produce maximum design levels. The component parts examined were:

- astronomic tide,
- storm surge (barometric and wind stress effects),
- wave setup at the entrance.

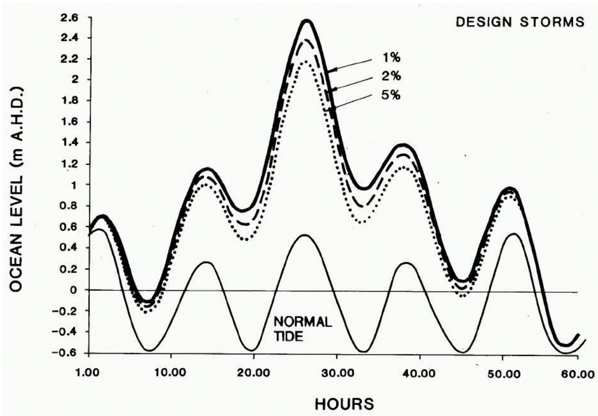
Table 5 and reproduced figures (Plans 4 and 5) set out the maximum design levels adopted in the 1989 Forster/Tuncurry Flood Study (Reference 2). The adopted astronomic tide level was 0.6 mAHD, which is approximately the Mean High Water Springs level and is exceeded around 10% of the time. The adopted storm surge component for the 100 year ARI event was 0.4 m. This was based on historical data from Fort Denison/Sydney Harbour and has a recurrence of around 1 in 5 years. However, by far the largest ocean level component adopted was the wave setup level of 1.6 m. This level was estimated assuming the entrance was shallow and unprotected, and using procedures for wave setup given in the Shore Protection Manual (Reference 9).

Table 5: 1989 Flood Study (Reference 2) Ocean Boundary Maximum Design Levels

Design Event (ARI)	Astronomic Tide (mAHD)	Storm Surge (m)	Wave Setup (m)	Adopted Peak Ocean Level (mAHD)
100 year	0.6	0.40	1.60	2.6
50 year	0.6	0.35	1.45	2.4
20 year	0.6	0.30	1.30	2.2



Plan 4: Figure D1 from Reference 2



Plan 5: Figure D2 from Reference 2

The procedures and assumptions used to determine the maximum design levels were "standard" at the time of the assessment. However, since 1989 further investigations and long term ocean and entrance water level data collection and analyses have provided a much better understanding of the processes operating at estuary entrances during storms. This is particularly the case for wave setup and the impacts on flood levels inside entrances. As a result, the assumptions and procedures used for the 1989 Flood Study (Reference 2) to determine wave setup are now considered to be conservative. At the time of the Flood Study (Reference 2) the ocean breakwaters had just been completed and the entrance was still relatively shallow where wave setup could be expected. Subsequently the entrance has deepened reducing the effect of wave setup.

The following sections examine relevant available data and determines design ocean hydrographs that better reflect the conditions applying at the Wallis Lake entrance.

6.2 Methodology

The basic methodology for this Flood Study Review is similar to that used for the 1989 Flood Study (Reference 2) in that the individual component parts that make up elevated ocean levels at the lake entrance were examined, and summed to produce possible 100 year, 50 year and 20 year ARI maximum design levels. An allowance for sea level rise due to climate change is considered in Section 8.

Based on this approach, the significant water level components affecting the entrance to Wallis Lake are:

- astronomic tide,
- tidal anomaly:
  - storm surge (barometric and wind stress effects),
  - oceanographic effects (shelf waves, ocean currents, temperature variations),
- wave setup,
- climate change.

6.3 Available Tidal Data

The tidal record for Fort Denison in Sydney Harbour is over 125 years long (though the early part is not continuous). Since completion of the 1989 Flood Study (Reference 2) the almost continuous record from 1914 has been digitised and analysed to accurately determine its astronomic and anomaly components (Reference 10). Since around 1984 there has also been accurate tidal data recorded at a number of ocean and estuary entrance locations along the NSW coast. These data sets have been analysed by numerous studies (References 11 and 12) and provide a much improved understanding of tidal conditions and influences along the NSW coast and inside estuary entrances.

The Fort Denison gauge, 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 (such as storm surge and oceanographic effects) 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 ocean tidal anomaly components, but also some wave and/or estuary effects. The Wallis Lake (Forster) gauge installed in 1986 is an example, as are the Hastings River (Port Macquarie), Manning River (Harrington) and Lake Macquarie (Swansea) gauges.

6.4 Astronomic Tides

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.

Analysis of the long term tidal harmonics for Fort Denison shows that the maximum possible astronomic tide level is less than 1.1 mAHD, and that a level of 0.6 mAHD is exceeded around 10% of the time. The 0.6 mAHD level is also approximately the Mean High Water Springs tide level (the average of two highest new moon and full moon tides).

Harmonic analyses for the other “deep still water” gauge locations along the NSW coast, as well as many of the entrance gauge locations, including the entrance to Wallis Lake (Forster gauge), give very similar harmonic constituents to Fort Denison (Reference 10). This similarity shows that the maximum astronomic tide level at these locations (including the Wallis Lake entrance) is also less than 1.1 mAHD and that an astronomic tide level of 0.6 mAHD would be exceeded around 10% of the time.

6.5 Ocean Tidal Anomaly

As mentioned, the ocean tidal anomaly component recorded at a "deep still water" gauge location is made up of storm surge and oceanographic effects. This anomaly is recorded as a variation from the predicted astronomic tide level.

The storm surge component 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 and strong onshore winds produce surface currents that cause a build up of water against the coastline.

The oceanographic component of the tidal anomaly covers a range of other factors that can affect ocean water levels. The most important of these are the shelf waves generated by large storms remote from the NSW coast. These waves are long and low, with heights of up to 0.2 m and periods of many days. When these waves reach the eastern continental shelf they are confined and migrate along the coast producing elevated ocean water levels.

The size and occurrence of oceanographic effects is hard to determine accurately. However, for the purposes of determining an ocean hydrograph for Wallis Lake this is not necessary, as statistically these effects are accounted for in the overall "deep still water" tidal anomaly analysis.

An analysis of "deep still water" anomalies along the NSW coast (Reference 11) found very good correlation between anomaly levels and occurrence north and south of Wallis Lake between Crowdy Head and Batemans Bay. This correlation reflected the size and similarity of the weather systems along the coast despite the more localised nature of the effects, and the remote nature of shelf waves. As a result of the correlation it is reasonable to assume that the tidal anomaly conditions near the entrance to Wallis Lake would be similar to those at Fort Denison.

Analysis of the tidal anomalies recorded at Fort Denison since 1914 shows that the maximum "deep still water" increase is around 0.6 m (as occurred in 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 (Reference 11). However, there is a correlation between a storm event capable of producing major flooding in a large catchment such as the Wallis Lake catchment and a storm event likely to produce a large storm surge tidal anomaly.

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) 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. On this basis, and considering the potential for other oceanographic effects, a level of between 0.5 m and 0.6 m was adopted as a reasonable/conservative upper bound tidal anomaly during a major flood event.

6.6 Wave Setup

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.

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. Wave setup can be relieved by a lull in wave energy, by alongshore rips and currents and at estuary entrances (Reference 13). The extent of the relief is highly dependent on the specific site conditions, but the implications for estuary entrances means that the method used to calculate setup as set out in the Shore Protection Manual (Reference 9) and as used in the 1989 Flood Study (Reference 2) is not appropriate for the Wallis Lake entrance.

“Deep still water” locations not in the breaker zone, such as Fort Denison, Coffs Harbour, Crowdy Head and Port Stephens (Tomaree) 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. This is reflected in the correlation between the astronomic tide predictions at these sites (as already discussed above). However, most estuary entrance locations are exposed to ocean waves and have shallow foreshore conditions capable of producing breaking waves under some high energy wave climate conditions. These locations are inside the breaker zone and under these conditions will be affected by wave setup to some extent.

The degree to which estuary entrance locations are affected by wave setup depends on the exposure of the site and the capacity of the waves to break and produce setup. It also depends on how quickly any setup can be relieved by flow into the estuary. Some locations with relatively high exposure and shallow bed conditions, such as the entrance to the Manning River, experience significant wave setup. Other locations with some protection but with shallow bed conditions such as the entrance to Lake Macquarie (Swansea) or the Hastings River (Port Macquarie), have significant setup during larger wave climate conditions, but none during low conditions. Other, semi-protected and deep entrances, such as the entrance to Wallis Lake, have very little wave setup under most conditions.

A detailed survey of the Wallis Lake entrance in 1998 showed that water depths across the entrance bar are between -4 to -6 mAHD. At this depth, the nearshore waves would need a significant wave height of at least 6 m to consistently break across the entrance and hence produce conditions conducive to developing wave setup. Storms that could sustain such conditions for a significant period (say 6 hours) have a recurrence of around 1 in 5 years (Reference 14). However, the Wallis Lake entrance is substantially protected from waves from all directions other than from the east to the north-northeast. As a result, the storms capable of producing high energy wave climate conditions are restricted to tropical cyclones and some eastern trough lows and southern secondary lows. This reduces by more than half the occurrence of storms likely to produce setup events at the entrance.

Analysis undertaken for this assessment on the 22nd and 23rd March 2005 large energy wave event confirms the above analysis. The low pressure system causing that event was centred off the coast of NSW between Sydney and Coffs Harbour moving south to north. The central pressure dropped to 996 hPa and winds were south easterly at around 35 knots. Under these conditions, a storm surge anomaly of between 0.3 and 0.4 m could be expected at "deep still water" gauge locations.

Table 6 sets out the tidal anomalies recorded at a number of "deep still water" gauges as well as the tidal anomaly plus wave setup at a number of estuary entrance gauges during the 22nd and 23rd March 2005 event. The table also shows an approximation of the tidal anomaly component at the estuary entrance locations based on the adjoining "deep still water" locations, and by subtraction the resultant wave setup component at the estuary entrances.

Table 6: Tidal Anomalies and Wave Setup (m) during March 2005 Large Wave Energy Event

Gauge Location	Gauge Type	Max. Anomaly + Setup	High Tide Anomaly + Setup	Est. Storm Surge	Resultant Wave Setup
Coffs Harbour	Deep S W	0.34	0.31	0.35	0.0
Hastings River	Estuary	0.65	0.33	0.40	0.25
Manning River	Estuary	0.77	0.65	0.40	0.37
Wallis Lake	Estuary	0.44	0.22	0.40	0.04
Port Stephens	Deep S W	0.45	0.43	0.45	0.0
Hunter River	Estuary	0.46	0.36	0.45	0.0
Lake Macquarie	Estuary	0.50	0.16	0.40	0.10
Port Jackson	Deep S W	0.29	0.28	0.30	0.0
Shoalhaven River	Estuary	0.26	0.11	0.25	0.0
Batemans Bay	Deep S W	0.27	0.12	0.25	0.0

The analysis shows that significant wave setup occurred at the Hastings River and Manning River entrances of 0.25 m and 0.37 m respectively. Such a response is in keeping with the wave exposure and shallow nature of the entrances. Similarly, the smaller 0.1 m results for the Lake Macquarie entrance, which is well sheltered from south easterly waves, and the even smaller 0.04 m setup for the Wallis Lake entrance, which is both well sheltered and deep, are as expected.

These wave setup differences were also reflected in the analysis of tidal anomalies for the years between 1987 and 1991 (Reference 11). All the estuary entrance sites show good correlation with

Port Jackson during low wave climate conditions, but the Hastings River and Lake Macquarie deviate significantly during larger wave climate conditions. However, there is very little variation between the Wallis Lake entrance (Forster) and Port Jackson, indicating little wave setup at the Wallis Lake entrance during the period. Further, analysis of the Forster gauge since 1986 shows that water levels at the entrance have never exceeded 1.1 mAHD, indicating that little if any wave setup has occurred in that time.

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. The level of setup would initially be partially relieved by flows into the estuary, and later by the bed scour and the entrance rip formed by catchment outflows. However, provided the wave energy is sufficiently large and sustained wave setup would occur. Based on the available information, the maximum likely wave setup during a major flood event is unlikely to be greater than 0.4 m.

6.7 Tidal Anomaly Analysis

Water level data at the breakwater at the mouth of Wallis Lake (termed the Forster tide gauge) have been recorded continuously since March 1986. It should be noted that this gauge is located near the boat harbour and thus is influenced by entrance conditions and is not representative of the ocean level. These data can be compared with the “predicted” tidal data to estimate the difference in water levels resulting from any tidal anomaly. To some extent the Forster gauge will also be influenced by elevated water levels in Wallis Lake, resulting from runoff from the catchment. However, this component is likely to be small as there have been no significant floods in the catchment since 1986 and thus has been ignored.

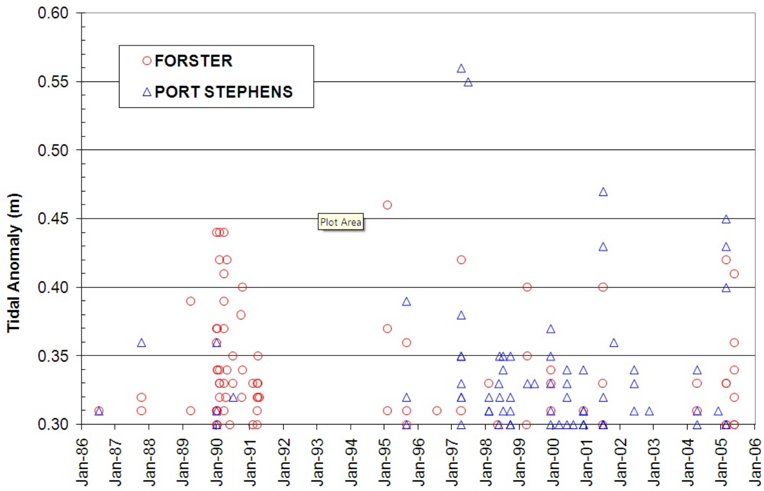
Manly Hydraulics Laboratory (MHL) were commissioned to compare the recorded v predicted water levels at the Forster and Port Stephens tidal gauges to obtain the residual or anomaly.

Initially it was expected that there would be a difference between the results from these two gauges reflecting the possible influence of wave set up or other entrance effects at Forster. However as will be seen from the results the maximum anomaly at Forster and at Port Stephens (except for two cases) is less than 0.5 m. Due to the relatively small amount of anomaly recorded in the 19 year period since 1986 it was not considered worthwhile to interrogate the data further and to try and separate the storm surge and (possible) wave set up components.

The results of the tidal anomaly analysis by MHL are summarised as follows:

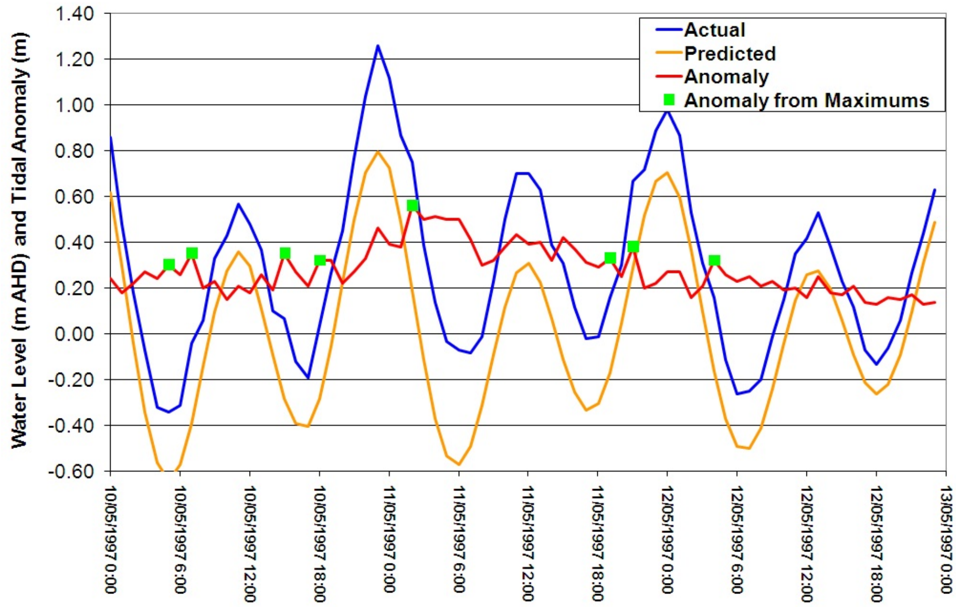
- The maximum water level recorded at Forster (19 years of record) is 1.0 mAHD (datum conversion of -1.061) and at Port Stephens (datum conversion of -0.944) is 1.34 mAHD. The maximum predicted levels (0.92 mAHD at Forster and 1.23 mAHD at Port Stephens) are approximately 0.1 m lower than the maximum recorded levels.

- 86 incidences of an anomaly greater than 0.3 m were recorded at Forster, with the largest being 0.46 m (March 1995). At Port Stephens 75 such incidences were recorded with the largest being 0.56 m (May 1997). Plan 6 shows these incidences and indicates some correlation between the timing of the events at the two locations but also many differences. For example, in the 18 month period from January 1990 there were approximately 30 incidences at Forster whilst there were only 4 recorded at Port Stephens. The opposite occurs in the four year period from June 1997 when there were a large number of incidences at Port Stephens but few at Forster. Both gauges recorded no incidences >0.3 m in the four year period from April 1991. Further more detailed analysis of the record may provide further explanation for these variations. This was not undertaken as the present study was primarily interested in the magnitude of the tidal anomaly. As this was relatively small (maximum of approximately 0.5 m at Forster) this additional work was not warranted.



Plan 6: Tidal Anomalies

- The highest two anomalies at Port Stephens were approximately 0.1 m greater than the third largest and further investigation of the record for the largest anomaly (May 1997) was undertaken. The results are shown on Plan 7. The graph also shows the anomaly values for this period of record identified in the 75 such incidences >0.3 m recorded at Port Stephens. One of the first points to note is that not all the values >0.3 m in the May 1997 record were included in the 75 recorded instances (only 8 such instances recorded by MHL). The record also shows that the anomaly is not a smooth line, rather it consists of peaks and troughs which can vary by over 0.1 m in an hour. The peak anomaly of 0.56 m is one such peak and a more representative anomaly value for this period is 0.5 m.



Plan 7: May 1997 Anomaly at Port Stephens Gauge

In conclusion the tidal anomaly analysis has indicated that in the last 19 years the maximum ocean anomaly for a period of several hours (storm surge and wave set up) is no greater than 0.5 m at either Forster or Port Stephens and the maximum recorded level is only 1.0 mAHD at Forster and 1.34 mAHD at Port Stephens. On this basis an estimated 100 year ARI ocean level of 2.6 mAHD appears high.

6.8 Summary

Based on the above assessment the maximum ocean boundary levels as set out in Table 7 have been determined for the Wallis Lake entrance for current and year 2060 and 2100 conditions (refer Section 8). The levels are based on the design ocean levels at Fort Denison (Section 5.4) with the addition of a wave setup component.

Table 7: Estimated Ocean Boundary Maximum Levels

Design Event (ARI)	Fort Denison Design Ocean Level (mAHD)	Wave Setup (m)	Adopted Peak Ocean Level (mAHD) NO Climate Change	Peak Ocean Level (mAHD) with 0.5m sea level rise (year 2060)	Peak Ocean Level (mAHD) with 0.9m sea level rise (year 2100)
Extreme	1.90	0.40	2.30	2.80	3.20
100 year	1.50	0.35	1.85	2.35	2.75
50 year	1.47	0.33	1.80	2.30	2.70
20 year	1.43	0.30	1.73	2.23	2.63
10 year	1.39	0.28	1.67	2.17	2.57
5 year	1.30	0.25	1.55	2.05	2.45

7. MODELLING

7.1 Approach

A diagrammatic representation of the Flood Study process is shown in Diagram 1. 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 the 1989 Study (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).

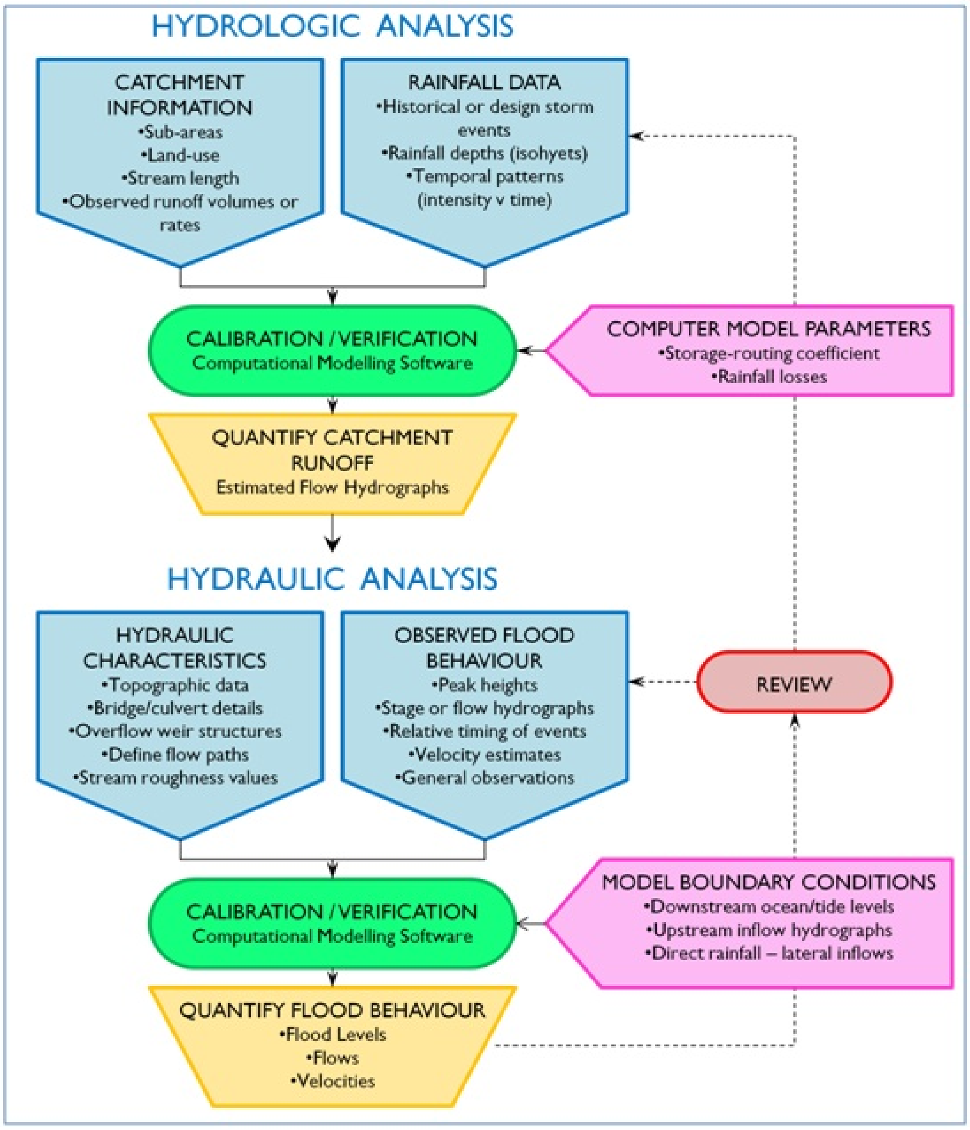


Diagram 1: Flood Study Process

7.2 Hydrologic Model

Hydrologic models suitable for design flood estimation are described in AR&R 1987 (Reference 15). 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 previously in the 1989 Flood Study (Reference 2), this same model was established for this study. The catchment was divided into sub-catchments (Figure 1) 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 the 1989 Flood Study (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.

7.3 Hydraulic Model

A 2D SOBEK model was established 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 by 100 m cell size grid covered the majority of the area, whilst a finer 10 m by 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 model. Tidal conditions at the entrance were input at the mouth of the entrance and included both synthetic and historical tidal data.

7.4 Calibration

Water level data are available from the Tiona and Tuncurry gauges since 1985 (Figure 3). However, given that the highest recorded lake level is only 0.7 mAHD there is no significant flood event for calibration. Two recent events, May 2003 and March 2005 were chosen 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 (Table 4).

Pluviometer data were available from the Tiona, Tuncurry and Nabiac gauges for the May 2003 event and from Tiona and Nabiac only for March 2005. Water level data were available for both events from the Tiona, Forster, Tuncurry and Port Stephens stations. Given the large variation in recorded rainfalls for the May 2003 event it would appear that the Tiona gauge did not record all the rainfall (47 mm compared to 258 mm at Tuncurry over the same period). Thus the Tiona gauge was not used for May 2003. Daily read data for both events were also available at ten daily read stations across the catchment (Figure 1).

The Forster water level recorder is within the lake itself (located inside the entrance) and thus does not accurately record the ocean tidal conditions. For this reason data from the Port Stephens tidal gauge was used as the ocean boundary as it is assumed that the ocean level at Port Stephens would be similar to that at the entrance to Wallis Lake.

The primary aim of the calibration was to match the peak water level in the lake, however some emphasis was also placed on matching to the shape of the stage hydrograph. The Manning's ‘n’ value was the only parameter that could be altered in the SOBEK model.

The calibration results for the May 2003 and March 2005 events are shown in Figures 4 and 5 respectively. Neither calibrations gave a particular close match, however this is not unexpected. Calibrating water levels in estuaries is a complex process as they are dynamic systems. The hydrosurvey is a snapshot taken at one point of time and it is recognised that the sand banks and shoals within the entrance area of Wallis Lake are constantly varying, and at the time of either event could be quite different compared to that represented by the hydrosurvey. The location and size of these shoals have the potential to significantly affect the match to the recorded hydrographs. The effect would likely vary according to the magnitude of the event. Large rainfall events would probably flush out some of the sand banks and scour the entrance. Smaller events are unlikely to have this effect. Similarly, the time between flood events and high ocean levels or similar would have an impact on the shoals and sand banks. For these reasons too much emphasis should not be placed on the calibration of estuary systems to relatively minor events using these types of models. The final Manning’s ‘n’ values adopted (0.015 throughout the lake with 0.03 at the entrance to represent shoaling and sand movement) are those that produced the best fit for both events. It is noted that the 1989 Flood Study (Reference 2) adopted Manning’s ‘n’ values ranging from 0.025 to 0.04 near the entrance.

7.5 Design Tides

A number of design tide scenarios were modelled in order to fully examine the tidal influence on water levels in the lake. The range of tides are shown in Figure 6 and detailed in Table 8.

Table 8: Design Tide Scenarios

Tide Name	Description
Normal Tide	A synthetic tide oscillating between –0.4 mAHD and 0.6 mAHD in 12.5 hour cycles. This tide differs to that used in the Forster/Tuncurry Flood Study (Reference 2) as the latter assumed every alternate high tide only reached 0.3 mAHD rather than 0.6 mAHD.
Elevated Tide	A synthetic tide oscillating between –0.4 mAHD and 1 mAHD in 12.5 hour cycles. The high tide is increased to incorporate a 0.4 m anomaly (say 0.2 m wave setup and 0.2 m storm surge) but still allowing for normal low tides.
Modified Normal Tide	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.
1974 Original Tide	The May 1974 Fort Denison (Sydney Harbour) tide which is the highest on record (1.45 mAHD). This tide encompasses a storm surge component (0.55 m) and the high tide (0.9 mAHD) however due to the gauge location in Sydney Harbour does not include any wave setup component.
Modified 1974 Tide	The historical 1974 tide data with 0.35 m added to represent wave setup creating a peak of 1.8 mAHD.

7.6 Design Rainfall

Design rainfall data (Table 9) were calculated in accordance with Australian Rainfall and Runoff (Reference 15). 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 1989 Flood Study (Reference 2).

Rainfall data were calculated from (Reference 15) at five locations distributed across the catchment. The rainfall at the catchment centroid was adopted across the entire catchment without any areal reduction fraction. This was justified as this centroid rainfall had the second lowest rainfall intensities and 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 1989 Flood Study (Reference 2).

Anthropogenic climate change has the potential to increase design rainfall intensities and this has been investigated in Section 8.

Table 9: Design Rainfall Intensities

Duration		Average Recurrence Interval							
		5y	10y	20y	50y	100y	200y	500y	PMF
12 hour	intensity (mm/h)	10.6	11.9	13.6	15.9	17.6	19.3	21.7	48.3
	depth (mm)	128	143	164	191	211	232	260	580
18 hour	intensity (mm/h)	8.34	9.35	10.7	12.4	13.8	15.1	16.9	n/a
	depth (mm)	150	168	192	224	248	272	305	n/a
24 hour	intensity (mm/h)	7.0	7.9	9.0	10.4	11.5	12.7	14.2	34.2
	depth (mm)	168	188	215	251	277	304	340	820
30 hour	intensity (mm/h)	6.1	6.8	7.8	9.1	10.0	11.0	12.3	n/a
	depth (mm)	183	205	234	273	301	331	370	n/a
36 hour	intensity (mm/h)	5.5	6.1	7.0	8.1	8.9	9.8	11.0	26.9
	depth (mm)	196	219	251	291	322	353	395	970
48 hour	intensity (mm/h)	4.5	5.1	5.8	6.7	7.4	8.1	9.1	22.5
	depth (mm)	217	242	277	321	355	389	435	1080
72 hour	intensity (mm/h)	3.4	3.8	4.3	5.0	5.6	6.1	6.8	18.2
	depth (mm)	245	274	312	362	400	438	489	1310

Design flow hydrographs were extracted from the WBNM model, including rainfall that fell on the lake itself, and were used as inflows into the SOBEK model. The critical storm duration was determined by using 100 year ARI inflows of various durations with a 0 mAHD static tide. The static tide was used to mitigate any timing influences introduced by using a dynamic tide. As shown in Figure 8a, the 36 hour 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. Design inflow hydrographs for the 36 hour storm duration are shown on Figure 7.

7.7 Sensitivity Analyses

Due to the complex nature of tidal influenced coastal systems, sensitivity analysis was undertaken for a number of key parameters and assumptions. The results of this sensitivity analyses were used to develop the adopted design flood scenarios.

7.7.1 Starting Level in the Lake

The "normal" water level in Wallis Lake is assumed to be 0 mAHD based on the gauge record at Tiona (Figure 3). However the lake level could be raised prior to the main storm event for a number of reasons, including preceding rain and/or a raised ocean level. During a period of elevated ocean levels th lake gets "pumped up" raising the mean water level to 0.1mAHD. The effect of varying starting lake levels on the peak water level were tested for the 100 year ARI 36 hour design event using five initial water levels: 0.0 m, 0.1 m, 0.3 m, 0.5 m and 0.7 mAHD with a constant ocean level of 0 mAHD (to eliminate timing effects). The results in Figure 8b indicate that a variation in starting water level of 0.7 m (between 0.0 mAHD starting level and 0.7 mAHD) had an effect of less than 0.2 m on the peak level. The main reason being that the lake water level falls prior to the bulk of the runoff arriving from upstream.

A starting water level of 0.0 mAHD was adopted for all design events and this is justified based on the historical record at Tiona and because even if a higher level of say 0.3 mAHD was assumed the resulting difference in the peak level is minor. It should also be noted that the inclusion of a tidally varying starting level would further decrease the effects of any assumed starting level.

7.7.2 Tidal Effects

The effects different tides have on water levels in the lake were analysed using a number of scenarios. Figure 9a indicates the effect of various tides on "pumping up" the lake level. The May 1974 recorded tide (ocean levels above 1 mAHD for seven days) indicates that it is reasonable to assume that an elevated ocean will occur for several days. For this reason the tides were simulated for a period of several days.

For example the modified 1974 tide (wave setup component added) will elevate the minimum water level to above 0.6 mAHD with a peak of over 1.2 mAHD (Figure 9a). The key points to be noted are that the increase in lake level for the modified 1974 tide takes several days to occur and the effect of the lake is to "dampen out" the peaks and troughs.

The elevated tide raises the levels above 0.3 mAHD with a peak of 0.5 mAHD (Figure 9a). However the peak level is reached within 30 hours which is shorter than with the modified 1974 tide.

The modified normal tide raises the levels above 0.4 mAHD with a peak of 0.65 mAHD with the peak level reached in a similar time to the elevated tide (Figure 9a).

Figure 9b indicates the impact of including design inflows in conjunction with the modified 1974 tide. Inclusion of inflows to the lake in conjunction with elevated ocean levels produces a significant increase in the resulting peak lake level. The 5 year ARI inflows increase the lake level by nearly 0.6 m. It should be noted that there is no historical data available at Wallis Lake indicating the likely joint occurrence of an ocean event with a rainfall event.

Figure 10a shows three different tides in combination with the 100 year ARI 36 hour duration inflows. The modified normal tide and elevated tide have the same high tide level (1 mAHD), however the elevated tide has a low tide of –0.4 mAHD compared to 0 mAHD for the modified normal tide. The normal tide, which has a high tide of 0.6 mAHD produces a peak water level of just greater than 1.7 mAHD, the elevated tide a peak level of approximately 1.85 mAHD and the modified normal tide a peak level of approximately 1.95 mAHD. Thus the effect of a minimum low tide of 0 mAHD (the modified normal tide) is to raise the peak water level by approximately 0.1 m compared to the elevated tide.

The modified normal tide in conjunction with the design rainfall events was adopted for the design flood analysis on the basis that it is not unreasonable to expect that the meteorologic conditions producing intense rainfalls will also produce some ocean anomaly. This scenario is confirmed in the

June 2007 event at Newcastle where the intense rain was preceded by significant ocean activity (resulting in the Pasha Bulker being beached outside Newcastle Harbour). In the absence of any other information on the joint occurrence of an ocean and rainfall event an ocean anomaly of 0.4m was assumed (the modified normal tide is the normal tide increased by 0.4m - refer Table 8).

7.7.3 Timing of Inflows

The effect of varying the coincidence of the peak ocean level and the peak inflow is provided on Figure 10b for the modified normal tide and the 100 year ARI 36 hour duration event. The timing had a maximum effect of approximately 0.1 m on the peak level. The adopted scenario assumed a coincidence which produced the highest lake level. This timing was adopted for all design events.

7.7.4 Manning's 'n'

The effect of Manning's 'n' on peak water levels is indicated on Figures 11a and 11b. The results (Figure 11a) indicate a significant impact when the ocean influence is dominant (i.e no inflows) but little impact when the inflow dominates (5 year ARI inflows).

Figure 11b indicates that the Manning's 'n' has a bigger influence on the peak level when a static ocean level is used as opposed to when a cyclical ocean level (modified normal tide) is used.

A Manning's 'n' of 0.03 was adopted for design based on the results from the calibration (Section 7.4).

7.7.5 Change in Design Rainfall Intensities

The effect of an increase or decrease in design rainfall intensities can be evaluated from the available design flood results. A 10% increase in the 100 year ARI 36 hour design rainfall intensity equals the 200 year ARI intensity whilst a 10% decrease equals the 50 year ARI intensity. Thus a +/- 10% change in design rainfall intensities for the 100 year ARI event changes levels by approximately +/- 0.2m (though a slightly different ocean level is adopted for the 50 year ARI event). The effect of a 10%, 20% and 30% increase in rainfall intensities is further investigated in Section 8.

7.7.6 Inclusion of ALS

This study was initiated prior to provision of the ALS overbank survey (i.e accurate survey above 0 mAHD) in 2009. In Reference 2 and in the work undertaken prior to 2009 no overbank survey (i.e survey above 0 mAHD) was available and the increase in storage area above 0 mAHD could not be accurately estimated. The inclusion of the ALS indicated that the previous assumptions on the extent of storage area on the floodplain above 0 mAHD were incorrect and the resulting design flood levels were reduced by of the order of 0.3m with the inclusion of the ALS. Part of the reason was that relatively conservative assumptions (i.e produced higher flood levels) were made on the available storage above 0m AHD in the past.

7.8 Design Events

As noted previously, peak water levels in Wallis Lake result from a combination of rainfall over the catchment and elevated ocean levels. However there is no definitive combination of rainfall and ocean levels that has been universally adopted in NSW. The Department of Environment and Climate Change (formerly Department of Infrastructure, Planning and Natural Resources) produced Floodplain Management Guideline No. 5 - Ocean Boundary Conditions in March 2004 (Reference 3) which recommended an envelope of:

- design runoff with a normal (neap) tide,
- elevated ocean levels (2.6 mAHD for the 100 year ARI) and a small flood (say 5 year ARI).

A similar approach to Guideline No. 5 (Reference 5) was adopted for the present study. Design flood levels were determined using an envelope approach of the design inflow (36 hour duration) in combination with an elevated tide (taken as the modified normal tide) and the design ocean tide in combination with a low inflow (taken as the 5 year ARI 36 hour event). The 100 year ARI design ocean tide was taken as the modified 1974 tide on the basis that this reflects the estimated 100 year ARI ocean level (refer Section 6).

The 100 year ARI design ocean tide was assumed to occur in conjunction with a 5 year ARI 36 hour inflow. There is no firm technical justification for this combination other than it is unrealistic to presume that a 100 year ARI ocean and 100 year ARI rainfall event occurring together represents a 100 year ARI event on Wallis Lake. Whilst it is expected that there would be some linkage between the two events, historical records indicate that on many occasions they occur independently of each other. In May 1974 the associated rainfall at Sydney was less than at 1 year ARI event (24 hour total). The design ocean tides for the smaller design events were obtained by factoring the 100 year ARI ocean tide to produce the peak design ocean water levels (Table 7). The 5 year ARI 36 hour inflows were adopted for all design ocean scenarios.

The modified normal tide was adopted in conjunction with the design inflow as it is presumed that some tidal anomaly will occur as part of the meteorological condition producing the design rainfalls. The design inflow/modified normal tide lake water level hydrographs results are shown on Figure 12a and longitudinal profiles for the two design combinations on Figure 12b.

Two design levels are given for each event (Table 10), from the entrance to the bridge (an area predominantly influenced by the ocean) and for the rest of the lake (influenced predominantly by the inflows). The peak levels have been rounded to the nearest 0.1m.

Table 10: Wallis Lake Design Flood Levels (mAHD) assuming **NO** Climate Change

Event (ARI)	Seaward limit of Breakwater to Bridge	Upstream of Bridge to extent limit shown on Figure 2a
PMF	4.2	4.4
200 year	2.1	2.2
100 year	1.9	2.0
50 year	1.7	1.8
20 year	1.5	1.5
10 year	1.4	1.5*
5 year	1.3	1.4*

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

Design flood contours for selected events are provided on Figure 13a to 13e with velocity profiles for the 20 year and 100 year ARI events shown on Figures 14a and 14b.

7.9 Comparison with Results from Forster/Tuncurry Flood Study (Reference 2)

The main differences between the approach taken in the present study and the 1989 Flood Study (Reference 2) are the difference in design ocean hydrographs and the hydraulic models. In addition the present study has incorporated the ALS overbank survey provided by Great Lakes Council. A comparison of the peak levels from these studies is provided in Table 11.

Table 11: Comparison of Peak Levels from 1989 Forster/Tuncurry Flood Study (Reference 2)

Event (ARI)	Entrance to Bridge			Upstream of Bridge		
	Reference 2 (m AHD)	This study (m AHD)	Difference (m)	Reference 2 (m AHD)	This study (m AHD)	Difference (m)
Extreme/PMF	3.69	4.24	+0.55	4.67	4.36	-0.31
100 year	2.32	1.87	-0.45	2.17	1.96	-0.21
50 year	2.14	1.68	-0.46	1.94	1.77	-0.17
20 year	1.95	1.49	-0.50	1.70	1.54	-0.16

8. CLIMATE CHANGE ASSESSMENT

8.1 Background

The 2005 Floodplain Development Manual (Reference 1) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change on flood behaviour.

Since completion of the 1989 Flood Study (Reference 2), current best practice for considering the impacts of climate change (ocean level rise and rainfall increase) have been evolving rapidly. Key developments in the last three years have included:

- release of the Fourth Assessment Report by the Inter-governmental Panel on Climate Change (IPCC) in February 2007 (Reference 16), which updated the Third IPCC Assessment Report of 2001 (Reference 17);

- preparation of Climate Change Adaptation Actions for Local Government by SMEC Australia for the Australian Greenhouse Office in mid 2007 (Reference 18);

- preparation of Climate Change in Australia by CSIRO in late 2007 (Reference 19), which provides an Australian focus on Reference 16;

- release of the Floodplain Risk Management Guideline Practical Consideration of Climate Change by the NSW Department of Environment and Climate Change in October 2007 (Reference 20 - referred to as the DECC Guideline 2007);

- Hunter, Central and Lower North Coast Regional Climate Change Project — Report 3: Climate Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW (Hunter and Central Coast Regional Environmental Strategy, 2009 (Reference 21);

- In October 2009 the NSW Government issued its Policy Statement on Sea Level Rise (Reference 22) which states: "*Over the period 1870–2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that the current trends will be reversed.*

  Sea level rise is an incremental process and will have medium to long-term impacts. The best national and international projections of sea level rise along the NSW coast are for a rise relative to 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100. However, the Intergovernmental Panel on Climate Change (IPCC) in 2007 also acknowledged that higher rates of sea level rise are possible";

- In November 2009 the NSW State Government Department of Environment, Climate Change and Water exhibited the following:
    - Draft Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments,
    - Draft Coastal Risk Management Guide: Incorporating sea level rise benchmarks in coastal risk assessments,

    The Department of Planning also exhibited:
    - Draft NSW Coastal Planning Guideline: Adapting to Sea Level Rise;

- In August 2010 the NSW State Government Department of Environment, Climate Change and Water issued the following:
    - Flood Risk Management Guide (Reference 23): Incorporating sea level rise benchmarks in flood risk assessments,
    - Coastal Risk Management Guide (Reference 24): Incorporating sea level rise benchmarks in coastal risk assessments,

  In addition an accompanying document *Derivation of the NSW Government's sea level rise planning benchmarks* (Reference 25) provided technical details on how the sea level rise assessment was undertaken.

As a result of the information provided in the above and other documents, and to keep up-to-date with current best practice, this study incorporates an assessment of climate change. It should be noted that the estimated rise in ocean/sea level along the NSW varies between the above reports and at this time there is no absolute value that has been adopted by all experts.

The climate change scenarios specified in the DECC Guideline 2007 are indicated below.

ocean level rise:

- low level ocean rise = 0.18 m,
- medium level ocean rise = 0.55 m,
- high level ocean rise = 0.91 m.

increase in peak rainfall and storm volume:

- low level rainfall increase = 10%,
- medium level rainfall increase = 20%,
- high level rainfall increase = 30%.

A high level rainfall increase of up to 30% is recommended for consideration due to the uncertainties associated with this aspect of climate change and to apply the "precautionary principle". It is generally acknowledged that a 30% rainfall increase is probably overly conservative and that a timeframe for the provision of definitive predictions of the actual increase is unknown. The DECC Guideline 2007 (Reference 20) is currently the only reference providing benchmarks for rainfall increases.

The most recent guidelines (Reference 23) indicates a 0.9m ocean level rise by the year 2010 and a 0.4 m rise by the year 2050 and thus supersedes those sea level rise benchmarks provided in the DECC Guideline 2007. However it should be noted that climate change (man made or due to natural processes) will still occur beyond 2100.

Great Lakes Council has adopted a 0.9 m sea level rise increase by the year 2100 and a 0.5 m rise by the year 2060 (refer Table 7).

8.2 Climate Change Scenarios Analysed

The following scenarios were modelled for the 5 year, 20 year and 100 year ARI events (results can be interpolated for intermediate events):

- **Rainfall Induced flooding**: increase in design rainfall of 10%, 20% and 30%,
- **Rainfall Induced flooding**: increase in ocean level of 0.5 and 0.9m for the modified normal tide,
- **Rainfall Induced flooding**: combination of increase in design rainfall (10%, 20% and 30%) and increase in ocean level (0.5 m and 0.9 m) for the modified normal tide,
- **Ocean Induced flooding**: increase in ocean level of 0.5 m and 0.9m.

8.3 Results

The results are provided on Figures 15a to e and are discussed below:

- **Figure 15a:** This figure shows the effect of the three rainfall increase scenarios for the design rainfall/modified normal tide scenario upstream of the bridge. The results indicate a 10% increase in rainfall raises the peak water level by approximately 0.1m at the 5 year ARI and up to 0.2m at the 100 year ARI. A 10% increase in design rainfalls exactly represents the increase from a 100 year ARI to a 200 year ARI event. Thus a 10% increase in design rainfall would increase the 100 year ARI lake level from 1.94 mAHD to 2.15 mAHD (approximately a 0.2m increase). It is also noted that the increase in rainfall from a 50 year ARI to 100 year ARI event is 10% and this also represents approximately a 0.2 m increase in lake level. 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.

- **Figure 15b:** This figure shows the effect of an ocean level rise on the design rainfall/modified normal tide scenario upstream of the bridge. The results indicate that an increase in ocean level produces an increase in peak water level of slightly less than the ocean level rise with the increase decreasing with flood magnitude. Thus at the 5 year ARI a 0.9m ocean level increase reduces to a 0.8m increase in the lake but for the 100 year ARI the increase is only 0.7m in the lake. The reason for this is that the significant temporary floodplain storage capacity surrounding the lake reduces the full impact of an ocean level increase at high water levels (at low water levels the impact is greater).

- **Figure 15c:** This figure shows the combined effect of rainfall increase and an ocean level rise on the design rainfall/modified normal tide scenario upstream of the bridge. The results indicate approximately a summation of the individual ocean level rise and rainfall increase effects.

- **Figure 15d:** This figure shows the effect of an ocean level rise on the design ocean/5 year ARI flows for downstream and upstream of the bridge. In summary the increase in ocean level due to climate change results in a slightly less increase in flood level in the lake.

- **Figure 15e:** provides a comparison of the effects of climate change on the Rainfall and Ocean induced flooding mechanisms. This is of importance as the effect of an ocean level rise may alter whether the peak level in the lake results from rainfall induced flooding or ocean induced flooding.

8.4 Maps in Appendix C

Maps have been provided in Appendix C for each of the following localities:

1. Tuncurry CBD,
2. Pacific Palms,
3. Green Point,
4. Forster Keys,
5. Forster CBD,
6. Coomba Park.

showing the following features:

- Ground levels in mAHD,
- Extent of Inundation (5 year, 20 year, 100 year and PMF) in the Year 2010, 2060 (0.5m ocean level rise) and 2100 (0.9m ocean level rise),
- Hazard mapping (100 year and PMF) in the Year 2010, 2060 and 2100.

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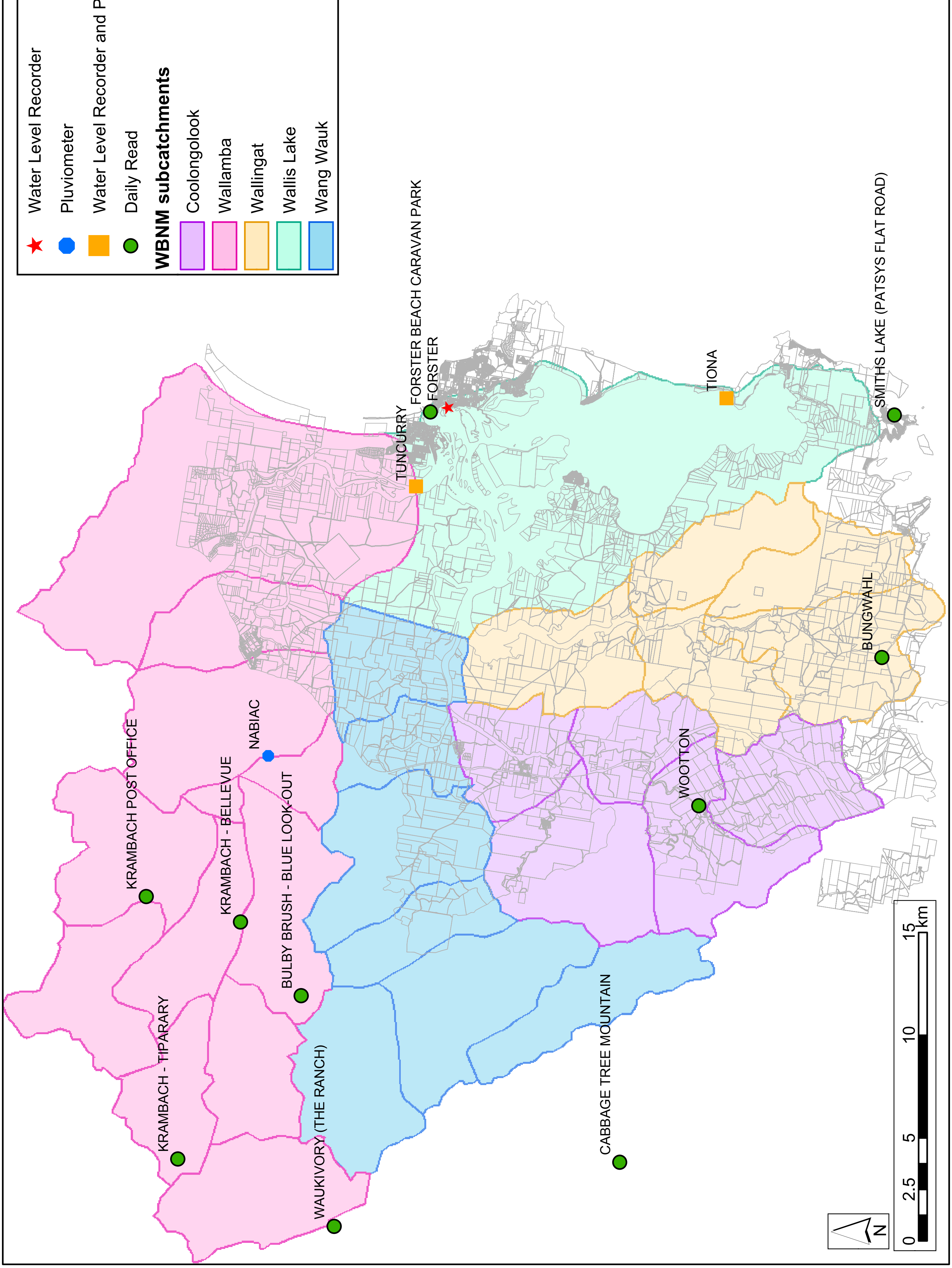
Figures

FIGURE 1

WALLIS LAKE

SUBCATCHMENT LAYOUT AND GAUGE LOCATIONS



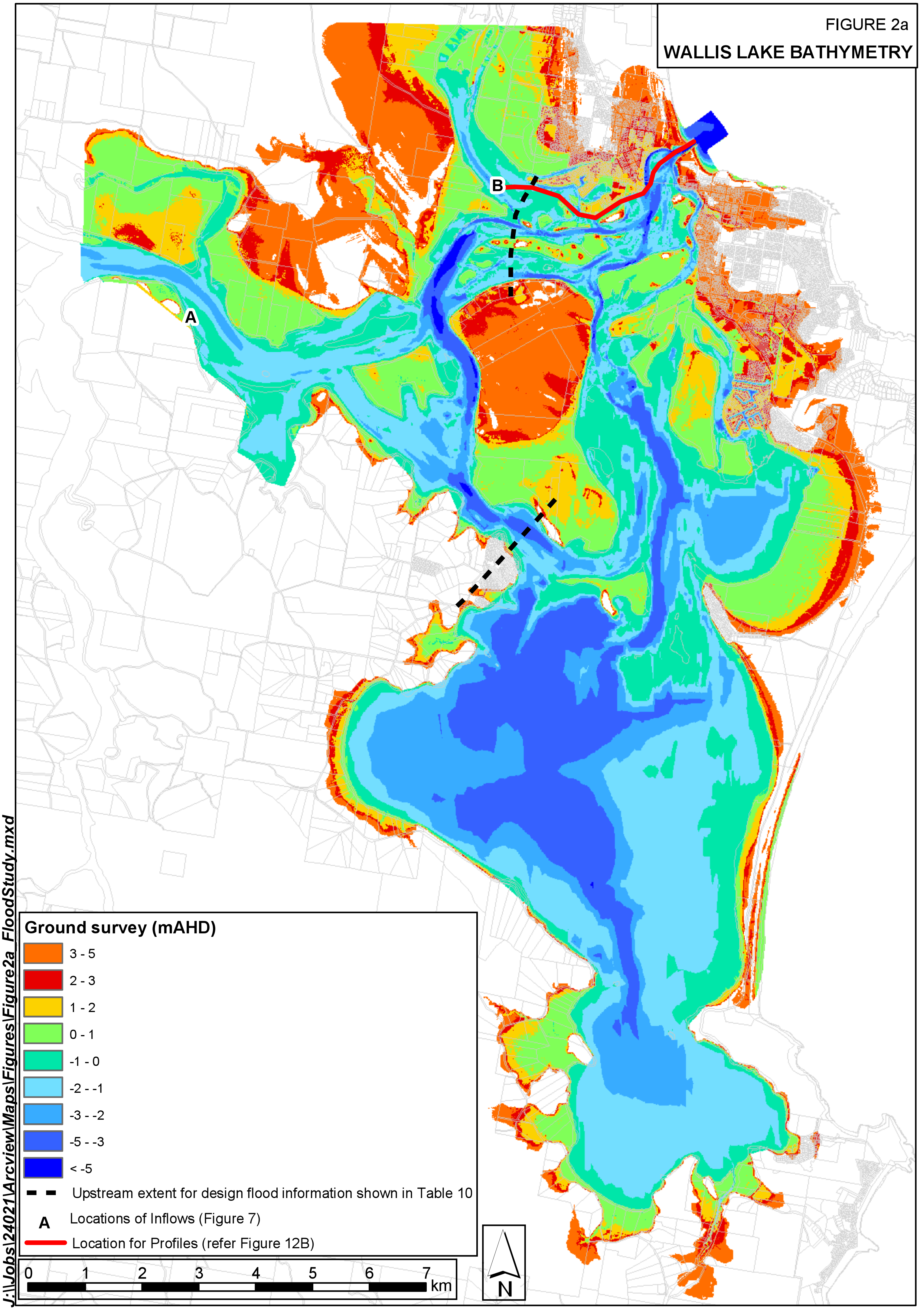


FIGURE 2a
WALLIS LAKE BATHYMETRY

FIGURE 2b
WALLIS LAKE BATHYMETRY
DETAIL NEAR ENTRANCE

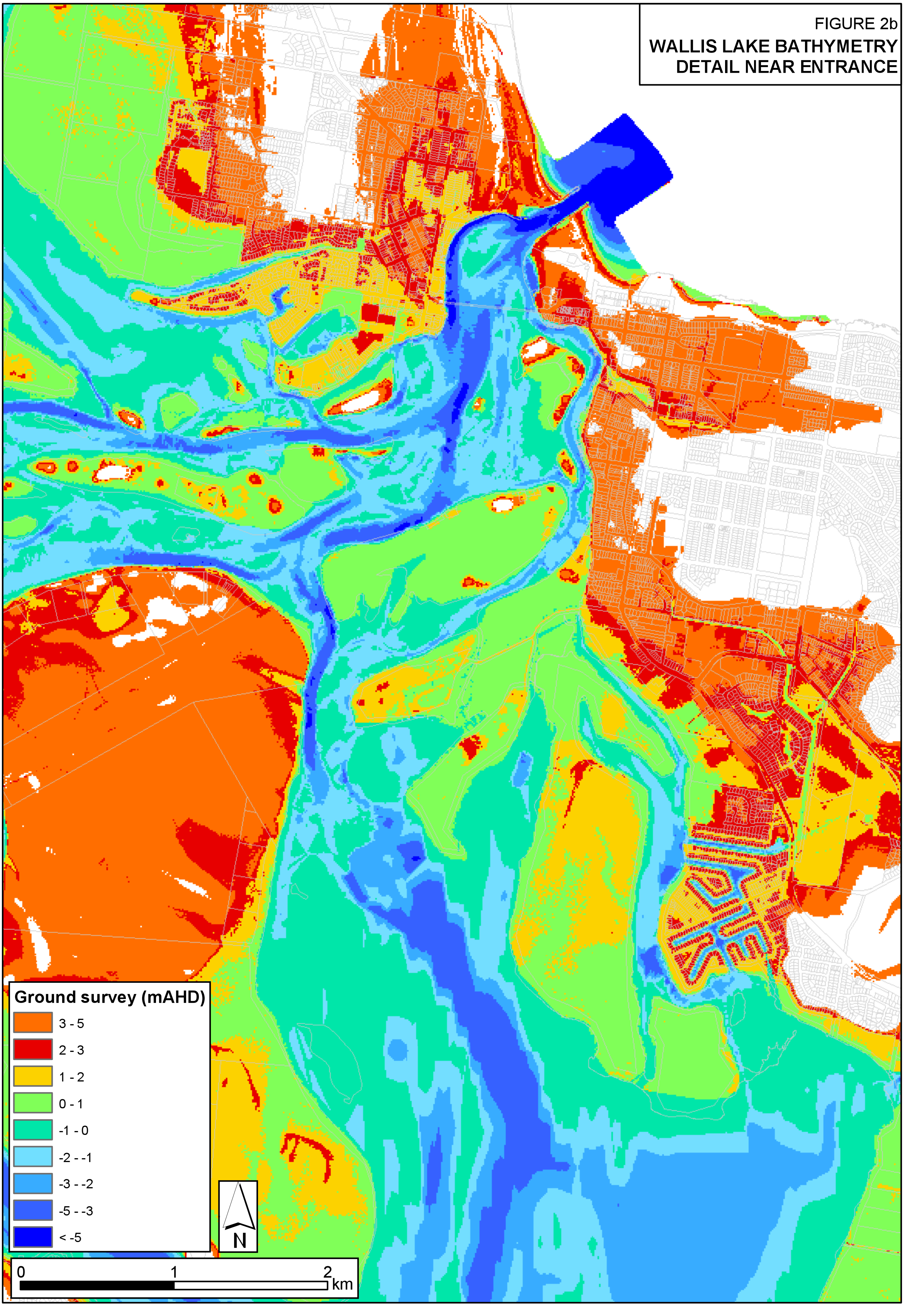


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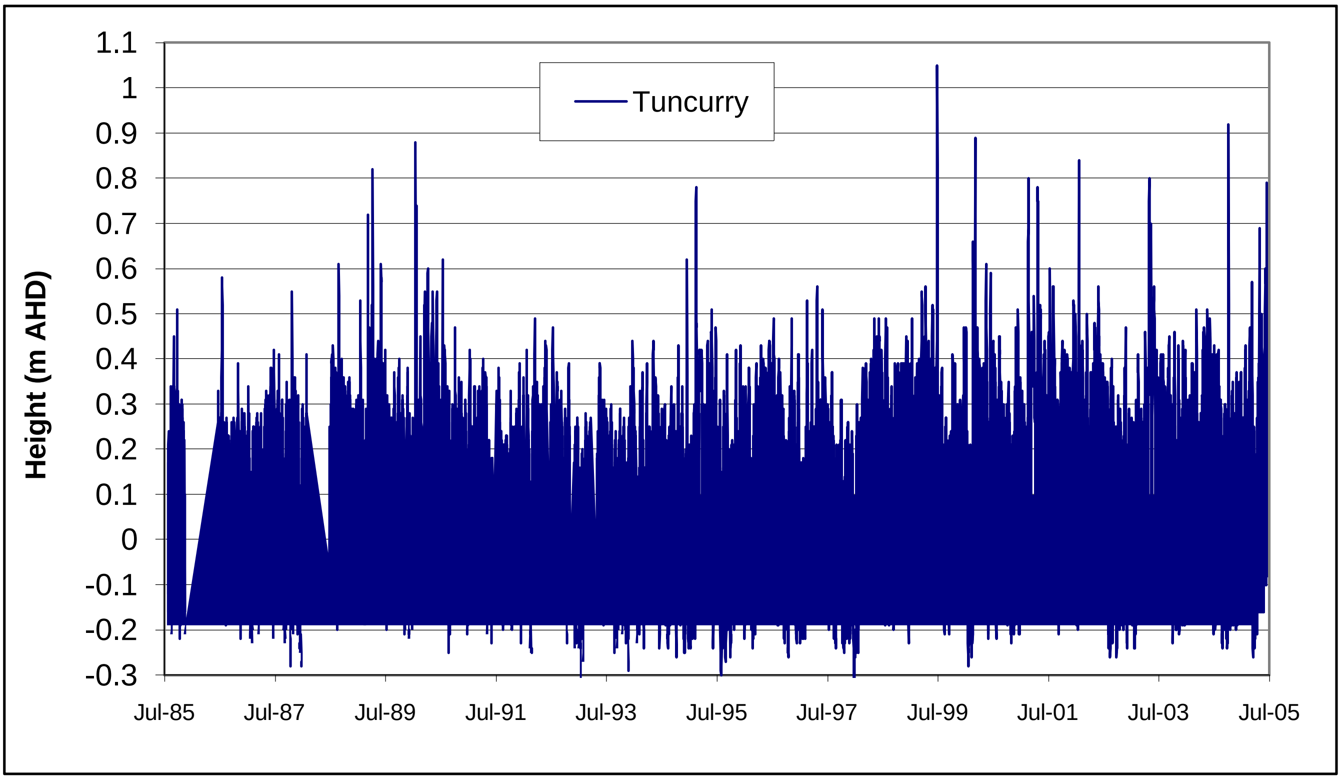
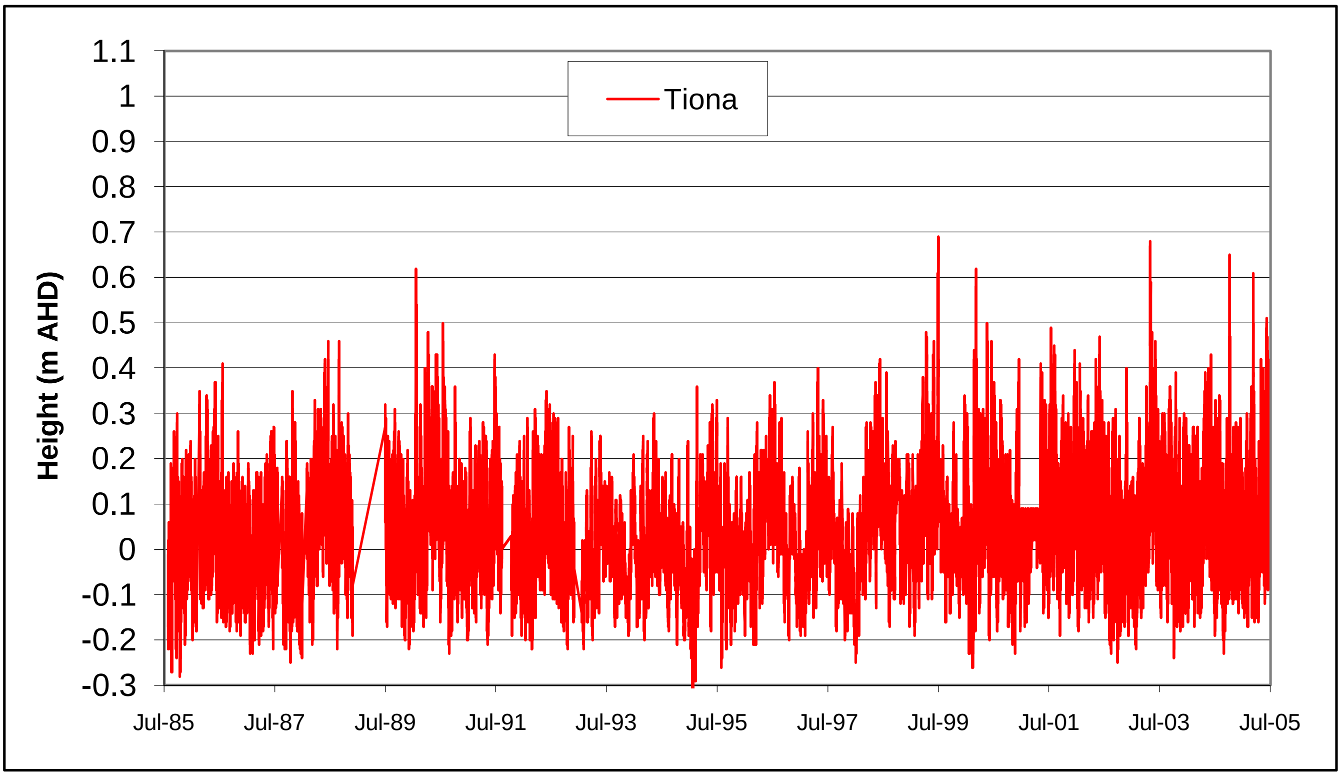
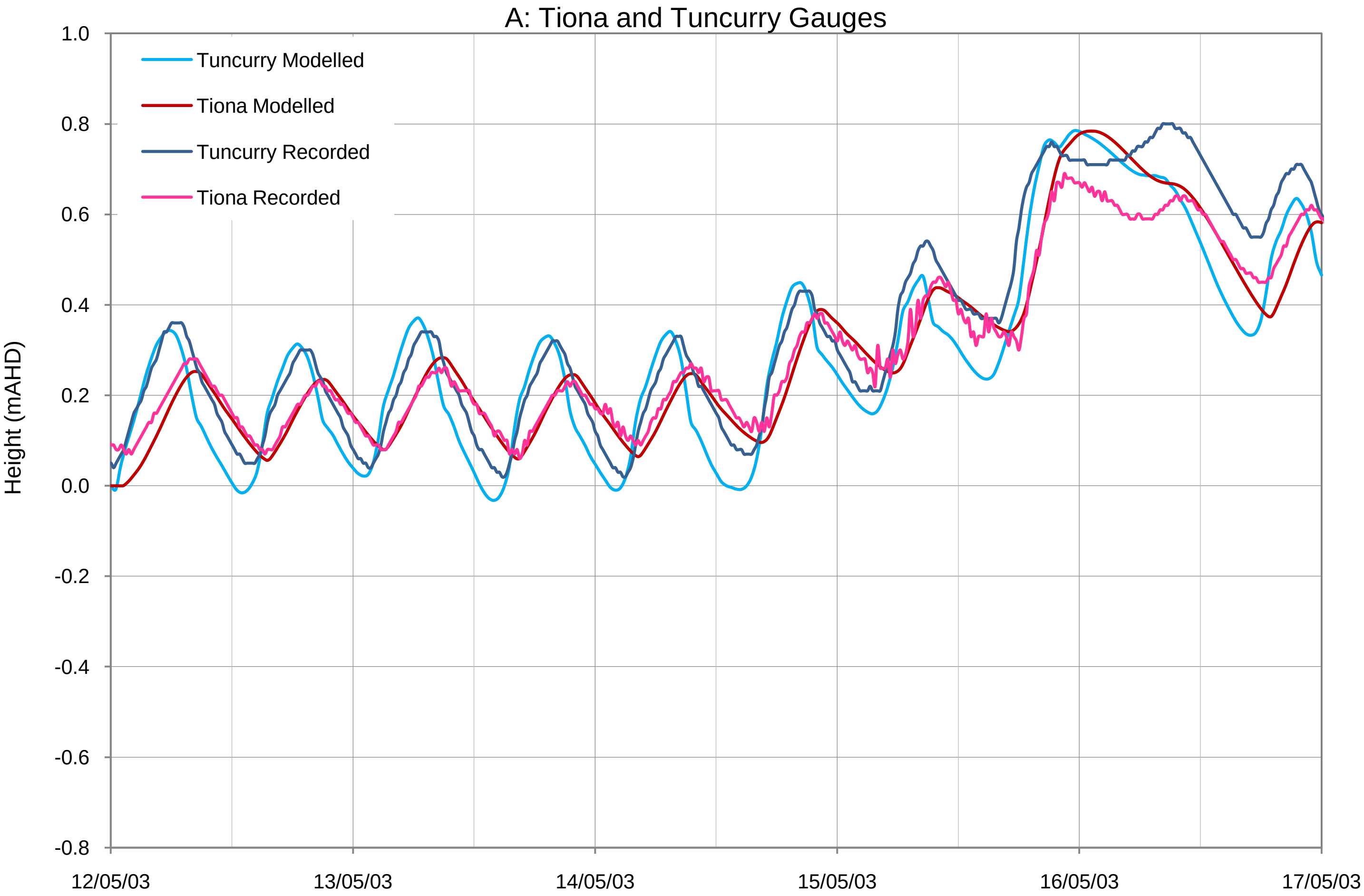
FIGURE 3
TIONA & TUNCURRY
HISTORICAL RECORD

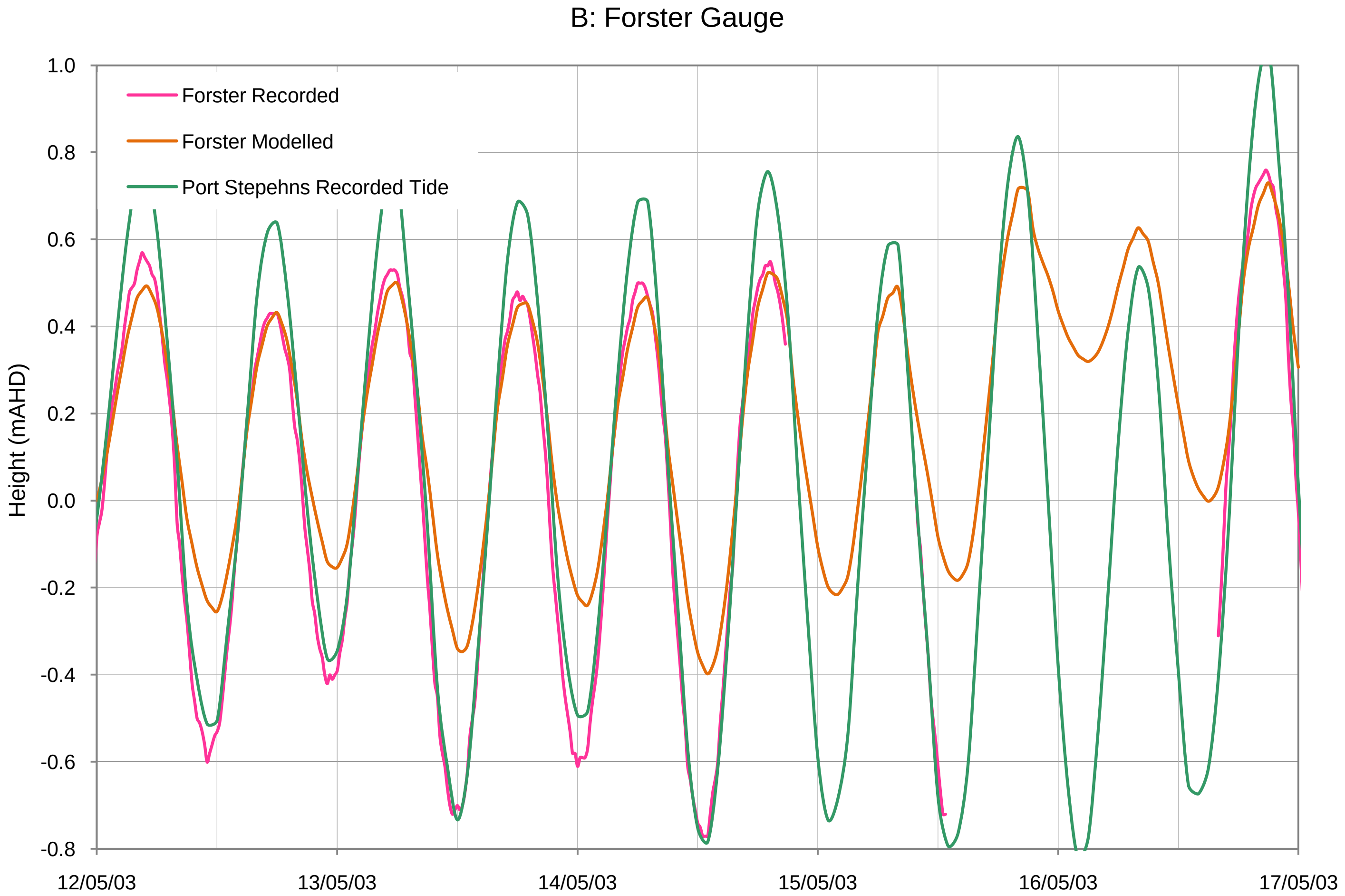




Note: Refer Figure 1 for location of gauges

FIGURE 4
MAY 2003 EVENT





Note: Refer to Figure 1 for location of gauges

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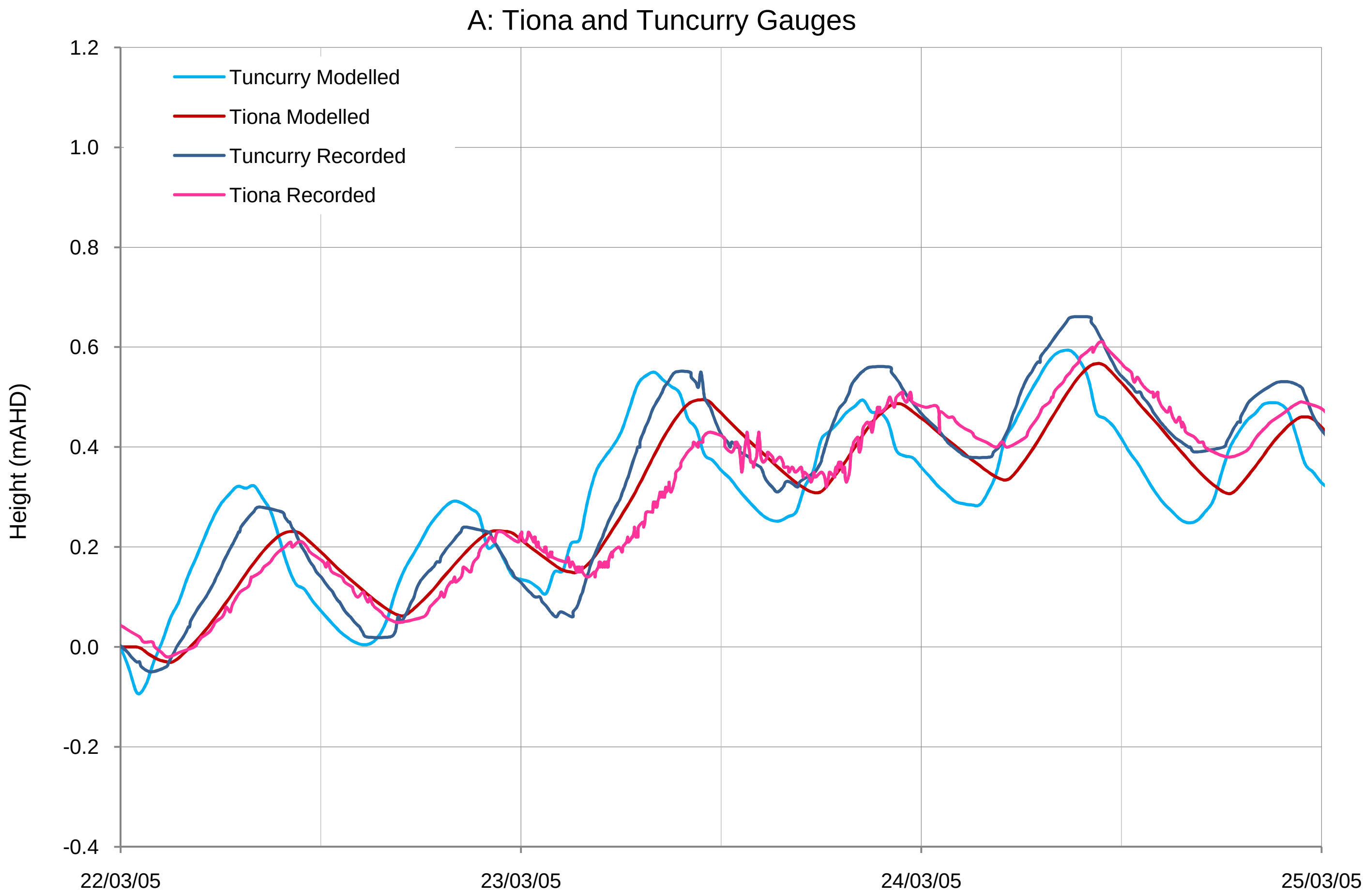
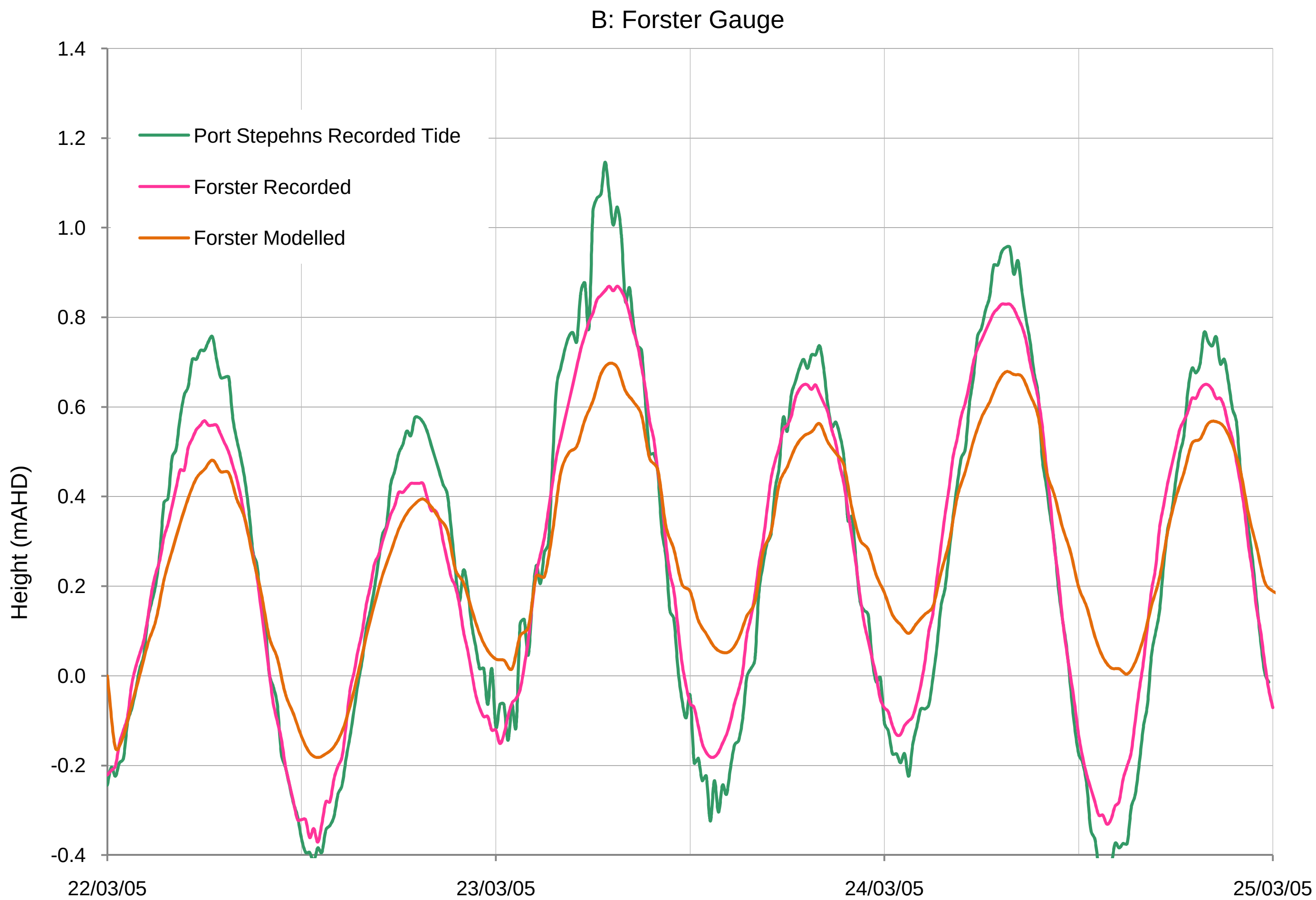
FIGURE 5
MARCH 2005 EVENT



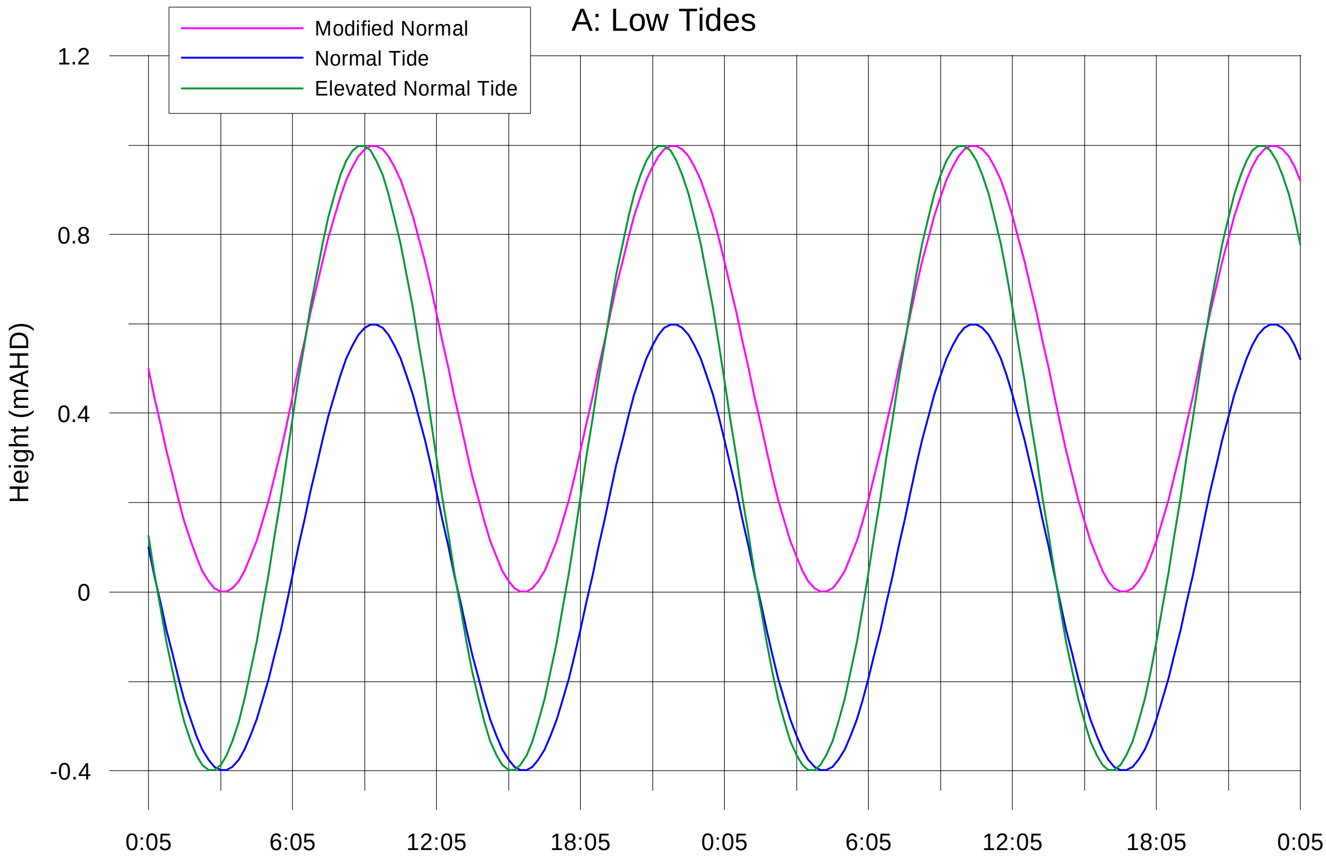


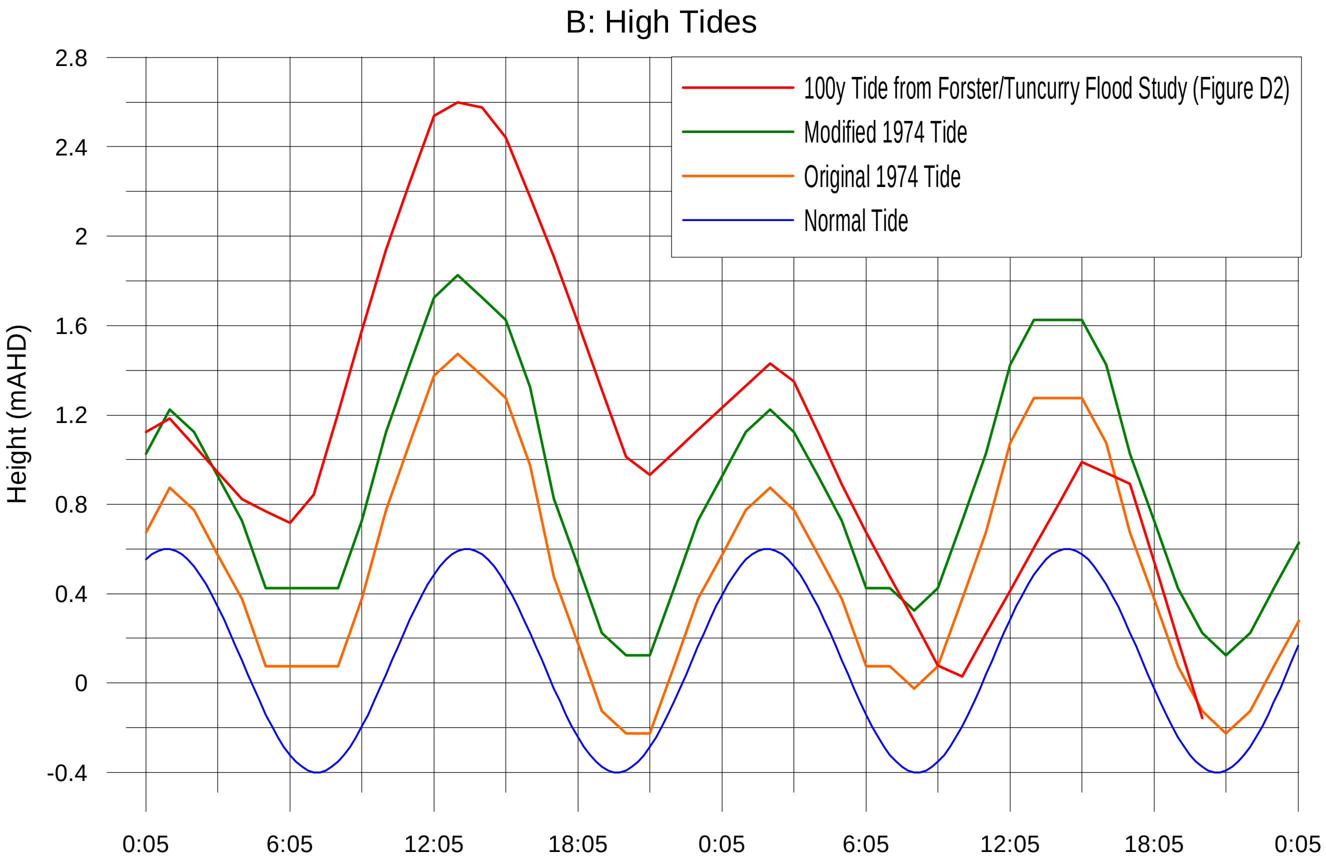
J:\Jobs\24021\SOBEK\Historical_results.xlsx

Note 1: Refer to Figure 1 for location of gauges
Note 2: Excludes possible effects of climate change

FIGURE 6

TIDAL VARIATIONS



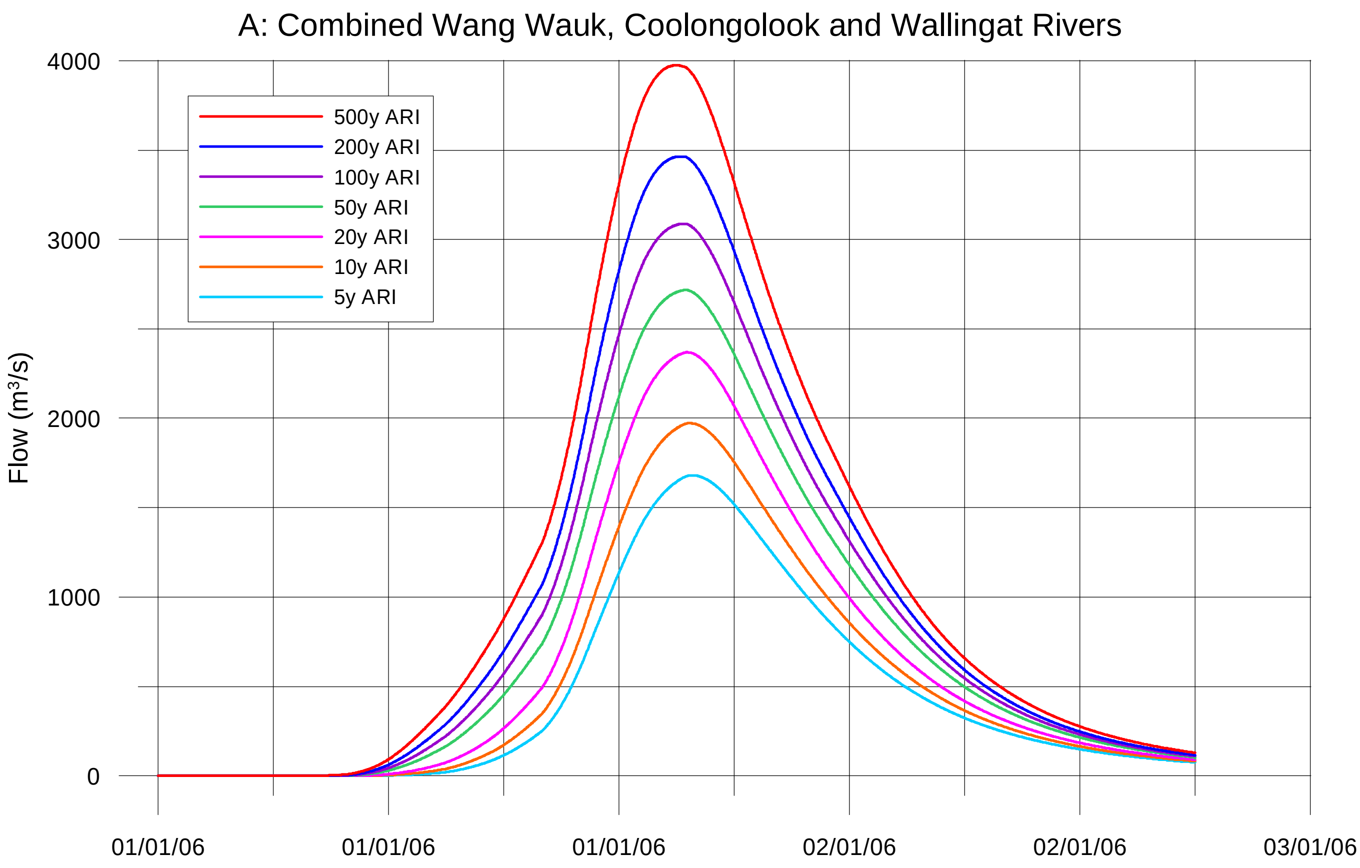


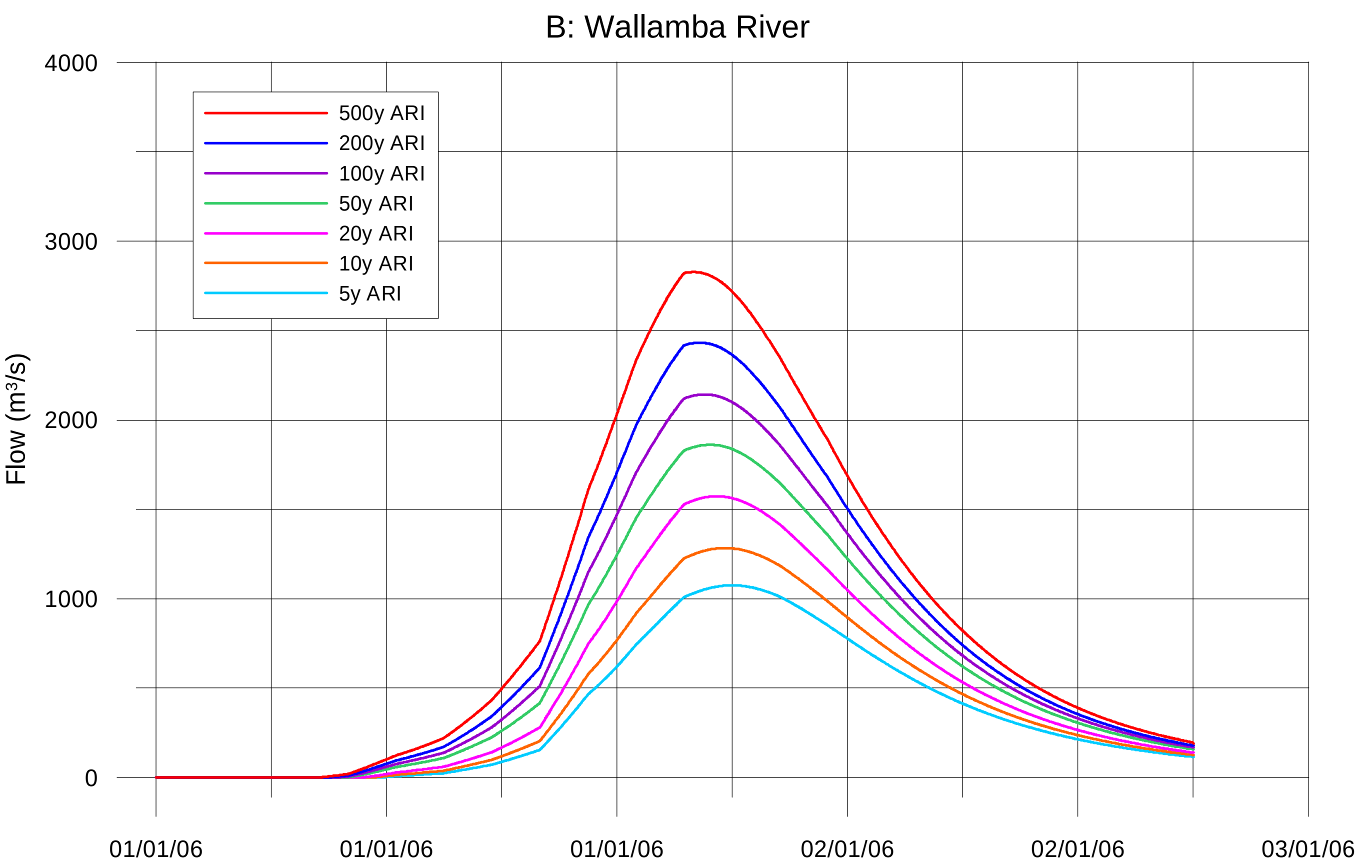
FILE > J:\JOBS\24021\SOBEK\FIGURE06_TIDES.grf MAY-2006

Note 1: Tides assumed to occur in the Pacific Ocean at the mouth of Wallis Lake

Note 2: Excludes possible effects of climate change

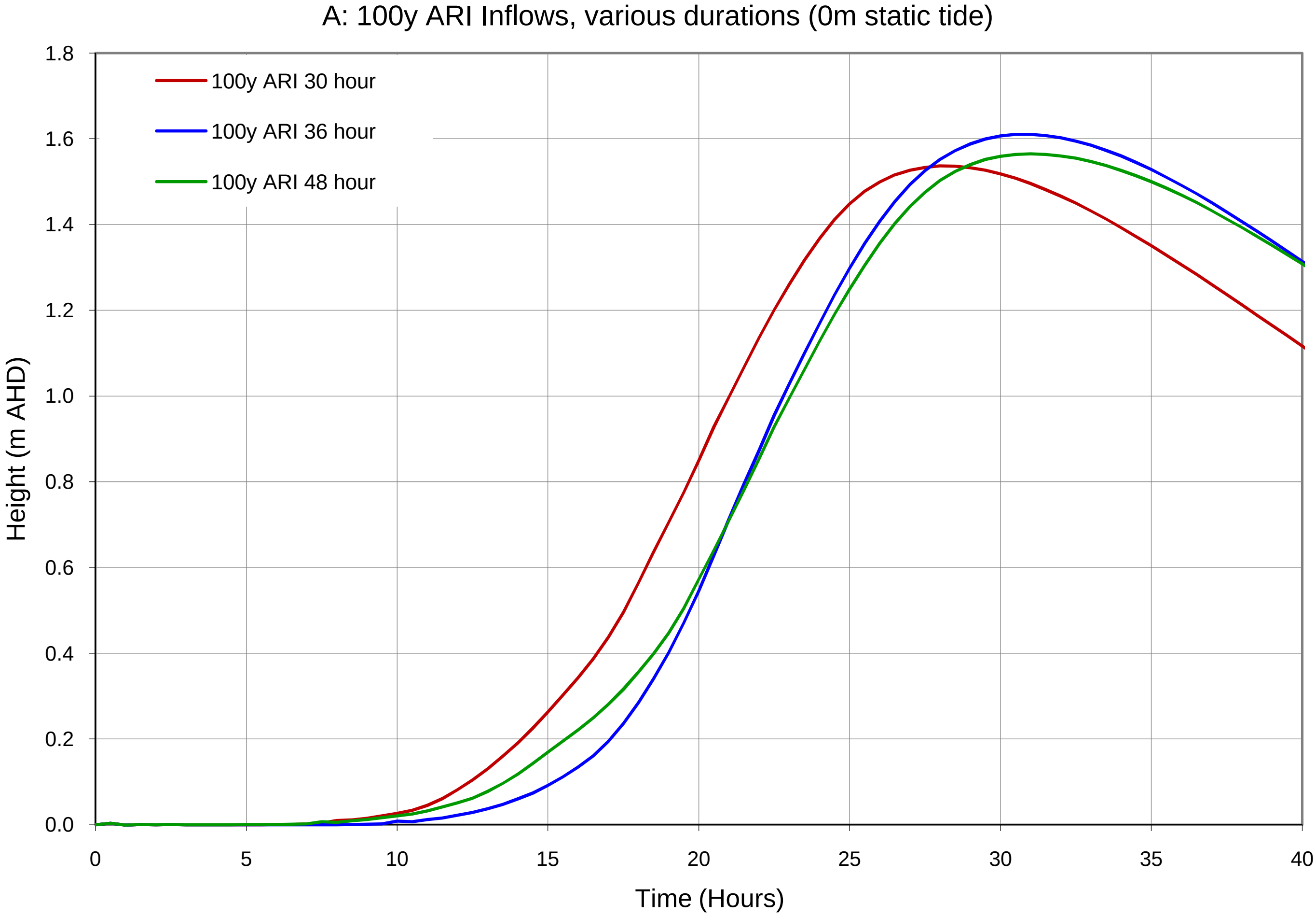
DESIGN INFLOW HYDROGRAPHS
36 HOUR DURATION

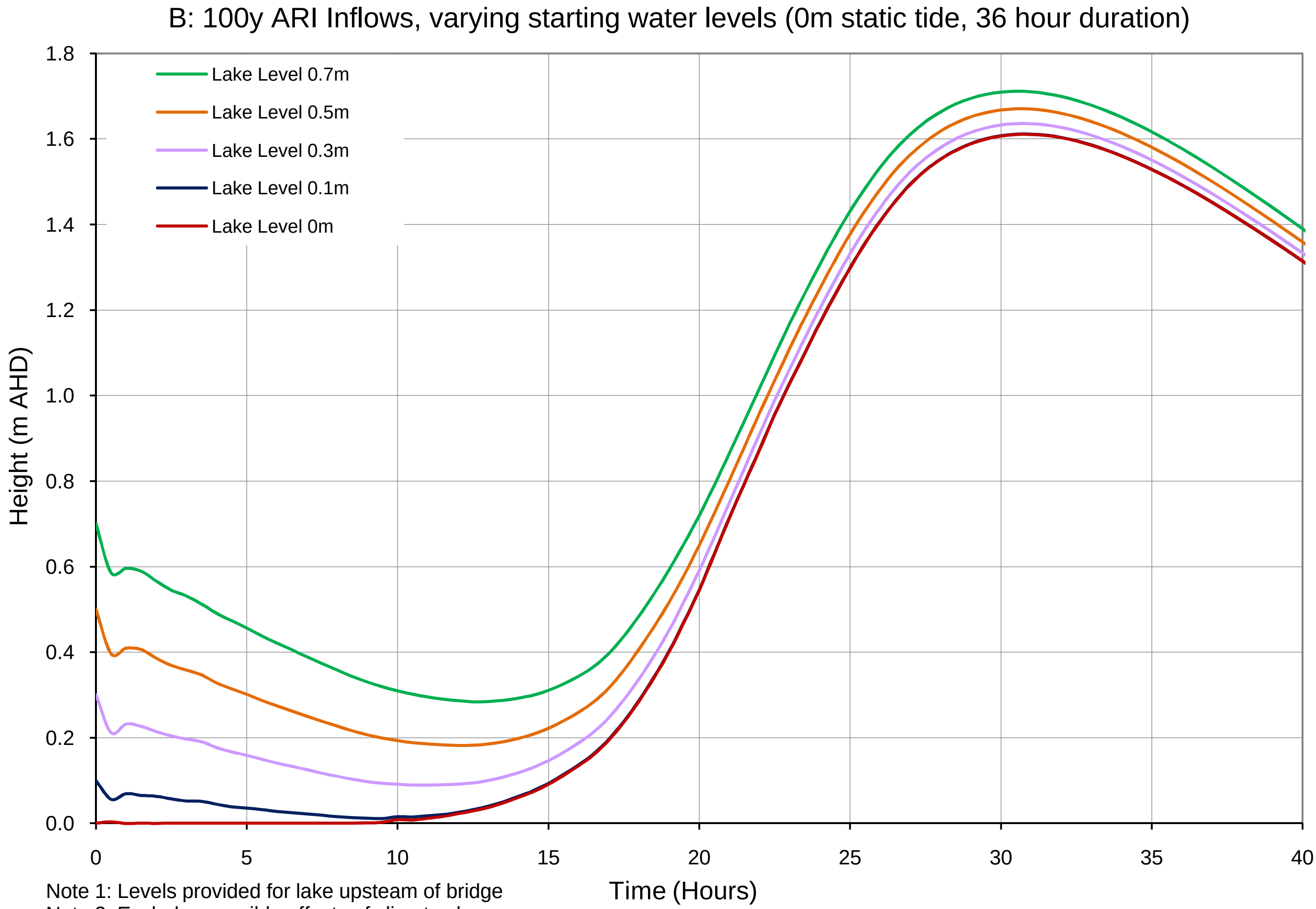




Note1: Refer to Figure 2 for location of inflows
Note 2: Excludes possible effects of climate change

FIGURE 8
100y ARI VARIOUS DURATIONS AND VARYING STARTING LEVEL





Note 1: Levels provided for lake upsteam of bridge
Note 2: Excludes possible effects of climate change

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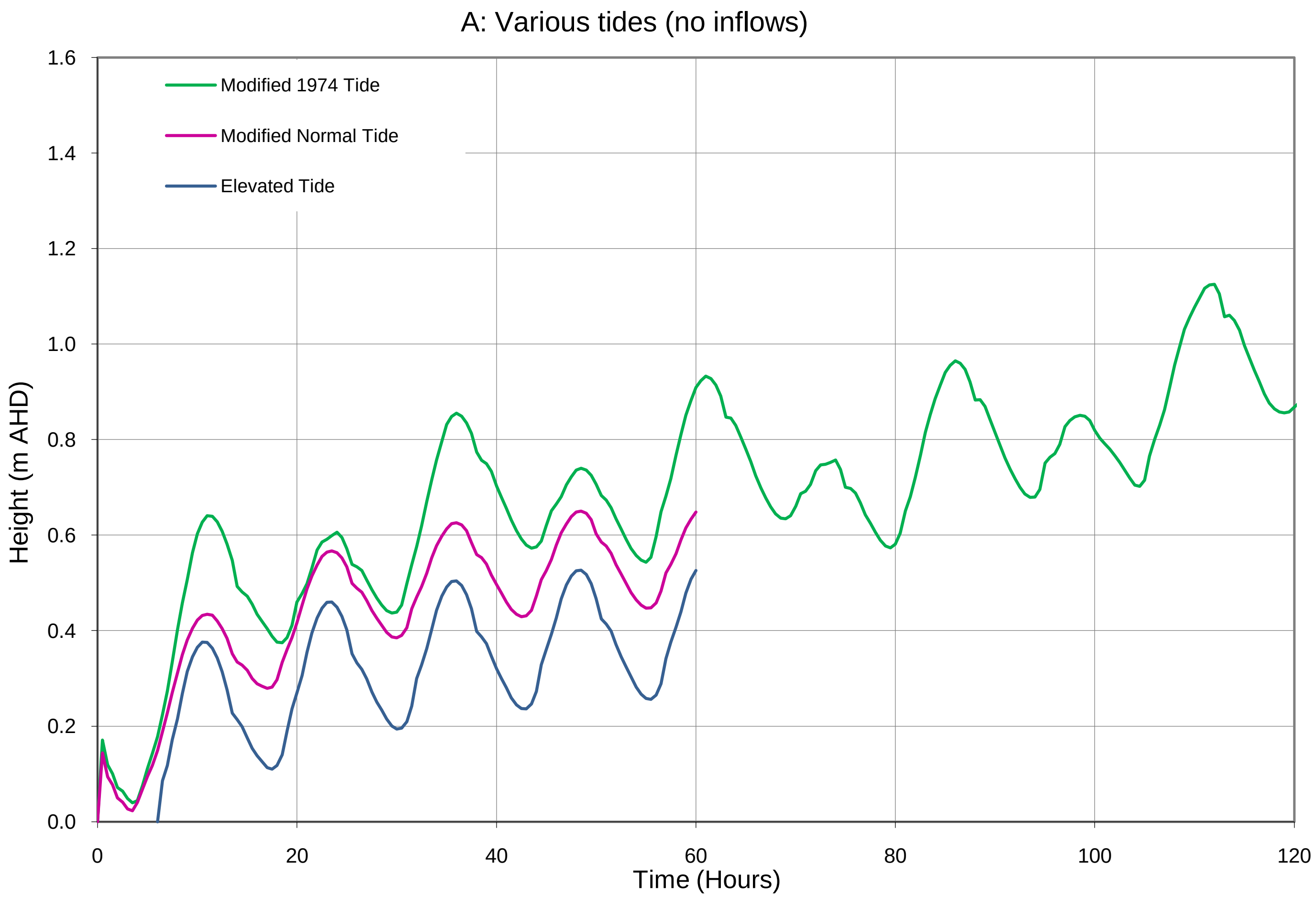
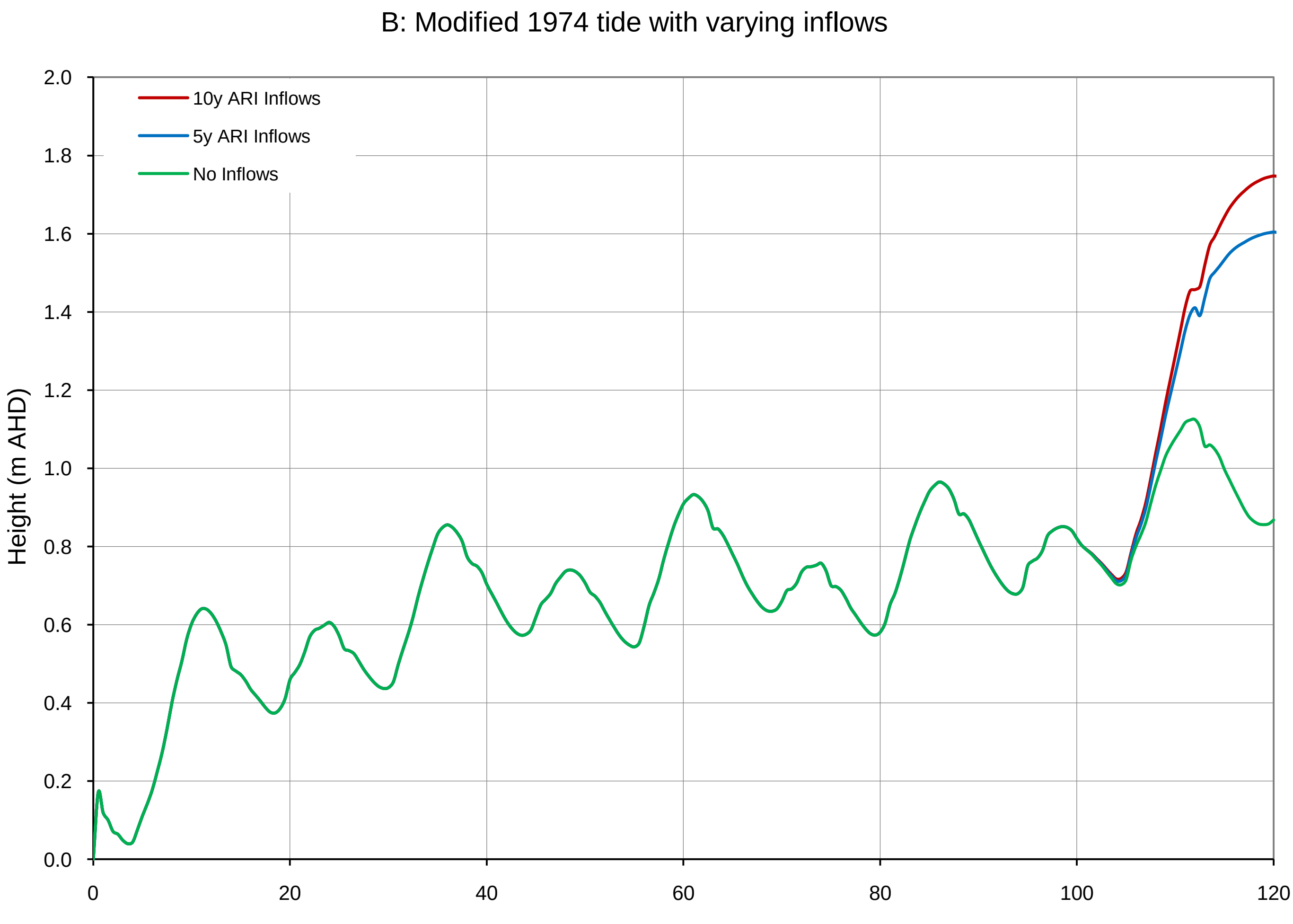
TIDAL EFFECTS ON LAKE LEVELS





Note 1: Levels provided for lake upsteam of bridge
Note 2: Excludes possible effects of climate change

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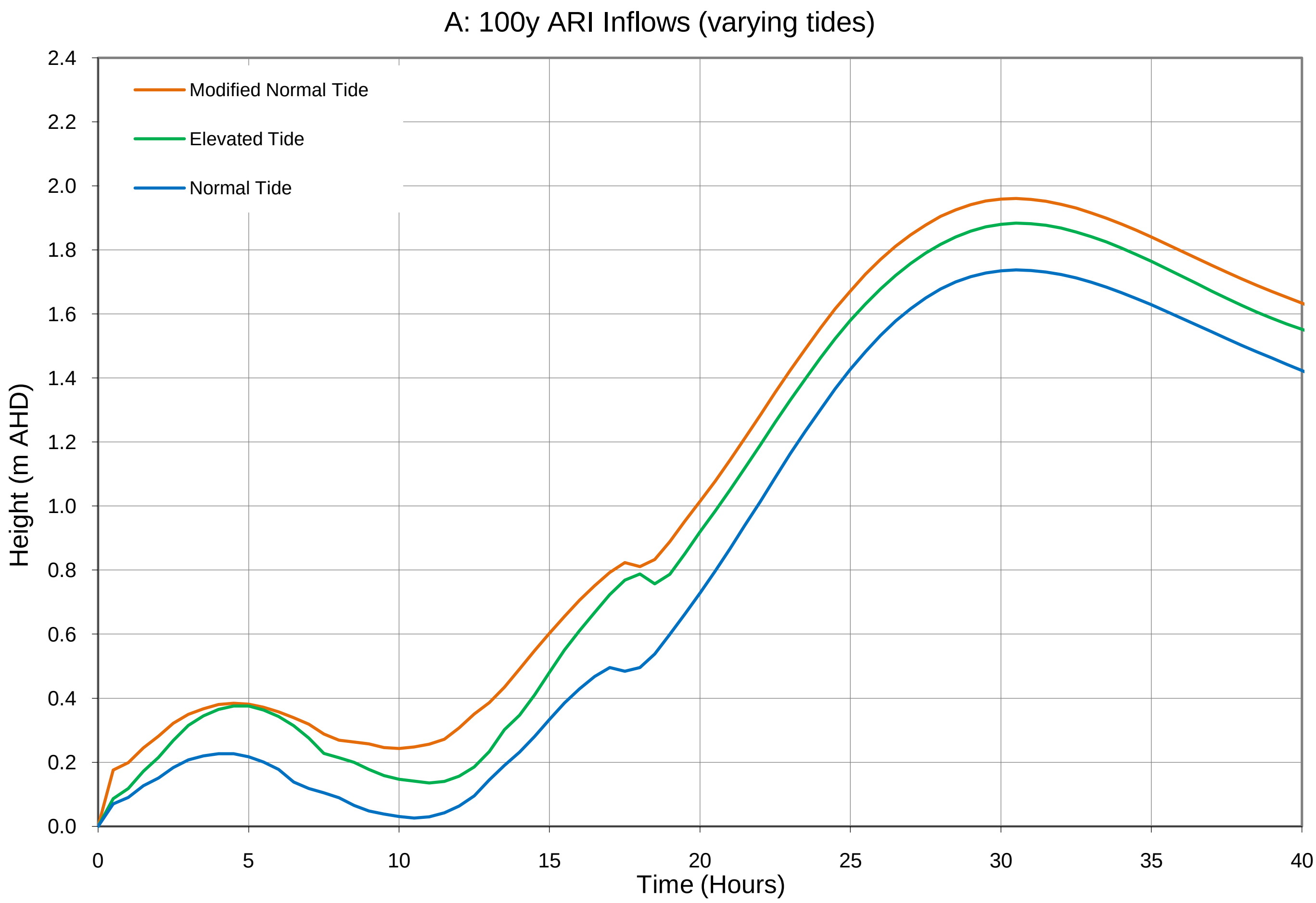
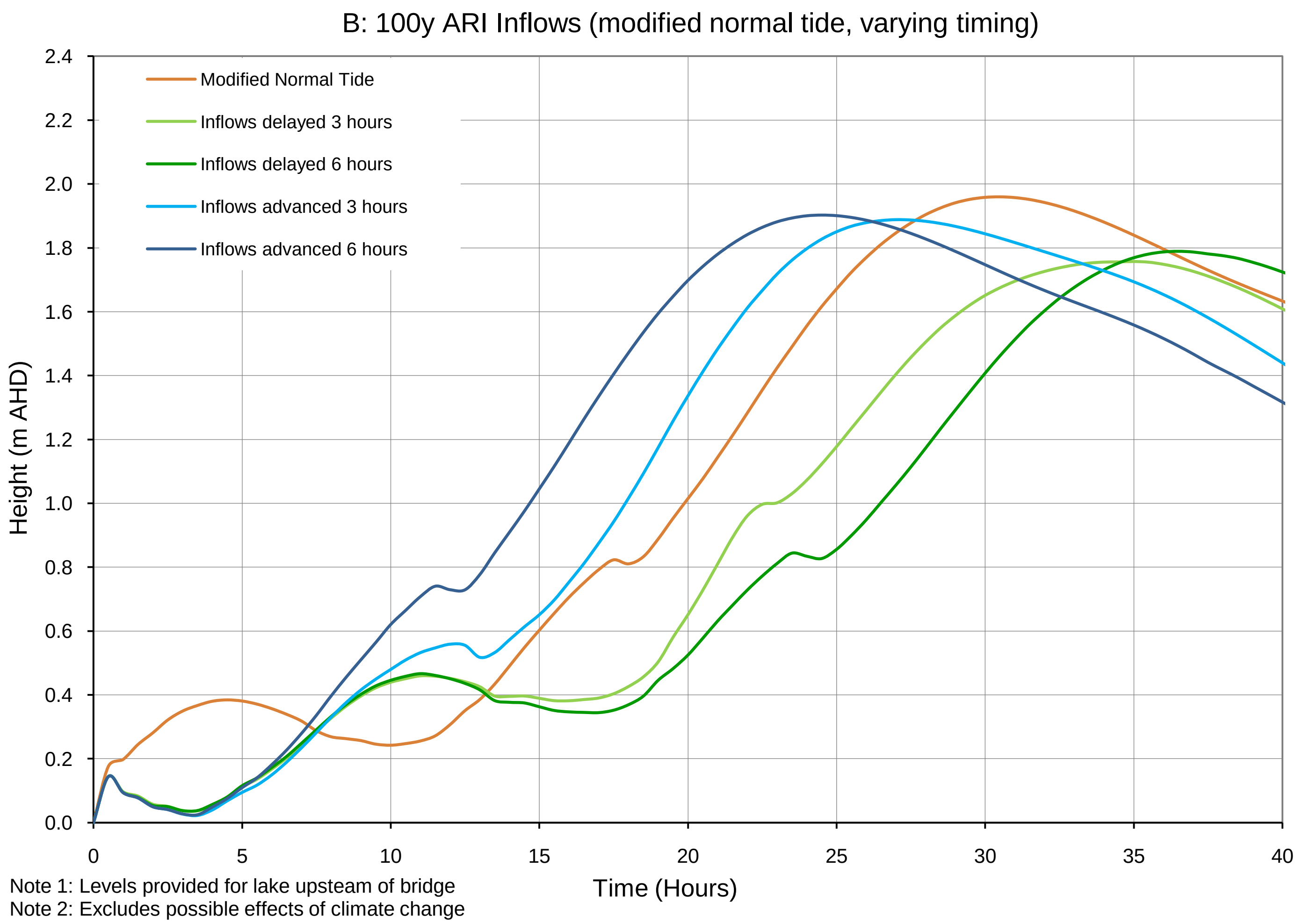
FIGURE 10
100y ARI INFLOWS
VARYING TIDES AND TIMING





Note 1: Levels provided for lake upsteam of bridge
Note 2: Excludes possible effects of climate change

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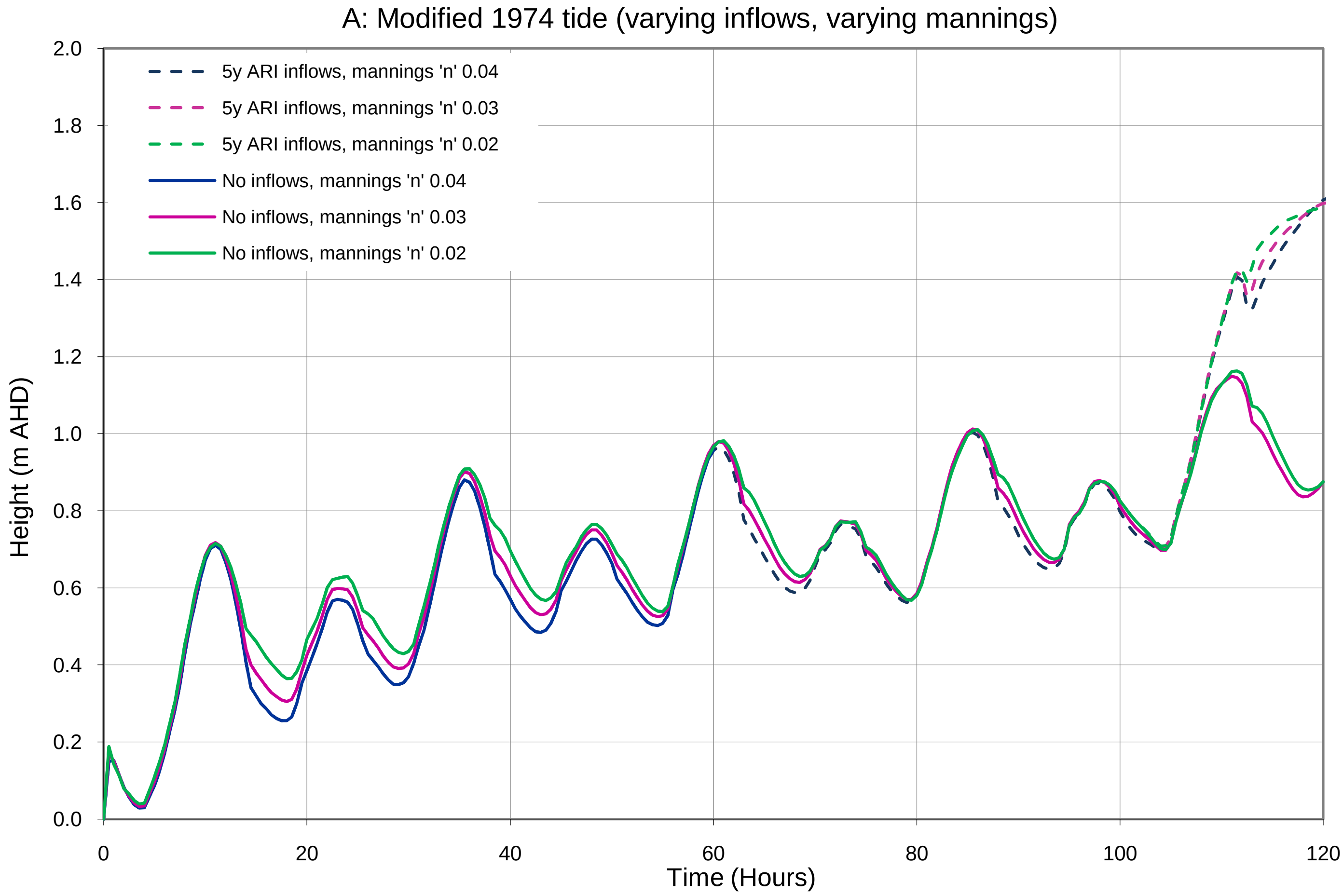
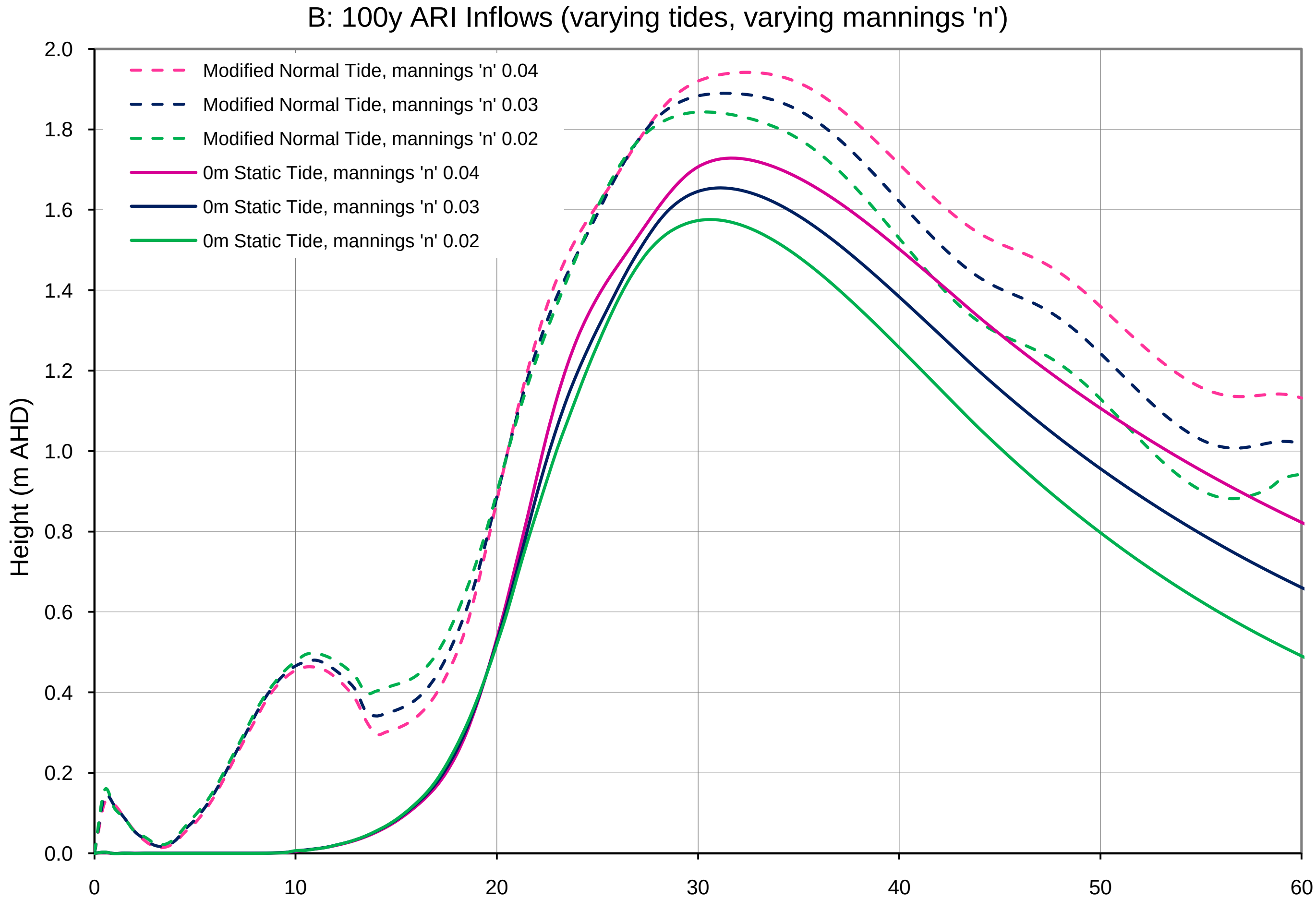
FIGURE 11
SENSITIVITY OF TIDES, INFLOWS AND MANNINGS 'n' VALUES





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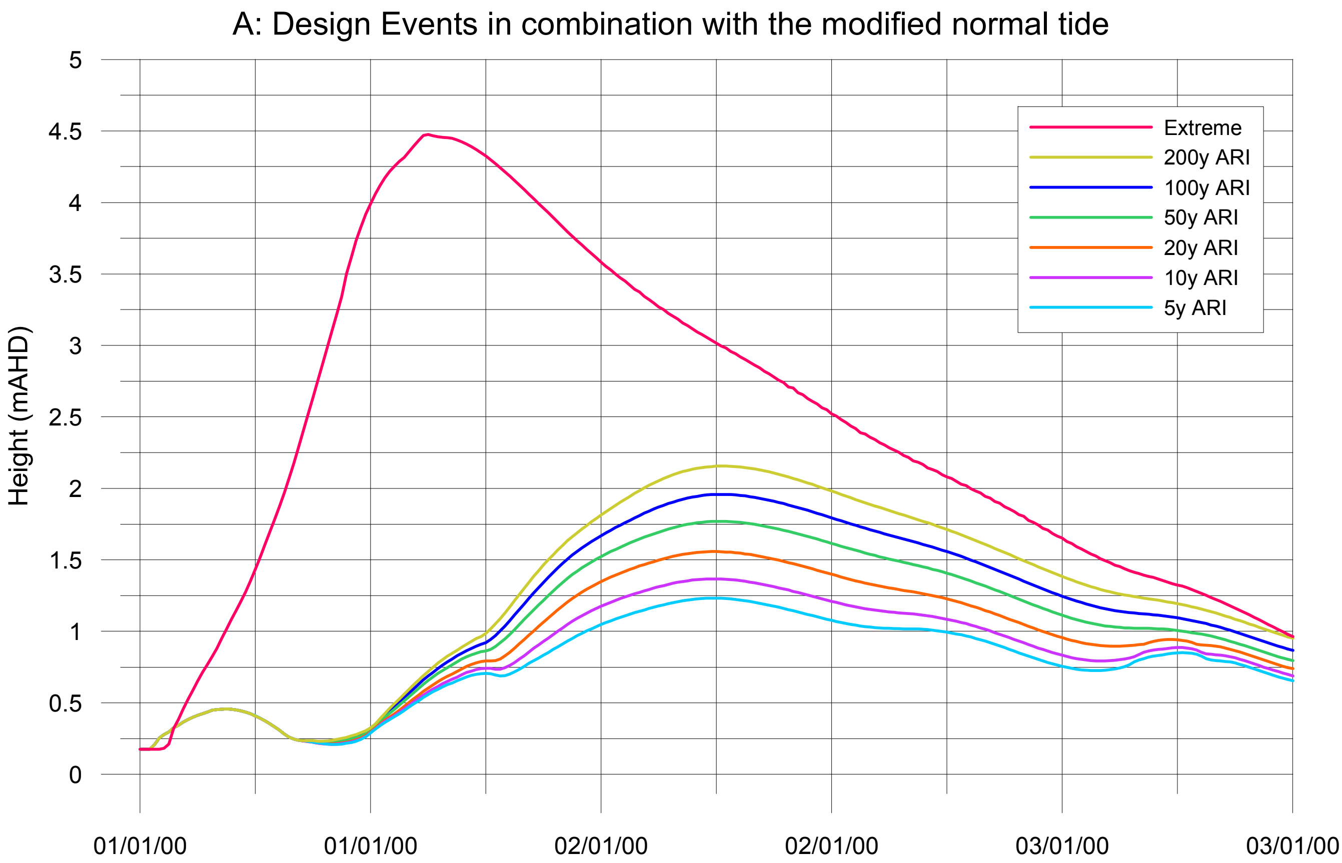
Time (Hours)

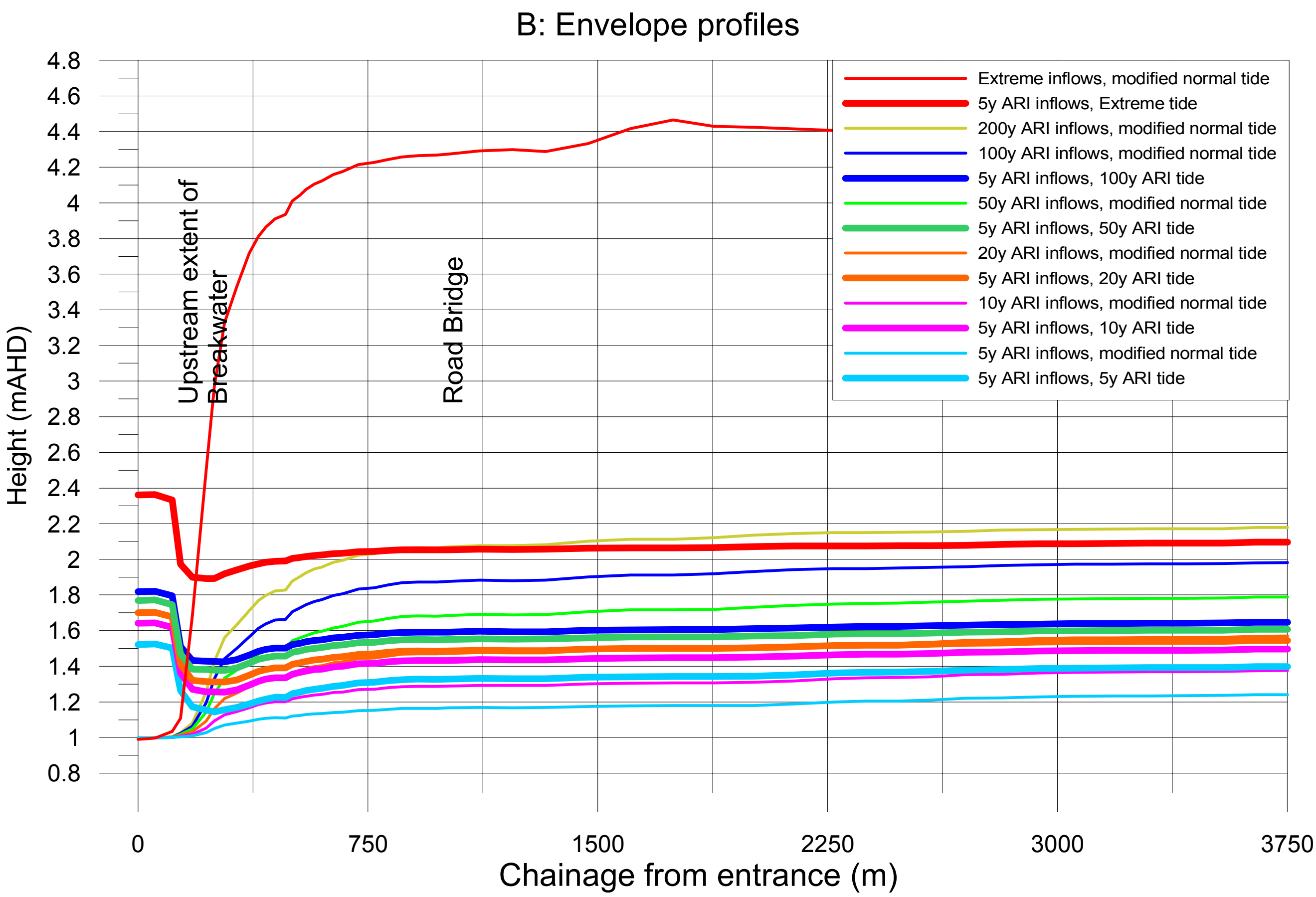
Note 1: Levels provided for lake upsteam of bridge
Note 2: Excludes possible effects of climate change

FIGURE 12

DESIGN EVENTS AND ENVELOPES



Note: Levels provided for lake upstream of bridge



Note 1: Refer to Figure 2 for location of profile
Note 2: Excludes possible effects of climate change

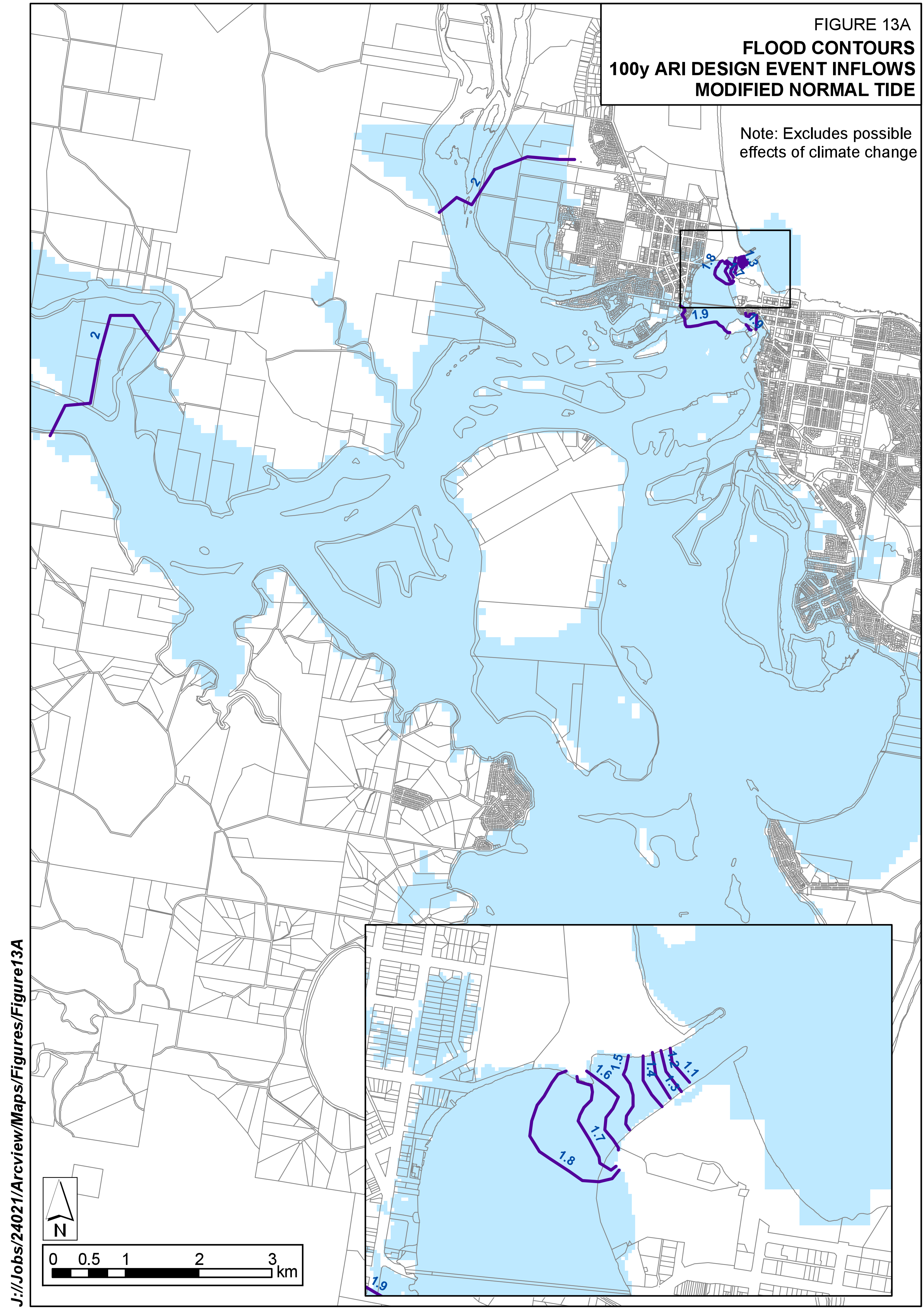


FIGURE 13A
FLOOD CONTOURS
100y ARI DESIGN EVENT INFLOWS
MODIFIED NORMAL TIDE
Note: Excludes possible effects of climate change
2
2
1.8
1.9
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.9
N
0 0.5 1 2 3 km
J://Jobs/24021/Arcview/Maps/Figures/Figure13A

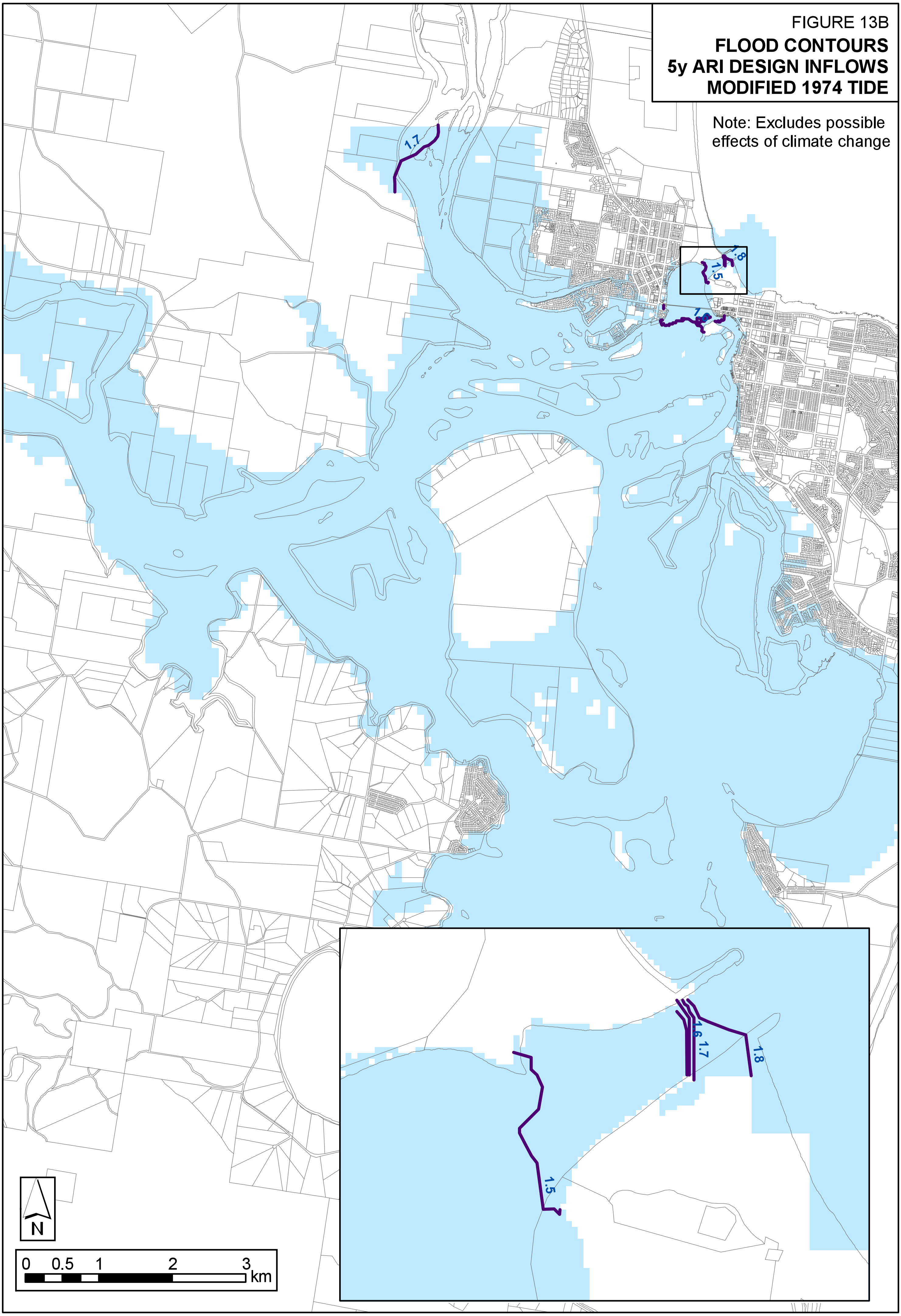
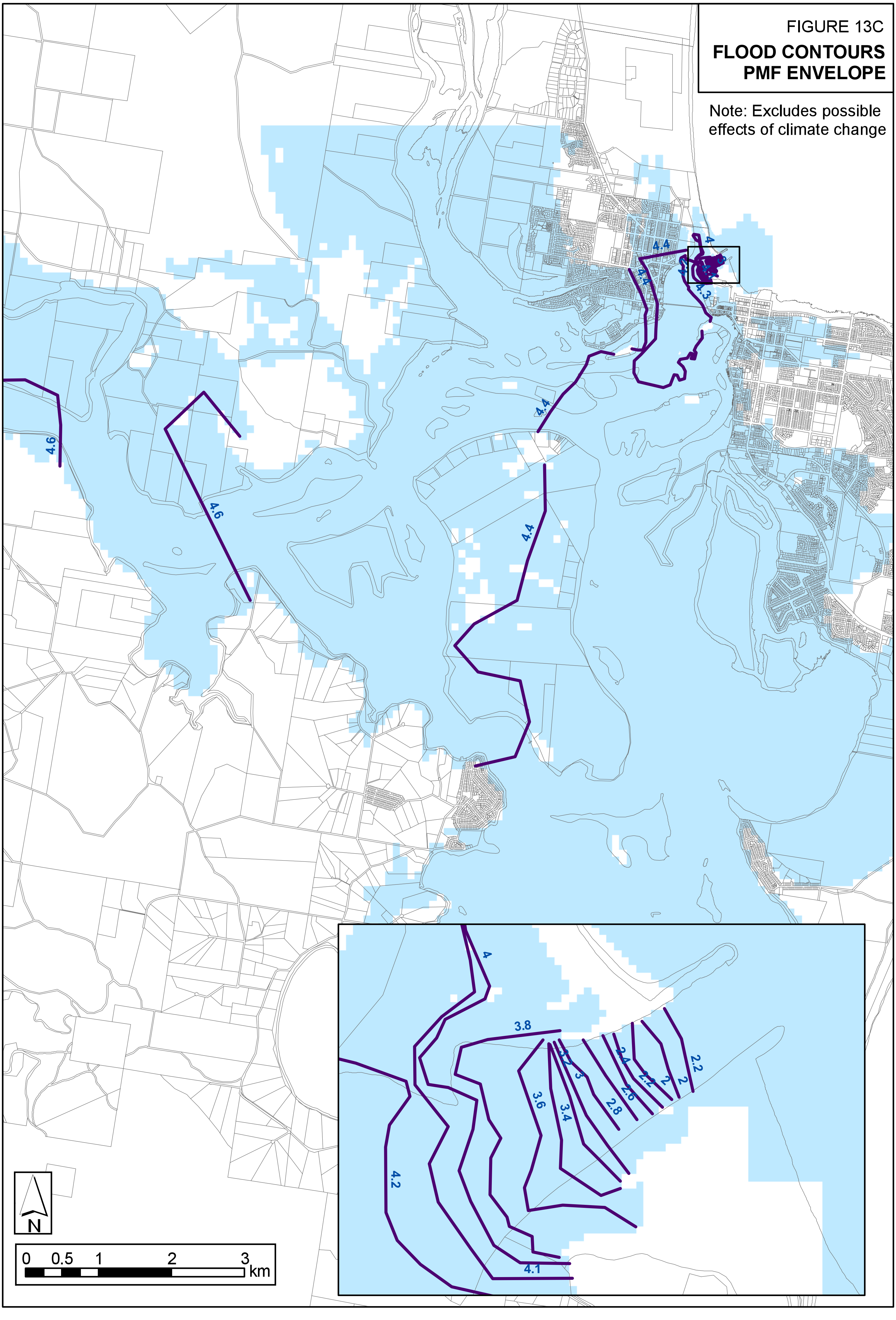


FIGURE 13B
FLOOD CONTOURS
5y ARI DESIGN INFLOWS
MODIFIED 1974 TIDE

J://Jobs/24021/Arcview/Maps/Figures/Figure13B



J://Jobs/24021/Arcview/Maps/Figures/Figure13C

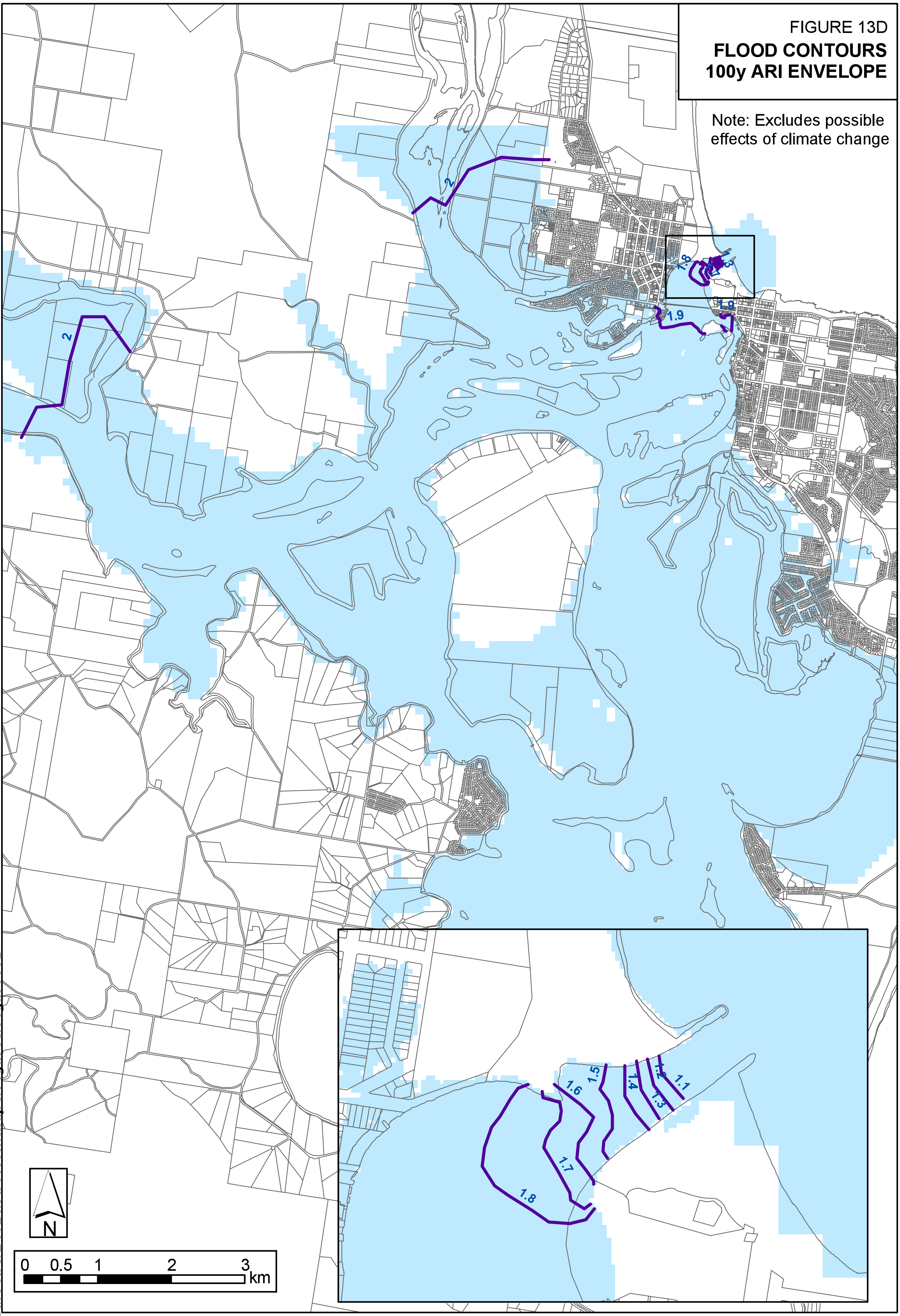


FIGURE 13D
FLOOD CONTOURS 100y ARI ENVELOPE

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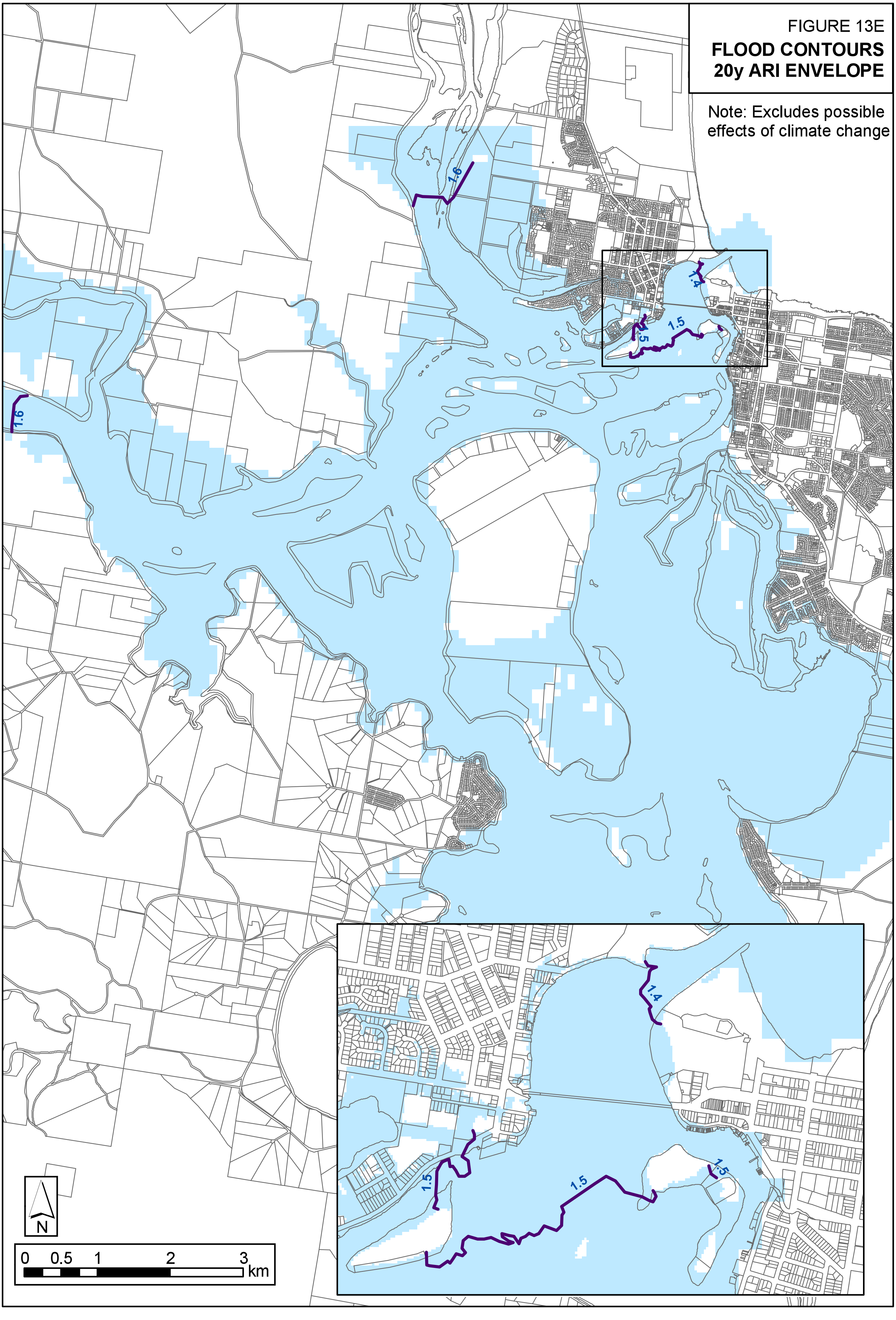
FIGURE 13E

FLOOD CONTOURS
20y ARI ENVELOPE

Note: Excludes possible effects of climate change



J://Jobs/24021/Arcview/Maps/Figures/Figure13E

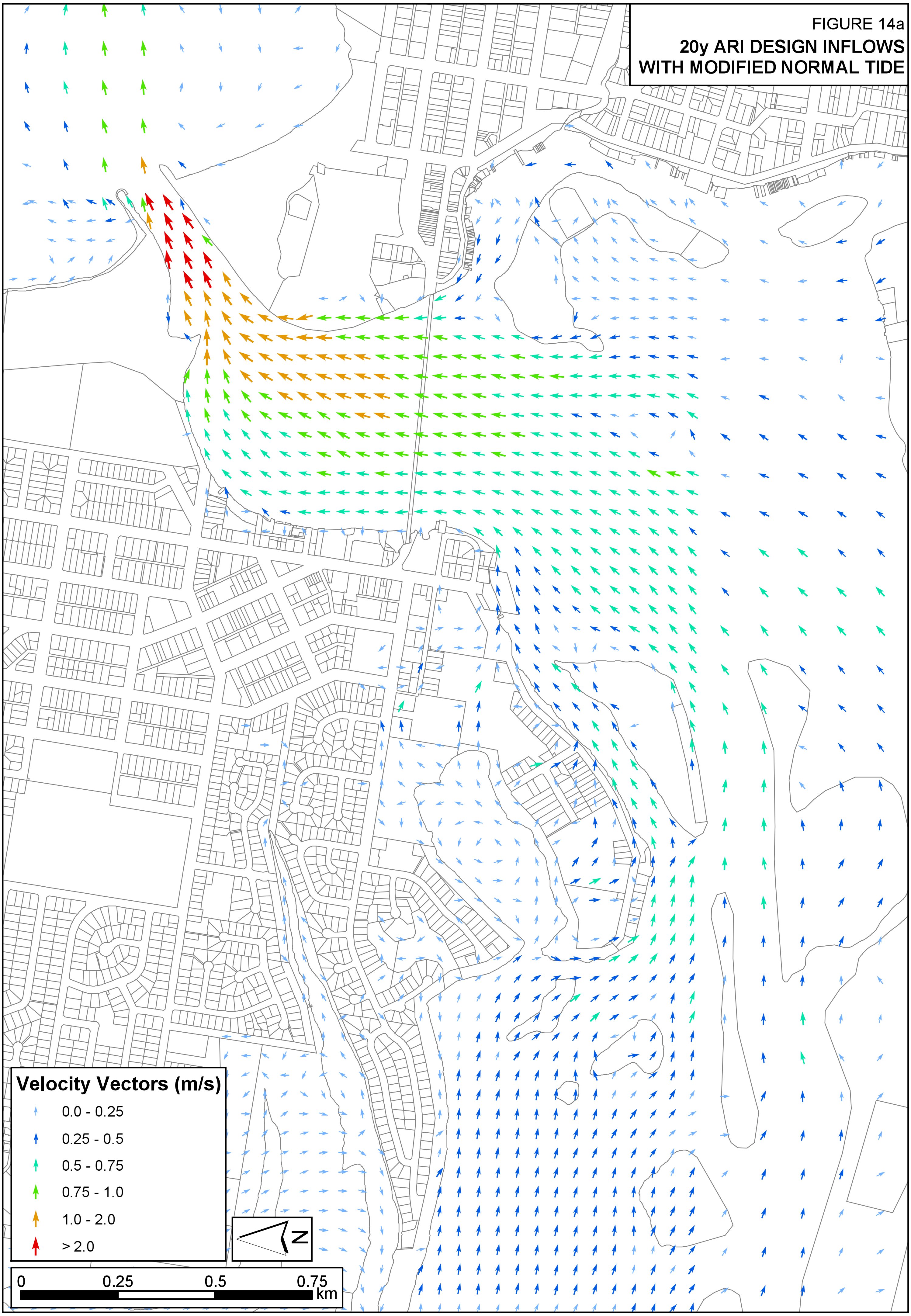


FIGURE 14a
20y ARI DESIGN INFLOWS
WITH MODIFIED NORMAL TIDE
Velocity Vectors (m/s)
0.0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 2.0
> 2.0
N
0
0.25
0.5
0.75
km
J:\Jobs\24021\Arcview\Maps\Figures\Figure14a

FIGURE 14b

100y ARI DESIGN INFLOWS WITH MODIFIED NORMAL TIDE

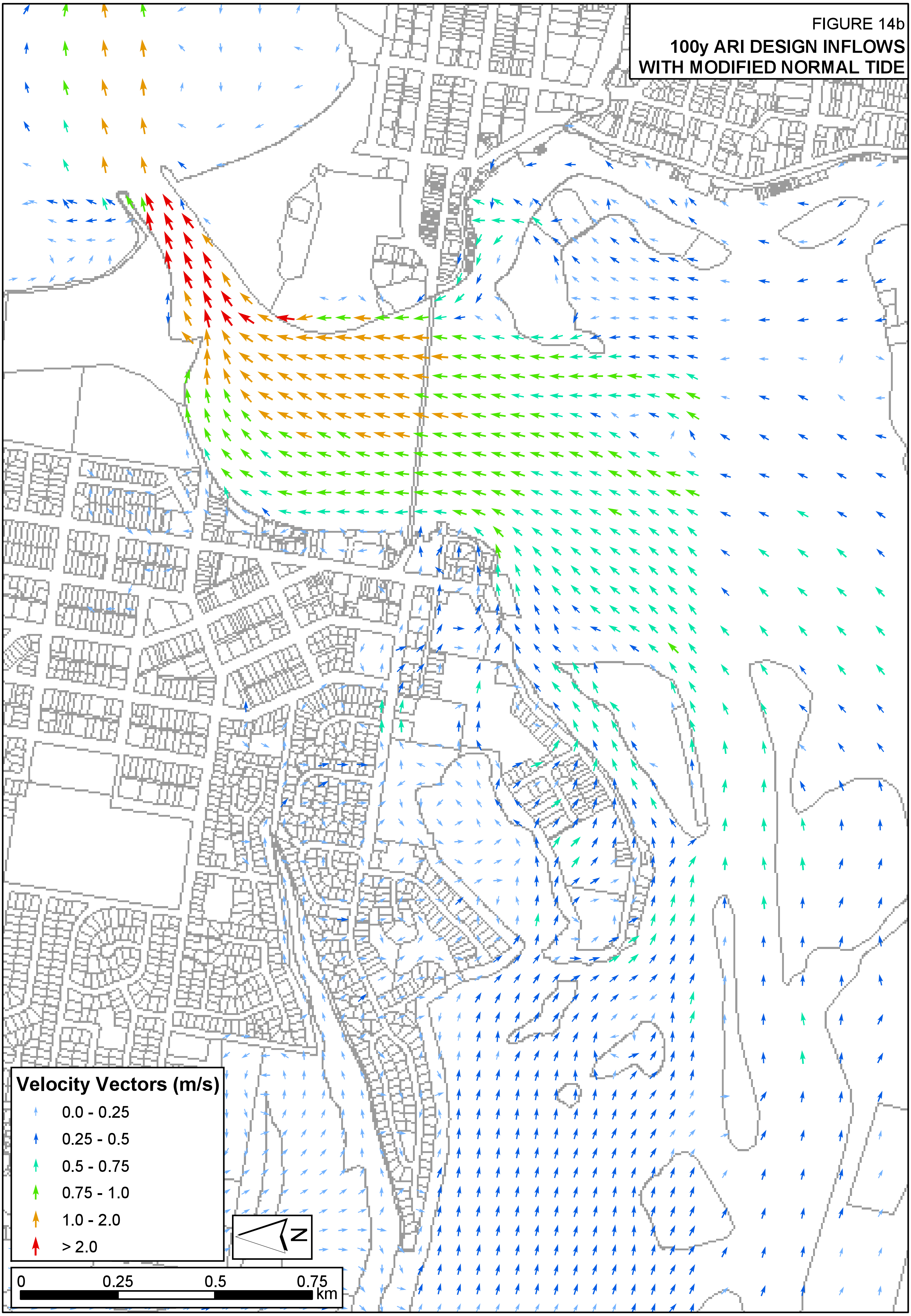


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FIGURE 15a

ASSESSMENT OF CLIMATE CHANGE RAINFALL INDUCED UPSTREAM OF BRIDGE WITH INCREASED RAINFALL

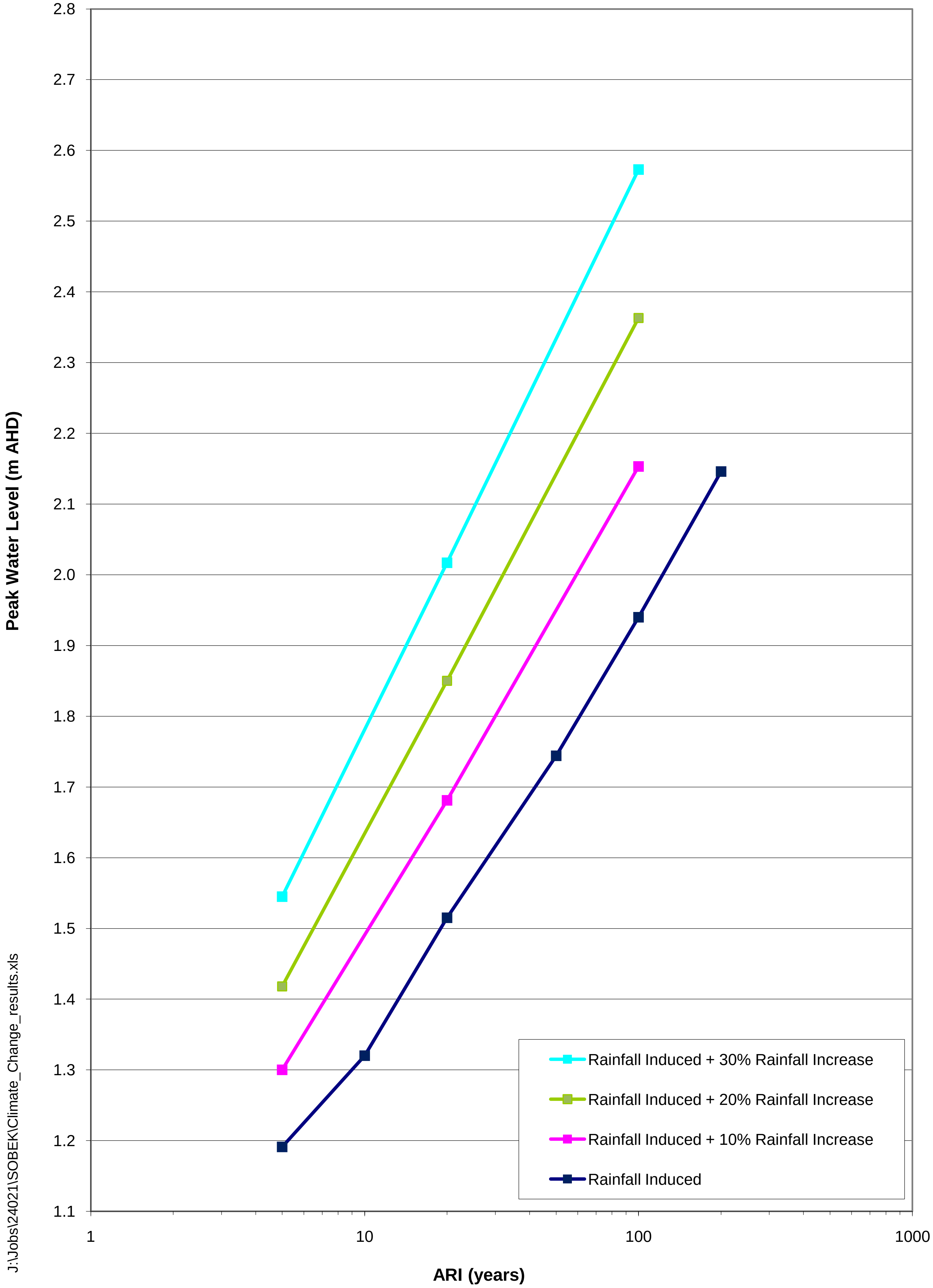

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FIGURE15b

ASSESSMENT OF CLIMATE CHANGE
RAINFALL INDUCED UPSTREAM OF BRIDGE
WITH OCEAN LEVEL RISE

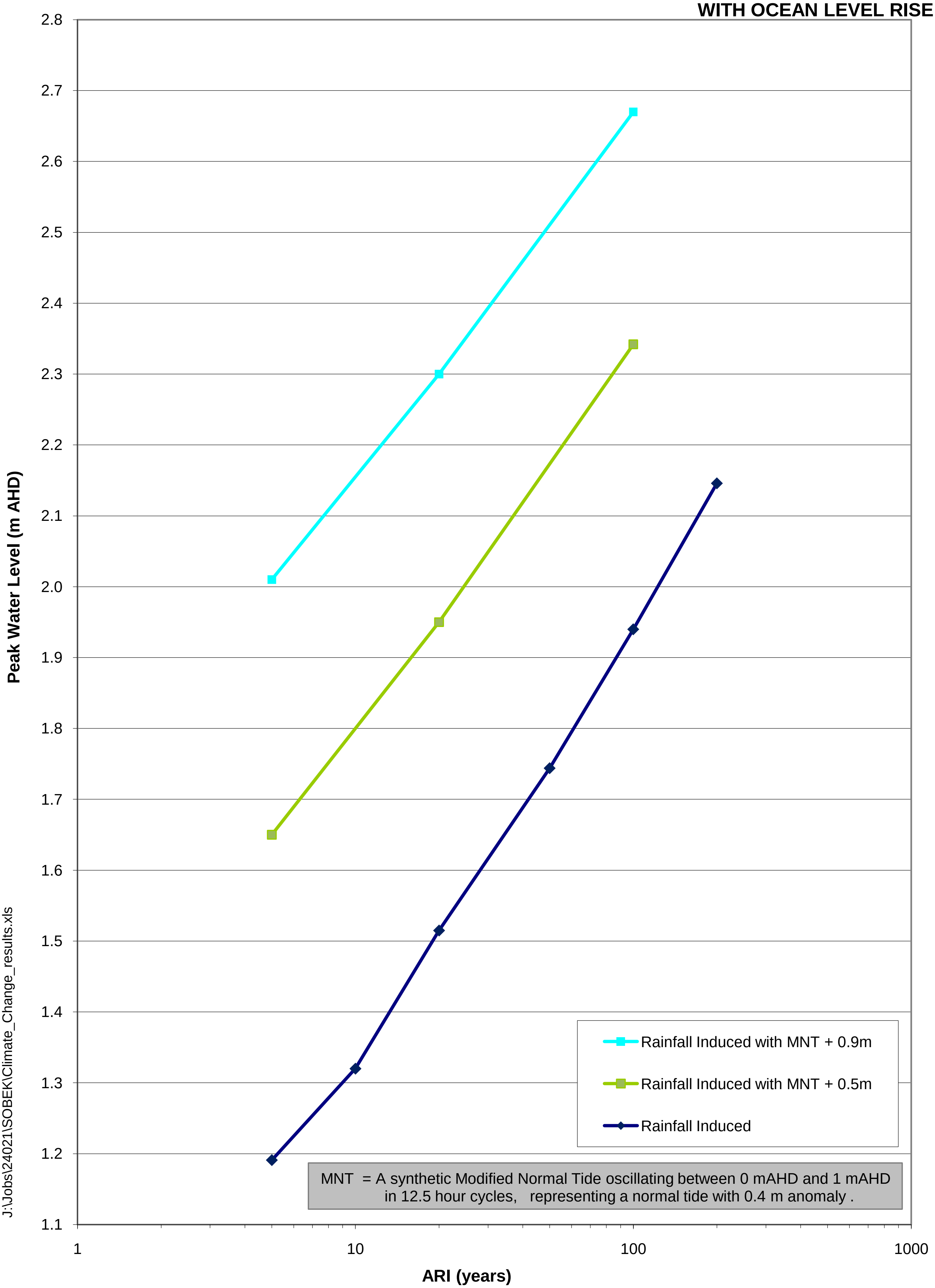

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FIGURE 15c
ASSESSMENT OF CLIMATE CHANGE
RAINFALL INDUCED UPSTREAM OF BRIDGE
COMBINATION OF OCEAN LEVEL RISE AND RAINFALL INCREASE

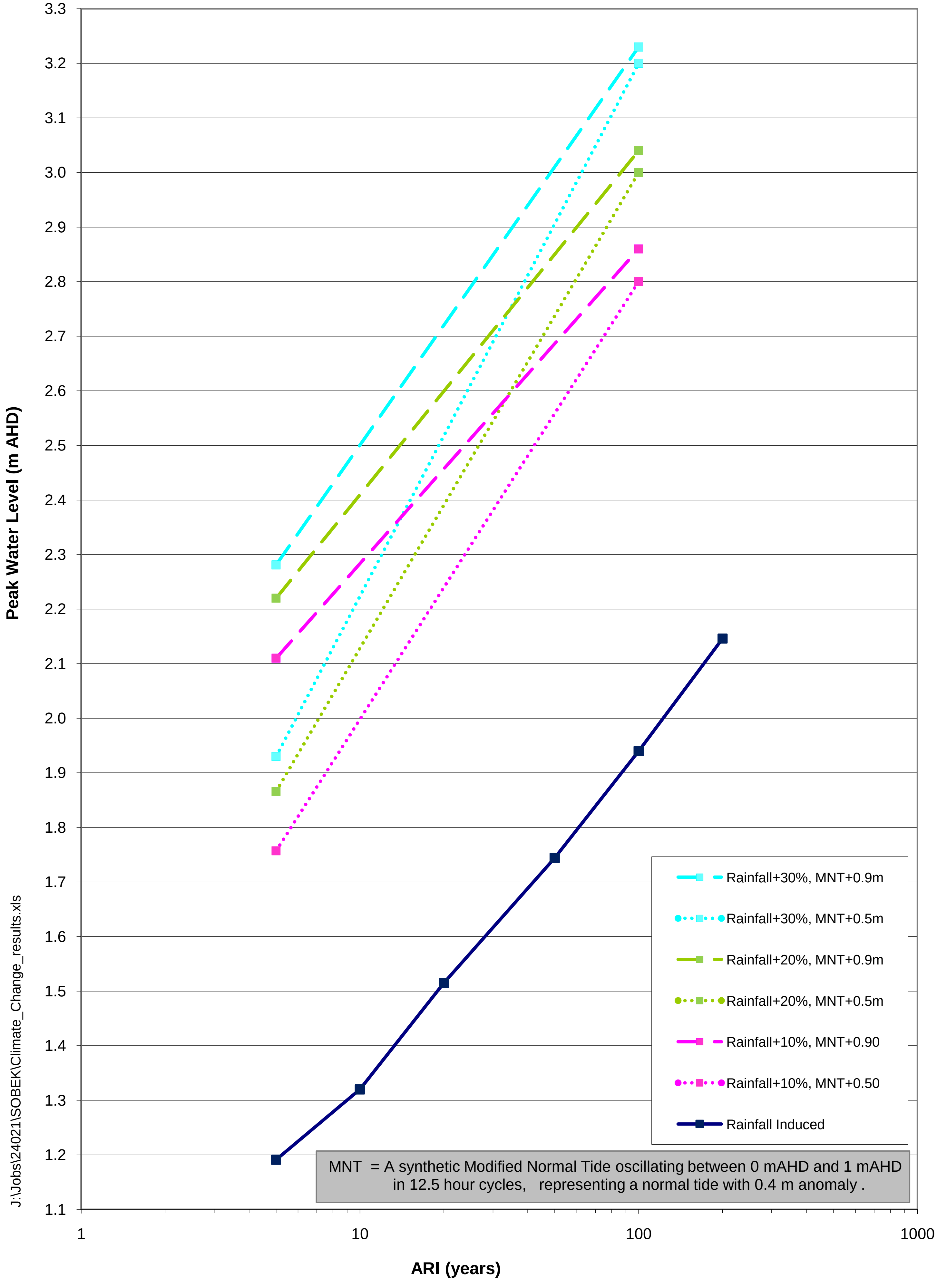

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FIGURE 15d

ASSESSMENT OF CLIMATE CHANGE

OCEAN INDUCED WITH OCEAN LEVEL RISE

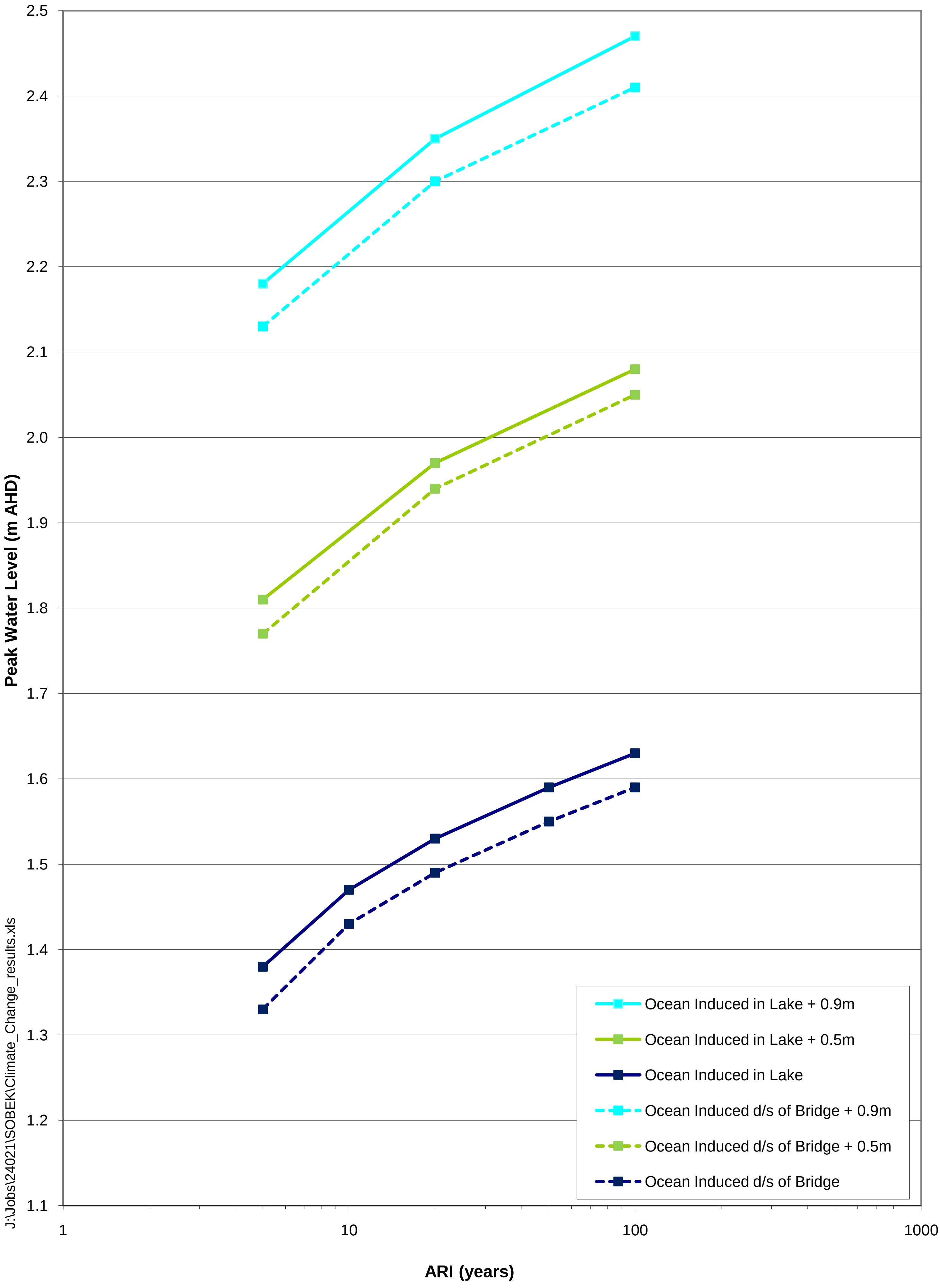

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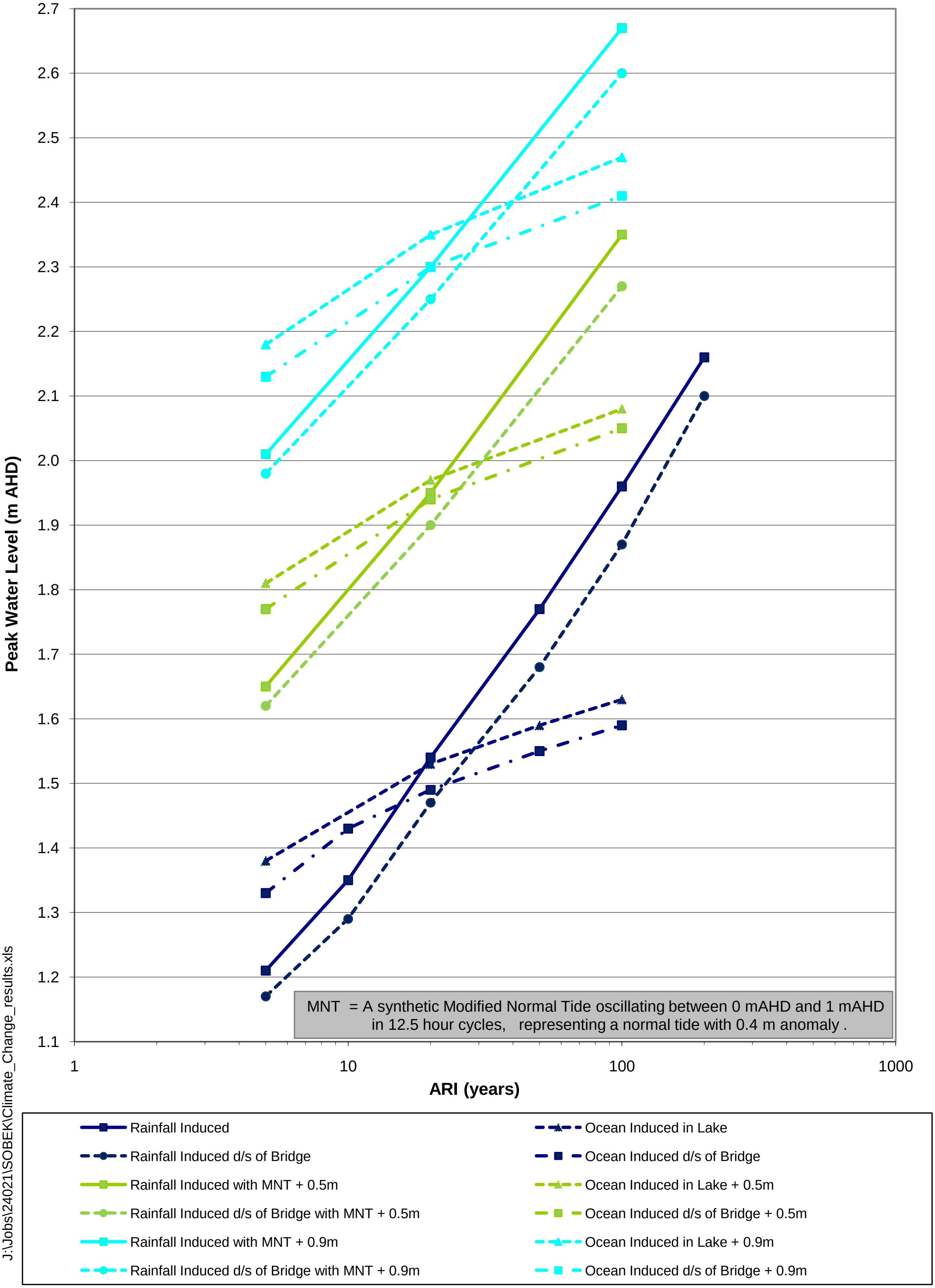
FIGURE 15e

ASSESSMENT OF CLIMATE CHANGE
COMPARISON OF OCEAN LEVEL RISE
ON FLOODING MECHANISMS



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Appendix A

APPENDIX A: GLOSSARY OF TERMS

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 a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves 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 "flood 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 "standard 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 “water 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.

Appendix B

Great Lakes Council
PO Box 450
FORSTER NSW 2428

24021 / L090724_GLC

16 October 2009

Attention: Mr Kumar Kuruppu

Dear Kumar,

Re: LIDAR Dataset Validation at Wallis Lake and Stroud

UPDATED TO EXCLUE SCIMS MARKS FROM COMPARISON

1. BACKGROUND

WMAwater advise that the validation survey of the Light Detection and Ranging (LIDAR) dataset at the above locations has been completed. Survey levels from the LIDAR Digital Elevation Models (DEMs) were compared with over 300 ground survey points collected using Differential GPS techniques by Rennie Golledge Surveyors of Maitland (refer to their methodology report – Attachment 1).

This check was deemed necessary due to potential errors in the LIDAR dataset resulting from the use of the AusGeoid98 model to reduce the LIDAR to Australian Height Datum (AHD). It is apparent that the AusGeoid98 model performs poorly in some coastal areas of NSW (such as Wallis Lake), and therefore the levels obtained from the LIDAR are not in close agreement with the local SCIMS network in some areas.

This potential source of error is relevant for flood modelling and mapping work undertaken by WMAwater.

The primary aims of the validation were to:

1. assess the errors in the LIDAR dataset relative to the additional ground survey points;
2. provide an additional independent quality control check for transformations of the LIDAR data by the Department of Lands (the transformation itself will be based on more detailed survey control works undertaken by the Department of Lands); and
3. determine a suitable interim adjustment to the LIDAR data for flood mapping work currently being undertaken by WMAwater around Wallis Lake (particularly at Tuncurry).

This letter report documents the outcomes of the survey comparison at various locations. A separate validation was undertaken for the Stroud and Wallis Lake study areas, and the Wallis Lake area was further broken up into sub-areas to highlight localised variations in the differences between the survey datasets.

0 366 075 980
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2. SURVEY SPECIFICATION LEVELS

Specifications for survey accuracy/confidence levels are generally expressed in terms of one standard deviation around the mean (1-σ), with the expectation of a roughly normal distribution with a mean and median error of zero. The specification for the LIDAR dataset was for a 1-σ variation of ±0.15m in the vertical direction, which means that approximately 67% of the points would be expected to lie within these bounds, and approximately 97% of the points would be expected to be within a 2-σ error band of ±0.30m.

The validation survey points were collected using Real Time Kinematic (RTK) GPS methods. Generally the AusGeoid98 model is used to reduce GPS data to AHD, so the levels obtained would be subject to the same limitations as the LIDAR. In order to compensate for this, the GPS levels were calibrated against local SCIMS benchmarks. The expected accuracy of the RTK GPS data was ±0.05m.

It is important to remember for the purposes of the comparison between datasets that both datasets have errors associated with them.

3. VALIDATION METHOD

A Triangular Irregular Network (TIN) of the raw LIDAR data points was created, which was then linearly sampled to create a 2m resolution gridded DEM. The value of the DEM at each of the validation point locations was then inspected, and the levels were compared.

4. STROUD STUDY AREA

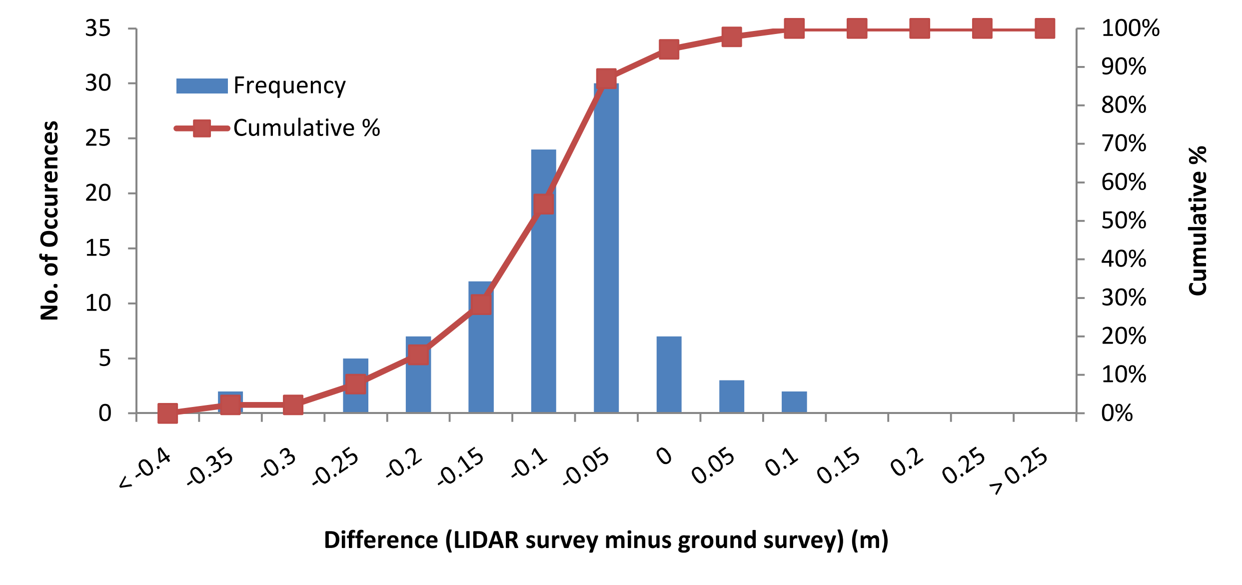
Over one-hundred point levels were collected in and around the township of Stroud. The statistical breakdown of the comparison with the LIDAR data (based on LIDAR level minus RTK level) is:

- a mean error of -0.12m;
- a median error of -0.11m; and
- a standard deviation of 0.08m.

State Survey Marks (SSMs) and Permanent Marks (PMs) were not included in the comparison.

For 70% of the points, the difference is less than ±0.15m, although there is a bias in the mean error of around 0.1m. Figure 1 shows a histogram of the errors between the LIDAR and the RTK survey in and around Stroud.

Figure 1: Aerial Survey Validation Histogram at Stroud



Based on this analysis, WMAwater consider that the LIDAR dataset at Stroud is suitable for our purposes "as-is." While the bias suggests there may be some justification for shifting the levels by around 0.1m for the DEM used in the Flood Study, it is considered that this would just introduce unnecessary complexity in the processing and implementation of the Flood Study results. Since the LIDAR dataset is likely to be extensively used as the primary reference for considering floodplain management options, it is advantageous for the Flood Study results to be consistent with the LIDAR dataset without manipulation. Technically the 1-σ criterion of ±0.15m is still satisfied, and in view of the expected error of both datasets, the bias of approximately 0.1m at Stroud is considered within reasonable limits.

A spreadsheet of the validation survey points, inspected LIDAR values and differences for the Stroud area is provided in Attachment 2. Highlighted values were excluded from the analysis, for one or more of the following reasons:

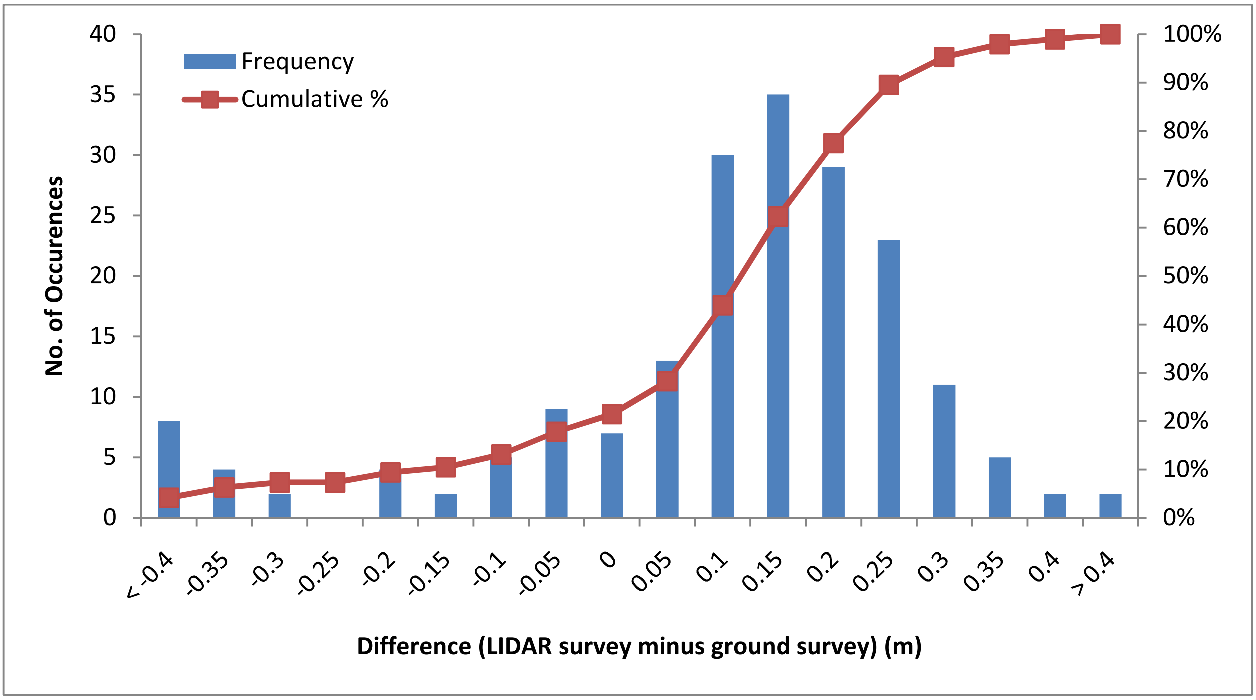
- points collected on bridge decks could not be compared, since the LIDAR sensor goes "through" the deck and picks up either the creek bed or water surface below;
- some of the validation points fell outside the available LIDAR extent; and

5. WALLIS LAKE STUDY AREA

Over two-hundred point levels were collected around Wallis Lake, with clusters of survey points at Tuncurry, Forster, Fairford, Boomerang Beach, Coomba Park, and Green Point. Figure 2 shows a histogram of the errors between the LIDAR and the RTK survey for the entire Wallis Lake area combined. The statistical breakdown of the comparison is:

- a mean error of 0.08m (LIDAR higher than ground survey);
- a median error of 0.12m; and
- a standard deviation of 0.19m.

Figure 2: Aerial Survey Validation Histogram for Wallis Lake Region



State Survey Marks (SSMs) and Permanent Marks (PMs) were not included in the comparison.

There were significant localised variations in the statistical distributions of errors over the study area. Figure 3 shows histograms of errors for clusters of points in different areas (following page).

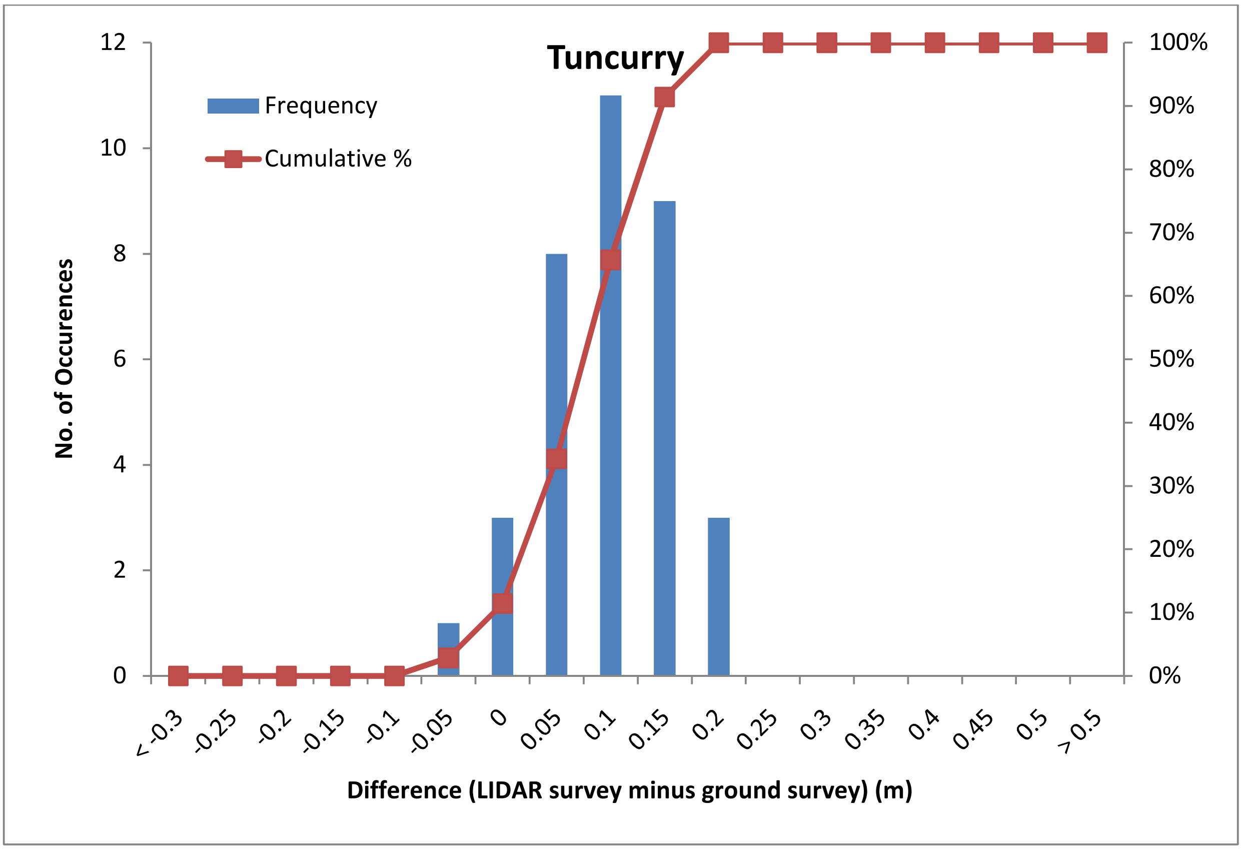
A spreadsheet of the validation survey points, inspected LIDAR values and differences for the Wallis Lake area is provided in Attachment 3. The clusters used for different locations are indicated by highlighted areas, and by the numbers in the ZONE column, which correspond to the localities in the table below:

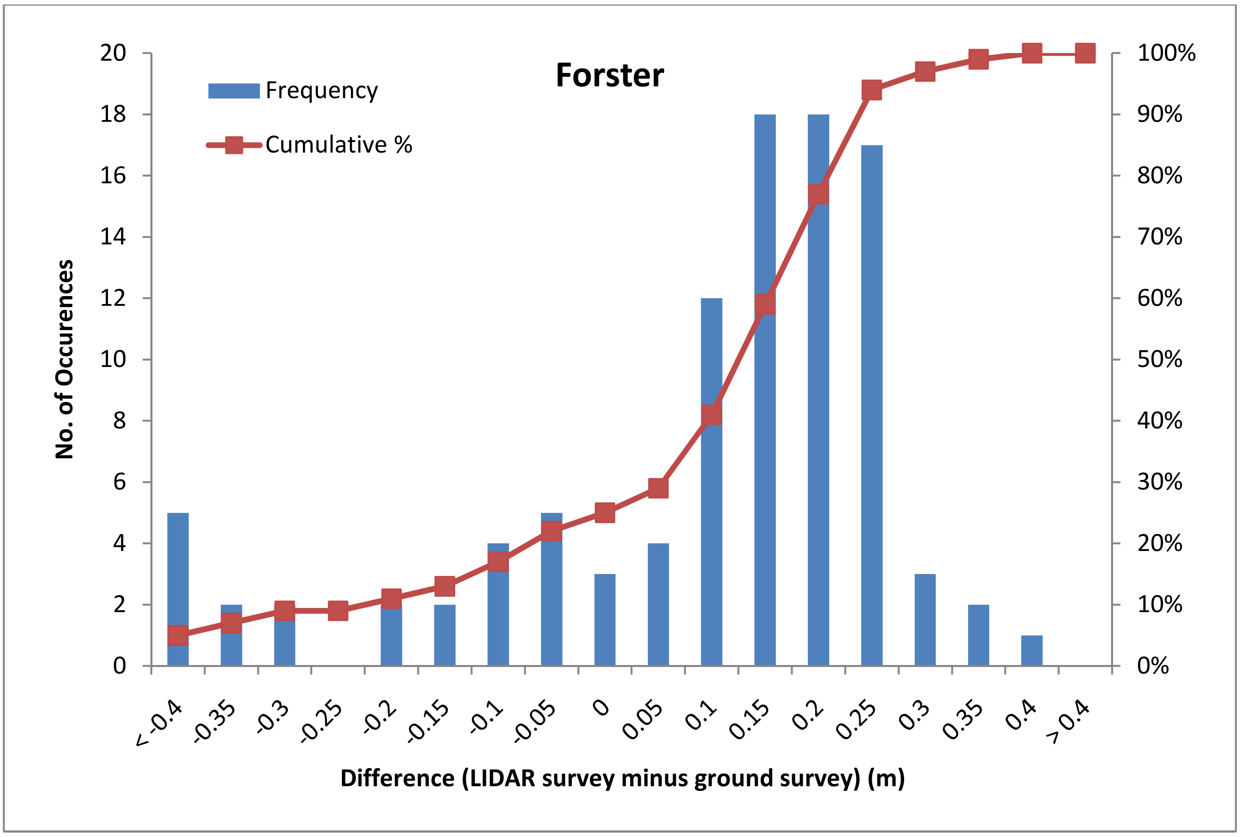
Area	ZONE number
Forster	1
Tuncurry	2
Green Point	3
Boomerang Beach	4
Failford	5
Coomba Park	6

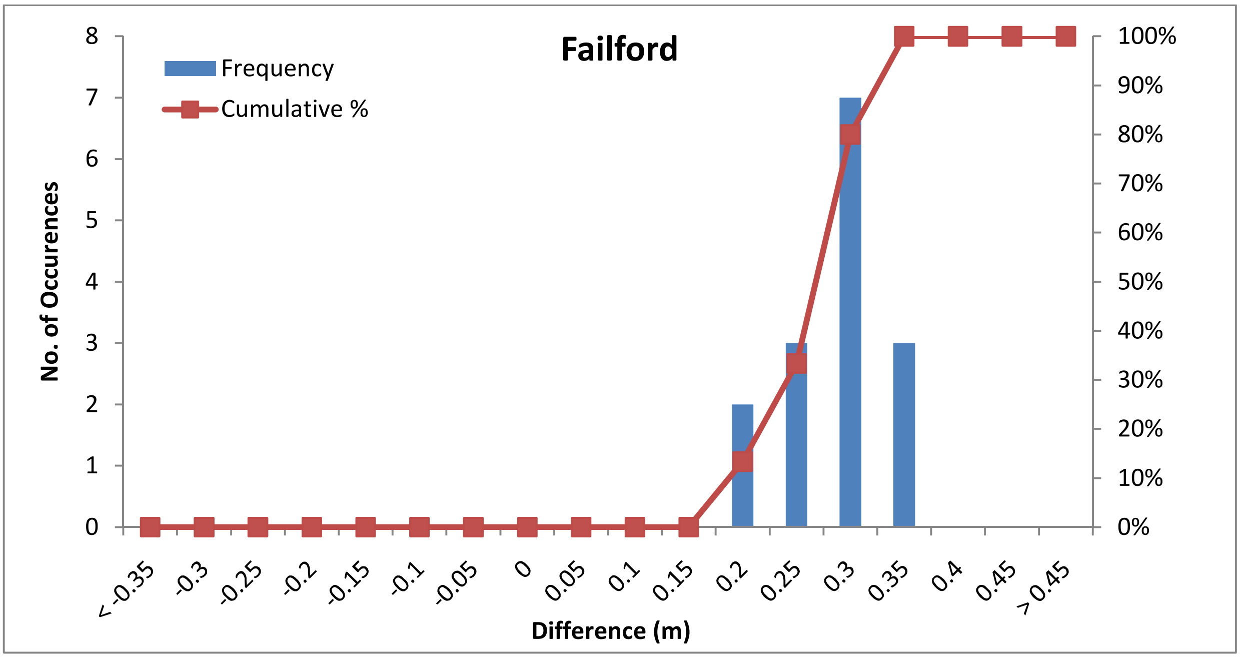
Certain values were excluded from the analysis, for the following reasons:

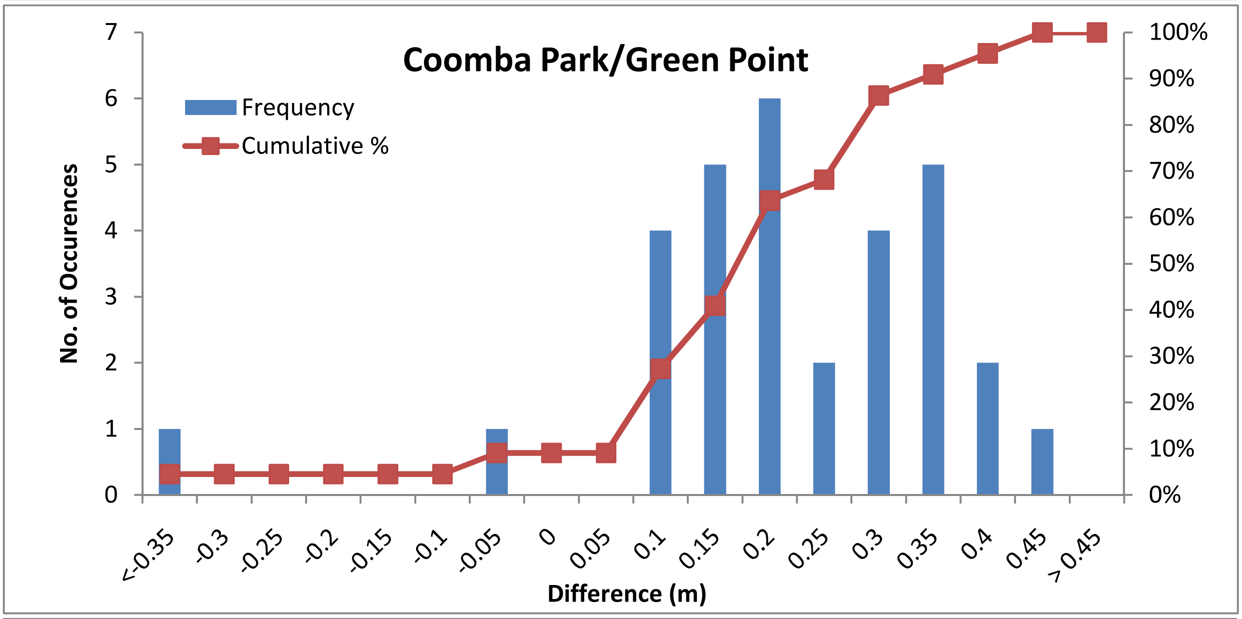
- some of the validation points fell outside the available LIDAR extent; and

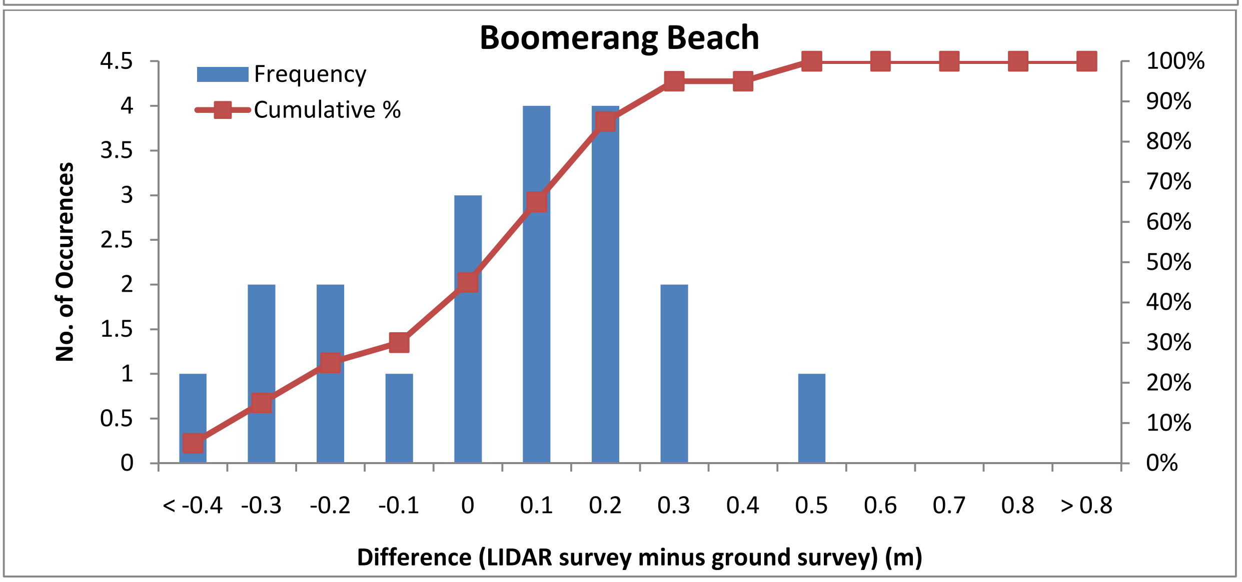
Figure 3: Localised Aerial Survey Validation Histograms






Failford
Frequency
Cumulative %
No. of Occurences
Difference (m)
0
1
2
3
4
5
6
7
8
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
< -0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
> 0.45


Coomba Park/Green Point
Frequency
Cumulative %
No. of Occurences
Difference (m)
0
1
2
3
4
5
6
7
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
<-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
>0.45


Boomerang Beach
Frequency
Cumulative %
No. of Occurences
Difference (LIDAR survey minus ground survey) (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
< -0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
> 0.8

The survey comparisons support the hypothesis that there are systematic biases in the LIDAR dataset around Wallis Lake, resulting from the discrepancy between AHD and AusGeoid98, and that the bias varies at across the study area. A summary of the statistical distribution of discrepancies in each area is provided in the following table.

Area	Number of Points	Mean Error (bias) (m)	Standard Deviation (1-σ) (m)
Forster	100	0.07	0.21
Tuncurry	36	0.07	0.06
Coomba Park/Green Point	19	0.14	0.18
Failford	15	0.26	0.04
Boomerang Beach	20	-0.01	0.22

It is considered that the findings above represent a reasonable understanding of the nature of the AHD/AusGeoid98 discrepancies in the area, except perhaps in the Coomba Park/Green Point areas where the distribution of errors was not normal, as expected. The mean bias observed at Forster, Tuncurry and Boomerang Beach was relatively low (< 0.1m), but the standard deviation was outside target values (that is, > 0.15m), except in Tuncurry. In other areas, the standard deviation was within the target, but there was a more significant bias in the mean and median values.

6. DISCUSSION

It is noted that the methodology report provided by the RTK survey providers (Attachment 1) is limited in regards to how base stations were established, and what quality control measures were undertaken. Rennie Golledge Surveyors indicate their confidence that the supplied data are "within the required scope outlined in the original brief," which was a standard deviation of ±0.05m error in the vertical direction. The data collected at Stroud are consistent with the LIDAR within the confidence limits.

A similar verification dataset obtained by Rennie Golledge at Maitland on behalf of WMAwater was found to be accurate and suitable for the purposes of adjusting LIDAR collected in that area. However due to the larger distance from the coast, the data at Stroud and Maitland were not subject to the AusGeoid98/AHD discrepancies. Therefore, confidence in the AHD levels from the RTK survey at Wallis Lake must depend on the quality of the local base stations that were established, and the resulting local calibration to AHD levels.

While it is unlikely that the RTK survey collected for this validation can be used as the sole dataset for spatial correction of the LIDAR to AHD datum in the Wallis lake area, the dataset should be useful as an independent check of the correction work being undertaken by the Department of Lands.

7. CONCLUSIONS

In regards to the primary aims of the validation assessment outlined above:

1. Discrepancies between verification survey collected by RTK techniques and LIDAR levels at Stroud and Wallis Lake have been quantified;
2. The verification survey dataset is considered suitable for use as an independent quality control check on LIDAR correction work being undertaken by the Department of Lands; and
3. For the purposes of the flood modelling and mapping work being undertaken by WMAwater, which was primarily concerned with the Tuncurry area, the LIDAR dataset was adjusted by a constant offset of -0.1m (lowered), consistent with the bias observed in that area.

If you require clarification of any of the above, please contact Rhys Hardwick Jones or the undersigned.

Yours faithfully,
WMAwater

R W Dewar
Director

Attachments:

1. Methodology Report for Ground Survey Collection (Rennie Golledge Surveyors)

2. Spreadsheet of Validation Points for Stroud Study Area

3. Spreadsheet of Validation Points for Wallis Lake Study Area

G.A. Golledge: B.Surv, Registered Surveyor (MIS Aust)
A.J. Rennie: B.Tech (Surv), (MIS Aust)

ATTACHMENT 1 - RENNIE GOLLEDGE METHODOLOGY REPORT

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Fax: (02) 4933 8579
Email: mail@renniegolledge.com.au
Web: www.renniegolledge.com.au

ABN: 55 002 622 317

Ref: 149.09

24021

7 September, 2009

The Manager
WMA Water
Level 2
160 Clarence Street
SYDNEY NSW 2000

Attention: Mr. R. Dewar

Dear Sir:

re: Stroud – Wallis Lake Validation Survey

We refer to the above and attach Methodology Report as requested.

If you require anything further, kindly contact the writer.

Yours faithfully
RENNIE GOLLEDGE PTY. LTD.

Geoff Golledge
REGISTERED SURVEYOR

Rennie Golledge Pty. Ltd.
CADASTRAL, ENGINEERING & MINING SURVEYORS
ENGINEERING DESIGN CONSULTANTS

Ref: 149.09

Stroud – Wallis Lake Aerial Validation Survey

Methodology Report

Under instruction from WHA Water our company undertook two separate ground surveys at Stroud as well as around Wallis Lake on the Mid North Coast of NSW. The purpose of the surveys was to validate aerial survey data previously obtained in the areas using Light Detection and Ranging (LiDAR) techniques.

The areas to be surveyed were both very extensive thus the equipment to be utilised would have to be mobile as well as accurate. We had previously undertaken a similar project in the Maitland Council area in which we utilised a Trimble R8 Global Positioning Unit to collect data. Results from this survey gave us enough confidence to ensure the same methodology for this project would provide the results to the desired accuracy.

The Trimble R8 GNSS System is "an intergrated system that delivers power, accuracy and performance..." (see Attachment "A").

(1) Stroud - In undertaking the survey in the Stroud area a base station was established on "Silo Hill". The rover was attached to the front bar of the survey vehicle (see photo 1) whilst the operator was seated in the passenger seat.

Once the GPS System was enabled the survey vehicle traversed the designated area stopping only to allow data collection at the required points, up to 5 seconds per point.

Apart from the ground points collected, known datum points were also surveyed to allow calibration of the information to be undertaken.

(2) Wallis Lake - The methodology for this area was similar to that undertaken at Stroud apart from the fact that since this area was considerably larger it was necessary to establish more than one base station. During the course of this survey, base stations were established at Nabiac, Cooloongolook, Coomba Park, Forster and Pacific Palms. As previously done, known datum points throughout the area were surveyed to allow calibration of the raw data collection during the survey.

The known datum points were either State Survey Marks or Permanent Marks whose values were obtained from the Department of Lands Database. All collected data was rotated and adjusted to these points.

Attachment 'A' outlines the technical qualities of the Trimble R8 GNSS system together with the accuracies one can expect in utilising the equipment. We have found the instrument extremely accurate and reliable on past projects and are confident the results obtained in this survey are within the required scope outlined in the original brief.

TRIMBLE R8 GNSS SYSTEM – THE NEW STANDARD FOR FULL FEATURED GNSS TECHNOLOGY

This integrated system delivers unmatched power, accuracy and performance in a rugged, compact unit.

- Advanced Trimble R-Track™ Technology
- Unmatched tracking of GNSS satellite signals
- Superior performance in challenging RTK applications
- Capacity to track up to 44 satellites
- Flexible system design
- Remote configuration and access

Advance surveying with Trimble R-Track

The latest advancements in Trimble R-Track technology consistently deliver precise positioning performance in the most challenging GNSS conditions. More satellites and better reception keep you working throughout the day. Our latest advancement, Trimble R-Track with Signal Prediction™ is a giant step for the surveying industry. Signal Prediction compensates for intermittent RTK signals, enabling extended operation after an interruption.

The new, CMRx protocol provides maximum compression of corrections to optimize communications bandwidth and fully utilize all of the satellites and signals in view.

The Trimble R8 GNSS supports a wide range of satellite signals, including GPS L2C and L5 and GLONASS L1/L2 signals. In addition, Trimble is committed to the next generation of modernized GNSS configurations by providing Galileo-compatible products available for customers well in advance of Galileo system availability In support of this plan, the new Trimble R8 GNSS is capable of tracking the experimental GIOVE-A and GIOVE-B test satellites for signal evaluation and test purposes.

Flexible System Design

The Trimble R8 GNSS receiver combines the most comprehensive feature set into an integrated and flexible system for demanding surveying applications.

- The Trimble R8 GNSS includes a built-in TX/RX UHF radio, enabling the ultimate flexibility for rover or base operation.
- As a base station, the internal NTRIP caster provides you with customized access to base station corrections via the internet (cellular modem required).

Trimble's exclusive, Web UI™ eliminates travel requirements for routine monitoring of base station receivers. Now you can assess the health and status of base receivers and perform remote configurations from the office. Through Web UI, you can also readily download post-processing data and save additional trips out to the field.

Enabling the Connected Site

Pair the speed and accuracy of the Trimble R8 GNSS receiver with flexibility and collaboration tools of Trimble Access software. Trimble Access brings the field and office teams closer by enabling data sharing and collaboration in a secure, web-based environment. With optional streamlined workflows, Trimble Access further empowers surveyors and survey teams for success. Now it is easier than ever to realize the potential of the Trimble Connected Site.

Connecting the right tools, techniques, services and relationships enables surveying businesses to achieve more every day.

Modernized GPS satellites are now in orbit, and all of these satellites are capable of transmitting L2C signals (civilian signals on the satellite L2 carrier). These satellites represent a significant first step in the GPS Modernization program planned by the United States.

Trimble R-Track technology in the Trimble R8 GNSS system and Trimble NetR5 Reference Station also supports GLONASS L1/L2 signals, the GNSS owned by the Russian Federation Government. In 2004 the United States and the Russian Federation issued a joint statement on cooperation, with the objective of maintaining and promoting interoperability between their two systems.

Trimble incorporates new technology when confident that it will provide surveying professionals with real field and business benefits. As evidence of this commitment to our customers, Trimble R-Track technology in the Trimble R8 GNSS now takes advantage of all currently available and imminent GNSS signals, including the new L2C signal and coming L5 band of GPS Modernization, plus GLONASS L1/L2. Trimble R-Track technology provides outstanding quality control in computing solutions using all available signals.

DATASHEET

The Trimble® R8 GNSS System is a multi-channel, multi-frequency GNSS (Global Navigation Satellite System) receiver, antenna, and data-link radio combined in one compact unit. The Trimble R8 combines advanced receiver technology and a proven system design to provide maximum accuracy and productivity.

trimBLe r-tracK technoLoGY for comPrehensiVe Gnss sUPPort

Powered by an enhanced RTK engine, Trimble R-Track technology supports both the modernized GPS L2C and L5 signals and GLONASS L1/L2 signals. The GNSS signals are capable of providing surveying professionals with real field benefits.

With the world's GNSS's in constant development, surveying businesses small and large can be confident that investment in a Trimble GNSS system is protected1. Trimble, already proven in GPS technology, will continue to lead the industry in GNSS support.

ProVen sYstem desiGn

From the powerful Trimble field software to the receiver itself, the Trimble R8 GNSS system's overall design has been tried, tested, and proven. As a rover it is rugged, lightweight and cable free for unsurpassed ergonomics in the field. As a base it is flexible and also cable free: use the Trimble R8 as a base or rover according to each job's needs.

The Trimble R8 GNSS system's flexible communication options include:

• An internal 450 MHz radio option for use as a cable-free base station

• An internal GSM/GPRS option for Internet connectivity and use as a rover in a Trimble VRS™ network

Simply choose the Trimble R8 model that best suits your needs.

the oriGinaL inteGrated sUrVeYinG soLUtion and BeYond

The Trimble R8 GNSS system is designed to support Trimble's original Integrated

Surveying™ solution. Combine your GPS and optical data in one job file in powerful Trimble field software such as Trimble Survey Controller™. Transfer the job file seamlessly to your Trimble office software for processing. The Trimble R8 can also be used as part of a Trimble® IS Rover. Simply add a prism to the rover pole and partner the Trimble R8 with a robotic optical system such as the Trimble® S6 Total Station. This integrated solution enables you to maximize the best of both surveying techniques for even greater efficiency in the field.

Whenever you're facing a new surveying challenge, your partnership with Trimble places the right tools and techniques, including GNSS technology, at your fingertips. Each Trimble system seamlessly integrates via shared workflows and technologies, making your everyday job site a place where the whole is greater than the sum of its parts: Welcome to the Connected Survey Site.

1. In addition, Trimble research and development divisions are already working closely with Galileo satellite system teams to ensure delivery of the benefits of this new GNSS in advance of the system being operational.

KeY featUres

Trimble R-Track technology for GNSS support

Advanced receiver technology and proven system design combined

Wireless technologies for flexibility and cable-free convenience

Base and rover communication options to suit any application

An important component of the Connected Survey Site model

www.trimble.com

Performance sPecifications

measurements

• Trimble R-Track technology
• Advanced Trimble Maxwell™ Custom Survey GNSS Chip
• High precision multiple correlator for GNSS pseudorange measurements
• Unfiltered, unsmoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
• Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
• Signal-to-Noise ratios reported in dB-Hz
• Proven Trimble low elevation tracking technology
• 72 Channels:
– GPS L1 C/A Code, L2C, L1/L2/L5 Full Cycle Carrier
– GLONASS L1 C/A Code, L1 P Code, L2 P Code, L1/L2 Full Cycle Carrier
– SBAS WAAS/EGNOS support1

code differential GPs positioning2

Horizontal . . . . ±0.25 m + 1 ppm RMS
Vertical . . . . ±0.50 m + 1 ppm RMS
WAAS differential positioning accuracy3 . . . . typically <5 m 3DRMS

static and faststatic GPs surveying2

Horizontal . . . . ±5 mm + 0.5 ppm RMS
Vertical . . . . ±5 mm + 1 ppm RMS

Kinematic surveying2

Horizontal . . . . ±10 mm + 1 ppm RMS
Vertical . . . . ±20 mm + 1 ppm RMS
Initialization time . . . . typically <10 seconds
Initialization reliability4 . . . . .typically >99.9%

hardware

Physical

Dimensions (W×H) . . . . 19 cm × 11.2 cm (7.5 in x 4.4 in),

RENNIE GOLLEDGE PTY. LTD.
SURVEYORS & PLANNERS

P.O. BOX 132
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MAITLAND NSW 2320
ABN: 55 002 622 317

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ATTACHMENT 2 - SPREADSHEET OF SURVEY COMPARISONS AT STROUD

X	Y	POINT	HEIGHT	CODE	NOTES	LIDAR	Difference
402750.649	6413973.691	2	64.871	Station	Data by GPS Survey	64.646	-0.225
402734.965	6414007.068	3	62.979	Centre Road	Data by GPS Survey	62.890	-0.089
402878.162	6414076.161	4	45.454	Centre Road	Data by GPS Survey	45.377	-0.077
402809.477	6414239.005	5	42.153	Centre Road	Data by GPS Survey	42.008	-0.145
402762.179	6414289.938	6	38.075	Centre Road	Data by GPS Survey	37.937	-0.138
402750.924	6414386.461	7	40.287	Centre Road	Data by GPS Survey	40.205	-0.082
402474.068	6414356.454	8	30.202	Centre Road	Data by GPS Survey	29.980	-0.222
402701.219	6414451.790	9	40.621	Centre Road	Data by GPS Survey	40.447	-0.174
402817.082	6414498.710	10	40.626	Centre Road	Data by GPS Survey	40.535	-0.091
402920.092	6414487.490	11	38.452	Centre Road	Data by GPS Survey	38.338	-0.114
403062.219	6414546.949	12	40.085	Centre Road	Data by GPS Survey	39.963	-0.122
403114.592	6414444.140	13	50.407	Centre Road	Data by GPS Survey	50.243	-0.164
403165.846	6414333.082	14	64.219	Centre Road	Data by GPS Survey	64.179	-0.040
403218.131	6414217.903	15	67.705	Centre Road	Data by GPS Survey	67.425	-0.280
403223.892	6414113.918	16	57.123	Centre Road	Data by GPS Survey	56.739	-0.384
403102.272	6414183.113	17	52.100	Centre Road	Data by GPS Survey	51.981	-0.119
403056.988	6414276.349	18	56.397	Centre Road	Data by GPS Survey	56.264	-0.133
402956.859	6414227.115	19	48.269	Centre Road	Data by GPS Survey	48.210	-0.059
403002.044	6414123.235	20	41.961	Centre Road	Data by GPS Survey	41.839	-0.122
403092.586	6413951.000	21	40.400	Centre Road	Data by GPS Survey	40.182	-0.218
403007.650	6413872.350	22	30.822	Centre Road	Data by GPS Survey	30.656	-0.166
402951.779	6413787.225	23	26.410	Centre Road	Data by GPS Survey	26.275	-0.135
402774.876	6413789.429	24	26.570	Centre Road	Data by GPS Survey	26.453	-0.117
402379.625	6413749.919	25	26.426	Centre Road	Data by GPS Survey	26.150	-0.276
401809.577	6413833.227	26	42.896	Centre Road	Data by GPS Survey	42.828	-0.068
401608.279	6414160.336	27	34.563	Centre Road	Data by GPS Survey	34.526	-0.037
401727.270	6414335.534	28	30.590	Centre Road	Data by GPS Survey	30.530	-0.060
401749.935	6414759.451	29	44.351	Centre Road	Data by GPS Survey	44.246	-0.105
402235.143	6414847.929	30	29.399	Centre Road	Data by GPS Survey	29.464	0.065
402436.878	6414915.175	31	30.950	Centre Road	Data by GPS Survey	30.890	-0.060
402481.741	6414824.317	32	32.735	Bridge	Data by GPS Survey	24.459	-8.276
402712.560	6414702.187	33	30.341	Park	Data by GPS Survey	30.270	-0.071
402680.101	6414719.365	34	30.181	Park	Data by GPS Survey	30.084	-0.097
402555.399	6414818.836	35	30.061	Park	Data by GPS Survey	29.965	-0.096
402744.456	6414870.521	36	30.998	Park	Data by GPS Survey	30.926	-0.072
402907.530	6414352.435	37	46.003	Centre Road	Data by GPS Survey	45.949	-0.054
403041.840	6414409.981	38	50.076	Centre Road	Data by GPS Survey	49.978	-0.098
403163.052	6414465.067	39	53.619	Centre Road	Data by GPS Survey	53.513	-0.106
403316.898	6414534.056	40	55.757	Centre Road	Data by GPS Survey	55.702	-0.055
403535.278	6414633.241	41	49.009	Centre Road	Data by GPS Survey	48.762	-0.247
403730.932	6414724.464	42	57.034	Centre Road	Data by GPS Survey	56.811	-0.223
403562.510	6414574.493	43	44.897	Centre Road	Data by GPS Survey	44.808	-0.089
403675.060	6414321.335	44	48.990	Centre Road	Data by GPS Survey	48.798	-0.192
402965.468	6413689.158	45	28.324	Bridge	Data by GPS Survey	22.468	-5.856
402966.898	6413514.794	46	30.470	Centre Road	Data by GPS Survey	30.367	-0.103
403207.239	6413501.971	47	46.374	Centre Road	Data by GPS Survey	46.250	-0.124
403504.154	6413485.708	48	43.634	Centre Road	Data by GPS Survey	43.388	-0.246
403976.208	6413364.823	49	33.763	Centre Road	Data by GPS Survey	33.464	-0.299
404750.284	6413404.473	50	38.641	Centre Road	Data by GPS Survey	38.268	-0.373
402948.760	6413351.076	51	26.073	Bridge	Data by GPS Survey	25.944	-0.129
402956.666	6413154.553	52	32.429	Centre Road	Data by GPS Survey	32.293	-0.136
403127.559	6413144.152	53	40.834	Centre Road	Data by GPS Survey	40.663	-0.171
402768.575	6413164.714	54	27.702	Centre Road	Data by GPS Survey	27.603	-0.099
402929.012	6413031.590	55	38.403	Centre Road	Data by GPS Survey	38.382	-0.021
402905.358	6412797.538	56	27.463	Centre Road	Data by GPS Survey	27.464	0.001
402916.980	6412441.915	57	42.720	Centre Road	Data by GPS Survey	42.664	-0.056
402917.004	6412441.695	58	42.729	Centre Road	Data by GPS Survey	42.664	-0.065
402892.918	6412087.110	59	40.472	Centre Road	Data by GPS Survey	40.497	0.025
402903.931	6411586.812	60	56.717	Centre Road	Data by GPS Survey	56.795	0.078
402918.781	6411331.633	61	45.800	Centre Road	Data by GPS Survey	45.710	-0.090
402925.441	6411025.998	62	50.094	Centre Road	Data by GPS Survey	50.092	-0.002

403150.519	6410366.263	63	21.665	Bridge	Data by GPS Survey	15.783	-5.882
402884.814	6413397.222	64	25.508	Centre Road	Data by GPS Survey	25.228	-0.280
403158.397	6413383.102	65	31.639	Centre Road	Data by GPS Survey	31.543	-0.096
402962.292	6414106.196	66	41.001	Centre Road	Data by GPS Survey	40.913	-0.088
402885.579	6414270.245	67	45.644	Centre Road	Data by GPS Survey	45.538	-0.106
402496.909	6414761.289	68	29.262	Centre Road	Data by GPS Survey	29.146	-0.116
402340.787	6415144.737	69	32.464	Centre Road	Data by GPS Survey	32.349	-0.115
402523.724	6415221.087	70	33.534	Centre Road	Data by GPS Survey	33.476	-0.058
402646.992	6415514.025	71	35.594	Centre Road	Data by GPS Survey	35.551	-0.043
402674.986	6416098.903	72	53.367	Centre Road	Data by GPS Survey	53.278	-0.089
402632.878	6416785.772	73	37.616	Centre Road	Data by GPS Survey	37.566	-0.050
402889.791	6417299.781	74	37.986	Centre Road	Data by GPS Survey	37.903	-0.083
402793.798	6417810.856	75	39.971	Centre Road	Data by GPS Survey	39.786	-0.185
402722.661	6418518.259	76	53.885	Centre Road	Data by GPS Survey	53.691	-0.194
402692.476	6419171.686	77	56.382	Centre Road	Data by GPS Survey	56.239	-0.143
402688.428	6419624.850	78	59.214	Centre Road	Data by GPS Survey	59.024	-0.190
402928.786	6420121.639	79	66.329	Centre Road	Data by GPS Survey	66.224	-0.105
401854.567	6415806.839	80	61.808	Centre Road	Data by GPS Survey	61.658	-0.150
401865.949	6416024.236	81	77.209	Park	Data by GPS Survey	77.117	-0.092
401412.801	6416333.259	82	36.283	Centre Road	Data by GPS Survey	36.314	0.031
401037.185	6417189.965	83	43.292	Centre Road	Data by GPS Survey	43.105	-0.187
400049.540	6417369.834	84	32.512	Centre Road	Data by GPS Survey	32.414	-0.098
399489.700	6418319.361	85	43.841	Centre Road	Data by GPS Survey	-99999.000	-100042.841
399165.218	6418872.462	86	36.150	Centre Road	Data by GPS Survey	-99999.000	-100035.150
398656.779	6419053.528	87	39.351	Bridge	Data by GPS Survey	-99999.000	-100038.351
400939.642	6417932.696	88	72.509	Bridge	Data by GPS Survey	72.379	-0.130
400937.436	6418564.478	89	84.848	Centre Road	Data by GPS Survey	84.699	-0.149
400804.148	6419106.527	90	62.880	Centre Road	Data by GPS Survey	62.782	-0.098
400690.091	6419597.231	91	76.779	Road	Data by GPS Survey	76.683	-0.096
400293.137	6420218.798	92	54.719	Centre Road	Data by GPS Survey	54.674	-0.045
400284.719	6420538.263	93	53.729	Centre Road	Data by GPS Survey	53.539	-0.190
399536.366	6420465.730	94	44.139	PM43563	Data by GPS Survey	-99999.000	-100043.139
402547.012	6415227.756	95	33.247	PM120011	Data by GPS Survey	33.148	-0.099
402759.704	6414750.012	96	30.753	Park	Data by GPS Survey	30.577	-0.176
402713.319	6414704.497	97	30.445	Road	Data by GPS Survey	30.249	-0.196
402701.163	6414663.951	98	31.028	Road	Data by GPS Survey	30.742	-0.286
402686.305	6414628.814	99	30.769	Road	Data by GPS Survey	30.650	-0.119
402771.757	6413975.140	100	66.030	Park	Data by GPS Survey	65.887	-0.143
402975.773	6413624.911	101	29.046	PM9448	Data by GPS Survey	28.980	-0.066
402981.181	6414201.016	102	48.481	PM13198	Data by GPS Survey	48.416	-0.065
402964.919	6414233.311	103	49.332	Footpath	Data by GPS Survey	49.106	-0.226
402957.546	6414248.074	104	49.527	SSM15576	Data by GPS Survey	49.169	-0.358
403224.463	6414225.754	105	68.584	PM13201	Data by GPS Survey	68.294	-0.290
403222.788	6414281.845	106	68.466	SV	Data by GPS Survey	68.315	-0.151
403164.597	6414333.758	107	64.254	Centre Road	Data by GPS Survey	64.179	-0.075
402975.773	6413624.911	5025	29.077	PM9448	Control Data from SCIMS	28.980	-0.097
402740.553	6414273.856	5026	40.000	PM13193	Control Data from SCIMS	36.720	-3.280
403311.974	6414523.784	5027	50.000	PM13195	Control Data from SCIMS	55.411	5.411
402981.185	6414201.273	5028	45.000	PM13198	Control Data from SCIMS	48.416	3.416
402994.300	6414494.300	5029	42.982	GB921	Control Data from SCIMS	43.049	0.067
402332.000	6415145.000	5030	31.727	PM10979	Control Data from SCIMS	31.898	0.171
402546.842	6415228.432	5031	33.217	PM120011	Control Data from SCIMS	33.176	-0.041

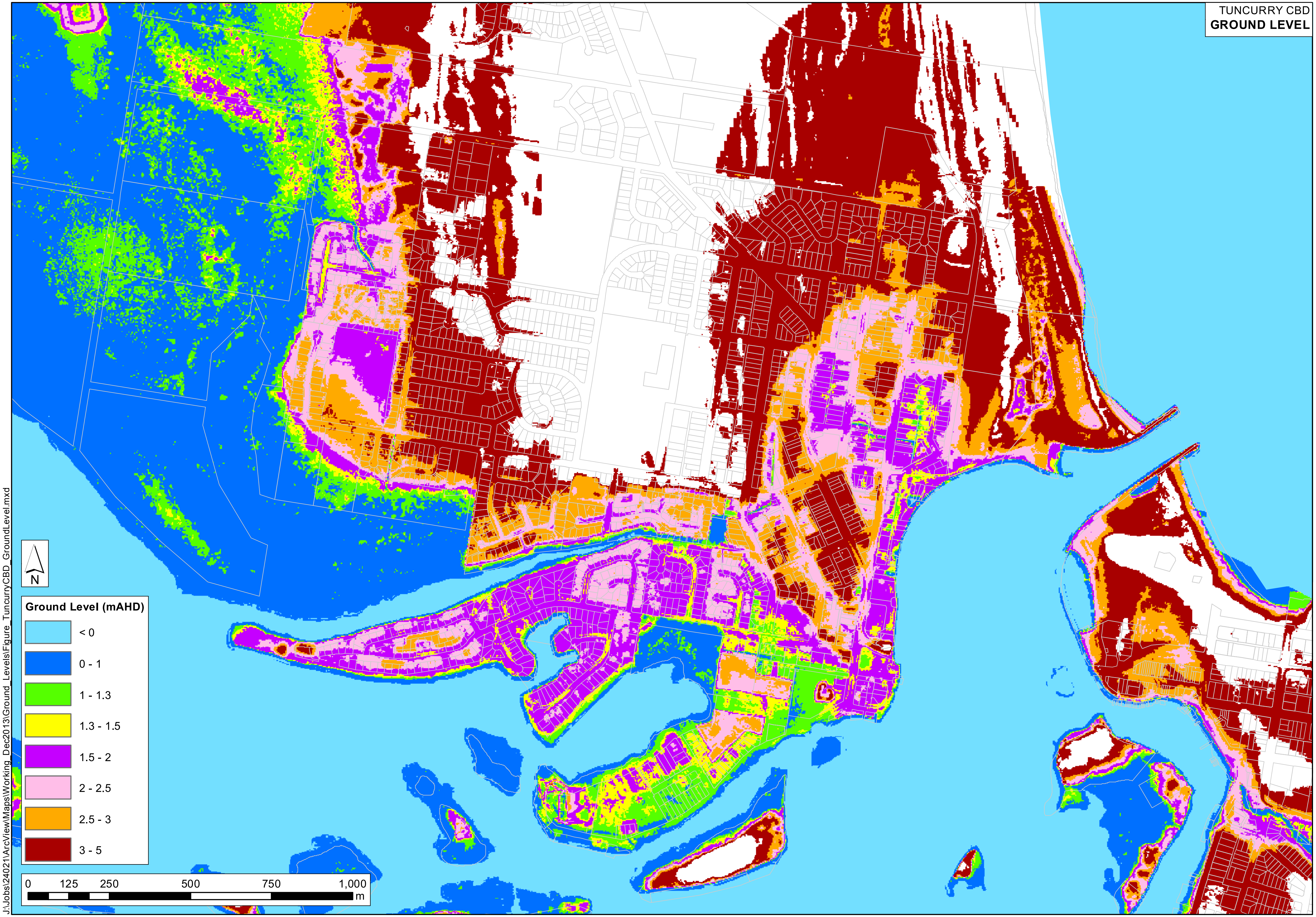
ATTACHMENT 3 - SPREADSHEET OF SURVEY COMPARISONS AT WALLIS LAKE

ZONE	EASTING	NORTHING	POINT	HEIGHT	CODE	NOTES	LIDAR	Difference
1	453652.478	6439974.147	1	2.641	Station	Data by GPS Survey	2.834	0.193
1	453618.587	6439904.059	2	2.191	Road	Data by GPS Survey	2.341	0.150
1	453639.923	6439577.322	3	2.985	Road	Data by GPS Survey	3.120	0.135
1	453760.911	6439657.299	4	2.515	Road	Data by GPS Survey	2.583	0.068
1	453982.411	6439629.016	5	7.116	Road	Data by GPS Survey	7.164	0.048
1	454439.990	6439691.863	6	15.335	Road	Data by GPS Survey	15.483	0.148
1	454208.104	6439513.356	7	5.103	Road	Data by GPS Survey	5.178	0.075
1	454052.165	6439257.900	8	2.487	Road	Data by GPS Survey	2.611	0.124
1	453942.676	6438795.114	9	4.055	Road	Data by GPS Survey	4.310	0.255
1	453981.182	6437979.383	10	4.117	Road	Data by GPS Survey	4.184	0.067
1	454458.849	6437812.233	11	4.221	Road	Data by GPS Survey	4.317	0.096
1	454550.148	6437882.050	12	6.061	Road	Data by GPS Survey	6.153	0.092
1	454786.568	6437847.988	13	31.924	Road	Data by GPS Survey	31.956	0.032
1	454785.405	6438130.975	14	10.657	Road	Data by GPS Survey	10.733	0.076
1	454925.458	6438395.962	15	44.875	Road	Data by GPS Survey	44.965	0.090
1	455341.901	6438328.923	16	20.259	Road	Data by GPS Survey	20.327	0.068
1	455161.607	6438696.992	17	5.828	Road	Data by GPS Survey	5.995	0.167
1	456168.049	6438509.721	18	5.207	Road	Data by GPS Survey	5.307	0.100
1	454653.075	6438973.634	19	3.524	Road	Data by GPS Survey	3.650	0.126
1	454063.902	6438069.407	20	4.934	SSM90326	Data by GPS Survey	5.061	0.127
1	454169.923	6437648.095	21	4.009	Road	Data by GPS Survey	4.148	0.139
1	453832.097	6439430.531	22	2.604	Road	Data by GPS Survey	2.695	0.091
1	454005.892	6439667.164	62	7.453	PM15079	Data by GPS Survey	7.985	0.532
1	455539.047	6437796.982	63	34.298	Station	Data by GPS Survey	34.487	0.189
1	455543.901	6437856.758	64	31.846	Road	Data by GPS Survey	31.898	0.052
1	455586.032	6438014.656	65	22.445	Road	Data by GPS Survey	22.784	0.339
1	455976.637	6437955.956	66	38.028	Road	Data by GPS Survey	38.146	0.118
1	456306.153	6437526.673	67	27.151	Road	Data by GPS Survey	27.268	0.117
1	456689.098	6437501.437	68	28.787	Road	Data by GPS Survey	28.949	0.162
1	456774.680	6437064.758	69	15.238	Road	Data by GPS Survey	15.414	0.176
1	457109.688	6436858.168	70	34.456	Road	Data by GPS Survey	34.670	0.214
1	456451.922	6437722.323	71	11.417	Road	Data by GPS Survey	11.600	0.183
1	456185.050	6437785.969	72	26.244	Road	Data by GPS Survey	26.445	0.201
1	456046.860	6438062.587	73	15.683	Road	Data by GPS Survey	15.831	0.148
1	456045.951	6438330.793	74	19.854	Road	Data by GPS Survey	19.997	0.143
1	455844.605	6437832.335	75	18.102	Road	Data by GPS Survey	18.262	0.160
1	455957.060	6437470.397	76	12.049	Road	Data by GPS Survey	12.420	0.371
1	456287.036	6437217.732	77	16.113	Road	Data by GPS Survey	16.292	0.179
1	455864.885	6437248.498	78	3.871	Road	Data by GPS Survey	4.047	0.176
1	455371.323	6437129.860	79	2.782	Road	Data by GPS Survey	3.097	0.315
1	455638.185	6436813.863	80	2.978	Road	Data by GPS Survey	3.223	0.245
1	455572.319	6435061.855	88	7.318	Road	Data by GPS Survey	7.525	0.207
1	455249.281	6435134.051	89	2.292	Road	Data by GPS Survey	2.453	0.161
1	456039.513	6435174.120	90	6.211	Road	Data by GPS Survey	6.355	0.144
1	456197.334	6435217.784	91	3.948	Road	Data by GPS Survey	4.188	0.240
1	456249.508	6435580.607	92	4.496	Road	Data by GPS Survey	4.640	0.144
1	456180.006	6435071.036	93	3.951	Road	Data by GPS Survey	4.178	0.227
1	455993.459	6434960.590	94	6.283	Road	Data by GPS Survey	6.496	0.213
1	455090.898	6435516.342	95	1.616	Road	Data by GPS Survey	1.801	0.185
1	455060.704	6435276.157	96	1.625	Road	Data by GPS Survey	1.812	0.187
1	454889.867	6435353.556	97	1.594	Road	Data by GPS Survey	1.792	0.198
1	455000.690	6435402.541	98	1.454	Road	Data by GPS Survey	1.722	0.268
1	454838.363	6435472.445	99	1.348	Road	Data by GPS Survey	1.565	0.217
1	454750.088	6435568.824	100	1.545	Road	Data by GPS Survey	1.683	0.138
1	454436.387	6435429.255	101	1.533	Road	Data by GPS Survey	1.746	0.213
1	454487.610	6435699.911	102	1.178	Road	Data by GPS Survey	1.413	0.235
1	454485.185	6435313.538	103	1.604	Road	Data by GPS Survey	1.794	0.190
1	454729.138	6435236.481	104	1.383	Road	Data by GPS Survey	1.503	0.120
1	454754.592	6435566.989	105	1.789	SSM63754	Data by GPS Survey	2.064	0.275
1	454656.561	6436117.314	106	1.538	Road	Data by GPS Survey	1.736	0.198
1	454995.725	6436161.567	107	2.254	Road	Data by GPS Survey	2.426	0.172
1	454985.277	6436326.111	108	2.354	Road	Data by GPS Survey	2.562	0.208
1	455200.212	6436522.374	109	1.878	Road	Data by GPS Survey	2.111	0.233
1	455132.536	6437076.788	110	3.339	Road	Data by GPS Survey	3.562	0.223
1	454164.291	6437579.590	111	3.981	Road	Data by GPS Survey	4.222	0.241
1	454435.762	6437548.795	112	2.452	Road	Data by GPS Survey	2.698	0.246
1	454402.146	6437660.837	113	3.040	Road	Data by GPS Survey	3.149	0.109
1	454930.402	6437596.228	114	3.772	Road	Data by GPS Survey	3.997	0.225
1	455452.967	6437861.327	115	37.470	Road	Data by GPS Survey	37.703	0.233
1	455539.047	6437796.982	140	34.298	Station	Data by GPS Survey	34.487	0.189
1	455989.847	6435843.212	141	8.242	Road	Data by GPS Survey	8.337	0.095
1	455915.718	6435912.081	142	3.972	Road	Data by GPS Survey	4.117	0.145
1	456011.873	6436003.429	143	4.027	Road	Data by GPS Survey	4.133	0.106
1	455974.913	6436356.891	144	2.097	Road	Data by GPS Survey	1.876	-0.221
1	456105.127	6436080.631	145	7.002	Road	Data by GPS Survey	6.494	-0.508
1	456100.097	6435873.973	146	8.891	Road	Data by GPS Survey	8.924	0.033

1	456341.896	6436198.165	147	4.936	Road	Data by GPS Survey	4.778	-0.158
1	456361.227	6436387.062	148	3.633	Road	Data by GPS Survey	3.614	-0.019
1	456631.869	6436570.346	149	13.060	Road	Data by GPS Survey	12.545	-0.515
1	456746.820	6436466.167	150	24.912	Road	Data by GPS Survey	24.539	-0.373
1	456814.766	6436423.613	151	34.573	Road	Data by GPS Survey	34.602	0.029
1	456496.817	6436314.848	152	7.058	Road	Data by GPS Survey	7.179	0.121
1	456361.724	6435787.244	153	5.541	Road	Data by GPS Survey	5.483	-0.058
1	456637.755	6436168.216	154	10.475	Road	Data by GPS Survey	10.155	-0.320
1	456641.939	6435885.825	155	6.539	Road	Data by GPS Survey	6.329	-0.210
1	457267.353	6435933.962	156	33.136	Road	Data by GPS Survey	33.129	-0.007
1	457254.547	6435736.960	157	18.143	Road	Data by GPS Survey	18.064	-0.079
1	457657.494	6435676.285	158	27.672	Road	Data by GPS Survey	27.232	-0.440
1	457968.701	6435225.963	159	22.972	Road	Data by GPS Survey	22.896	-0.076
1	458383.375	6435613.579	160	147.314	Road	Data by GPS Survey	147.209	-0.105
1	454708.873	6439448.620	161	4.533	Road	Data by GPS Survey	4.435	-0.098
1	455252.019	6439356.525	162	5.667	Road	Data by GPS Survey	5.797	0.130
1	455360.383	6439202.553	163	5.092	Road	Data by GPS Survey	4.978	-0.114
1	455557.344	6439176.056	164	8.581	Road	Data by GPS Survey	8.207	-0.374
1	455596.942	6439366.418	165	26.712	Road	Data by GPS Survey	26.385	-0.327
1	456013.505	6439253.544	166	54.205	Road	Data by GPS Survey	53.445	-0.760
1	455663.213	6439106.681	167	19.086	Road	Data by GPS Survey	19.058	-0.028
1	455938.979	6439070.676	168	13.159	Road	Data by GPS Survey	13.441	0.282
1	456130.739	6439036.409	169	12.988	Road	Data by GPS Survey	12.840	-0.148
1	456104.900	6438878.259	170	5.816	Road	Data by GPS Survey	5.726	-0.090
1	455694.849	6438997.050	171	14.659	Road	Data by GPS Survey	14.488	-0.171
1	455524.729	6438939.875	172	5.496	Road	Data by GPS Survey	4.948	-0.548
1	455212.030	6439069.884	173	4.283	Road	Data by GPS Survey	4.155	-0.128
1	456163.374	6437776.611	174	27.894	PM43499	Data by GPS Survey	29.113	1.219
1	455626.024	6438320.098	175	47.243	SSM68352	Data by GPS Survey	47.469	0.226
1	455459.691	6438188.536	176	48.693	SSM63742	Data by GPS Survey	49.449	0.756
2	452881.479	6439498.216	23	1.508	Road	Data by GPS Survey	1.592	0.084
2	452961.830	6439391.304	24	1.360	Road	Data by GPS Survey	1.402	0.042
2	452451.850	6439136.054	25	1.158	Road	Data by GPS Survey	1.210	0.052
2	451957.511	6439023.826	26	0.677	Road	Data by GPS Survey	0.786	0.109
2	452343.058	6439309.052	27	0.936	Road	Data by GPS Survey	1.018	0.082
2	452756.284	6439585.380	28	1.705	Road	Data by GPS Survey	1.783	0.078
2	451970.330	6439717.418	29	1.536	Road	Data by GPS Survey	1.553	0.017
2	451958.112	6439723.147	30	1.413	PM48479	Data by GPS Survey	1.758	0.345
2	451258.489	6439532.169	31	1.633	Road	Data by GPS Survey	1.792	0.159
2	452621.903	6439795.494	32	2.263	Road	Data by GPS Survey	2.315	0.052
2	452410.086	6440075.716	33	4.630	PM15001	Data by GPS Survey	5.050	0.420
2	451783.497	6440177.003	34	4.220	Road	Data by GPS Survey	4.249	0.029
2	451474.440	6440237.559	35	2.289	Road	Data by GPS Survey	2.330	0.041
2	451499.661	6440327.604	36	2.311	PM48472	Data by GPS Survey	2.688	0.377
2	451548.313	6440691.219	37	3.159	Road	Data by GPS Survey	3.139	-0.020
2	451251.290	6440746.197	38	1.382	Road	Data by GPS Survey	1.425	0.043
2	451770.772	6440620.779	39	4.638	Road	Data by GPS Survey	4.548	-0.090
2	452056.624	6440376.643	40	5.937	Road	Data by GPS Survey	5.946	0.009
2	452346.192	6440494.500	41	6.075	Road	Data by GPS Survey	6.067	-0.008
2	452485.068	6440539.577	42	4.458	Road	Data by GPS Survey	4.446	-0.012
2	452146.418	6441078.899	43	6.268	Road	Data by GPS Survey	6.353	0.085
2	451517.035	6441172.563	44	4.965	Road	Data by GPS Survey	5.117	0.152
2	452045.232	6441316.786	45	6.442	Road	Data by GPS Survey	6.491	0.049
2	452017.651	6441551.342	46	5.223	Road	Data by GPS Survey	5.323	0.100
2	451728.443	6441621.680	47	3.729	Road	Data by GPS Survey	3.826	0.097
2	451808.572	6441841.237	48	4.379	Road	Data by GPS Survey	4.450	0.071
2	451690.804	6442071.086	49	5.178	Road	Data by GPS Survey	5.256	0.078
2	451029.391	6442184.294	50	1.614	Road	Data by GPS Survey	1.641	0.027
2	452555.648	6441555.596	51	5.282	Road	Data by GPS Survey	5.419	0.137
2	452512.364	6440850.218	52	4.567	Road	Data by GPS Survey	4.708	0.141
2	452793.364	6440724.656	53	3.458	Road	Data by GPS Survey	3.568	0.110
2	452972.451	6440938.417	54	2.599	Road	Data by GPS Survey	2.677	0.078
2	453238.995	6440655.407	55	4.354	Road	Data by GPS Survey	4.428	0.074
2	453141.534	6440176.150	56	1.864	Road	Data by GPS Survey	1.975	0.111
2	453105.627	6440098.893	57	1.367	Road	Data by GPS Survey	1.489	0.122
2	453466.112	6440228.768	58	3.024	Road	Data by GPS Survey	3.147	0.123
2	452960.030	6439977.047	59	2.654	Road	Data by GPS Survey	2.830	0.176
2	453005.035	6439969.222	60	1.127	Road	Data by GPS Survey	1.235	0.108
2	452986.251	6439834.574	61	1.431	Road	Data by GPS Survey	1.505	0.074
2	451637.144	6442817.001	5007	2.732	PM57582	Control Data from SCIMS	3.188	0.456
2	451853.820	6443553.950	5008	5.254	SSM13832	Control Data from SCIMS	5.641	0.387
2	452060.666	6443729.225	5009	6.194	SSM13646	Control Data from SCIMS	5.997	-0.197
2	452410.251	6440075.873	5020	4.659	PM15001	Control Data from SCIMS	5.050	0.391
2	451362.756	6440241.944	5021	2.185	PM46270	Control Data from SCIMS	2.808	0.623
2	451830.986	6440460.466	5022	4.662	PM48471	Control Data from SCIMS	4.950	0.288
2	451499.465	6440327.781	5023	2.294	PM48472	Control Data from SCIMS	2.688	0.394
2	451958.112	6439723.147	5024	1.402	PM48479	Control Data from SCIMS	1.758	0.356

3	454328.431	6431780.890	81	25.727	Road	Data by GPS Survey	25.921	0.194
3	454196.223	6432071.673	82	19.143	Road	Data by GPS Survey	19.274	0.131
3	454091.329	6432462.329	83	3.499	Road	Data by GPS Survey	3.863	0.364
3	454585.927	6431596.201	84	15.017	PM76362	Data by GPS Survey	15.323	0.306
3	454766.986	6431657.369	85	3.852	SSM48614	Data by GPS Survey	4.175	0.323
3	454776.449	6431595.618	86	5.836	Road	Data by GPS Survey	6.058	0.222
3	456270.776	6431335.675	87	9.273	Road	Data by GPS Survey	9.420	0.147
3	454585.818	6431596.181	5010	15.020	PM76362	Control Data from SCIMS	15.323	0.303
3	454766.986	6431657.369	5011	3.850	SSM48614	Control Data from SCIMS	4.175	0.325
4	456688.663	6420814.253	116	20.520	Station	Data by GPS Survey	17.619	-0.417
4	456688.663	6420814.253	117	20.520	Station	Data by GPS Survey	17.619	-0.417
4	456545.674	6420838.463	118	17.614	Road	Data by GPS Survey	15.341	0.211
4	456303.791	6420498.461	119	18.273	Road	Data by GPS Survey	15.717	-0.072
4	456057.184	6420050.630	120	24.791	Road	Data by GPS Survey	22.226	-0.081
4	456047.718	6420050.905	121	24.547	SSM12339	Data by GPS Survey	22.880	0.817
4	456152.298	6420385.002	122	7.671	Road	Data by GPS Survey	5.328	0.141
4	456496.788	6420902.497	123	18.167	Road	Data by GPS Survey	15.559	-0.124
4	455984.843	6421271.453	124	9.390	Road	Data by GPS Survey	7.003	0.097
4	456756.217	6420876.592	125	43.776	Road	Data by GPS Survey	40.941	-0.351
4	456404.153	6421026.835	126	41.087	Road	Data by GPS Survey	38.399	-0.204
4	456467.022	6421135.815	127	9.135	Road	Data by GPS Survey	6.724	0.073
4	456565.161	6421467.236	128	20.200	Road	Data by GPS Survey	17.793	0.077
4	456833.494	6421702.159	129	10.796	Road	Data by GPS Survey	8.074	-0.238
4	456795.594	6422321.929	130	8.051	Road	Data by GPS Survey	5.706	0.139
4	457065.587	6422134.777	131	19.869	Road	Data by GPS Survey	17.393	0.008
4	457166.718	6422251.094	132	11.932	Road	Data by GPS Survey	9.093	-0.355
4	455867.851	6422219.106	133	39.855	Road	Data by GPS Survey	37.325	-0.046
4	456945.629	6421967.142	134	23.621	Road	Data by GPS Survey	21.253	0.116
4	457052.242	6422289.954	135	10.344	Road	Data by GPS Survey	7.968	0.108
4	456926.900	6421773.879	136	12.985	Road	Data by GPS Survey	10.958	0.457
4	457081.034	6422038.986	137	13.050	Road	Data by GPS Survey	10.802	0.236
4	456705.465	6421141.092	138	11.530	SSM90325	Data by GPS Survey	9.276	0.230
4	456344.363	6420884.131	139	13.344	SSM78733	Data by GPS Survey	10.703	-0.157
5	441157.305	6448250.773	177	8.774	Station	Data by GPS Survey	9.113	0.339
5	441927.055	6448086.146	178	8.647	Road	Data by GPS Survey	8.816	0.169
5	441690.756	6448402.474	179	7.689	Road	Data by GPS Survey	7.930	0.241
5	441809.078	6448492.876	180	7.415	Road	Data by GPS Survey	7.718	0.303
5	442133.425	6448056.379	181	6.808	Road	Data by GPS Survey	7.073	0.265
5	441689.520	6448669.350	182	9.951	Road	Data by GPS Survey	10.199	0.248
5	442244.715	6449051.996	183	9.834	Road	Data by GPS Survey	10.014	0.180
5	442452.443	6448787.203	184	22.501	Road	Data by GPS Survey	22.814	0.313
5	442530.370	6449064.116	185	11.761	Road	Data by GPS Survey	12.018	0.257
5	441361.203	6448492.761	186	7.411	Road	Data by GPS Survey	7.673	0.262
5	441286.595	6448460.652	187	7.650	Road	Data by GPS Survey	7.926	0.276
5	440854.714	6448496.089	188	9.490	Road	Data by GPS Survey	9.744	0.254
5	440986.899	6448699.493	189	8.767	Road	Data by GPS Survey	9.040	0.273
5	440960.385	6448544.017	190	8.854	Road	Data by GPS Survey	9.075	0.221
5	441091.972	6448495.882	191	8.322	Road	Data by GPS Survey	8.580	0.258
5	441270.398	6448460.756	192	7.936	SSM10246	Data by GPS Survey	8.087	0.151
5	441373.621	6448442.501	193	6.568	PM86763	Data by GPS Survey	7.003	0.435
5	441373.659	6448442.522	5012	6.750	PM73915	Control Data from SCIMS	7.003	0.253
5	441597.866	6448605.752	5013	10.257	PM76378	Control Data from SCIMS	10.575	0.318
5	441524.038	6448861.992	5014	15.459	SSM33160	Control Data from SCIMS	15.592	0.133
5	441270.398	6448460.756	5015	7.936	SSM10246	Control Data from SCIMS	8.087	0.151
6	447462.536	6429717.978	204	3.720	Station	Data by GPS Survey	4.136	0.416
6	447454.919	6429716.185	205	4.431	Centre Road	Data by GPS Survey	4.555	0.124
6	450645.689	6427213.425	206	4.652	Centre Road	Data by GPS Survey	4.748	0.096
6	449728.046	6427792.727	207	1.731	Centre Road	Data by GPS Survey	1.833	0.102
6	448719.868	6428081.675	208	3.935	Centre Road	Data by GPS Survey	4.090	0.155
6	447906.432	6428237.238	209	14.966	Centre Road	Data by GPS Survey	15.128	0.162
6	447229.338	6428842.335	210	9.750	Centre Road	Data by GPS Survey	9.847	0.097
6	447595.738	6430164.592	211	3.039	Centre Road	Data by GPS Survey	3.133	0.094
6	448147.137	6430711.802	212	1.593	Centre Road	Data by GPS Survey	1.774	0.181
6	448632.347	6431136.140	213	13.988	Centre Road	Data by GPS Survey	14.139	0.151
6	449020.499	6431871.563	214	20.032	Centre Road	Data by GPS Survey	20.230	0.198
6	448493.278	6430904.013	215	17.250	Station	Data by GPS Survey	16.772	-0.478
6	449005.371	6431864.966	216	20.246	SSM65642	Data by GPS Survey	20.345	0.099
6	447986.387	6430562.434	217	1.242	PM71763	Data by GPS Survey	1.525	0.283
6	448218.368	6427965.065	218	15.560	Station	Data by GPS Survey	15.497	-0.063
6	447462.564	6429717.963	219	3.836	Station	Data by GPS Survey	4.136	0.300
6	447986.387	6430562.434	5000	1.242	PM71763	Control Data from SCIMS	1.525	0.283
6	448879.783	6432474.099	5001	46.600	SSM42339	Control Data from SCIMS	46.886	0.286
6	449005.806	6431865.493	5002	20.237	SSM65642	Control Data from SCIMS	20.481	0.244
6	449941.121	6432822.200	5003	40.853	SSM65679	Control Data from SCIMS	41.212	0.359
6	449240.281	6431028.225	5004	4.063	SSM77978	Control Data from SCIMS	4.202	0.139
6	448650.841	6431143.842	5005	13.109	SSM77979	Control Data from SCIMS	13.412	0.303

Appendix C


TUNCURRY CBD
GROUND LEVEL
N
Ground Level (mAHD)
< 0
0 - 1
1 - 1.3
1.3 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 5
0
125
250
500
750
1,000
m
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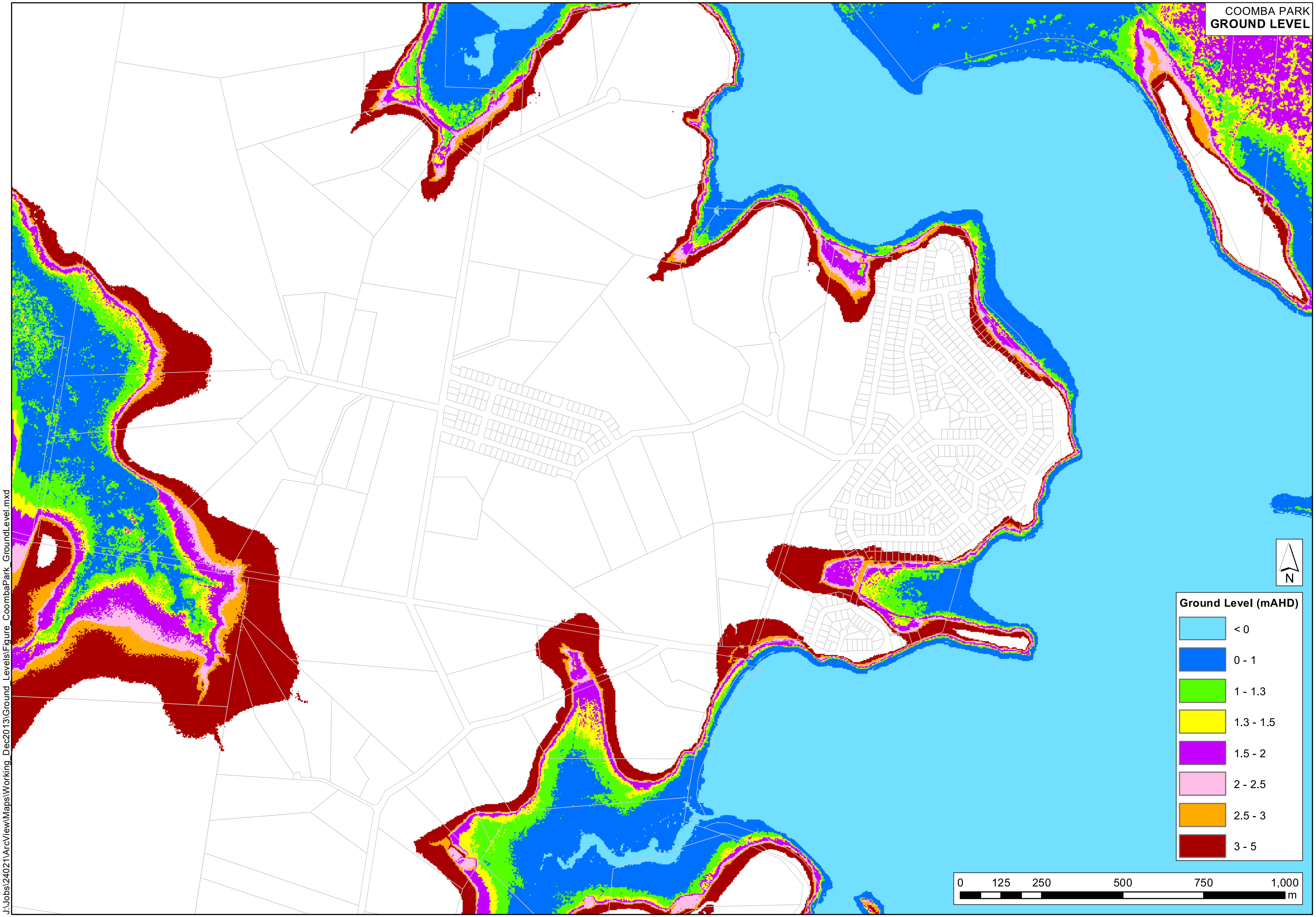

COOMBA PARK
GROUND LEVEL
N
Ground Level (mAHD)
< 0
0 - 1
1 - 1.3
1.3 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 5
0
125
250
500
750
1,000
m
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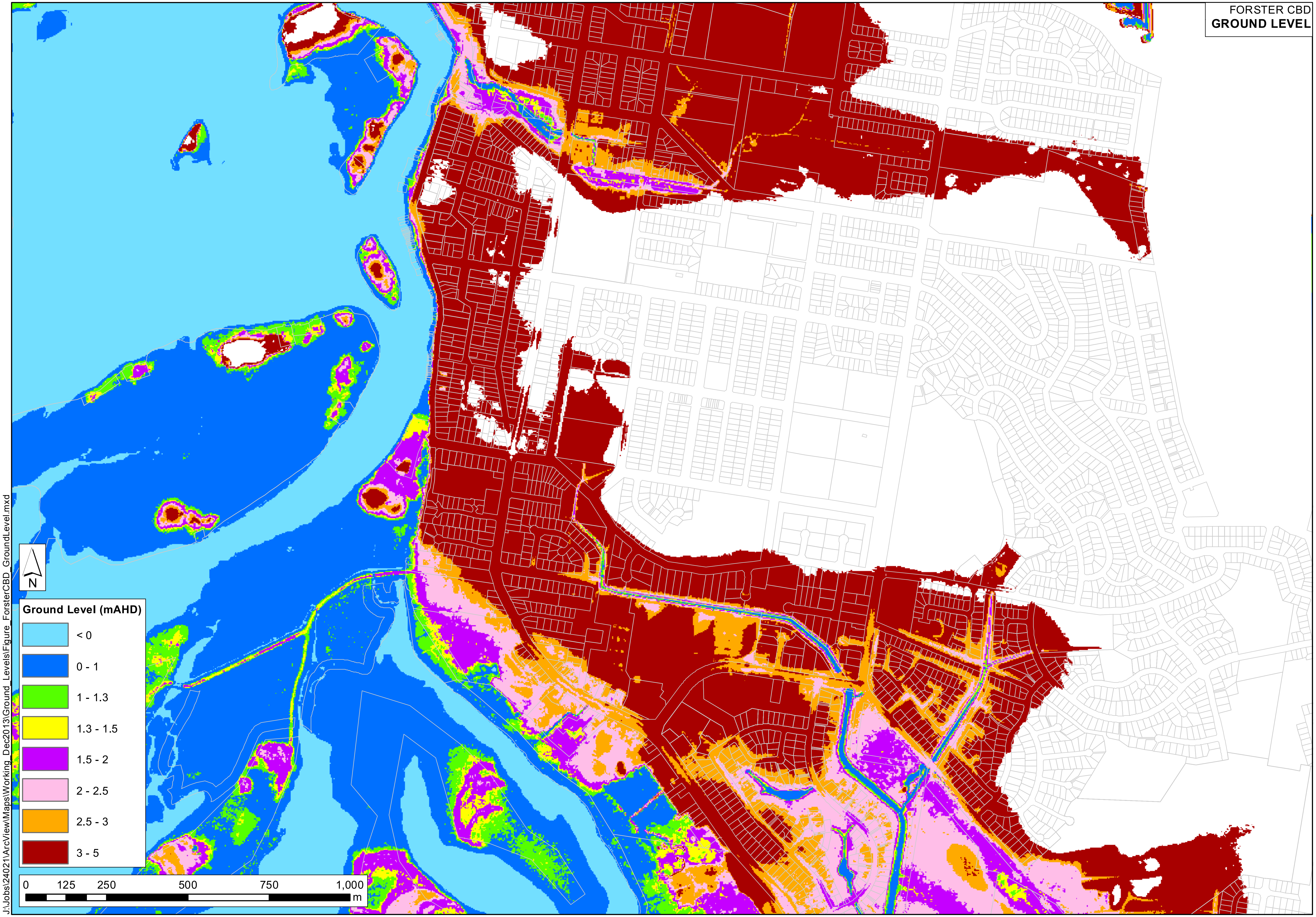

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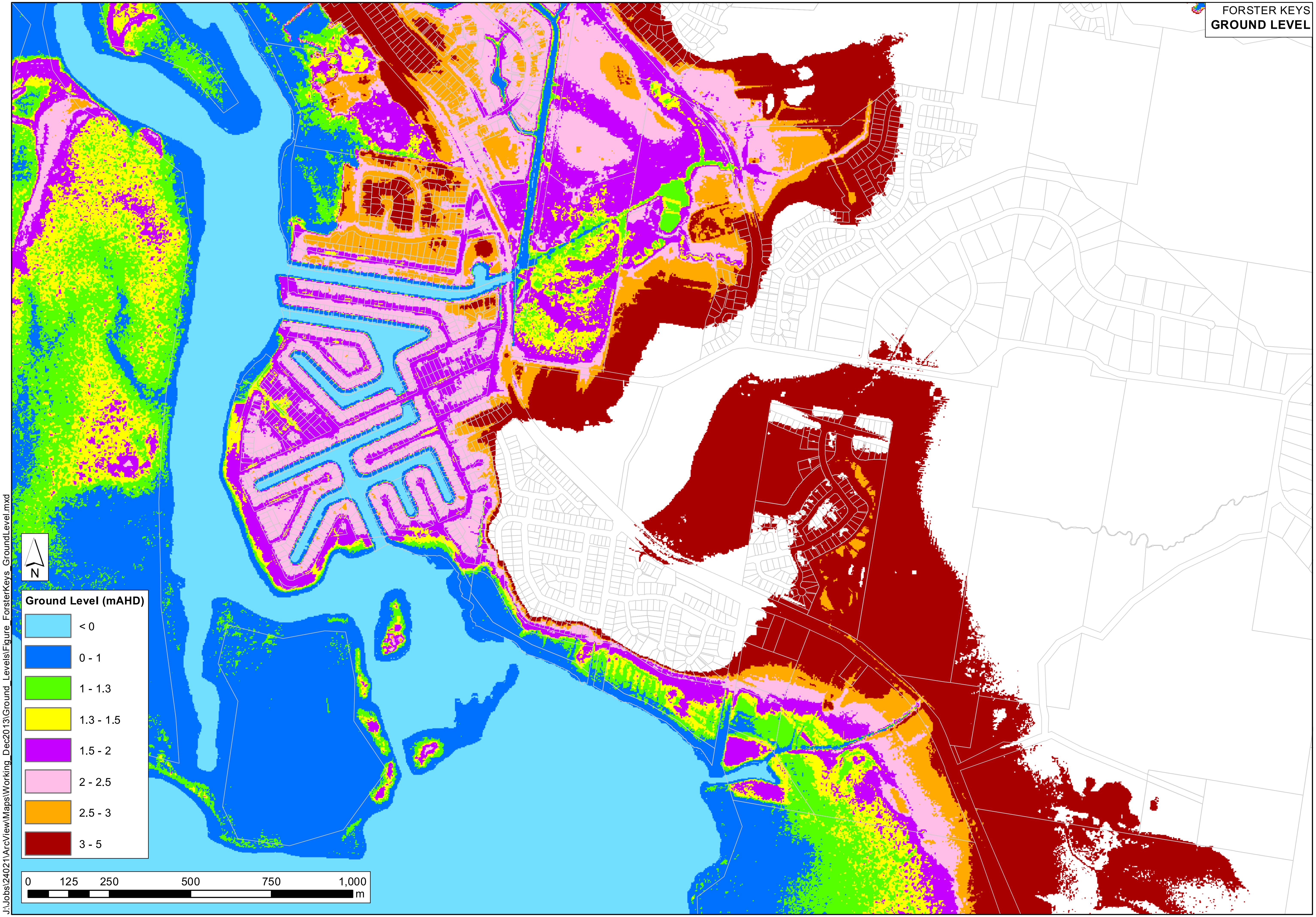

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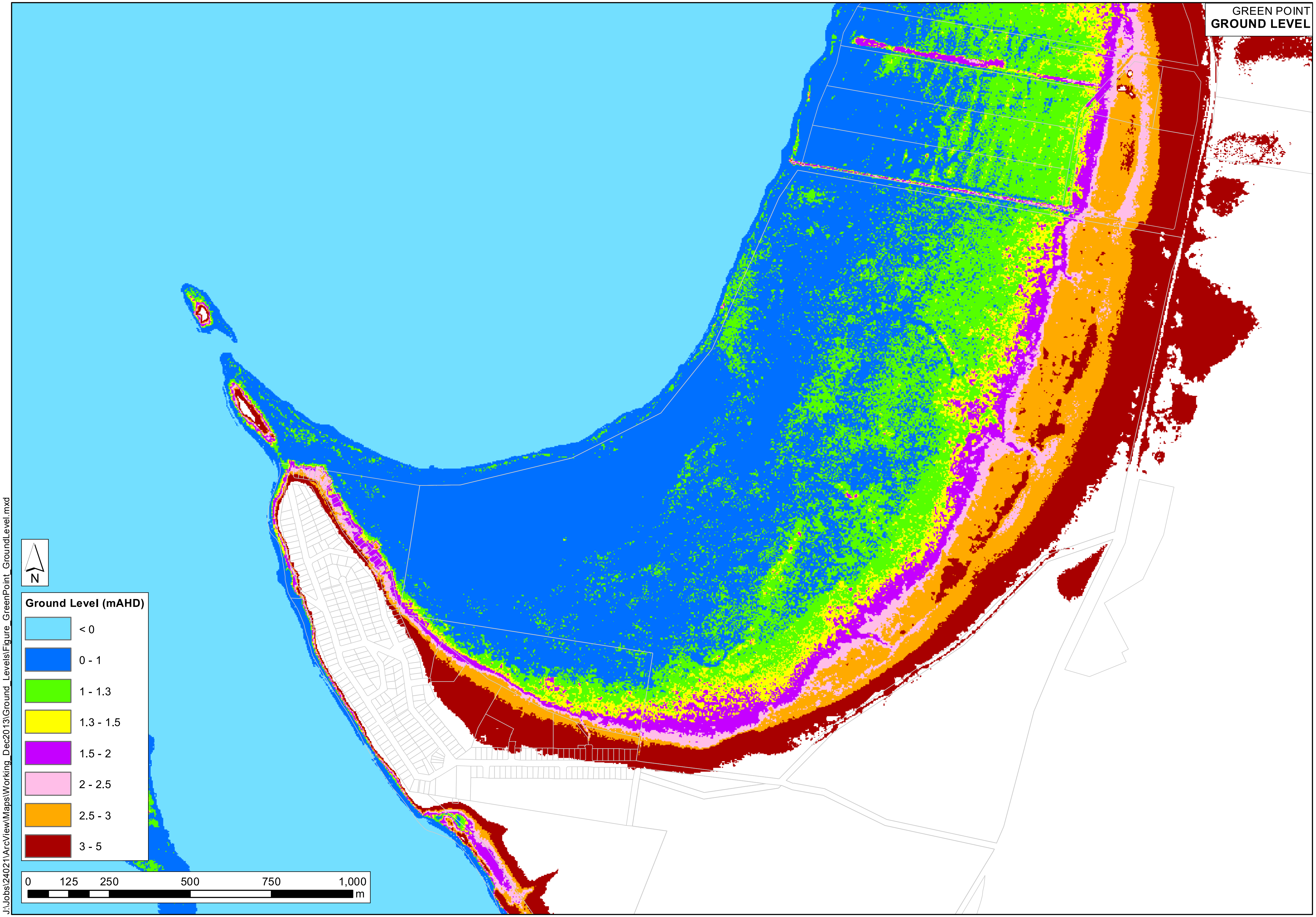

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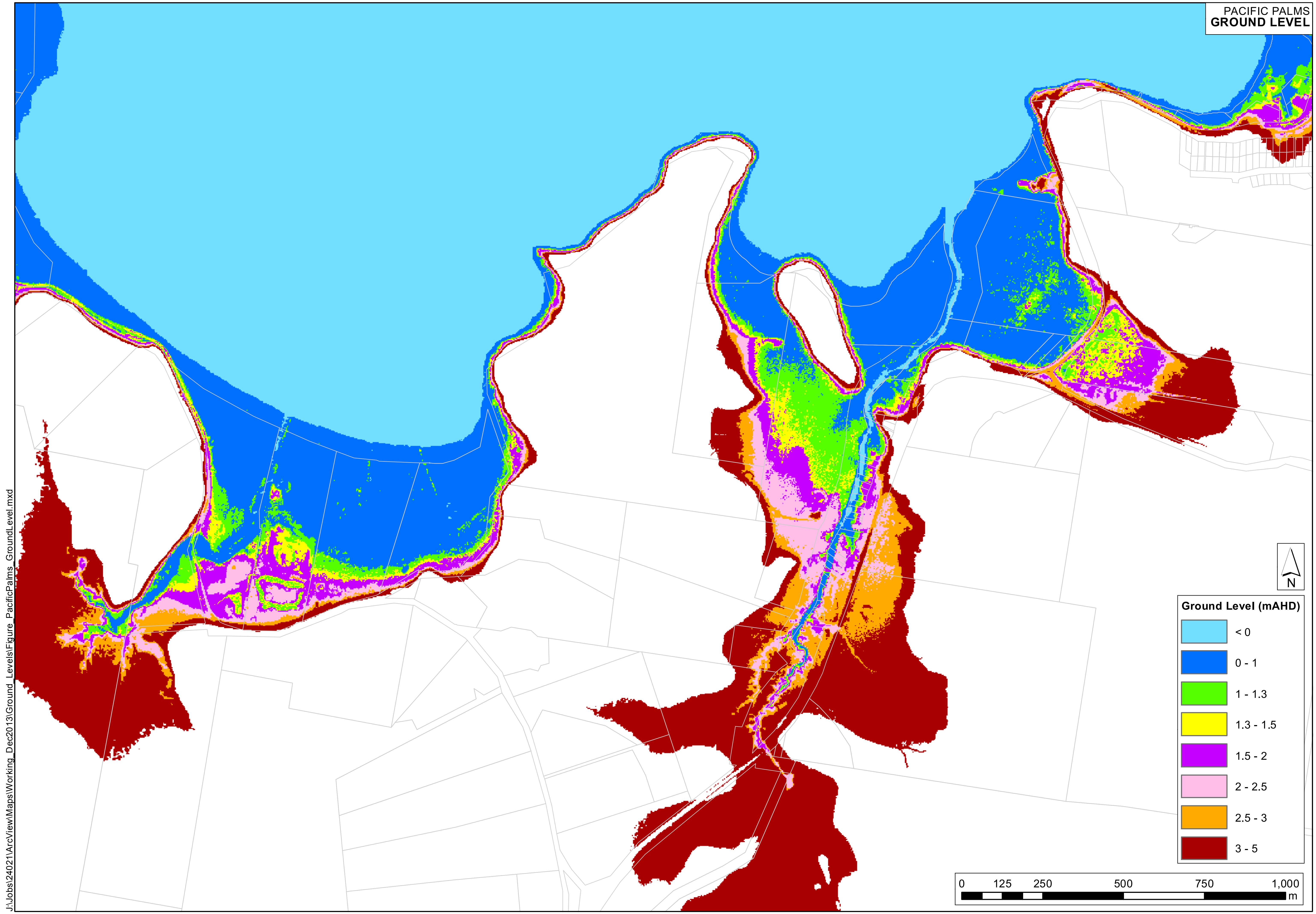
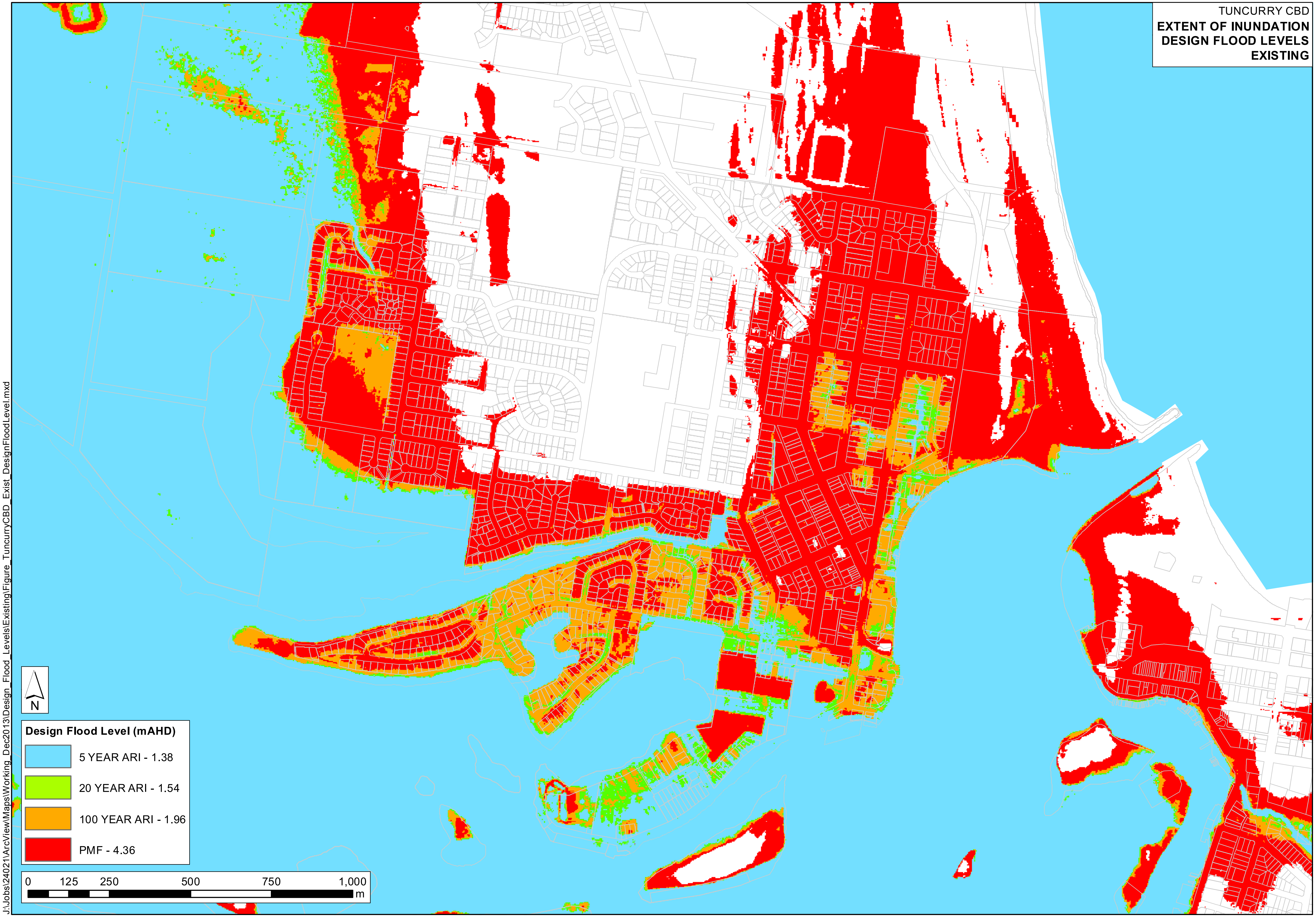

PACIFIC PALMS
GROUND LEVEL
N
Ground Level (mAHD)
< 0
0 - 1
1 - 1.3
1.3 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 5
0
125
250
500
750
1,000
m
J:\Jobs\240211\ArcView\Maps\Working_Dec2013\Ground_Levels\Figure_PacificPalms_GroundLevel.mxd



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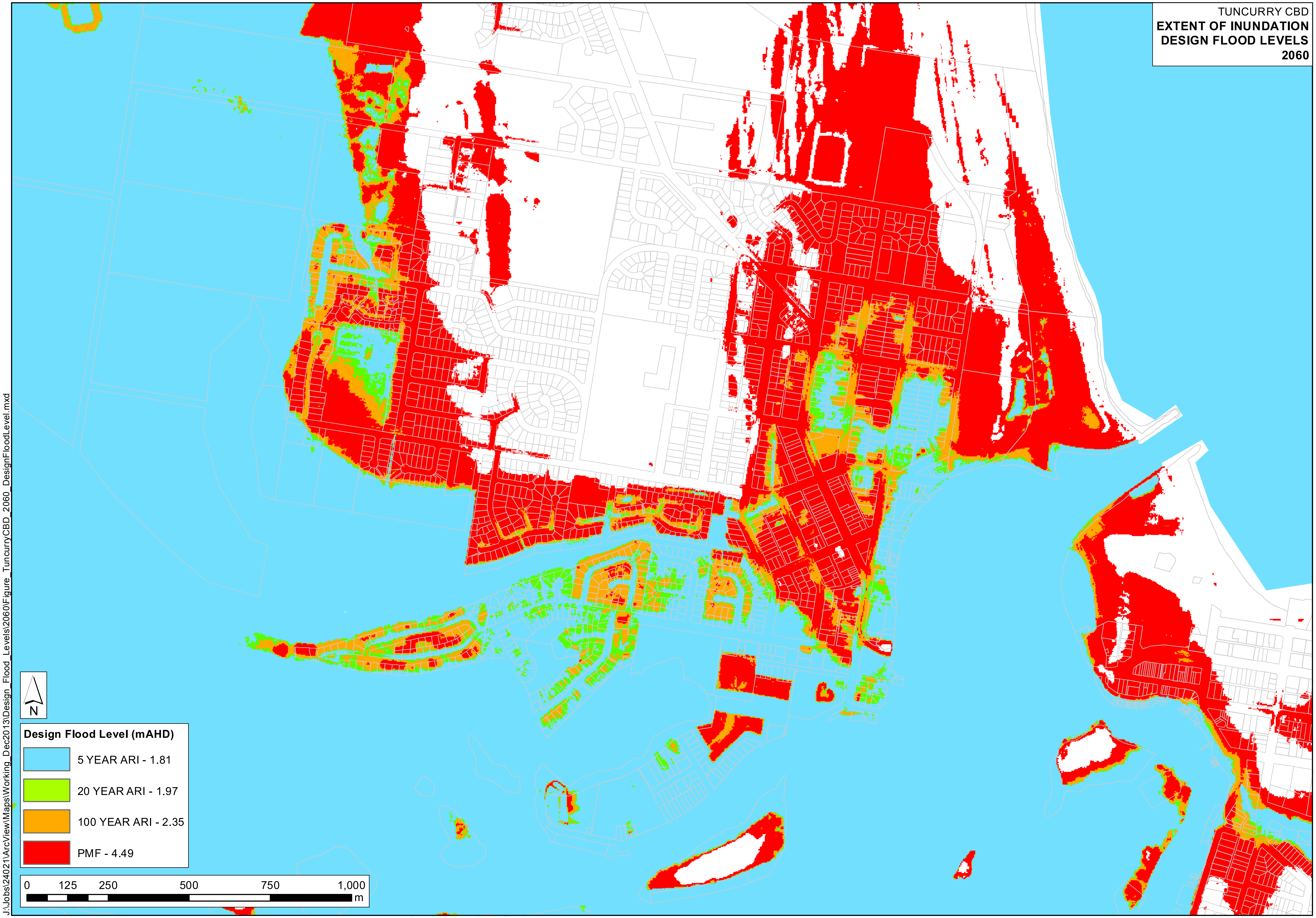
TUNCURRY CBD
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
2060
N
Design Flood Level (mAHD)
5 YEAR ARI - 1.81
20 YEAR ARI - 1.97
100 YEAR ARI - 2.35
PMF - 4.49
0
125
250
500
750
1,000
m
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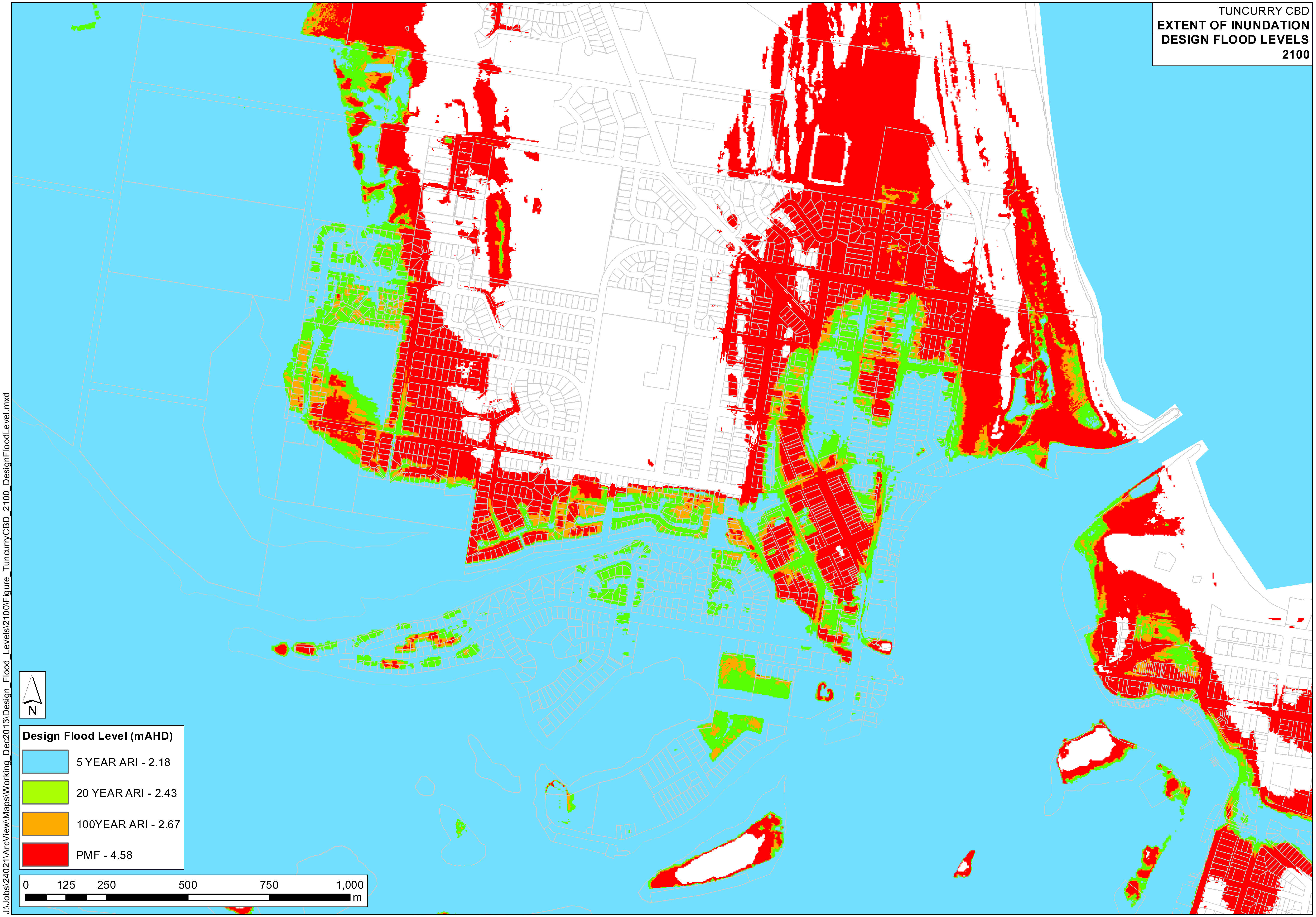
TUNCURRY CBD
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
2100
N
Design Flood Level (mAHD)
5 YEAR ARI - 2.18
20 YEAR ARI - 2.43
100YEAR ARI - 2.67
PMF - 4.58
0 125 250 500 750 1,000
m
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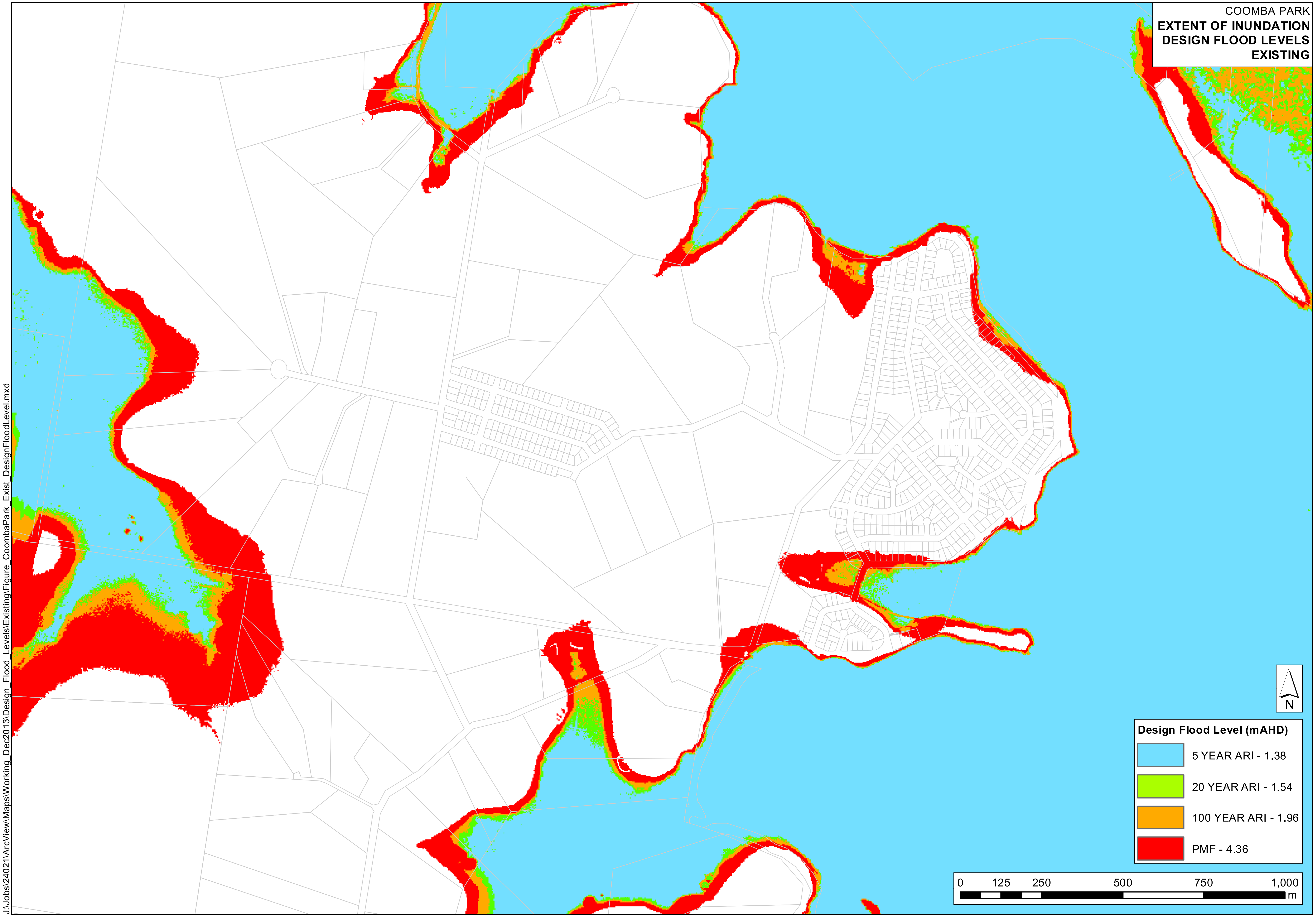

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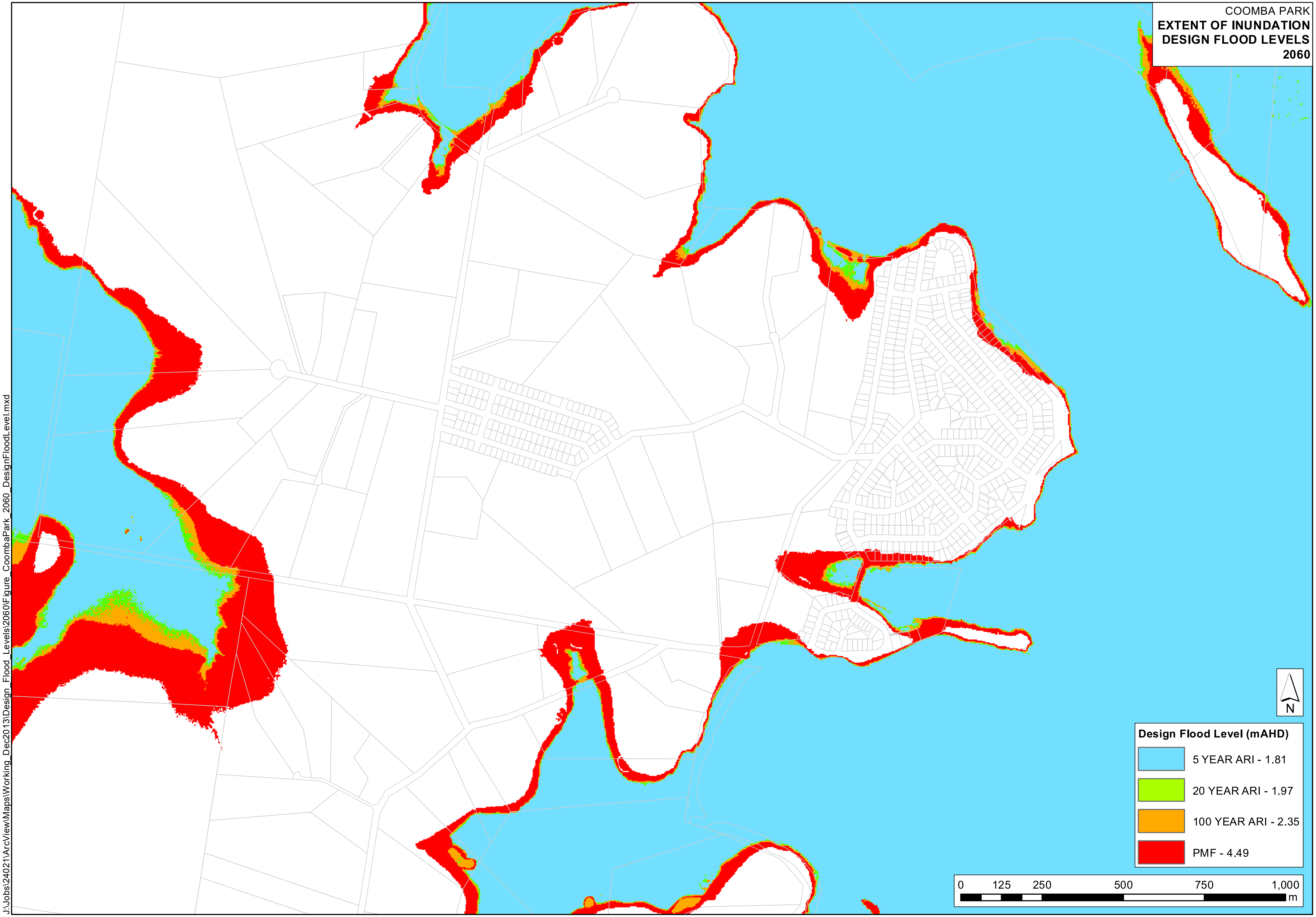

COOMBA PARK
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
2060
N
Design Flood Level (mAHD)
5 YEAR ARI - 1.81
20 YEAR ARI - 1.97
100 YEAR ARI - 2.35
PMF - 4.49
0
125
250
500
750
1,000
m
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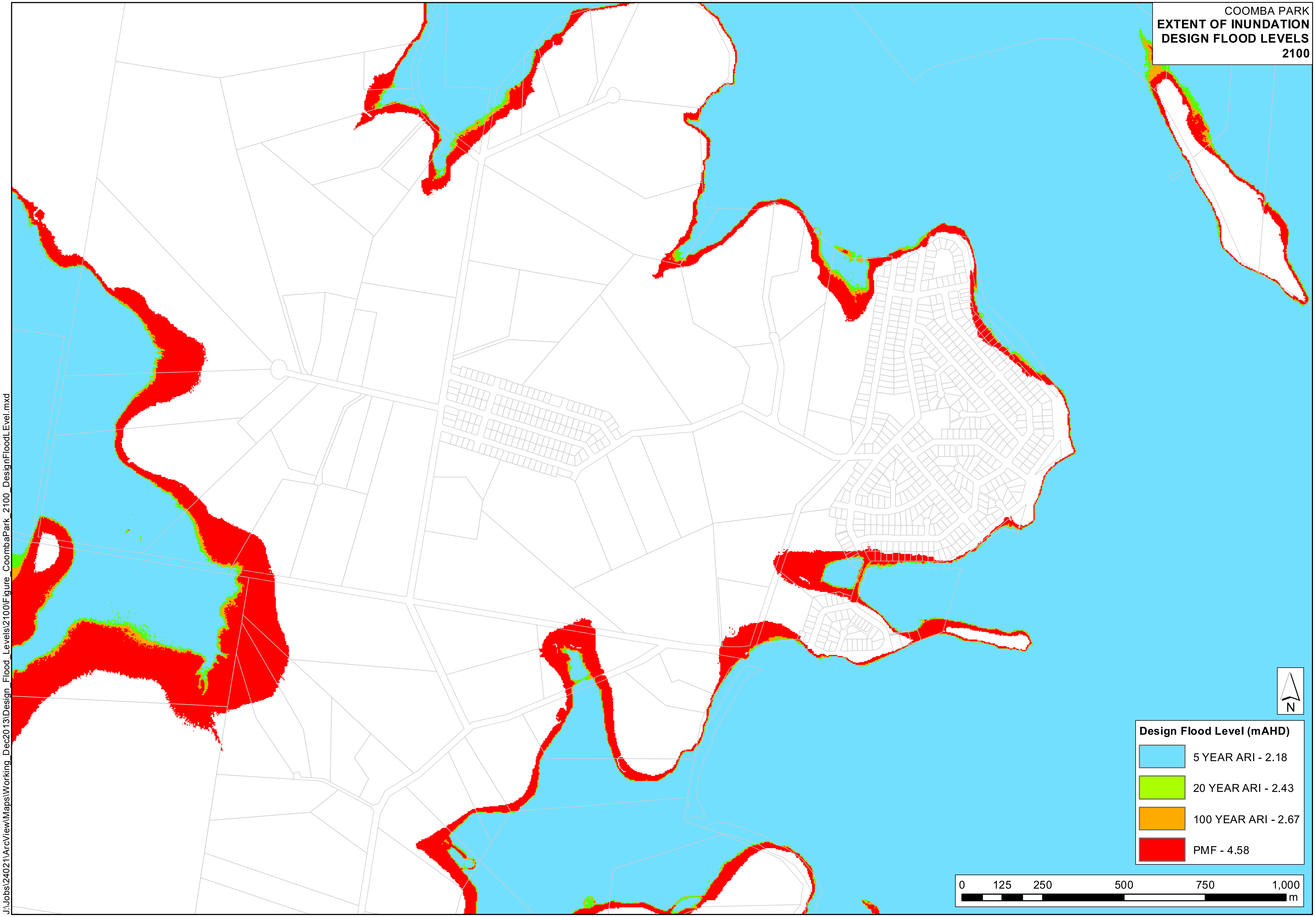

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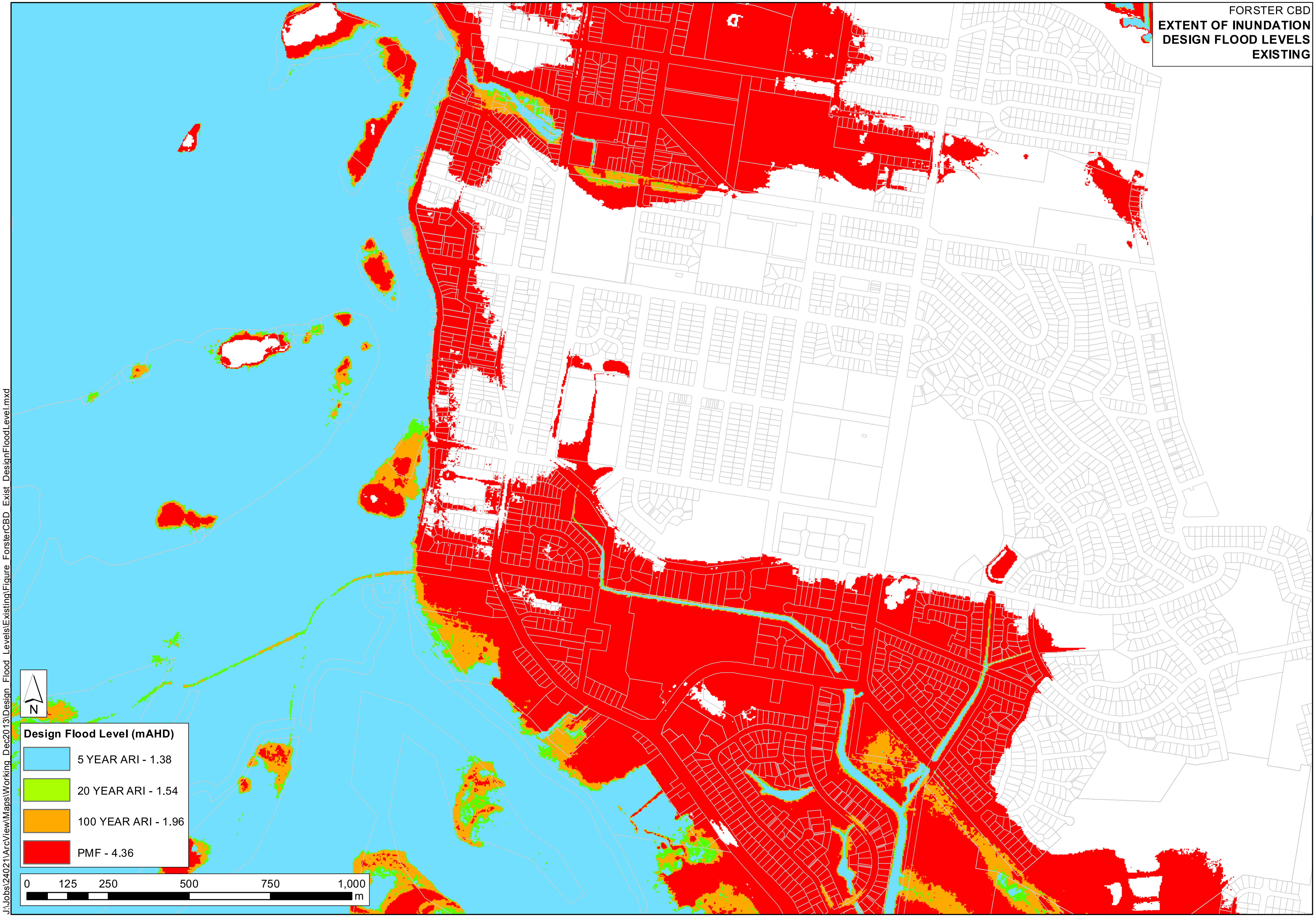

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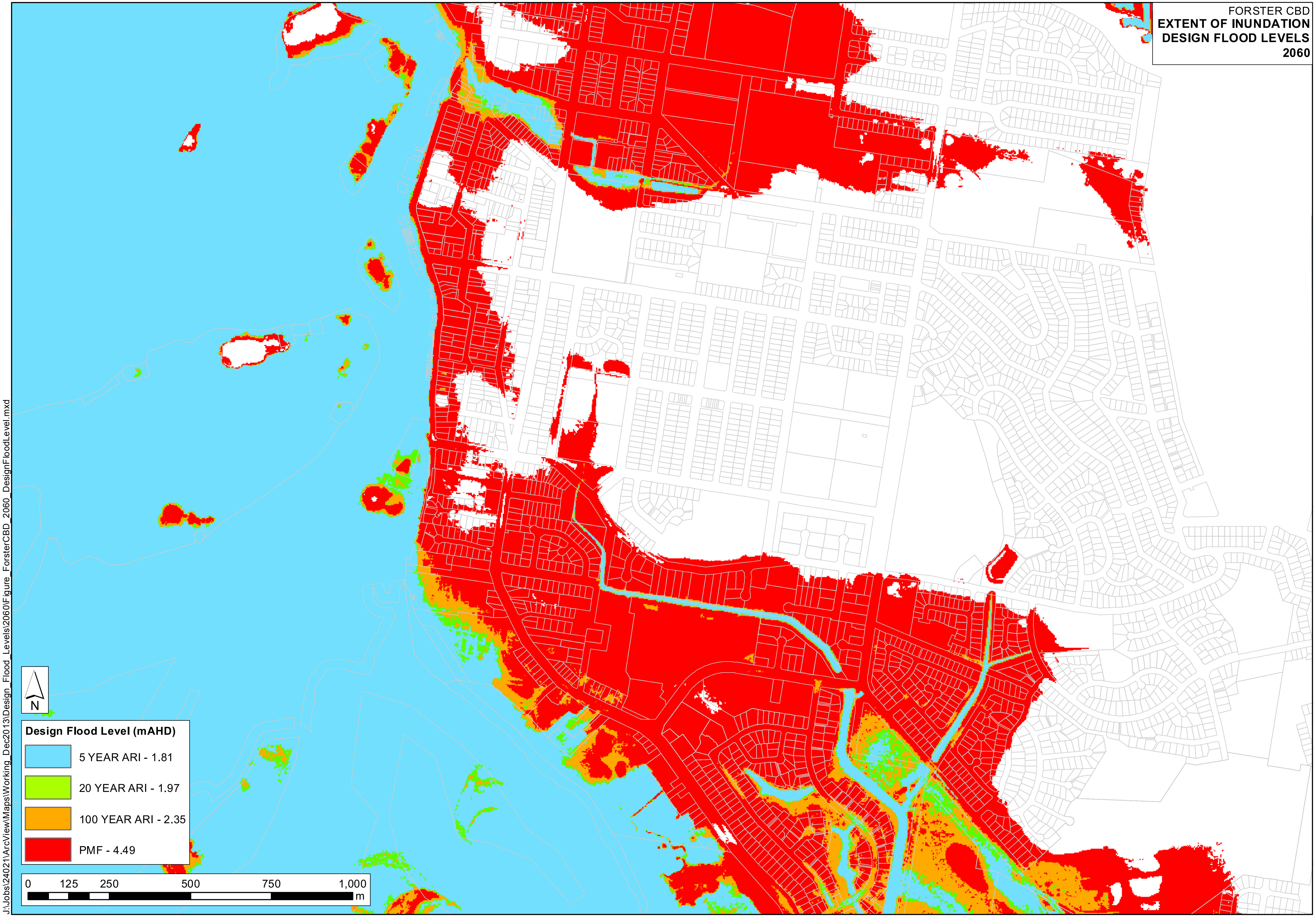

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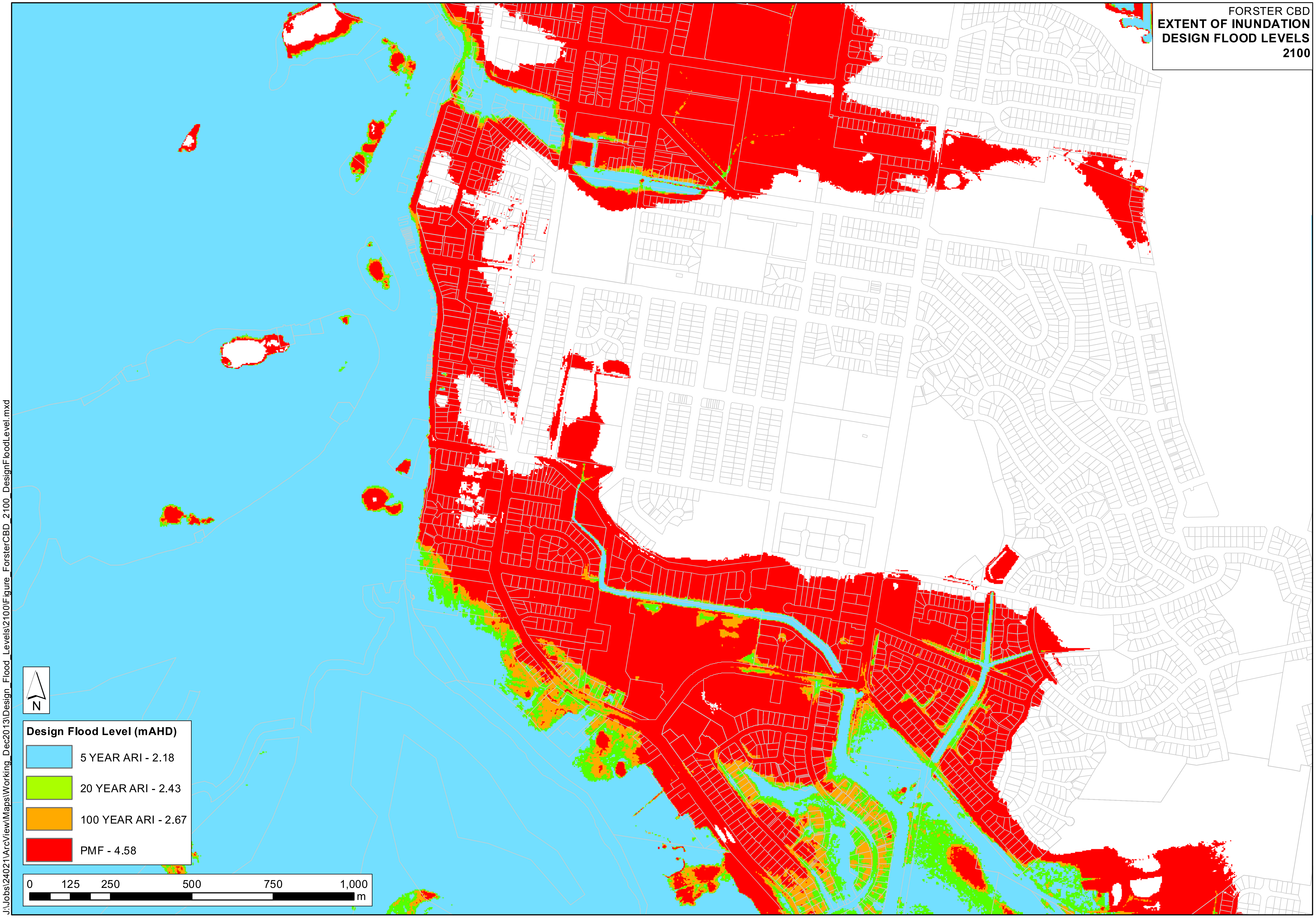

FORSTER CBD
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
2100
N
Design Flood Level (mAHD)
5 YEAR ARI - 2.18
20 YEAR ARI - 2.43
100 YEAR ARI - 2.67
PMF - 4.58
0
125
250
500
750
1,000
m
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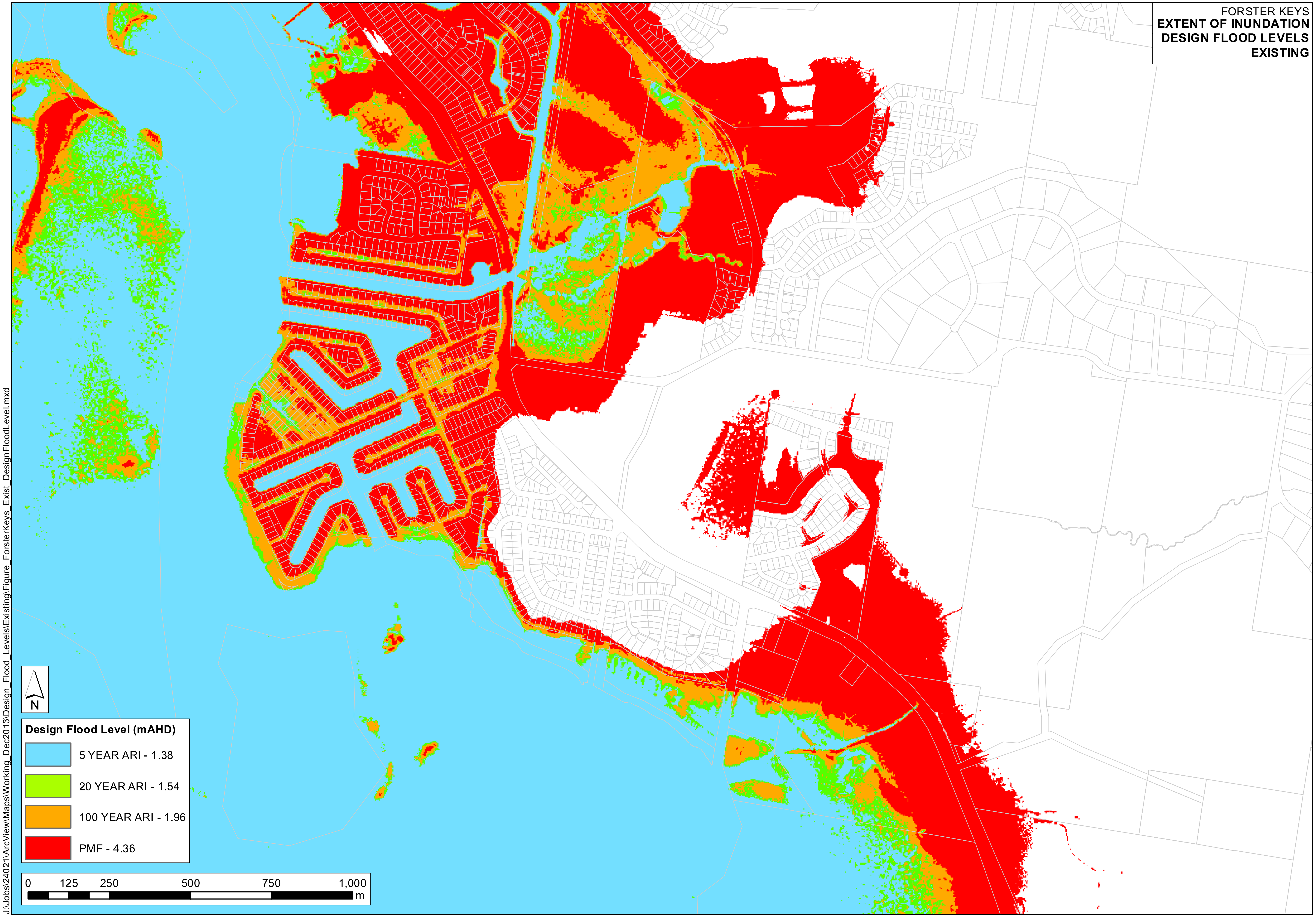

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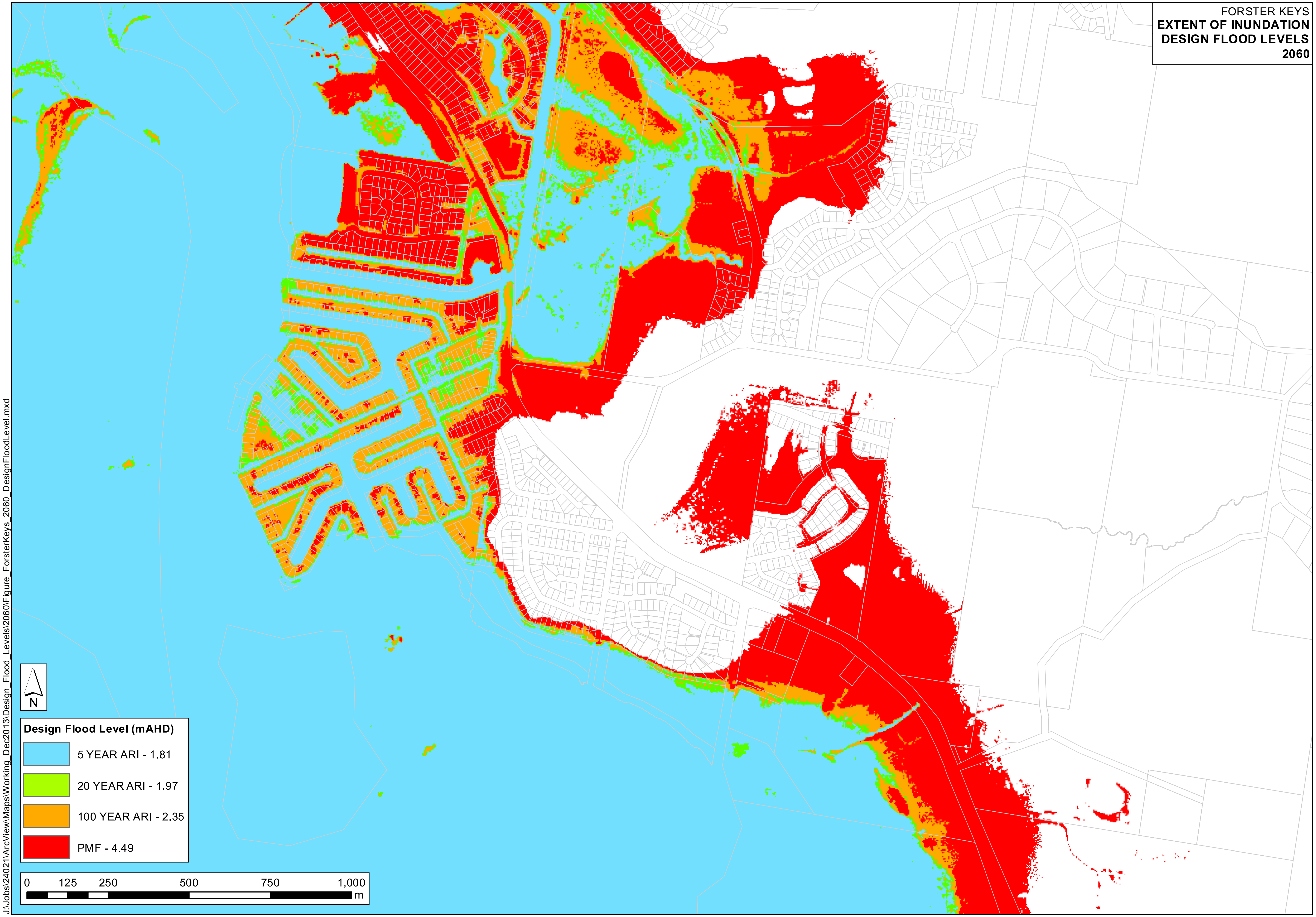

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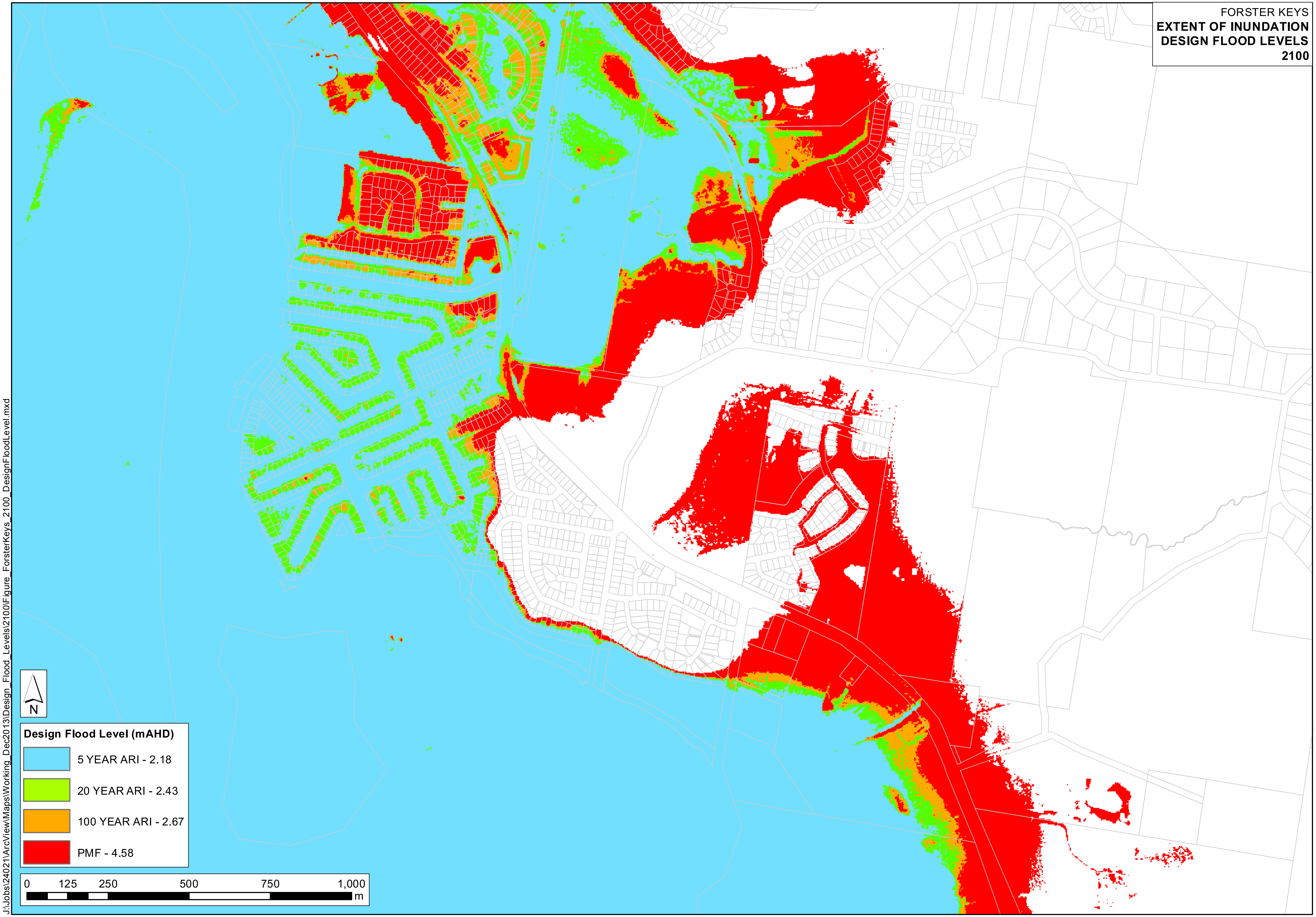

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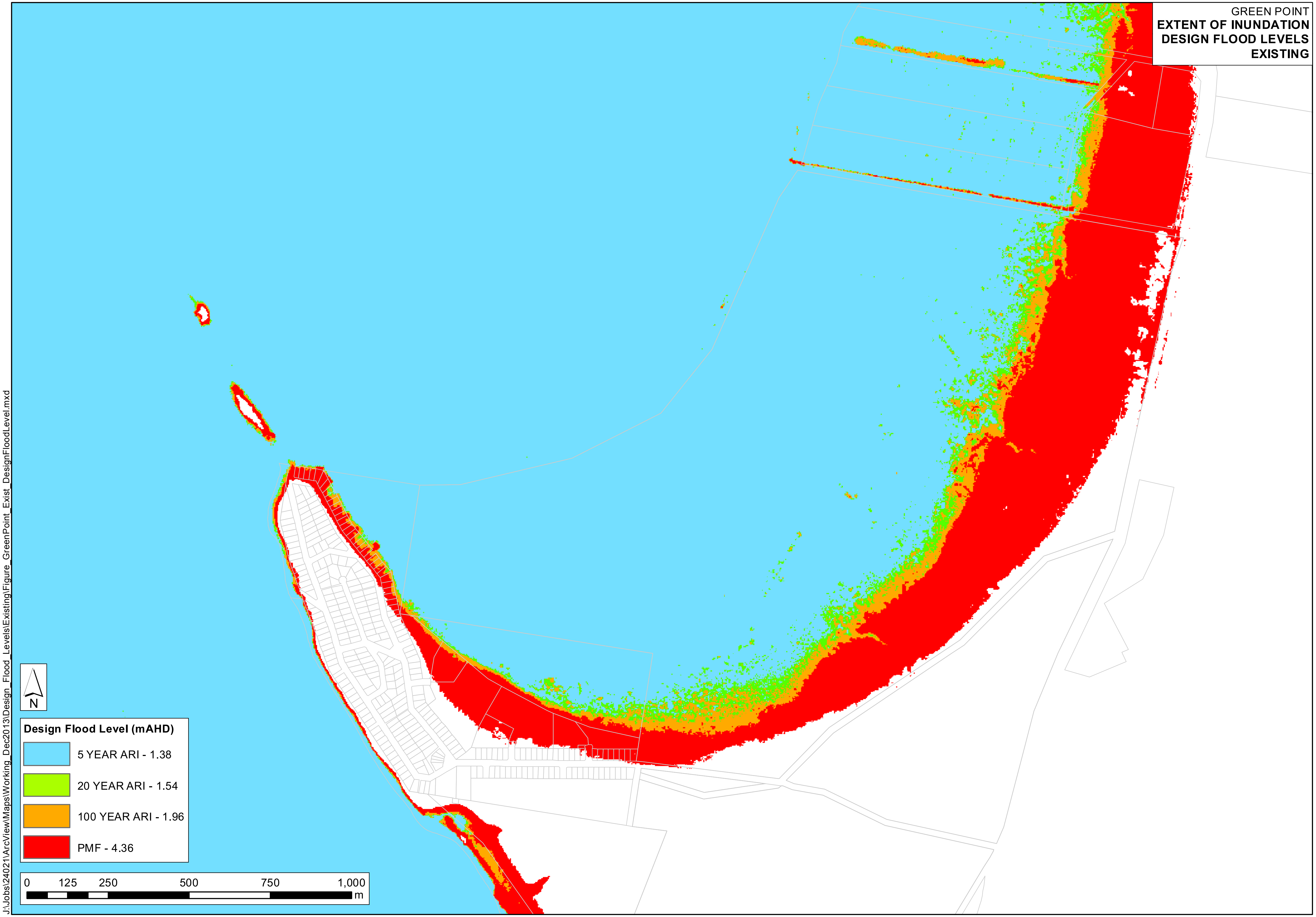

GREEN POINT
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
EXISTING
N
Design Flood Level (mAHD)
5 YEAR ARI - 1.38
20 YEAR ARI - 1.54
100 YEAR ARI - 1.96
PMF - 4.36
0
125
250
500
750
1,000
m
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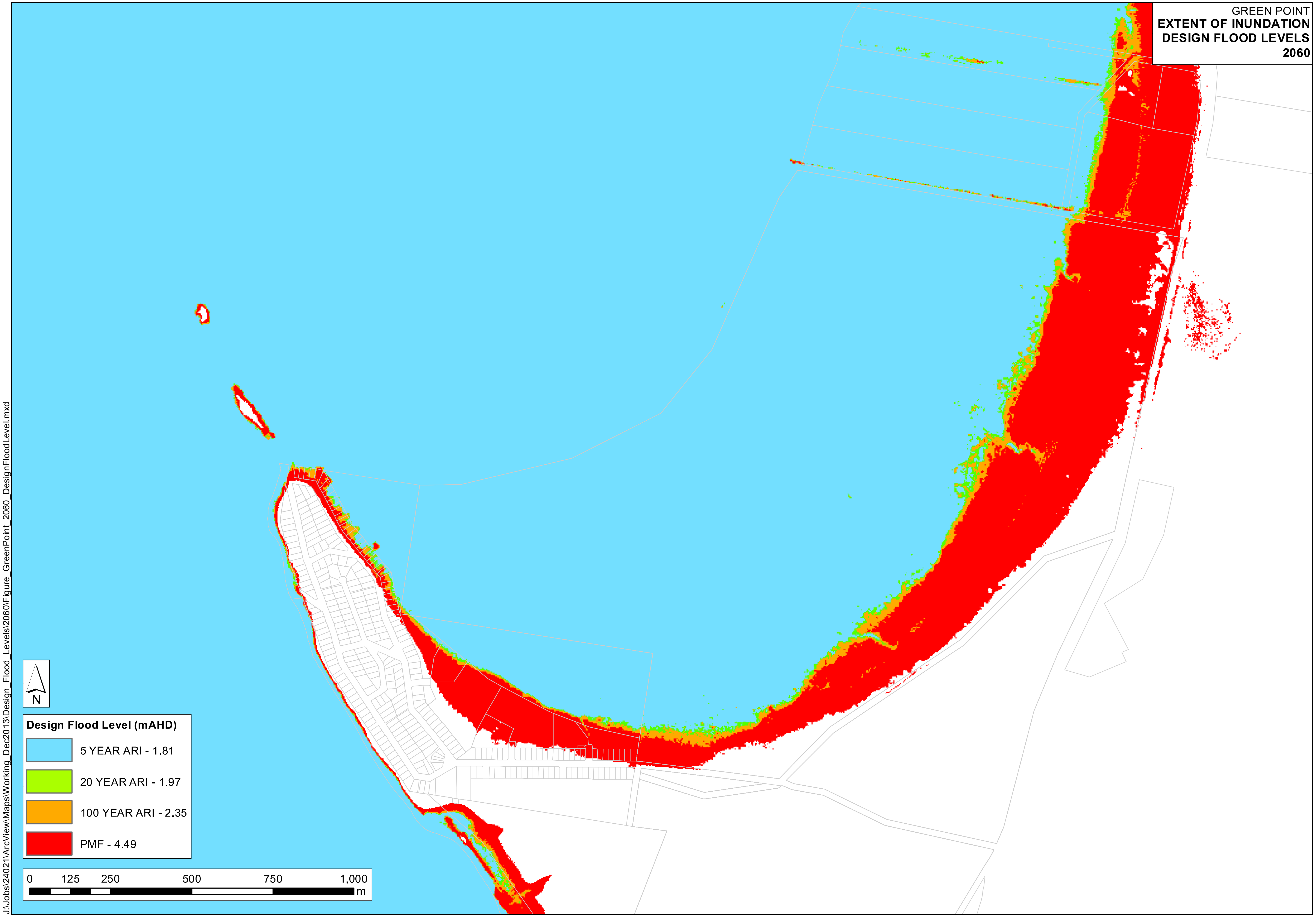

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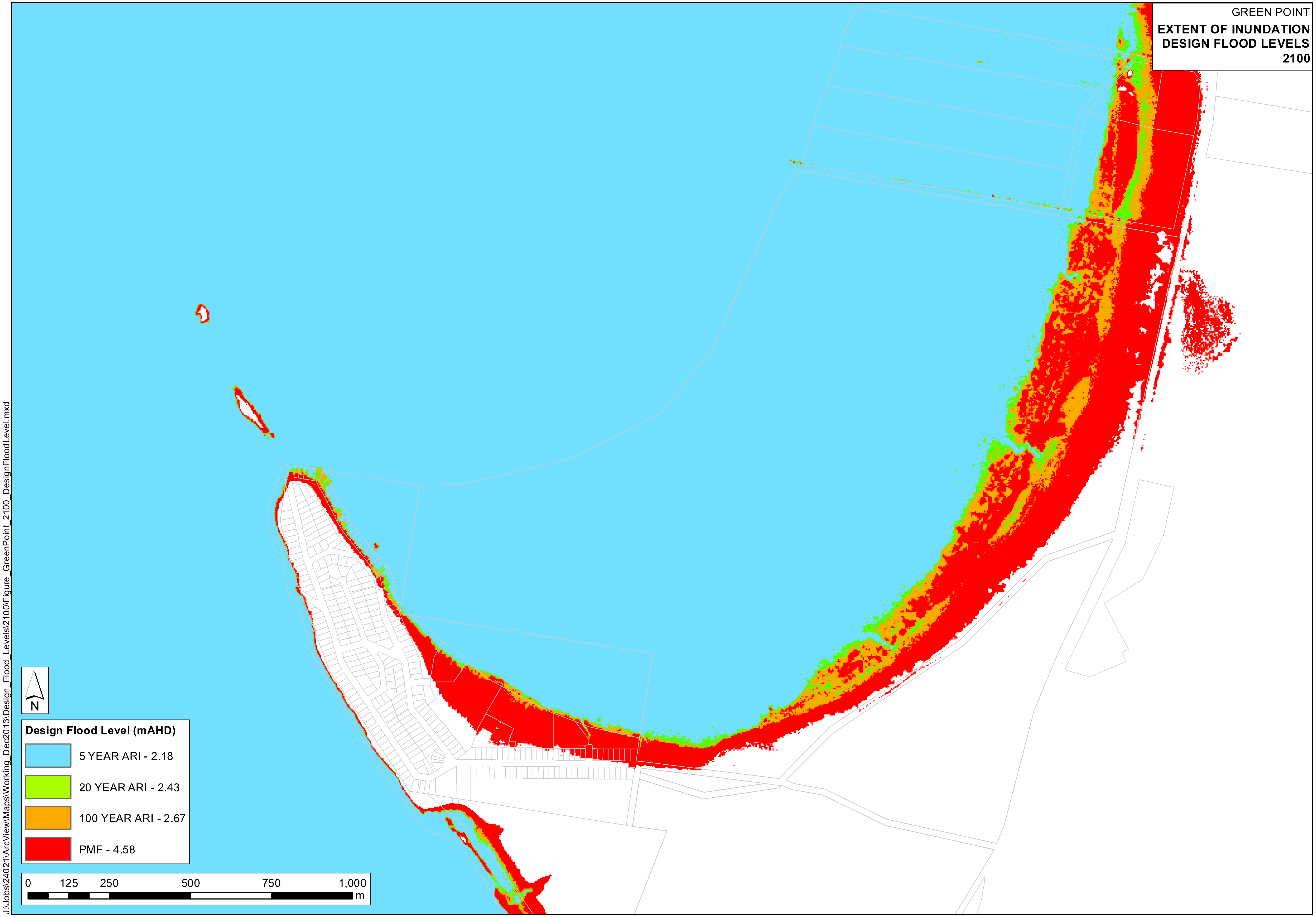
GREEN POINT
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
2100
N
Design Flood Level (mAHD)
5 YEAR ARI - 2.18
20 YEAR ARI - 2.43
100 YEAR ARI - 2.67
PMF - 4.58
0 125 250 500 750 1,000
m
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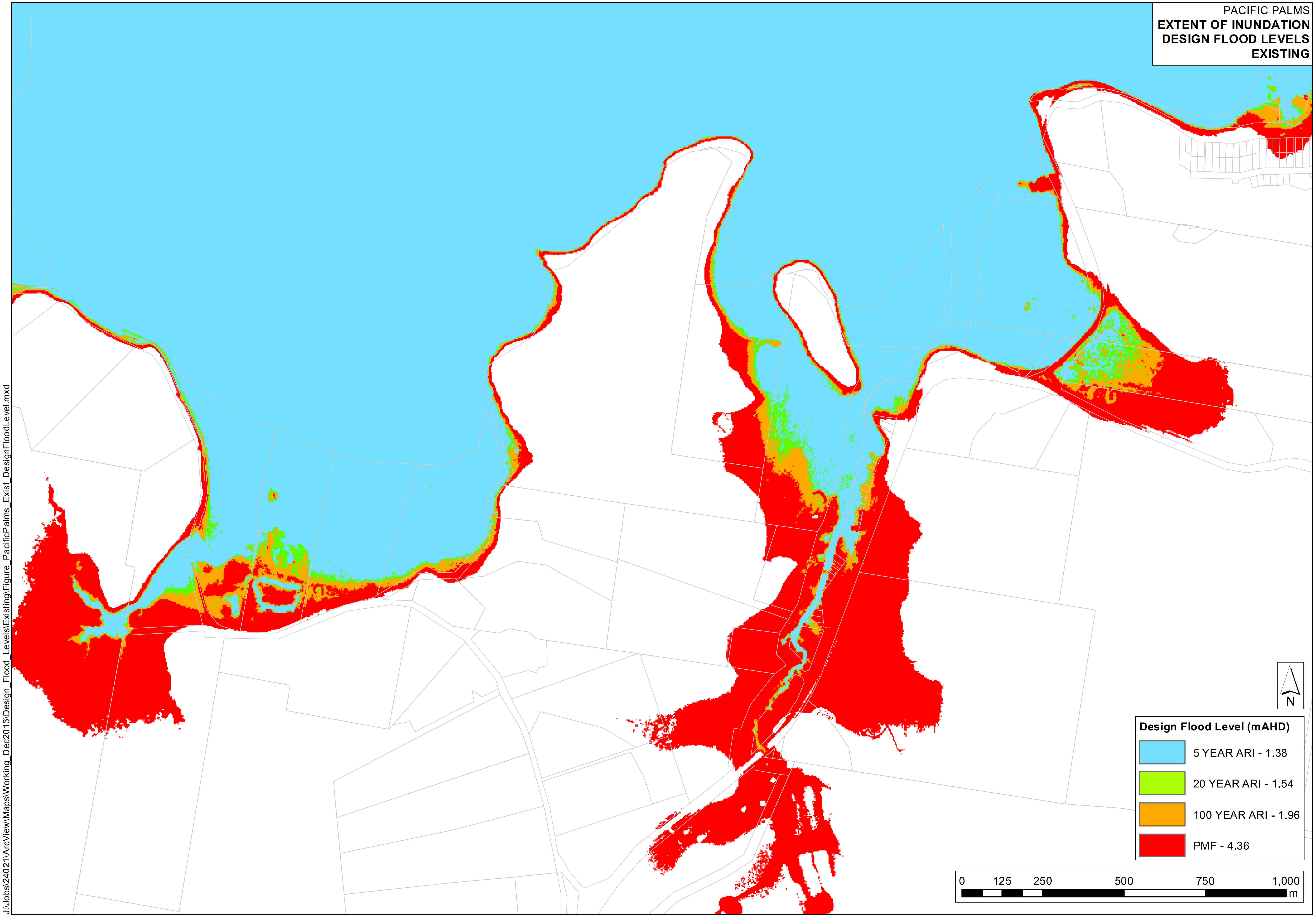

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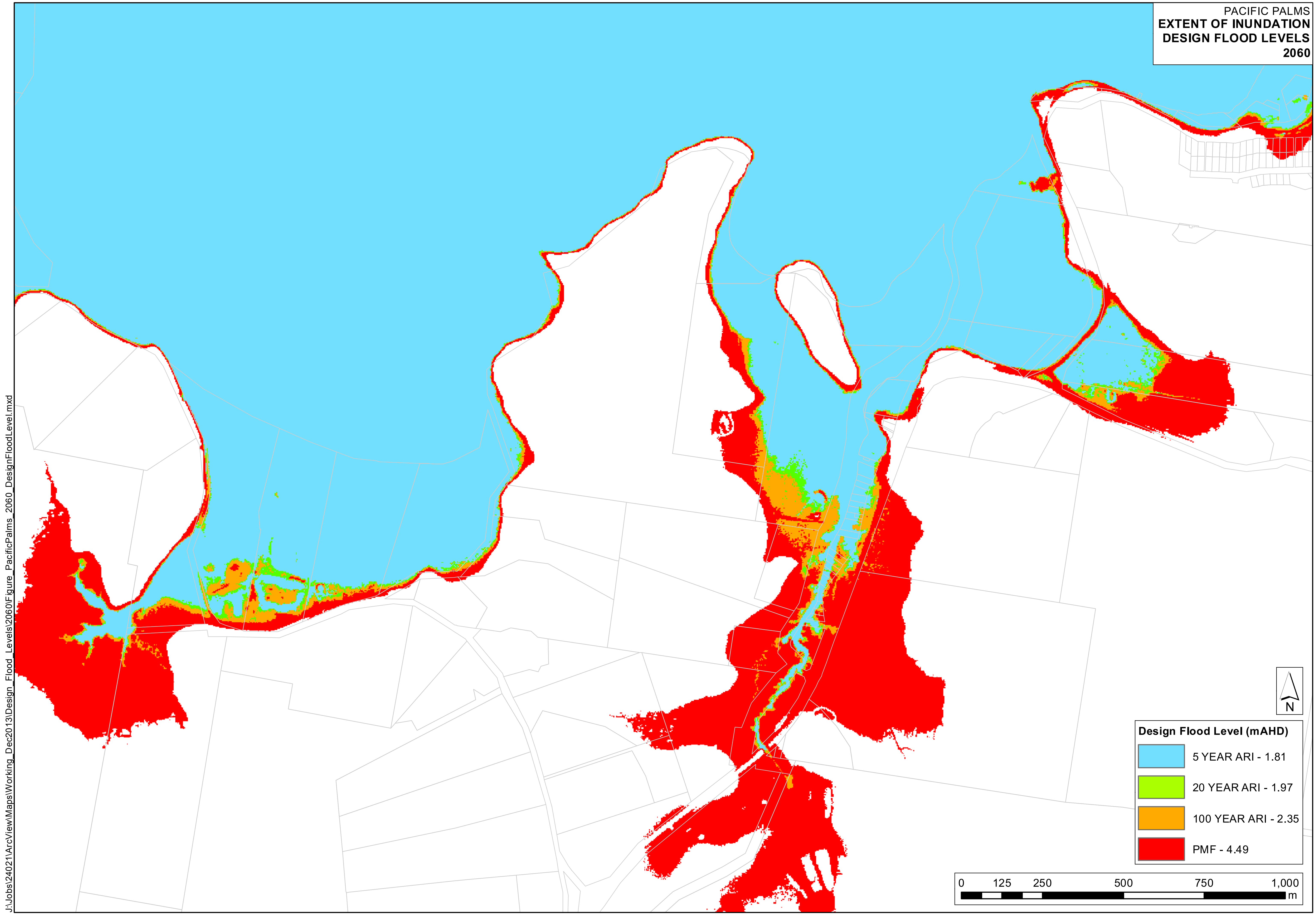

PACIFIC PALMS
EXTENT OF INUNDATION
DESIGN FLOOD LEVELS
2060
N
Design Flood Level (mAHD)
5 YEAR ARI - 1.81
20 YEAR ARI - 1.97
100 YEAR ARI - 2.35
PMF - 4.49
0 125 250 500 750 1,000
m
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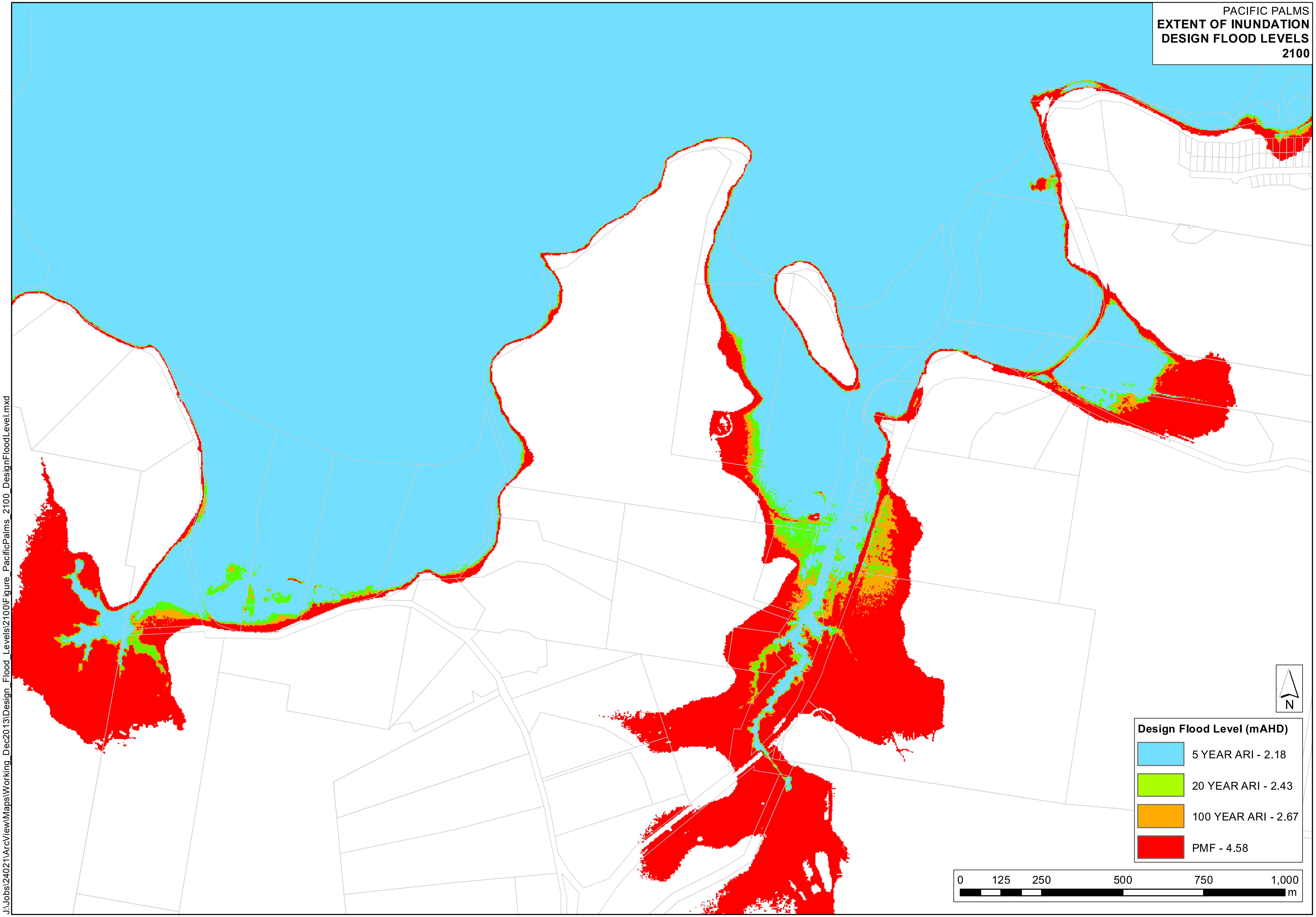

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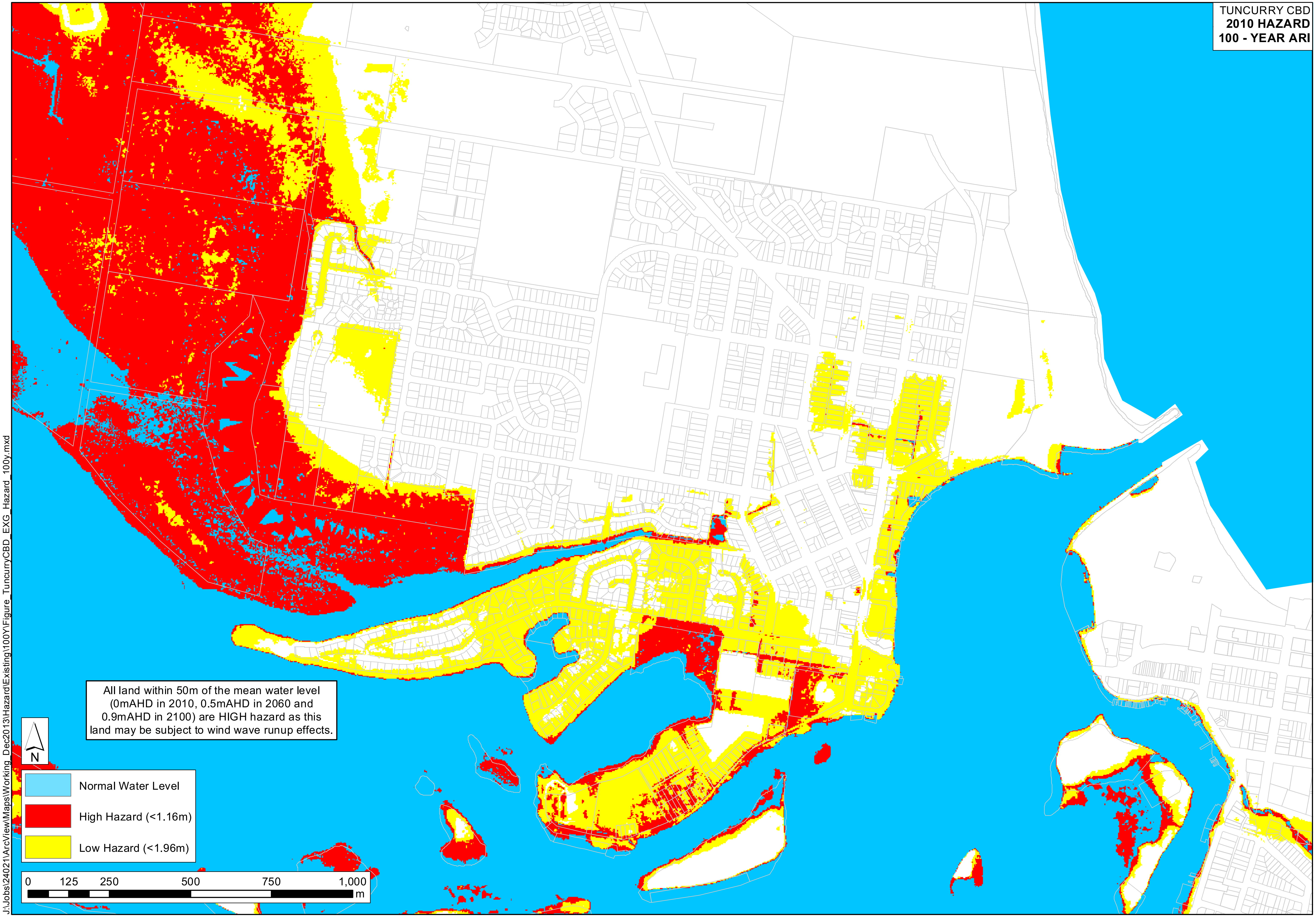
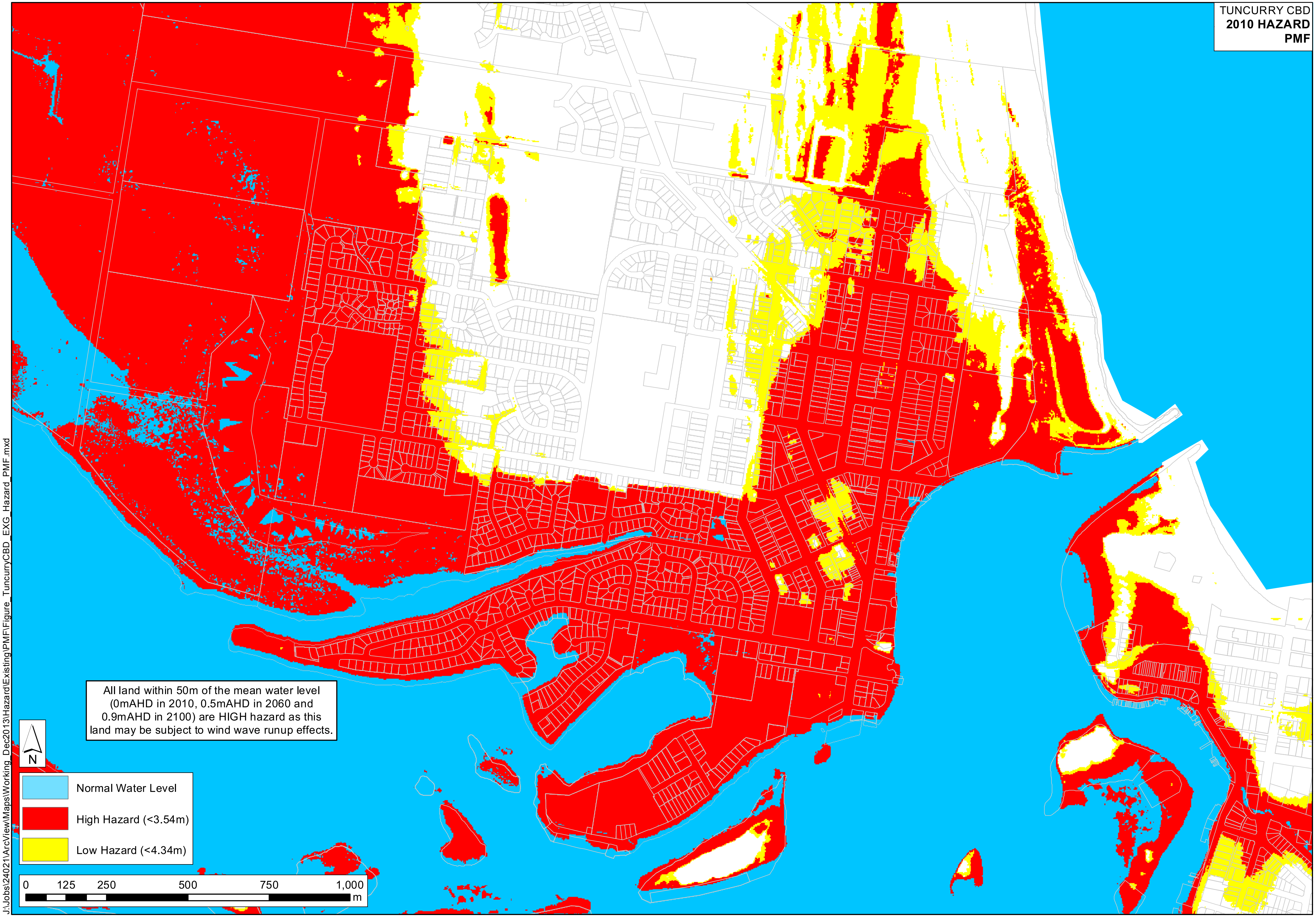

TUNCURRY CBD
2010 HAZARD
100 - YEAR ARI
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<1.16m)
Low Hazard (<1.96m)
0
125
250
500
750
1,000
m
J:Jobs\24021\ArcView\Maps\Working_Dec2013\Hazard\Existing\100Y\Figure_TuncurryCBD_EXG_Hazard_100y.mxd


TUNCURRY CBD
2010 HAZARD
PMF
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<3.54m)
Low Hazard (<4.34m)
0 125 250 500 750 1,000
m
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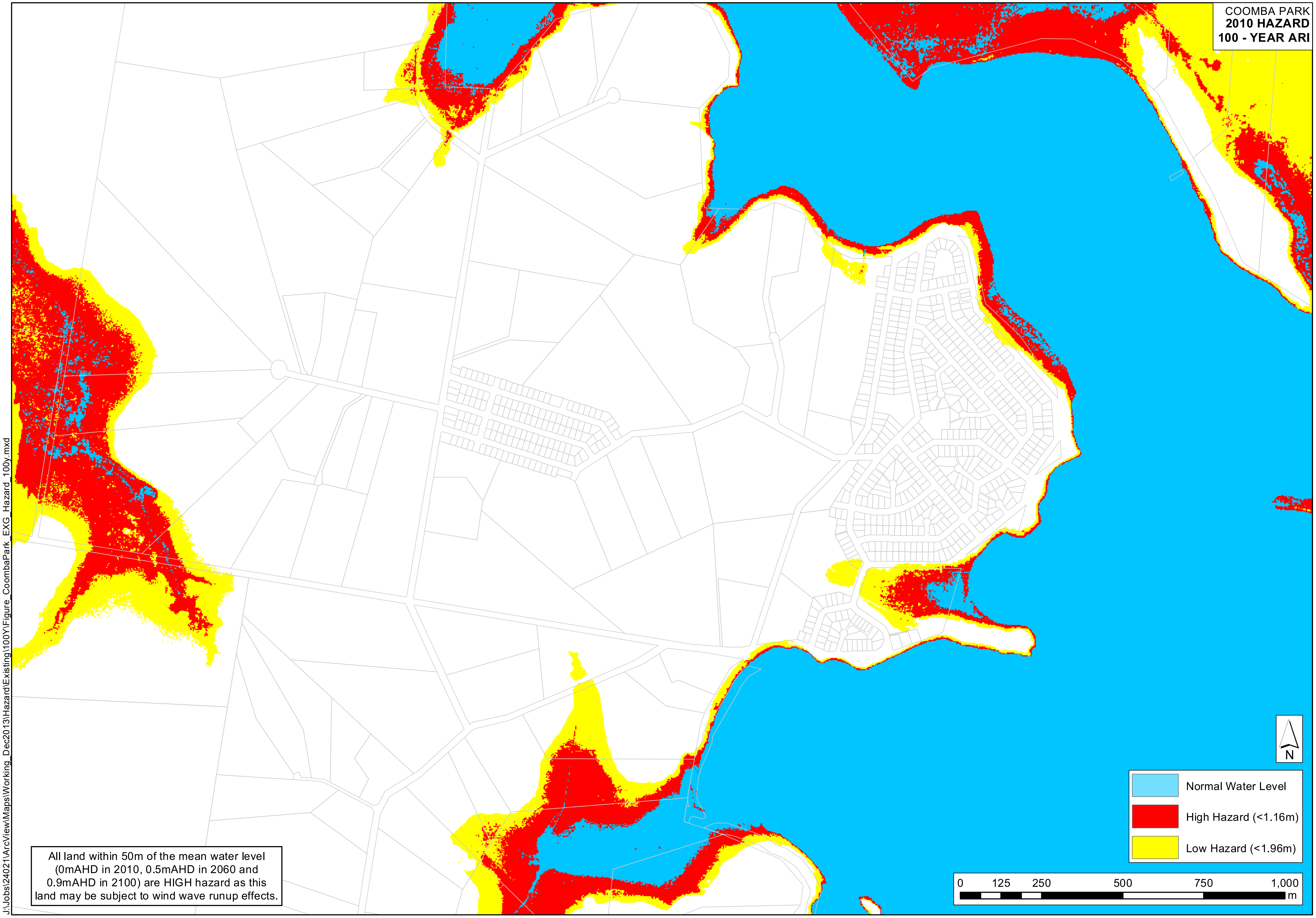

COOMBA PARK
2010 HAZARD
100 - YEAR ARI
N
Normal Water Level
High Hazard (<1.16m)
Low Hazard (<1.96m)
0
125
250
500
750
1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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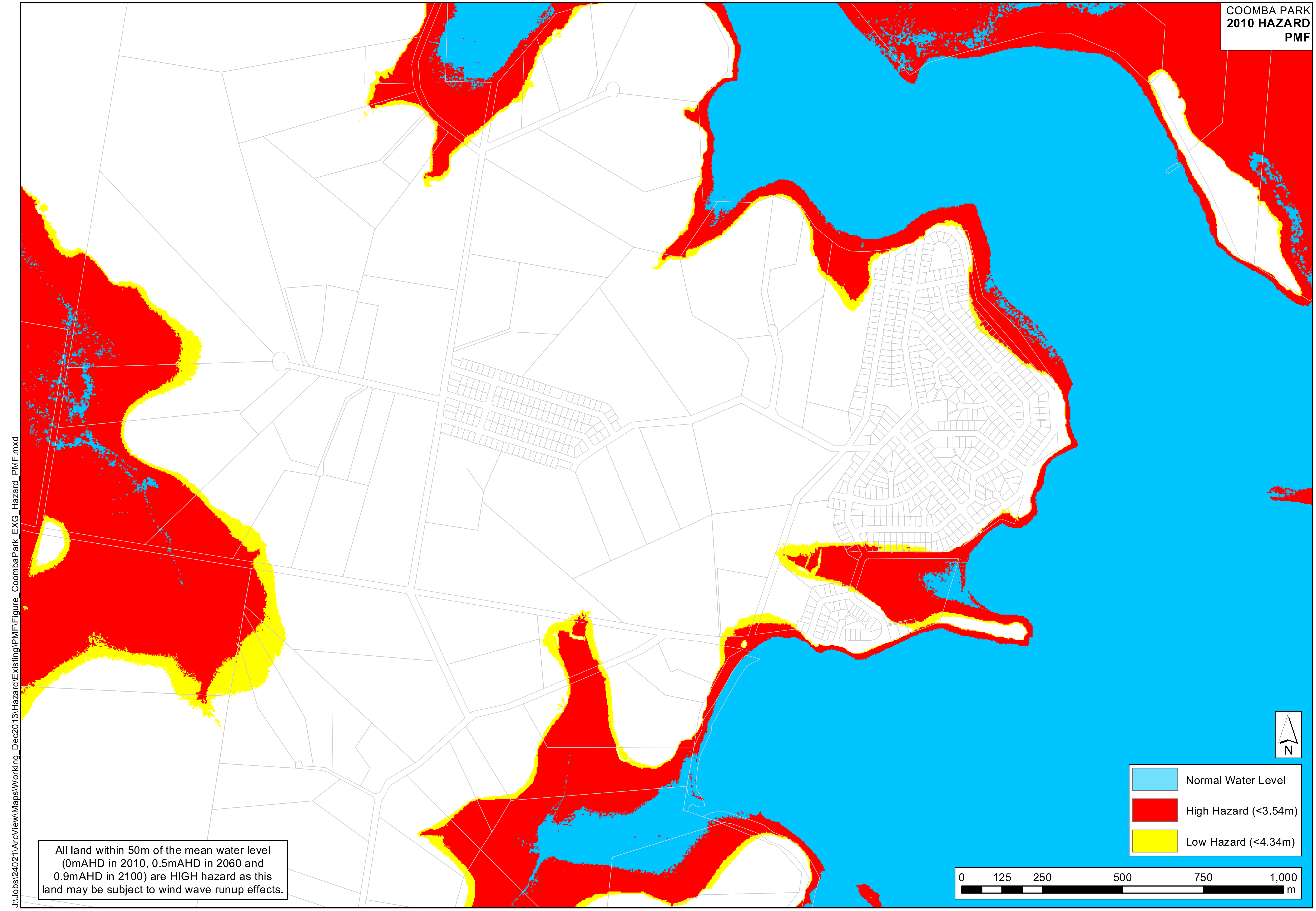

COOMBA PARK
2010 HAZARD
PMF
Normal Water Level
High Hazard (<3.54m)
Low Hazard (<4.34m)
N
0
125
250
500
750
1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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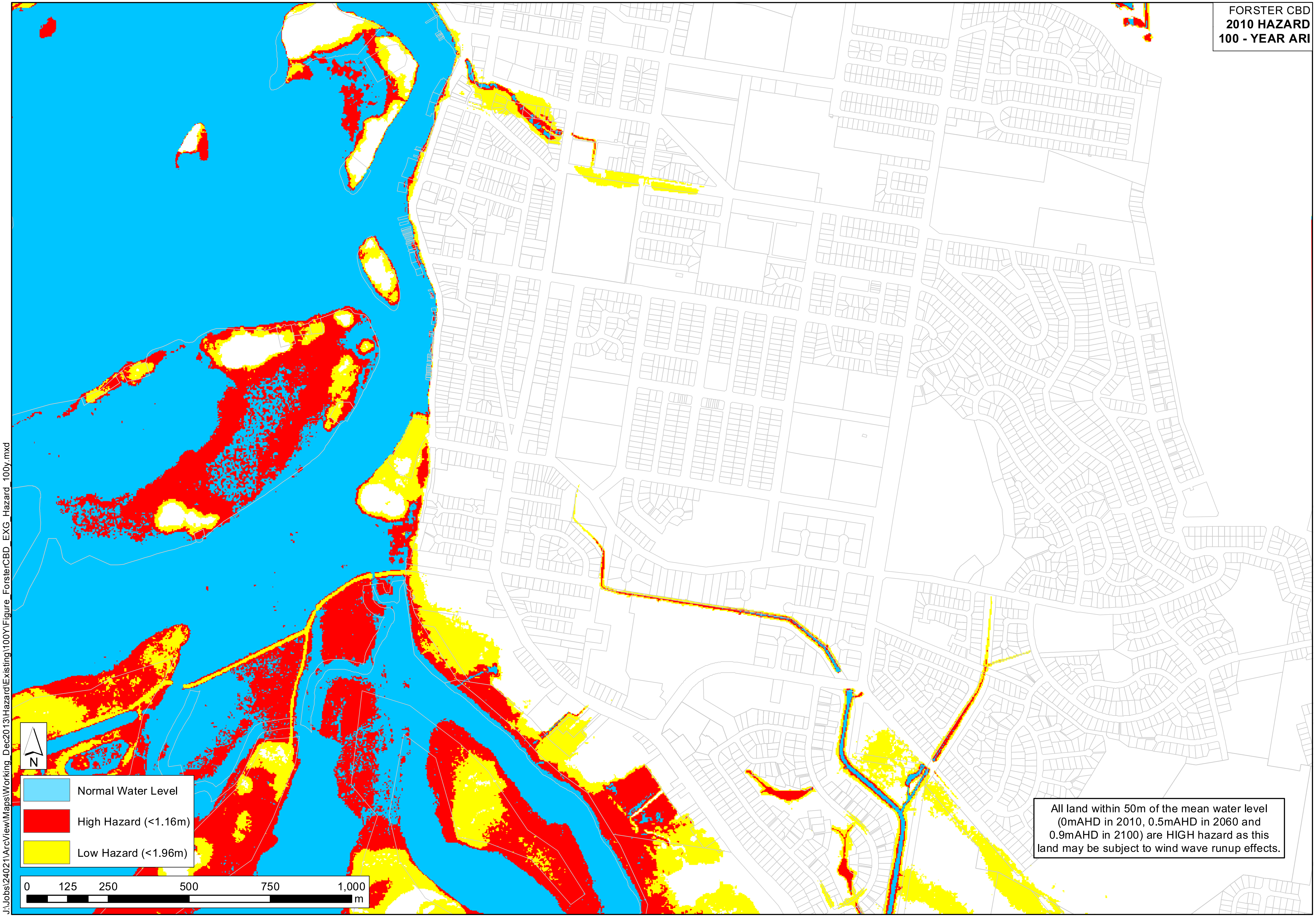
FORSTER CBD
2010 HAZARD
100 - YEAR ARI
N
Normal Water Level
High Hazard (<1.16m)
Low Hazard (<1.96m)
0 125 250 500 750 1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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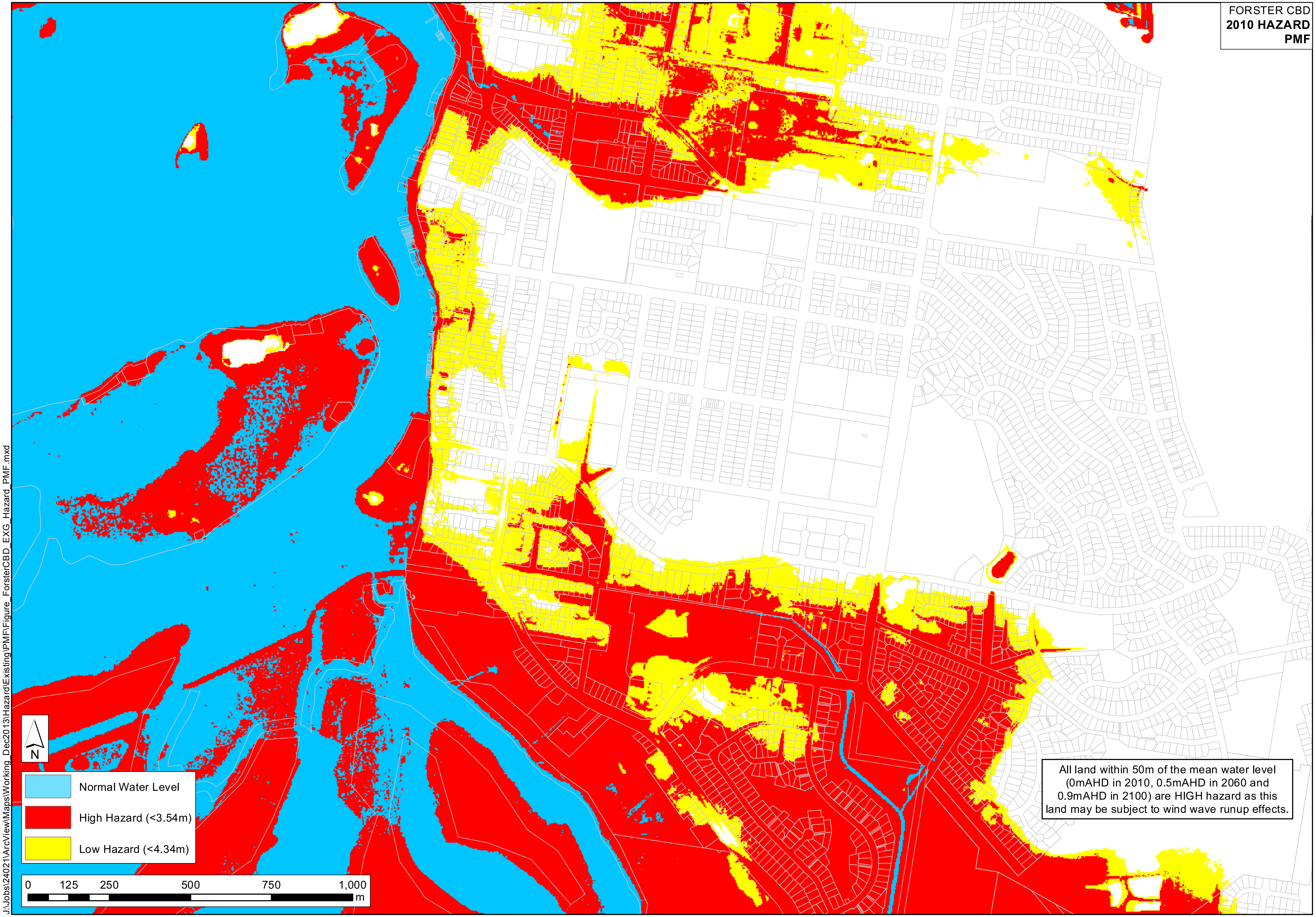

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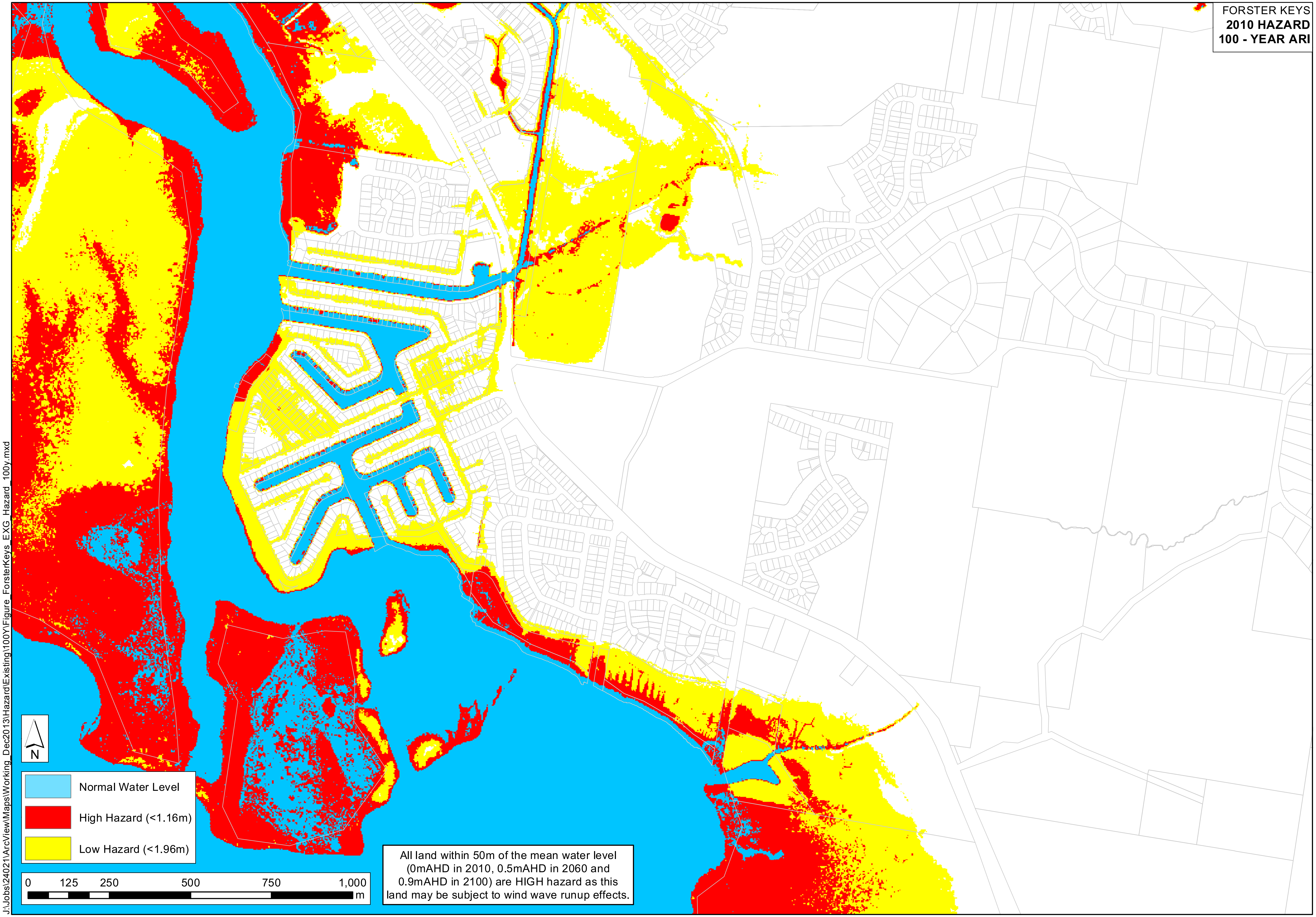

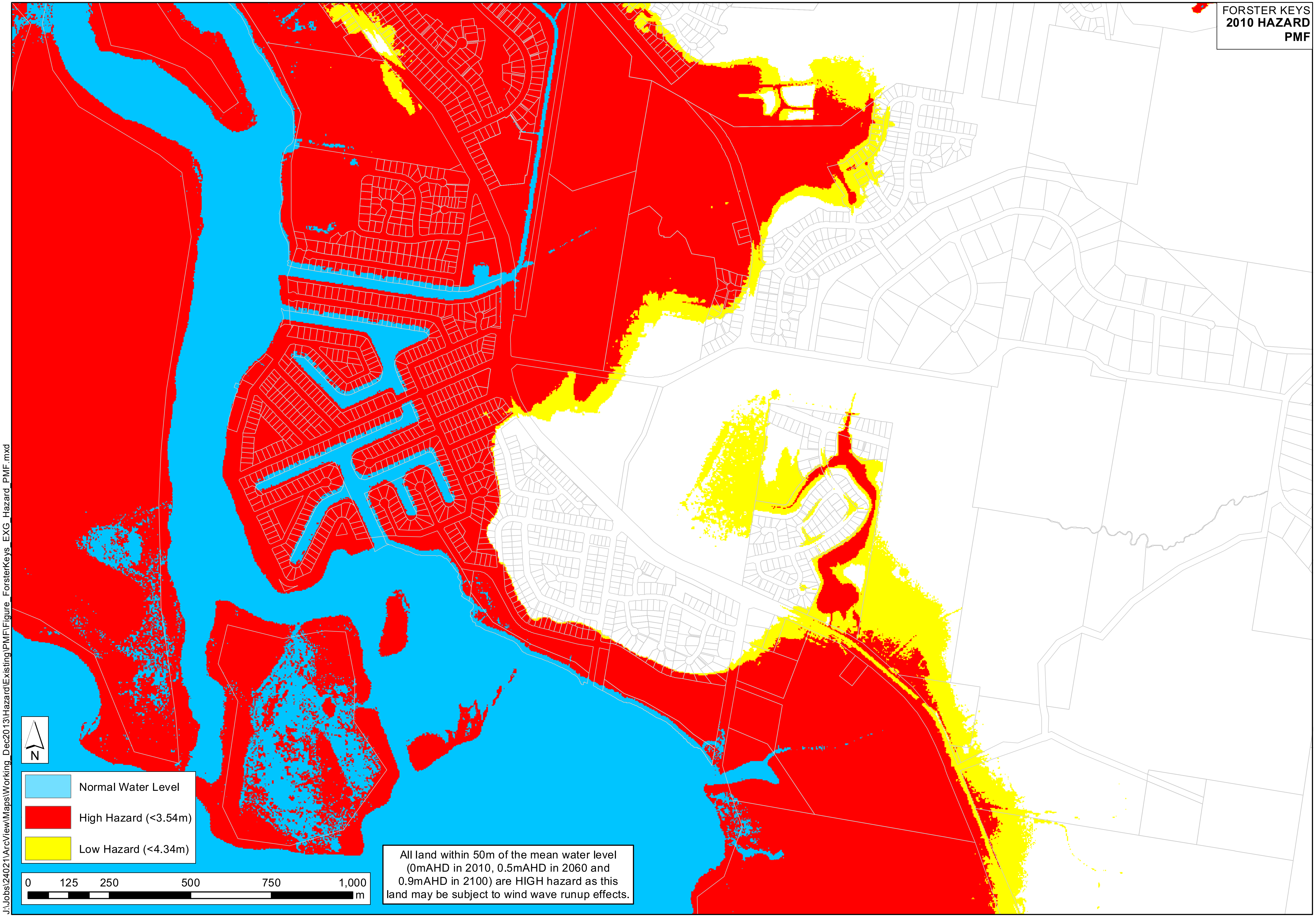

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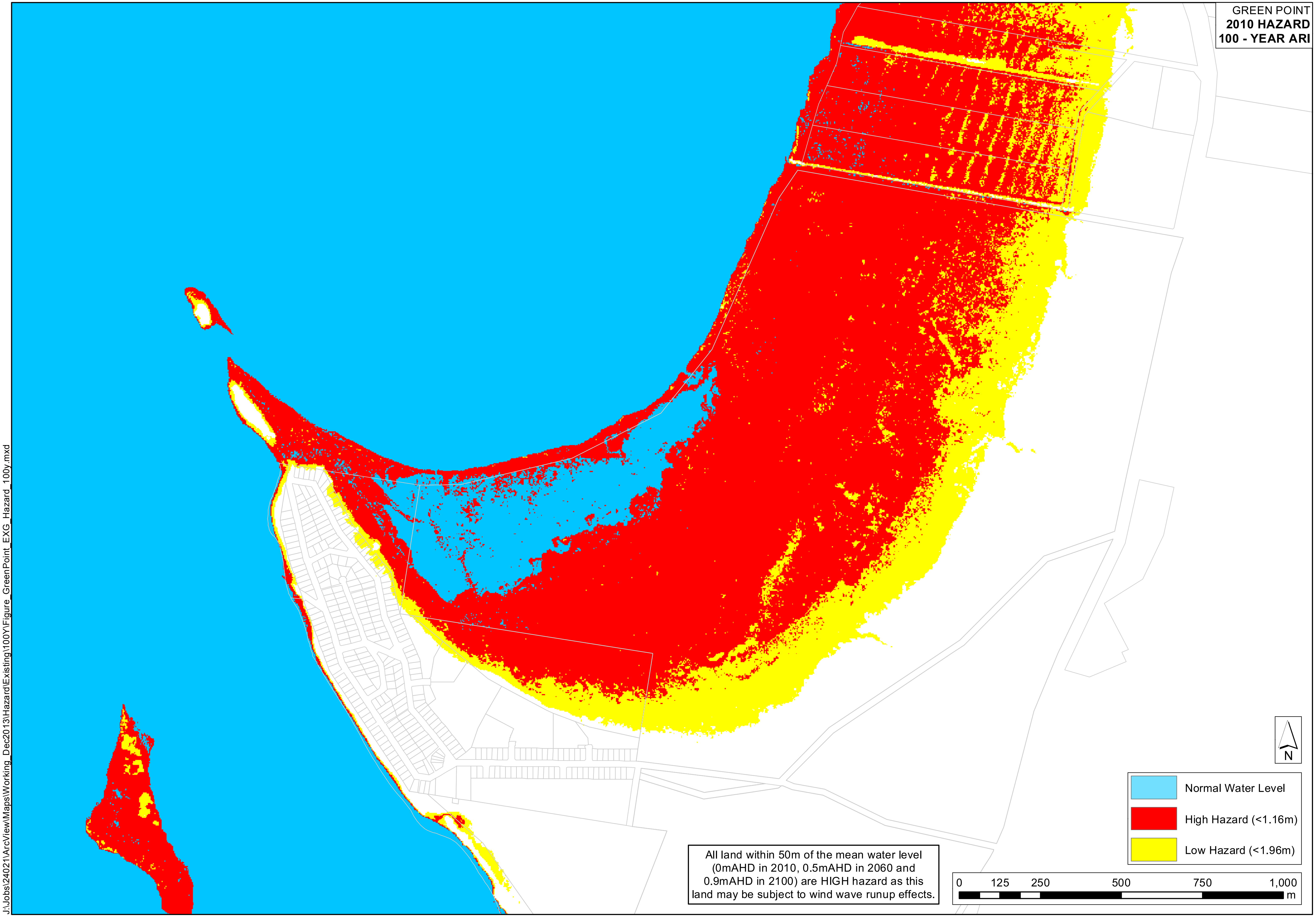

GREEN POINT
2010 HAZARD
100 - YEAR ARI
N
Normal Water Level
High Hazard (<1.16m)
Low Hazard (<1.96m)
0 125 250 500 750 1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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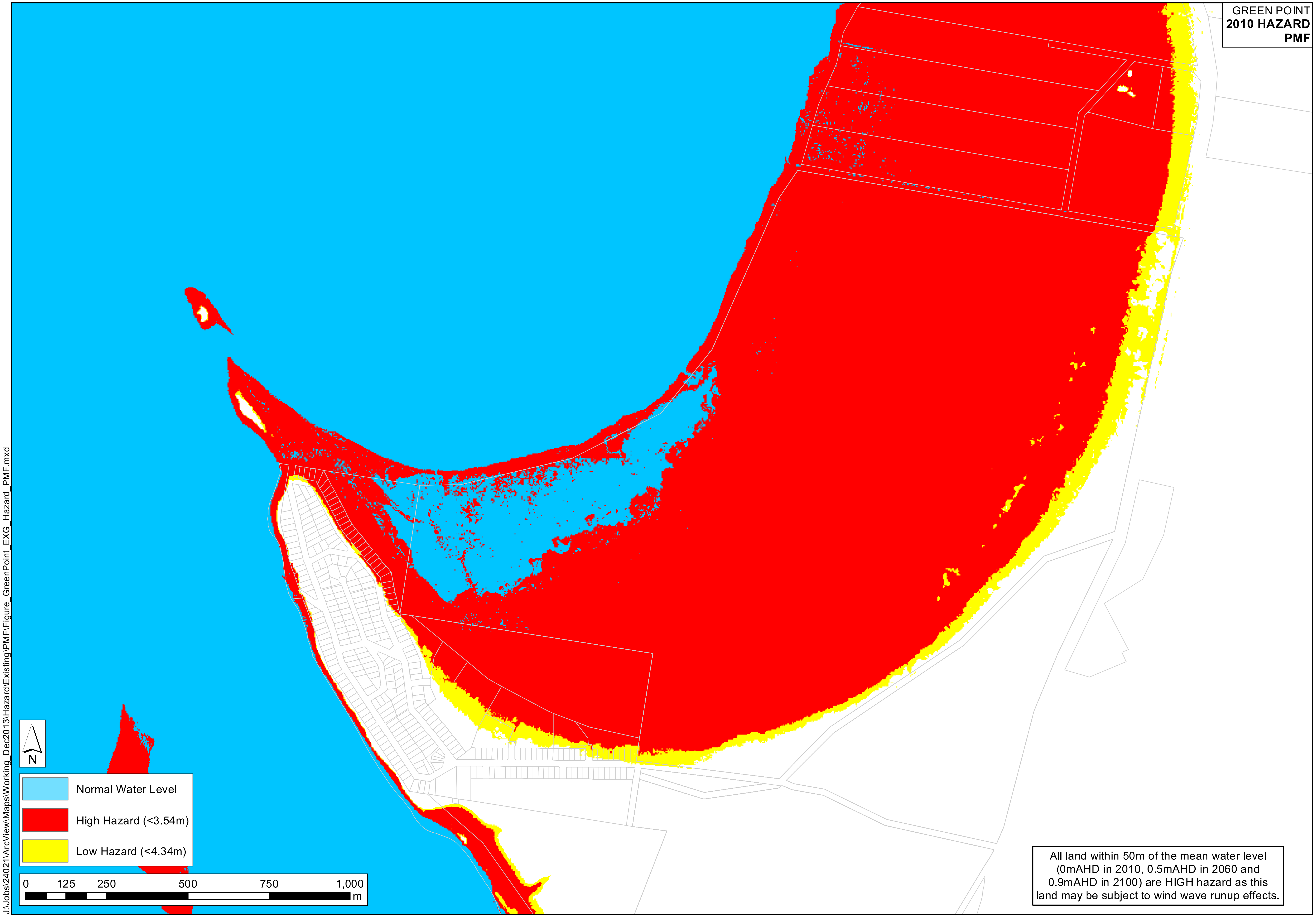

GREEN POINT
2010 HAZARD
PMF
N
Normal Water Level
High Hazard (<3.54m)
Low Hazard (<4.34m)
0
125
250
500
750
1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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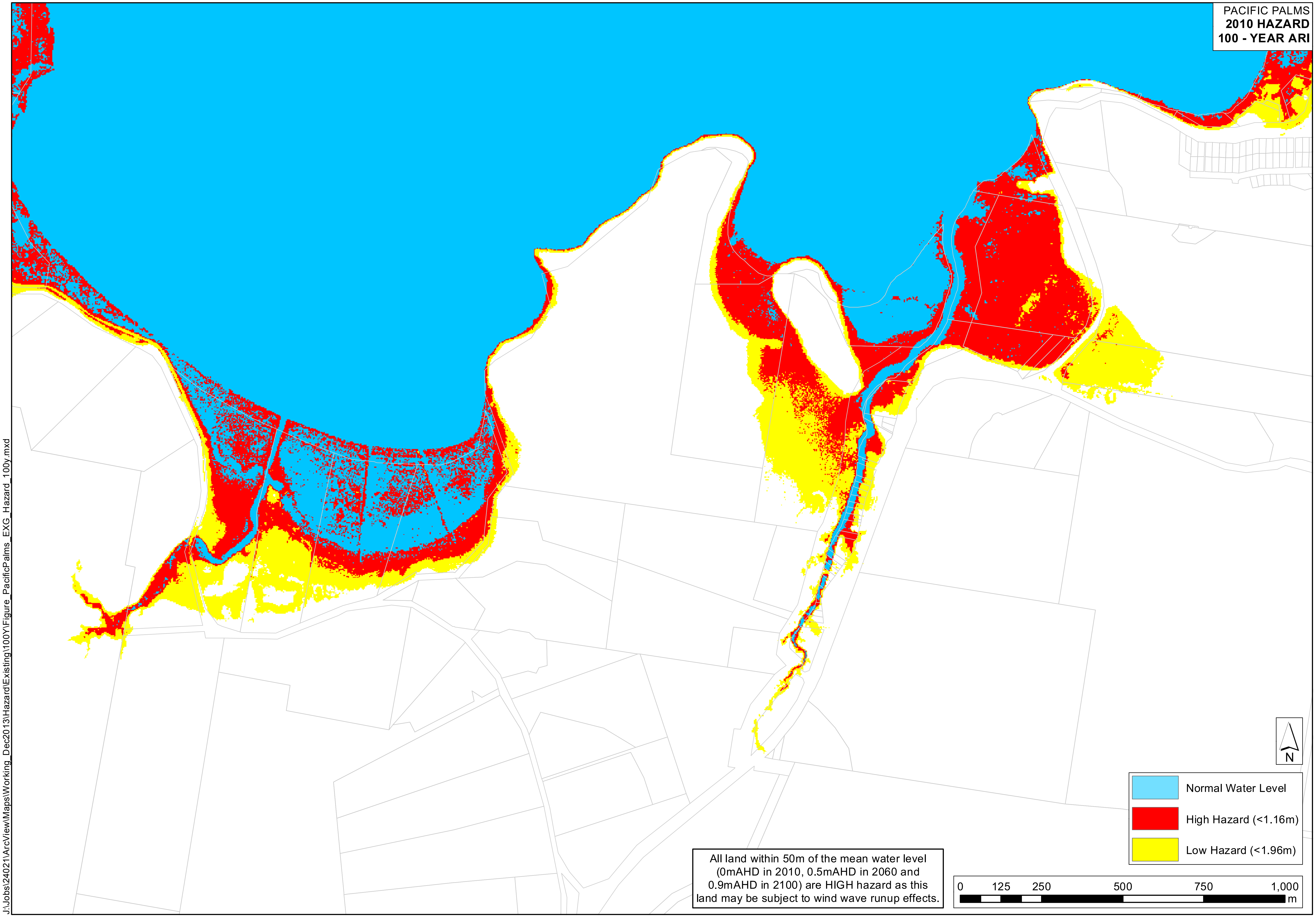
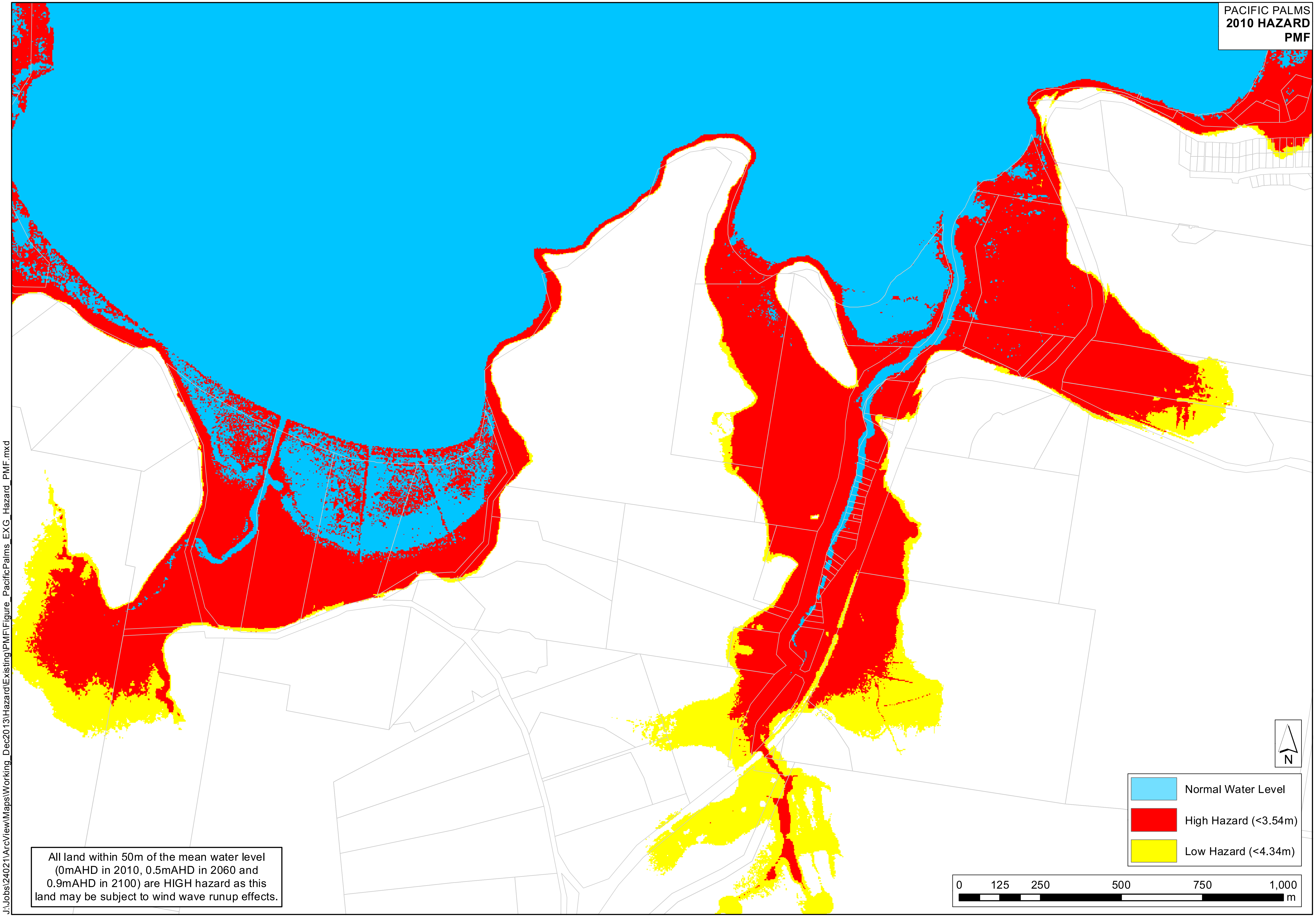

PACIFIC PALMS
2010 HAZARD
100 - YEAR ARI
N
Normal Water Level
High Hazard (<1.16m)
Low Hazard (<1.96m)
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
0 125 250 500 750 1,000 m
J:\Jobs\24021\ArcView\Maps\Working_Dec2013\Hazard\Existing\100Y\Figure_PacificPalms_EXG_Hazard_100y.mxd



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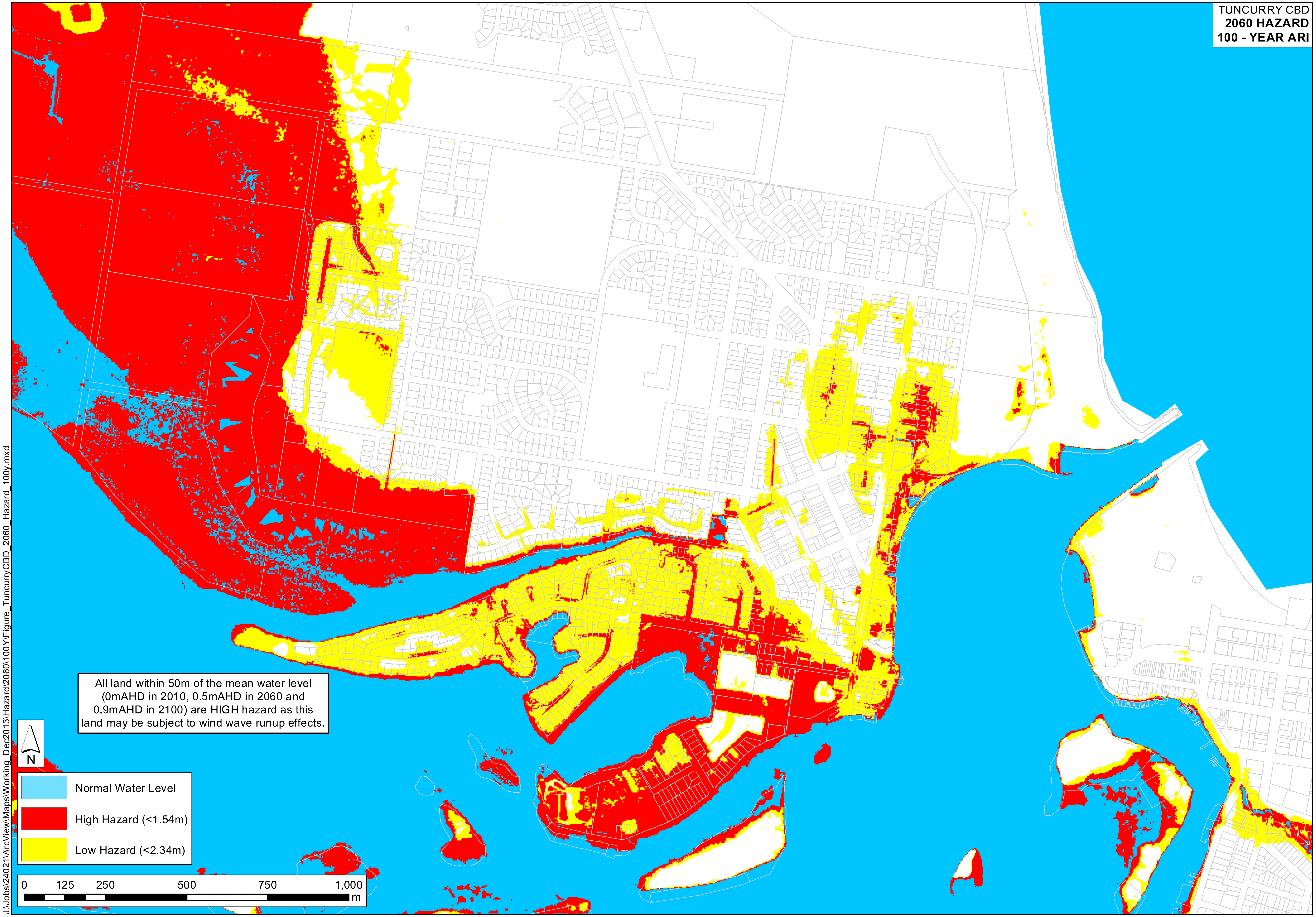

TUNCURRY CBD
2060 HAZARD
100 - YEAR ARI
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<1.54m)
Low Hazard (<2.34m)
0 125 250 500 750 1,000
m
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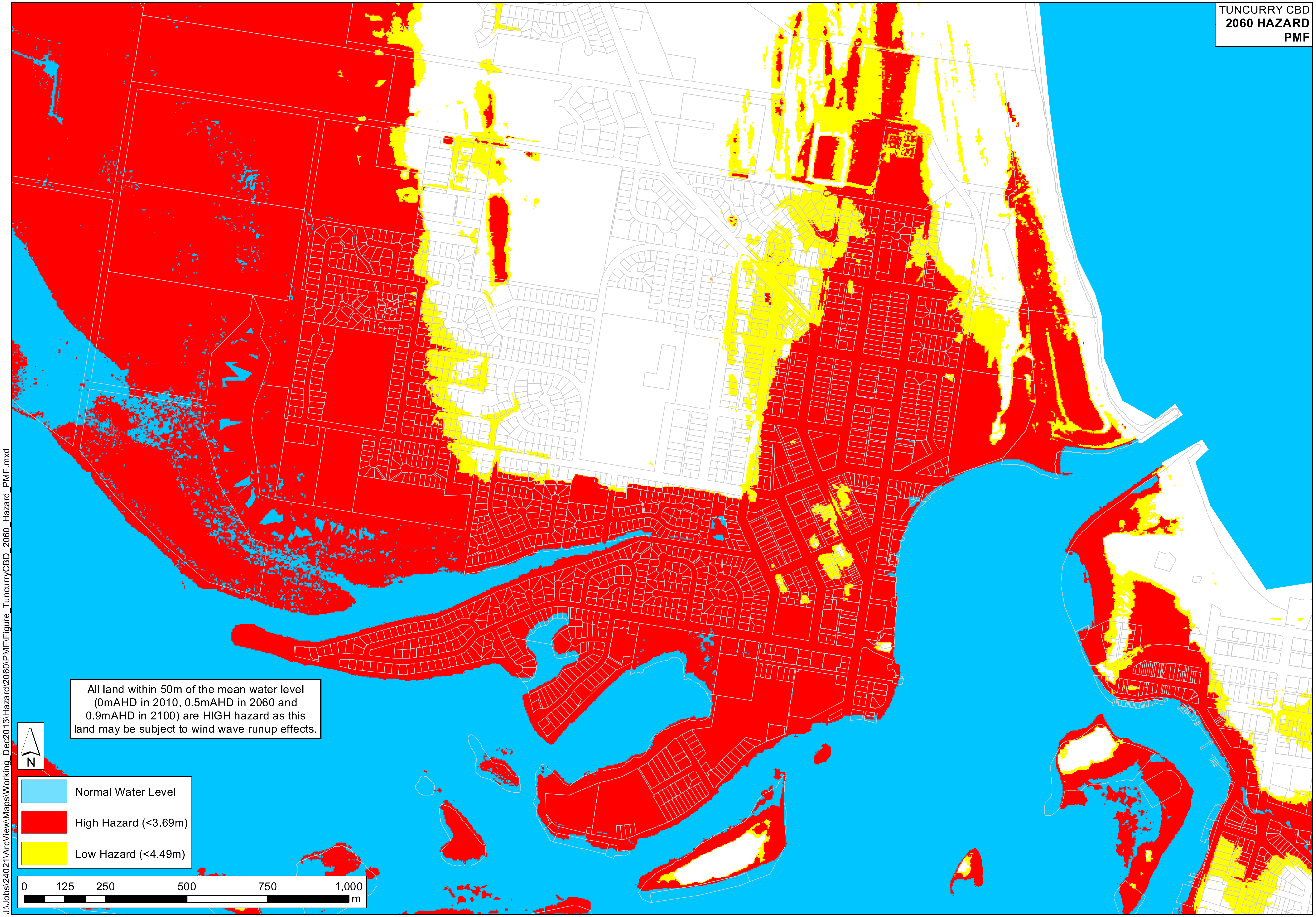

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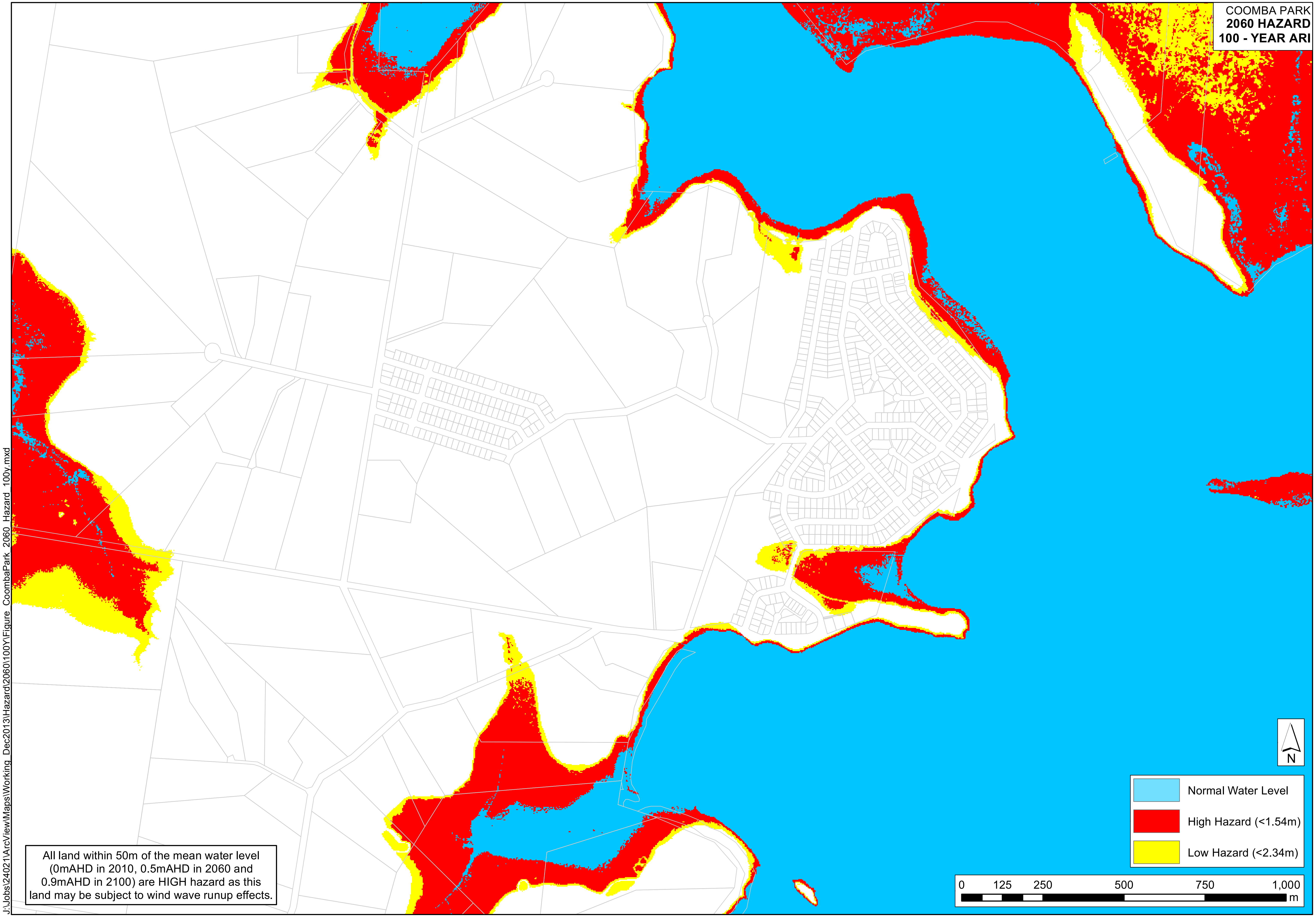

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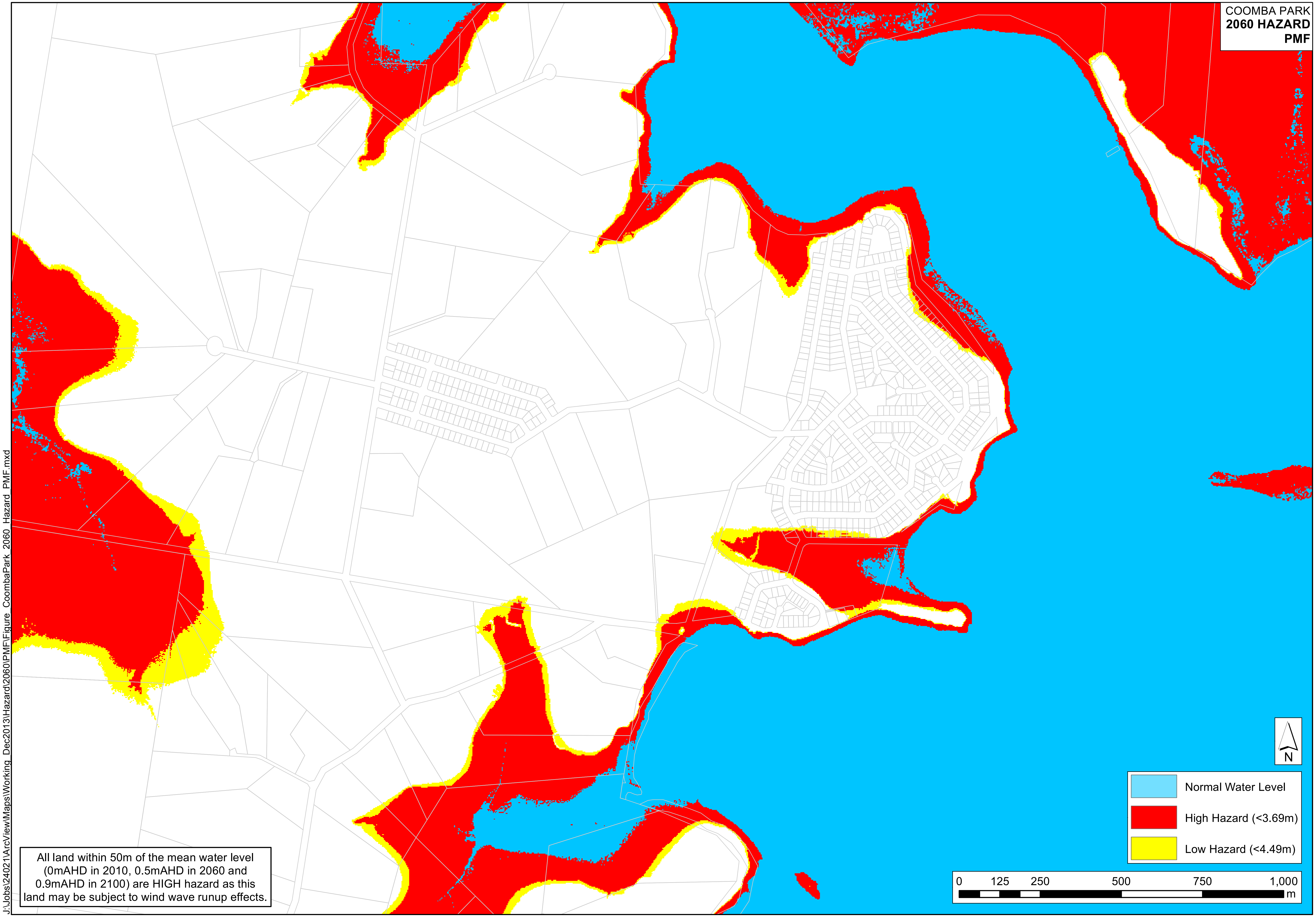

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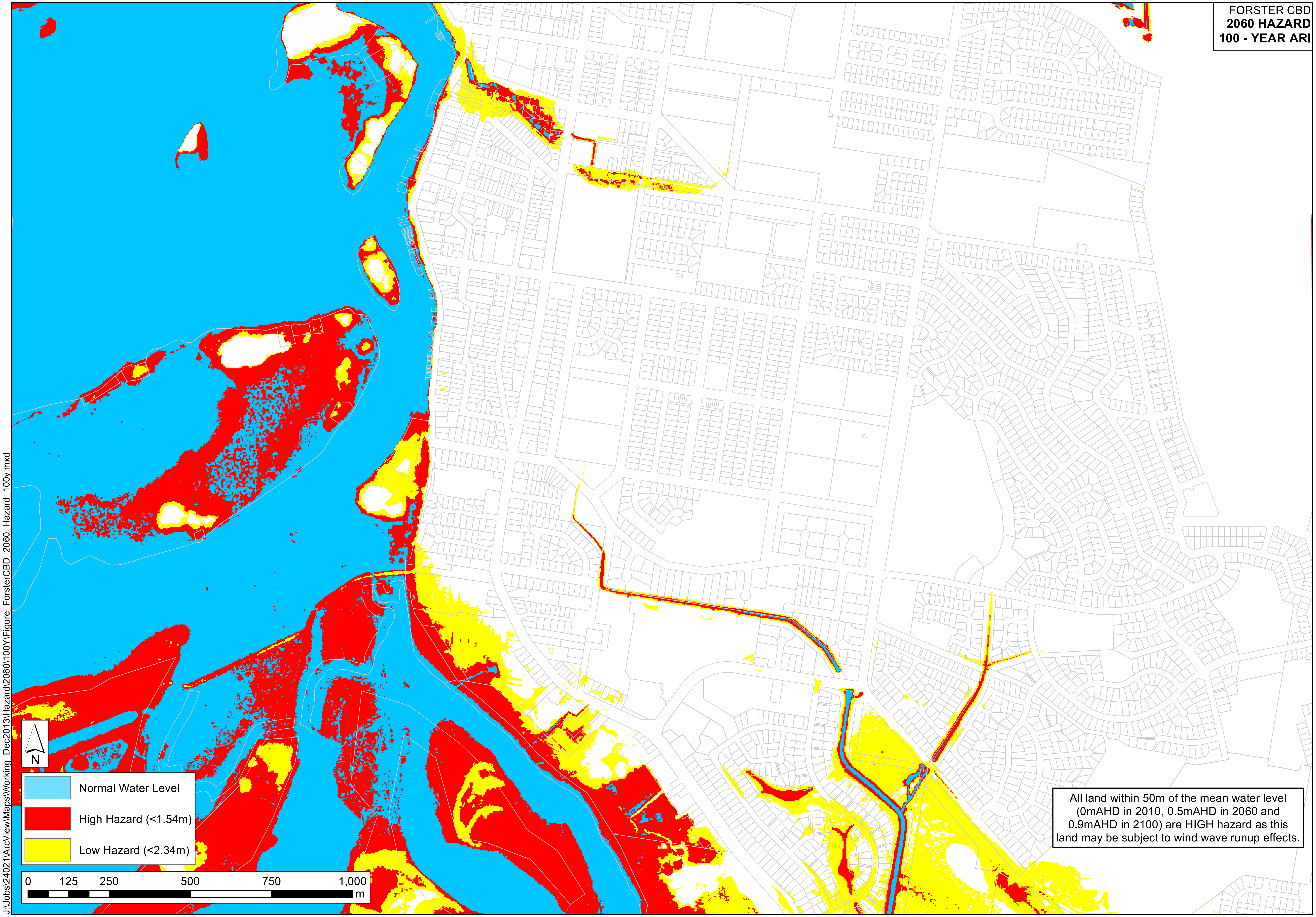

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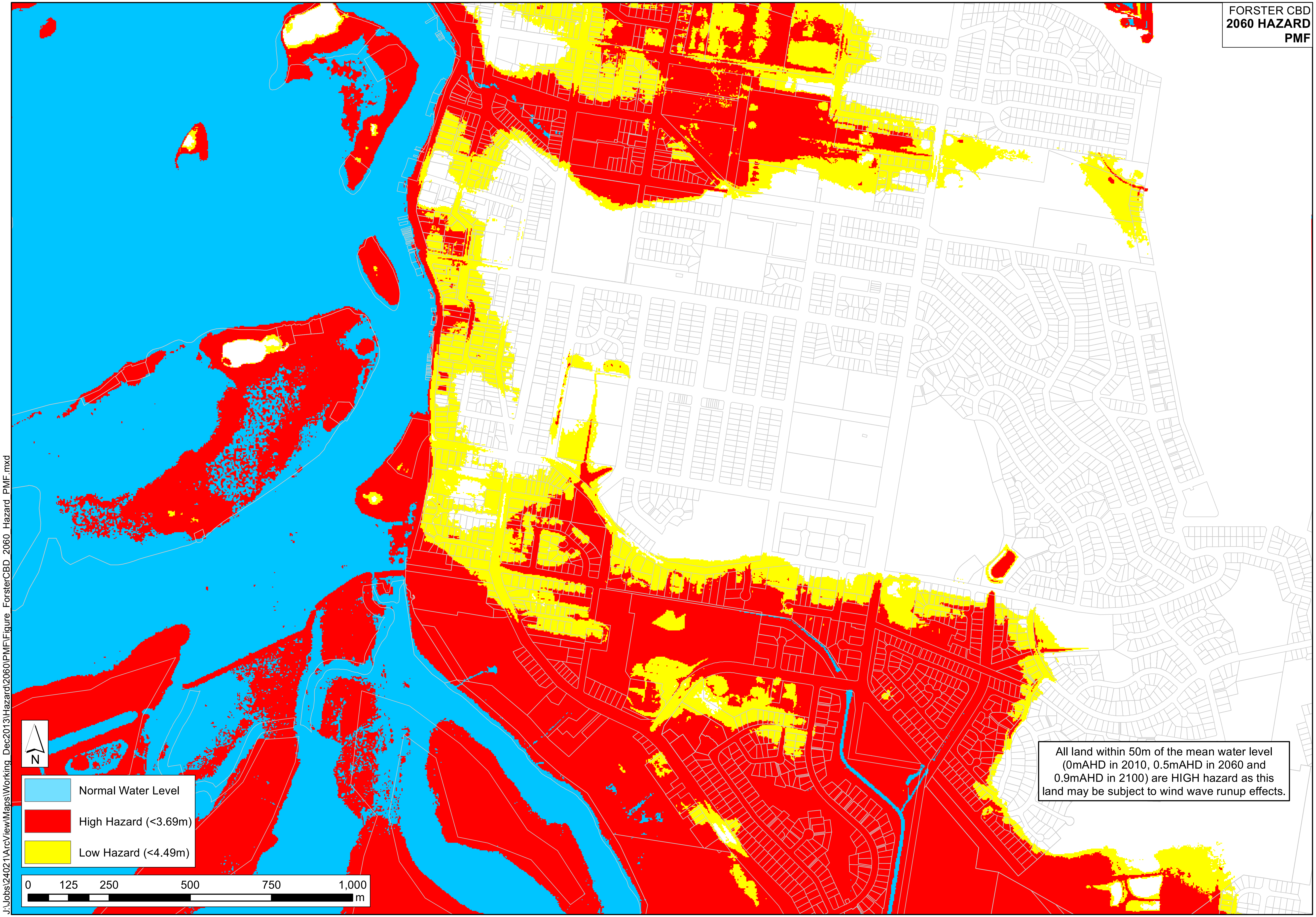
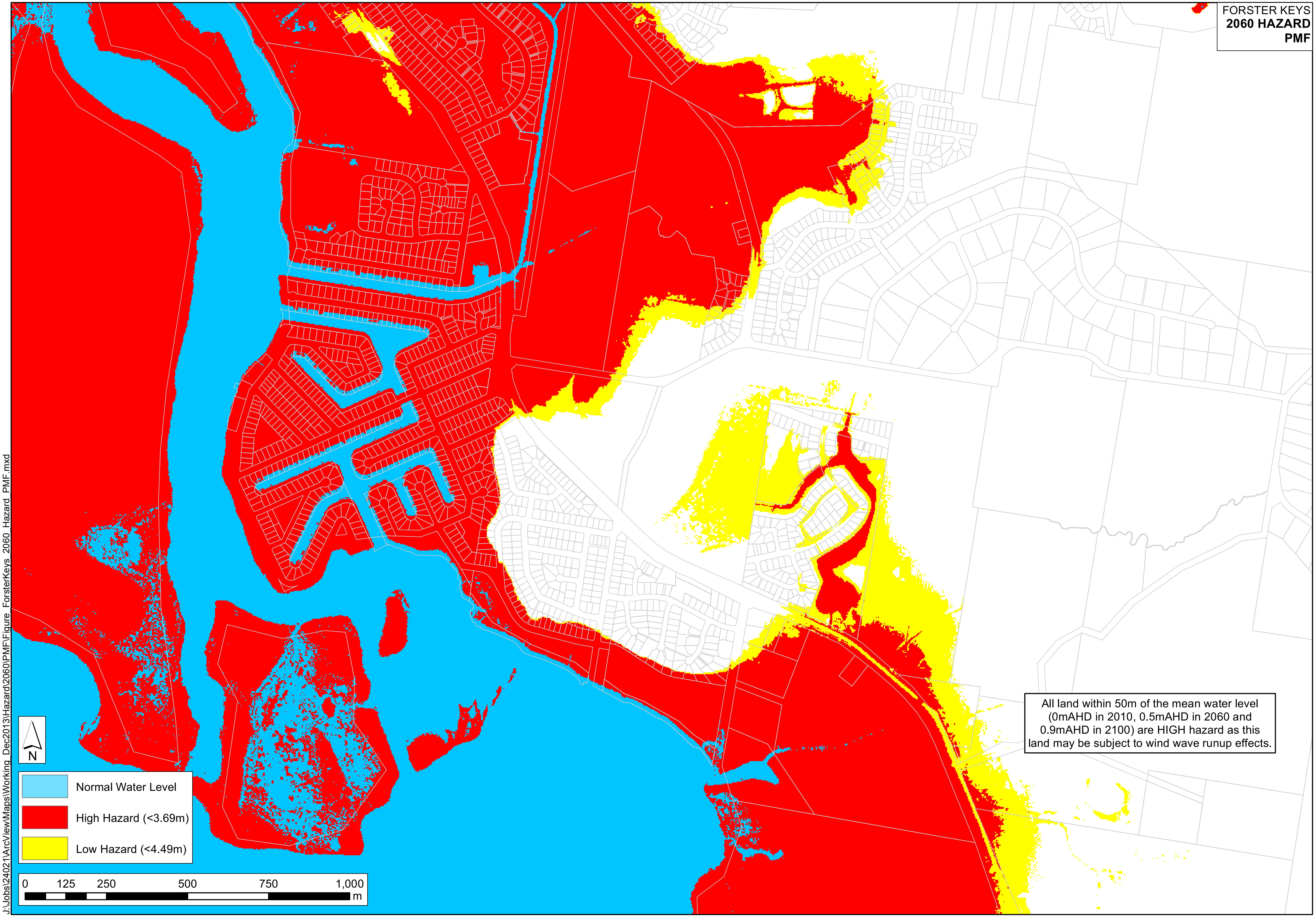


FORSTER CBD
2060 HAZARD
PMF
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<3.69m)
Low Hazard (<4.49m)
0 125 250 500 750 1,000
m
J:\Jobs\24021\ArcView\Maps\Working_Dec2013\Hazard\2060\PMF\Figure_ForsterCBD_2060_Hazard_PMF.mxd

J:\Jobs\24021\ArcView\Maps\Working Dec2013\Hazard\2060\100Y\Figure ForsterKeys 2060 Hazard 100y.mxd



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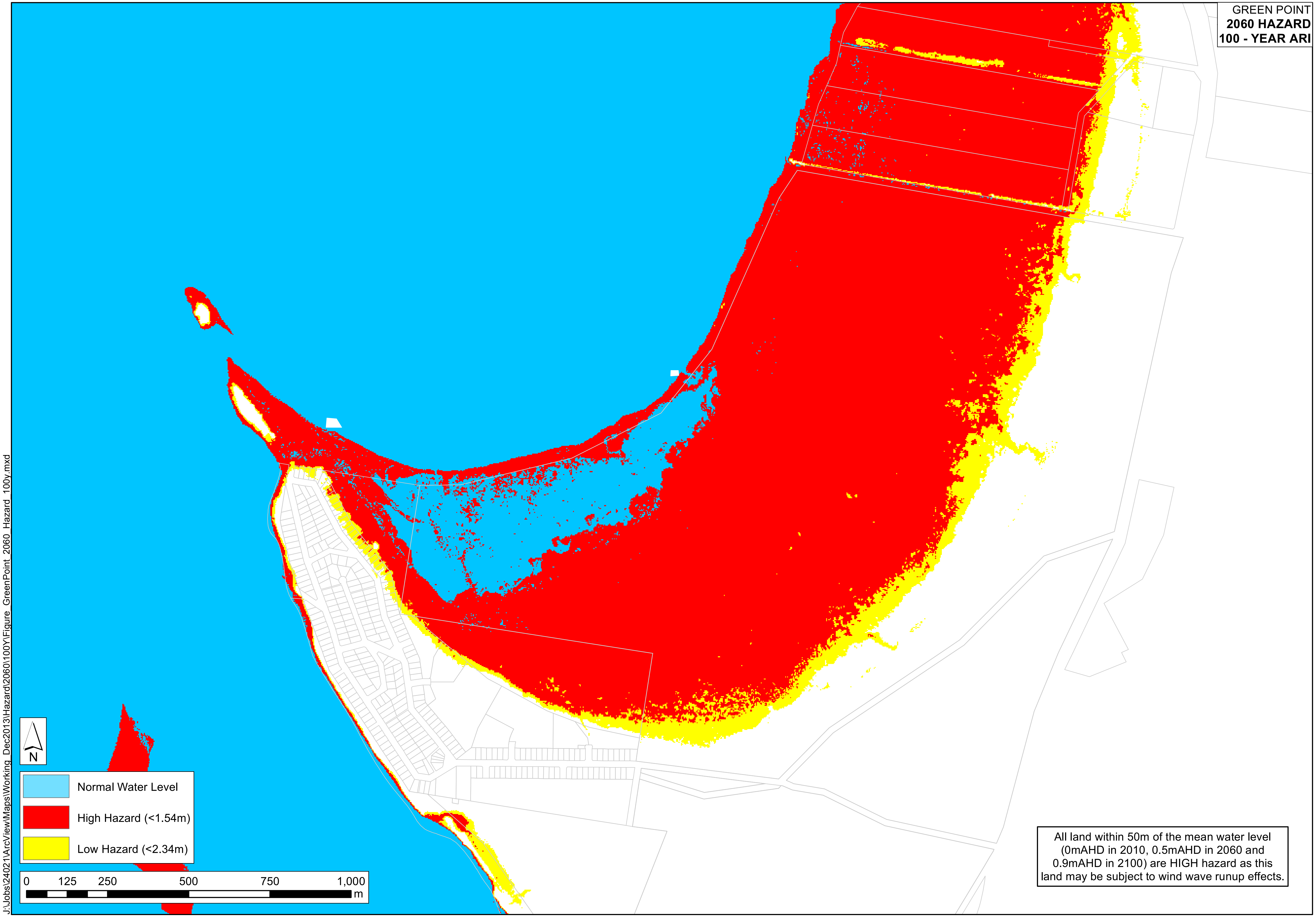

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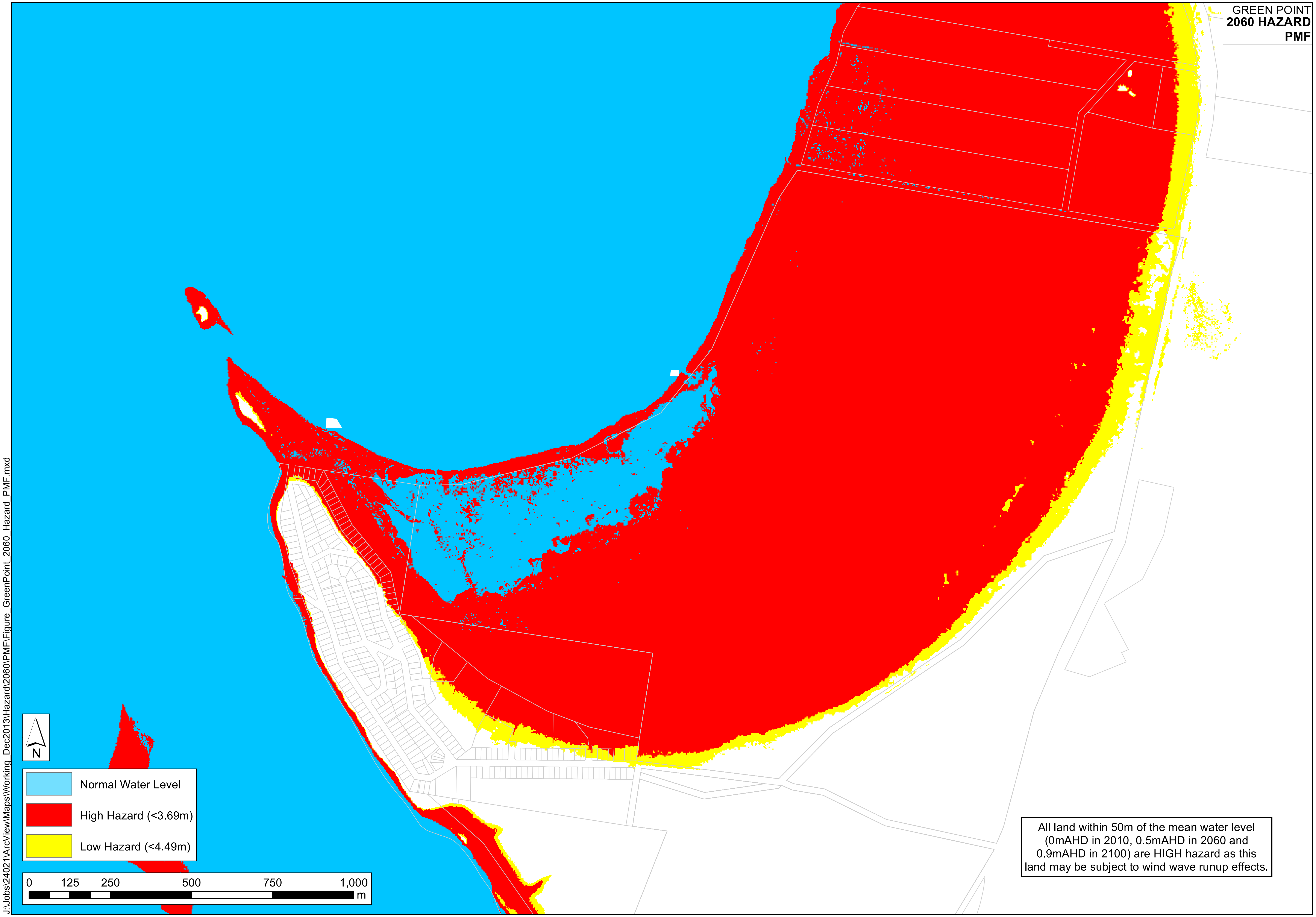

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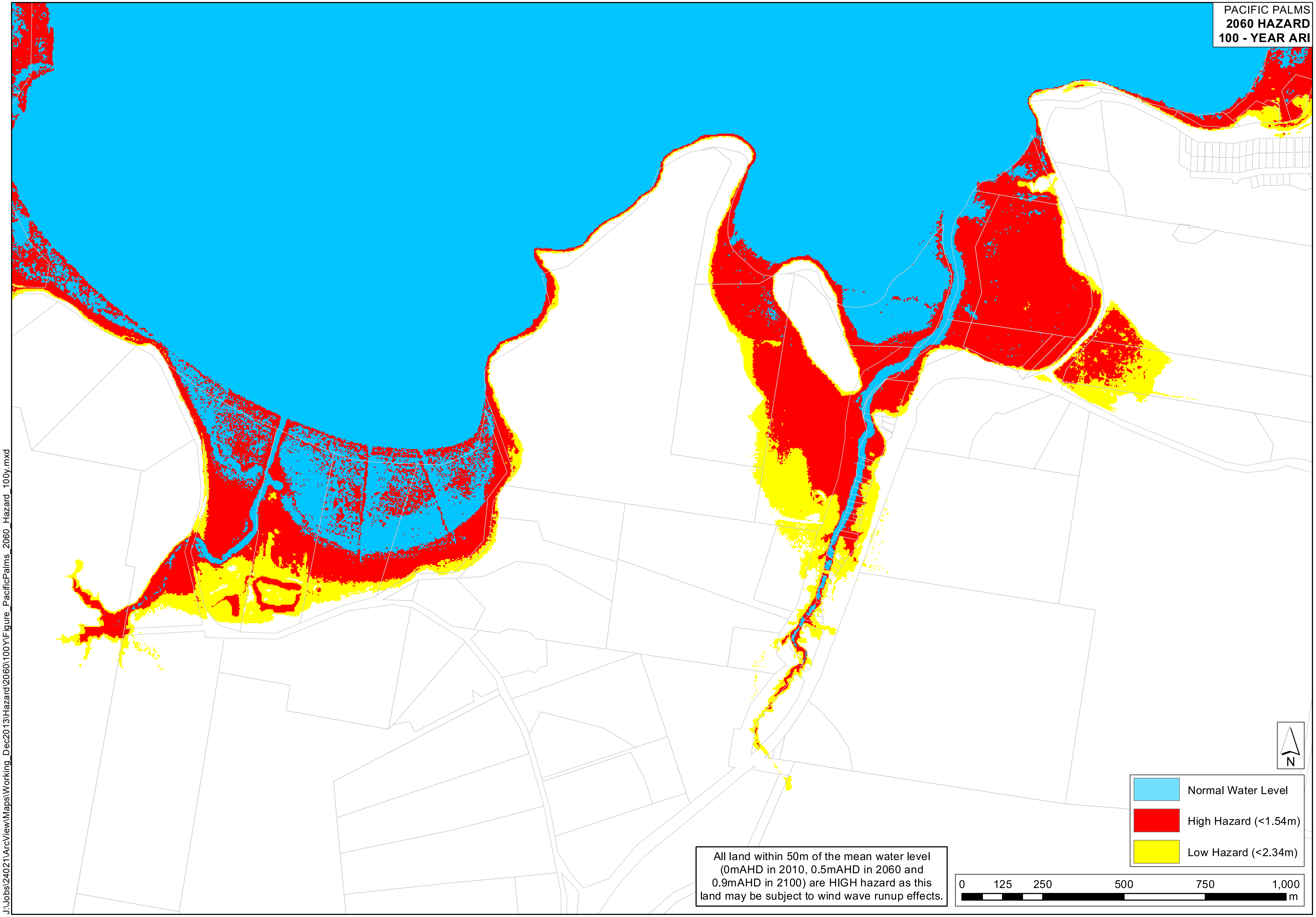

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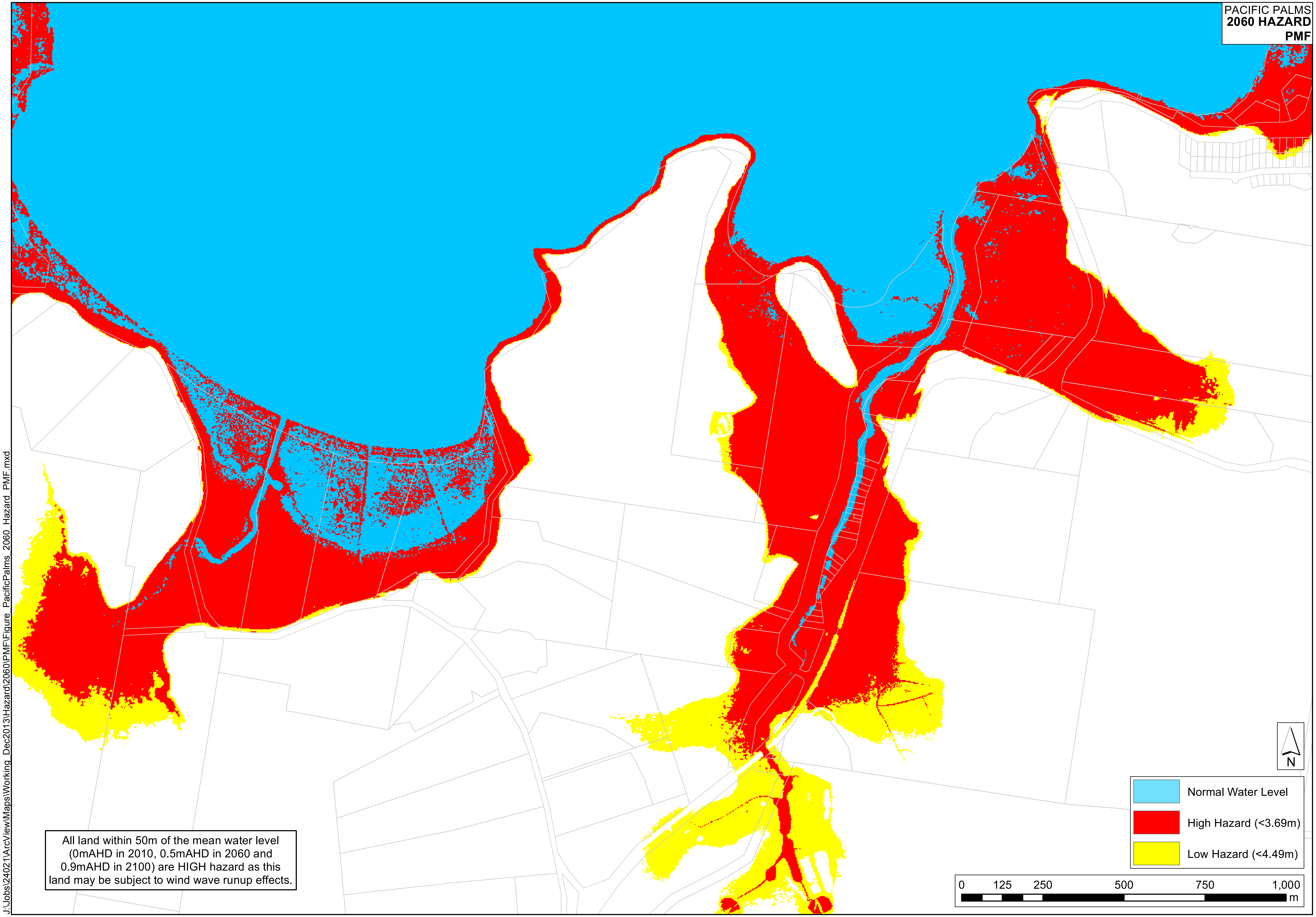
PACIFIC PALMS
2060 HAZARD
PMF
Normal Water Level
High Hazard (<3.69m)
Low Hazard (<4.49m)
0 125 250 500 750 1,000
m
N
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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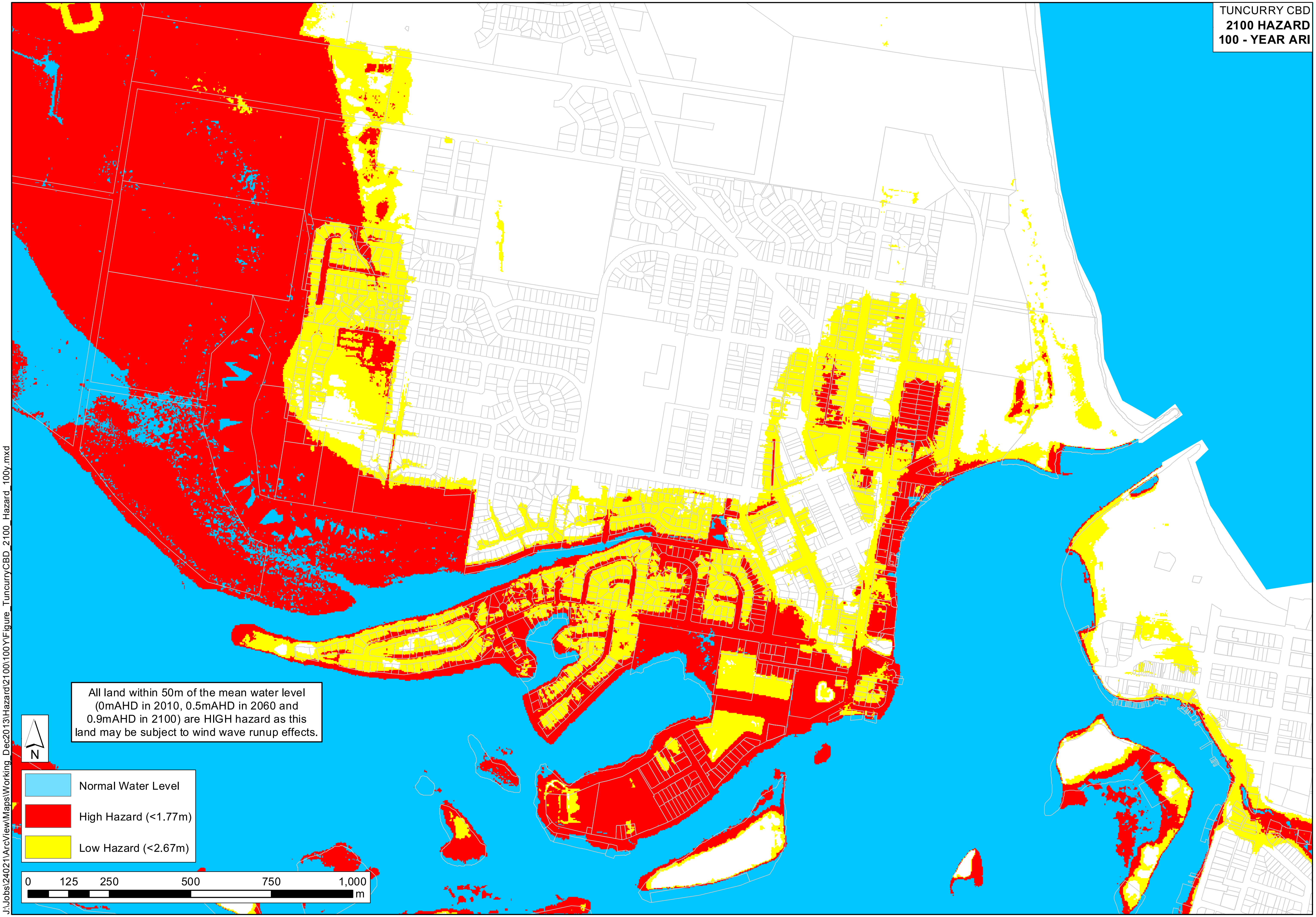
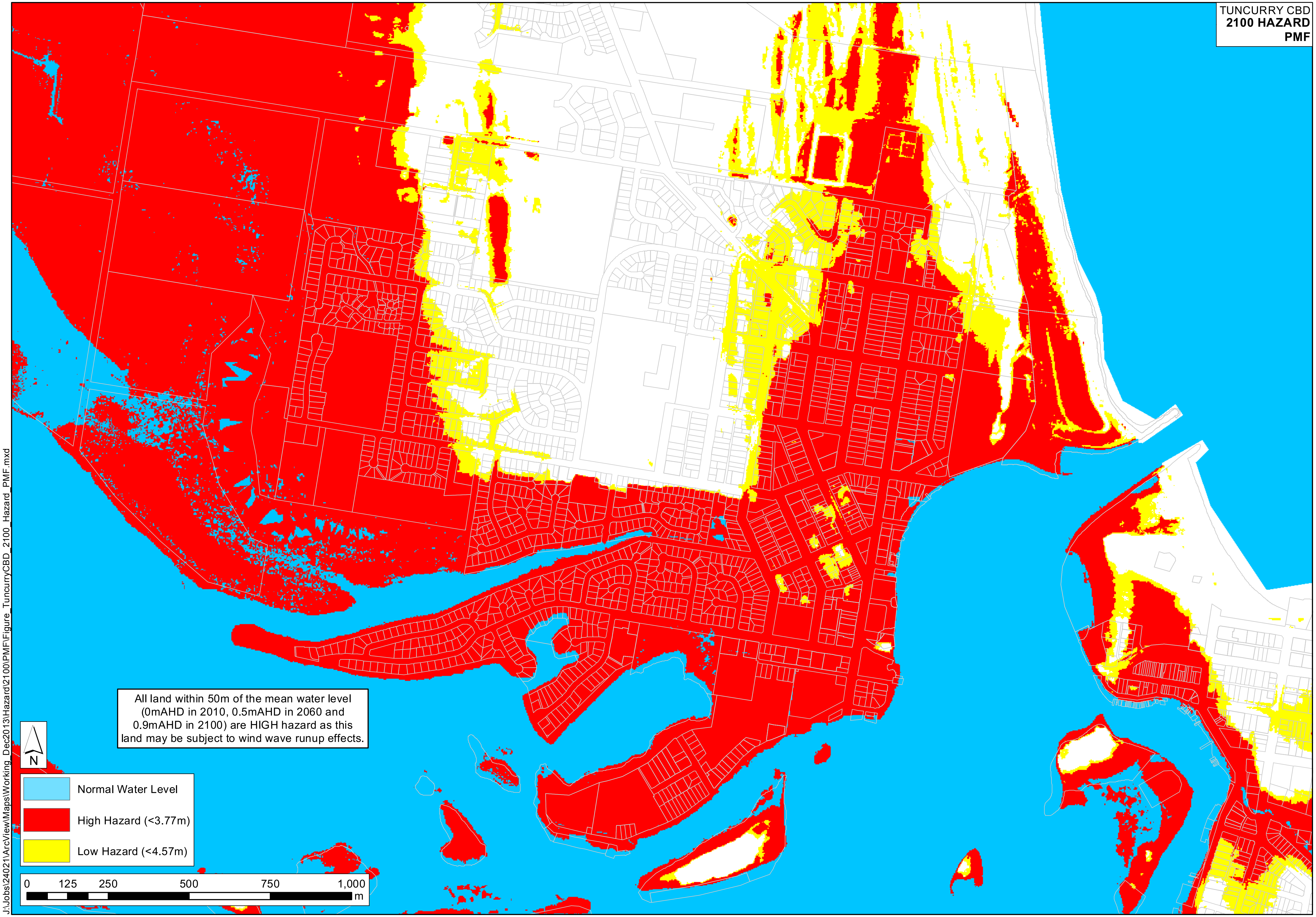
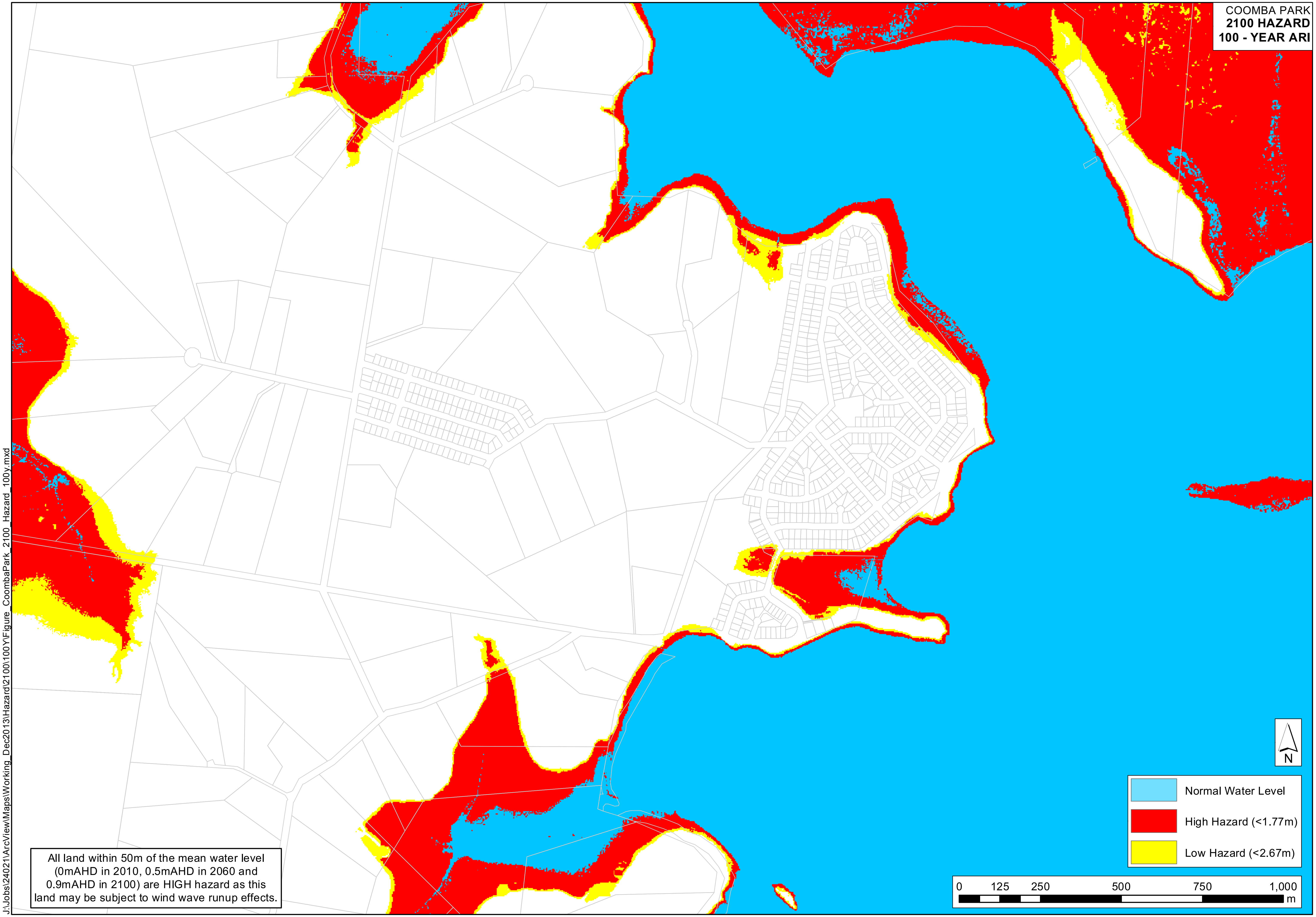

TUNCURRY CBD
2100 HAZARD
100 - YEAR ARI
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<1.77m)
Low Hazard (<2.67m)
0
125
250
500
750
1,000
m
J:\Jobs\240211\ArcView\Maps\Working_Dec2013\Hazard\2100\100Y\Figure_TuncurryCBD_2100_Hazard_100y.mxd



TUNCURRY CBD
2100 HAZARD
PMF
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<3.77m)
Low Hazard (<4.57m)
0 125 250 500 750 1,000
m
J:\Jobs\240211\ArcView\Maps\Working_Dec2013\Hazard\2100\PMF\Figure_TuncurryCBD_2100_Hazard_PMF.mxd



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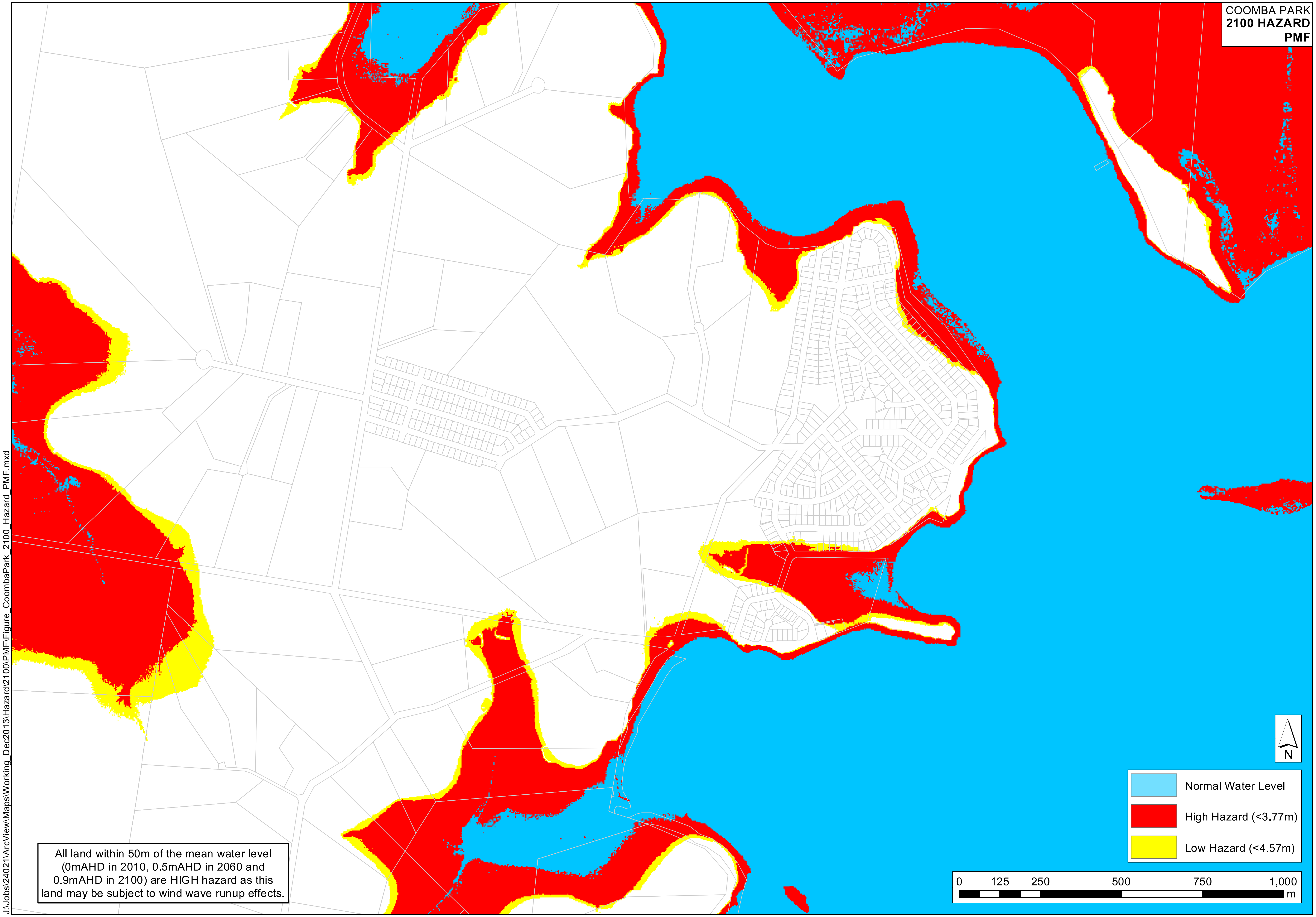

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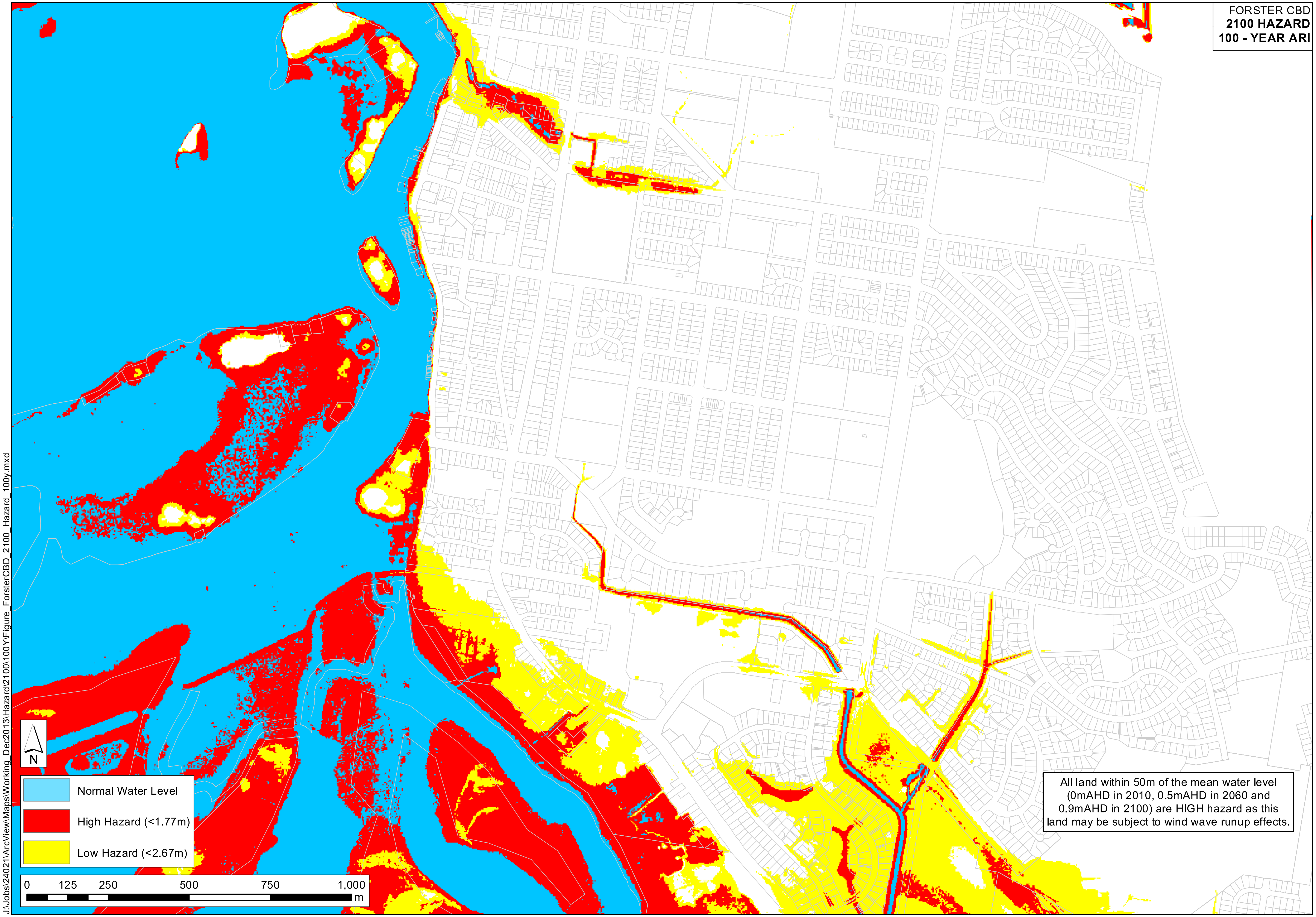

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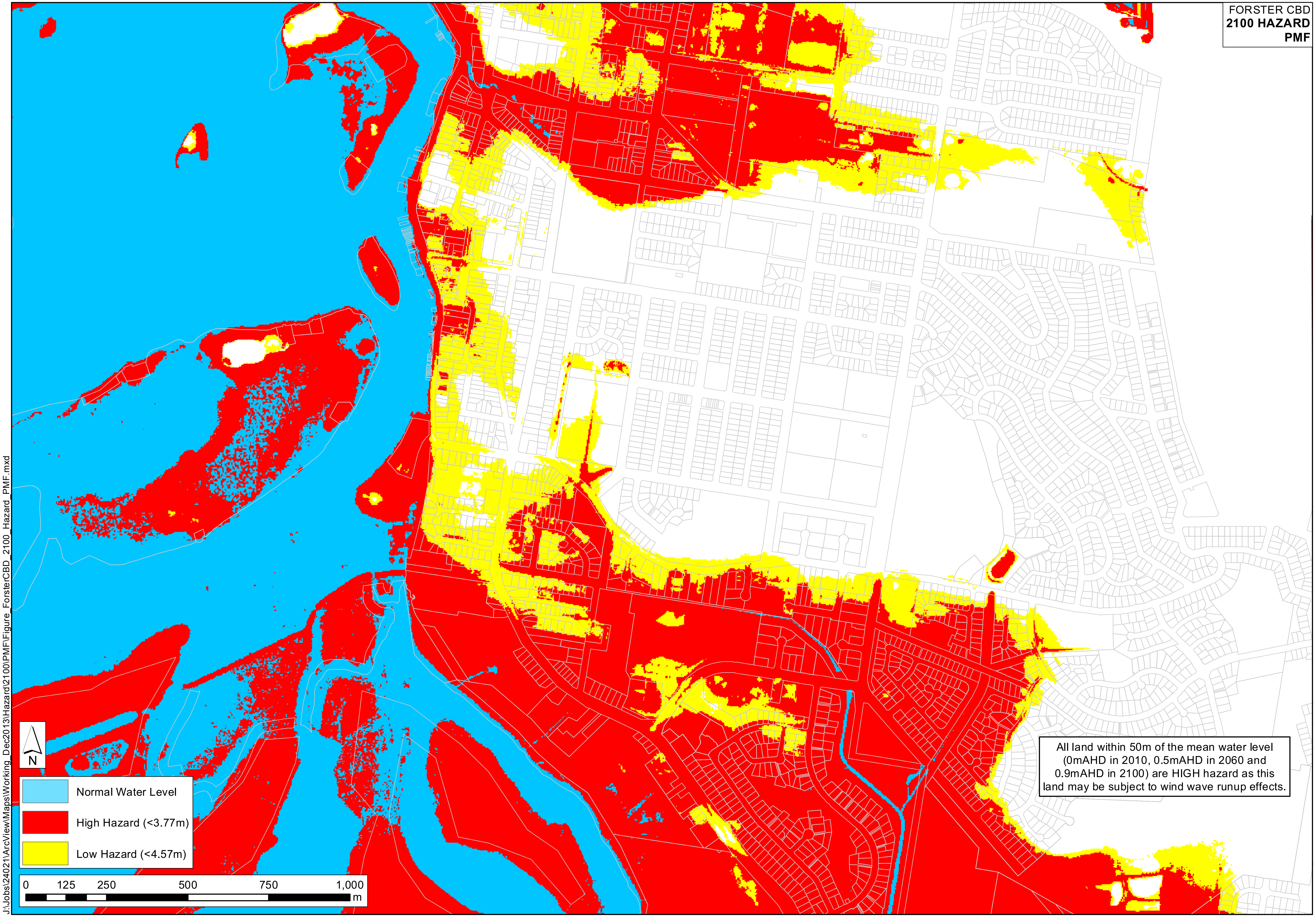
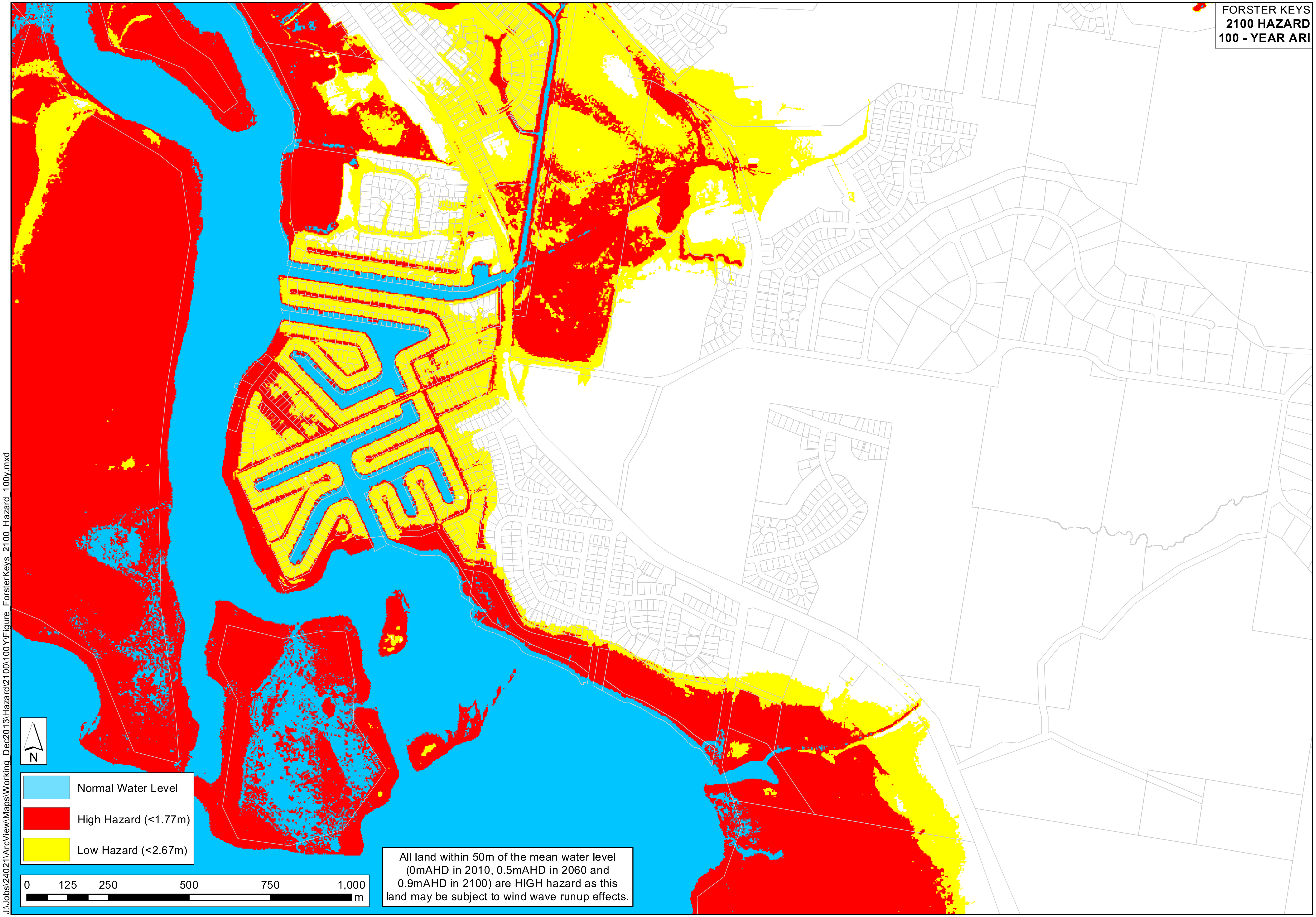


FORSTER CBD
2100 HAZARD
PMF
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
N
Normal Water Level
High Hazard (<3.77m)
Low Hazard (<4.57m)
0
125
250
500
750
1,000
m
J:\Jobs\240214\ArcView\Maps\Working_Dec2013\Hazard\2100\PMF\Figure_ForsterCBD_2100_Hazard_PMF.mxd



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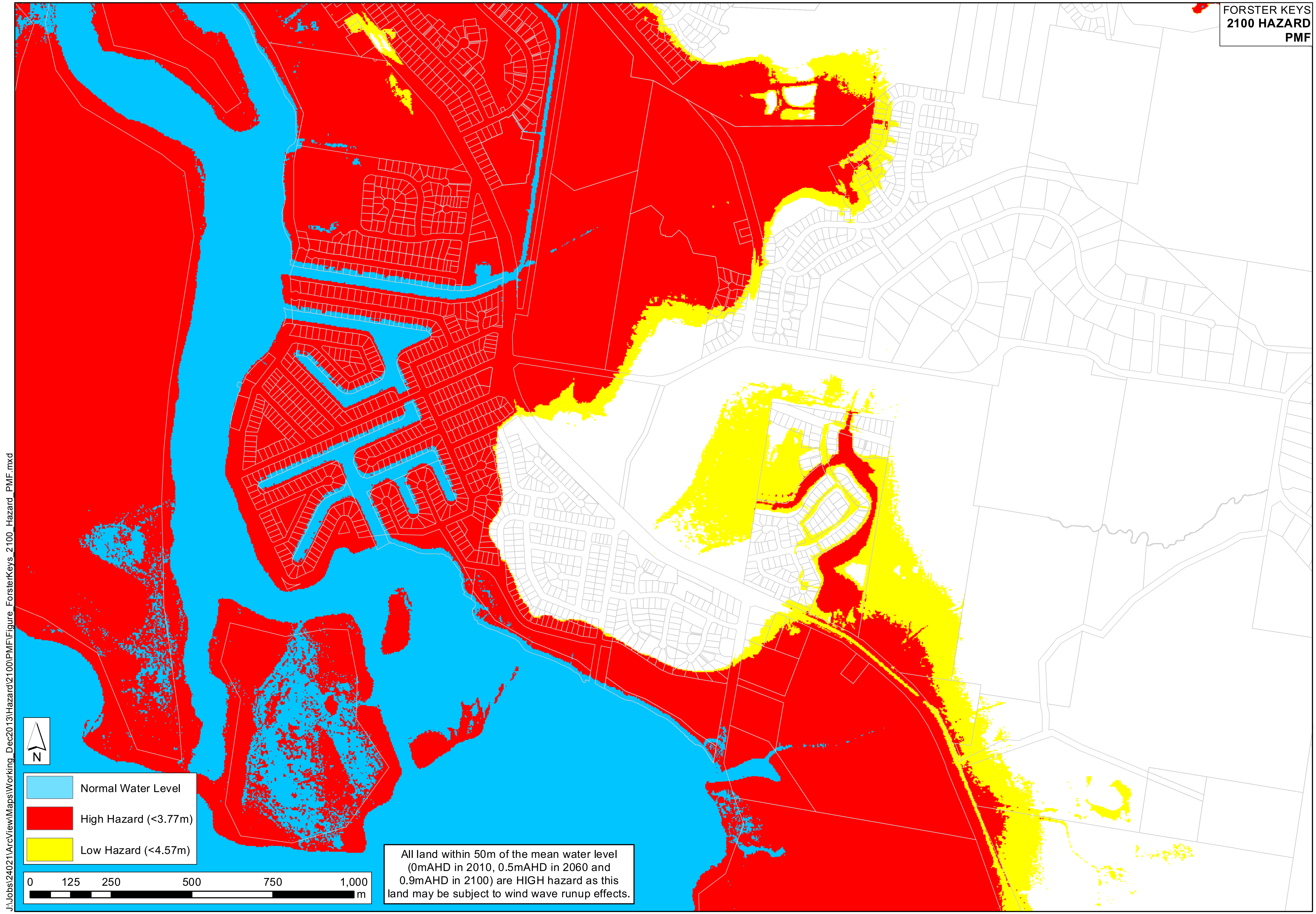

FORSTER KEYS
2100 HAZARD
PMF
N
Normal Water Level
High Hazard (<3.77m)
Low Hazard (<4.57m)
0 125 250 500 750 1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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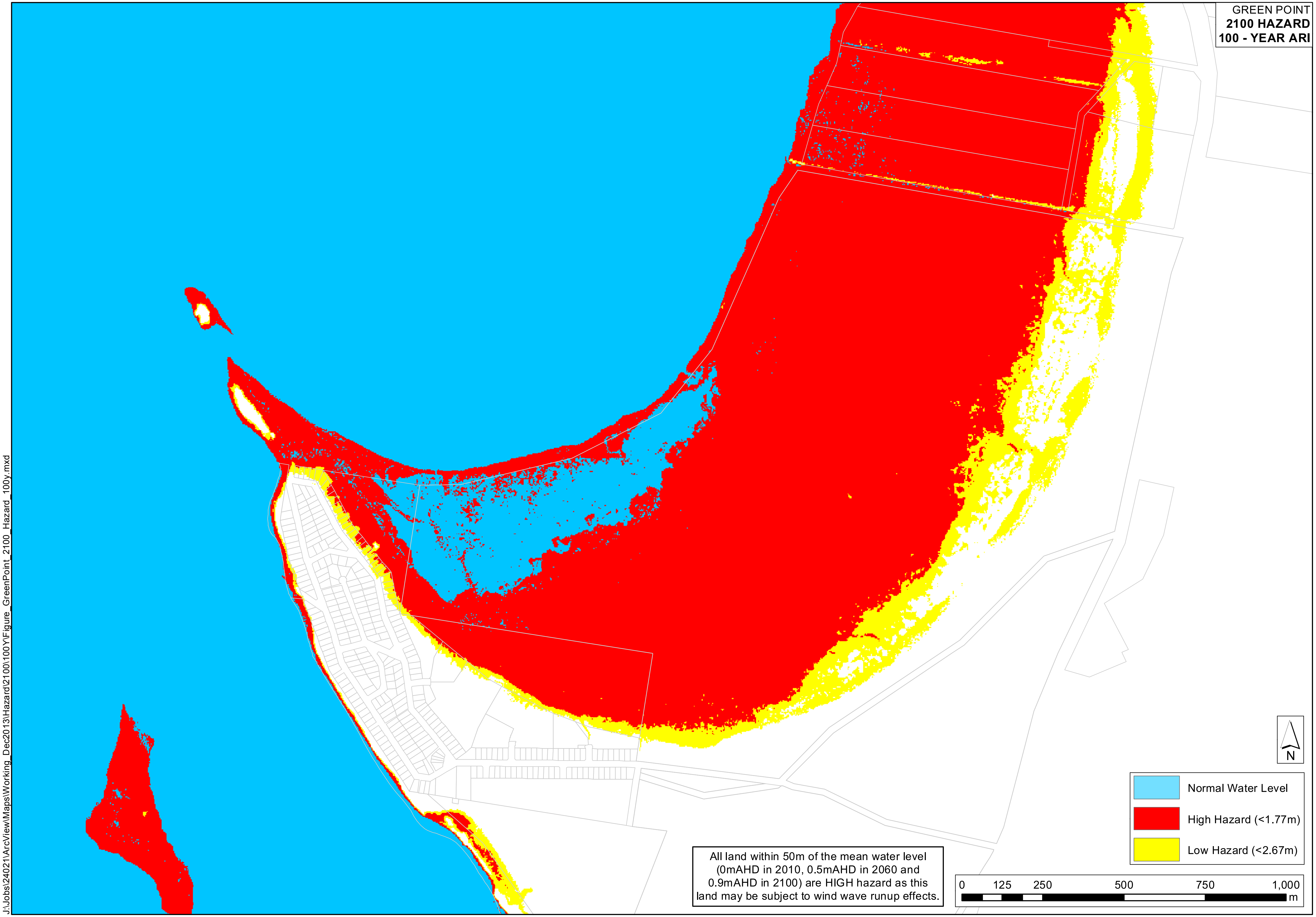

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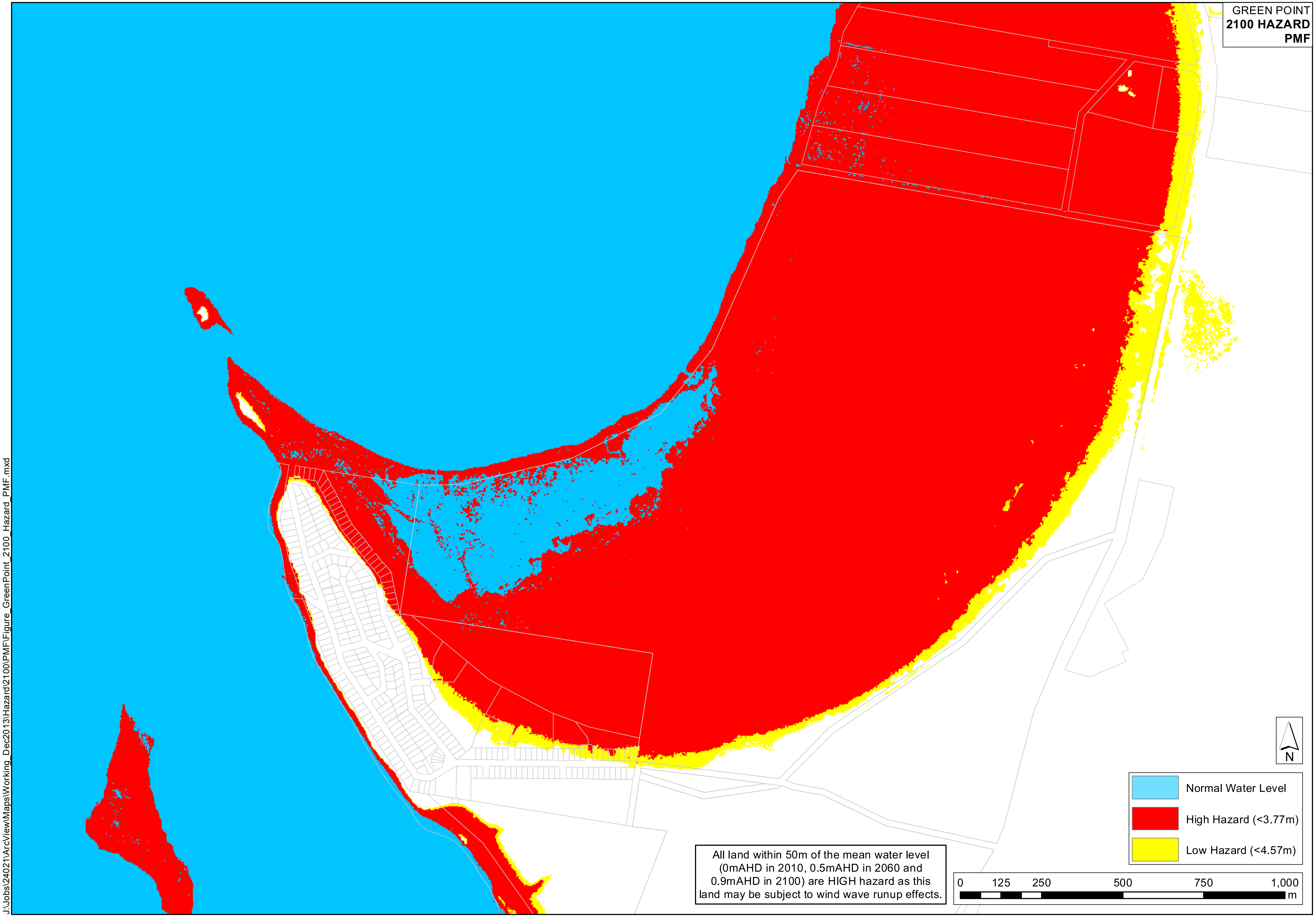
GREEN POINT
2100 HAZARD
PMF
N
Normal Water Level
High Hazard (<3.77m)
Low Hazard (<4.57m)
0
125
250
500
750
1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
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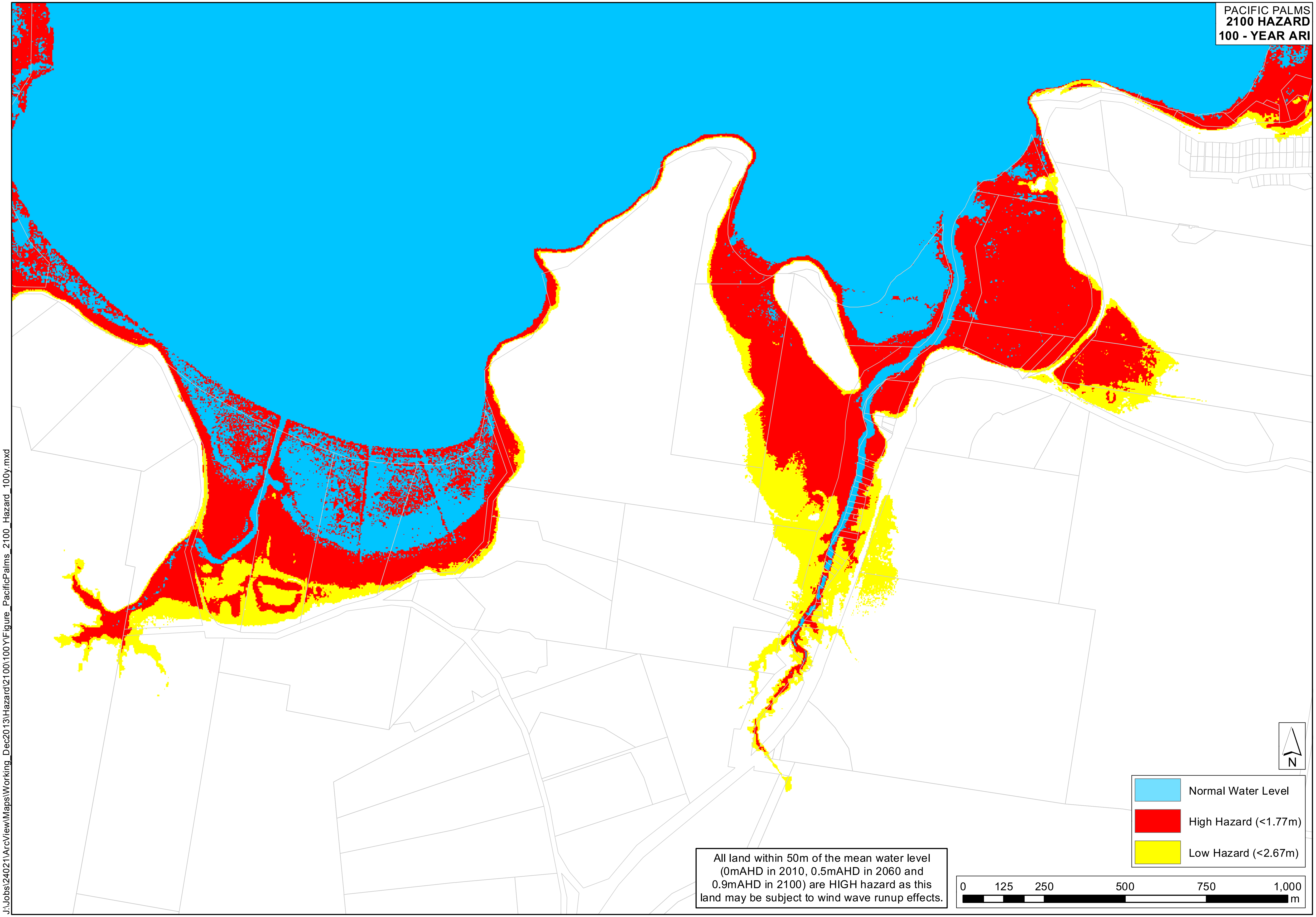

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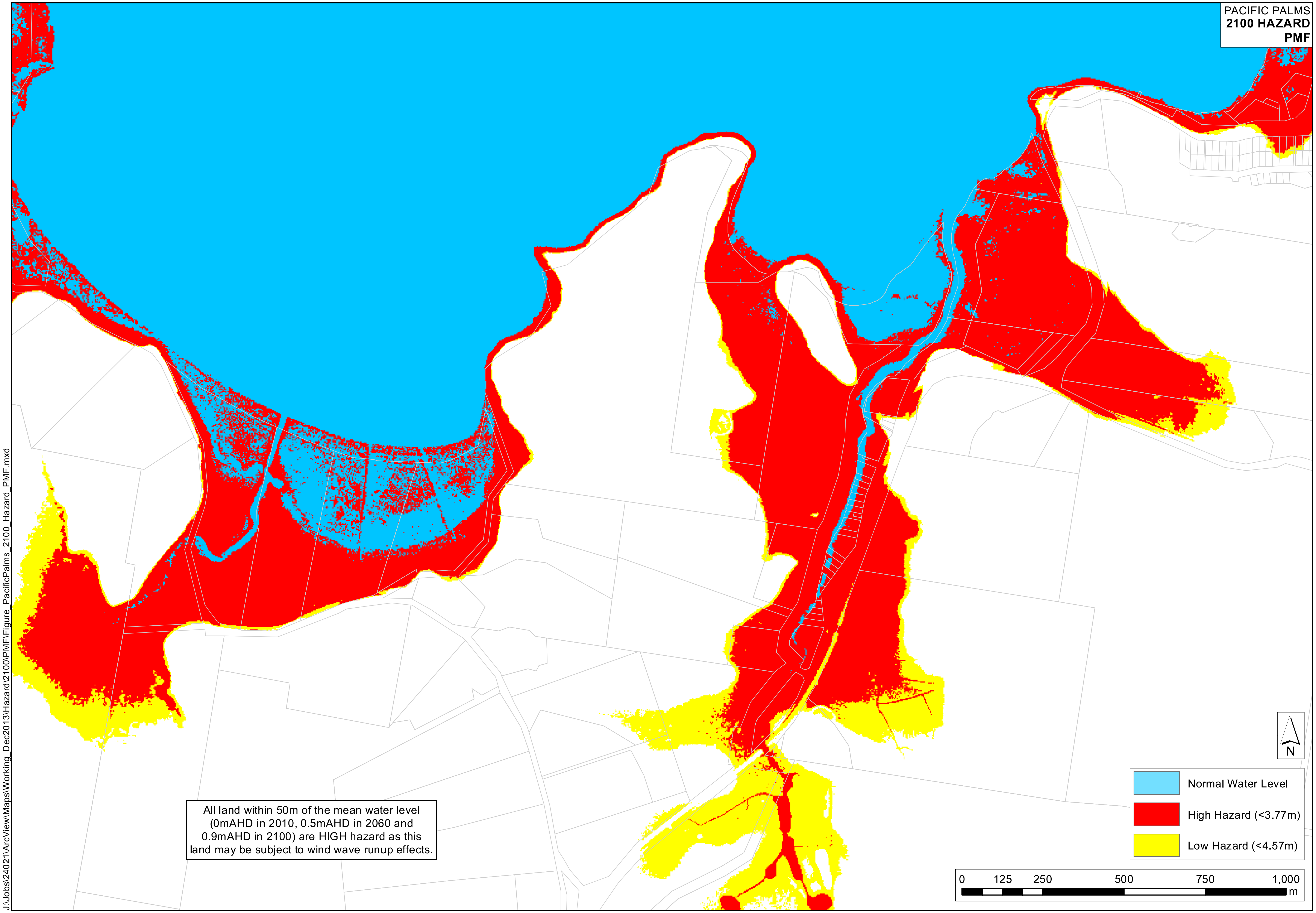
PACIFIC PALMS
2100 HAZARD
PMF
N
Normal Water Level
High Hazard (<3.77m)
Low Hazard (<4.57m)
0
125
250
500
750
1,000
m
All land within 50m of the mean water level (0mAHD in 2010, 0.5mAHD in 2060 and 0.9mAHD in 2100) are HIGH hazard as this land may be subject to wind wave runup effects.
J:\Jobs\24021\ArcView\Maps\Working_Dec2013\Hazard\2100\PMF\Figure_PacificPalms_2100_Hazard_PMF.mxd