SUTHERLAND SHIRE COUNCIL

KURNELL TOWNSHIP FLOOD STUDY

FINAL REPORT

MAY 2009

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KURNELL TOWNSHIP FLOOD STUDY

TABLE OF CONTENTS

PAGE

1. INTRODUCTION 10

1.1. General 10

1.2. Objectives 11

1.3. Outline 11

2. BACKGROUND 12

2.1. Catchment Description 12

2.2. Development of Kurnell 13

2.3. Hydrology and Drainage 14

2.4. Previous Studies 16

2.4.1. *Blair and Stuckey Drainage Study (Reference 1)* 16

2.4.2. *Draft Kurnell Planning Scheme (Reference 1)* 16

2.4.3. *Kurnell Village Drainage Investigation (Reference 1)* 17

2.4.4. *Georges River Floodplain Risk Management Study and Plan (Reference 6)* 17

2.4.5. *Initial Subjective Assessment of Major Flooding (Reference 2)* 18

2.4.6. *Flood Assessment of Lot 105 Torres Street, Kurnell (Reference 7)* 18

3. AVAILABLE DATA 19

3.1. General 19

3.2. Historical Rainfall 19

3.2.1. Overview 19

3.2.2. Available Historical Rainfall Data 20

3.2.3. Analysis of Historical Rainfall Data 21

3.2.4. Historical Rainfall for the May 2003 Event 23

3.3. Design Rainfall 25

3.4. Tidal Data 26

3.4.1. Historical Tidal Levels 26

3.4.2. Design Tidal Levels 27

3.5. Historical Flood Information 27

3.5.1. Previous Reports and Survey 28

3.5.2. Council Records 28

3.5.3. Community Consultation 28

3.5.4. Flood level survey 32
3.5.5. Summary of Historical Flood Information 32
3.6. Topographic and Drainage Information 34
3.6.1. Council Drainage Network 34
3.6.2. Topographic Data 34
3.6.3. Additional Survey Data 35
4. APPROACH ADOPTED 36
5. HYDROLOGIC MODELLING 38
5.1. WBNM Model 38
5.1.1. General 38
5.1.2. Model Configuration 38
5.1.3. Model Parameters 39
5.2. TUFLOW Model – Hydrology 40
5.2.1. General 40
5.2.2. Model Configuration 41
5.2.3. Adopted Hydrologic Model Parameters 42
6. HYDRAULIC MODEL 43
6.1. General 43
6.2. Model Extents 43
6.3. Model Topography 44
6.4. Drainage Network 44
6.5. Manning's Roughness for Overland Flow 45
6.6. Infiltration 45
7. MODEL VALIDATION 47
7.1. General 47
7.2. Approach 47
7.3. Results and Discussion 48
8. DESIGN EVENT MODELLING 50
8.1. Approach 50
8.2. Boundary Conditions 50
8.2.1. Inflow Hydrographs 50
8.2.2. Direct Rainfall 51
8.2.3. Downstream Boundaries 51
9. DESIGN FLOOD RESULTS 52
9.1. Overview 52

9.2. Critical Storm Duration 52
9.3. Model Results and Discussion 53
10. SENSITIVITY ANALYSES 55
10.1. Overview 55
10.2. Results 56
10.3. Tailwater Conditions 61
11. CLIMATE CHANGE 63
11.1. General 63
11.2. Potential Impacts of Climate Change on Flooding in Kurnell 64
11.2.1. Boundary Conditions 64
11.2.2. Results and Discussion 66
11.2.3. Summary 67
12. CONCLUSIONS 72
13. ACKNOWLEDGEMENTS 73
14. REFERENCES 74

LIST OF APPENDICES

APPENDIX A: GLOSSARY OF TERMS
APPENDIX B: HISTORICAL FLOOD INFORMATION

LIST OF TABLES

Table 1: Rainfall Stations within 9km of Kurnell Township (Reference 8) 21
Table 2: Daily Rainfall Exceeding 100 mm at Kurnell (Caltex Oil Refinery) 22
Table 3: Rainfall Events Exceeding 100 mm over 24 hours at Cronulla STP, Sydney Airport and Malabar STP from 1980 to April 2007 23
Table 4: Design Rainfall Data 25
Table 5: Top Five Recorded Tidal Levels from Fort Denison (1965 – 2006) 26
Table 6: Recorded Tidal Levels at Fort Denison for Significant Rainfall Events at Kurnell (Caltex Oil Refinery Daily Gauge) 27
Table 7: Recommended Tidal Levels 27
Table 8: Surveyed Flood Levels 32
Table 9: Summary of WBNM Parameters 39
Table 10: Summary of Manning's 'n' Values 45
Table 11: Design Flood Levels for Tidal Flooding 51

Table 12: Summary of peak flood levels at key locations 53
Table 13: Sensitivity Analyses – Change in Peak Flood Height for 1% AEP Design Flood Event (m) 58
Table 14: Change in Peak Flood Height for Varying Tailwater Conditions (m) 62
Table 15: Climate Change Scenarios 65
Table 16: Potential Increase in Flood Levels for the 20% AEP Catchment Flood due to Climate Change 68
Table 17: Potential Increase in Flood Levels for the 1% AEP Catchment Flood due to Climate Change 69
Table 18: Potential Increase in Flood Levels due to Climate Change for the 5% AEP Ocean Flood combined with a 20% AEP Catchment Flood 70
Table 19: Potential Increase in Flood Levels due to Climate Change for the 1% AEP Ocean Flood combined with a 20% AEP Catchment Flood 71

LIST OF PHOTOGRAPHS

Photograph 1: House in Depression due to Adjacent Infilling (Reference 1) 16
Photograph 2: Flooding at 87 Torres Street during the May 2003 storm 33

LIST OF DIAGRAMS

Diagram 1: Study Location 10
Diagram 2: Study Area 12
Diagram 3: Kurnell population growth between 1930 and 2001 (Source: References 1 and 4) . 13
Diagram 4: Comparison of Daily Rainfall from Caltex Oil Refinery against nearby Pluviograph Records – May 2003 Rainfall Event 24
Diagram 5: Number of Years Respondents have Lived or Owned a Property in Kurnell 30
Diagram 6: Flood Events Identified by Respondents to the Community Questionnaire 30

LIST OF FIGURES

Figure 1: Kurnell Township
Figure 2: Kurnell Pit and Pipe Drainage System
Figure 3: 1980 Reported Flooding – Kurnell Village Drainage Investigation
Figure 4: 1980 Recommended Fill (Source: Kurnell Village Drainage Investigation)
Figure 5: Recommended Remedial Works (Source: Kurnell Village Drainage Investigation)
Figure 6: Location of Rainfall Stations
Figure 7: 1975 Cook Street Flooding (Source: Kurnell Village Drainage Investigation)
Figure 8: 1974 Tidal Inundation (Source: Kurnell Village Drainage Investigation)
Figure 9: Reported Flooding – Current Study
Figure 10: Contour Comparison
Figure 11: Additional Survey
Figure 12: Subcatchment Layout
Figure 13: TUFLOW Model Layout
Figure 14: Peak Flood Depths Historical Evant May 2003
Figure 15: Flood Levels 20% AEP Event
Figure 16: Flood Levels 20% AEP Event Inset
Figure 17: Flood Levels 20% AEP Rainfall Event with a 1% Storm Tide
Figure 18: Peak Flood Levels 5% AEP Event
Figure 19: Peak Flood Levels 5% AEP Event Inset
Figure 20: Peak Flood Levels 1% AEP Event
Figure 21: Peak Flood Levels 1% AEP Event Inset
Figure 22: Peak Flood Levels PMF Event
Figure 23: Peak Flood Levels PMF Event Inset
Figure 24: Peak Flood Levels 20% AEP Event
Figure 25: Peak Flood Levels 20% AEP Event Inset
Figure 26: Peak Flood Levels 5% AEP Rainfall Event With 1% Storm Tide
Figure 27: Peak Flood Depths 5% AEP Event
Figure 28: Peak Flood Depths 5% AEP Event Inset
Figure 29: Peak Flood Depths 1% AEP Event
Figure 30: Peak Flood Depths 1% AEP Event Inset
Figure 31: Peak Flood Depths PMF Event
Figure 32: Peak Flood Depths PMF Event Inset
Figure 33: Flood Velocity 20% AEP Event
Figure 34: Flood Velocity 20% AEP Rainfall Event with a 1% Storm Tide
Figure 35: Flood Velocity 5%AEP Event
Figure 36: Flood Velocity 1%AEP Event
Figure 37: Flood Velocity PMF Event
Figure 38: Provisional Hydraulic Hazard Categories 1% AEP Event
Figure 39: Provisional Hydraulic Hazard Categories PMF Event
Figure 40: 2m and 4m Grid Comparison
Figure 41: Potential Change in Dominant Flood Mechanism Due to Climate Change by 2100
Figure 42: Increase in 1% AEP Flood Level for High Climate Change Scenario by 2100 (Peak Envelope of Ocean and Catchment Flood Events)

Foreword

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any 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 subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Council's in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through 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 following Kurnell Flood Study constitutes the first stage of the management process for this catchment area. WMAwater (formerly Webb, McKeown & Associates) were commissioned by Sutherland Shire Council to prepare this flood study on behalf of the Council's Floodplain Risk Management Committee. Funding for this study was provided by Sutherland Shire Council and the Department of Environment and Climate Change (DECC). This report documents the work undertaken and presents outcomes that define flood behaviour for existing catchment conditions.

Executive Summary

Kurnell is susceptible to flooding from both rainfall and tidal inundation. Kurnell's low lying topography and localised depressions can make it vulnerable to extensive flooding. Development has been a significant contributor to the flooding problem, by increasing runoff, filling in storage areas, and blocking flow paths. In a recent flooding investigation covering the Sutherland Shire Council Local Government Area, Kurnell was given a very high priority in terms of the extent and frequency of flooding (Reference 2).

Sutherland Shire Council has engaged WMAwater to undertake a Flood Study for Kurnell township, which is the first component of the four stage Floodplain Risk Management process. The specific aims of the current study are to:

- define the existing flood behaviour in the Kurnell catchment,
- prepare flood extent and provisional flood hazard maps, and
- provide hydrologic and hydraulic models which can be used to develop the subsequent Floodplain Risk Management Study and Plan.

The Kurnell Flood Study involved the collection of available data to enable an adequate representation of the Kurnell catchment within the hydrologic and hydraulic models. The data collection process included:

- a review of previous reports, photographs and Council records,
- community consultation, including a questionnaire survey and direct consultation with a number of residents,
- the collection of historical rainfall, tidal and flood level data, and
- the collection of survey data, including Airborne Laser Scanning (ALS) and details of major drainage channels.

Due to the absence of long term historical flood data, a rainfall-runoff computer modelling approach was adopted. This involved the development of two computer models – a hydrologic model to convert rainfall to runoff, and a hydraulic model to route runoff through the catchment. Direct rainfall was applied to the hydraulic model, to improve the representation of flows throughout the study area.

The model calibration and validation process was limited by a lack of adequate historical flood data. A comprehensive sensitivity analysis was therefore also conducted, in order to investigate the sensitivity of the model to different model parameters and components.

Design flood levels and extents for the 20%, 5%, 1% and Probable Maximum Flood (PMF) events were determined using design rainfall data from Australian Rainfall and Runoff (1987). The models were also used to analyse the impact of tidal inundation.

The model results indicated that Kurnell is susceptible to extensive flooding throughout the majority of the study area. However, a significant proportion of the flooding is caused by shallow, slow moving floodwaters. Flood risk is increased by the lack of clear evacuation routes, and the length of time taken for floodwaters to recede.

Whilst flooding is currently dominated by runoff from rainfall, predicted sea level rise has the potential to increase the impact of tidal inundation. Future management strategies therefore need to consider the effects of both rainfall and tidal flooding.

It is recommended that these issues are taken into consideration in the subsequent Floodplain Management Study.

1. INTRODUCTION

1.1. General

The township of Kurnell is located within the north eastern region of the Sutherland Shire Council Local Government Area. It is approximately 17km south of the Sydney CBD on the south east coast of NSW, as shown in Diagram 1.

Diagram 1: Study Location

Kurnell has experienced flooding issues since its development in the 1950's, which impacted upon much of the area's natural drainage paths and storage areas. Filling of land for industrial purposes to the south east of the town in the early 1950's reclaimed a significant proportion of the natural swamp, which intensified flooding in the north east of Kurnell village (Reference 1). With the exception of the high ground in the vicinity of Polo Street (as shown in Figure 1), the residential area of Kurnell is entirely located on low lying sandy flats extending into Quibray Bay.

The town's low lying nature and proximity to the Bay also makes it susceptible to flooding from tidal inundation. In an *Initial Subjective Assessment of Major Flooding* report prepared for Sutherland Shire Council (Council) in 2004 (Reference 2), the Kurnell township subcatchment was given a very high priority within the Council area in terms of the extent and frequency of flooding.

In light of these flooding issues, Council has undertaken to develop a Floodplain Risk Management Plan for Kurnell township. The Plan aims to address existing and future flood problems in accordance with the NSW Flood Prone Land Policy. Development of the Floodplain

Risk Management Plan is a four stage process, consisting of:

- a Flood Study,
- Floodplain Risk Management Study,
- a Floodplain Risk Management Plan, and
- implementation of the Plan by local government.

This report forms the first stage of the process, whilst the Floodplain Risk Management Study and Plan will be presented in subsequent reports.

1.2. Objectives

Sutherland Shire Council engaged Webb, McKeown & Associates to prepare the Kurnell Township Flood Study, utilising current technology and data. The information and results obtained from the study will be used in the preparation of the Floodplain Risk Management Study and Plan. The specific objectives of the Kurnell Township Flood Study are to:

- Develop suitable hydrologic and hydraulic models to define flood behaviour, and that can be used in the subsequent Floodplain Risk Management Study and Plan.
- Use these models to quantify flood levels, velocities, flows and flood extents for the 20%, 5% and 1% Annual Exceedence Probability (AEP) design storm events and the Probable Maximum Flood (PMF). The impact of both surface runoff and tidal inundation will be considered.
- Assess the provisional hydraulic categories and undertake provisional flood hazard mapping in accordance with the *NSW Floodplain Development Manual 2005* (Reference 2).

1.3. Outline

This report details the methodology, results and findings of the Kurnell Township Flood Study, the key elements of which include:

- a background to the study area (Chapter 2),
- a summary of available flood related data (Chapter 3),
- the development and validation of the hydrologic and hydraulic models (Chapters 4 to 7),
- the definition of the design flood behaviour for existing conditions through the analysis and interpretation of model results (Chapters 8 and 9), and
- a sensitivity analysis of key model parameters and an analysis of the potential impacts of climate change (Chapters 10 and 11).

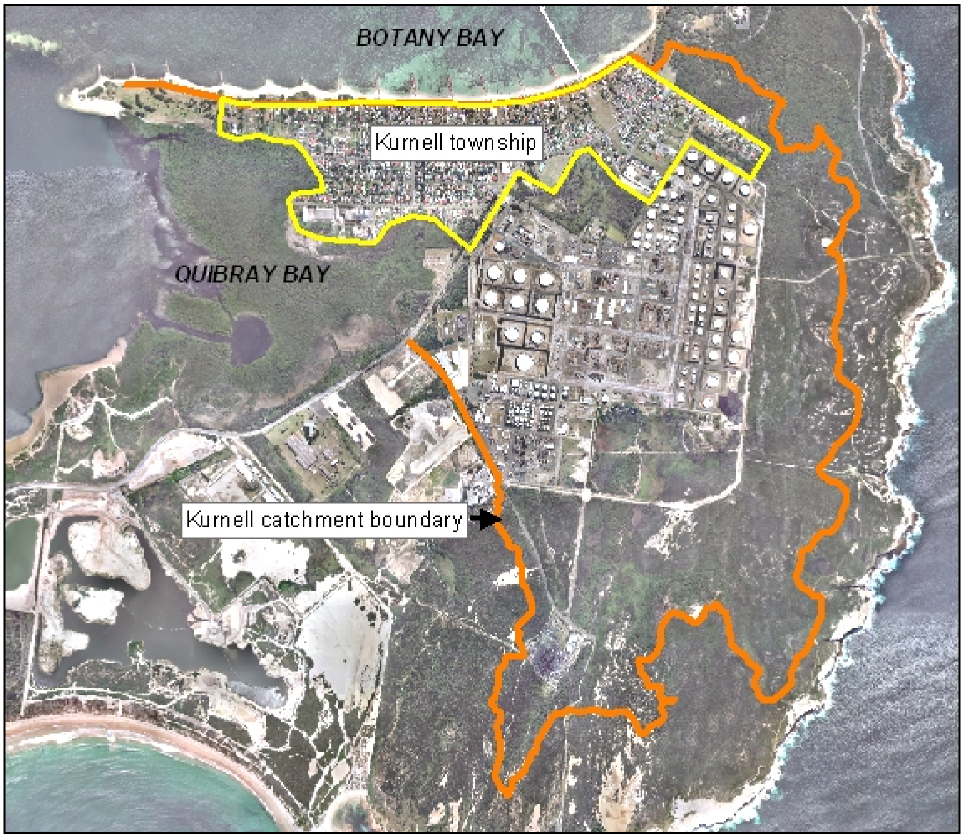
A glossary of flood related terms is provided in Appendix A.

2. BACKGROUND

2.1. Catchment Description

The study area consists of the Kurnell township, as shown in Diagram 2. Its catchment area extends further east and south, and is bounded by Botany Bay to the north, Quibray Bay to the west, and Botany Bay National Park to the east and south, as shown in Diagram 2.

Diagram 2: Study Area and Catchment Area



The extent of the catchment area has been defined in consultation with Council, and covers the area draining to Quibray Bay north of Sir Joseph Banks Drive. This includes the entire township of Kurnell, as well as the Caltex Oil Refinery and part of the Botany Bay National Park.

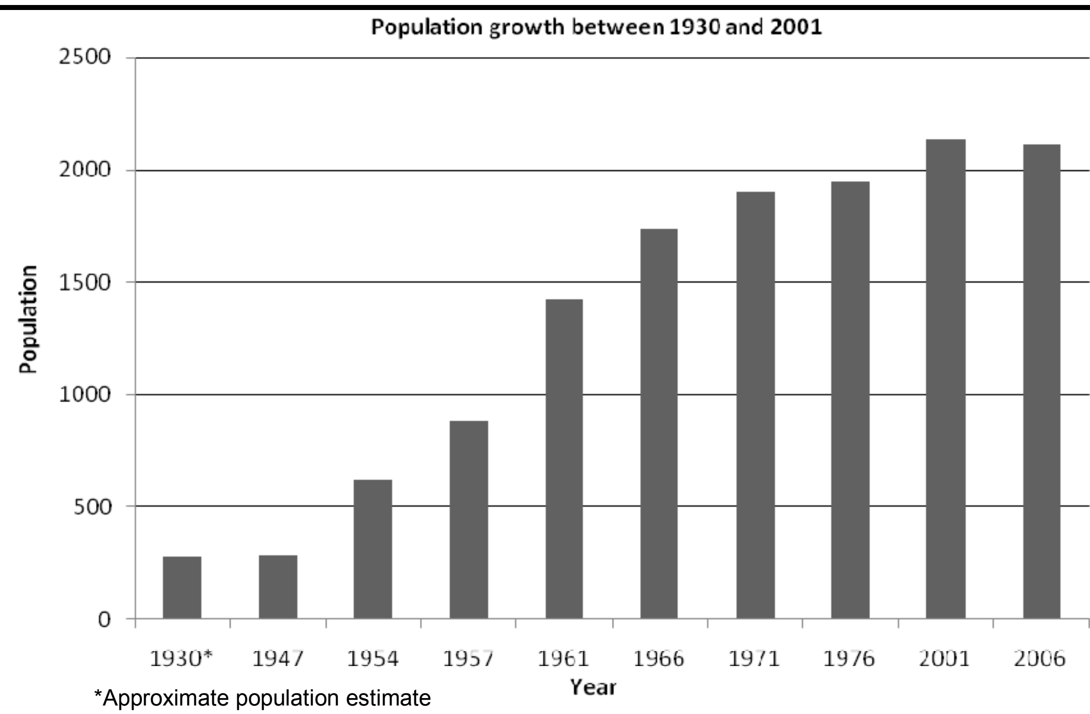
The catchment encompasses an area of approximately 6.5km^2, of which approximately 25% is national park, 15% is residential, 20% is swamp or wetland, and 40% is industrial. The upper reaches of the catchment are predominantly steep, particularly within Botany Bay National Park where slopes of up to 25% can be found. However, the lower reaches of the catchment, including the Kurnell Township itself, is typically flat and low lying. Elevations are generally below 3 m Australian Height Datum (AHD) with the exception of the north east corner, which reaches approximately 19.5 mAHD.

2.2. Development of Kurnell

Kurnell is the site of Captain James Cook's first landing along the east coast of Australia in 1770. However, it was not until 1815 that the first land holding was taken. Minimal development occurred during the 1800's, with the majority of land owned by only a few individuals. There was no direct access to Kurnell in the 1800's and early 1900's other than by a small track, which limited development of the area. The introduction of a ferry service from Kurnell to San Souci in 1903 and to La Perouse in 1912 encouraged some expansion of the village. During the 1930's and 40's, Kurnell became a small fishing village with a population of less than 300 residents. It was not until the construction of the oil refinery and access road in the 1950's that Kurnell's development greatly advanced. By 1961, the population had reached 1424 (Reference 1).

Despite rapid growth following construction of the Caltex Oil Refinery, there has only been relatively minor development since the late 1980's. This would appear to be at least partly due to a risk assessment for Kurnell Peninsula (*Kurnell Peninsula Land Use Safety Study*), which was initially conducted in 1986, and was last updated in 2007 (Reference 3). The assessment found that the likelihood of catastrophic failure of the oil refinery and other industries was minimal. However, the impacts were considered potentially severe should failure occur. This in combination with the provision of only a single evacuation route via Captain Cook Drive resulted in residential development restrictions being imposed through regional planning controls. Consequently, the population had stabilised to just over 2000 residents by the 2001 Census (Reference 4). This can be seen from Diagram 3, which depicts the change in population since 1930.

Diagram 3: Kurnell population growth between 1930 and 2001 (Source: References 1 and 4)



*Approximate population estimate

Based on recommendations from the *Kurnell Peninsula Land Use Safety Study*, it would appear that extensive new development in Kurnell is unlikely in the near future (Reference 3). However, Sutherland Shire Council note in the Project Brief for this study that there is still potential for redevelopment of Kurnell township.

2.3. Hydrology and Drainage

Two main mechanisms govern hydrologic processes in Kurnell. These are local rainfall and runoff, and tidal inundation. The majority of the township is below 3 mAHD, with the exception of areas in the vicinity of Polo Street in the north east of the catchment. A combination of flat topography and proximity to Quibray Bay makes Kurnell highly susceptible to flooding.

Unlike many catchments, Kurnell does not have a single main drainage line with associated tributaries. Runoff from the Botany Bay National Park enters the Kurnell township area to the north, whilst runoff to the east and south is largely diverted via the Caltex Oil Refinery to Botany Bay and Quibray Bay. Within the township, overland flow paths occur along depressions formed by remnant dunes, running southwest toward Quibray Bay. Formalised drainage and development also influences runoff at a smaller scale.

Early development of Kurnell township did not take the natural drainage regime into consideration. Both the expansion of residential development and the construction of the oil refinery have had a significant impact on the hydrology of the area. Infiltration and storage areas have been reduced, and natural flow paths have been constricted. Sandy soils dominate the area, allowing rapid infiltration until the groundwater table rises to the surface. However, urbanisation has led to an increase in paved areas, thus reducing the area available for infiltration. Areas providing stormwater detention during large storm events have also been lost through cut and fill for residential development.

The swamp system in the vicinity of Solander Street and Cook Street (Figure 1) plays an important role in the drainage of the area, collecting runoff from the National Park to the east and south as well as the surrounding residential areas to the north and west. Prior to construction of the refinery, this swamp system covered a much larger area, and the Cook Street and Solander Street swamps were directly connected to each other. The northern corner of the refinery was constructed on reclaimed swamp, restricting the connectivity between the two swamps and pushing the main body of the Cook Street swamp closer to the residential properties in Cook Street.

The Cook Street Swamp is now connected to the Solander Street Swamp via a pipe, which discharges into Solander Street Swamp at the southern end of Cook Street, as shown in Figure 2. Flow from Solander Street Swamp is conveyed across Captain Cook Parade via a box culvert and drains to Quibray Bay by way of an open channel. Catchment flows also discharge directly into Quibray Bay from Balboa, Torres, Bridges, Tasman, Horning and Dampier Streets.

Whilst a number of different drainage schemes have been developed over the years, these have had varying success, and flooding remains an issue in Kurnell. These schemes are described in greater detail in the following section. In some cases, partial implementation of a scheme has had a detrimental effect, such as the creation of localised depressions by partial filling due to the 1957 Blair and Stuckey scheme. The 1980 Revised Drainage Scheme (Reference 1) provided a number of more appropriate recommendations, some of which have since been implemented. These included the improvement of drainage in the Cook Street area, with the construction of a 375 mm pipe running from Cook Street Swamp to Cook Street. A 1050 mm diameter pipe has also been constructed along the northern side of Captain Cook Drive, adjacent to the National Park. However, the recommendation to fill Cook Street Swamp and provide tidal protection along Balboa and Torres Streets has not been carried out.

A number of additional changes to the drainage system have been made since 1980. These have included the construction of pipes in Solander Street Swamp, and the completion of the regrading of Dampier Street. The existing drainage system currently consists of a conventional pit and pipe network in a number of locations throughout the catchment, as shown in Figure 2. Kerb and guttering along the majority of roads also provide trunk drainage in areas without pit inlets. Piped drainage conveys stormwater to Botany Bay, Quibray Bay and Cook Street Swamp. The majority of pipes are on a very flat or zero grade due to the flat nature of the catchment topography. This makes the piped drainage system susceptible to blockage due to a build up of silt and debris. This is confirmed by comments from residents in questionnaire responses, as discussed in Section 3.5.3.

The Caltex Oil Refinery site captures runoff from part of the Botany Bay National Park. The Caltex Oil Refinery's drainage system is designed to provide a level of treatment for runoff entering or generated within the site, prior to discharge into downstream areas. Runoff entering the site is therefore collected and treated along with uncontaminated runoff generated within the site. Contaminated runoff is contained within bunded areas, and undergoes additional treatment prior to discharge. After treatment, flows from the Caltex Oil Refinery are discharged to three main locations. The first of these is via a 1050 mm diameter pipe which runs along a drainage easement and discharges into Botany Bay near the Caltex Wharf. Flows also discharge through a 1050 mm diameter pipe under Captain Cook Drive and into Quibray Bay. Runoff from the Australian Lubricating Oil Refinery (ALOR) site to the west of site drains into an open channel, which runs along Sir Joseph Banks Drive and into Quibray Bay (Reference 5).

2.4. Previous Studies

A summary of previous flooding and drainage investigations for Kurnell is provided in the following sections. The first three studies listed were presented and discussed in the *Kurnell Village Drainage Investigation* (Reference 1). Reference 1 contains a review of flooding and drainage in Kurnell, and presented an independent recommended drainage scheme.

2.4.1. *Blair and Stuckey Drainage Study (Reference 1)*

The first drainage assessment and plan for Kurnell was undertaken by Blair and Stuckey in the mid 1950's (Reference 1). Their proposed scheme was based on a conventional pit and pipe network system, which relied on infilling much of the town to create sufficient grade to allow drainage. A minimum fill level of 1.75 m was set, based on providing sufficient hydraulic head to allow drainage and protection against the highest anticipated tide of 1.45 mAHD. However, in the years between when the investigation began and when the plan was completed in 1957, much of Kurnell had already been developed. This limited the number of properties which could be raised, and meant filling of developed areas could only occur when redevelopment took place. This also had the effect of leaving some houses in trapped depressions, creating artificial storage areas during flooding. One such example is shown in Photograph 1. The cost of filling was also prohibitive, and hence in 1978 the scheme was abandoned.

Photograph 1: House in Depression due to Adjacent Infilling (Reference 1)

2.4.2. *Draft Kurnell Planning Scheme (Reference 1)*

Having abandoned the Blair and Stuckey scheme, Sutherland Shire Council proposed an alternative *Draft Kurnell Planning Scheme,* which was presented to the Planning and Environment Commission in 1979. The new scheme relied more upon utilising the natural drainage of the area. It involved identification and maintenance of natural storage areas and drainage paths by restricting development in these locations. In addition, development was to be prohibited in areas below 1.53 mAHD due to the risk of tidal inundation. The level of 1.53 mAHD was based on a predicted 2% AEP tidal level of 1.43 mAHD (provided by the Maritime Services Board), plus an additional 0.1m to allow for a sufficient hydraulic head for drainage to occur. However, when the scheme was exhibited in 1980, it was rejected by the community due to the necessary restrictions on subdivision and development. By 1980, Council had also completed a detailed survey of Kurnell which indicated that the low points identified as part of the study did not correspond with the actual depressions. Consequently, the scheme was not implemented.

2.4.3. *Kurnell Village Drainage Investigation (Reference 1)*

Following the rejection of the *Draft Kurnell Planning Scheme* (Reference 1) Council commissioned Warner to undertake a review of the existing drainage system in Kurnell and to provide recommendations for improvements. The proposed improvements utilised similar principles to those in the *Draft Kurnell Planning Scheme* (Reference 1), with a focus on the use of natural drainage paths.

Property interviews were conducted in areas identified as susceptible to inundation, and were used to assist in evaluating the severity of flooding at these locations. Figure 3 shows locations where flooding problems were reported. The resident survey identified two main flooding problems. The first of these was in the vicinity of Cook Street, where flooding was considered to be caused by runoff from the Botany Bay National Park and infilling to Cook Street swamp. The second was tidal inundation from Quibray Bay near Balboa and Torres Streets.

Recommendations were made to modify Council’s previously proposed locations for seepage basins to reflect the recent ground survey completed in 1980. In order to address flooding in the Cook Street area, it was recommended that Cook Street Swamp be filled and conventional pit and pipe drainage be installed. To minimise tidal inundation from Quibray Bay one recommendation was to fill areas which were below 1.53 mAHD. The presence of existing development meant that this could only be implemented as a long term strategy, hence a levee along the corner of Balboa and Torres Streets was also suggested. The proposed system involved the use of either a tidal flap or a small pumping station adjacent to the levee.

Findings from the resident survey indicated that there was adequate on-site drainage for the majority of properties which were not in the Cook Street or Balboa Street areas. This assumption greatly reduced the requirement for fill and for the installation of conventional pit and pipe drainage. However, there were some properties which collected runoff from outside the boundary areas, and hence the on-site drainage may not have been adequate. There were also some locations where fill and additional drainage works were recommended. These are shown on Figures 4 and 5 respectively.

2.4.4. *Georges River Floodplain Risk Management Study and Plan (Reference 6)*

In 2001, Bankstown and Liverpool City Council’s engaged Bewsher Consulting to undertake the *Georges River Floodplain Risk Management Study & Plan* (Reference 6). The project was later expanded to include Fairfield City Council and Sutherland Shire Council, and was completed in 2004. This study provided an assessment of design tidal levels in Botany Bay. This information has been used in the present study, as discussed in Section 3.4.

2.4.5. *Initial Subjective Assessment of Major Flooding (Reference 2)*

Sutherland Shire Council engaged Bewsher Consulting in 2003 to prepare an *Initial Subjective Assessment of Major Flooding* (Reference 2) for the Council area. The assessment was based on:

- the location of flooding complaints,
- preliminary hydrologic and hydraulic modelling using the Urban Rational Method and the principles of open channel flow, and
- knowledge of flood risk in the area.

For the modelled 1% AEP and PMF events, 776 and 787 properties respectively were estimated to be flooded in Kurnell township. Kurnell was also given the highest risk rating as part of a qualitative assessment. For these reasons, Kurnell was identified as has having the second highest risk in terms of the extent and frequency of flooding within the Council area.

2.4.6. *Flood Assessment of Lot 105 Torres Street, Kurnell (Reference 7)*

This study was carried out by Webb, McKeown & Associates, and involved the assessment of potential flooding impacts resulting from a proposed development in Torres Street, Kurnell. The assessment included a hydrologic analysis of the site both with and without the proposed development.

As part of the study, aerial photographs and survey data of the site was obtained. Survey data and contour maps from 1991 were also provided by Council. This information provides details on the topography of the site and adjacent areas.

The hydrologic analysis included an estimation of infiltration rates at the site, which was calculated using observed ponding times and the surface area in contact with the ponded water. Ponding times of 24 to 48 hours were estimated to equate to an infiltration rate of approximately 1.5×10^{-6} m/s.

3. AVAILABLE DATA

3.1. General

The first stage in the investigation of flooding is to define the nature, size and frequency of the problem. One method of measuring flood frequency and size is through the use of stream gauges, which provide stream heights for historical flood events. These are generally located along major river systems such as the Georges River, and may date back to the early 1900's, or in some cases further. However, in small urban catchments with no major rivers or creeks such as Kurnell, there are typically no stream gauges or official historical records available. Historical flood information must therefore be obtained from an examination of rainfall records and local knowledge. For this reason, a comprehensive data collection exercise was undertaken.

Data collated for this study includes historical and design rainfall data, tidal levels, historical flood information and topographical and drainage information. This section provides an overview of this information, giving a background to flood behaviour in the study area. This information can then be used to develop, calibrate and/or verify hydrologic and hydraulic models established for the study area.

3.2. Historical Rainfall

3.2.1. Overview

Rainfall data is recorded either daily (24hr rainfall totals to 9:00am) or continuously (pluviometers measuring rainfall in typically 0.1 to 1 mm rainfall increments). Daily rainfall data has been recorded for over 100 years at many locations within the Sydney basin, including at Observatory Hill since 1858. In general, pluviometers have only been installed since the 1970's. These records provide an indication of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error, or limitations inherent to the type of recording instrument used. Examples of limitations that may impact on the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall, and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00am in the morning. Thus if the storm encompasses this period it becomes “split” between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00am reading.

- Where the time taken for the whole catchment to contribute to runoff is less than 24 hours, daily rainfall records may not provide a sufficient reflection of rainfall intensity to indicate subsequent flooding. For example, high intensity, short duration storms may produce a relatively low total daily rainfall, and hence may not provide a reflection of any associated flooding. Alternatively, the rainfall may be relatively consistent throughout the day, producing a large maximum rainfall depth but only minor flooding.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has fewer limitations than daily read data. However, pluviometers can also fail during storm events due to the extreme weather conditions.
- Rainfall records can frequently have "gaps" ranging from a few days to several weeks or even years.
- Rainfall events which cause flooding in the Kurnell catchment can be localised and as such are only accurately "registered" by a nearby gauge. Gauges sited only a few kilometres away can show very different intensities and total rainfall depths.

3.2.2. Available Historical Rainfall Data

Table 1 presents a summary of both operational and non-operational rainfall gauges located within or close to the study catchment. Gauges that are currently operational are shown on Figure 6. These gauges are operated by either Sydney Water (SW) or the Bureau of Meteorology (BoM). There may also be other private gauges in the area, but data from these has not been collected as there is no public record of their existence. Of the 20 gauges listed in Table 1, nine have now closed.

There is one official operational gauge within the study catchment, a BoM daily rainfall gauge at the Kurnell (Caltex Oil Refinery (operational since 1956)). In addition, within 9 km of Kurnell there are four daily read gauges and three pluviometers in operation.

Table 1: Rainfall Stations within 9km of Kurnell Township (Reference 8)

Station No.	Owner	Station	Elevation (mAHD)	Distance from Kurnell (km)*	Date Opened	Date Closed	Type
066072	BoM	Kurnell (Caltex Oil Refinery)	3.0	1.0	Feb-56		Daily
066030	BoM	Kurnell		1.3	Aug-48	Dec-50	Daily
066086	BoM	Cronulla WWTP	10.0	4.4	Jul-58		Daily
066051	BoM	Little Bay (The Coast Golf Club)	22.0	5.2	1925		Daily
066051	BoM	Little Bay (The Coast Golf Club)	22.0	5.2	Apr-97		Operational
566018	SW	Cronulla STP	10.0	6.2	Aug-58		Continuous
566018	SW	Cronulla STP	10.0	6.2	Aug-58		Daily
66104	BoM	Lilli Pilli		6.7	Apr-02	Dec-41	Daily
566088	SW	Malabar	15	7.1	Dec - 90		Continuous
66058	BoM	Sans Souci (Public School)	9	7.2	Oct-1899	Dec-01	Daily
66058	BoM	Sans Souci (The Boulevarde)	9	7.4	Apr-97		Operational
66147	BoM	Long Bay	30.5	7.5	Feb-11	Dec-18	Daily
66122	BoM	Maroubra RSL Bowling Club		7.9	Oct-64	Dec-74	Daily
66132	BoM	Carlton	30.5	8.2	Jan-07	Dec-24	Daily
66014	BoM	Cronulla South Bowling Club	30	8.2	Jun-97		Operational
66014	BoM	Cronulla South Bowling Club	30	8.2	Jan-34		Daily
66037	BoM	Sydney Airport Amo	6	8.3	Jan-60		Continuous
66037	BoM	Sydney Airport Amo	6	8.3	Jun-94		Synoptic
66192	BoM	Sydney Airport Tbrg	3	8.3	Jan-93	Jan-97	Continuous
66007	BoM	Botany No.1 Dam	6.1	8.7	Jan-1870	Jan-78	Daily
566061	SW	Caringbah (Davies Kent P/L)	25	9.0	Apr-66	Dec-73	Continuous

BoM= Bureau of Meteorology
SW = Sydney Water Corporation
* Distances are approximations only.
Operational refers to flood alert gauges
Continuous refers to pluviometers
Synoptic refers to stations which provide discrete observations of total rainfall at some synoptic hours (eg. 6am, 12am and 3pm) in addition to 9am.

3.2.3. Analysis of Historical Rainfall Data

Recorded rainfall data was analysed to identify significant rainfall events in the past and the rainfall behaviour during these events. Analysis was undertaken using the following rainfall gauge data:

- 066072 Kurnell (Caltex Oil Refinery) – daily,
- 566018 Cronulla STP – pluviometer,
- 566018 Cronulla STP – daily,
- 66058 San Souci (Public School) – daily,
- 66037 Sydney Airport – pluviometer and
- 566088 Malabar - pluviometer.

The Kurnell (Caltex Oil Refinery) and Cronulla STP data were used as the basis of this analysis, as they are the closest daily and continuous gauges respectively to the study area. The additional gauges were used as a comparison, and to provide supplementary data where it is missing for the Kurnell (Caltex Oil Refinery) and Cronulla STP gauges. The Kurnell (Caltex Oil Refinery) gauge has data missing from 2004 to 2006, while data from the Cronulla STP continuous gauge is only available from 1980 onwards (Reference 9).

Table 2 shows rainfall events with a daily reading of greater than 100 mm at the Kurnell (Caltex Oil Refinery) gauge. These are compared with corresponding readings at Cronulla STP and San Souci (Public School) daily gauges, and accumulated 24 hour totals to 9 am for the Cronulla STP, Sydney Airport and Malabar pluviometers. Note that the daily gauges are (typically) read at 9 am each day. Therefore, accumulated 24 hour totals to 9 am from the pluviometers provides a comparison with the daily read gauges. The comparison shows that the larger rainfall events that occurred at Kurnell generally registered significantly more rain than at other stations. This highlights the variability in rainfall over the area. Another point to note is the variability in recorded rain between the pluviometer and the daily read gauge at Cronulla STP. As noted previously, pluviometers can be susceptible to failure during intense rainfall. This may possibly explain the discrepancy in readings between the daily and pluviograph records for Cronulla STP.

Table 2: Daily Rainfall Exceeding 100 mm at Kurnell (Caltex Oil Refinery)

Rank	Year	Day and Month	Daily Total (mm)					
			Kurnell (Caltex Oil Refinery)	Cronulla STP (pluviogrpah)	Cronulla STP (daily)	Sans Souci (public school) (daily)	Sydney Airport (pluviograph)	Malabar (pluviograph)
1	1975	11 Mar	242	Not available	106	168	202	Not available
2	1990	4 Feb	235	149	191	165	167	Not available
3	1969	14 Nov	213	Not available	99.5	161	144	Not available
4	1988	30 Apr	200	208	151	191	174	Not available
5	2002	5 Feb	190	199	Not available	128	Not available	124.5
6	1959	30 Oct	187	Not available	39.8	28.7	Not available	Not available
7	1995	25 Sep	153	143	82.5	140	155	Not available
8	1998	7 Aug	151	73	57.4	46	Not available	133.5
9	1958	11 Mar	149	Not available	Not available	164	Not available	Not available
10	2001	1 May	144	76	Not available	60	Not available	55
11	1984	6 Nov	141	129	80.3	68	Not available	Not available
12	1986	6 Aug	141	117	134	174	Not available	Not available
13	1963	13 Dec	100	Not available	81	109.5	181	Not available

Note: Daily totals for pluviometers based on accumulated 24 hour totals to 9am.

Table 3 shows rainfall events exceeding 100mm in 24 hours as recorded by the Cronulla STP pluviometer, being the pluviometer located closest to the study area. These are compared with corresponding 24 hour totals from the Sydney Airport and Malabar pluviometers. Note that unlike the 24 hour totals from the daily read gauges (which are read at 9 am each day), these 24 hour totals could be from any 24 hour period at Cronulla STP. Corresponding maximum rainfall depths occurring on the same day at the Sydney Airport and Malabar gauges are provided as a comparison. It should be noted that in some cases, the 24hr maximum at the Sydney Airport or Malabar gauges may occur on a different day, as specified Table 3.

Table 3: Rainfall Events Exceeding 100 mm over 24 hours at Cronulla STP

Rank (Cronulla STP gauge)	Year	Day and Month	Cronulla STP (mm) (max 24hr total)	Sydney Airport (mm) (max 24hr total)	Malabar (mm) (max 24hr total)
1	1990	3 February	228	224	Not available
2	2002	5 February	215.5	144	158
3	1988	30 April	213.5	178	Not Available
4	2003	13 May	186.5	103	113
5	1995	25 September	183.5	170	148
6	1992	9 February	175.5	208	Not available
7	1983	21 March	139.5	135	Not available
8	1991	10 June	132.5	163$^+$	105.5$^+$
9	1984	5 November	130	4$^+$	Not available
10	1998	7 August	125.5	0	172.5
11	1986	5 August	121	222$^+$	Not available
12	1990	1 August	114.5	91	Not available
13	1996	31 August	111	17$^+$	95
14	1988	17 January	104.5	124	Not available
15	1993	14 September	103	92	46.5
16	2006	5 June	101	Not available	66.5$^+$
17	1997	30 January	100.5	81	90.5

$^+$ 24 hour totals for the Sydney Airport and Malabar gauges are the maximum recorded within 1 day of the corresponding Cronulla record. For records with a $^+$ the actual maximum 24 hour total for these rainfall events were found to occur on a different day.

It can be seen from Table 3 that there is a significant variation between the Cronulla STP, Sydney Airport and Malabar pluviographs for the majority of rainfall events. This is likely to be due to the spatial variation in rainfall patterns and volumes.

Comparing Tables 2 and 3, it can be seen that there is some variation between gauge readings. This variation is partially caused by the 9am to 9am period over which daily gauges record rainfall. As it is possible that significant rainfall occurs either side of 9am, the daily total recorded by these gauges does not necessarily represent the 24 hour maximum rainfall.

3.2.4. Historical Rainfall for the May 2003 Event

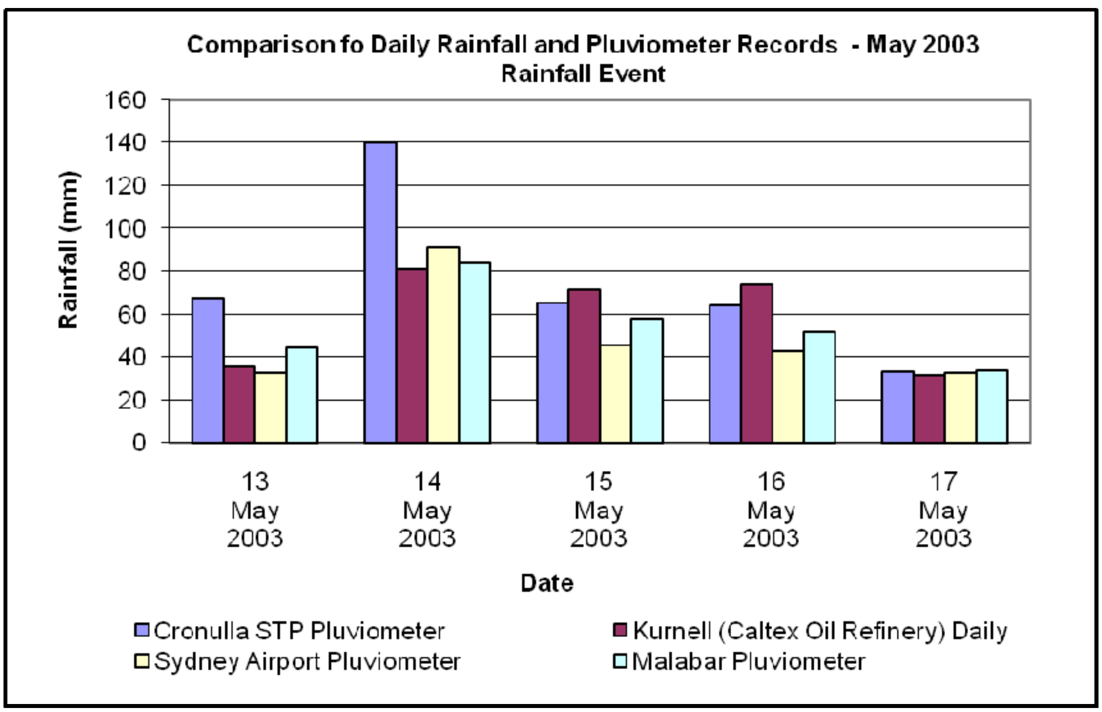
A review of available historical flood level information found that the best available information for recent flood events was the May 2003 event. This is discussed further in Section 3.5.

In order to use the May 2003 event for calibration/verification of the hydrologic and hydraulic numerical models, it was necessary to have a historical rainfall pattern for this event. Due to its proximity, the daily read gauge at the Kurnell (Caltex Oil Refinery) is most representative of the rainfall occurring within the study area. However, a more detailed breakdown of the rainfall intensity over time is required for use in the hydrologic/hydraulic numerical models. To achieve this, the daily rainfall totals from the Kurnell (Caltex Oil Refinery) gauge were applied to available pluviograph data from nearby stations.

The daily rainfall records for the May 2003 event at the Kurnell (Caltex Oil Refinery) were compared to pluviograph records at Cronulla STP, the Sydney Airport and Malabar to determine which pluviograph data most closely resembled the daily data. This comparison is summarised in Diagram 4, and suggests that the Malabar pluviograph data most closely resembles the Kurnell (Caltex Oil Refinery) daily data in terms of rainfall pattern and volume. The Malabar pluviograph data was therefore used to develop a historical rainfall pattern for the May 2003 event. The daily rainfall totals from the Kurnell (Caltex Oil Refinery) gauge were applied to the rainfall patterns derived from the Malabar pluviograph data to generate a rainfall pattern that approximates the May 2003 historical rainfall pattern for the catchment. This was then used in calibration/verification of the flood models.

It is difficult to compare the daily rainfall totals at the Kurnell (Caltex Oil Refinery) with design intensities. However, comparison of the pluviograph data from the Malabar gauge with design rainfall intensities would suggest that May 2003 event was between a 50% and 20% AEP in magnitude for durations between 3 and 9 hours and also for a 48 hour duration. For durations between 9 and 48 hours peak recorded intensities correspond to design intensities of less than 50% AEP in magnitude.

Diagram 4: Comparison of Daily Rainfall from Kurnell (Caltex Oil Refinery) with nearby Pluviograph Records – May 2003 Rainfall Event



3.3. Design Rainfall

Design rainfall can be applied to hydrologic and hydraulic modelling to estimate the likely flood behaviour of storms of different intensities and durations.

Design rainfall was calculated in accordance with Australian Rainfall and Runoff, 1987 (AR&R 1987, Reference 10). The Probable Maximum Precipitation (PMP) was calculated using procedures developed by the Bureau of Meteorology (Reference 11). Calculated design rainfall values for the 20%, 5% and 1% AEP event and the PMP are listed in Table 4.

Table 4: Design Rainfall Data

Duration		Annual Exceedance Probability (AEP)			PMP*
		20%	5%	1%	
30 minutes	intensity in mm/h	76	101	134	460
	depth in mm	38	51	67	230
1 hour	intensity in mm/h	53	71	95	340
	depth in mm	53	71	95	340
1.5 hours	intensity in mm/h	41	55	73	290
	depth in mm	61	83	110	430
2 hours	intensity in mm/h	34	45	60	250
	depth in mm	68	90	120	500
3 hours	intensity in mm/h	26	34	45	200
	depth in mm	77	102	135	610
4 hours	intensity in mm/h	21	28	37	180
	depth in mm	85	112	148	700
6 hours	intensity in mm/h	16	21	28	140
	depth in mm	97	128	168	810
9 hours	intensity in mm/h	12	16	21	
	depth in mm	111	145	191	
12 hours	intensity in mm/h	10	13	17	
	depth in mm	121	160	209	
18 hours	intensity in mm/h	8	10	14	
	depth in mm	141	185	243	
24 hours	intensity in mm/h	7	9	11	
	depth in mm	156	205	269	
30 hours	intensity in mm/h	6	7	10	
	depth in mm	169	222	291	
36 hours	intensity in mm/h	5	7	9	
	depth in mm	179	235	310	

* PMP data is only presented up to 6 hours duration as this covered all events modelled as part of the Flood Study. For PMP events greater than 6 hours, different methodology needs to be applied.

3.4. Tidal Data

Kurnell's low lying nature and proximity to Quibray Bay means that flood behaviour is influenced by storm tide effects. Flooding in Kurnell can be caused by intense rainfall over the catchment, elevated tidal levels, or a combination of both.

3.4.1. Historical Tidal Levels

Hourly tidal data was obtained from the Fort Denison records (Reference 12). Records were available from January 1965 until November 2006. As with rainfall data, tidal data is susceptible to errors and gaps in the record set, and hence may not always provide a completely accurate record. Of the data sets used for this study, contained no missing values, although inaccuracies may still be present.

A summary of historical tidal data from Fort Denison is presented in Tables 5 and 6. Table 5 provides a list of the top five recorded tidal levels between 1965 and 2006. The largest recorded event occurred on 25 May 1974, which corresponds with reported tidal flooding in Kurnell.

Table 6 provides a summary of tidal levels on days of significant rainfall recorded at the Kurnell (Caltex Oil Refinery) daily gauge. The dates presented correlate to those in Table 2, representing daily rainfall totals in excess of 100 mm. The data shows that the high tide on days of significant rainfall was typically higher than a mean high tide (0.6 mAHD) but was typically lower than a high spring tide (0.9 mAHD). It should be noted that the peak rainfall burst of a storm would not necessarily coincide with the timing of the high tide.

Table 5: Top Five Recorded Tidal Levels from Fort Denison (1965 – 2006)

Date	Height (mAHD)
25/05/1974	1.475
27/04/1990	1.425
26/04/1990	1.375
19/08/2001	1.342
22/07/1978	1.315

Table 6: Recorded Tidal Levels at Fort Denison for Significant Rainfall Events at Kurnell (Caltex Oil Refinery Daily Gauge)

Date*	High Tide		Low Tide	
	Level (mAHD)	Time (24 hr)	Level (mAHD)	Time (24 hr)
11/03/1975	0.575	23:00	-0.625	5:00
4/02/1990	0.995	19:00	-0.085	1:00
14/11/1969	0.934	2:00	-0.681	9:00
30/04/1988	0.775	10:00	-0.435	4:00
5/02/2002	0.59	18:00	-0.4	12:00
30/10/1959	No Data	No Data	No Data	No Data
25/09/1995	0.875	11:00	-0.545	18:00
7/08/1998	1.235	11:00	-0.425	18:00
11/03/1958	No Data	No Data	No Data	No Data
1/05/2001	0.791	18:00	-0.413	24:00
6/11/1984	0.725	21:00	-0.425	4:00
6/08/1986	1.055	12:00	-0.415	6:00
21/03/1983	No Data	No Data	No Data	No Data

*Note: Dates correspond to recorded daily rainfall exceeding 100 mm at the Kurnell (Caltex Oil Refinery) Gauge (presented in Table 2).

3.4.2. Design Tidal Levels

Design tidal levels adopted for this study are listed in Table 7. These levels are based on design data for Botany Bay provided in the *Georges River Floodplain Risk Management Study* (Reference 6). While Reference 6 notes that no formal investigations on tidal levels have been carried out in Botany Bay, a number of studies have been carried out in Sydney Harbour and at other nearby coastal locations. Consequently, values provided in Reference 6 were recommended by the Coastal Branch and Flood branch of the former Department of Land and Water Conservation based on available information from nearby studies.

Table 7: Recommended Tidal Levels

Type of Tide	Peak Water Level (mAHD)
Normal High Tide	0.6
High Spring Tide	0.9
5% AEP Design Tide	1.5
1% AEP Design Tide	1.7
Extreme Design Tide	2.0

3.5. Historical Flood Information

A data search was carried out to identify the dates and magnitudes of historical floods. Historical flood data provides information on past flood behaviour, and can be used to calibrate and verify the hydrologic and hydraulic numerical models. This is done by comparing modelled runoff and levels generated using historical rainfall data, with the corresponding recorded historical flood levels.

Historical flood information was obtained from the following sources:

- previous reports and surveys,
- Council records,
- Community questionnaire, and
- flood level survey.

A detailed review of rainfall records was also undertaken (as discussed in previous sections), to establish the likely dates of flooding.

3.5.1. Previous Reports and Survey

The *Kurnell Village Drainage Investigation* (Reference 1) provided a summary of historical flood information available for Kurnell up until publication in 1980. The community survey conducted as part of this study provides an indication of which properties were affected by flooding, and of water depths and ponding times experienced at these locations. This information is presented in Table B-1 in Appendix B, and the locations are shown in Figure 3. It should be noted that reported water depths are estimations only, rather than surveyed flood levels. They can therefore only be used as a general check of flood extents. Of the 35 properties where flooding had been reported, 46% had experienced flooding during the 1975 event. Affected properties are scattered throughout the township, with higher concentrations to the southern and eastern sections. However, this is partially a reflection of where the property interviews were conducted.

The *Kurnell Village Drainage Investigation* (Reference 1) also provided an estimated extent of flooding in the Cook Street area during the 1975 event, as shown in Figure 7. Figure 7 also shows properties which required pumping during 1976. In addition, the extent of tidal inundation in 1974 was mapped, which was the maximum recorded historical tide. This is shown in Figure 8, along with the extent of more frequent historical tidal inundation. It can be seen that the majority of tidal inundation occurs in the vicinity of Balboa and Torres Streets.

3.5.2. Council Records

Sutherland Shire Council maintains a record of flooding and drainage related community complaints. These can be used to identify rainfall events which resulted in flooding in particular areas. A summary of these complaints from 2001 and 2003 is contained in Table B2 in Appendix B. Complaints from additional years was not available. The main issues raised by these complaints were insufficient drainage and blocked drains. One resident also experienced flooding problems due to the property being lower than surrounding areas. Of the residents who reported flooding related complaints, three also participated in the community questionnaire conducted as part of the current study.

3.5.3. Community Consultation

A community survey was undertaken as part of the current study in March 2007 to obtain additional historical flood information. The survey involved the distribution of a questionnaire to residents and owners of properties within Kurnell township. The questionnaire was used to collect the following information:

- locations and dates of different historical flood events,
- flood levels and time for flood waters to subside,
- any additional information regarding flood events, such as newspaper articles, and
- any additional comments relating to flooding.

Questionnaire responses are provided in an Addendum to this report, whilst a summary of responses is shown in Table B3 in Appendix B. A brief discussion of responses is provided below.

Of the 941 questionnaires issued, 66 (7%) were returned. Of these, 38 (58%) had experienced flooding at some stage during their residency at Kurnell, three of which also referred to tidal inundation as a cause of flooding. It should be noted that where no flooding was reported, this does not exclude the possibility of flooding prior to the current residents moving to the area. For example, some residents who moved to Kurnell in 2006 reported no flooding, as there have been no known significant flood events in the area since 2006. However, there may have been flooding at these properties in previous years. Diagram 5 shows the number of years each respondent has lived or owned a property in Kurnell, whilst Diagram 6 shows the 11 flood events which were identified.

Diagram 5: Number of Years Respondents have Lived or Owned a Property in Kurnell

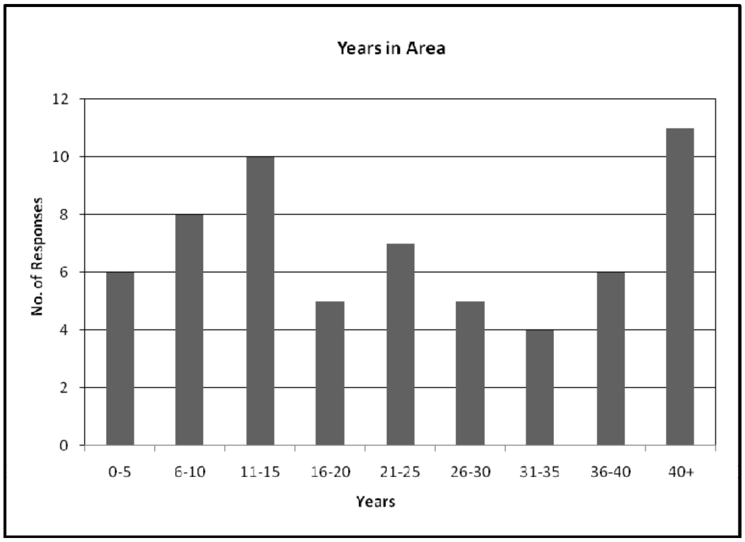
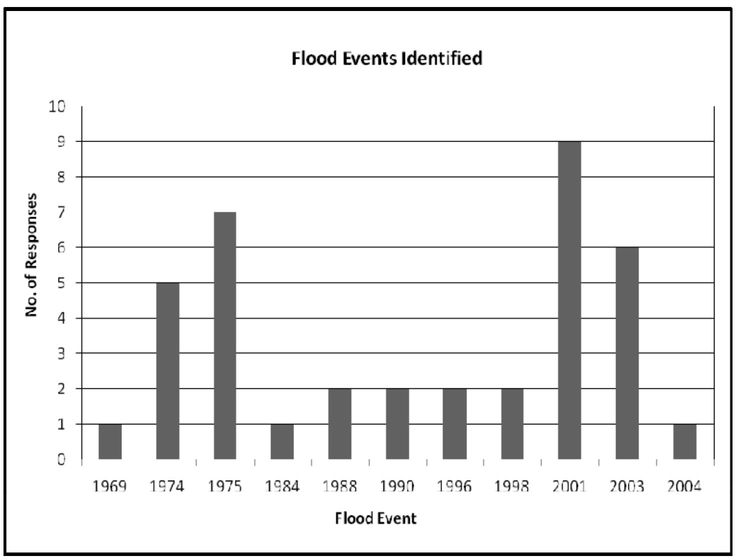


Diagram 6: Flood Events Identified by Respondents to the Community Questionnaire



It can be seen from Diagram 5, that whilst the majority of responses were from those with more than 20 years of residing in or owning a property in Kurnell, approximately 10% have resided in Kurnell for less than 5 years. Given that the last significant known rainfall event was in 2003, the majority of these are unlikely to have experienced any significant flooding.

Comparing flood events in Diagram 6 with the historical rainfall records listed in Tables 1 and 2 (Section 3.2), it can be seen that in the majority of cases there was consistency between the years identified. Where there were discrepancies, possible reasons include:

- Residents have lived in the area for only a few years, and hence have only identified more recent but smaller events.
- Residents having a greater recollection of more recent events than those many years ago.
- Missing rainfall data at the Kurnell (Caltex Oil Refinery) rain gauge from 2004 onwards.
- Respondent uncertainty of the date of flooding events, and may accidentally provide the wrong year for a flood event, especially if there has been no documentation of the event.
- Significant rainfall occurring either side of 9 am (i.e. when daily rainfall is recorded). This could mean that a significant rainfall event is spread across two consecutive daily rainfall records.
- Flooding caused by high tidal levels rather than significant rainfall. The flood event in 1974 is known to be caused by an elevated storm tide. Based on tidal records presented in Table 5, flooding in 1990 may also have been due to elevated tide levels.

For dates where significant rainfall occurred either side of 9 am, reported flooding is likely to correspond with rainfall over consecutive days. Two examples of this are:

- the 6th and 7th January 1996 where 52 mm and 40 mm of rainfall were recorded at the Kurnell (Caltex Oil Refinery) rain gauge respectively, and
- the 13th and 14th May 2003 where 36 mm and 81 mm of rainfall were recorded at the Kurnell rain gauge respectively.

Figure 9 shows the location of properties where flooding was experienced by respondents. In a number of cases, the date of flooding was not indicated, whilst in others residents expressed uncertainty about when flooding occurred. Where two possible dates were given, the date corresponding with high rainfall and documented flooding was used.

Comparing Figure 9 with the community responses from 1980 shown on Figure 3, it can be seen that whilst there is some similarity in the responses, there are also some locations where no flooding has been reported in the most recent survey. However, as previously stated, this is partially due to residents having not been present during significant storm events. It is also possible that properties have been filled and raised since 1980.

Two residents provided photographic evidence of flooding events as part of the questionnaire, as shown in Appendix B. However, the residents were unable to provide dates for these flood events, and hence the photographs cannot be used to directly compare historical flood levels with modelled flood levels. An additional three residents provided photographs during the site visit, as discussed in the following section.

Some of the responses highlighted a variety of issues, which were believed by residents to have exacerbated flooding on their property or surrounding areas. The most common issue raised was blocked drains, with 12 respondents believing these to be a component of the flooding problem. These blockages are more likely to affect flooding during low intensity, high frequency events by reducing the capacity of the drainage network and increasing the period for water to pond. However, they are less likely to have a significant impact on flooding during larger events, except in the time for floodwaters to recede.

Four respondents referred to the re-grading of Balboa, Bridges, Tasman and Torres Streets as having an effect on flooding and drainage. One respondent saw it to be an improvement, whilst three believed it to have increased flooding by directing road drainage onto their properties. Issues such as these will be considered in greater detail in the Floodplain Risk Management Study.

3.5.4. Flood level survey

Based on the information collected from the community questionnaire, a number of respondents had indicated they had either photographs of flood events, or could indicate the location of flood marks on their property. These were contacted by phone to obtain more specific information, and to arrange a site visit where respondents were happy to provide additional information. Consequently, eight residents were visited on the 31st May 2007. Five residents were able to indicate the approximate location of flood marks, three of which had photographic evidence. However, only one resident was able to identify the date of the flood event associated with the flood mark, being for the May 2003 flood event. A sample of the photos provided by residents as part of the questionnaire and survey is included in Appendix B.

Based on the information above, Sutherland Shire Council undertook a survey of historical flood marks. Six levels were taken from the five properties where residents were able to identify the location of flood marks. The results of the survey are shown in Table 8.

Table 8: Surveyed Flood Levels

Property	Recorded Flood Level (mAHD)	Flood Event*
51 Torres Street	2.255	Year not known (after 1997)
87 Torres Street	1.52	May 2003
116 Torres Street (Location 1)	1.635	Year not known (after 1985)
116 Torres Street (Location 2)	1.63	Year not known (after 1985)
132 Torres Street	1.61	Year not known (after 1996)
142 Torres Street	1.47	2000 to 2001

There was uncertainty at four of the locations presented in Table 8, as to the exact flood event, or the exact location of the peak flood level. The approximate timeframe provided in Table 8 is based on the resident's estimation of when flooding occurred, or refers to the period of time they have resided at that location.

3.5.5. Summary of Historical Flood Information

To enable the use of historical flood levels in the calibration and verification of hydrologic and hydraulic numerical models, it is preferable to have:

- recorded flood levels at the peak of the flood which have a reasonable level of certainty and accuracy,

- flood levels from a number of floods of different magnitude to ensure the models are representative of a range of flows,
- a number of data points for each historical flood event to ensure that the model is representative of the flood gradient over the area.

Of the historical flood data provided, the only recorded flood level which has sufficient information to be used in model calibration and verification is at 87 Torres Street. The residents at this location also have photographic evidence of the May 2003 flood event at their property, which assists in comparing historical flood levels with modelled results. Photograph 2 shows flooding during the 2003 storm at the back of 87 Torres Street.

Photograph 2: Flooding at 87 Torres Street during the May 2003 storm

It should be noted that there are a number of limitations associated with historical flood data. For example, photographs may not have been taken at the peak of the flood event, and hence do not always represent maximum flood depths. In the majority of cases, the flood marks identified by residents were also approximations of where they remembered flood waters to reach, rather than actual marks made by flood waters. These values therefore provide an approximation only.

3.6. Topographic and Drainage Information

3.6.1. Council Drainage Network

Council's formalised drainage network consists of drainage pits, pipes and open channels, as shown in Figure 2. Details regarding the network was collected from the following sources:

- Council's Geographic Information System (GIS) database,
- available design and work-as-executed drawings,
- information provided in the *CRL/ALOR Stormwater Management Study* (Reference 5),
- additional survey data (discussed further in Section 3.6.3, and
- field inspections.

Where pipe sizes could not be obtained, they were assumed to be the same as the upstream and downstream pipe.

3.6.2. Topographic Data

Available topographic information consisted of:

- Airborne Laser Scanning (ALS) data of the entire study area, surveyed by AAM Hatch in 2005.
- two metre interval contour information from Council's GIS database,
- field survey of Kurnell from 1980 (Reference 1),
- survey data of Lot 105 Torres Street (Reference 7).

The ALS data has a quoted accuracy of +/- 200mm horizontal & +/- 150mm vertical. The ALS survey provides numerous ground level spot heights, from which a Digital Terrain Model (DTM) can be constructed. The raw ALS data has been refined to remove points located over water, vegetation and elevated structures. However, the accuracy of the final ALS data set can still be adversely affected by the nature and density of vegetation and/or the presence of steeply varying terrain. For this reason the ALS data was verified and supplemented with additional field survey in critical areas. This is discussed further in the following section.

The two metre contour information provided by Council was used to supplement the ALS in defining catchment boundaries, and to provide an overview of the topography of the study area.

The field survey of Kurnell from 1980 was provided in the *Kurnell Village Drainage Investigation* (Reference 1). The hardcopy data from this report, in the form of 0.2 m contour information, was scanned and digitally overlayed over 0.2 m contour information generated from the ALS data. This information is shown in Figure 10, which indicates some changes in ground topography that has occurred within the catchment. This includes localised filling that has occurred in some areas such as the properties along Charles and Torres Streets, as well as regrading to Dampier Street. Changes in the ground topography make it difficult to replicate conditions from earlier historical events with any level of confidence.

The survey data collected as part of *Flood Assessment of Lot 105 Torres Street, Kurnell* (Reference 7) also provides some detail of ground topography within and adjacent to Lot 105 in 2001 prior to filling.

3.6.3. Additional Survey Data

A field survey was carried out by Sutherland Shire Council to verify the ALS data in critical areas, and to obtain additional details of drainage structures. The extent of the survey data collected is shown in Figure 11 and included:

- cross-sections of the open channel within Solander Street Swamp and along Captain Cook Drive,
- cross-sections of the stormwater outlet channel at the southern end of Dampier Street,
- levels along raised embankments in Marton Park and near the corner of Balboa and Torres Streets,
- spot heights within Quibray Bay to ground truth the ALS data in areas of dense mangrove vegetation,
- spots heights at various locations within the catchment where ground level definition in was more critical, and
- details of the open channel structures and pipe outlets at the southern end of Dampier Street.

Spot heights collected in the mangrove region of Quibray Bay were compared with the ALS data and it was found that ALS heights were generally higher than the spot heights by up to 0.2m. The greatest variation in values appeared to be in the mangroves south of Dampier and Tasman Streets, where there was a difference of up to 0.6 m. This is to be expected given the extensive foliage and root systems which could be mistaken for ground strikes in the ALS data set. In order to compensate for these differences, the elevation of Quibray Bay was lowered by 0.5 m within the 2D hydraulic model.

4. APPROACH ADOPTED

The approach adopted for this study has been influenced by the study objectives, accepted practice and the quality and quantity of available data. There are two basic approaches to determining design flood levels, namely:

- a *flood frequency approach* based upon a statistical analysis of the flood record, and
- using a *rainfall/runoff routing* approach (hydrologic modelling) to obtain flows, and then inputting these flows into a hydraulic model of the floodplain.

The flood frequency approach was not possible as there are no historical stream gauge records within the catchment. This is typical of urban catchments such as Kurnell. The second approach was therefore adopted.

Both hydrologic and hydraulic models were developed that best suited the nature of the catchment, taking into consideration:

- the nature of the upper reaches of the catchment, which is predominantly national park apart from areas of the Caltex Oil Refinery,
- the urbanised nature of the lower reaches of catchment with its mixture of pervious and impervious surfaces,
- the relatively flat topography with localised depressions in the lower reaches of the catchment, which creates a complex system of multiple overland flow paths and makes it difficult to delineate subcatchment boundaries for different flow conditions,
- surcharging within the piped drainage system due to the flat grades and the interaction between the pipe network and overland flow,
- the need to estimate the nature of overland flows at critical locations in the catchment in terms of flood levels, flows and velocities.

The Kurnell study area was modelled using the Watershed Bounded Network Model (WBNM) and TUFLOW. WBNM was used to establish a hydrologic model of the upper reaches of the catchment, upstream of the hydraulic model extent. It was used convert rainfall data into flows to be used as upstream inflow boundaries for the hydraulic model. TUFLOW was used to model the hydrology and hydraulics within the hydraulic model extent.

Conventional methods of modelling apply inflows into the hydraulic model both at the upper boundary (primary inflows) and within the hydraulic model extent (local inflows). Local inflows are applied at finite locations where flows are expected to concentrate. This typically requires the delineation of subcatchment areas within the hydraulic model, and the use of a lumped hydrologic model (such as WBNM) to define inflows hydrographs. The hydrologic model defines the conversion of rainfall to runoff (accounting for losses due to storage and infiltration) and the routing of runoff to the subcatchment outlet (representing local inflows). These local inflows are then applied to the hydraulic model.

However, Kurnell is a unique catchment that requires consideration of less conventional methods of defining local inflows. Within the extent of the hydraulic model, the topography is flat with numerous localised depressions and ill defined flow paths, which makes it difficult to delineate subcatchment boundaries. Even at a local scale, flow paths are likely to change with different flow conditions, resulting in varying subcatchment delineation with varying flow conditions. Furthermore, the resulting local inflows from each subcatchment are difficult to define as finite boundaries.

In light of the above, modelling of local inflows over the extent of the hydraulic model was undertaken using a direct rainfall approach. Rainfall was applied directly to the hydraulic model once losses had been applied. Conversion of rainfall to runoff is therefore performed within the hydrologic component of TUFLOW, whilst the routing of runoff throughout the model extent is performed within the hydraulic component. This method overcomes the need to accurately delineate subcatchment boundaries for varying flow conditions, as they are inherent in the ground topography. It also overcomes the need to apply finite local inflows within the hydraulic model.

As noted previously, in the lower portions of the catchment within the extent of the hydraulic model, the ground topography contains significant localised variations, which are largely due to the non-uniform nature of filling and reclamation of low-lying lands that has taken place since the 1950's. Field inspections in combination with a review of corresponding topographic survey data indicates that potential overflow paths through some areas are ill-defined and would reflect the nature of the complex localised controls formed by the ground topography. In order to better represent the complexity of overland flow behaviour in this area, a combined one- and two-dimensional (1D/2D) hydraulic modelling approach was employed using the TUFLOW modelling package (Reference 13).

In the absence of comprehensive information for historical events, the models were configured using typical or recommended parameters. A limited process of model validation was then undertaken based on the flood event of May 2003. The sensitivity of model results to the adopted model parameters was also assessed for the 1% AEP design storm.

5. HYDROLOGIC MODELLING

5.1. WBNM Model

5.1.1. General

Hydrologic models suitable for design flood estimation are described in AR&R 1987 (Reference 10). In current Australian engineering practice, examples of the more commonly used runoff routing models include RORB (Reference 10), RAFTS (Reference 10) and the Watershed Bounded Network Model (WBNM, Reference 14). These models allow the rainfall depth to vary both spatially and temporally over the catchment, and can be easily calibrated against recorded data.

WBNM has been adopted for the current study due to:

- it has a proven record of reliability in NSW,
- it being readily available,
- its ease of use,
- less data requirements compared to other commonly used models, and
- its widespread use in similar applications.

5.1.2. Model Configuration

The WBNM model simulates a catchment and its tributaries as a series of sub-catchment areas based on watershed boundaries, linked together to replicate the rainfall-runoff-routing process through a natural stream network. The model input data includes definition of physical characteristics such as:

- surface area,
- proportion developed (imperviousness),
- stream shortening.

The model established for this study is shown in Figure 12. It comprises a total of 98 subcatchments and includes all areas upstream of the hydraulic model extent. The layout of the subcatchments was defined to provide a reasonable level of spatial detail within the catchment and to provide primary inflows at the upstream limits of the hydraulic model. Subcatchment areas were determined based on ALS, 2 m topographic contour information provided by Council in GIS format, and plan details showing the location of bunded areas within the Caltex Oil Refinery site.

Based on information provided by the Caltex Oil Refinery it is understood that rainfall and runoff that enters bunded areas is treated and then discharged directly into Botany Bay and Quibray Bay. These areas were therefore excluded from the WBNM model. A sensitivity analysis was conducted to assess the potential impacts on catchment flows and flood behaviour should these bunds fail. Whilst it is unlikely that complete failure should occur due to the multi-celled arrangement of the bunds, it is possible that some overflow may occur during extreme events. This is discussed further in Chapter 10.

Estimation of percentage impervious for each subcatchment was based on a review of aerial photography provided by Council.

5.1.3. Model Parameters

In addition to defining the physical layout of the catchment, model parameters are also required to define how rainfall is converted to runoff and then routed through the subcatchments. Table 9 provides a brief description of the main parameters, and the values adopted for this study. A more detailed description is contained in Reference 14.

Table 9: Summary of WBNM Parameters

Parameter	Description	Value
Non-linearity Exponent	Describes the relationship between storage and discharge, and hence varies the lag time depending on the discharge.	0.77
Lag Parameter	Determines how quickly runoff is routed through pervious subareas.	1.7
Impervious Lag Factor	Used to reduce the lag parameter, and defines the time taken for runoff on impervious areas to reach the outlet.	0.1
Stream Lag Factor	Used to reduce the lag parameter for flow within stream channels.	1.0
Stream routing Type	Describes how runoff from an upstream catchment is routed through a downstream catchment.	Non-linear routing
Initial Loss	The initial rainfall loss on pervious areas.	0.0 mm
Impervious Initial Loss	The initial rainfall loss on impervious areas.	0.0 mm
Continuing Loss Rate	The continuing rainfall loss for pervious areas. WBNM assumes there is no continuing loss on impervious areas.	2.5 mm/hr

Due to a lack of streamflow data available for calibrating the hydrologic model, the parameters chosen have been based on recommended values and previous experience with catchments of a similar nature.

A non-linearity exponent value of 0.77 and stream lag factor of 1.7 are currently recommended design values in the WBNM User Manual (Reference 14).

An initial loss of 0 mm for both pervious and impervious areas was chosen as a conservative estimation of rainfall losses. It is likely that the catchment has already received some rainfall and hence reduced the available depression storages prior to the modelled events. AR&R 1987 suggests values for initial loss ranging from 0 mm to 35 mm for eastern NSW catchments. The adopted value of 2.5 mm/hr for continuing loss has been found to be applicable over a wide range of catchments in Eastern Australia.

The sensitivity of the model to the adopted parameters was tested, as discussed in Chapter 10.

5.2. TUFLOW Model – Hydrology

5.2.1. General

Conventional methods of estimating local inflow hydrographs in Australia have typically involved lumped rainfall-runoff-routing methods (such as WBNM). However, there have been recent examples of the application of two-dimensional (2D) hydraulic modelling software for the task of simulating the runoff-routing component of hydrograph estimation. This has been undertaken by applying rainfall directly onto the 2D model grid once losses have been accounted for (Reference 15).

The nature of the study area lends itself to the use of a direct rainfall approach, which overcomes some of the shortfalls of a more conventional lumped rainfall-runoff-routing procedure to develop local inflows. These shortfalls, as applicable to the study area include:

- the difficulty in accurately delineating local subcatchment boundaries due to varying flow paths for varying flow conditions,
- ill-defined flow paths meaning that flows do not concentrate in localised areas. Hence the application of finite local inflows within the hydraulic model extent is not necessarily appropriate,
- the potential for finite local inflow boundaries to impede flows from upstream areas.

The TUFLOW modelling software provides two options for the application of direct rainfall:

- rainfall is evenly distributed to every active cell of the defined region of the 2D grid (an active cell is one containing a defined ground elevation), or
- rainfall is evenly distributed between every wet cell within the defined region of the 2D grid. If all cells within the region are dry then rainfall is initially applied to the lowest cell.

A recent study by Clark, Ball and Babister (Reference 15) compared the flow hydrographs generated from TUFLOW and SOBEK 2D hydraulic models using the first option (direct rainfall applied to every active cell) with a traditional rainfall-runoff model (WBNM). The study found that the hydrographs developed from both TUFLOW and SOBEK were highly sensitive to parameter values and varied significantly from those generated using the WBNM model. These results suggest that further work is required before this method is used to estimate runoff routing.

Potential issues with the application of rain to every cell is magnified in an urban catchment such as Kurnell, where the 2D grid is too coarse to represent the accumulation of flows from roof gutters, along roadways and other urban features.

The conclusion made in Reference 15 is supported by the latest TUFLOW Manual (July 2007) which provides the following disclaimer on applying the rainfall distributed to every active cell approach:

> *"Note, this approach is being further trialled and tested as of Build 20006-06-AA and is considered an under-development feature that may be subject to change. Of particular note is that very small cell wet/dry depth and cell side wet/dry depth values (less than a mm) are likely to be required to minimise mass errors associated with frequent wetting and drying of cells."*

The second option (direct rainfall applied to wet cells) effectively lumps rainfall from each subcatchment to areas where it is likely to collect. The main limitation of this approach is that there is no routing of runoff from the subcatchment to the areas where the rainfall is applied. TUFLOW allows the user to apply either routed flows from a lumped hydrologic model (such as WBNM) or a rainfall hyetograph. The selection of the most suitable method comes down to the size of subcatchment areas, the response time of subcatchments and the proportion of cells that are wet. Application of routed flows would be more applicable to subcatchments where the area of wet cells is significantly smaller than the total area of the subcatchment. If the area of wet cells dominates the subcatchment area then double routing will occur using this approach. Due to the topography of the study area, a large proportion of subcatchments become wet across the majority of cells. Furthermore, the urbanised nature of the catchment is likely to produce short response times from individual subcatchments. For these reasons, the method of applying rainfall hyetographs was selected for Kurnell.

None of the currently available methods of defining local inflow boundaries provides a completely ideal representation, either conventional lumped rainfall runoff routing method or the direct rainfall methods given in TUFLOW. However, the direct rainfall approach of applying rainfall hyetographs to wet grid cells is considered the best compromise. The main limitation of directly applying rainfall to the wet cells (and hence there being no routing time), is less of an issue in urban areas with quick response times and a sufficiently fine subcatchment definition where the majority of the subcatchment becomes wet.

5.2.2. Model Configuration

The TUFLOW hydraulic model extent was divided into 91 subcatchments, as shown in Figure 12. Subcatchments were delineated along watershed boundaries, road centrelines and major property boundaries and were defined so as to contain a maximum of one significant trapped low point. Subcatchment areas are typically in the order of 1.5 ha in size.

Subcatchments generally contained a combination of pervious and impervious areas. The percentage impervious across the catchment was estimated by measuring areas within a representative part of the catchment using aerial photography provided by Council. It was estimated that approximately 50% of the catchment was impervious.

Rainfall was initially applied to the lowest cell in each subcatchment. As additional cells became wet, the rainfall hyetograph was distributed between all wet cells within the subcatchment. TUFLOW applies losses to the rainfall prior to application to the ground grid.

5.2.3. Adopted Hydrologic Model Parameters

Model parameters relating to runoff routing (such as the lag parameter in WBNM) are inherently accounted for through the use of direct rainfall applied to the low points within each subcatchment. This is discussed in Section 5.2.1. However, rainfall losses must be defined for each subcatchment. Some of the rainfall on a catchment will be lost at the point at which it lands, through either ponding in trapped depressions, or infiltration into the ground or both. These rainfall losses can be represented in a conventional hydrologic model as initial losses and continuing losses. The current approach necessitated the removal of losses before rainfall was applied, as rainfall was directed to the low point within each subcatchment instead of being applied throughout the whole catchment. This approach therefore does not account for ongoing infiltration once rainfall has ceased.

Ongoing infiltration was considered to be a significant process within the Kurnell catchment due to the long ponding times. Infiltration was therefore applied within the hydraulic model as an additional loss, as discussed in Section 6.6. It differs from continuing loss in that it is applied where runoff ponds, rather than at the point where rain initially falls.

Adopted rainfall losses for the TUFLOW model are consistent with those for the WBNM model and consist of an initial loss of 0 mm for both pervious and impervious areas and a continuing loss rate of 2.5 mm/hr for pervious areas.

6. HYDRAULIC MODEL

6.1. General

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in both one and two dimensions. The TUFLOW software is produced by WBM Pty Ltd (Reference 13). TUFLOW has been widely used for a range of projects both internationally and within Australia. The model is capable of dynamically simulating complex overland flow regimes and interactions with sub-surface drainage systems. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short-duration events with complex overland flow regimes of supercritical and sub-critical flow behaviour.

For the hydraulic analysis of complex overland flow paths (such as those identified in the present study), a 2D model such as TUFLOW provides several key advantages when compared to a traditional 1D only model. For example, in comparison to a purely 1D approach, a 2D model can:

- provide localised detail of any topographic and /or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically model the interaction between the drainage system and complex overland flow paths, including surcharging effects, and
- inherently represent the available flood storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council's planning activities.

The following sections provide a summary of the model characteristics.

6.2. Model Extents

The extent of the hydraulic model was determined based on field inspections, discussions with Council and DECC and review of ground topography information. The hydraulic model was extended upstream beyond the study limit to encompass part of the Caltex Oil Refinery. This enables the definition of flood behaviour throughout the study area for all design storms up to the Probable Maximum Flood (PMF), and minimises the effects of boundary assumptions on modelled flood behaviour within the study area. Consequently, results are only presented within the study limits. Model and study extents are shown in Figure 13.

6.3. Model Topography

In the majority of areas, the ground topography was represented in the TUFLOW model using a 2D digital elevation model. In some areas 1D elements were used to define open channels and other localised features. The 2D component of the model was established based on a digital terrain model (DTM) compiled from the available survey information, incorporating ALS and detailed field survey as appropriate. The extents of the TUFLOW model grid are shown in Figure 13. The model topography was derived using a regular 4m grid across the model extent. This level of resolution was adopted as it provided the best compromise between definition of localised ground features and model run times. The sensitivity of modelled flow behaviour to grid resolution was assessed by establishing and running a 2 m grid for the 1% AEP event. This is discussed further in Section 10.

Buildings and other significant features likely to act as flow obstructions were incorporated into the model network. These types of features were modelled as impermeable obstructions to the flood waters. In some instances it is possible for flow to enter underneath buildings, and therefore the approach adopted provides a conservative estimate of floodplain storage. Again an assessment was made to the sensitivity of the modelled flood behaviour to this assumption.

6.4. Drainage Network

Figure 13 shows the location and extent of drainage branches within the study catchment which have been included in the TUFLOW model. The drainage system defined in the model comprises:

- over 230 drainage pits, including surface inlets, junctions and headwalls,
- over 180 links representing underground conduits (circular pipe or box).

The location and dimensions of network elements were generally obtained from Council's GIS database. This information was supplemented as necessary with information collected from field survey and inspections.

Pit inlets were represented in TUFLOW as rectangular orifice inlets of specified height, width and invert (invert representing the surface level of the inlet). Standard TUFLOW parameters were adopted to define contraction/expansion and entry/exit losses for pit inlets. The potential for pit blockage was accounted for by adopting a blockage factor of 50%, which is typical of the values commonly adopted for these types of studies in similar urban catchments. A blockage factor of 50% was also consistent with the degree of debris observed in the pits during site visits, as well as documented by community members in the survey questionnaire.

Losses within pits occur due to changes in flow direction, changes in elevation and the expansion and contraction of flow as it passes through a pit. TUFLOW represents these losses by incorporating an orifice at each exit from a pit. Standard TUFLOW coefficients were adopted to represent expansion/contraction and entry/exit losses at the pit exit. As a conservative assumption, rectangular culverts have been modelled using a less efficient square edge opening contraction coefficient.

Pit surface levels were estimated based on ALS data. Invert levels of pits and pipes were not available from available GIS data. Field survey data was collected for major pipe inlets and outlets. Where no pipe invert data was available, a nominal value of 400mm was typically adopted, but was adjusted where necessary to achieve a positive pipe grade.

The 400 mm cover assumption is considered reasonable since:

- it is conservative as it is the minimum pipe cover that would generally be expected, and
- during pipe full flow under pressure, the invert level of the pipe generally has minimal effect on the Hydraulic Grade Line (HGL) of the water surface.

6.5. Manning's Roughness for Overland Flow

Surface roughness influences the hydraulic efficiency of overland flow. TUFLOW uses Manning's 'n' roughness value to represent the influence of surface roughness, and the effects of vegetation and other features which may affect the efficiency of flow.

Manning's 'n' roughness values were assigned based on aerial photography. The majority of the model extent consists of residential areas interspersed with roads and some open space or pockets of vegetation. There are also large expanses of mangrove and wetland areas, which impede the movement of low depth flow and consequently have been assigned a higher Manning's 'n' value. A summary of the Manning's 'n' values adopted within the TUFLOW model for overland flow is shown in Table 10.

Table 10: Summary of Manning's 'n' Values

Surface	Manning's 'n' Adopted
Roads and concrete	0.02
Residential	0.06
Mangrove / wetland	0.50
Grass / Open space	0.04
Grassed open channels	0.08

6.6. Infiltration

Due to the flat topography throughout the majority of Kurnell, flood waters have been observed by community members to remain ponded for approximately 2-4 days, with some reports of ponding remaining for more than a week. Infiltration is therefore a significant process in accounting for the reduction of flood waters after the initial storm event.

Infiltration was applied to the TUFLOW model at a rate of 5.4 mm/hr, to simulate seepage from ponded areas. This rate is based on a previous study at Lot 105 Torres Street (Reference 7). The study reported that water was observed to remain ponded for 24-48 hours at the site. Using this information as well as details on the surface area, an infiltration rate of 1.5×10^{-6} m/s (5.4 mm/hr) was calculated. As similar soil characteristics occur throughout the catchment, and similar ponding times have been observed at other locations within Kurnell, the same infiltration rate was adopted for the current study. To assess the appropriateness of this assumption, and the influence of infiltration on flooding impacts, different infiltration rates were trialled as part of the sensitivity analysis in Chapter 10.

7. MODEL VALIDATION

7.1. General

Ideally, once the various models have been established, it is preferable to calibrate the model parameters using a suitable historical event. The performance of the calibrated model can then be verified against one or more other historical events. To calibrate/verify the models, a sufficient amount of flood data for each historical event within the modelling extent is required.

Limited relevant historical flood information was obtained during the data collection process of the current study. The March 2003 storm is the only recent event with a known recorded flood level. Another four historical flood levels were obtained, as documented in Section 3.5.4. However, the exact location of the peak flood height was unknown. The corresponding dates of flooding were also unknown, making use of these historical flood levels for model validation limited.

Flood extents for the 1974 and 1975 flood events were provided in the *Kurnell Village Drainage Investigation* (Reference 1) based on reported flooding. However, this information is limited in that the mapped flood extents only covered a section of the township, and actual flood levels were unknown. In the case of the 1975 flood, extents are provided for the Cook Street area, as shown in Figure 7. Rainfall and tidal records show that the 1974 flood was mainly caused by elevated tidal levels rather than intense rainfall. The topography has significantly changed in some of the catchment since the 1970's, mainly due to local infilling of properties and road regrading works to Dampier Street. Hence these events are limited in their use for model validation.

Due to the relative lack of detailed flood data, the following is a limited model validation only. However the outcomes are still useful as they provide an indication of the ability of the hydrologic and hydraulic models to perform within reasonable limits.

When flooding occurs within the catchment in future, it is recommended that Council (or the relevant authority) undertake to collect any available information (such as rainfall data and flood heights) as soon as practicable after the event.

7.2. Approach

The hydrologic/hydraulic models were validated using the storm event of 13-14th May 2003. Compared with existing conditions, there is likely to have been some minor infilling of residential lots. However, the exact extent of filling across the catchment and the catchment conditions prior are generally not known.

Filling is known to have occurred in the vicinity of Torres Street, and survey data obtained as part of *Flooding Assessment of Lot 105 Torres Street, Kurnell* (Reference 7) indicated the ground levels of Lot 105 Torres Street as of 2002. Discussions with the resident at Lot 105 indicated that the property and the adjacent property were not filled until after the 2003 flood event. The model ground grid was therefore adjusted in this location to represent conditions prior to filling. However, due to a lack of similar information in other parts of the catchment, no other changes were made, and existing catchment conditions were assumed.

As there is no continuous rainfall recording device within the study catchment, pluviometer records from the Malabar gauge were adjusted to match daily rainfall records from the Kurnell (Caltex Oil Refinery) gauge. The resulting rainfall pattern has the same rainfall totals as that recorded at the Kurnell (Caltex Oil Refinery), with the storm pattern of the Malabar gauge records. Gauge records from Cronulla STP, the Sydney Airport and Malabar pluviograph stations were compared with the daily totals at Kurnell (Caltex Oil Refinery). Malabar records were found to produce the best match in terms of rainfall total and distribution.

The model was run using a 48 hour dataset covering the 13th and 14th May 2003 storm event. Historical tidal data obtained for Fort Denison (Reference 12) was used to define downstream boundary conditions for the model.

The initial model was run using a 4 m grid. To determine the influence of grid resolution on flood levels, the model was also run using a 2 m grid.

7.3. Results and Discussion

Modelled flood results for the May 2003 historical event using a 4 m grid are presented on Figure 14, showing flood depths and extents. At the location of the one observed flood level (at 87 Torres Street), the modelled flood level was 1.74 mAHD while the reported flood level was 1.52 mAHD. This discrepancy can be attributed in part to the following factors:

- Uncontrolled filling has known to occur along the rear of some properties in Torres Street, impeding overland flow from upstream areas. Thus the catchment conditions have changed since 2003. While some of these changes have been accounted for by modification of the ground grid for the historical event, it is possible that not all changes have been accounted for.

- A comparison between the surveyed flood level and surrounding ALS data suggests that the ALS data is slightly higher. This could be due to readings in thick vegetation such as gardens and grassed areas. Thus the ALS is likely to be slightly higher than the actual ground levels in this area, and hence resulting flood levels will also be higher.

- The surveyed flood level was based on photographs of the flood height at the surveyed location. However, as there were no actual flood marks, it is possible that the photographs were not taken at the peak of the flood, and that flood waters reached a slightly higher level.

- There was no pluviograph rainfall data for the catchment area, hence rainfall patterns had to be estimated using the Malabar pluviograph. It is possible that this had some impact on the resulting modelled flood levels.

Given the limited quantity of calibration data, and the above uncertainties in topography and peak flood level, the discrepancy between surveyed and modelled levels is considered to be acceptable for the purposes of this study.

Comparing the flood levels with those produced by the 2 m grid indicated that grid size did not make a significant difference to flood levels across the majority of catchment or to the surveyed location. In both cases, flow paths within the grid surrounding the property surveyed were restricted by the areas nulled by the buildings. In a few areas such as Cook Street Swamp adjacent to Polo Street, the 4m grid reached 0.16m above the level of the 2m grid. This difference flood levels resulting from grid size is discussed in more detail in Chapter 10.

8. DESIGN EVENT MODELLING

8.1. Approach

The hydrologic and hydraulic models described previously were used to estimate the design flood behaviour across the study catchment under existing conditions. Design storm events were analysed for the 20%, 5% and 1% AEP and the Probable Maximum Flood (PMF).

The traditional AR&R 1987 approach to design storm hydrology is based on the estimation of a peak flow generated by a critical duration peak burst rainfall pattern. The method assumes that antecedent rainfall prior to the critical duration burst does not impact upon the peak flow estimates (Reference 16). Several other studies indicate that a failure to incorporate antecedent conditions prior to the critical duration peak burst may result in the underestimation of peak flows for some catchments (References 17 and 18). As noted in Reference 16, this is particularly the case for catchments where the AR&R 1987 critical burst durations are much shorter than the duration of historic flood-producing storms. For the Kurnell catchment, there is a significant chance that high-intensity short duration storm bursts likely to cause major flooding will occur during a broader low intensity, longer duration storm.

A further complication within the Kurnell catchment is that this flood behaviour within the catchment cannot be represented using a single peak burst rainfall pattern, since the design temporal pattern producing flooding in the upper reaches is different from that producing flooding in the lower reaches. This is due to the difference in topography between the steeper north eastern part of the catchment in the vicinity of Polo Street, and the flat topography throughout the remainder to the catchment. Flooding in steeper areas is generally caused by high intensity, short duration storms, whereas in flatter areas, flooding is more dependent upon total volume of rainfall, which is caused by longer, low intensity storms.

To address these issues, this study adopts an alternative approach to design flood estimation, whereby a short duration design storm burst is embedded within a longer duration storm of the same AEP. This approach was originally presented in Reference 17 and has been further documented in Reference 16. Initially, the shorter burst is embedded to coincide with the peak of the larger duration storm. To ensure that the average intensities reflect the original AEPs, the intensities of the longer duration storm are adjusted on either side of the peak burst such that the total rainfall depth is consistent with that of the original longer duration storm. Further details regarding the procedure can be found in References 16 and 17.

8.2. Boundary Conditions

8.2.1. Inflow Hydrographs

Design rainfall intensities and temporal patterns were derived from AR&R 1987 (Reference 10) and input into the WBNM hydrologic model. Uniform depths of rainfall with zero areal-reduction factor were applied across the entire catchment. The resulting rainfall hyetographs were converted by the WBNM model into design inflow hydrographs.

Design inflow hydrographs obtained from the WBNM model were then applied to the TUFLOW model at the upstream boundary locations shown on Figure 13.

8.2.2. Direct Rainfall

The design rainfall hyetographs developed for the WBNM model were also applied to the TUFLOW model as direct rainfall within the extent of the hydraulic model. Before applying these rainfall hyetographs to the 2D ground grid, rainfall losses were applied as discussed in Section 5.2.3.

8.2.3. Downstream Boundaries

In addition to runoff from the catchment, Kurnell can also be influenced by high tailwater levels in Quibray Bay. These two distinct flooding mechanisms may or may not result from the same storm. Consideration must therefore be given to the joint probability of coincident flooding from both catchment runoff and tailwater effects from Quibray Bay.

A full joint probability analysis is beyond the scope of the present study. Traditionally, it is common practice to estimate flood levels in these situations using a ‘peak envelope’ approach that adopts the highest of the predicted flood levels obtained from the two mechanisms.

There is no rigorous or commonly adopted procedure for determining an appropriate tailwater level in Botany Bay to be used in conjunction with design flows. Catchment flooding due to rainfall is completely independent of tides and has an equal chance of occurring on high or low tide.

A constant level of 0.6 mAHD was adopted as the tailwater condition for design flows in Kurnell. This level represents mean high tide level and is consistent with that adopted for Botany Bay in the *Georges River Floodplain Risk Management Study* (Reference 6). An assessment of the sensitivity of model results to varying tailwater conditions was undertaken and is presented in Chapter 10.

Design flood levels due to tidal flooding were also based on recommended levels for Botany Bay in the *Georges River Floodplain Risk Management Study* (Reference 6) as reproduced in Table 11. Design flood levels across the catchment should therefore be taken as the maximum of the levels obtained from the two mechanisms.

Table 11: Design Flood Levels for Tidal Flooding

Event	Design Flood Level (mAHD)
20% AEP	1.4*
5% AEP	1.5
1% AEP	1.7
PMF	2.0

*Note: Estimated using the shape of the key ocean level curve presented in Reference 19.

9. DESIGN FLOOD RESULTS

9.1. Overview

The numerical models were run for a number of design events, and the results were used to provide a description of the design flood behaviour of the study area. Information such as peak flood levels, flows and velocities were extracted, and have been documented as part of this report. In addition, the model results have also been produced in a digital format that can be readily imported into Council's GIS systems.

9.2. Critical Storm Duration

The determination of the critical storm duration for an urban catchment is more complex than for a rural catchment. Consideration must be taken of:

- the peak flow from the subcatchment surface,
- a range of durations to cover both short durations and long durations
- the peak flow in drainage networks,
- the volume temporarily collected in ponding areas, and
- the location within the catchment.

Standard AR&R 1987 storm burst durations ranging from 90 minutes to 24 hours, were run for the 1% AEP event. The corresponding peak flow and water level estimates were then compared to determine which durations produced the maximum water levels.

The critical burst duration was found to vary across the catchment. However, generally there were two dominant patterns. For the 1% AEP event, the critical duration in the upper reaches typically ranged between 60 minutes and 120 minutes, and in the lower reaches ranged between 12 hours and 24 hours. In the upper reaches, the 90 minute storm typically dominated, while in the lower reaches the 12 hour storm typically dominated. The 90 minute in 12 hour embedded storm was therefore adopted as the representative critical duration for the study area for the 1% AEP storm. A detailed comparison of results across the entire study area showed that the difference between the embedded storm and the maximum of all durations were less than 0.05 m, and this was limited to relatively localised areas.

The nature of flooding in Kurnell, particularly in the lower reaches, is largely volume driven. Therefore the critical duration would be expected to increase for more frequent (lower intensity) storms. Consequently, the approach adopted to assess the critical duration for the 1% AEP storm was also applied to the 20% and 5% AEP storms. The 120 minute in 36 hour embedded storm was found to be critical for the 20% AEP event and the 120 minute in 30 hour embedded storm was critical for the 5% AEP storm.

For the extreme event (PMF), the 120, 180 and 360 minute storms were run. The 180 minute storm produced the maximum flood level over the majority of the catchment except for some small areas at the eastern end of the drainage channel along Polo Street. The 180 minute storm was therefore adopted as the critical duration for the PMF.

9.3. Model Results and Discussion

Design model results for the 20%, 5%, 1% AEP and PMF events are presented in Figures 15 to 37 whilst a summary of peak flood levels and at 9 key locations are shown in Table 12. These key locations were chosen based on their position along major overland flow paths. The location of these points are shown in Figure 13.

Table 12: Summary of peak flood levels at key locations

Location*	Description	Peak Flood Levels (mAHD)			
		20% AEP	5% AEP	1% AEP	PMF
2	Road on the corner of Dampier and Tasman Streets	1.84	2.01	2.27	2.85
5	Road on Cook Street, near Marton Park Swamp	2.58	2.69	2.92	3.24
9	Road on the corner of Torres and Balboa Streets	1.55	1.59	1.67	2.01
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	1.68	1.73	1.86	2.33
14	Road on Captain Cook Drive near Shepherd Street	2.58	2.68	2.91	3.21
15	Road on the corner of Captain Cook Drive and Torres Street	2.57	2.67	2.87	3.17
16	Road on Captain Cook Drive near Tasman Street	2.68	2.71	2.82	3.18
17	Road on Captain Cook Drive at southern end of the open channel	2.69	2.74	2.81	3.15
18	Road at north western end of Captain Cook Drive	2.38	2.54	2.77	3.05
19	Torres Street, between Dampier Street and Captain Cook Drive	2.52	2.61	2.80	3.07

* Refer to Figure 13 for location number.

The flood levels shown in Table 12 reflect the general south westerly direction of the flood gradient across the study area, with floodwaters typically flowing from the national park toward Quibray Bay. The greatest change in flood level between events occurs at location 2, on the corner of Dampier and Tasman Streets.

Figures 20 to 21 and 29 to 30 show the flood levels and depths for the 1% AEP event. It can be seen that whilst the majority of the catchment area is inundated, a substantial area is covered by floodwaters with a depth of less than 0.25m. In a number of locations, such as the residential area along Polo Street, depths are typically less than 0.1m. Hence despite the expanse of flooding, a significant proportion of floodwaters are relatively shallow and slow moving. Peak flow velocities for the 1% AEP event are shown in Figure 36, and it can be seen that there are relatively few locations where velocities exceed 0.5 m/s. Higher velocities are generally restricted to roadways, and a few localised areas adjacent to the oil refinery.

For the purposes of floodplain risk management in NSW, the floodplain is broadly divided into one of three hydraulic categories (floodway, flood storage or flood fringe) and two provisional hazard categories (Low or High). Further details of this process are outlined in the *NSW Government's Floodplain Development Manual* (Reference 20). Floodways are defined as being areas where a significant proportion of flow occurs, and where any blockage would have a significant impact on the surrounding flood behaviour. Flood storage occurs where water is temporarily held during a flood, and where complete filling would cause an increase in surrounding flood levels of 0.1m or more, or an increase in discharge of greater than 10% downstream. Any remaining areas are described as flood fringe.

Flood behaviour in Kurnell does not easily allow for the division of the catchment into these hydraulic categories. A number of flow paths exist through residential areas as well as on roads, as seen in Figure 36. The majority of these flows are shallow and slow moving. Hence they do not fit the typical definition of floodways, which generally refers to areas with high velocities and deeper water. Partial blockage will also not necessarily result in a substantial increase in surrounding flood levels due to the distributed nature of the flow paths, although complete blockage is likely to have an adverse impact.

Whilst there are a few areas which can be defined as being flood storage, such as Solander Street Swamp (Marton Park) and Cook Street Swamp adjacent to Polo Street, there are a number of small storage areas in localised depressions throughout the catchment which are not easily defined. In some cases, these storage areas are located in the same area as flow paths.

In catchments where flooding is primarily caused by a defined creek or river, flood fringe areas are typically located on the fringe of flood extents, adjacent to high ground. Evacuation routes are therefore easily defined. However, the location of high ground is less obvious in Kurnell, and is highly dependent upon the severity of the flood event.

The lack of easily identified high ground and evacuation areas increases the flood risk within Kurnell, as evacuation paths may not be clear to an evacuee during a flood. Areas on higher ground also become isolated, requiring travel through floodwaters in order to reach evacuation points. Flood model results indicate that Captain Cook Drive, the single evacuation route out of Kurnell, is cut off in the 20% AEP flood event and thus safe evacuation is restricted. Extended ponding times increase the duration of flooding, which further increases the flood impact and risk to residents. These issues will be discussed in greater detail as part of the Floodplain Management Study.

Based on the design flood information produced from this Flood Study, it is envisaged that detailed hazard mapping and hydraulic categorisation would be undertaken as part of a subsequent Floodplain Management Study. However, in the interim, maps of the provisional hydraulic hazard (peak velocity x peak depth product) for the 1% AEP and the PMF have been produced, as shown in Figures 38 and 39. For the purposes of the present study, this approach provides a conservative estimate of provisional flood hazard.

10. SENSITIVITY ANALYSES

10.1. Overview

The models established for the present study rely on a number of assumed parameters, the values of which are considered to be the most appropriate for urban catchments based on previous use and experience in other studies of similar catchments. Although a limited model validation has been performed, a range of sensitivity analyses were also undertaken to quantify the potential variation in the model results due to different assumptions in the key modelling parameters adopted.

Sensitivity of modelled flood behaviour was assessed for model parameters, definition in the hydraulic model and the impacts or effects of various catchment features.

The following scenarios were considered to represent the envelope of likely parameter values:

- ± 10% change in rainfall,
- a range of infiltration rates from 0 mm/hr, to 2.5 times and 5 times the base case,
- ± 25% change in Manning's 'n' roughness value, and
- ± 20% change in the WBNM lag parameter.

Other model sensitivities assessed were:

- The grid resolution was reduced to a 2 m cell size. A 4 m grid was used in the base case.
- Buildings were modelled as non impermeable obstructions to flow but with a high Manning's 'n' value. This was used to represent potential storage under buildings, with the high Manning's 'n' values accounting for the fact that the buildings would not be providing a pathway for flow conveyance. In the base case, buildings were modelled as completely impermeable to flow, and thus no available flood storage was assumed.
- A ± 50% change in percentage impervious throughout the catchment.
- Removal of the pit and pipe drainage network from the model.
- The Caltex Oil Refinery was modelled with all the bunds removed to assess the potential impacts of bund failure. Bunds can fail either due to loss of structural integrity and/or due to overtopping. The complete removal of all bunds is considered a conservative estimate of the potential impacts resulting from bund failure, as it is unlikely that all bunds would fail at the same time.

For each of the scenarios outlined above, the models were run for the 1% AEP design storm. Results are discussed in Section 10.2.

Sensitivity of model results to varying tailwater conditions was also assessed. Results and discussion are provided in Section 10.3.

10.2. Results

Results of the various sensitivity scenarios outlined in the previous section, at 19 key locations, are presented in Table 13 for the 1% AEP embedded 90 minute in a 12 hour design storm. These locations included those shown in Table 12, as well as an additional 10. Whilst the additional 10 locations were not located along a road, they were also within a flow path or a localised depression. The locations were chosen based on where the most impacts are likely to occur from changing the different model parameters and boundary conditions.

The results of the sensitivity analyses can be summarised as follows:

Model parameters

- Changing the rainfall by ±10% had a relatively small impact on peak flood levels, with only a maximum change of ±0.1 m.
- Changing the infiltration in the TUFLOW hydraulic model also had a relatively small impact on modelled flood behaviour. Reducing the infiltration rate to zero typically resulted in an increase in flood level of no greater than 0.01m. Even increasing the rate of infiltration by a factor of 5 (to 27 mm/hr) only resulted in a maximum decrease of 0.06 m. Infiltration rates are likely to have a greater bearing on how long it takes floodwaters to recede rather than on peak design flood levels.
- Decreasing the Manning's 'n' value produces a slight decrease in peak flood levels in the majority of locations, with the maximum decrease being 0.14 m. These results are to be expected since a reduction in Manning's 'n' value increases the hydraulic efficiency of flow paths, resulting in a lower flood level for the same magnitude of flow. The converse of these observations holds true for the effect of increasing Manning's 'n' value by a similar amount.
- Changing the WBNM lag parameter produced a maximum change in flood level of 0.01 m or less in the majority of locations. The greatest change occurred in the upstream areas of the catchment, but the maximum was still only 0.04m. A reduction in lag parameter increases the catchment response time. This has greater influence in the upper areas, whereas in the lower areas flood behaviour is more largely driven by rainfall volume.

Definition of the hydraulic model

- Increasing the grid resolution from 4m to 2m had a significant impact on flood levels across the majority of the catchment. The 2m grid caused a reduction in levels in the order of 0.15m across the study area, with values typically in the range of 0 to 0.3m.
- Applying flood storage under all buildings generally resulted in a decrease in flood levels. These decreases were typically less than 0.05 m, with the maximum being 0.17 m near Cook Street.
- Changing the percentage impervious by ± 50% resulted in only minor changes in flood levels, with variations less than 0.03 m.

Impacts and effects of catchment features

- Removal of the piped drainage network from the model typically resulted in a slight increase in peak flood levels, with the maximum increase being 0.08 m. These results would suggest that the piped drainage only provides a slight effect on reducing peak design flood levels in the 1% AEP event. However, benefits would be greater for more frequent storms, and the influence of the piped drainage system to reduce nuisance flooding and prolonged ponding of waters should not be discounted.
- Removal of the bunds within the Caltex Oil Refinery resulted in an increase in flood levels of less than 0.01m over the majority of the study extent. Areas which exhibited a greater change where adjacent to the Caltex Oil Refinery. However, these changes were not significant throughout the residential areas.

The sensitivity analysis has shown that the hydrologic and hydraulic models are relatively insensitive to changes in model parameters, and catchment features. Whilst the models were relatively insensitive to some changes in the hydraulic model definition, an increase in grid resolution from 4m to 2m resulted in a larger impact on flood levels across the majority of the catchment compared with that found in other studies.

In order to investigate the possible causes for this discrepancy, the 2m and 4m ground grids were compared in terms of available storage volume and flow paths. It was found that the 4m grid had a slightly greater volume of available storage at most flood levels, and hence is not the primary reason for the differing flood levels. Figure 40 shows a section of the 2m and 4m ground grids near Dampier and Bridges Streets, showing representation of buildings in the two grids. Where buildings are located close together, the pathway between them may not be adequately represented in the model, depending on the grid resolution. Typically, the 2m grid provides a better definition of the flowpaths between buildings. Consequently, the 2m grid would generally give a greater conveyance for flows between buildings, which would contribute to the lower flood level results. Whilst the 2m grid generally provides better definition of the flow paths between buildings, there are some instances where the 4m grid was found to provide better detail.

The 4m grid was adopted for the design runs due to the computation time required to run the 2m grid for all scenarios. It is acknowledged that the 2m grid may produce a better definition of flow between buildings. However, there are a range of other factors that would require consideration, such as obstructions to flows due to fences, garden beds and sheds, and the effects of these at different grid resolutions. Given these factors cannot be reliably modelled or managed, it is recommended that a 4m grid resolution is adopted as it is slightly conservative.

Table 13: Sensitivity Analyses – Change in Peak Flood Height for 1% AEP Design Flood Event (m)

Comparison			Rainfall		Infiltration*			Manning's 'n'		Lag Parameter		DEM Definition		Percentage Impervious		No Pipe Network	Caltex Oil Refinery
Location	Description	1% AEP Base Case (m AHD)	+10%	-10%	0mm/h	13.5mm/h	27mm/h	- 25%	+25%	+20%	-20%	2m Grid	Flood Storage under Buildings	-50%	+50%		Bunds Removed
1	Local depression in residential area behind properties in Torres and Dampier Streets	2.76	0.04	-0.05	0.01	-0.01	-0.03	-0.02	0.02	0.00	0.00	-0.16	-0.06	-0.01	0.01	0.01	0.01
2	Road on the corner of Dampier and Tasman Streets	2.27	0.05	-0.05	0.01	-0.01	-0.03	-0.04	0.04	0.00	0.00	-0.15	-0.07	-0.02	0.02	0.00	0.01
3	Local depression in residential area to the east of Cook Street	3.47	0.03	-0.04	0.00	0.00	-0.01	-0.02	0.02	-0.02	0.01	-0.13	-0.17	0.00	0.00	0.01	0.05
4	Local depression in industrial/commercial area to the east of Cook Street	3.07	0.01	-0.01	0.00	0.00	0.00	-0.05	0.02	-0.01	0.01	-0.03	0.01	0.00	0.00	0.00	-0.13
5	Road on Cook Street, near Marton Park Swamp	2.92	0.04	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.17	-0.04	-0.01	0.01	0.01	0.01
6	Marton Park Swamp	2.91	0.04	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.16	-0.03	-0.01	0.01	0.01	0.01
7	Residential area north of Gannon Street	2.90	0.03	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.18	-0.03	-0.01	0.01	0.01	0.01
8	Local depression in residential area south of Prince Charles Parade and east of Dampier Street	2.70	0.02	-0.01	0.00	0.00	0.00	-0.02	0.02	0.00	0.00	-0.11	-0.08	-0.01	0.01	0.00	0.00

Comparison			Rainfall		Infiltration*			Manning's 'n'		Lag Parameter		DEM Definition		Percentage Impervious		No Pipe Network	Caltex Oil Refinery
Location	Description	1% AEP Base Case (m AHD)	+10%	-10%	0mm/h	13.5mm/h	27mm/h	- 25%	+25%	+20%	-20%	2m Grid	Flood Storage under Buildings	-50%	+50%		Bunds Removed
9	Road on the corner of Torres and Balboa Streets	1.67	0.01	-0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.03	-0.01	-0.01	0.01	0.01	0.00
10	Reserve near Quibray Bay adjacent to the corner of Torres and Balboa Streets	1.51	0.03	-0.05	0.01	-0.01	-0.02	-0.07	0.03	0.00	0.00	-0.17	-0.08	-0.02	0.02	0.02	0.01
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	1.86	0.04	-0.04	0.00	-0.01	-0.01	-0.06	0.05	0.00	0.00	-0.10	-0.01	-0.02	0.02	0.00	0.00
12	Local depression in residential area east of Horning Street, close to Quibray Bay	1.98	0.09	-0.10	0.01	-0.02	-0.06	-0.14	0.09	0.01	-0.01	-0.15	-0.05	-0.03	0.02	0.00	0.02
13	Local depression in residential area to the east of Silver Beach Road	2.90	0.04	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.16	-0.03	-0.01	0.01	0.01	0.01
14	Road on Captain Cook Drive near Shepherd Street	2.91	0.04	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.16	-0.03	-0.01	0.01	0.01	0.01
15	Road on the corner of Captain Cook Drive and Torres Street	2.87	0.03	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.14	-0.03	-0.01	0.01	0.01	0.01
16	Road on Captain Cook Drive near Tasman Street	2.82	0.04	-0.04	0.00	0.00	0.00	-0.05	0.05	-0.02	0.04	0.03	-0.01	0.00	0.00	0.01	0.04
17	Road on Captain Cook Drive at southern end of the open channel	2.81	0.03	-0.02	0.00	0.00	0.00	-0.04	0.03	-0.03	0.04	0.00	-0.01	0.00	0.00	0.01	0.01

Comparison			Rainfall		Infiltration*			Manning's 'n'		Lag Parameter		DEM Definition		Percentage Impervious		No Pipe Network	Caltex Oil Refinery
Location	Description	1% AEP Base Case (m AHD)	+10%	-10%	0mm/h	13.5mm/h	27mm/h	- 25%	+25%	+20%	-20%	2m Grid	Flood Storage under Buildings	-50%	+50%		Bunds Removed
18	Road at north western end of Captain Cook Drive	2.77	0.06	-0.08	0.01	-0.02	-0.04	-0.02	0.02	0.00	0.00	-0.08	-0.03	-0.03	0.02	0.08	0.02
19	Torres Street, between Dampier Street and Captain Cook Drive	2.80	0.03	-0.04	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.00	-0.13	-0.04	-0.01	0.01	0.01	0.01

10.3. Tailwater Conditions

The influence of varying tailwater conditions on design flood behaviour was assessed for the 5% and 1% AEP design storm events. As noted previously, a tailwater level of 0.6 m was adopted for the design event modelling. For sensitivity analyses the 5% AEP storm was run with a 1.7 mAHD (1% AEP tide) and a 2.0 mAHD (extreme tide) tailwater level, while the 1% AEP storm was run with a 0.9 mAHD (high spring tide) and 1.7 mAHD tailwater level.

Results of the various tailwater level conditions are presented in Table 14. Results show that any change in the tailwater level results in a similar change to flood levels in the lower reaches with the effects dissipating further upstream. The impact on flood levels is generally greater for the 20% AEP event, as tidal flooding becomes the dominant cause of flooding adjacent to Quibray Bay, whereas during the 1% AEP event, flooding from rainfall is still a significant component.

Table 14: Change in Peak Flood Height for Varying Tailwater Conditions (m)

Location	Description		Change in Flood Level			Change in Flood Level	
		20% AEP Base Case with Normal High Tide (0.6m) (m AHD)	20% AEP with 1 % AEP Tide (1.7m)	20% AEP with Extreme High Tide (2.0m)	1% AEP Base Case (0.6m) (m AHD)	Spring High Tide (0.9m)	1% AEP Tide (1.7m)
1	Local depression in residential area behind properties in Torres and Dampier Streets	2.42	0.00	0.02	2.76	0.00	0.01
2	Road on the corner of Dampier and Tasman Streets	1.84	0.11	0.30	2.27	0.00	0.06
3	Local depression in residential area to the east of Cook Street	3.27	0.00	0.00	3.47	0.00	0.00
4	Local depression in industrial/commercial area to the east of Cook Street	2.99	0.00	0.00	3.07	0.00	0.00
5	Road on Cook Street, near Marton Park Swamp	2.58	0.03	0.05	2.92	0.00	0.01
6	Marton Park Swamp	2.58	0.03	0.05	2.91	0.00	0.01
7	Residential area north of Gannon Street	2.45	0.00	0.06	2.90	0.00	0.01
8	Local depression in residential area south of Prince Charles Parade and east of Dampier Street	2.50	0.00	0.05	2.70	0.00	0.00
9	Road on the corner of Torres and Balboa Streets	1.55	0.16	0.46	1.67	0.00	0.12
10	Reserve near Quibray Bay adjacent to the corner of Torres and Balboa Streets	1.08	0.63	0.93	1.51	0.00	0.29
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	1.68	0.10	0.34	1.86	0.00	0.09
12	Local depression in residential area east of Horning Street, close to Quibray Bay	1.50	0.38	0.61	1.98	0.01	0.18
13	Local depression in residential area to the east of Silver Beach Road	2.58	0.03	0.05	2.90	0.00	0.01
14	Road on Captain Cook Drive near Shepherd Street	2.58	0.03	0.05	2.91	0.00	0.01
15	Road on the corner of Captain Cook Drive and Torres Street	2.57	0.03	0.04	2.87	0.00	0.01
16	Road on Captain Cook Drive near Tasman Street	2.68	0.00	0.00	2.82	0.00	0.02
17	Road on Captain Cook Drive at southern end of the open channel	2.69	0.00	0.00	2.81	0.00	0.01
18	Road at north western end of Captain Cook Drive	2.38	-0.03	0.04	2.77	0.00	0.02
19	Torres Street, between Dampier Street and Captain Cook Drive	2.52	0.03	0.04	2.80	0.00	0.01

11. CLIMATE CHANGE

11.1. General

Research conducted by the United Nations Intergovernmental Panel on Climate Change (IPCC) (Reference 21), has shown that there has been an observable change in global climatic conditions over the last 100 years. Observed changes include an increase in global surface temperature of 0.74^{o}C between 1906 and 2005, and a global sea level rise of 1.8 mm/yr on average (a total of 0.08m) between 1961 and 2003. Reference 21 also found long term changes in precipitation for a number of continents.

Based on IPCC research, ignoring ice flow melt, global sea levels are predicted to rise between 0.18 and 0.59m, by between 2100. When the influence of ice melt and the predicted higher than global average sea level rise on the east coast of Australia are included the predicted sea level rise on the NSW coast is between 0.18 and 0.91m by 2100. It should be noted that there are still a number of uncertainties in these predictions,

The effects of climate change are also predicted to result in a change in average and seasonal rainfall patterns, including flood producing rainfall events. These changes have the potential to increase the frequency and severity of flooding. However, there is still much uncertainty about the specific nature of such changes on a regional basis and research continues.

These changes have the potential to influence the occurrence and impact of flooding. The *2005 Floodplain Development Manual* (Reference 20) therefore requires the consideration of climate change as part of all flood studies. In 2007, DECC produced a Floodplain Risk Management Guideline titled *Practical Consideration of Climate Change*. The guideline recommends that sensitivity analyses be undertaken to examine different climate change scenarios to inform flood risk management decision making. The following climate change scenarios have been considered in this assessment:

The scenarios for sea level rise are:

- Low: +0.18m
- Medium: +0.55m
- High: +0.91m

The scenarios for peak rainfall/storm volume are:

- Low: +10% rainfall
- Medium: +20% rainfall
- High: +30% rainfall

The climate change scenarios are a sensitivity analysis and should not be confused with Flood Planning Levels which will be considered in the Floodplain Risk Management Study.

11.2. Potential Impacts of Climate Change on Flooding in Kurnell

Increases in rainfall intensity and sea level rise have the potential to increase the impact of flooding in Kurnell. As Kurnell is affected by both catchment and ocean flooding, climate change has the potential to impact on both of these flooding mechanisms. In order to investigate the potential impacts of climate change on flooding in Kurnell, additional modelling was conducted for the scenarios listed in Table 15.

These scenarios consider the potential impacts of climate change on both ocean (sea level rise) and catchment flooding (an increase in rainfall intensity) separately, as well as the combined effects. The sensitivity of both the 20% and 1% AEP events to climate change has been modelled to provide an indication of the magnitude of impacts for both smaller, more frequent flood events as well as major events.

11.2.1. Boundary Conditions

Ocean Levels

Fixed ocean levels instead of variable tides have been applied for catchment flooding scenarios, to provide consistency with model runs for existing conditions. This is a conservative assumption.

For ocean flooding scenarios, higher peak ocean levels are used, and variable ocean levels have been modelled to provide a more realistic estimate of peak flood levels. Peak ocean levels were derived based on Reference 6 plus sea level rise. The tide peaks were timed such that they coincided with peak flood levels throughout the majority of the catchment for the 20% AEP catchment flood event.

Rainfall

A 10, 20 or 30% increase in rainfall was used to estimate sensitivity to rainfall increase. A 10% increase in rainfall for the 1% AEP storm had already been modelled as part of the sensitivity analysis discussed in Section 10.

Table 15: Climate Change Scenarios

	Scenario Number	Event	Ocean Conditions			Sea Level Rise		Rainfall Conditions			
			Normal high tide	*5% AEP variable tide*	*1% AEP variable tide*	Medium	High	Current Design	+10%	+20%	+30%
Effect of sea level rise on design catchment flooding events	1	20% AEP	■			■		■			
	2	20% AEP	■				■	■			
	3	1% AEP	■			■		■			
	4	1% AEP	■				■	■			
Effect of sea level rise on ocean flooding events	5	20% AEP		■		■		■			
	6	20% AEP		■			■	■			
	7	20% AEP			■	■		■			
	8	20% AEP			■		■	■			
Effect of increase in rainfall on catchment flooding for normal ocean conditions	9	20% AEP	■						■		
	10	20% AEP	■							■	
	11	20% AEP	■								■
	12	1% AEP	■						■		
	13	1% AEP	■							■	
	14	1% AEP	■								■
Combined effect of increased rainfall and sea level rise on a catchment flooding event	15	20% AEP	■			■			■		
	16	20% AEP	■			■					■
	17	20% AEP	■				■		■		
	18	20% AEP	■				■				■
	19	1% AEP	■			■			■		
	20	1% AEP	■			■					■
	21	1% AEP	■				■		■		
	22	1% AEP	■				■				■

11.2.2. Results and Discussion

Tables 16 to 19 show the change in flood levels for a number of locations throughout the catchment for selected climate change scenario. A summary of the estimated impacts of sea level rise, rainfall increase, and the combined effects is discussed below.

Impact of sea level rise on catchment flooding
Modelling indicates that both medium and high sea level rise scenarios have minimal impact (generally less than 20mm) on flood levels throughout the majority of the catchment for a catchment flood event. However, properties adjacent to Quibray Bay are likely to be affected by increased flood levels, particularly with a high sea level rise scenario. Areas which appear to be particularly vulnerable are those near the corner of Tasman and Horning streets, and Balboa and Torres streets.

Ocean Flooding
Sea level rise is likely to result in a significant increase in flood levels during ocean flood events. Generally, the areas affected are confined to locations west of Dampier Street, and south of Bridges Street in the eastern areas. A 5% AEP ocean flood combined with a medium sea level rise (Scenario 5) produced an increase in flood levels of between approximately 200-500mm, with the greatest impacts in areas closer to Quibray Bay. A 5% AEP ocean flood combined with a high sea level rise (Scenario 6), resulted in an increase in flood levels of up to 900mm.

A 1% AEP ocean flood combined with a high sea level rise (Scenario 8) resulted in similar increases in flood levels near Quibray Bay, and an increase of approximately 40mm in flood levels in the eastern part of the catchment. The majority of areas to the west of Dampier Street and areas along eastern Tasman Street are predicted to be flooded by over 500mm.

Rainfall Increase
An increase in rainfall intensity results in an increase in flood levels across the majority of the catchment. For a 20% AEP catchment flood, an increase in rainfall has the most impact on residential areas to the east of the Caltex Oil Refinery easement between Prince Charles Parade and Captain Cook Drive. There is also a similar increase in flood levels within the road easement at the southern end of Dampier Street. Increases in flood levels range between 10 and 80mm across the majority of the catchment for the 20% AEP flood, with localised impacts as high as 150mm.

A 1% AEP catchment flood with a +10% to +30% increase in rainfall results in increased flood levels between 30 and 100mm for depending on the location.

Combined Rainfall Increase and Sea Level Rise
Sea level rise combined with an increase in rainfall has resulted in a slight increase in flood levels throughout the catchment, due to the reduced ability for runoff to flow into the bay. Large increases in flood levels occurred along Tasman, Horning and Bridges Streets, with increases being greater for the 20% AEP combined flood (130-450mm) than the 1% AEP combined flood event (100-300mm).

11.2.3. Summary

The combination of an ocean flood event with sea level rise has the most significant impact on flooding in Kurnell, and is estimated to increase flood levels by as much as 900mm in areas close to Quibray Bay.

Figure 41 shows that it is likely that the dominant flooding mechanism in some areas of Kurnell will shift from catchment flooding, to ocean flooding with climate change.

The peak envelope of the 1% AEP catchment flood and 1% AEP ocean flood for existing conditions was also compared with that resulting from the climate change scenarios. The increase in flood levels resulting from climate change are shown in Figure 42. It can be seen that east of Dampier Street, the increase in flood levels is generally less than 200mm. However, areas closer to Quibray Bay are likely to experience a significant increase in flood levels.

These results suggest that any future flood management strategies for Kurnell need to consider the effects of flooding caused by both rainfall and storm tides. This will be further discussed as part of the Floodplain Risk Management Study.

Table 16: Potential Increase in Flood Levels for the 20% AEP Catchment Flood due to Climate Change

Comparison			Rainfall			Sea Level Rise		Combined Rainfall Increase and Sea Level Rise			
ID	**Description**	**20% AEP Current Design Event (mAHD)**	**Scenario 9**	**Scenario 10**	**Scenario 11**	**Scenario 1**	**Scenario 2**	**Scenario 15**	**Scenario 16**	**Scenario 17**	**Scenario 18**
1	Local depression in residential area behind properties in Torres and Dampier Streets	2.42	0.01	0.03	0.05	0.00	0.00	0.01	0.06	0.02	0.06
2	Road on the corner of Dampier and Tasman Streets	1.84	0.03	0.09	0.13	0.00	0.03	0.04	0.13	0.07	0.17
3	Local depression in residential area to the east of Cook Street	3.27	0.02	0.04	0.05	0.00	0.00	0.02	0.05	0.02	0.05
4	Local depression in industrial/commercial area to the east of Cook Street	2.99	0.01	0.02	0.03	0.00	0.00	0.01	0.03	0.01	0.03
5	Road on Cook Street, near Marton Park Swamp	2.58	0.03	0.06	0.08	0.01	0.02	0.04	0.08	0.05	0.09
6	Marton Park Swamp	2.58	0.03	0.06	0.08	0.01	0.02	0.04	0.08	0.04	0.09
7	Residential area north of Gannon Street	2.45	0.05	0.10	0.15	0.00	0.00	0.05	0.15	0.05	0.16
8	Local depression in residential area south of Prince Charles Parade and east of Dampier Street	2.50	0.01	0.02	0.03	0.00	0.00	0.01	0.03	0.01	0.03
9	Road on the corner of Torres and Balboa Streets	1.55	0.01	0.02	0.03	0.01	0.03	0.02	0.03	0.04	0.05
10	Reserve near Quibray Bay adjacent to the corner of Torres and Balboa Streets	1.08	0.01	0.03	0.08	0.10	0.44	0.12	0.17	0.44	0.45
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	1.68	0.02	0.03	0.04	0.00	0.01	0.02	0.05	0.03	0.06
12	Local depression in residential area east of Horning Street, close to Quibray Bay	1.50	0.02	0.08	0.13	0.08	0.26	0.13	0.23	0.30	0.37
13	Local depression in residential area to the east of Silver Beach Road	2.58	0.03	0.06	0.08	0.01	0.02	0.04	0.08	0.04	0.09
14	Road on Captain Cook Drive near Shepherd Street	2.58	0.03	0.06	0.08	0.01	0.02	0.04	0.08	0.04	0.09
15	Road on the corner of Captain Cook Drive and Torres Street	2.57	0.03	0.05	0.07	0.01	0.02	0.03	0.07	0.04	0.08
16	Road on Captain Cook Drive near Tasman Street	2.68	0.01	0.02	0.03	0.00	0.00	0.01	0.03	0.01	0.03
17	Road on Captain Cook Drive at southern end of the open channel	2.69	0.01	0.03	0.04	0.00	0.00	0.01	0.04	0.01	0.04
18	Road at north western end of Captain Cook Drive	2.38	0.03	0.07	0.11	-0.01	-0.01	0.03	0.11	0.03	0.11
19	Torres Street, between Dampier Street and Captain Cook Drive	2.52	0.03	0.06	0.07	0.01	0.02	0.03	0.08	0.04	0.09

Table 17: Potential Increase in Flood Levels for the 1% AEP Catchment Flood due to Climate Change

Comparison			Rainfall			Sea Level Rise		Combined Rainfall Increase and Sea Level Rise			
ID	Description	1% AEP Current Design Event (mAHD)	Scenario 12	Scenario 13	Scenario 14	Scenario 3	Scenario 4	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	Local depression in residential area behind properties in Torres and Dampier Streets	2.76	0.04	0.07	0.09	0.00	0.01	0.04	0.09	0.04	0.09
2	Road on the corner of Dampier and Tasman Streets	2.27	0.05	0.10	0.15	0.01	0.03	0.06	0.15	0.09	0.17
3	Local depression in residential area to the east of Cook Street	3.47	0.03	0.06	0.09	0.00	0.00	0.03	0.09	0.03	0.09
4	Local depression in industrial/commercial area to the east of Cook Street	3.07	0.01	0.02	0.04	0.00	0.00	0.01	0.04	0.01	0.04
5	Road on Cook Street, near Marton Park Swamp	2.92	0.04	0.07	0.10	0.00	0.01	0.04	0.10	0.04	0.10
6	Marton Park Swamp	2.91	0.04	0.07	0.10	0.00	0.01	0.04	0.10	0.04	0.10
7	Residential area north of Gannon Street	2.90	0.03	0.07	0.09	0.00	0.01	0.04	0.10	0.04	0.10
8	Local depression in residential area south of Prince Charles Parade and east of Dampier Street	2.70	0.02	0.03	0.06	0.00	0.00	0.02	0.06	0.02	0.06
9	Road on the corner of Torres and Balboa Streets	1.67	0.01	0.02	0.04	0.00	0.02	0.01	0.04	0.04	0.08
10	Reserve near Quibray Bay adjacent to the corner of Torres and Balboa Streets	1.51	0.03	0.08	0.12	0.02	0.17	0.07	0.17	0.20	0.27
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	1.86	0.04	0.09	0.13	0.00	0.03	0.05	0.14	0.09	0.18
12	Local depression in residential area east of Horning Street, close to Quibray Bay	1.98	0.09	0.16	0.22	0.04	0.12	0.12	0.24	0.18	0.29
13	Local depression in residential area to the east of Silver Beach Road	2.90	0.04	0.07	0.10	0.00	0.01	0.04	0.10	0.04	0.10
14	Road on Captain Cook Drive near Shepherd Street	2.91	0.04	0.07	0.10	0.00	0.01	0.04	0.10	0.04	0.10
15	Road on the corner of Captain Cook Drive and Torres Street	2.87	0.03	0.06	0.09	0.00	0.01	0.04	0.09	0.04	0.09
16	Road on Captain Cook Drive near Tasman Street	2.82	0.04	0.07	0.10	0.00	0.01	0.04	0.10	0.05	0.11
17	Road on Captain Cook Drive at southern end of the open channel	2.81	0.03	0.05	0.08	0.00	0.01	0.03	0.08	0.03	0.08
18	Road at north western end of Captain Cook Drive	2.77	0.06	0.10	0.13	0.00	0.01	0.06	0.13	0.06	0.13
19	Torres Street, between Dampier Street and Captain Cook Drive	2.80	0.03	0.06	0.09	0.00	0.01	0.03	0.09	0.04	0.09

Table 18: Potential Increase in Flood Levels due to Climate Change for the 5% AEP Ocean Flood combined with a 20% AEP Catchment Flood

Comparison			Change in Flood Level	
ID	**Description**	**5% AEP Ocean with a 20% AEP Catchment Flood Current Design Event**	**Scenario 5**	**Scenario 6**
1	Local depression in residential area behind properties in Torres and Dampier Streets	2.42	0.00	0.00
2	Road on the corner of Dampier and Tasman Streets	3.42	0.23	0.58
3	Local depression in residential area to the east of Cook Street	4.42	0.00	0.00
4	Local depression in industrial/commercial area to the east of Cook Street	5.42	0.00	0.00
5	Road on Cook Street, near Marton Park Swamp	6.42	0.00	0.00
6	Marton Park Swamp	7.42	0.00	0.00
7	Residential area north of Gannon Street	8.42	0.00	0.00
8	Local depression in residential area south of Prince Charles Parade and east of Dampier Street	9.42	0.00	0.00
9	Road on the corner of Torres and Balboa Streets	10.42	0.50	0.86
10	Reserve near Quibray Bay adjacent to the corner of Torres and Balboa Streets	11.42	0.55	0.91
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	12.42	0.37	0.73
12	Local depression in residential area east of Horning Street, close to Quibray Bay	13.42	0.53	0.89
13	Local depression in residential area to the east of Silver Beach Road	14.42	0.00	0.00
14	Road on Captain Cook Drive near Shepherd Street	15.42	0.00	0.00
15	Road on the corner of Captain Cook Drive and Torres Street	16.42	0.00	0.00
16	Road on Captain Cook Drive near Tasman Street	17.42	0.00	0.00
17	Road on Captain Cook Drive at southern end of the open channel	18.42	0.00	0.00
18	Road at north western end of Captain Cook Drive	19.42	0.00	0.05
19	Torres Street, between Dampier Street and Captain Cook Drive	20.42	0.00	0.00

Table 19: Potential Increase in Flood Levels due to Climate Change for the 1% AEP Ocean Flood combined with a 20% AEP Catchment Flood

Comparison			Change in Flood Level	
ID	**Description**	**1% AEP Ocean with a 20% AEP Catchment Flood Current Design Event**	**Scenario 7**	**Scenario 8**
1	Local depression in residential area behind properties in Torres and Dampier Streets	2.42	0.00	0.20
2	Road on the corner of Dampier and Tasman Streets	1.84	0.42	0.77
3	Local depression in residential area to the east of Cook Street	3.27	0.00	0.00
4	Local depression in industrial/commercial area to the east of Cook Street	2.99	0.00	0.00
5	Road on Cook Street, near Marton Park Swamp	2.58	0.01	0.04
6	Marton Park Swamp	2.58	0.01	0.04
7	Residential area north of Gannon Street	2.45	0.00	0.01
8	Local depression in residential area south of Prince Charles Parade and east of Dampier Street	2.50	0.00	0.12
9	Road on the corner of Torres and Balboa Streets	1.70	0.55	0.91
10	Reserve near Quibray Bay adjacent to the corner of Torres and Balboa Streets	1.70	0.55	0.91
11	Road at the western end of Tasman Street, adjacent to Quibray Bay	1.70	0.55	0.91
12	Local depression in residential area east of Horning Street, close to Quibray Bay	1.72	0.54	0.90
13	Local depression in residential area to the east of Silver Beach Road	2.58	0.01	0.04
14	Road on Captain Cook Drive near Shepherd Street	2.58	0.01	0.04
15	Road on the corner of Captain Cook Drive and Torres Street	2.57	0.01	0.04
16	Road on Captain Cook Drive near Tasman Street	2.68	0.00	0.00
17	Road on Captain Cook Drive at southern end of the open channel	2.69	0.00	0.00
18	Road at north western end of Captain Cook Drive	2.37	0.00	0.24
19	Torres Street, between Dampier Street and Captain Cook Drive	2.52	0.01	0.09

12. CONCLUSIONS

Detailed numerical models to quantify the hydrology and hydraulics of the Kurnell catchment have been established, making best use of the data currently available. These models have been used to define the design flood behaviour for existing conditions.

Results indicate that flooding in Kurnell is currently dominated by relatively shallow, slow moving water throughout the majority of the study area. However, the extent of flooding, the ponding times, and the lack of clear evacuation routes have the potential to increase the flood risk. Whilst rainfall is currently the primary cause of flooding for most areas within Kurnell, the impacts of climate change has the potential to increase the dominance of tidal flooding. Hence future management strategies should consider the effects of both rainfall and tidal flooding.

The current models are significantly more detailed and refined compared with any previous studies or investigations. Given the level of detail used in the present study and the ability of the current models to better represent dynamic flow and the complex overland flow paths through much of the floodplain, means that the results can be interpreted with a greater level of confidence compared with any previous estimates of flood behaviour.

Importantly, the models developed for the current study are suitable for use in a subsequent Floodplain Risk Management Study and/or other assessments of redevelopment options within the catchment. However, it should be noted that any specific site investigations should undertake more detailed flood analyses to gain sufficient information specific to the area. The current results are intended for use at a catchment scale rather than an individual site basis.

13. ACKNOWLEDGEMENTS

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Figures

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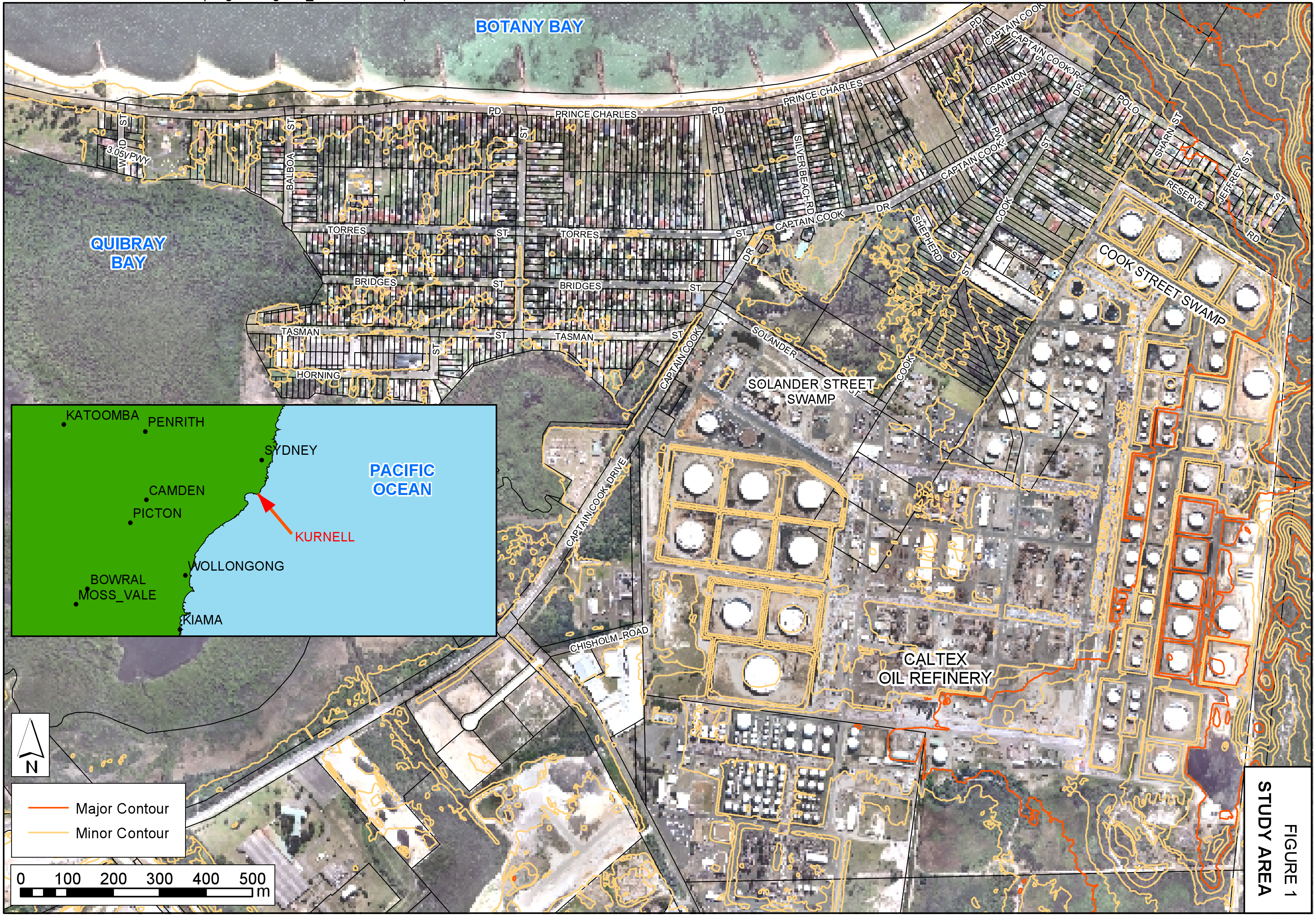

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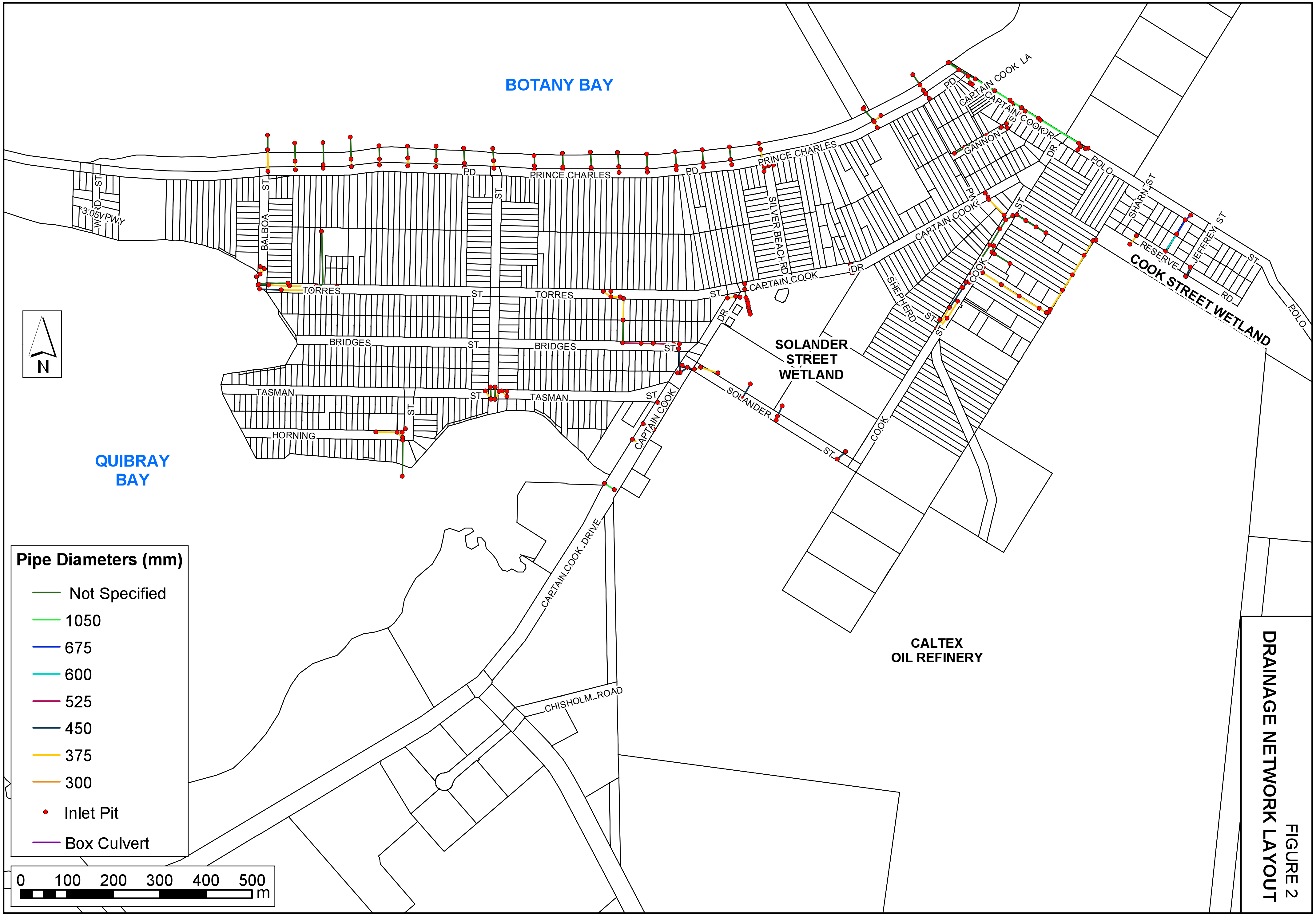

FIGURE 2
DRAINAGE NETWORK LAYOUT

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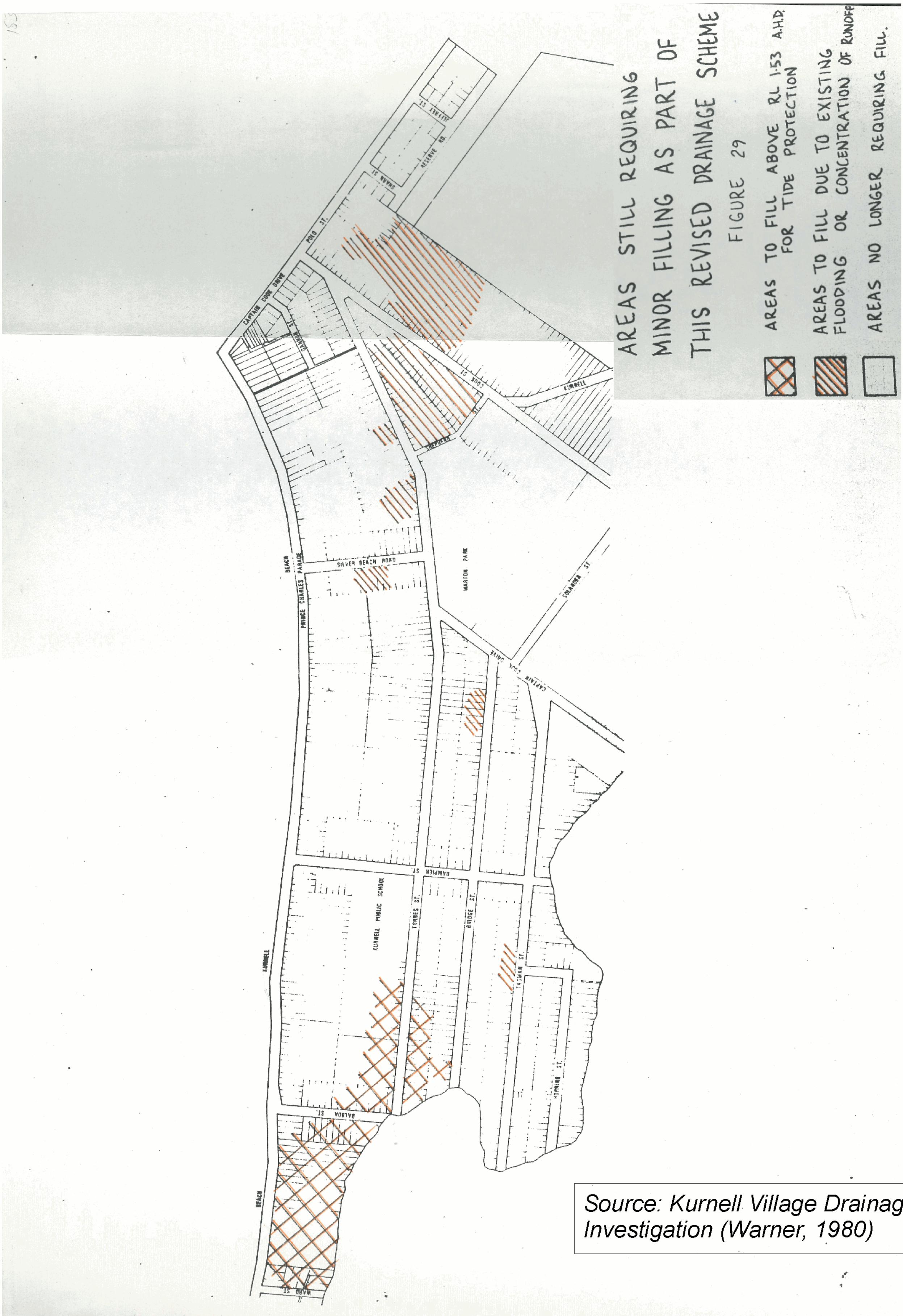
FIGURE 3
1980 KURNELL VILLAGE DRAINAGE INVESTIGATION
REPORTED FLOODING

FIGURE 4

1980 KURNELL VILLAGE DRAINAGE INVESTIGATION

RECOMMENDED FILL

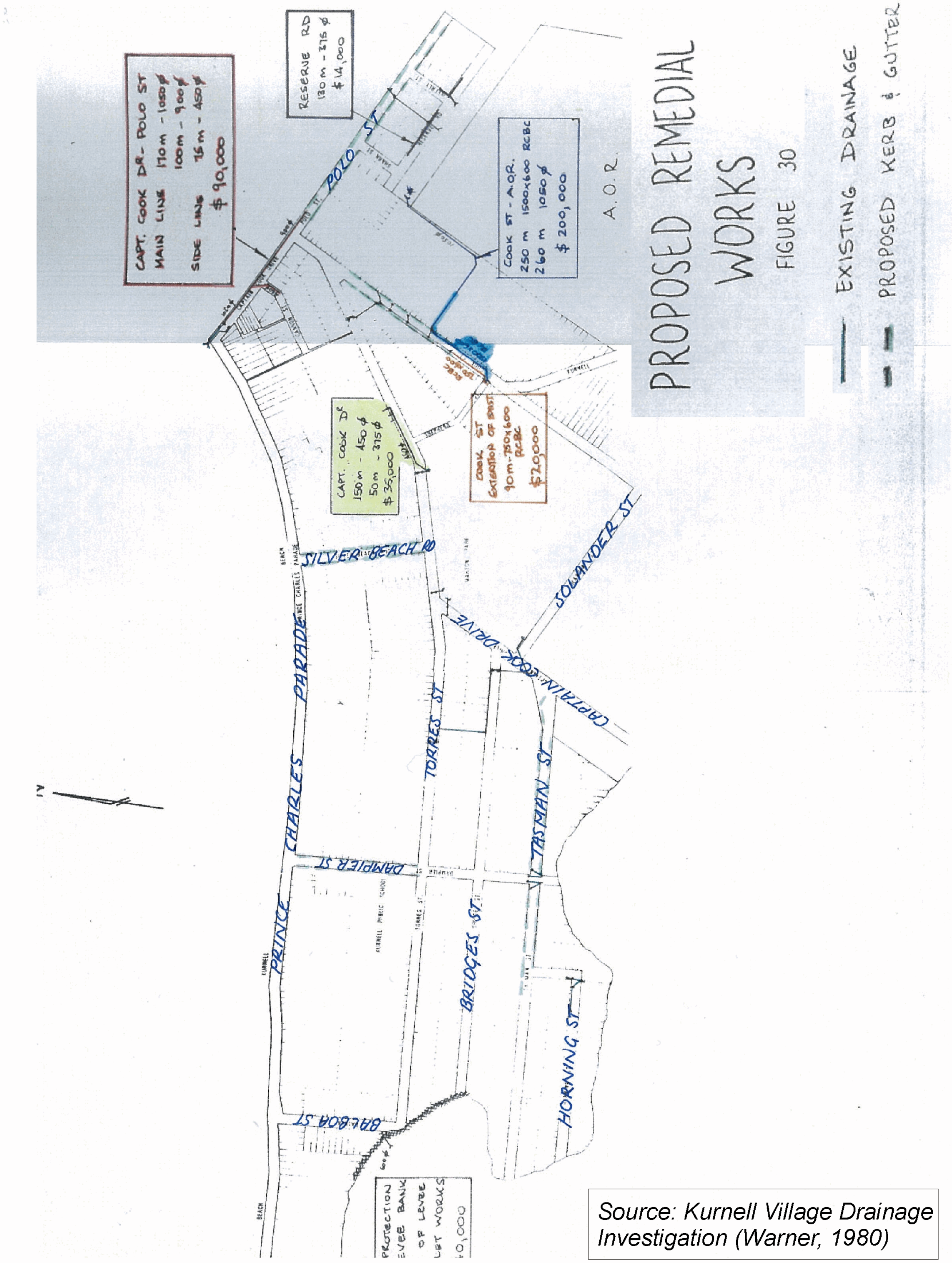


Source: Kurnell Village Drainage Investigation (Warner, 1980)

FIGURE 5

1980 KURNELL VILLAGE DRAINAGE INVESTIGATION

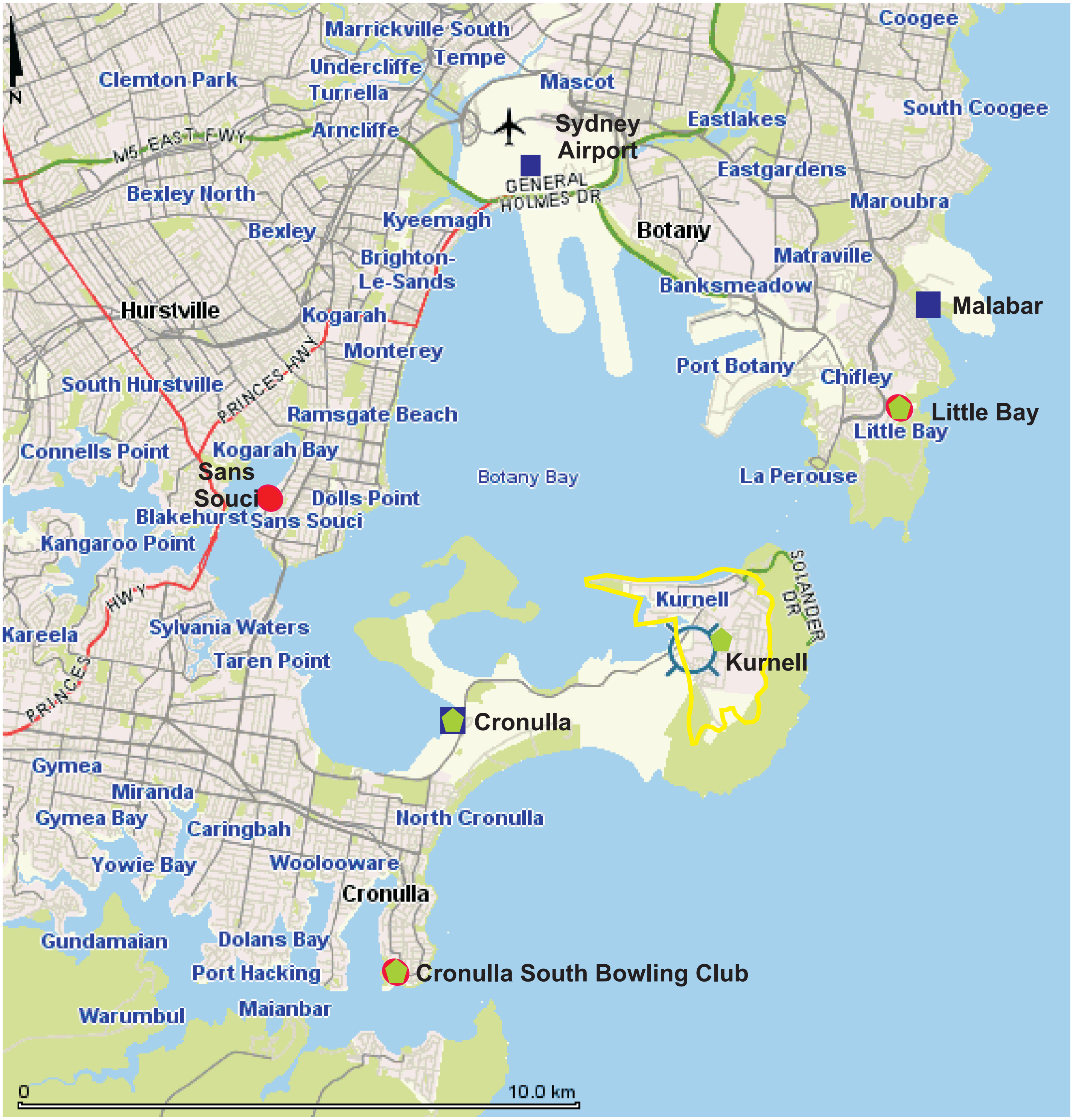
RECOMMENDED REMEDIAL WORKS



Source: Kurnell Village Drainage Investigation (Warner, 1980)

FIGURE 6

LOCATION OF RAINFALL STATIONS



STUDY AREA

DAILY READ RAINFALL STATION

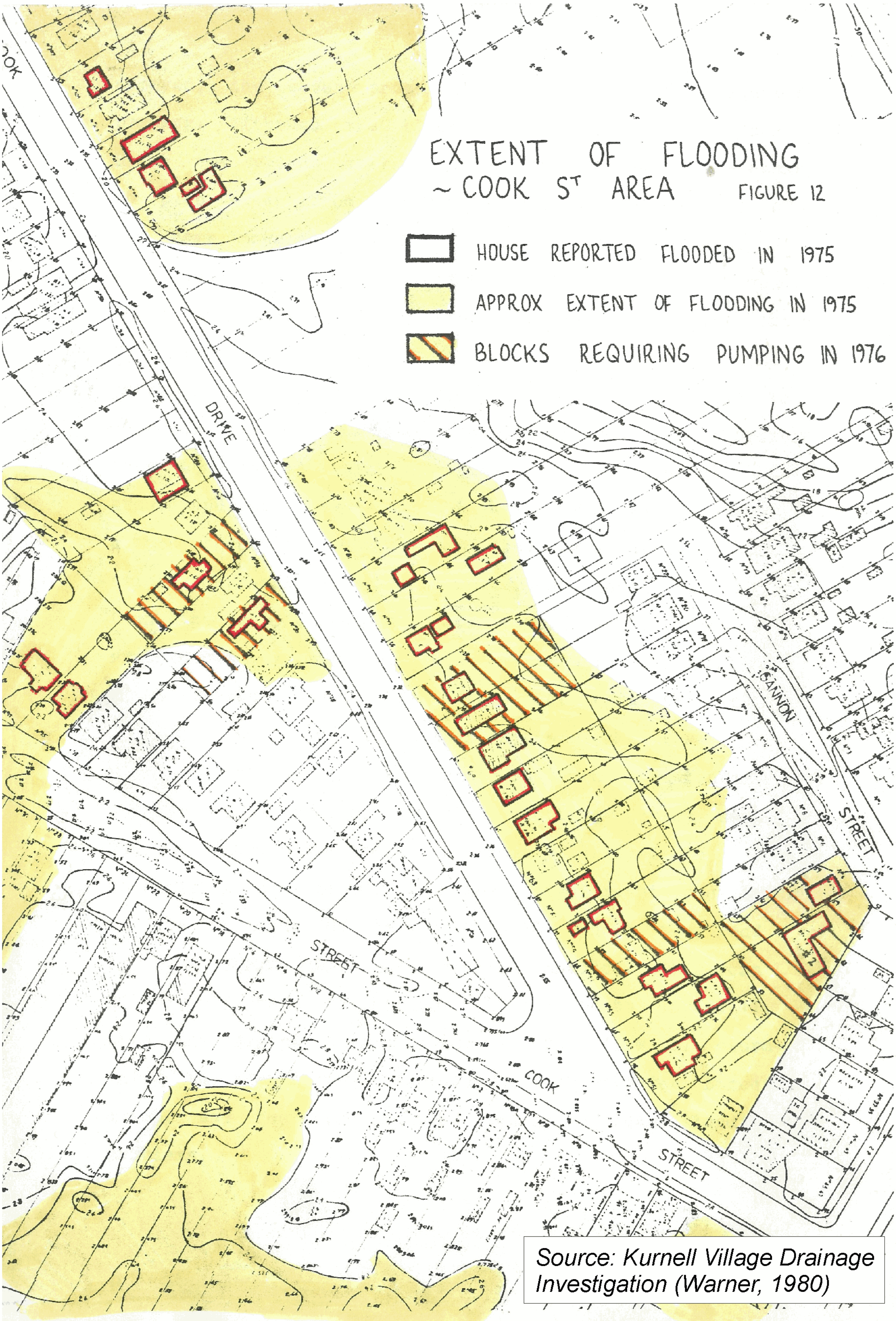
PLUVIOMETER RAINFALL STATION

OPERATIONAL RAIN GAUGE

FIGURE 7

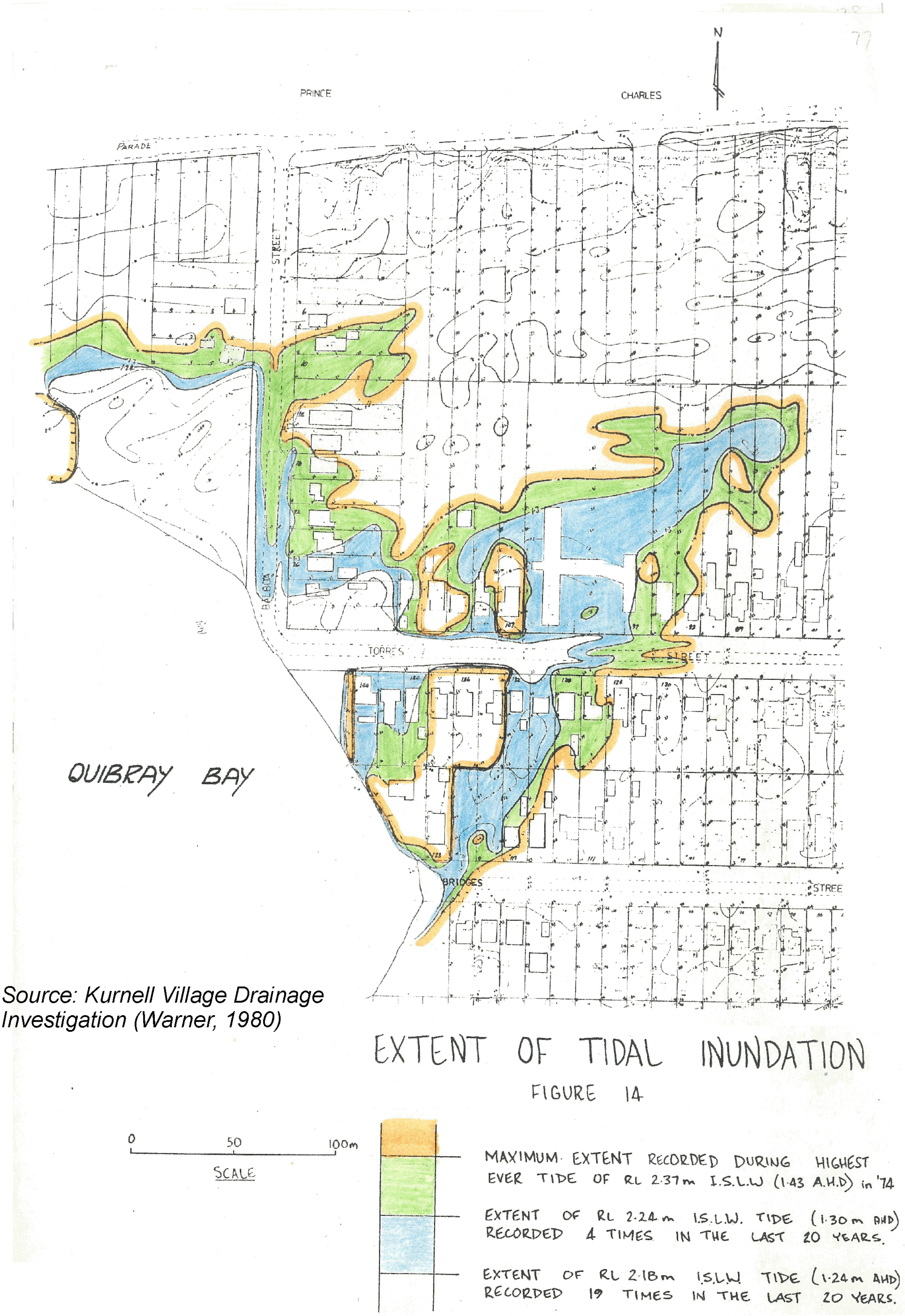
1980 KURNELL VILLAGE DRAINAGE INVESTIGATION

1975 COOK STREET FLOODING



Source: Kurnell Village Drainage Investigation (Warner, 1980)

1980 KURNELL VILLAGE DRAINAGE INVESTIGATION
1974 TIDAL INUNDATION



Source: *Kurnell Village Drainage Investigation (Warner, 1980)*

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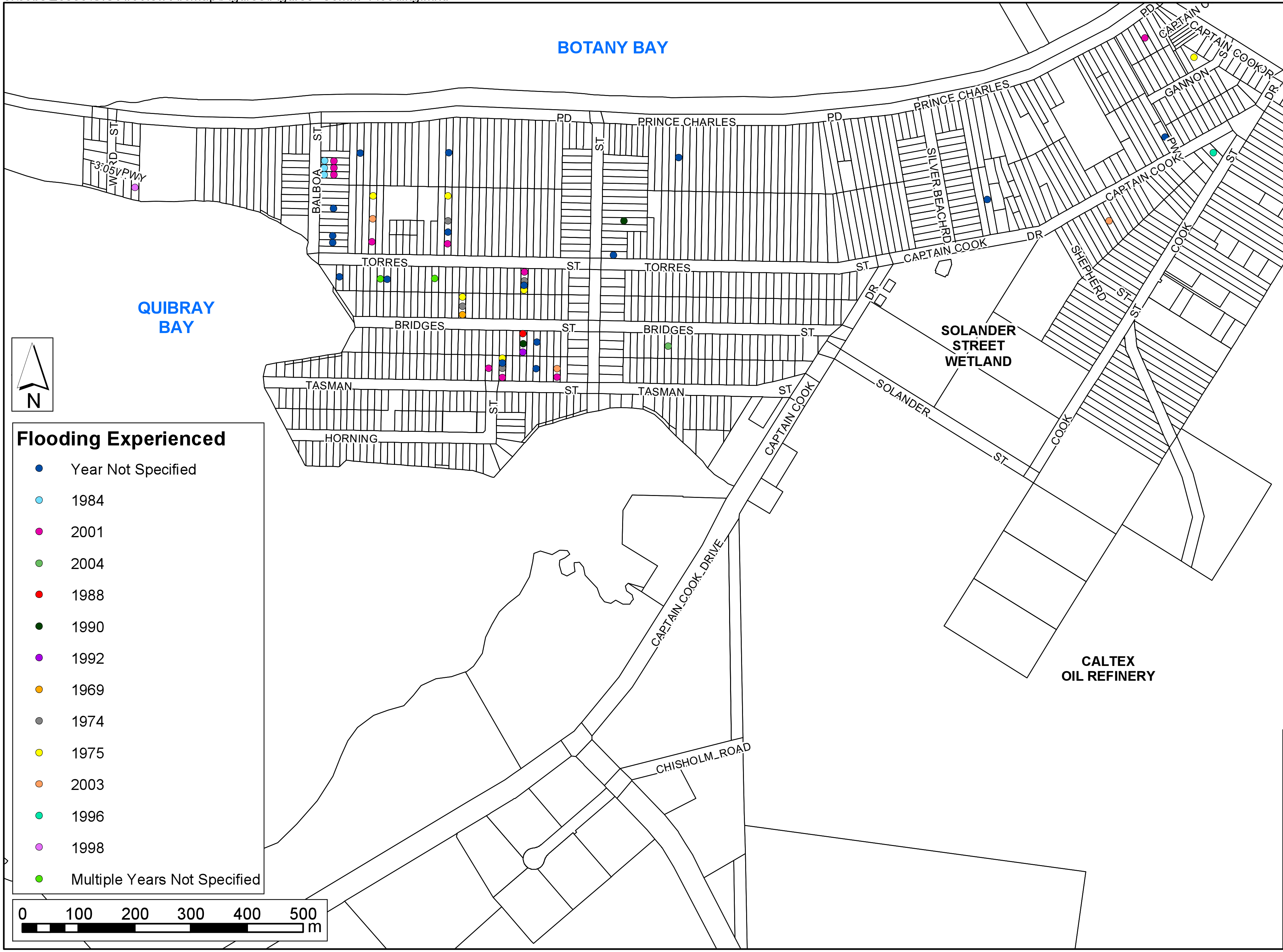

FIGURE 9
REPORTED FLOODING
2007 SURVEY

J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure10_ContourComparison2.mxd

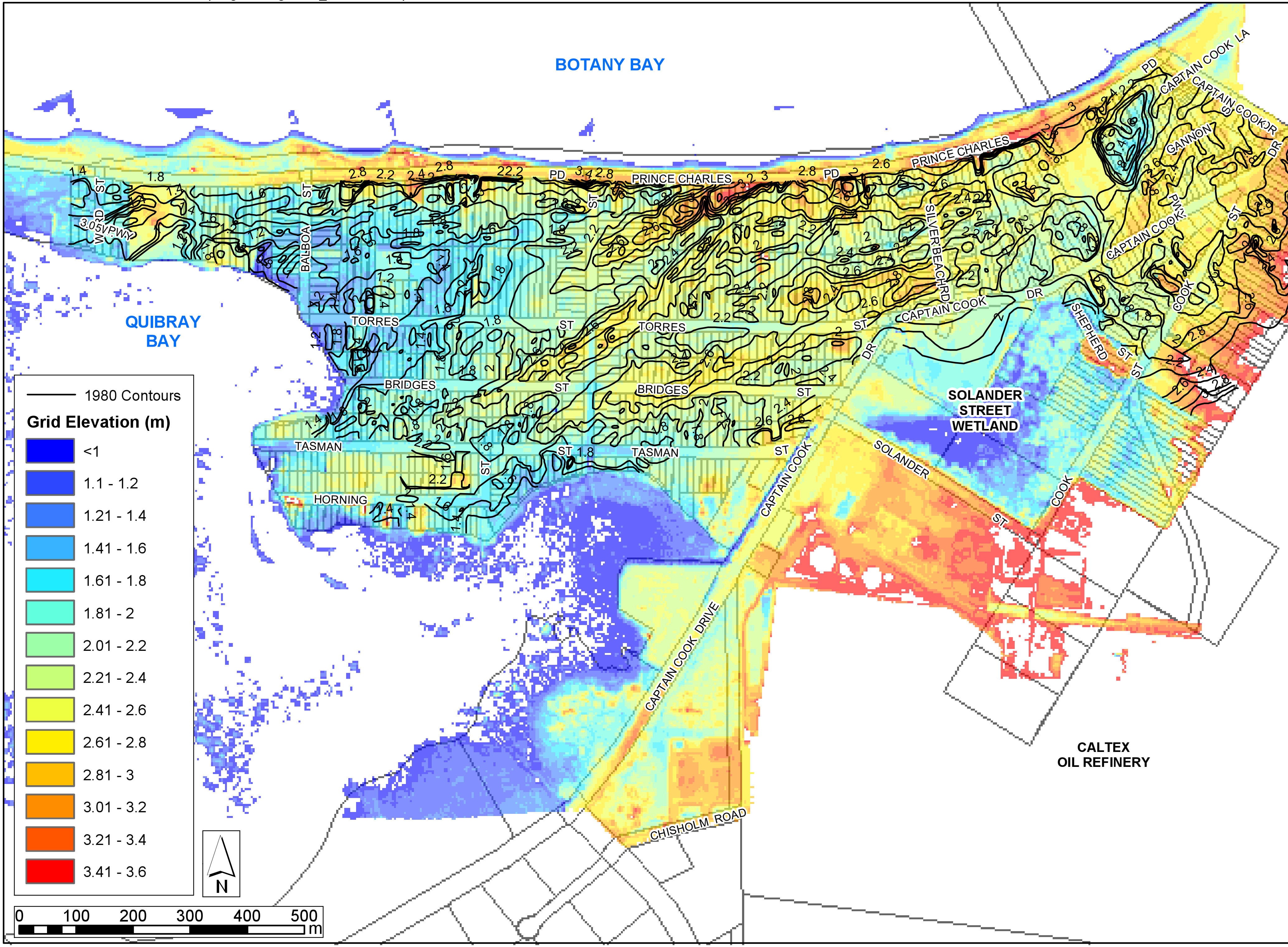

FIGURE 10

CONTOUR COMPARISON

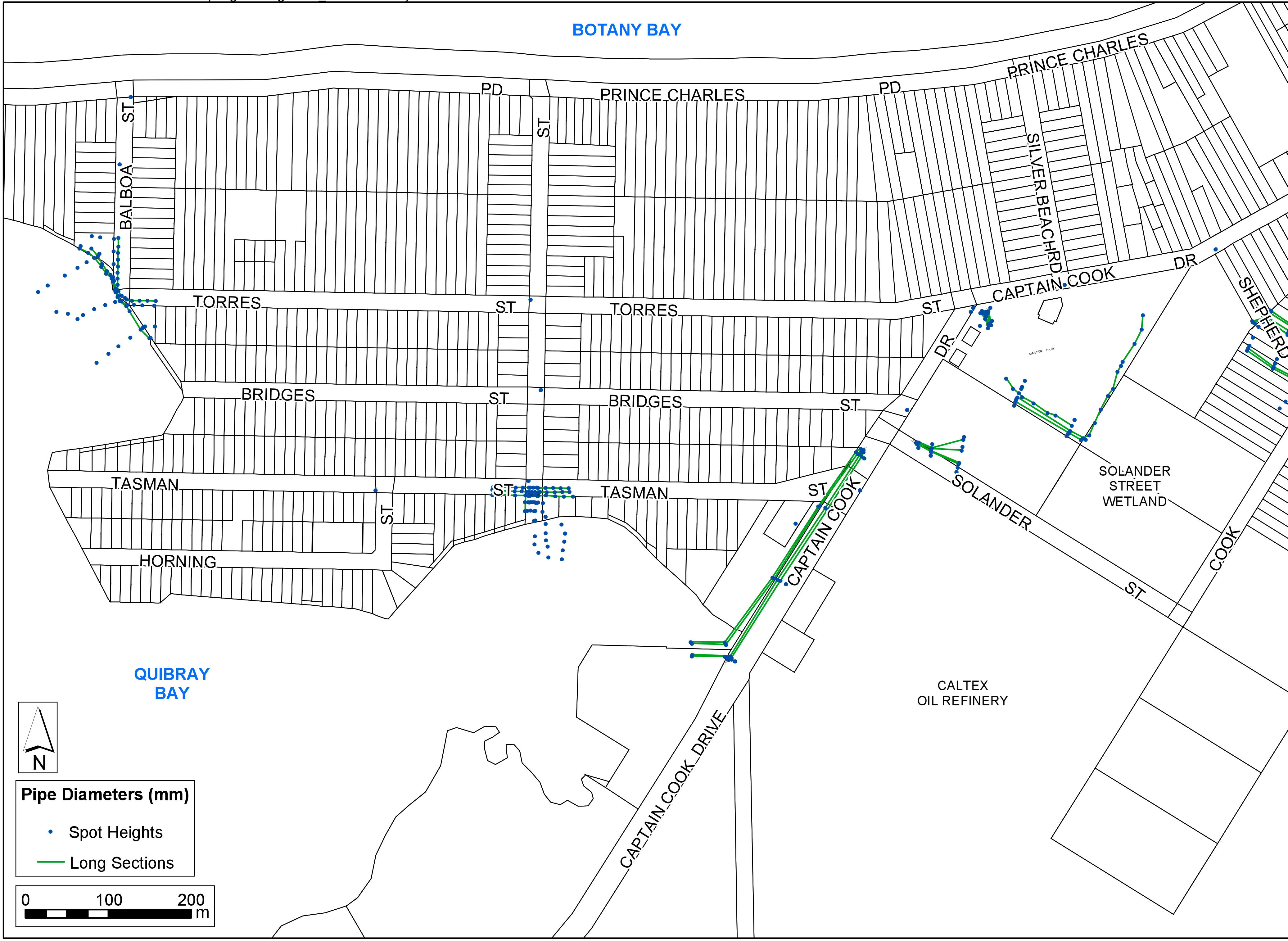

FIGURE 11
ADDITIONAL SURVEY

J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure12_Subcatchments.mxd

FIGURE 12
HYDROLOGIC MODEL LAYOUT

FIGURE 13
TUFLOW MODEL LAYOUT

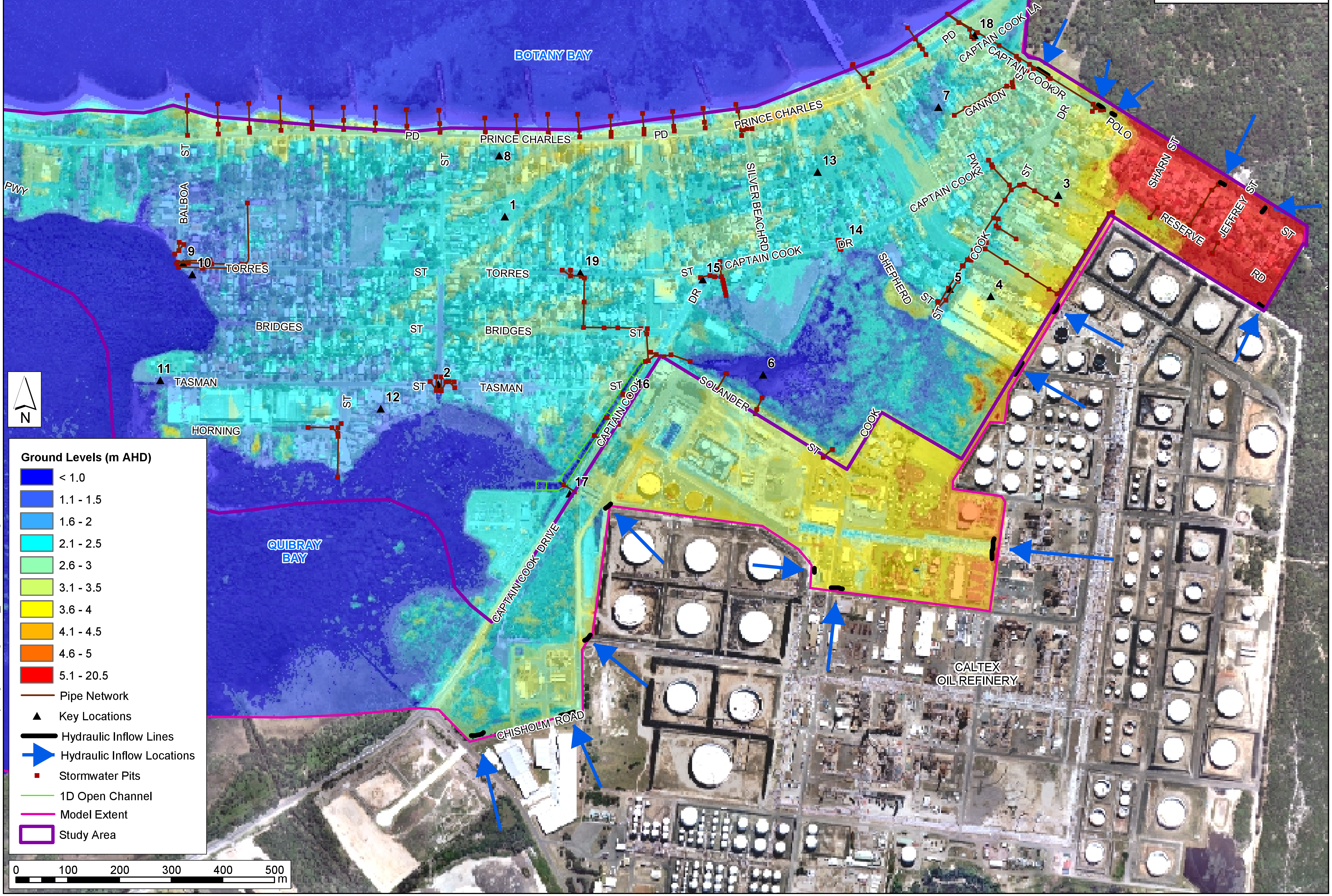

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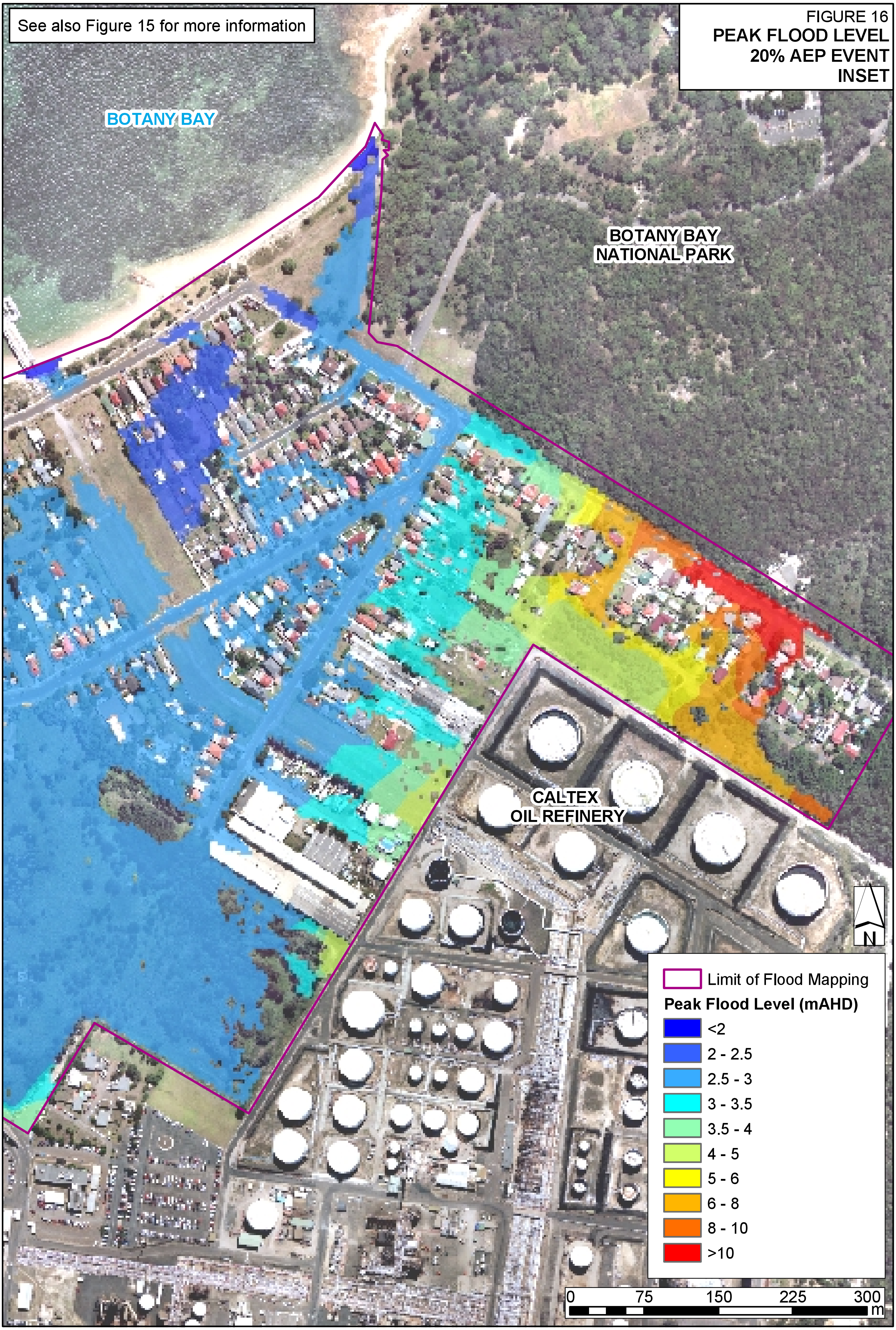
FIGURE 14
PEAK FLOOD DEPTHS
HISTORICAL EVENT
MAY 2003
BOTANY BAY
BOTANY BAY
NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
Modelled Level 1.52
Surveyed Level 1.74
CALTEX
OIL REFINERY
QUIBRAY
BAY
N
Limit of Flood Mapping
Surveyed Flood Level (mAHD)
Peak Flood Depth (m)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 1.5
1.5 - 3
0 100 200 300 400 500
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure14_Historical_Depths.mxd

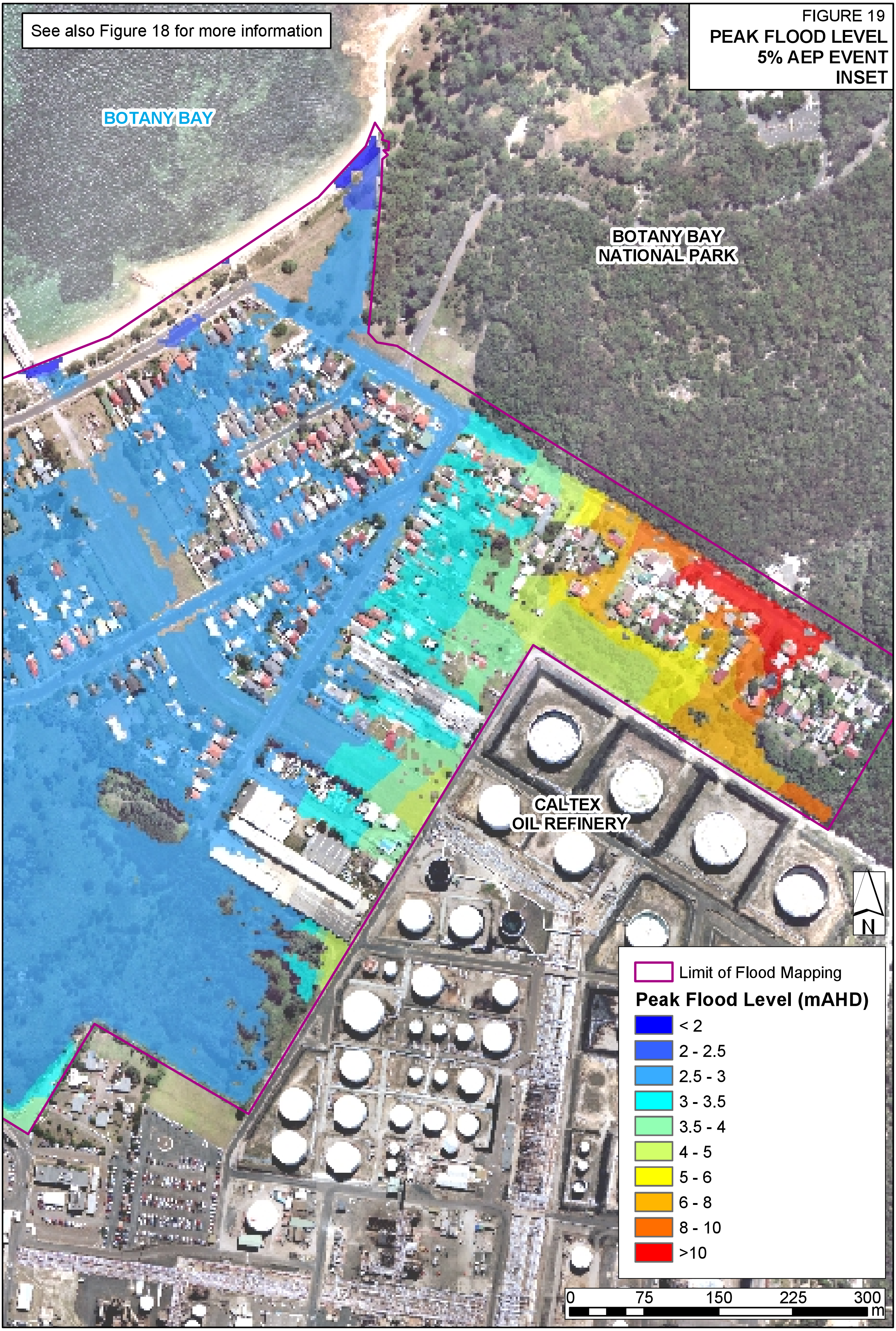

FIGURE 15
PEAK FLOOD LEVELS
20% AEP EVENT
BOTANY BAY
BOTANY BAY
NATIONAL PARK
Prince Charles Drive
Prince Charles Drive
Refer to Figure 16
for more detail
CALTEX
OIL REFINERY
QUIBRAY
BAY
N
Limit of Flood Mapping
Peak Flood Level (mAHD)
<1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 4
4 - 5
>5
0 100 200 300 400 500
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure15_k005y_FloodLevels.mxd



See also Figure 15 for more information
FIGURE 16
PEAK FLOOD LEVEL
20% AEP EVENT
INSET
BOTANY BAY
BOTANY BAY NATIONAL PARK
CALTEX OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Level (mAHD)
<2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 5
5 - 6
6 - 8
8 - 10
>10
0
75
150
225
300
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure16_k005y_FloodLevels_Inset.mxd

FIGURE 17
PEAK FLOOD LEVELS
20% AEP RAINFALL EVENT
WITH A 1% STORM TIDE


FIGURE 18
PEAK FLOOD LEVELS
5% AEP EVENT
BOTANY BAY
BOTANY BAY NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
Refer to Figure 19 for more detail
CALTEX OIL REFINERY
QUIBRAY BAY
N
Limit of Flood Mapping
Peak Flood Level (mAHD)
<1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 4
4 - 5
>5
0 100 200 300 400 500
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure18_k020y_FloodLevels.mxd



See also Figure 18 for more information
FIGURE 19
PEAK FLOOD LEVEL
5% AEP EVENT
INSET
BOTANY BAY
BOTANY BAY
NATIONAL PARK
CALTEX
OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Level (mAHD)
< 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 5
5 - 6
6 - 8
8 - 10
>10
0
75
150
225
300
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure19_k020y_FloodLevel_Inset.mxd

FIGURE 20
PEAK FLOOD LEVELS
1% AEP EVENT

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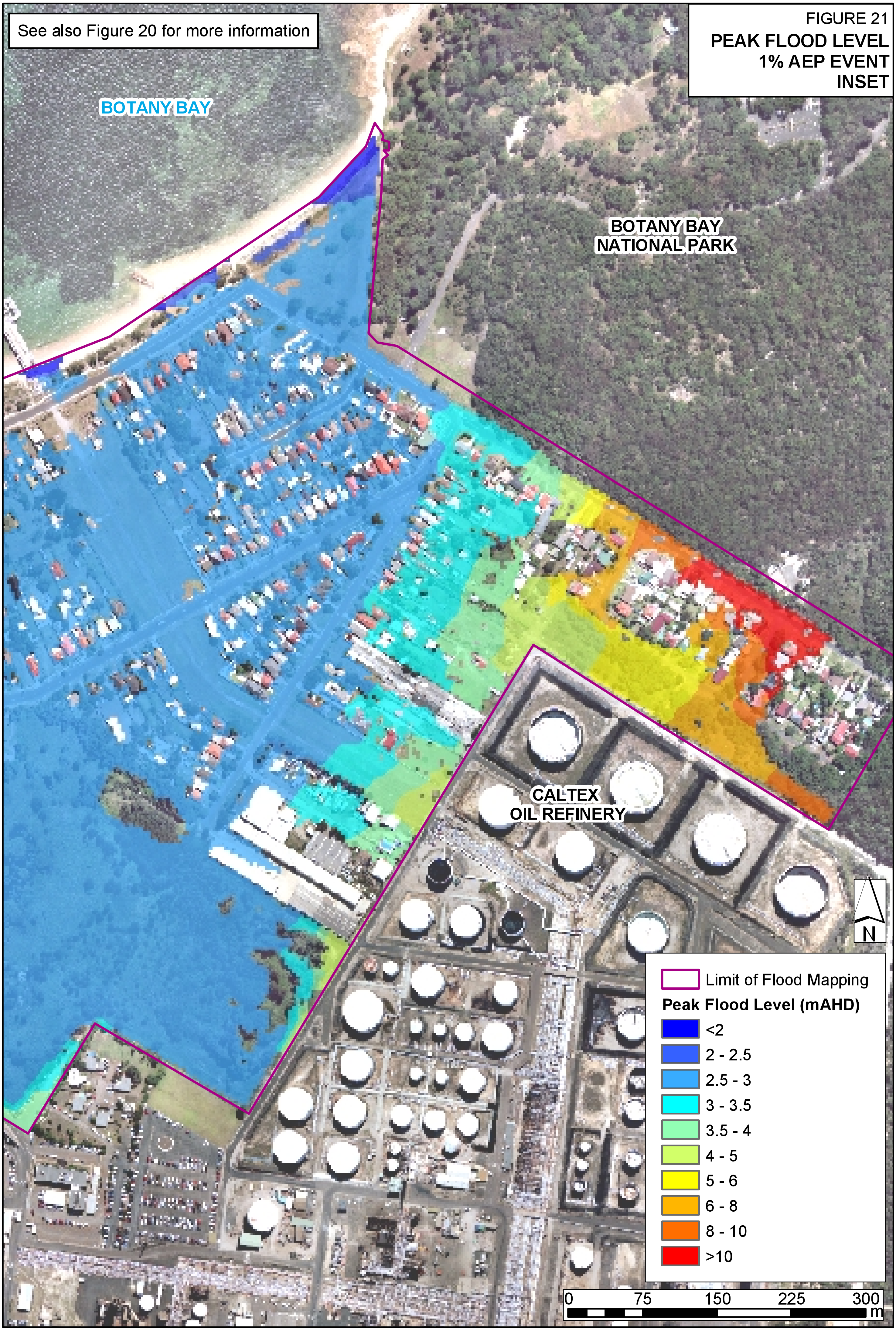

FIGURE 21
PEAK FLOOD LEVEL
1% AEP EVENT
INSET

J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure21_k100y_FloodLevel_Inset.mxd

FIGURE 22
PEAK FLOOD LEVELS
PMF EVENT

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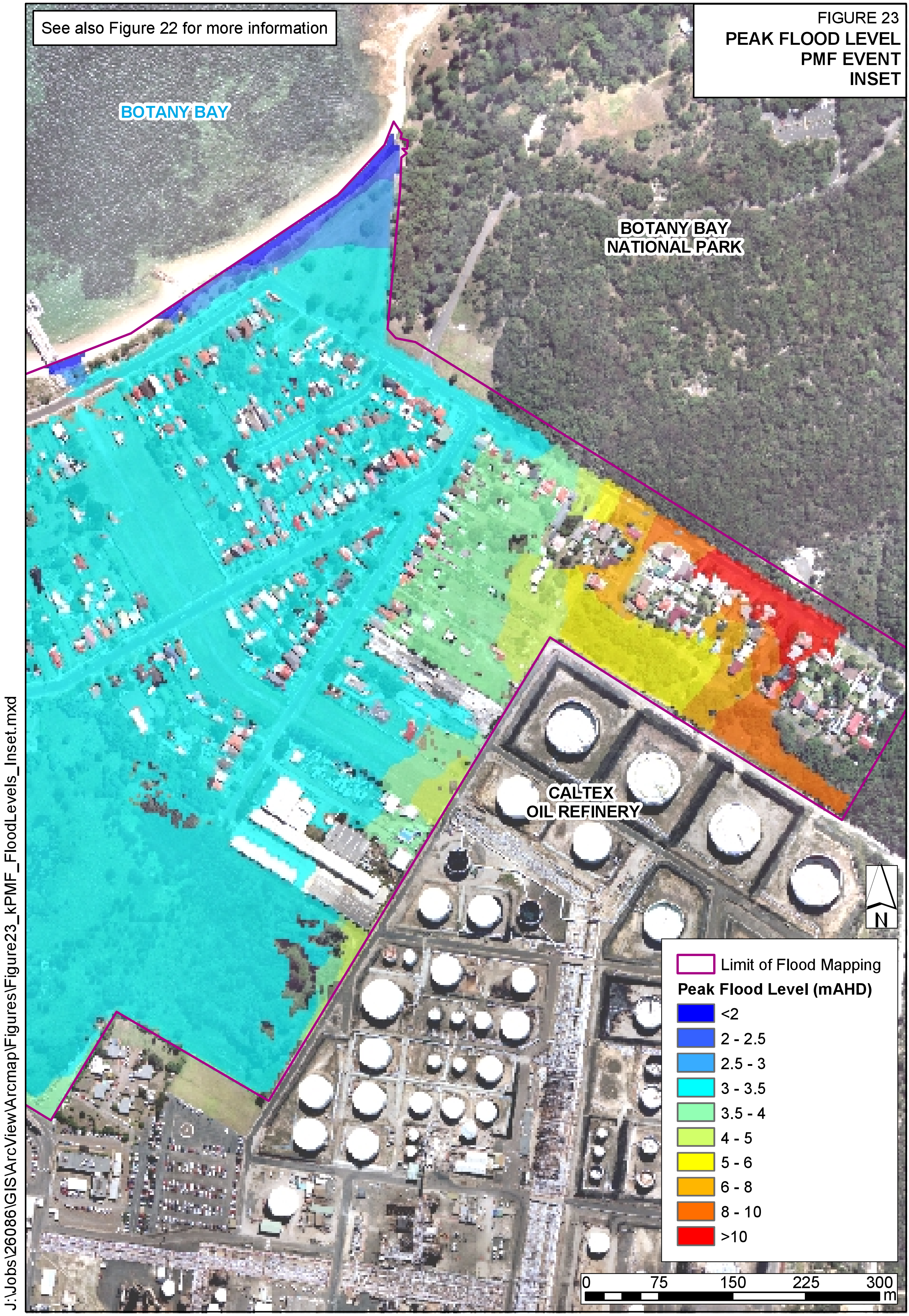
See also Figure 22 for more information
FIGURE 23
PEAK FLOOD LEVEL
PMF EVENT
INSET
BOTANY BAY
BOTANY BAY
NATIONAL PARK
CALTEX
OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Level (mAHD)
<2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 5
5 - 6
6 - 8
8 - 10
>10
0
75
150
225
300
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure23_kPMF_FloodLevels_Inset.mxd

J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure24_k005y_Depths.mxd

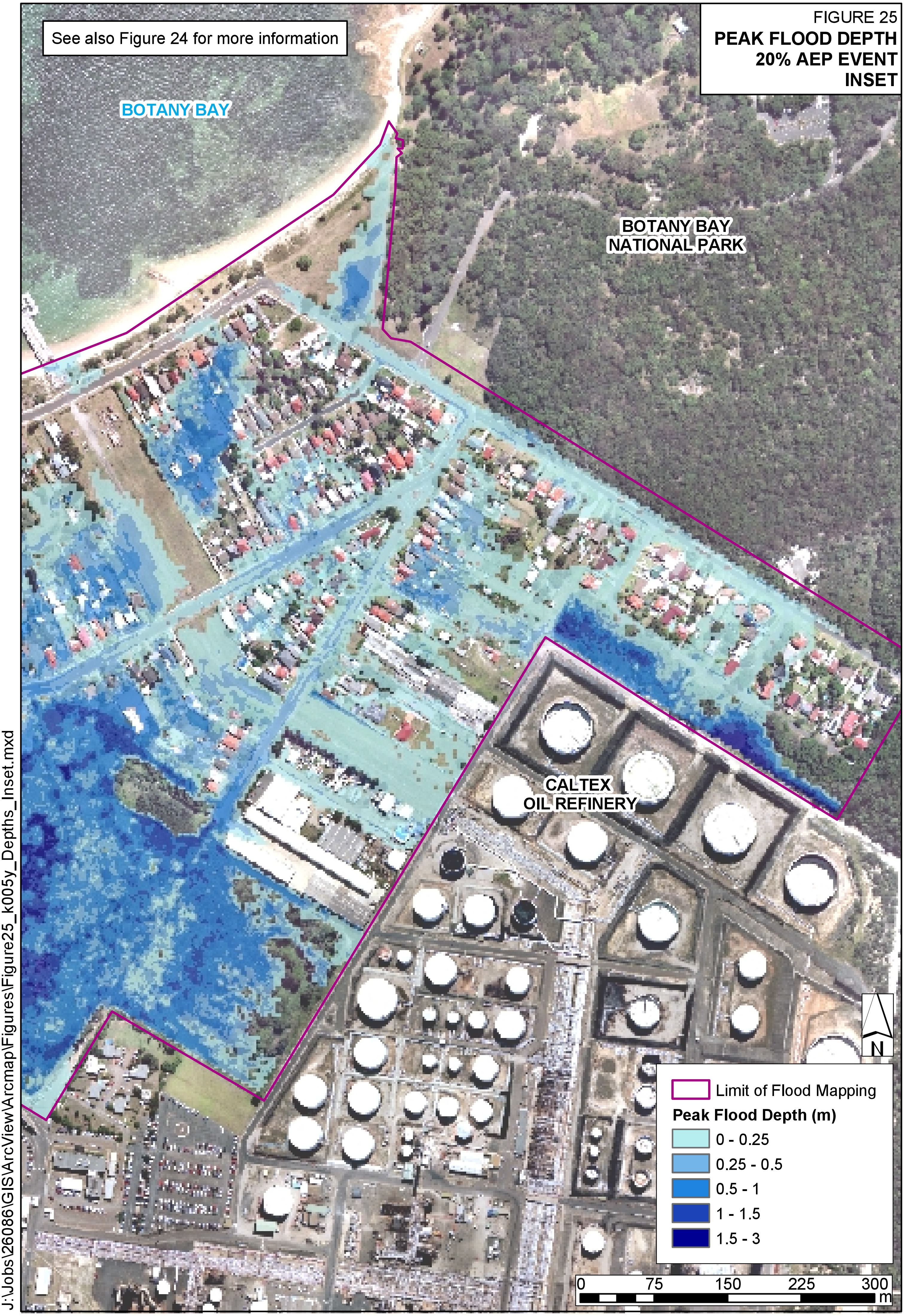

FIGURE 25
PEAK FLOOD DEPTH
20% AEP EVENT
INSET
See also Figure 24 for more information
BOTANY BAY
BOTANY BAY
NATIONAL PARK
CALTEX
OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Depth (m)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 1.5
1.5 - 3
0
75
150
225
300
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure25_k005y_Depths_Inset.mxd

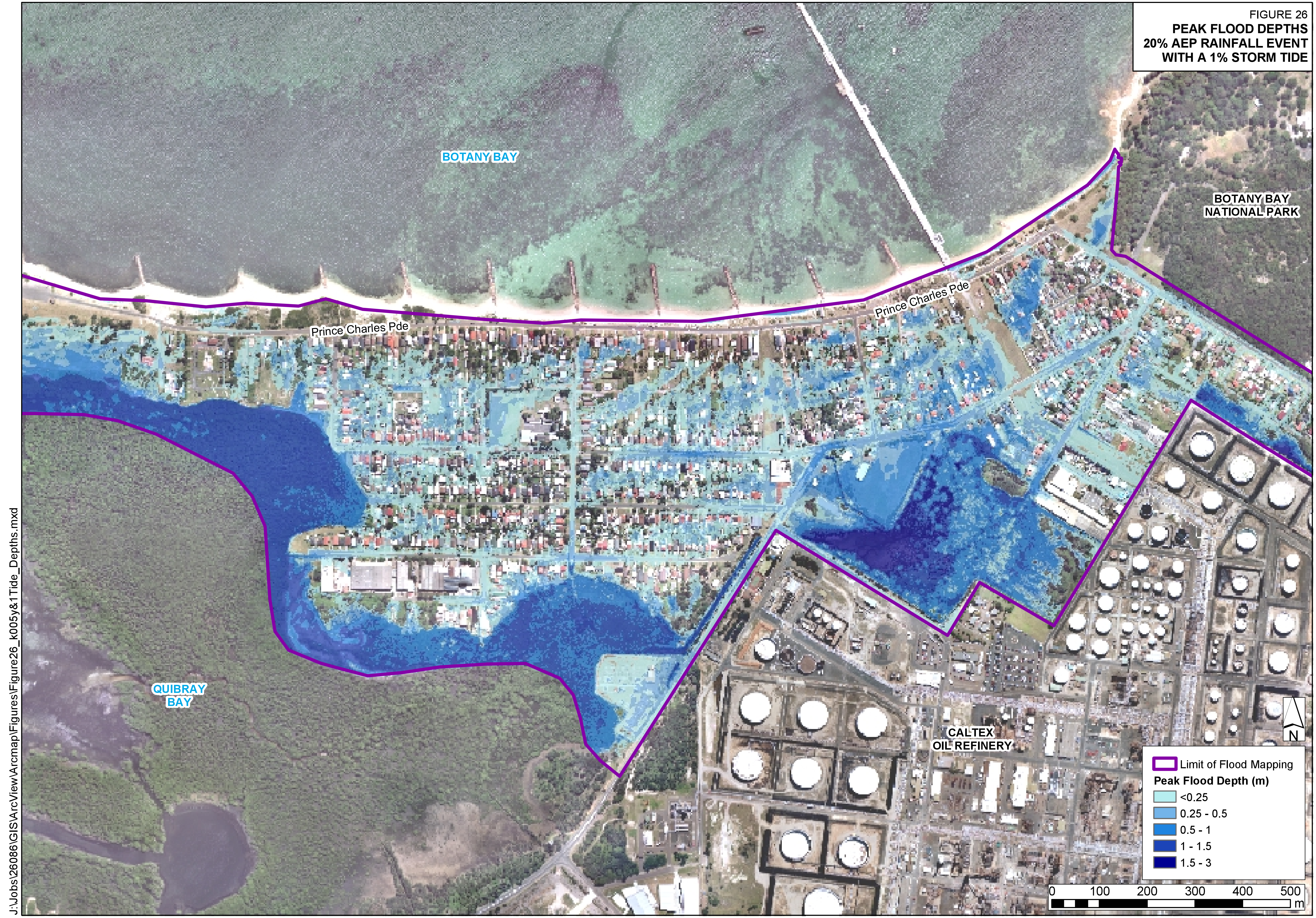

FIGURE 26
PEAK FLOOD DEPTHS
20% AEP RAINFALL EVENT
WITH A 1% STORM TIDE
BOTANY BAY
BOTANY BAY NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
QUIBRAY BAY
CALTEX OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Depth (m)
<0.25
0.25 - 0.5
0.5 - 1
1 - 1.5
1.5 - 3
0 100 200 300 400 500
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure26_k005y&1Tide_Depths.mxd

FIGURE 27
PEAK FLOOD DEPTHS
5% AEP EVENT

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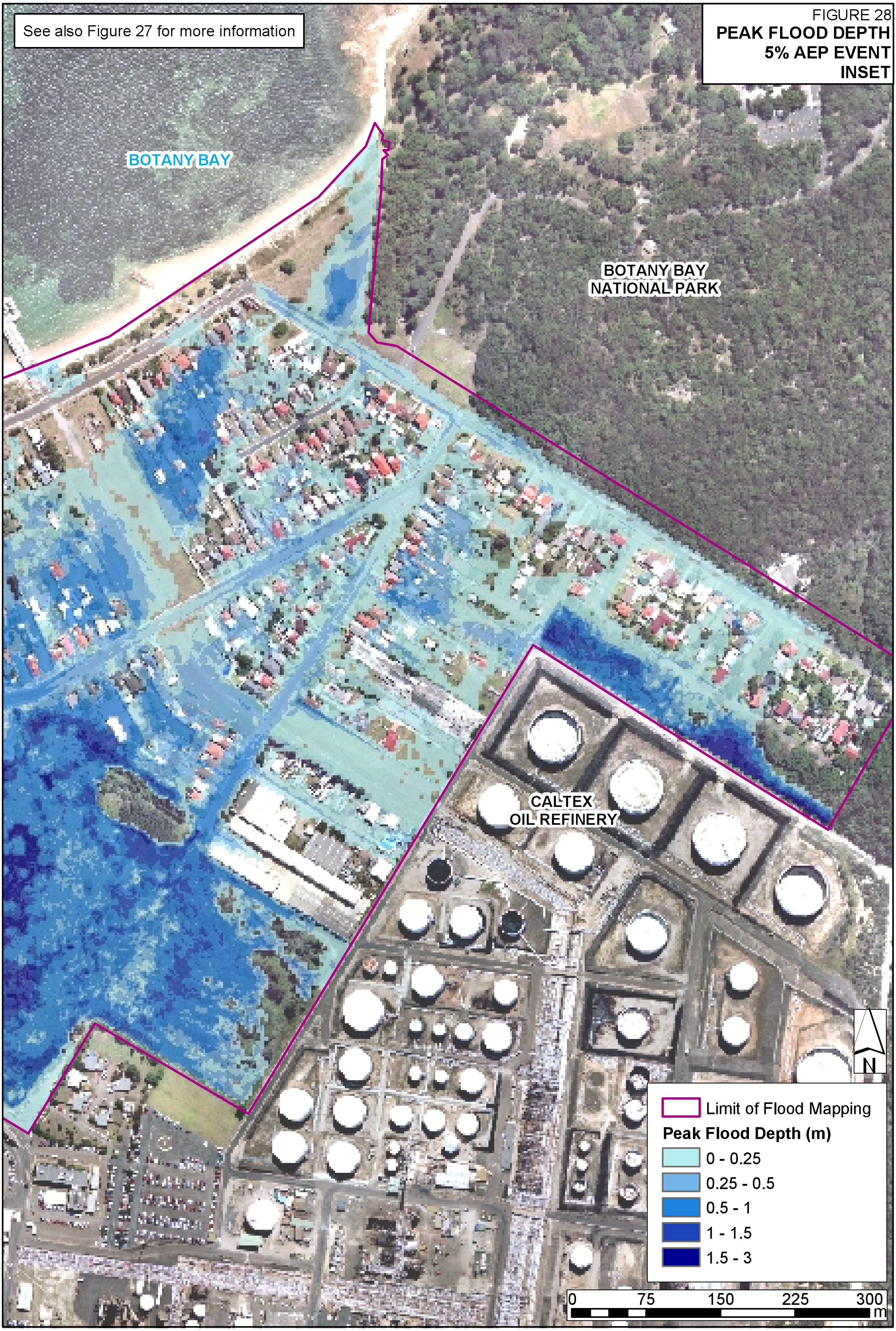

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FIGURE 29
PEAK FLOOD DEPTHS
1% AEP EVENT
BOTANY BAY
BOTANY BAY NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
Refer to Figure 30 for more detail
QUIBRAY BAY
CALTEX OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Depth (m)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 1.5
1.5 - 3
0 100 200 300 400 500
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure29_k100y_Depths.mxd

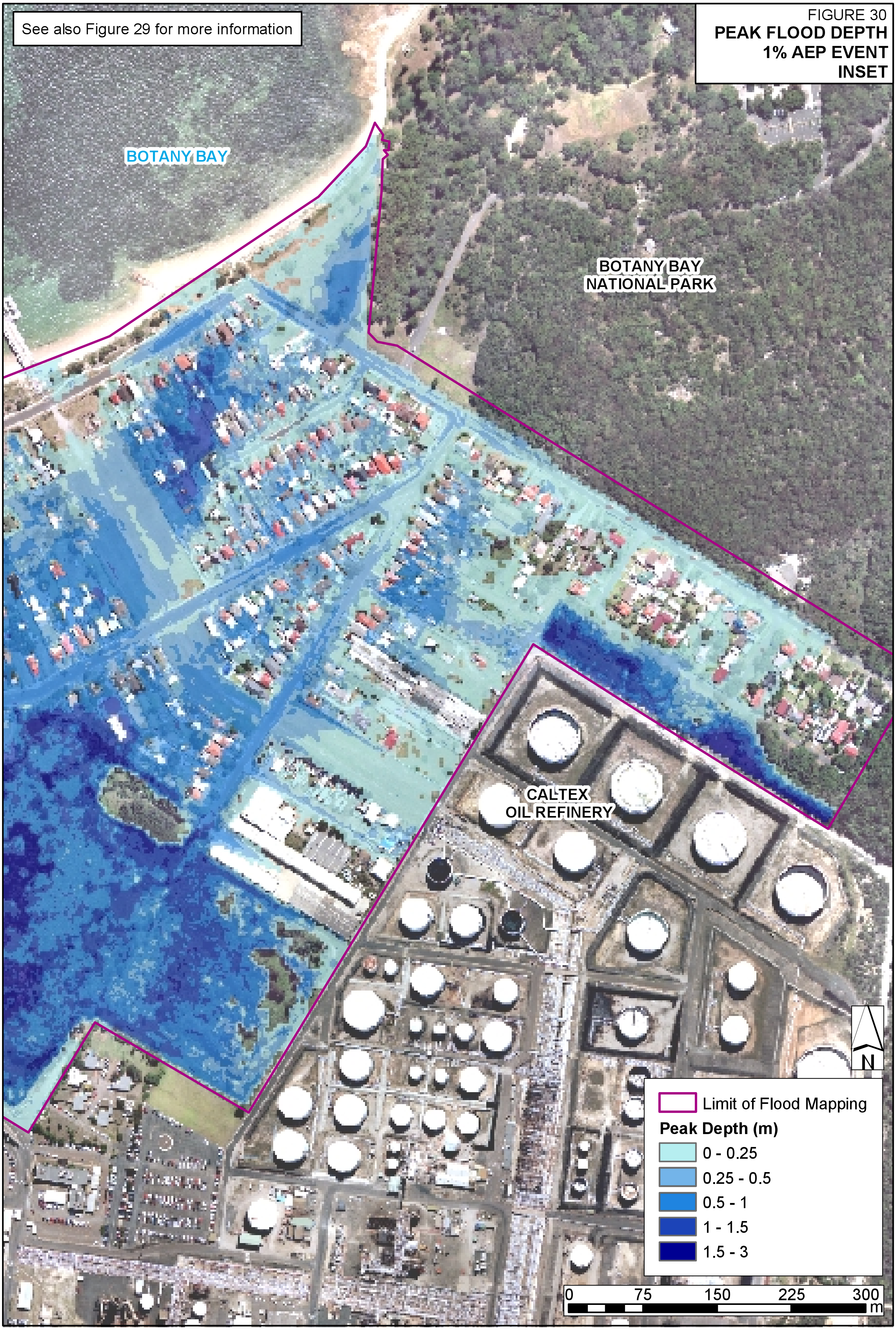

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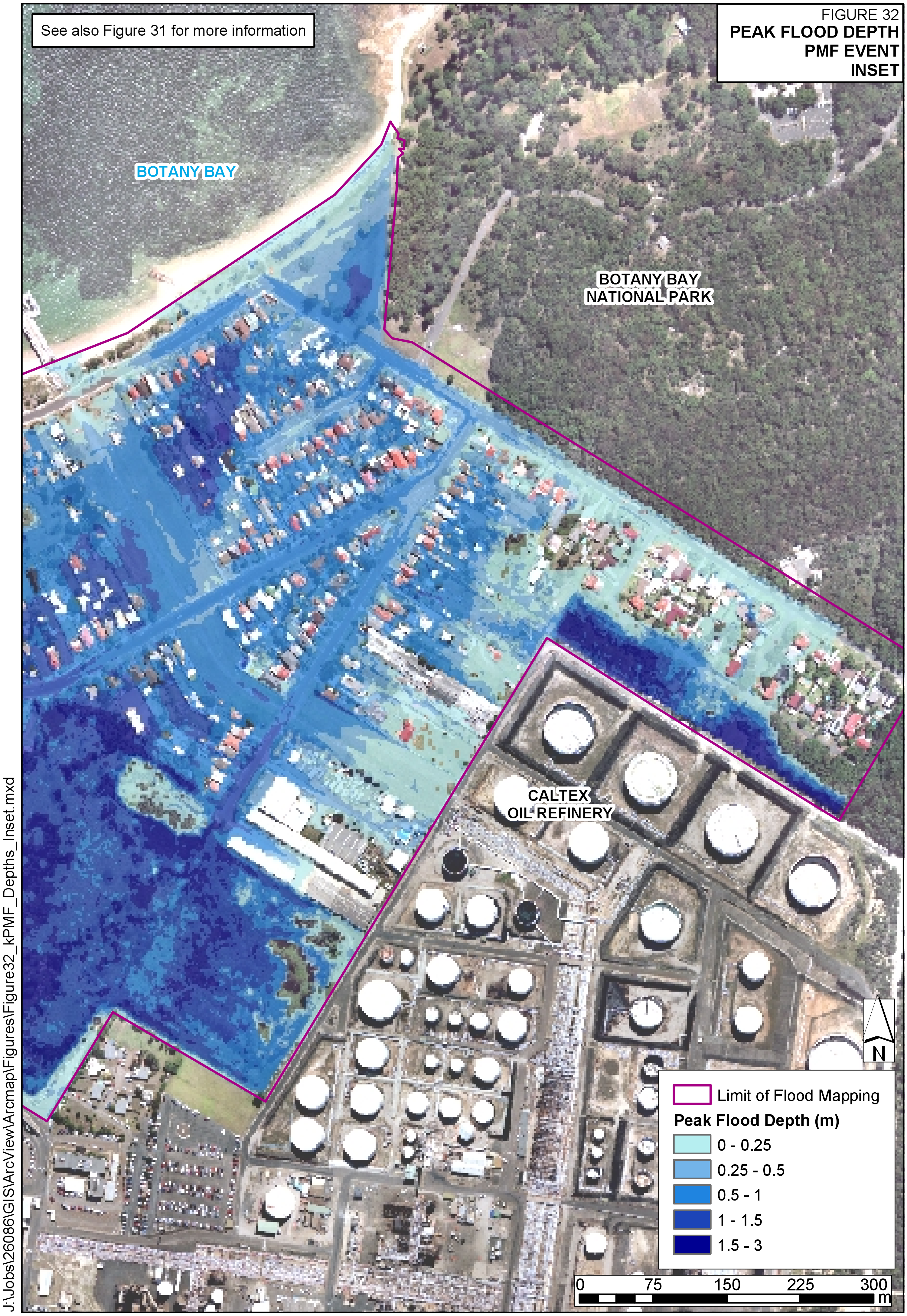
FIGURE 31
PEAK FLOOD DEPTHS
PMF EVENT
BOTANY BAY
BOTANY BAY
NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
Refer to Figure 32
for more detail
QUIBRAY
BAY
CALTEX
OIL REFINERY
Limit of Flood Mapping
Peak Flood Depth (m)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 1.5
1.5 - 3
0 100 200 300 400 500
m
N
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure31_kPMF_Depths.mxd



See also Figure 31 for more information
FIGURE 32
PEAK FLOOD DEPTH
PMF EVENT
INSET
BOTANY BAY
BOTANY BAY NATIONAL PARK
CALTEX OIL REFINERY
N
Limit of Flood Mapping
Peak Flood Depth (m)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 1.5
1.5 - 3
0
75
150
225
300
m
J:\Jobs\126086\GIS\ArcView\Arcmap\Figures\Figure32_kPMF_Depths_Inset.mxd

FIGURE 33
PEAK FLOOD VELOCITY
20% AEP EVENT

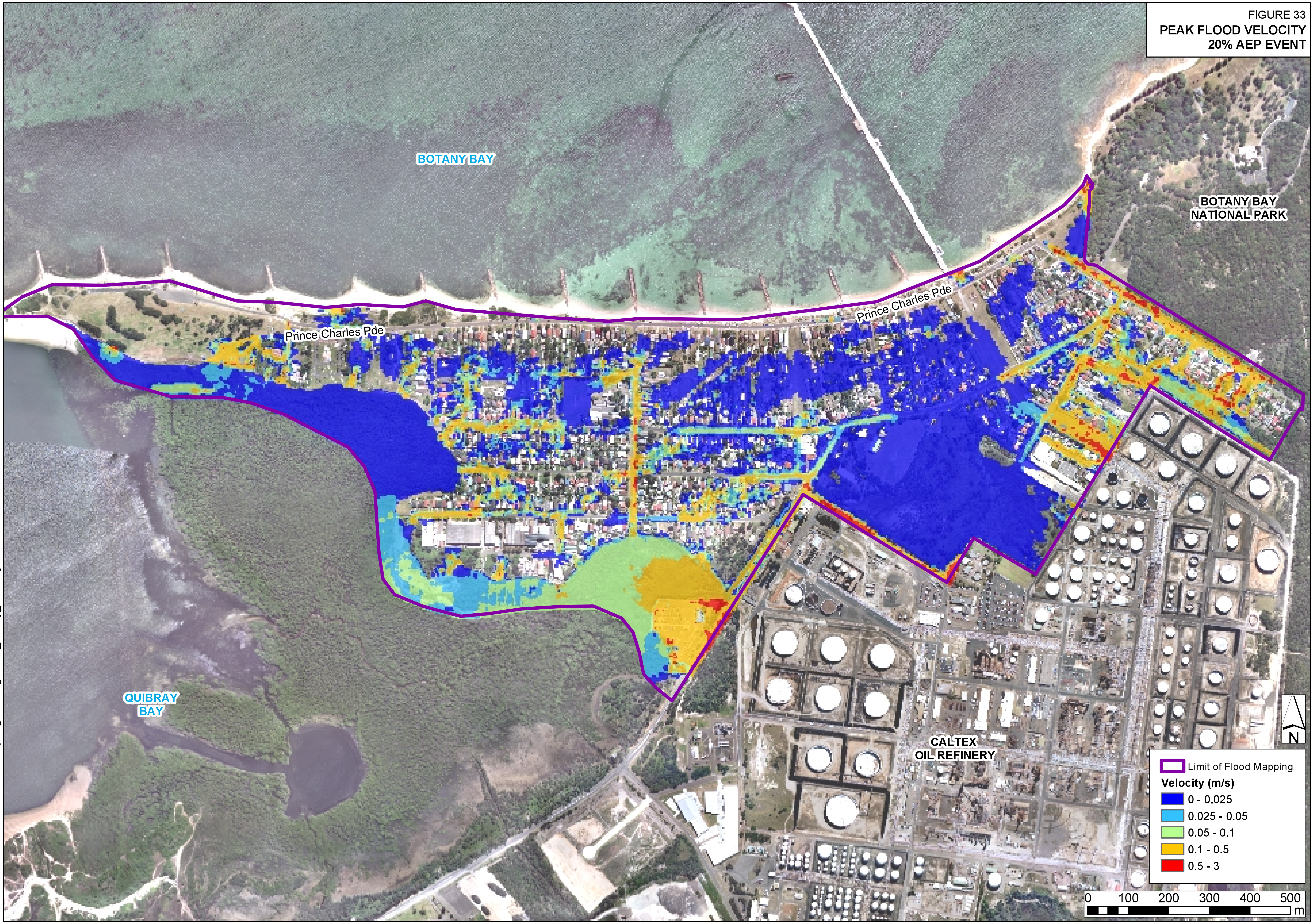


FIGURE 34
PEAK FLOOD VELOCITY
20% AEP RAINFALL EVENT
WITH A 1% STORM TIDE

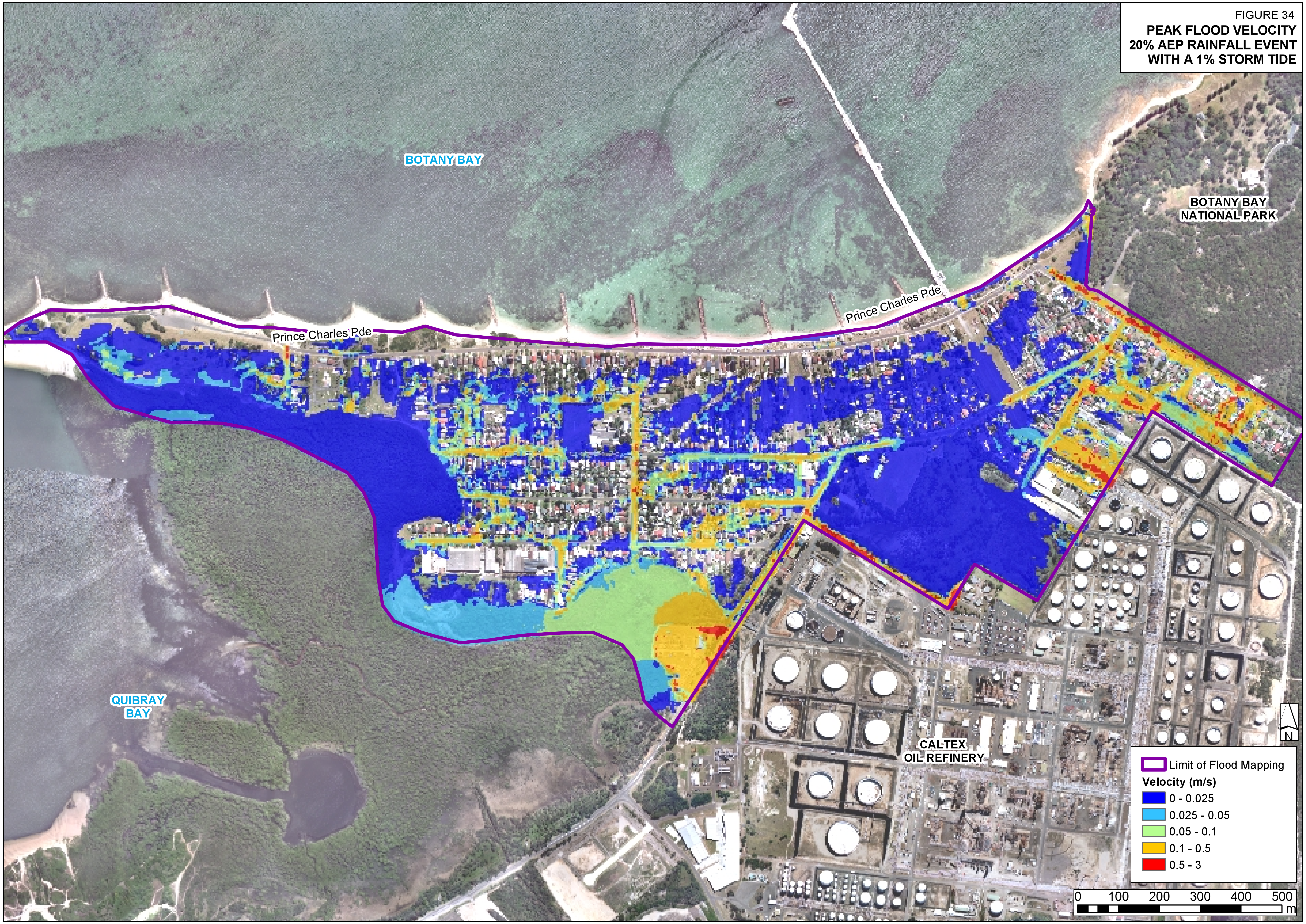


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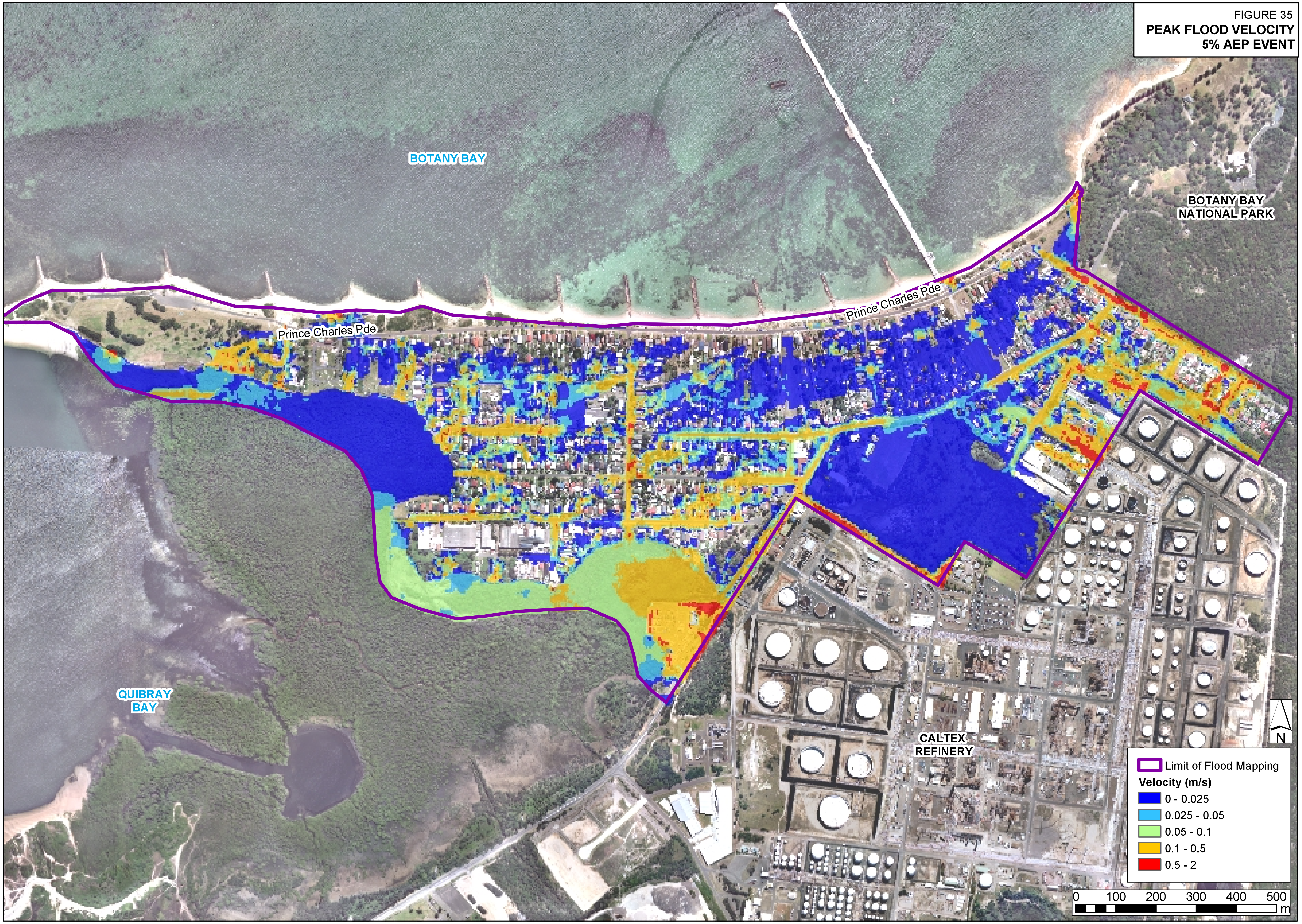
FIGURE 35
PEAK FLOOD VELOCITY
5% AEP EVENT



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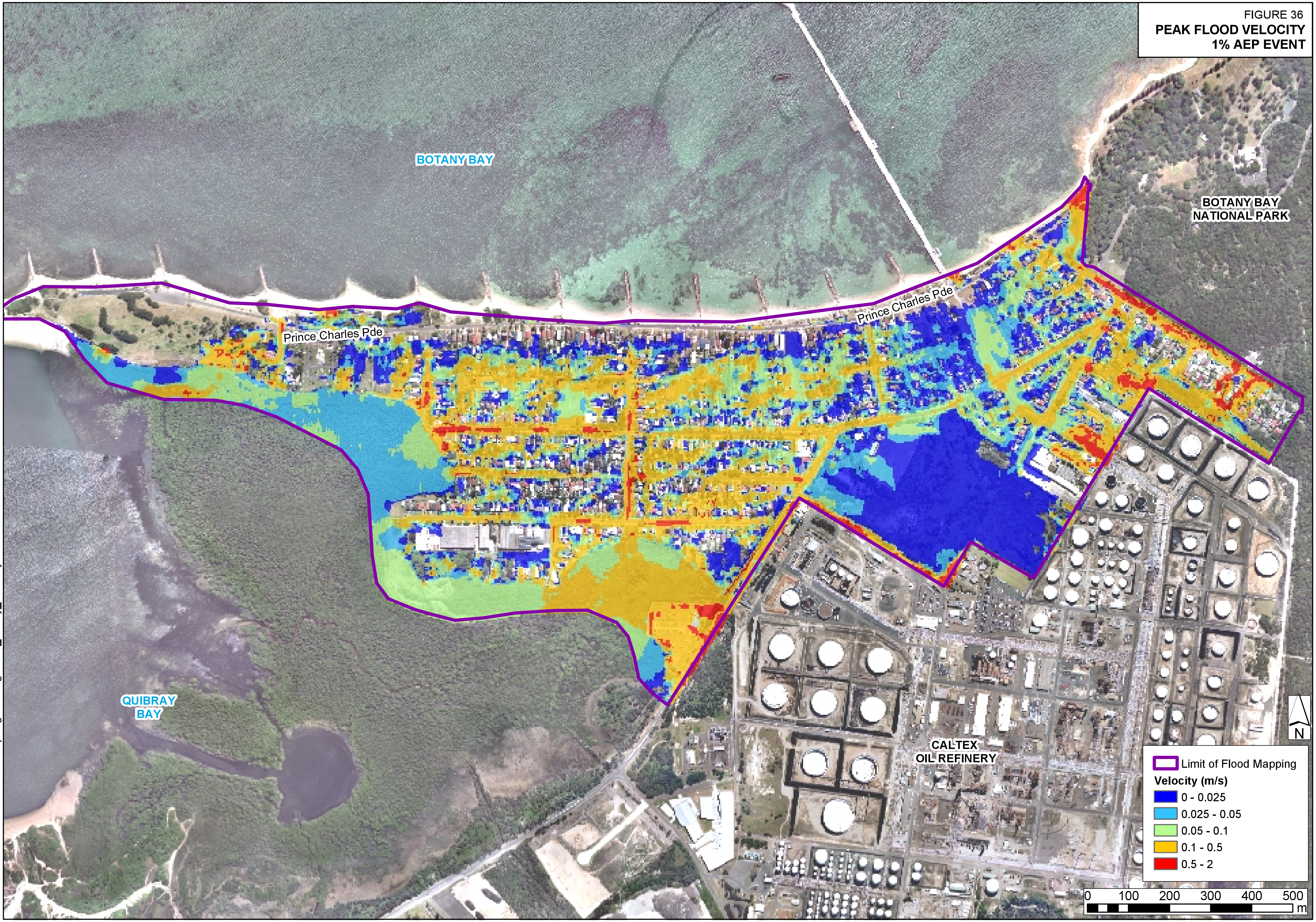

FIGURE 36
PEAK FLOOD VELOCITY
1% AEP EVENT

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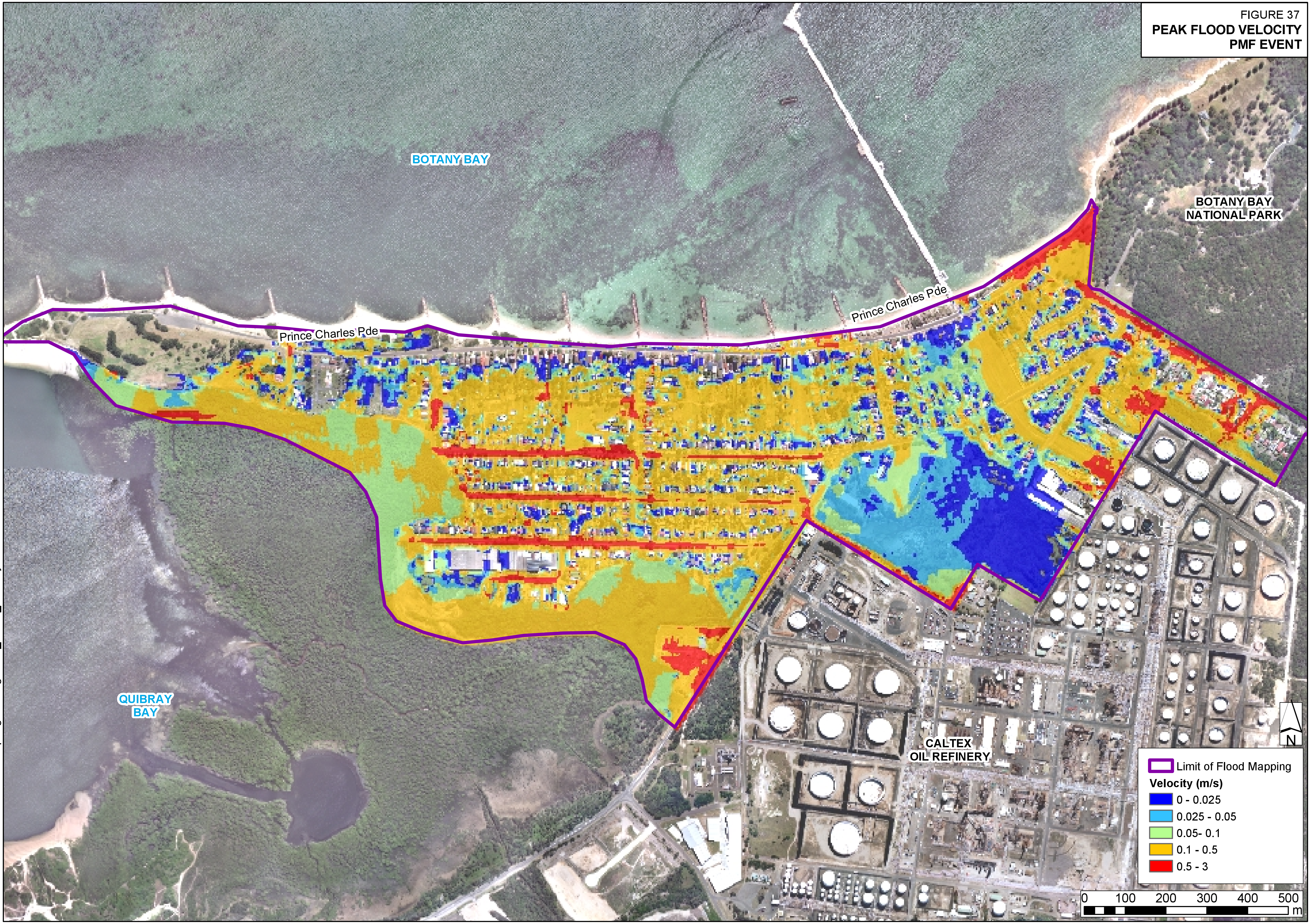
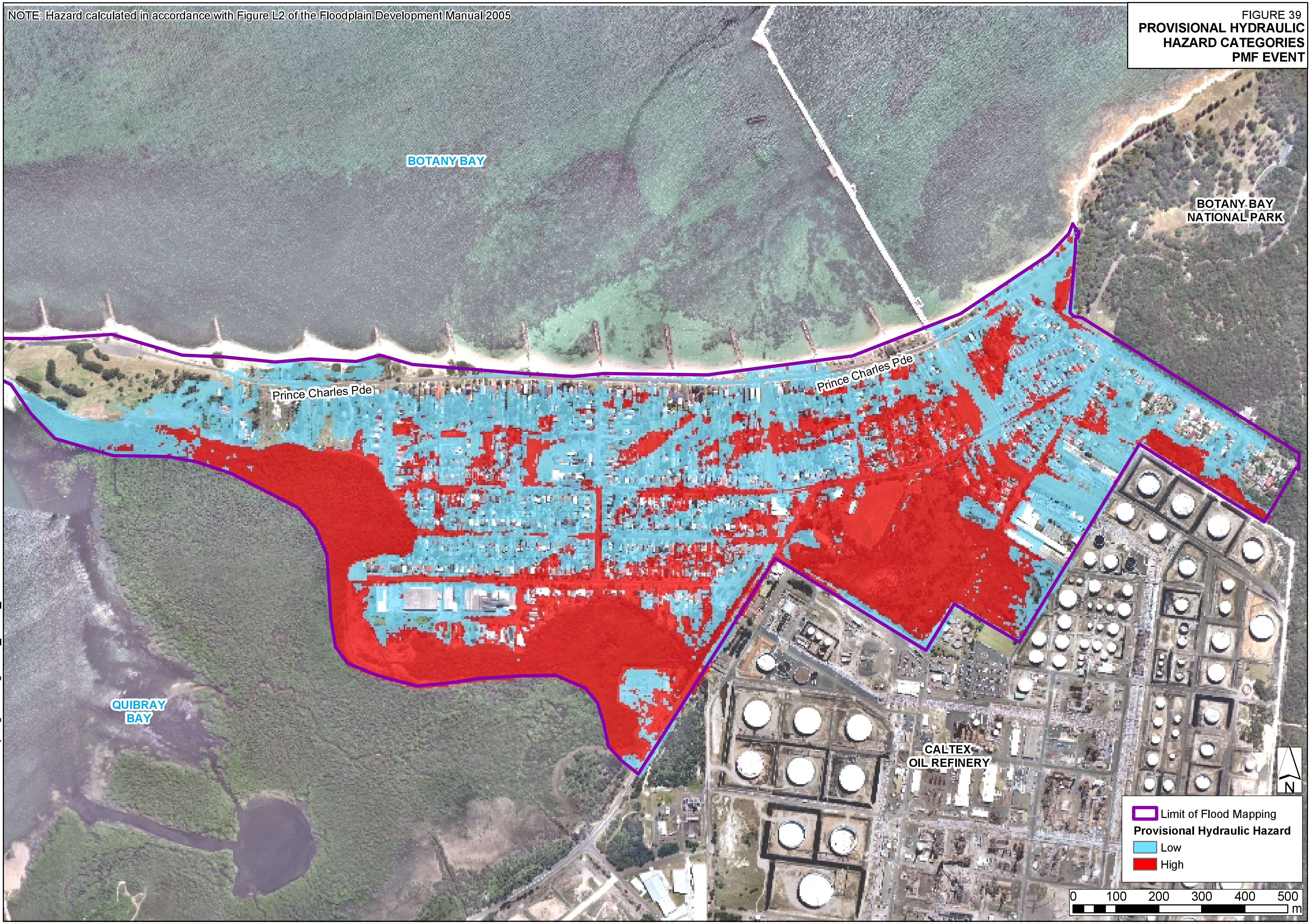


FIGURE 37
PEAK FLOOD VELOCITY
PMF EVENT
BOTANY BAY
BOTANY BAY NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
QUIBRAY BAY
CALTEX OIL REFINERY
Limit of Flood Mapping
Velocity (m/s)
0 - 0.025
0.025 - 0.05
0.05- 0.1
0.1 - 0.5
0.5 - 3
0 100 200 300 400 500 m
N
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure37_kPMF_Velocity.mxd

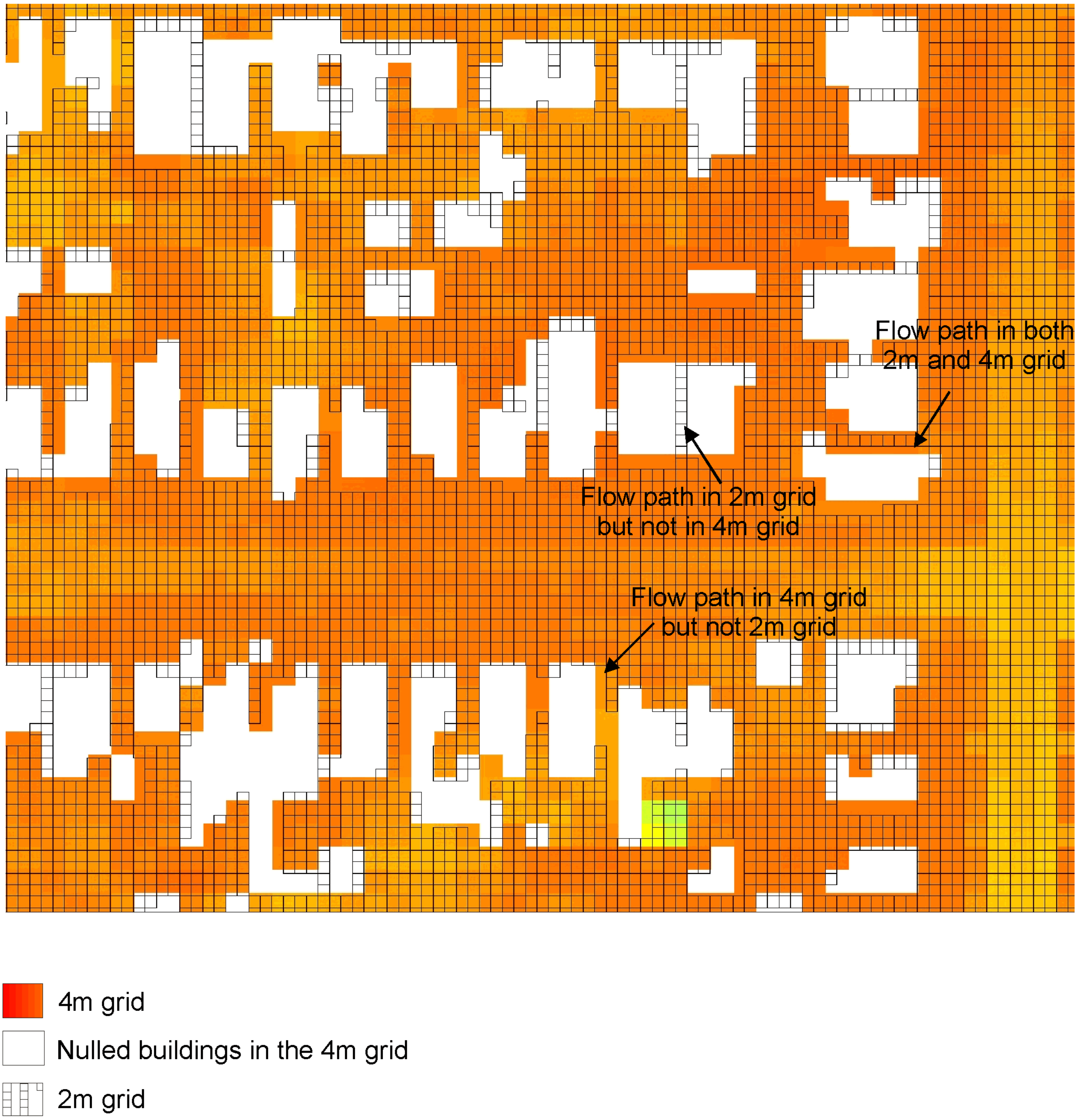
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure38_k100y_Hazard.mxd



NOTE: Hazard calculated in accordance with Figure L2 of the Floodplain Development Manual 2005
FIGURE 39
PROVISIONAL HYDRAULIC
HAZARD CATEGORIES
PMF EVENT
BOTANY BAY
BOTANY BAY
NATIONAL PARK
Prince Charles Pde
Prince Charles Pde
QUIBRAY
BAY
CALTEX
OIL REFINERY
N
Limit of Flood Mapping
Provisional Hydraulic Hazard
Low
High
0
100
200
300
400
500
m
J:\Jobs\26086\GIS\ArcView\Arcmap\Figures\Figure39_kPMF_Hazard.mxd

FIGURE 40

2m AND 4m GRID COMPARISON



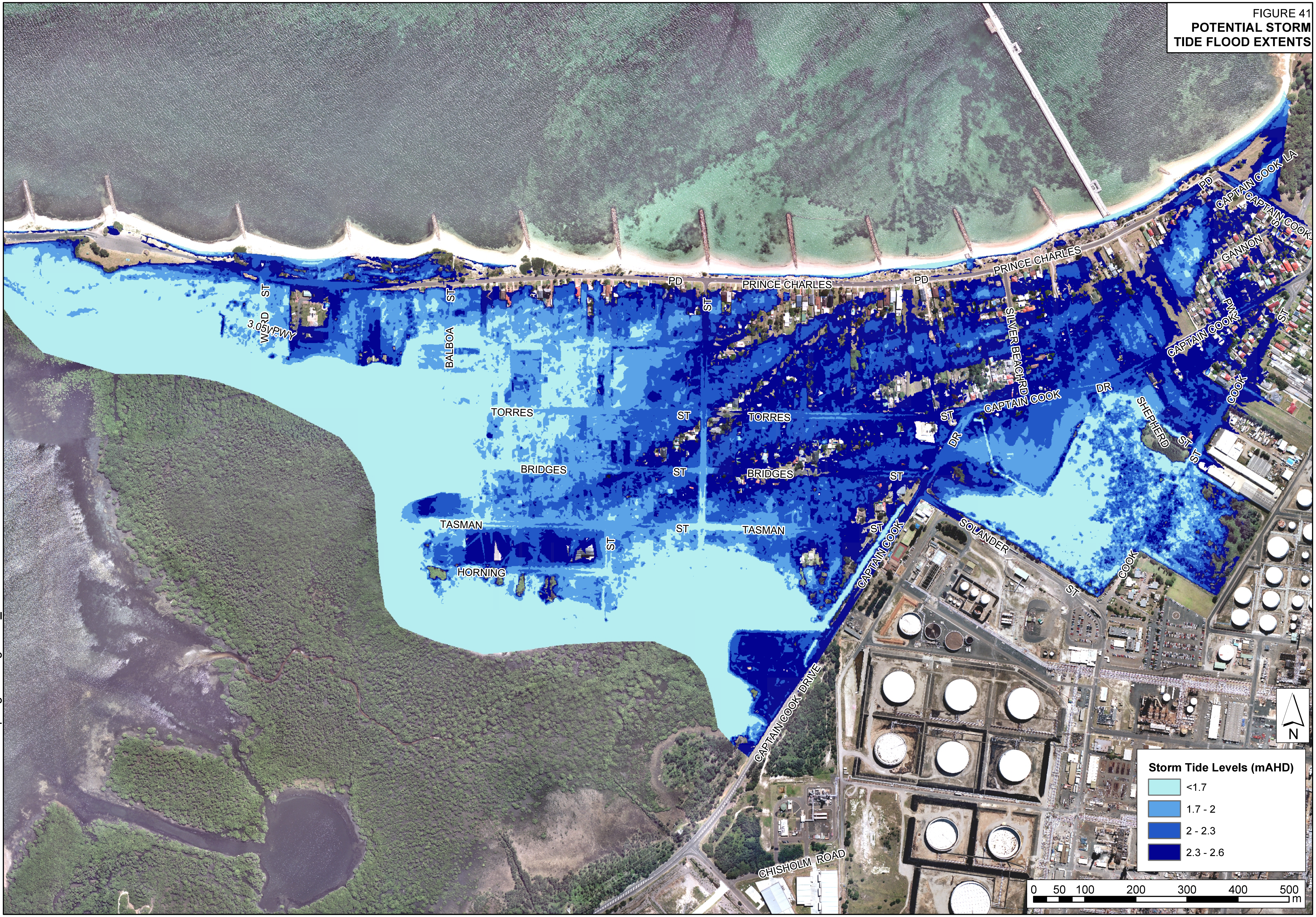


FIGURE 41
POTENTIAL STORM TIDE FLOOD EXTENTS

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FIGURE 42
INCREASE IN 1% AEP FLOOD LEVEL FOR HIGH CLIMATE CHANGE SCENARIO
(PEAK ENVELOPE OF OCEAN AND CATCHMENT FLOOD EVENTS by 2100)

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Appendix A

APPENDIX A: GLOSSARY OF FLOOD 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 Council's 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 of the Manual together with further discussion.

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

APPENDIX B: HISTORICAL FLOOD INFORMATION

Table B1: Summary of the 1980 Community Interview Responses

Address	Years in Area	Property affected by flooding	Date of flooding	Flood Level	Ponding Time	Comment
11 Bridges Street	2.5	No				some ponding, but is not seen as a problem
112 Bridges Street	<1	No				ponding at E.O.B
115 Bridges Street	20	No				tidal inundation on Torres St and near property but no stormwater issues
119 Bridges Street	8	Yes				tidal inundation
121 Bridges Street	8	Yes				tidal inundation
125 Bridges Street	8	Yes				some problem with tidal inundation, no stormwater problems
13 Bridges Street	20	No				no problems observed
15 Bridges Street	20	No				used to have drainage problems, but none in the last 10 years. Water soaks away quickly
19 Bridges Street	10	Yes	1975	300mm		ponding, since then area has been filled 3-400mm to Council's levels, some ponding may still occur but soaks away quickly
20 Bridges Street	1	No				no problems since moved there
21 Bridges Street	8	Yes				some ponding, near and under house
23 Bridges Street	8	Yes				some ponding
24 Balboa Street	12	Yes				some ponding
24 Bridges Street	8	Yes	1975			water generally soaks away okay, high water table
26 Balboa Street	12	Yes				some tidal inundation into garage, no stormwater problem
26 Bridges Street	8	Yes	1975			some ponding
28 Balboa Street	12	Yes				some ponding
28 Bridges Street	10	No				no drainage problems and water soaks away quickly
30 Bridges Street	30	No				
32 Bridges Street	30	No				have not had any flooding problems, any ponding has gone within 1/2 hr
82 Bridges Street	18	No				road water ponds at E.O.B
86 Bridges Street	18	Yes				thinks there are some drainage problems
87 Bridges Street	11	Yes				ponding, since then area has been filled
89 Bridges Street	11	Yes			days	some ponding
93 Bridges Street	11	Yes	1975			ponding, since then area has been filled
97 Bridges Street	8	No				ponding at E.O.B
16 Captain Cook Drive	10	No				Was better off than most in 1975 storm
32 Captain Cook Drive	30	Yes	1975			Also flooded in years prior to 1975, although none since then
34 Captain Cook Drive	42	No				block filled before the 1975 flood, and has had no flooding problems although some surrounding properties do
40 Captain Cook Drive	4	Yes		300mm		Cook St drainage thought to have reduced flooding, have done some filling of yard
49 Captain Cook Drive	5	Yes	1975			Flowed across Capt. Cook Drive and through block. Not been a problem other than in 1975.
51 Captain Cook Drive	8	Yes	1975			Water from Cook St Swamp and National Park, across Capt. Cook Dr and into Gannon St. Been filled and no problems since.
75 Captain Cook Drive	5	Yes	1975			Was there for 1975 storm, hasn't been as bad since but may be potential drainage issues

77 Captain Cook Drive	1	No				
81 Captain Cook Drive	8	No				some water at back but soaks away
97 Captain Cook Drive	1	No				
99 Captain Cook Drive	3	No				no problems since moved there
101 Captain Cook Drive		Yes	1975			some ponding, water came into house in 1975, water from road runs into properties
105 Captain Cook Drive	1	No				no problems since moved there
4 Dampier Street	6	Yes	1975		less than 1 hr	some ponding
6 Dampier Street	6	No				
14 Dampier Street	14	No				
16 Dampier Street	30	No				
18 Dampier Street	25	No				Ponding at EOB
26 Dampier Street	15	No				
28 Dampier Street	15	No				Water soaks away quickly
42 Dampier Street	24	No				No problem with block, but suggests roadwork in Dampier St to alleviate street drainage problems.
2 Gannon Street	8	Yes	1975	50-150mm		
3 Gannon Street	1	No				
8 Gannon Street	15	Yes				Some flooding from back fence in heavy storms
80 Prince Charles Parade	16	No				
86 Prince Charles Parade	18	No				
90 Prince Charles Parade	25	No				
94 Prince Charles Parade	3	No				
146 Prince Charles Parade	3	No				
152 Prince Charles Parade	3	No				
154 Prince Charles Parade	13	No				
162 Prince Charles Parade	<1	No				
164 Prince Charles Parade	25	No				
1 Silver Beach Road	15	No				
9 Silver Beach Road	3	Yes				Water comes into garage from road, ponding at EOB for days. Remainder of block has no problems.
17 Silver Beach Road	9	Yes	1975	400-500mm		
18 Silver Beach Road	8	No				Water ponding at EOB
26 Silver Beach Road	25	No				
30 Silver Beach Road	20	No				Water ponding at EOB
13 Tasman Street	18	No				Some ponding in 1975 but soaked away quickly
15 Tasman Street		Yes		<100mm		

17 Tasman Street		Yes		100mm		
27 Tasman Street	3	No				some ponding for couple hours in back yard but is not a problem
33 Tasman Street	2	No				
35 Tasman Street	20	Yes				some ponding on driveway from road water
65 Tasman Street	8	Yes		50mm		
69 Tasman Street	10	Yes	1975	250-300mm		
71 Tasman Street	2	Yes				some ponding
115 Tasman Street	23	No				Block been filled so no problem from high tides, stormwater runs away into swamp.
7 Torres Street	20	No				
9 Torres Street	18	No				
13 Torres Street	21	No				
20 Torres Street	2.5	No				
41 Torres Street	3.5	No				
43 Torres Street	9	No				
44 Torres Street	7	No				
46 Torres Street	12	No				
51 Torres Street	<1	No				
53 Torres Street	1	No				
54 Torres Street		Yes	1975			some ponding
57 Torres Street	2.5	No				
58 Torres Street	44	No				
64 Torres Street	2.5	No				
67 Torres Street	10	No				
96 Torres Street	19	No				Back part of block has been filled
102 Torres Street	<1	No				
108 Torres Street	10	No				some ponding in backyard but soaks away quickly
118 Torres Street	2.5	No				
122 Torres Street	6	No				yard has been filled, no problems since
132 Torres Street	13	Yes	1975			some ponding
144 Torres Street	35	Yes	1975			tidal water flooded house

Table B2: Sutherland Shire Council Complaints Register

Location	Request Description	Incident Category	Action	CRMS Date
(south of unmade Shepherd St) Cook Street Kurnell	Council easement is higher than the ground. The water from the reserve is flooding customers property. The water is currently flooding customers property. It is approx 1 foot deep. It is flooding back yard and is approx 6 inches fr	General Flooding		
Marton Park	Flooding of Marton Park, Kurnell	General Flooding		22/05/2003
13 Reserve Road KURNELL	caller has reported every time it rains her drive is being washed away it is due to no kerb and gutter. caller has no drains on her property and water runs down the hill at great speed taking all in the way please go out and check what Council can do to	General Flooding	: Action - Finalised - Action - Operationally Finalised	2/06/2003
2 Cook Street	I can't find a category for this request. Customer is requesting more drainage to be place in his street, at Kurnell. He believe that one which is currently in the street is not enough to carry all the water from all the homes in the area.	General Flooding	: these properties low lying and suffer from inundation regularly, additional drainage lines not the answer	15/05/2003
20 Dampier Street KURNELL	MKerr MP for Mr S Hiskins, 20 Dampier Street, Kurnell - Concerns with flooding at Kurnell and Council maintenance of drains. LETTER SCANNED AND ON FILE	General Flooding	: there are no drains in vicinity of 20 dampier st, kerb and gutter exists and is clear and operational, this propably is a request on localised flooding on private land. response outlining the kurnell flood mapping is required.	2/06/2003
87 Torres Street	General flooding in torres st, Kurnell	General Flooding		24/05/2003
91 Bridges Street KURNELL	Resident claims damage to his property during the recent severe flooding necessitating his hiring of pumps on at least 2 occasions. He is concerned because of lack of storm water drain at rear of property, the construction of a dish drain, etc.	General Flooding	: Action - Finalised - Action - Operationally Finalised - Met and spoke to owner and advised the situation. The natural slope is low-lying and we can not do an	29/05/2003
248 Prince Charles Parade KURNELL	Refer CRMS 760603876 - customer has complained about this blocked drain before. All Council have every done in the past is shovel out debris, customer is suggesting that there need to be a proper clearing of the pipes. Every time it rains, the road is	Maintenance	: Action - Finalised - Action - Operationally Finalised - incorrect assumption by customer, if pit does block then the resultant flows run down to next pit along prince charles parade, prince charles parade	21/05/2003
90 Torres Street KURNELL	The stormwater drain is blocked between No 90-100 possibly around No 96 where it is obstructed by tree roots, as Council has made repaired previously. It it causing flooding to private properties land.	Maintenance	: Action - Finalised - Action - Operationally Finalised - ses and Council onsite now, waterjet also programmed	16/05/2003
Captain Cook Drive KURNELL	The open drain is blocked due to the Swamp Oaks have fallen in approx 3 places and therefore blocking the water from getting away. This is now causes	Maintenance	: Action - Finalised - Action - Operationally Finalised - Instruction issued 2 trees fallen into creek, to be removed.	19/05/2003

	flooding.			
62 Bridges Street KURNELL	Due to heavy rains of last week residents neighbouring property has decided to pump out all the flooding of property out onto the road - i.e. running off into other properties etc - cars driving through it etc.- Health Dept in morning meeting have phoned t	Private Drainage	: advised that the property was pumped out by the SES. The family will clean up the sandy deposit on the weekend.	21/05/2003
62 Bridges Street KURNELL	Customer claims a neighbouring property's yard was flooded in the rain last week. The owner pumped the water from his yard to the street, however there was also a lot of sand and rubbish as well which has made its way two houses down to in front of comp	Private Drainage	: Action - Finalised - Action - Operationally Finalised - Inspected property and observed sandy material in gutter outside of No	21/05/2003
142 Torres St KURNELL			Reported flooding by SES	10/05/2001
107 Torres St KURNELL			Reported flooding by SES	11/05/2001
26 Balboa St KURNELL			Reported flooding by SES	13/05/2001
28 Balboa St KURNELL			Reported flooding by SES	12/05/2001
81 Torres St KURNELL			Reported flooding by SES	11/05/2001

* Owners/residents also participated in the community questionnaire issued as part of the current study.

Table B3: Summary of Current Questionnaire Responses

Address	Years in Area	Property affected by flooding	Date of flooding	Flood Level	Ponding Time	Comment	Blocked Drains Mentioned	Effect of Regrading Road
4 Balboa Street		Yes	1984; 2001					
6 Balboa Street	23	Yes	1984 Nov; 2001 May		72hrs	4,8 and vacant Council block next to 8 also become inundated. Drain becomes blocked in Prince Charles Pde		
8 Balboa Street		Yes	1984; 2001					
18 Balboa Street	43	Yes	since Council raised road by 4 feet	up to back door		Road raised by 4 feet, made flooding worse		Worse
26 Balboa Street		Yes						
28 Balboa Street	26	Yes		50cm inside house	3 days to 1.5 weeks	Ponding occurred at 28 Balboa and to a lesser extent at 26. Drain trap installed in 1990's which has reduced flooding. A combination of rain and a king tide can still cause runoff and ponding.		
1 Bridges Street	44	No	none since 1963					
2 Bridges Street	44	No	none since 1963					
3 Bridges Street	44	No	none since 1963					
9 Bridges Street								
28 Bridges Street		Yes	May 2001; May 2003					
42 Bridges Street	11	No				When house purchased, were informed it was subject to flooding. During heavy rain any ponding has drained into soil within minutes. May 2001 and May 2003, flooding was observed in vicinity of #28 and the end of Bridges St.		
44 Bridges Street	3	Yes	2004	40mm	<24hrs	Rear 10% of property		
65 Bridges Street	11	No	none since 1996					
66 Bridges Street		Yes	1996/1998??	thigh level	2-4 days	Grates and drains to the beach installed in street in 2004		
70 Bridges Street	28	Yes	1988, 1990, 1992		few days	Back room and all around house has been inundated. Flood waters were observed to move swiftly from the main road and next door.		
73 Bridges Street	16	No	none since 1991					

93 Bridges Street	39	Yes	1969; 1974; 1975	covered yard and septic				Better????
106 Bridges Street	32	No	none since 1975					
125 Bridges Street	17	No	none since 1990					
22 Captain Cook Drive	11	Yes	1996	back and front yard	3 days			
52 Captain Cook Drive	6	Yes	2003	rear yard to back of house				
53 Captain Cook Drive	3	No						
75 Captain Cook Drive	10	Yes	twice in past 8 yrs					
115 Captain Cook Drive	39	Yes				At some stage block was raised		
127 Captain Cook Drive	54	Yes	mid 80's	50-100mm above crown of road		Lake at rear of Marton Park flooded. Blockage of drain in Torres St adjacent to Marton Park, as well as the open drain at the end of Tasman Street		
street Captain Cook Drive	21		1988; 1998		4-6 days; up to 4 days outside 59 Cpt Cook Dr		Yes	
44 Cook Street	6	No	none since 2001					
46 Cook Street	6	No	none since 2001					
48 Cook Street	6	No	none since 2001					
58-64 Cook Street	1	No	none since 2006					
2 Dampier Street						blocked drain bottom end Dampier St	Yes	
20 Dampier Street	47	Yes	1990 + others	rear yard		Flooding in yard caused by swamp level; 1974 - beach front washed away; drain in Captain Cook Drive blocked (drains Marton Park Swamp)		
30 Dampier Street	72	Yes				Yard flooded		
39 Dampier Street	8	No	none since 1999					
54 Dampier Street	10			cnr Tasman & Dampier St	1.5 days			
1 Gannon Street	7	Yes	2001	minor				
street Gannon Street	48		1975					
3-11 (street) Horning Street	13		2001	150mm over road				

12 Prince Charles Parade	25	Yes	May-01	level with gutter	2 days	In street, ponding occurred between cnr Cpt Cook Dr and Prince Charles Pde outside No. 20; also other days before 2001. Blockage can occur in two drains running into Botany Bay		
34 Prince Charles Parade	29	No	none since 1978					
58 Prince Charles Parade	39	No	none since 1968					
148 Prince Charles Parade	17		???	???		Has been some flooding of either house or street		
150 Prince Charles Parade	49	Yes		part of backyard				
166 Prince Charles Parade	11	No	none since 1996					
184 Prince Charles Parade	30	No	none since 1977					
216 Prince Charles Parade	47	Yes	mid 1990's	75-100mm	4hrs	Back blocks flooded		
242 Prince Charles Parade	32	Yes	1990's	50cm		In back yard; since then drainage valve installed cnr Balboa St & Torres St and had no problems		
258 Prince Charles Parade	4	No	none since 2003			Outlets from Prince Charles Parade to the beach haven't been cleared in last 3 years		
234 Prince Charles Parade	11	No	none since 1996			Street has flooded due to blocked sea outlet	Yes	
2-4 Prince Charles Parade	44	No	none since 1963					
1 Silver Beach Road	15	No	none since 1992			Some flooding in Tasman St has been observed, no ponding due to sandy soil		
3 Tasman Street	25	No	none since 1982			Open drain between Cpt Cook Dr and Tasman Street requires maintenance		
11 Tasman Street	1	No	none since 2006					
19 Tasman Street	27							
34 Tasman Street		Yes	Jun-05					
50 Tasman Street	9	No				Drainage outfall next to house which requires regular cleaning		
51 Tasman Street	15	Yes	2001, 2003			Flooding in backyard. Flooding also infront of 49 Tasman St in the old easement.		
57 Tasman Street		Yes	1955-1969?					
58 Tasman Street	23	No	none since 1984					
61 Tasman Street	43			see photos				
67 Tasman Street	46	Yes	1974;1975;2			Drainage improved when		

			001;2003			Tasman Street upgraded and low level drain installed.		
71 Tasman Street	5	Yes	May-03	10-15cm	few days	Front and back yard		
51 Torres Street	9	Yes	prior to resident moving in	entered house	short			
55 Torres Street	57	Yes	1985??			Blocked drain in Torres St, also need for cleaning of drain in Cook Street		
77 Torres Street	18	No	none since 1989					
87 Torres Street	40	Yes	1974;1975;2001;2003	50-450mm	longer than surrounding properties: 2-3 weeks	Ponding ankle to knee height; recommends a drainage system along the right of way between Prince Charles Pde and Torres St		
90 Torres Street	36	Yes	1974; 1975; 2001; 2003 + other times					
109 Torres Street	32	Yes	1975; 2001; 2003		2-3 days	Back yard flooded, waters moved slowly halfway down the block. Road raised in 1980's - made flooding problem worse as drained into surrounding properties. Front of property has also been raised during residency.		
116 Torres Street	22	Yes	every winter	ankle to knee deep		Ponding both back and front. A combination of being on a tidal channel and heavy rain can cause flooding.		
130 Torres Street	15	Yes						
132 Torres Street	11	Yes		1-2 feet over whole property		House is lowest in street		
144 Torres Street	16	Yes	after 1991	yard	quickly	Occurs if heavy rain, especially if high tide as well		
10-20 Torres Street	44	No	none since 1963					
street Torres Street			1990 Feb					
street Torres Street	57		1985??	enough for boat on Torres St		Blocked drain in Torres St		
street corner Torres&Balboa								
8 Ward Street	21	Yes	1998 August 17-20	garden ponded				
???	9	Yes	February 2001			Yard and house flooded		
???	32	No						

???	36	Yes	1974; 1975; 2001			1975 Council drains badly blocked; 1974 water level 1.5 foot deep		

Photos: Provided by Residents from 93 Bridges Street

Photograph B1: Flooded Street

Photograph B2: Outside 93 Bridges Street

Photos: Provided by Residents from 61 Tasman Street

Photograph B3: Flooding in front of 63 (left) and 61 (right) Tasman Street in front of 63 (left) and 61 (right)Tasman Street

Photograph B4: Flooding in front of 63 (left) and 61 (right) Tasman Street

Photograph B5: Additional Flooding in front of 61 Tasman Street (left)

Photograph B6: Flooding in front of 61 Tasman Street (left)

Photograph B7: Flooding in front of 61 Tasman Street

Photograph B8: Flooding in front of 61 Tasman Street

Photograph B9: Flooding in front of 61 Tasman Street

Photograph B10: Flooding outside 61 Tasman Street

Photograph B11: Flooding in the Backyard of 61 Tasman Street