SHOALHAVEN CITY COUNCIL

ST GEORGES BASIN FLOODPLAIN RISK MANAGEMENT STUDY & PLAN

CLIMATE CHANGE ASSESSMENT

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Project **St Georges Basin Floodplain Risk Management Study & Plan Climate Change Assessment**	**Project Number** **112001**
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TABLE OF CONTENTS

PAGE

LIST OF APPENDICES

LIST OF GRAPHS

LIST OF TABLES

LIST OF FIGURES – Main Body of Report

LIST OF FIGURES – APPENDIX B

LIST OF FIGURES – APPENDIX C

LIST OF FIGURES – APPENDIX D

1. INTRODUCTION

1.1. Background

The main objective of this study is to undertake a review of the existing St Georges Floodplain Risk Management Study and Plan (study area shown on Figure 1) to incorporate the predicted impacts of climate change.

In September 2001, Webb, McKeown & Associates (now WMAwater) prepared the "*St Georges Basin Flood Study*" (Reference 1) report which constitutes the first stage of the management process for the St Georges Basin and its catchment area.

Subsequently, in December 2006, the "*St Georges Basin Floodplain Risk Management Study and Plan*" reports (References 2 and 3) were prepared by Webb, McKeown & Associates for the next stage of the risk management process, providing the basis for the future management of flood prone lands within the St Georges Basin Floodplain.

This Climate Change Assessment report provides an in depth response regarding climate change and builds upon previous studies already conducted for the study area.

In addition, this report provides advice regarding the impacts of climate change on flood damages and the number of buildings inundated for various design scenarios. Further the report discusses adaptation strategies and the future approach for inclusion of climate change impacts in development controls and floodplain management plans.

1.2. Terminology used in this Report

The magnitudes of design flood events are expressed in terms of their probability of occurrence. One approach is to use the term Annual Exceedance Probability (AEP) which indicates the chance of such an event in terms of probability of occurrence, thus a 1% AEP event has a 1% chance of being equalled or exceeded in a year. Another approach is to use the term Average Recurrence Interval (ARI) which indicates the long term average number of years between such events, thus a 1% AEP event is equivalent to the 100 year ARI event.

The former (AEP) is the preferred approach as the latter (ARI) can indicate to a lay person that once there has been a 100 year event, another will not occur for another 99 years. The use of the term AEP less ambiguously indicates that, regardless of the number and magnitude of floods in the past that there is a 1% chance of a 1% AEP event occurring each and every year. There are several instances of 1% AEP events occurring within a short period in NSW (e.g. 1949 and 1950 at Kempsey).

In this report the term ARI has been adopted as it was considered that it would be too confusing to have a % term for AEP as well as to express the % increase in design rainfall and the use of % to indicate increases in flow or increases in flood damages.

The term Extreme flood has been used rather than PMF (Probable Maximum Flood) for consistency with the St Georges Basin Flood Study which approximated a rarer flood than the 100 year ARI by multiplying the 100 year ARI design inflows by three. As this report is principally concerned with assessing the impacts of climate change it was not considered necessary to determine the PMF based on current hydrologic approaches. When a new Flood Study of the study area is undertaken using 2D hydraulic modelling and ALS data the "true" PMF should be calculated using the most appropriate method at the time.

The % increase in design rainfall was estimated by multiplying the design inflows by the % increase. This assumption is not strictly correct as the catchment response is non linear however is appropriate for the purposes of this study.

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

1.3. Climate Change

The *2005 Floodplain Development Manual* (Reference 4) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change on flood behaviour.

Current best practice for considering the impacts of climate change (sea level rise and rainfall increase) have been evolving rapidly. Key developments have included:

- the release of the Fourth Assessment Report by the Inter-governmental Panel on Climate Change (IPCC) in February 2007 (Reference 5), which updated the Third IPCC Assessment Report of 2001 (Reference 6);
- the preparation of *Climate Change Adaptation Actions for Local Government* by SMEC Australia for the Australian Greenhouse Office in mid 2007 (Reference 7);
- the preparation of *Climate Change in Australia* by CSIRO in late 2007 (Reference 8), which provides an Australian focus on Reference 5;
- the release of the Floodplain Risk Management Guideline *Practical Consideration of Climate Change* by the NSW Department of Environment and Climate Change in October 2007 (Reference 9 - referred to as the DECC Guideline 2007);
- Hunter, Central and Lower North Coast Regional Climate Change Project — Report 3: Climate Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW (Reference 10);
- NSW Policy Statement on Sea Level Rise (October 2009) (Reference 11) which states: "*Over the 20th century, global sea levels have risen by 17 cm and are continuing to rise. The current global average rate is approximately three times higher than the historical average. Sea level rise is a gradual process and will have medium- to long-term impacts. The best national and international projections of sea level rise along the NSW coast are for a rise relative to 1990 mean sea levels of up to 40 cm by 2050 and 90 cm by 2100. There is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that the current trends will be reversed*";
- In August 2010 the NSW State Government Department of Environment, Climate Change and Water published the following:
    - *Flood Risk Management Guide* (Reference 12)*: Incorporating sea level rise*

benchmarks in flood risk assessments,

- *Coastal Risk Management Guide* (Reference 13)*: Incorporating sea level rise benchmarks in coastal risk assessments*,

The Department of Planning also published:

- *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* (Reference 14).

1.4. Approach

As a result of the information provided in the aforementioned and other documents, and to keep up-to-date with current best practice, the requirements of the Floodplain Risk Management Study and Plan need to be updated to provide a more rigorous assessment of climate change. It should be noted that the estimated rise in sea level along the NSW varies between the previously mentioned reports and at this time there is no absolute value that has been adopted by all experts.

The DECC Guideline 2007 indicated as below:

- ***sea level rise by the year 2090:***
  - *low level sea rise = 0.18 m,*
  - *medium level sea rise = 0.55 m,*
  - *high level sea rise = 0.91 m.*

- ***increase in peak rainfall and storm volume:***
  - *low level rainfall increase = 10%,*
  - *medium level rainfall increase = 20%,*
  - *high level rainfall increase = 30%.*

The NSW Policy Statement on Sea Level Rise (Reference 11 - October 2009) provided guidelines as indicated below:

- ***sea level rise***
  - *by the Year 2050 = 0.4m,*
  - *by the Year 2100 = 0.9m.*

The climate change analysis in this report assumes the NSW Policy Statement on Sea Level Rise (October 2009) and the DECC Guideline 2007 for the increase in peak rainfall and storm volume (as no other guideline is available).

The high level rainfall increase of up to 30% is recommended for consideration due to the uncertainties associated with this aspect of climate change and to apply the "precautionary principle". It is generally acknowledged that a 30% rainfall increase is probably overly conservative and that a timeframe for the provision of definitive predictions of the actual increase in rainfall intensities has not been advised by the Bureau of Meteorology or any other public authority in Australia. This issue is currently being considered as part of the review of the 1987 edition of Australian Rainfall and Runoff.

1.5. Reporting

The outcomes from the assessment herein were to:

- recommend the climate change scenarios that should be adopted for flood related development control;
- provide the updated flood extent and hazard mapping;
- provide updated flood damages assessment; and
- include the final findings from the investigation works into the St Georges Basin Floodplain Risk Management Study and Plan and comment made on all existing Plan recommendations and the impact of the findings of this assessment.

2. METHODOLOGY TO ASSESS EFFECTS OF CLIMATE CHANGE ON FLOOD LEVELS

2.1. Overview

Council has determined that the existing St Georges Basin Floodplain Risk Management Study and Plan should be reviewed in light of recent advice regarding climate change. Climate change has the potential to influence flood levels and floodplain management for the St Georges Basin as a result of:

1. Sea level rise, which may influence the rate of outflow of the Basin to the ocean;
2. Increased design rainfall intensities;
3. Changes to the morphologic regime of the Sussex Inlet channel and its ocean entrance. For example; “will climate change affect the dimensions of the channel or the build up (or erosion) of sediments?” and
4. Changes to the wind wave action across the fetch of the Basin may influence the wave setup component adopted in the design flood analysis.

The methodology addresses the Issues 1 and 2 identified above. Issues 3 and 4 are outside the scope of the present study.

Combinations of all the following design scenarios have been evaluated.

Rainfall Design Events	Extreme Flood, 100y, 50y, 20y, 10y, 5y, 2y ARI,
Ocean Level Increases	+0.9m, +0.4m,
Rainfall Increases	+10%, +20%, +30%.

The following sections present detailed discussion of the approach.

2.2. Modelling Approach

The existing flood levels in the St Georges Basin Flood Study are based on a WBNM hydrologic and RUBICON hydraulic model (model layout shown on Figure 2) completed in 2001 (Reference 1) with the modelling undertaken in the mid 1990’s. Since that time there have been significant advances in computer technology and this has enabled more sophisticated hydraulic models to be used. There have been little significant advances in hydrologic modelling and if the Flood Study was re done today the same WBNM hydrologic model would be used, although there has been some advancement in the applications of design rainfalls but the fundamental theories have not changed.

In the field of hydraulic modelling the significant advancements are the inclusion of Airborne Laser Scanning (ALS or sometimes known as LIDAR) and the use of 2 Dimensional models (TUFLOW, SOBEK, RMA2, Mike21). WMAwater now uses 2D models on every new flood study, however the 2D model would still have to be calibrated to the same flood height data as the 2001 Flood Study and therefore the change in flood level along the creeks and within the Basin (where calibration data are available) would probably not change significantly. Our experience is that there would be changes in the overbank areas (flood level and velocity) where the 2D model provides significantly greater definition (particularly for velocity which is not well defined in the RUBICON model). The magnitude of the change in floodplain extent as defined in the St Georges Basin Flood Study (Reference 1) has not been accurately defined.

The present approach is to use the existing hydrologic and hydraulic models as this permits a cost effective and “quick” response to the task. An updating of the St Georges Basin Flood Study is recommended if a 10 year ARI or greater event occurs as this would significantly enhance the hydrologic/hydraulic model calibration.

As the floodplain mapping provided in this report is based on ALS, the quality of the present mapping is much greater than that provided in all previous reports. However in order to make full use of the ALS the hydraulic modelling would also need to be upgraded to include the ALS, this has not been undertaken for this study but as noted above will be undertaken following any major future flood.

2.3. Hydrologic Inputs

The hydrology to derive design flows for input to the hydraulic model in the St Georges Basin Flood Study was determined using the WBNM model (Reference 15).

Design rainfall intensities and temporal patterns were derived from AR&R (Reference 15). Uniform depths of rainfall, with depth-reduction factors ranging between 0.84 and 0.95 for different durations, were applied across the whole catchment.

The model was run for a range of storm durations (1 hour to 72 hours) for the 100 year ARI design event to determine the critical storm duration, i.e. the duration which produced the highest peak flow. It was found that the different tributary sub-catchments had different critical durations. The 2hour, 9hour and 48hour storms were adopted for the range of critical events, and were run through the hydraulic model for the other design flood frequencies. The design peak at each location was then determined by adopting the maximum value obtained from the three storm durations.

An approximation to the extreme flood was obtained by multiplying the 100 year ARI design inflow hydrographs by three. This approach is consistent with other studies in the area at the time and provides an indication of the effects of a flood much rarer than the 100 year ARI event. However since that time more accurate methods of estimation of extreme events (termed the Probable Maximum Flood or PMF) are available.

2.4. Design Ocean Scenarios

2.4.1. Background

Water levels in St Georges Basin are affected by elevated ocean levels. These occur along the NSW coastline as a result of a large number of factors, the most significant of which are associated with storm conditions. Design ocean levels are assessed as a combination of:

1. *Astronomical Tide*. This varies depending upon the type of tide, e.g. Spring, Neap.
2. *Barometric Effect* (or storm surge). This results from a drop in barometric pressure causing the sea level to rise. Levels can be raised by up to 0.3 m in this manner.
3. *Wind Stress*. As wind associated with a storm moves across the ocean it creates a water surface current which moves in the same direction as the wind. When this current reaches the coastline the water piles up increasing the adjacent water levels. Still water levels may be raised by up to 0.3 m in this manner.
4. *Wave Setup*. This occurs as a result of transport of water from offshore by wave action. Elevation of standing water levels by up to 1.5 m has been known to occur along the NSW Coast.

For a large coastal catchment it is reasonable to assume that a single meteorological condition (e.g. east coast low pressure system, cyclone) will produce both the elevated ocean level and the flood producing (long duration) rainfall. However, for a smaller catchment such as the tributaries to the St Georges Basin, the short duration rainfall is likely to be produced from a local thunderstorm which may not necessarily be associated with ocean activity.

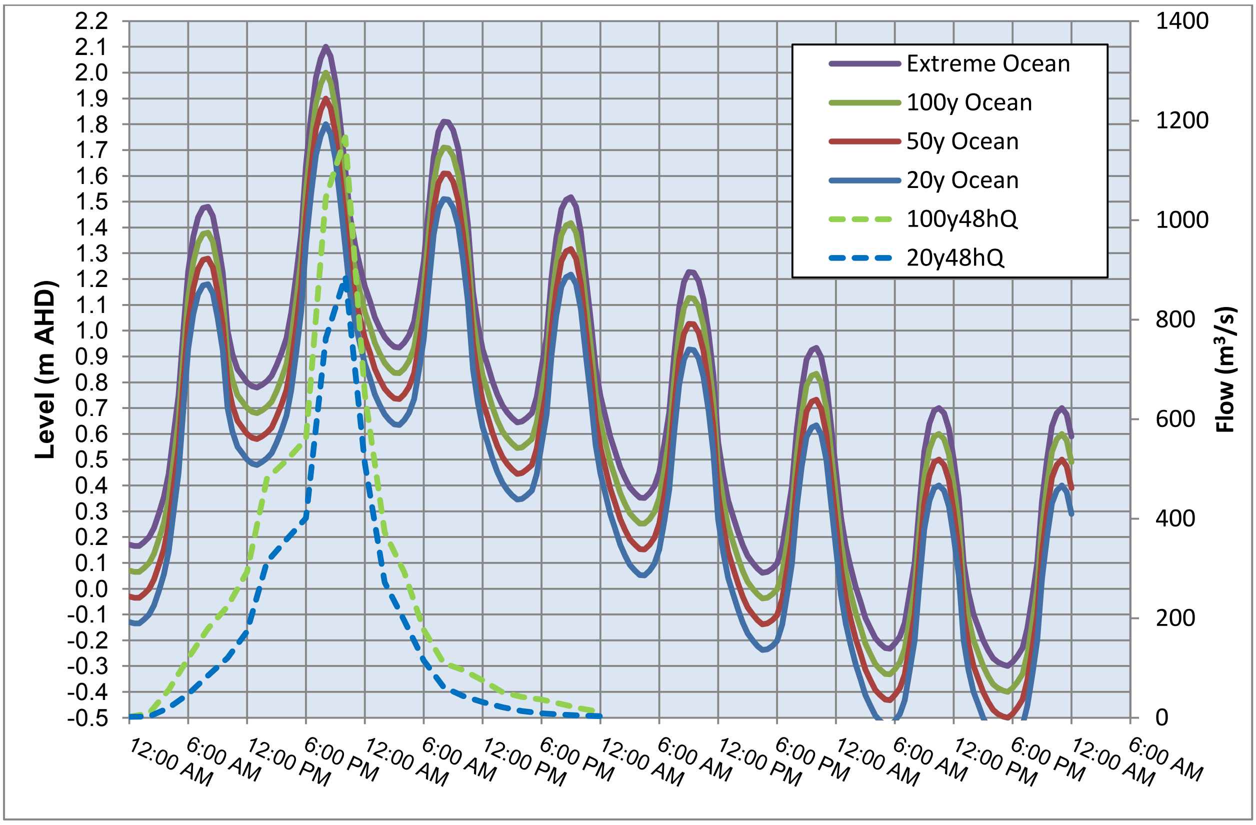
2.4.2. Approach – 2001 Flood Study

The storm tide adopted for the design events in the 2001 St Georges Basin Flood Study was based on the storm tide derived in a 1993 Estuarine Study (Reference 16). This was determined by analysing elevated water levels and using a modified Monte Carlo modelling technique. The approximate composition of the 100 year ARI ocean level was a 0.7 m astronomical tide together with a barometric pressure and wind stress effect of around 0.5 m and a wave setup of 0.8 m. The peak ocean levels used for design events in the study were, therefore:

- Extreme Event 2.1 mAHD,
- 100 year ARI Event 2.0 mAHD,
- 50 year ARI Event 1.9 mAHD,
- 20 year ARI Event 1.8 mAHD.

The St Georges Basin Flood Study assumed that the 100 year ARI rainfall event coincided with the 100 year ARI ocean event with the peak ocean level occurring at approximately the same time as the peak rainfall (48 hour duration was the critical storm duration for the Basin). This scenario is illustrated in Graph 1.

Graph 1: 2001 St Georges Basin Flood Study Ocean Scenario



2.4.3. Approach for Present Study

Since publication of the 2001 Flood Study there have been advances in the procedures for simulating the design ocean/estuary interface in flood studies. The latest approach is outlined in Reference 12. As part of this present study experts from the Office of Environment and Heritage (OEH) undertook a review of the design ocean levels pertinent for the St Georges Basin estuary. The outcomes as summarised below were agreed with Council and adopted for use in this study.

The agreed design ocean water level boundaries are provided in Table 1.

Table 1: Design Ocean Water Level Boundaries

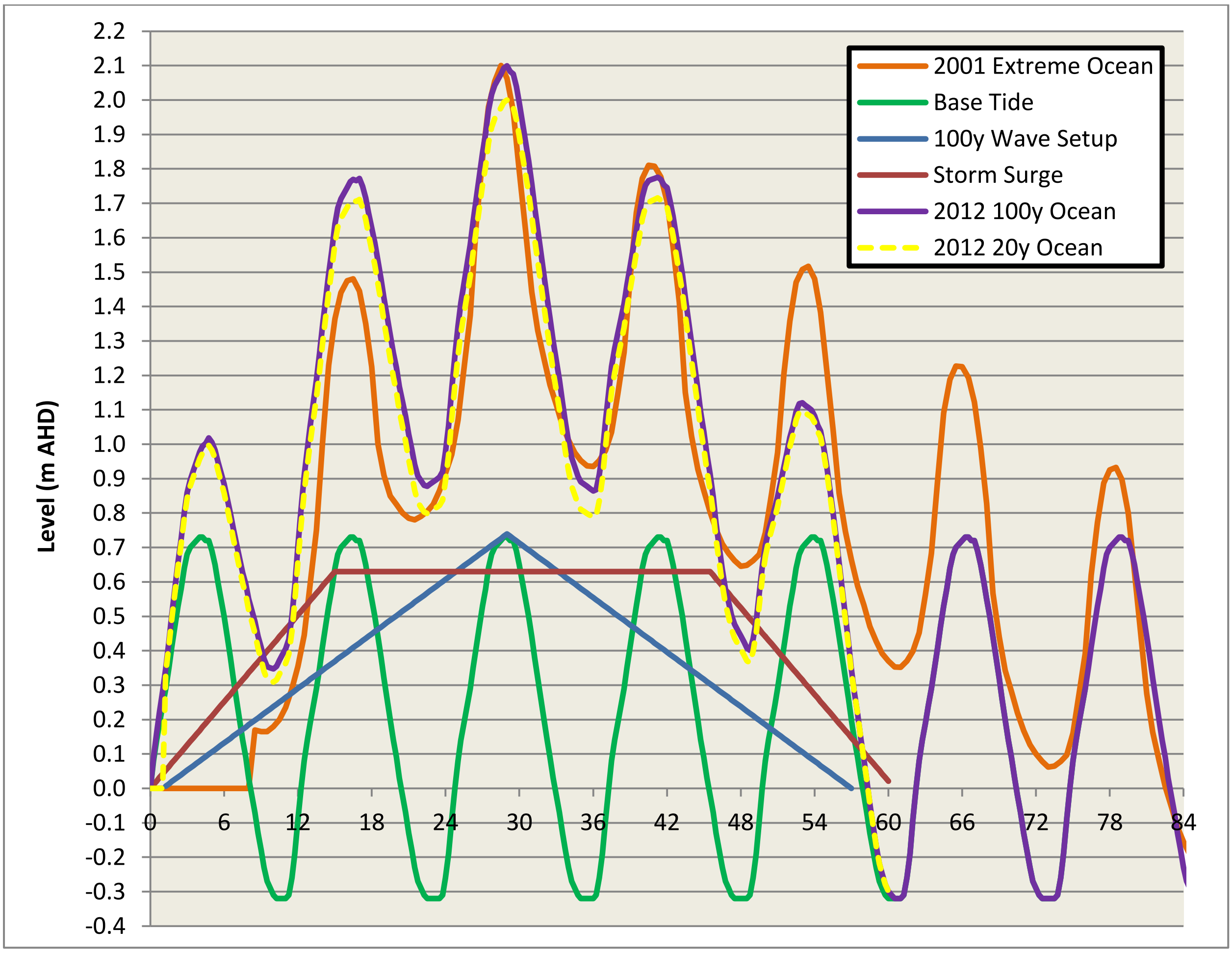
Event	Ocean Water Level (mAHD)	Wave Setup(m)	Total [(1)] (mAHD)
Extreme	1.40	0.93	2.30
100 year ARI	1.37	0.74	2.10
50 year ARI	1.36	0.70	2.05
20 year ARI	1.35	0.65	2.00

[(1)] rounded

The “shape” of the ocean hydrograph is also important, particularly for a coastal lake where the volume of runoff is important and not just the peak flow from the various tributaries. There is no definitive advice available regarding the shape of ocean hydrographs. For this study it was assumed that the ocean water level (Table 1 – 100 year ARI) is based on a 0.73m AHD peak tide with a low at approximately -0.3m AHD and a 0.63m storm surge component, plus the 0.74m wave setup component.

The storm surge component was assumed to increase from nil to its peak in 15 hours, be at its peak for 30 hours and then decrease to nil in the following 15 hours. The wave setup component was assumed to increase from nil at the start of the event to its peak at the mid point of the storm surge component (approximately 30 hours) and then decrease back to nil. This is shown in graphical form on Graph 2 together with the Extreme ocean hydrograph from the 2001 St Georges Basin Flood Study (for comparison as it assumed a similar peak of 2.1 mAHD).

Graph 2: Adopted Ocean Hydrographs



Reference 12 advised that a 100 year ARI ocean event in conjunction with a 100 year rainfall event would likely produce flood levels greater than the 100 year ARI. Table 2 sets out the agreed joint probabilities of the ocean and rainfall design events. Thus a 100 year ARI event (shown as blue row in Table 2) is an envelope of the 100 year ARI ocean event (2.1m AHD peak ocean level combined with a 20 year ARI rainfall event) and a 100 year ARI rainfall event (20 year ARI 2.0m AHD peak ocean level combined with a 100 year ARI rainfall event). For the 20 year ARI and smaller events the same ocean and rainfall conditions are used for the ocean and rainfall event scenarios.

Table 2: Adopted Co-incidence of Ocean and Rainfall Events

OCEAN Envelope		DESIGN FLOOD EVENT (ARI)	RAINFALL Envelope	
Peak Design Ocean Event (ARI) and level (m AHD)	Co incident Design Rainfall Event (ARI)		Design Rainfall Event (ARI)	Co incident Design Ocean Event (ARI) and level (m AHD)
Extreme (2.30)	100 year	**Extreme**	Extreme	100 year (2.10)
100 year (2.10)	20 year	**100 year**	100 year	20 year (2.00)
50 year (2.05)	20 year	**50 year**	50 year	20 year (2.00)
20 year (2.00)	20 year	**20 year**	20 year	20 year (2.00)
10 year (1.80)*	10 year	**10 year**	10 year	10 year (1.80)*
5 year (1.60)*	5 year	**5 year**	5 year	5 year (1.60)*
2 year (1.40)*	2 year	**2 year**	2 year	2 year (1.40)*

* estimated as part of this study

The relative timing of the peak ocean and rainfall event is also of importance. Initially sensitivity analysis was undertaken for the 100 year ARI event to assess the peak levels in the basin from different coincidences of the ocean and rainfall peaks. The resulting peak level in the basin was found to be largely independent of the peak level in the ocean (an increase of 0.14m if the "worst" case scenario adopted). This conclusion is the same as found in the 2001 St Georges Basin Flood Study (a 0.2m change reported). In the absence of any definitive advice, other than the peak flow occurs after the peak ocean level, it was assumed that the peak rainfall occurred at approximately the same time as the peak ocean level (i.e the most intense rainfall and ocean effects occur at the same time).

In conclusion the above approach was adopted for this study but it is acknowledged that a multitude of combinations of conditions can be used to create a given design flood event and there is no technical basis for stating that one scenario is necessarily more correct than any other. As more information becomes available in this regard the approach should be modified.

3. RESULTS

3.1. Overview of Baseline Results

Flood levels are calculated in the one dimensional RUBICON model at cross-sections as shown on Figure 3. These levels were updated in the subsequent 2006 St Georges Basin Floodplain Risk Management Study (minor modifications to some sections and inclusion of additional design events). As part of this study these design flood levels have been further changed as a result of the revised approach for modelling the ocean/runoff interface described in the previous section.

In the 2001 St Georges Basin Flood Study for clarity locations where design flood levels were provided were reduced to those shown on Figure 1. The same locations have been adopted in this study for the provision of design flood levels, although results at every cross-section are still available.

For this study the 2 hour, 9 hour and 48 hour design events have been adopted as the critical storm durations and the peak level results are an "envelope" of these events. For the 2 hour and the 9 hour events the downstream water level in the basin was taken as an arbitrary constant level of 0.9 mAHD. This level is of little significance as the peak level in the basin is produced from the 48 hour duration event.

A comparison between the previous design flood levels (Table 5 from the 2001 St Georges Basin Flood Study) and those derived as part of the present study are provided in Table 3 and indicate a maximum increase in flood level of up to 0.2m (there are no reductions in peak level). It should be noted that for the events smaller than the 20 year ARI the peak levels were not provided in the previous reports.

Table 3: Increase in Peak Flood Levels from 2001 Flood Study

No.	Location	Creek	Extreme	100y	50y	20y
1	Basin	Inlet	0.1	0.1	0.2	0.2
2	Badgee Lagoon Jtn	Inlet	0.1	0.1	0.1	0.2
3	Jacobs Drive	Inlet	0.1	0.1	0.2	0.2
4	Cater Canal	Inlet	0.1	0.1	0.1	0.2
5	Coastal Patrol	Inlet	0.1	0.1	0.1	0.2
6	The Haven	Inlet	0.1	0.1	0.1	0.2
7	D/s Sussex Inlet Rd Bridge	Badgee	0.1	0.1	0.1	0.2
8	U/s Badgee Bridge	Badgee	0.1	0.1	0.1	0.2
9	Jacobs Dr Bridge	Cater	0.1	0.1	0.1	0.2
10	U/s Cater Bridge	Cater	0.1	0.1	0.1	0.2
11	1 km D/s Sussex Inlet Rd	Cow	0.1	0.0	0.0	0.0
12	200 m D/s Princes Highway	Wandandian	0.0	0.0	0.0	0.0
13	Sawmill U/s	Wandandian	0.0	0.1	0.1	0.1
14	Sawmill D/s	Wandandian	0.1	0.1	0.1	0.1
15	Bewong	Wandandian	0.1	0.1	0.1	0.1
16	Wool Rd	Pats	0.1	0.0	0.0	0.0

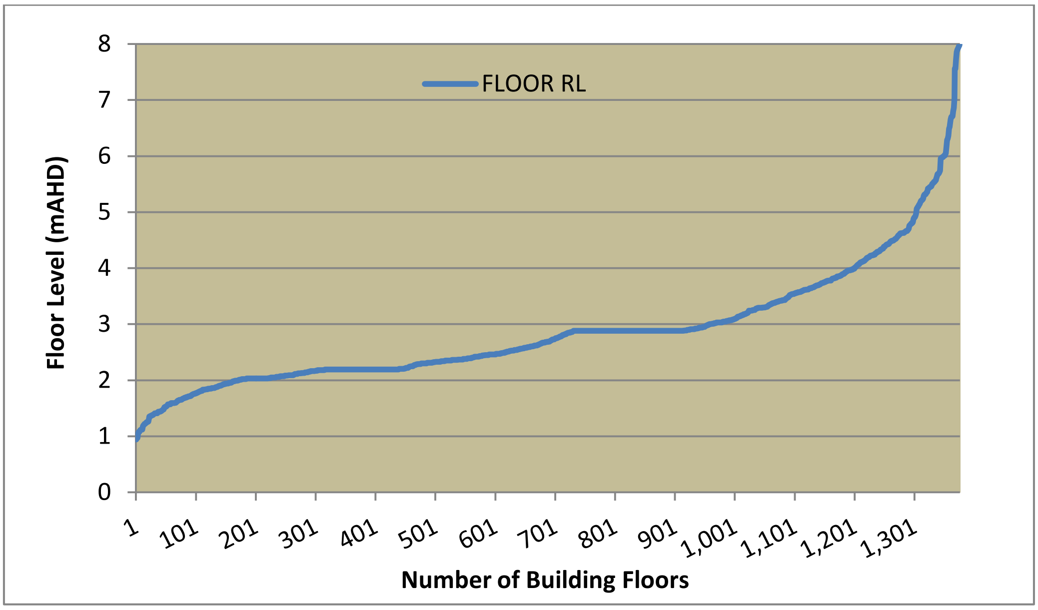
17	U/s Wool Rd	Home	0.1	0.0	0.0	0.0
18	Wool Rd	Tomerong	0.1	0.0	0.0	0.0
19	Boronia Ave	Tomerong	0.1	0.0	0.0	0.0
20a	U/s Larmer Ave	Tomerong	0.1	0.1	0.2	0.1
20b	D/s Larmer Ave	Tomerong	0.1	0.1	0.2	0.2
21a	U/s Wool Rd	Worrowing	0.0	0.0	0.0	0.0
21b	D/s Wool Rd	Worrowing	0.0	0.0	0.1	0.2
22	Fitzpatrick St	Worrowing	0.1	0.0	0.0	0.0
23	Kallaroo Rd	Erowal	0.0	0.0	0.0	0.0
24	Killarney Rd	Erowal	0.1	0.0	0.0	0.0

Note: Refer Figure 1 for locations.

The main reason for the differences shown in Table 3 is the different assumptions regarding the co-incidence of ocean and runoff events for the design scenarios (refer Section 2.4.3), thus slightly modified peak ocean levels, tidal hydrograph shape and timing of the relative peaks have been adopted. The other minor reason is the use of different computers (this generally only accounts for <0.05m difference in level and can be rather random).

Whilst the changes in flood levels between the 2001 St Georges Basin Flood Study and the present study are relatively small (only 0.2m) this does make a significant change to the number of floors inundated and consequent flood damages. This is because there are many building floors surrounding the foreshore that are at similar levels. Thus a small increase in level results in a significant increase in the number of floors inundated (refer Graph 3).

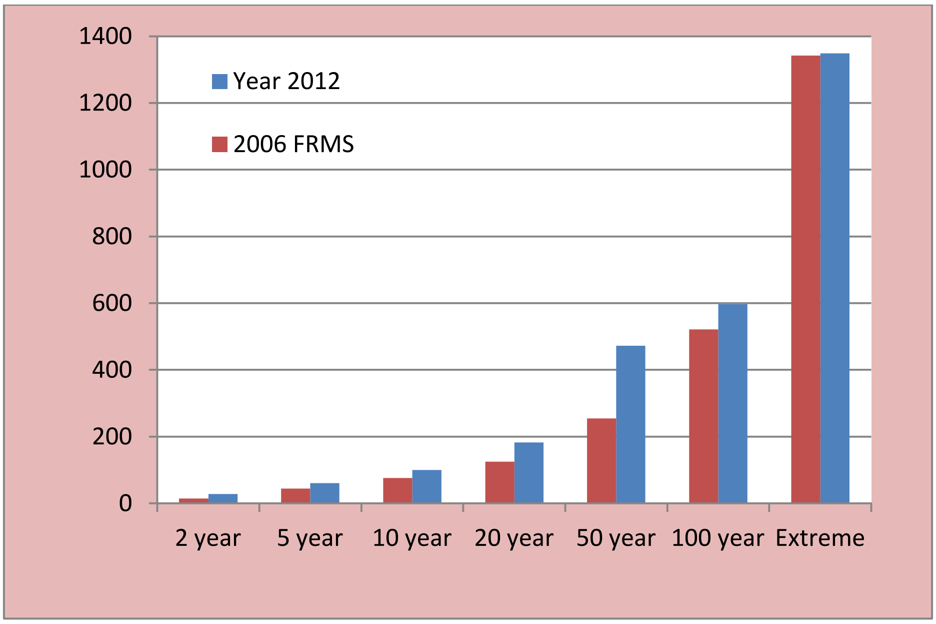
Graph 3: Residential Floor Levels Surrounding St Georges Basin



Note: Some floor levels have been interpolated

The increase in number of building floors inundated is provided in Graph 4. It should be noted that above the 100 year ARI event the floor level survey is probably missing building floors and for this reason in the Extreme Flood there is little change in the number of floors inundated.

Graph 4: Increase in Number of Building Floors Inundated from 2006 Floodplain Risk Management Study (FRMS)



The year 2012 design peak height profiles for the various branches (refer Figure 1) are shown on Figures 4 to 11.

3.2. Climate Change Assumptions

3.2.1. Sea Level Rise

To assess the effects of sea level rise each ordinate of the ocean level hydrograph at the mouth of the St Georges Basin entrance was increased by the assumed ocean/sea level rise (0.4m by the year 2050 or 0.9m by the year 2100).

A sea level rise of 0.4m equates to four times the difference between the 20y and the 100y ARI design flood levels at the entrance to St Georges Basin. Thus approximately the year 2012 7 year ocean event (peak ocean level of 1.7 mAHD) will reach the current 100 year ARI ocean level (2.1 m AHD) in the year 2050. A sea level rise of 0.9 m represents a significant increase in the design ocean levels (the 2012 say 1 year ARI ocean event will reach the current 100 year ARI ocean level in the year 2100).

By comparison, at Fort Denison in Sydney Harbour the 100y ARI ocean level is only 1.5 mAHD and the 20 year ARI approximately 1.4 mAHD and a 0.4m rise equates to the difference between the highest annual astronomic tide (1.1 mAHD) and the 100y ARI level (1.5 mAHD).

3.2.2. Rainfall Increase

To assess the effects of an increase in peak rainfall and storm volume each ordinate of all the inflow hydrographs was increased by the nominated DECC 2007 value.

It should be noted that due to the non-linearity of the catchment a 10% increase in rainfall does not equate to exactly a 10% increase in peak flow. However, for this assessment this assumption was considered a reasonable approximation, particularly as the 10%, 20% and 30% increases in rainfall are nominal values and are not based on a rigorous hydrologic procedure.

Whilst it is generally regarded that sea levels will rise by the year 2100 (the amount of the rise is as yet not definitive), the effect of climate change on design rainfalls is less well understood. For example, it is possible that design rainfall intensities may decrease in some parts of NSW and for many parts there will only be less than 10% increase. There is no definitive data on possible changes in design rainfall intensities across NSW. This issue is being addressed in the current review of the 1987 edition of Australian Rainfall and Runoff and by the BOM.

It should be noted that the increase in the existing peak flow (at the entrance) from a 20y to a 50y ARI event is approximately 25% and from a 20y to the 100y ARI event is approximately 50%. On Tomerong Creek the increase in the existing peak flow from a 20y to a 50y ARI event is approximately 22% and from a 20y to the 100y ARI event is approximately 42%.

4. IMPACT OF CLIMATE CHANGE ON FLOOD LEVELS

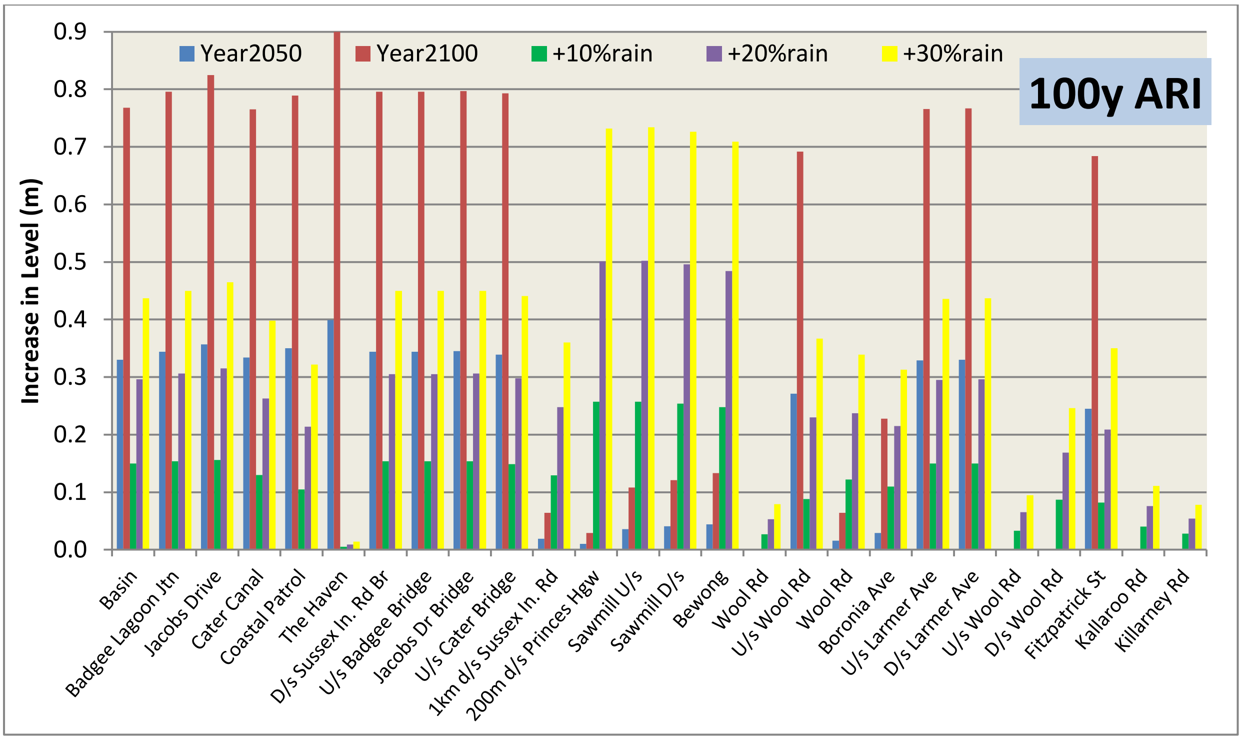
4.1. Overview

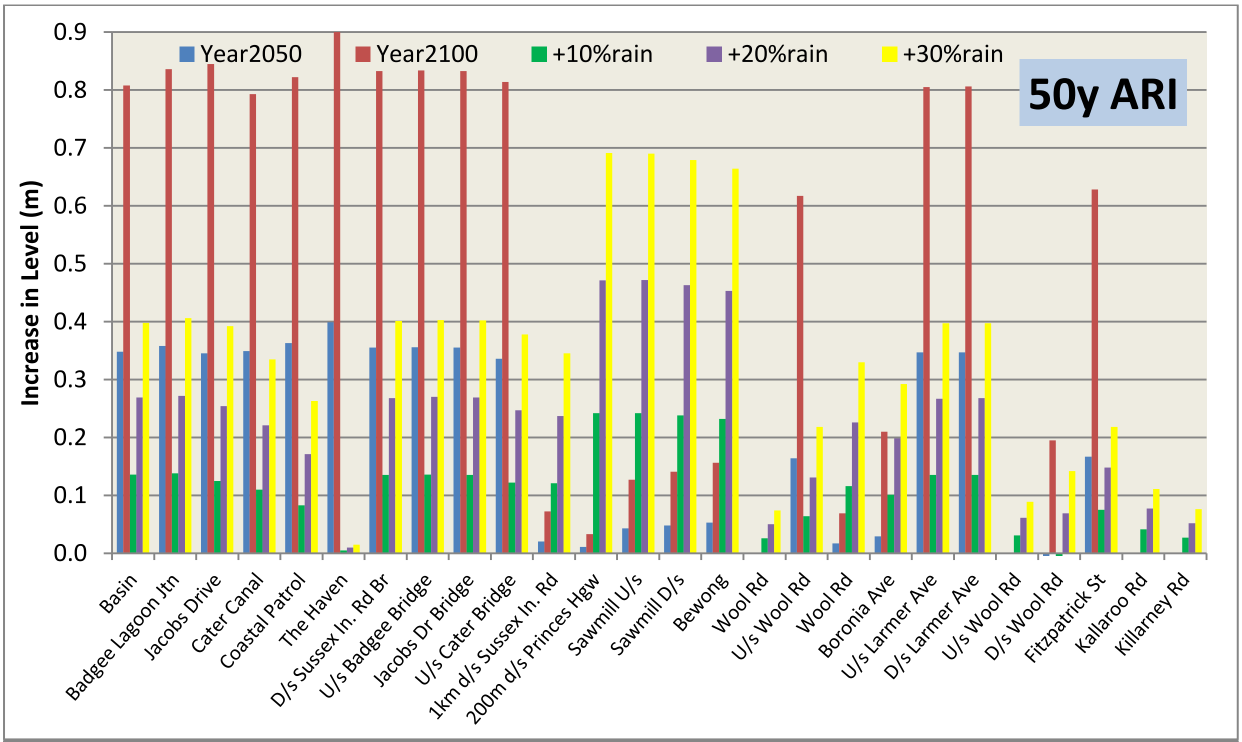
The boundary conditions of the hydraulic model used in the 2001 St Georges Basin Flood Study to determine design flood levels were adjusted to reflect the adopted sea level rise and increase in rainfall climate change scenarios as discussed in the previous section.

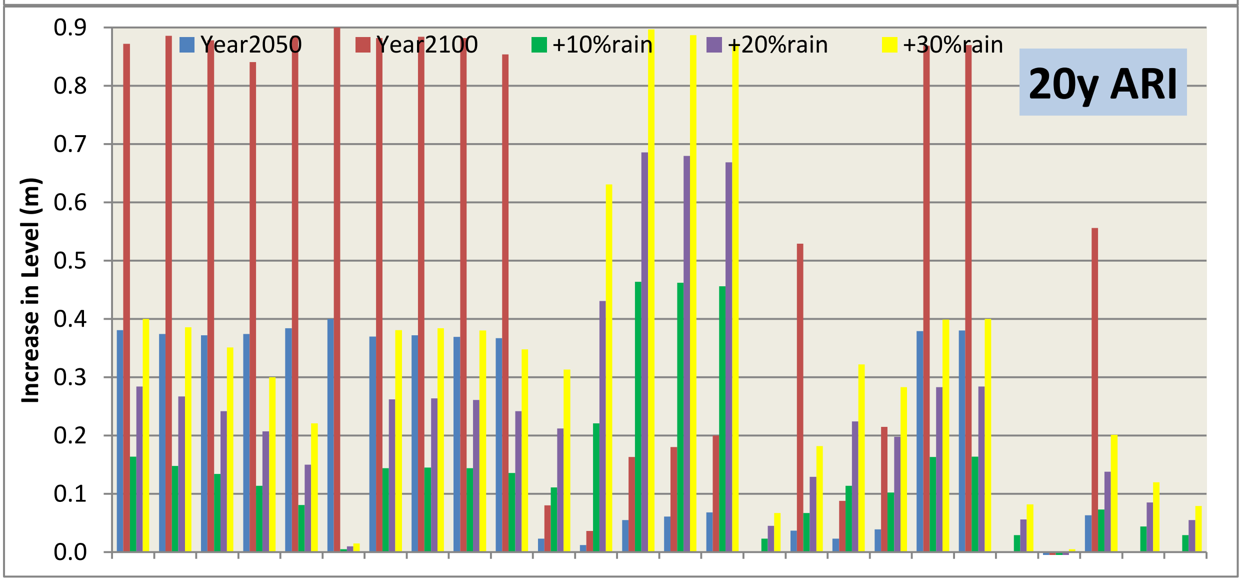
The results are provided in the following formats.

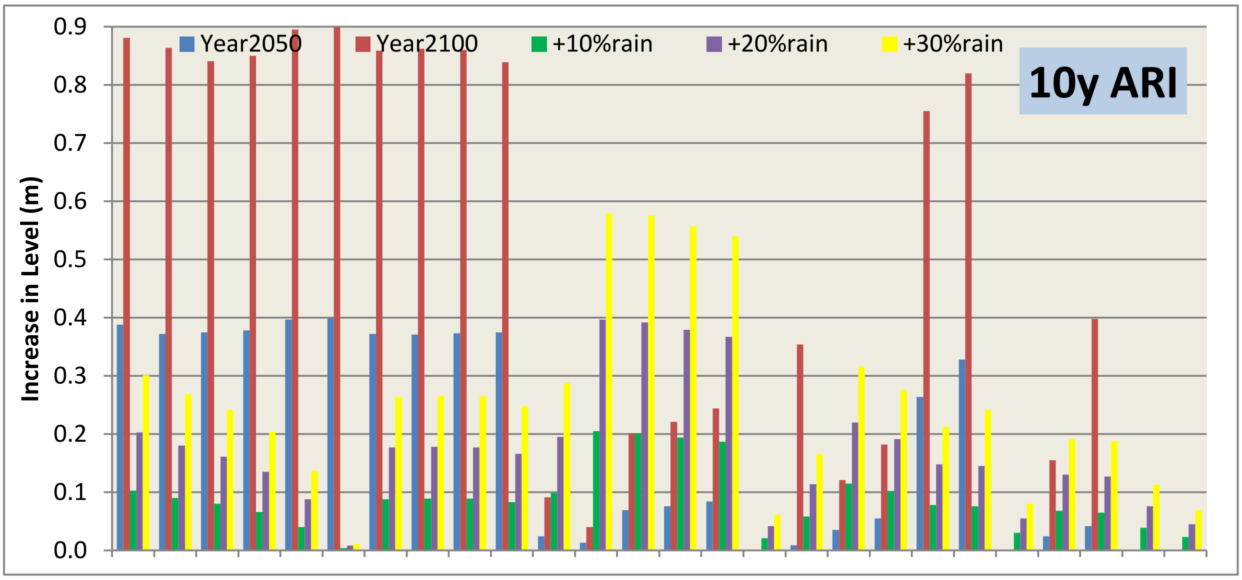
- peak height profiles along the branches (refer Figure 1) show the relative changes in flood level for the various climate change scenarios (Figures 4 to 11). *The results have been provided along the rivers based on the modelled river level at each cross section. It should be noted that this hydraulic model (RUBICON) was established prior to geo-referencing of cross section locations and the use of GIS etc. Thus the cross section locations and the river chainages are approximate and this data should not be used for any purpose where a precise location of the cross section is required. This information is suitable for flood related development control purposes,*
- histograms of changes in flood level (Graph 5) for the various climate change scenarios and flood events at the key locations shown on Figure 1,
- histogram of changes in flood level (Graph 6) for the various climate change scenarios and flood events within the Basin,
- peak flood extents (Appendix B), velocities (Appendix C) and contours (Appendix D).

Graph 5: Change in Flood Levels for Climate Change Scenarios




50y ARI
Increase in Level (m)
Year2050
Year2100
+10%rain
+20%rain
+30%rain
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Basin
Badgee Lagoon Jtn
Jacobs Drive
Cater Canal
Coastal Patrol
The Haven
D/s Sussex In. Rd Br
U/s Badgee Bridge
Jacobs Dr Bridge
U/s Cater Bridge
1km d/s Sussex In. Rd
200m d/s Princes Hgw
Sawmill U/s
Sawmill D/s
Bewong
Wool Rd
U/s Wool Rd
Wool Rd
Boronia Ave
U/s Larmer Ave
D/s Larmer Ave
U/s Wool Rd
D/s Wool Rd
Fitzpatrick St
Kallaroo Rd
Killarney Rd


20y ARI
Increase in Level (m)
Year2050
Year2100
+10%rain
+20%rain
+30%rain
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


10y ARI
Increase in Level (m)
Year2050
Year2100
+10%rain
+20%rain
+30%rain
0.0
0.1
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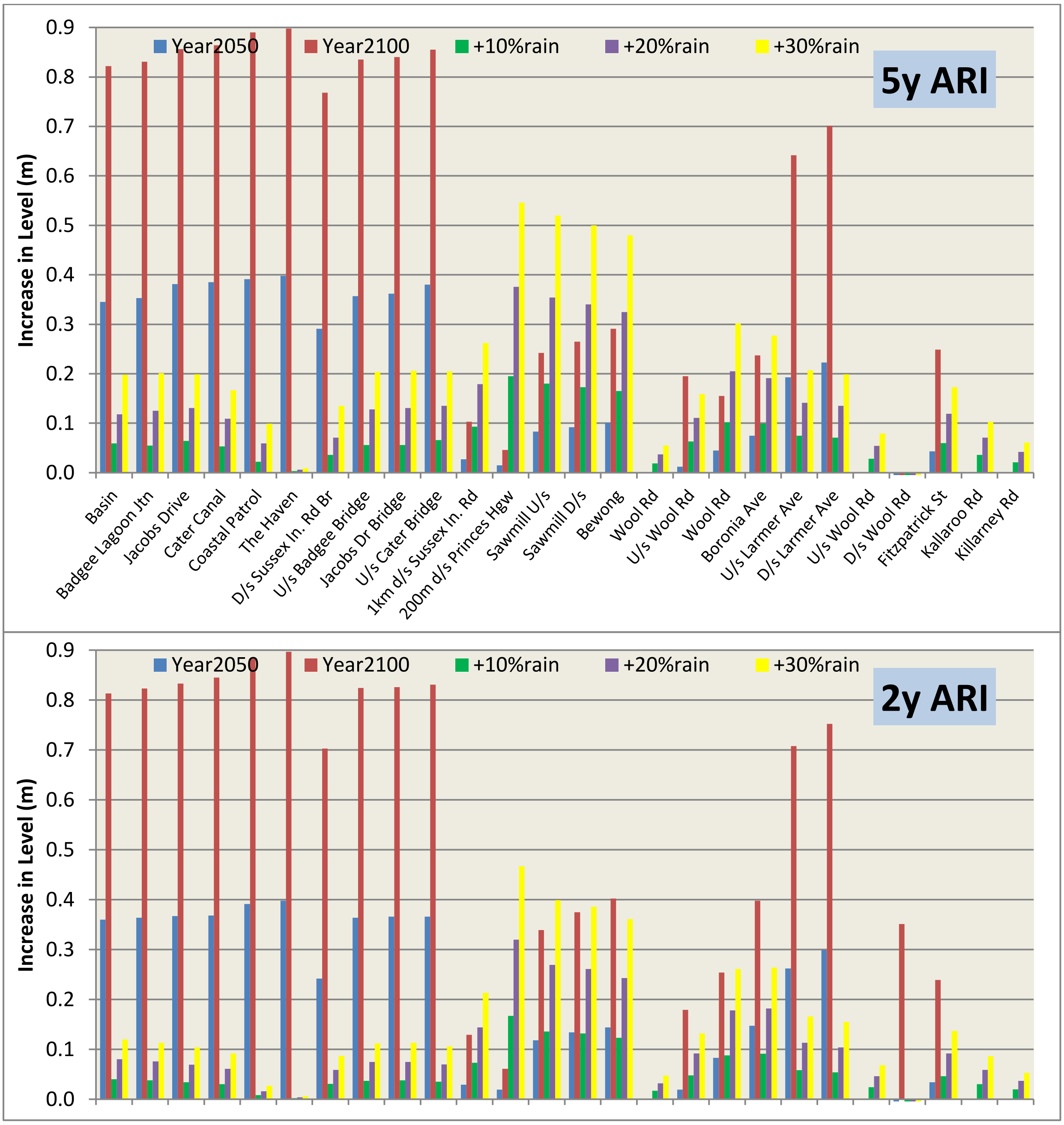
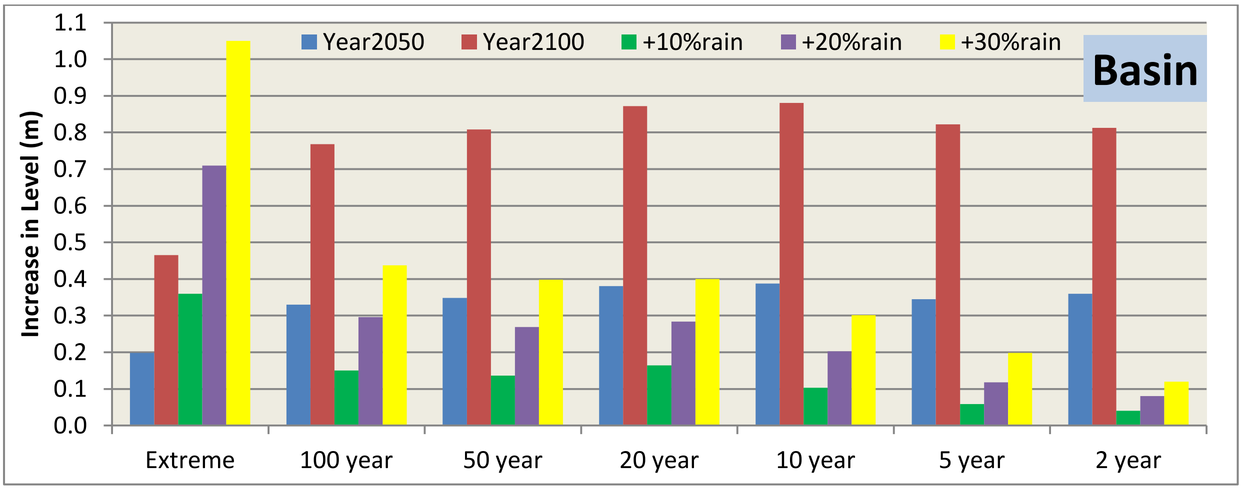
0.9



Graph 6: Change in Flood Levels for Climate Change Scenarios within the Basin



4.2. Discussion of Results

Some key points regarding the above results are:

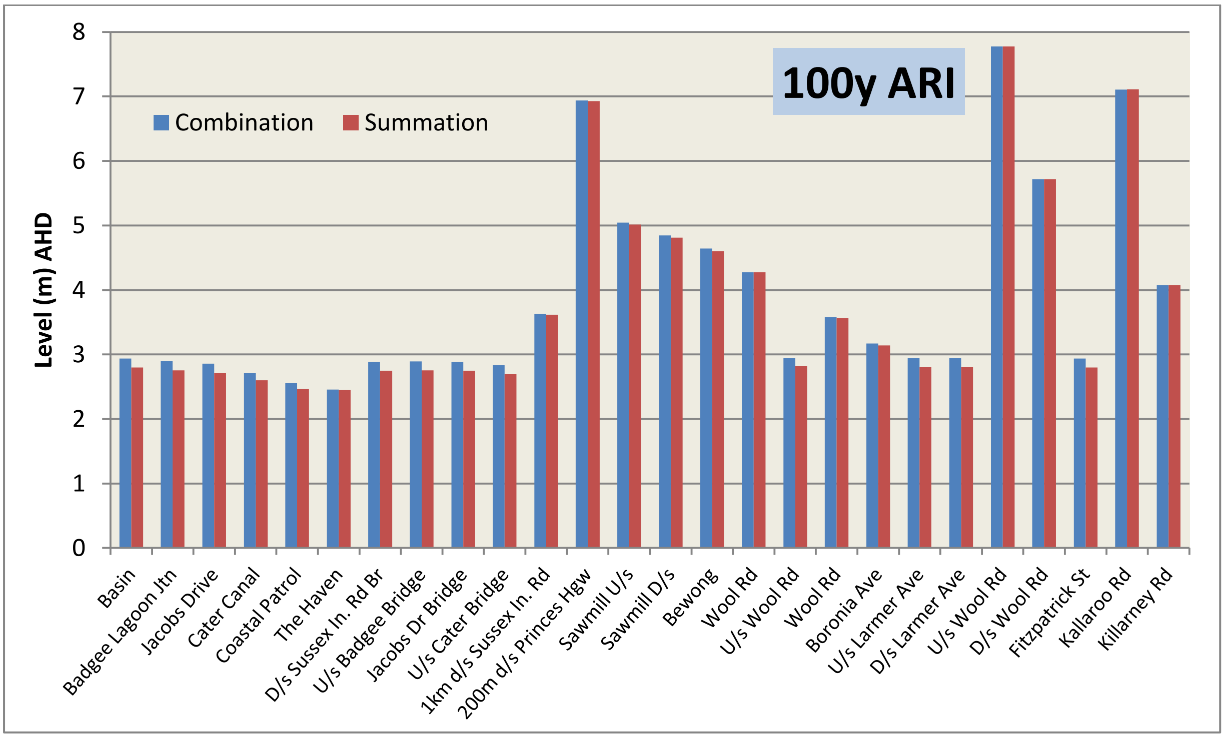
- the effect of increased rainfall in the Basin has a greater impact in the larger events than the smaller events,
- the effect of sea level rise in the Basin is generally greater in the smaller events than the larger events,
- the increase in level in the Basin due to rainfall increase is in proportion to the percentage increase in rainfall,
- the peak level rise in the Basin due to sea level rise is of the order of 90% of the sea level rise,
- the effect of sea level rise diminishes the further upstream along a creek (Wandandian Creek - U/s Sawmill to Bewong),
- the effect of rainfall increase does vary across different locations and with different ARIs.

The effect of combining the sea level rise and rainfall increase was also undertaken and a comparison between:

- a summation of the individual increases in flood level for the following two scenarios: a 0.4m sea level rise and the 10% rainfall increase scenario, and
- a scenario that assumes the 0.4m sea level rise and 10% rainfall increase in combination,

is provided for the 100 year ARI event at all locations shown on Figure 1 on Graph 7.

Graph 7: Change in Flood Levels for Climate Change Scenarios within the Basin – 100 year ARI

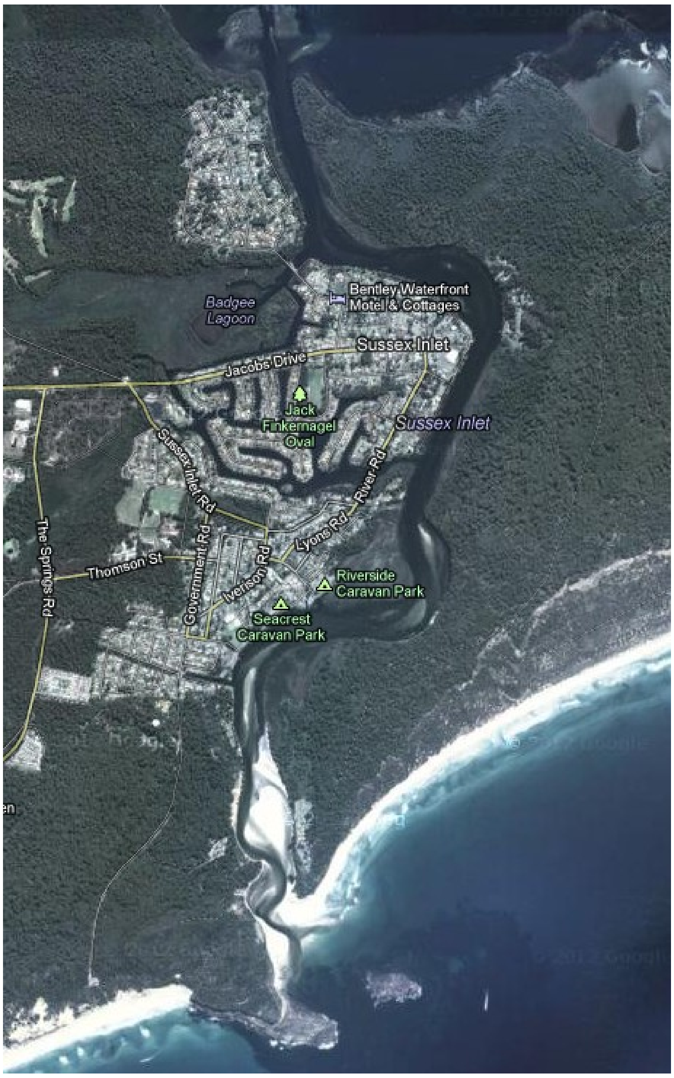


In general Graph 7 indicates that the "combination" scenario produced slightly greater levels than the "summation" for the 100 year ARI event within the Basin and downstream. This result indicates that it is not correct to "sum" the individual increases of any rainfall or sea level rise scenario as together the individual scenarios combine to produce a slightly greater increase.

5. IMPACT OF CLIMATE CHANGE ON FLOOD RISK AND MANAGEMENT MEASURES

5.1. Overall

A climate change sea level rise and a rainfall increase will affect flood levels in the St Georges Basin waterway and along the tributary creeks. Current (September 2010 – Reference 12) NSW guidelines indicate that a 0.4m and a 0.9m sea level rise should be adopted for the 2050 and 2100 planning horizons respectively. No guideline has been provided for the impacts of a rainfall increase.



Apart from increasing flood levels, one of the other potential effects of climate change (predominantly sea level rise) on flooding is the impact on the sedimentation/erosion regime along the entrance channel (refer aerial photograph on left – courtesy Google Maps).

Undoubtedly climate change will impact on this regime, though as yet the mechanisms and resulting impacts cannot be clearly determined.

This study has not investigated these potential impacts.

The following sections describe the potential impacts of climate change on flood risk and floodplain management measures, namely:

- **Section 5.2** provides a general discussion of the impacts on water levels,
- **Section 5.3** provides a general discussion of mitigation/adaptation measures to protect existing development,
- **Section 5.4** provides a general discussion of mitigation/adaptation measures to protect future development,

- **Section 5.5** provides a general discussion of the issues that may threaten the long term viability of areas,
- **Section 5.6** provides comments on the implications of climate change for all floodplain management measures outlined in the St Georges Basin Floodplain Risk Management Plan (Reference 3),
- **Section 5.7** provides a summary and recommendations regarding inclusion of climate change impacts in flood related development controls.

5.2. How will Climate Change Affect Water Levels?

Climate change has the potential to alter the water level in both non flood and flood times.

5.2.1. During Non Flood Times

The main impacts in non flood times will be:

- The range of “normal” water levels in the basin will rise. An indicative increase is the same as the expected sea level rise (0.4m by the year 2050 and 0.9m by the year 2100),
- It is possible that the tidal range and seasonal variation in water level may also change in response to rainfall or temperature changes but the extent is unknown at this time.

The increase in the range of “normal” water levels on low lying land surrounding the basin in “non flood” times may result in increased maintenance costs and/or modifications costs for existing developments and infrastructure due to more frequent inundation. For example, low lying roads will be more frequently inundated during elevated water levels in the basin or inflows of floodwaters to sewer surcharge vents in backyards may occur more frequently. The increased cost for residents and Shoalhaven City Council to maintain the existing developments and infrastructure is unknown. A separate study is required to quantify the effect in non flood times but it is likely that at some time in the future the existing services will (say a road) become unable to be maintained and it will have to be relocated or re-built. This may mean that the existing developments will need to be relocated or exist without the current standard of services.

Possibly it may mean that some of the existing developments on the floodplain cannot continue due to semi-permanent inundation.

A general raising of the river levels through a sea level rise will also potentially impact on the erosional/sedimentation regime along the river banks. It should be noted that the floodplain of all rivers and waterways such as St Georges Basin is dynamic and is continually adapting to changing conditions (drought and flood).

Any change in the range of “normal” water levels may also impact on the ecology of the estuary and riverine systems. The implications of this are outside the scope of this study.

5.2.2. During Flood Times

There are several broad ways in which climate change will affect water levels in the St Georges Basin during floods, namely:

1. *The increase in sea level* will raise the "normal" water level in the St Georges Basin waterway as well as the assumed ocean level adopted for design flood analysis as indicated in Section 2.4.3. The impacts of sea level have been quantified for various design scenarios with the results shown on Figures 4 to 11.
2. *The increase in peak rainfall intensity and storm volume* will increase design flood levels along the tributary creeks and within the St Georges Basin waterway itself. The impacts of increases in rainfall intensity have been quantified for various design scenarios with the results shown on Figures 4 to 11.
3. *The extent of erosion and sedimentation within the entrance channel* may be affected by an increase in sea level, this in turn will affect the outflow characteristics of the entrance during a flood and the resulting design flood levels. It is also possible that increased rainfall intensities may cause the entrance to become wider and deeper. At this time the impact on the entrance channel cannot be reliably estimated.
4. *A change in wind activity* may affect wind wave activity along the ocean foreshore and along the foreshore of the St Georges Basin waterway. At this time the impact of this effect is unknown.

According to the best available advice from the Inter-governmental Panel on Climate Change (IPCC) and NSW Government experts (summarised in Reference 12) it is likely that design flood levels will increase due to a climate induced sea level rise. Any sea level rise increase may be exacerbated by a further say 0.1m+ if the increase in rainfall intensity and volume occurs concurrently.

5.2.3. Flood Damages

Flood damages assessments have been undertaken as part of the St Georges Basin Floodplain Risk Management Study and Plan (References 2 and 3). This flood damages database has been used in this present study to assess the effects of climate change on the number of building floors inundated and flood damages. The same approach to flood damages assessment has been undertaken in the present study except with the damages updated to the year 2012. Details of the damages assessment approach can be found in the above references (in Reference 2 and 3 Table 8 has reversed the labels for Sussex Inlet and Basin Foreshore).

The following points are made regarding the approach:

- Buildings are separated into 3 geographic regions (Sussex Inlet, Basin Foreshore and Sanctuary Point) with sewage pumping stations and caravan parks from each of these areas amalgamated together,
- The floor level database was accurate as at the year 2001 and it is likely that some developments may have changed since then. Some interpolation of building floors has been undertaken,

- The damages to caravan parks and sewage pumping stations are very difficult to quantify and the values should be used as a guide only,
- Intangible damages have not been quantified and it is likely that in some floods buildings and caravans may be completely destroyed. Thus the true damages may be higher than indicated.

The number of flood liable buildings and flood damages assessment for existing conditions (2012), year 2050 (0.4m sea level rise), year 2100 (0.9m sea level rise) are provided in Table 4. The Average Annual Damages (AAD) for existing conditions is estimated as $2.58 million (year $2012). The AAD increases to $6.17 million for a 0.4m sea level rise and to $17.18 million (year $2012) for a 0.9m rise.

Table 4: Increase in Number of Building Floors Inundated and Damages for Year 2050 and Year 2100 Scenarios

Year 2012	Basin Foreshore	Sussex Inlet	Sanctuary Point	Total	Damages
Extreme	188	894	267	1349	$137,970,000
100 year	27	485	85	597	$31,360,000
50 year	17	387	68	472	$17,040,000
20 year	8	117	58	183	$9,110,000
10 year	8	50	42	100	$3,970,000
5 year	5	28	28	61	$1,740,000
2 year	2	12	14	28	$560,000
				AAD	$2,580,000
Year 2050	**Basin Foreshore**	**Sussex Inlet**	**Sanctuary Point**	**Total**	**Damages**
Extreme	191	900	272	1363	$139,810,000
100 year	50	579	120	749	$54,900,000
50 year	34	541	101	676	$40,660,000
20 year	22	430	68	520	$24,730,000
10 year	9	147	57	213	$11,100,000
5 year	8	77	41	126	$5,690,000
2 year	8	45	31	84	$2,870,000
				AAD	$6,170,000
Year 2100	**Basin Foreshore**	**Sussex Inlet**	**Sanctuary Point**	**Total**	**Damages**
Extreme	197	906	274	1377	$142,170,000
100 year	85	807	173	1065	$85,940,000
50 year	73	795	156	1024	$73,130,000
20 year	52	594	117	763	$59,650,000
10 year	31	550	83	664	$39,190,000
5 year	17	418	57	492	$20,290,000
2 year	9	195	54	258	$11,920,000
				AAD	$17,180,000

Table 5 shows the number of flood liable buildings and flood damages assessment for the rainfall increase scenarios. The AAD increases to $3.31 million for a 10% rainfall increase, to

$4.41 million for a 20% increase and to $5.16 million for a 30% increase. Comparison with Table 4 indicates that sea level rise will have a much greater impact on damages than rainfall increase.

Table 5: Increase in Number of Building Floors Inundated and Damages for 10%, 20% and 30% Rainfall Increase Scenarios

Year 2012	Basin Foreshore	Sussex Inlet	Sanctuary Point	Total	Damages
Extreme	188	894	267	1349	$137,970,000
100 year	27	485	85	597	$31,360,000
50 year	17	387	68	472	$17,040,000
20 year	8	117	58	183	$9,110,000
10 year	8	50	42	100	$3,970,000
5 year	5	28	28	61	$1,740,000
2 year	2	12	14	28	$560,000
				AAD	$2,580,000
+10% Rain	**Basin Foreshore**	**Sussex Inlet**	**Sanctuary Point**	**Total**	**Damages**
Extreme	195	905	276	1376	$141,420,000
100 year	34	541	110	685	$41,550,000
50 year	23	435	77	535	$25,940,000
20 year	10	203	65	278	$12,890,000
10 year	8	67	47	122	$5,290,000
5 year	5	34	29	68	$2,320,000
2 year	2	14	15	31	$720,000
				AAD	$3,310,000
+20% Rain	**Basin Foreshore**	**Sussex Inlet**	**Sanctuary Point**	**Total**	**Damages**
Extreme	200	909	277	1386	$144,230,000
100 year	49	565	121	735	$53,500,000
50 year	30	513	89	632	$34,470,000
20 year	17	390	68	475	$17,240,000
10 year	8	86	55	149	$6,990,000
5 year	8	40	38	86	$2,990,000
2 year	2	16	16	34	$920,000
				AAD	$4,130,000
+30% Rain	**Basin Foreshore**	**Sussex Inlet**	**Sanctuary Point**	**Total**	**Damages**
Extreme	206	909	279	1394	$145,930,000
100 year	55	587	136	778	$60,950,000
50 year	40	548	111	699	$45,500,000
20 year	23	430	76	529	$25,050,000
10 year	8	114	61	183	$8,940,000
5 year	8	47	44	99	$3,920,000
2 year	2	19	21	42	$1,130,000
				AAD	$5,160,000

Table 6 shows the percentage increase in flood damages for the various scenarios. Care should be taken in interpreting the results for the following reasons:

- Flood damages do not necessarily increase linearly with flood level increase. This depends on the stage/damage functions and the floor levels of inundated buildings,
- An increase in damages from say $5,000 to $10,000 represents a 100% increase but in terms of an overall flood damages viewpoint the magnitude of the increase is insignificant,
- Overall the sea level rise results shown on Table 6 indicate a greater % increase in damages for the smaller events than the larger events. For the rainfall increase scenarios the greater % increase in damages occurs in the 50 year and 20 year ARI events.

Table 6: Flood Damages for Various Scenarios compared to Year 2012

	Year 2050	Year 2100	+10% Rain	+20% Rain	+30% Rain
Extreme	101%	103%	103%	105%	106%
100 year	175%	274%	132%	171%	194%
50 year	239%	429%	152%	202%	267%
20 year	271%	655%	141%	189%	275%
10 year	280%	987%	133%	176%	225%
5 year	327%	1166%	133%	172%	225%
2 year	513%	2129%	129%	164%	202%
AAD	239%	666%	128%	160%	200%

5.2.4. Flood Extent and Hazard Mapping

A digital terrain model (DTM) of the floodplain around the St Georges Basin waterway and along the tributary creeks (as shown on Figure 1) has been created based on the airborne laser scanning (ALS) survey provided by Shoalhaven City Council.

The RUBICON model (Section 2.2) is a one dimensional model that represents the floodplain of the creeks and waterway as a series of cross sections with the flood level calculated at these cross sections. Flood extent and hazard mapping have been undertaken based on the results of the RUBICON model and with the use of the DTM. It should be noted that the accuracy of the mapping is limited by the nature of the output from the RUBICON model. As noted above the results are only available at each cross section and thus interpolation is required to extend the flood extent to the perimeter of the floodplain and between cross sections. Also the available velocity data is of limited use and generally only applicable in the river channel.

The flood extent and peak velocity maps have been provided in Appendix B and Appendix C.

5.2.5. Are the Implications of Climate Change Significant?

At some localities in NSW an increase in flood level (due to sea level rise or rainfall increase) or the "normal water level" will have little impact on the existing or development potential of the area. For the St Georges Basin waterway floodplain the impact on the "normal" water level will generally not have a significant impact except around the town of Sussex Inlet and other developments on ground below say 2m AHD. However climate change will have significant implications on design flood levels and flood damages for the area and needs to be addressed.

5.3. Mitigation/Adaptation Measures to Protect Existing Developments

5.3.1. Flood Warning and Awareness

Flood warning and flood awareness are measures that are currently employed within the Shoalhaven LGA to lessen the impacts of flooding. It is unlikely that significant advances can be made in these measures to negate the adverse impacts of climate change. However the present flood awareness program by the SES and Shoalhaven City Council should be updated to include potential climate change impacts.

5.3.2. Flood Modification Measures

Flood modification measures such as dredging the entrance channel or other channel works are likely to be cost prohibitive and would introduce many environmental issues that would need to be addressed. In other areas measures considered are a “Thames” style barrage to prevent elevated ocean levels from entering. Unfortunately such a barrier is unlikely to be successful for all events as the same meteorological event that produces elevated ocean levels (storm surge) also produces intense rainfall causing flooding. Thus a barrier would provide little benefit in such a scenario for the St Georges Basin waterway.

5.3.3. Levees

Levees are one such measure that could be used to protect existing development (as they do already at say Riverview Road, Nowra). Whilst at first glance levees may appear a viable means of protection there are a number of concerns with their application, including:

- High cost,
- Landtake cost and can the land be obtained?
- Flooding from rainfall within the leveed area can itself be a major problem. Pumps or gravity systems to remove this runoff are not always successful,
- Levees restrict access (boating, fishing etc) and views of the water – the main reason why residents live in such areas,
- To be 100% secure they need to be constructed to the PMF level. Construction costs of a levee to the PMF will be greater than for a lower levee crest and will have a greater impact on views, access and other social impacts. Additional land take may be required and possibly increased maintenance costs,
- Vehicle access to the leveed area and services relocation will generally require extensive additional works,
- Levees require on going maintenance and a failure in any part during a flood (bank collapse, flap gated culvert fails) renders the structure of little value.

There are no existing levees within the St Georges Basin waterway but one was suggested as part of the consultation process for the St Georges Basin Floodplain Risk Management Study

(Reference 2) at Fairview Crescent at Sussex Inlet. This levee would protect 16 existing buildings and was considered a viable measure subject to further more detailed investigation.

Levees at other localities could also be considered if there is sufficient justification and acceptance by the community.

5.3.4. House Raising

House raising has been used at many places in NSW (Maitland, Lismore, Kempsey, Fairfield) as a viable means of flood protection. It is likely that some of the existing flood liable buildings could be raised but not all buildings are viable for raising for the following reasons:

- it is more cost effective to construct a new house,
- generally only single storey houses can be raised,
- generally only timber, fibro and other non masonry construction can be raised,
- generally only pier and non slab on ground construction can be raised,
- there can be many additional construction difficulties (brick fire place, brick garage attached to house, awnings or similar attached to house).

In conclusion it will not be possible to raise all the flood liable buildings and other measures need to be employed. However for existing "suitable" houses raising is a viable solution if the area remains serviceable with climate change (adequate sewer and roads).

5.3.5. Areas that Cannot be Protected by Adaptation Measures

It may be that some areas protection by the above adaptation measures cannot be justified on economic, environmental or social considerations. For these areas Council will need to establish a retreat policy. A rigorous engineering investigation and public consultation program will be required before such a retreat policy could be adopted as it will likely involve significant social disruption. However it should be noted that such policies have been undertaken elsewhere (for a variety of natural hazard reasons) and this policy was implemented following the disastrous floods of 1860 and 1870 with the move from Terara to Nowra.

5.4. Mitigation/Adaptation Measures to Protect Future Developments

5.4.1. Flood Related Development Controls

Flood related development controls (largely stipulation of a minimum floor level at say the 100 year ARI plus a freeboard of 0.5m – termed the Flood Planning Level or FPL) is the most constructive measure for reducing flood damages to new residential developments. More vulnerable developments to flooding (hospitals, electricity sub stations, "seniors" housing) must consider rarer events greater than the 100 year ARI when determining their FPL. Flood warning and awareness measures are employed to provide damages minimisation in larger events (such as the June 2007 flood at Newcastle) than the design standard (generally the 100 year ARI). Thus the simplest and most effective measure to protect future development is to raise the FPL to account for climate change. However this measure does not address the associated range of issues when considering flood risk such as access and failure of essential services.

Whilst raising the floor levels will ensure that the floors are not inundated in the design event (with sea level rise) there is still the issue of whether adequate services (sewer, roads) can be provided and that private land will be suitable for habitation (i.e not regularly inundated so as to make the land unsuitable).

5.4.2. Review of Freeboard

The 0.5m freeboard should still be included in the FPL and it should not be assumed that the freeboard can take account of climate change. According to the 2005 Floodplain Development Manual (Reference 4) the *purpose of the freeboard is to provide reasonable certainty that the reduced flood risk exposure provided by selection of a particular flood as the basis of a FPL is actually provided given the following factors*:

- uncertainties in estimates of flood levels,
- differences in water level because of “local factors”,
- increases due to wave action,
- the cumulative effect of subsequent infill development on existing zoned land,
- climate change.

In a real flood some of these factors may reduce the flood level (local factors) or not apply at all (no wave action). Whilst climate change is included as one of the above factors there is no advice as to what the contribution for each factor should be. The Flood Risk Management Guide (Reference 12) states “*Freeboard should not be used to allow for sea level rise impacts, instead these should be quantified and applied separately*..”. The 0.5m freeboard allowance allows for uncertainties, thus if the best advice is that sea levels will rise by 0.9m by the year 2100 then the FPL should be raised by the increase in flood level occurring as a result of this 0.9m sea level rise. The climate change component in the 0.5m freeboard allowance accounts for any uncertainty regarding the 0.9m sea level rise (in reality the true rise may be less or more).

Whilst a freeboard of 0.5m is generally adopted in establishment of the FPL there is no definitive advice that states that a different freeboard cannot be adopted and this is documented in the Floodplain Development Manual (Reference 4). Some Councils have adopted a freeboard of 0.3m for residential developments (adjacent to major rivers) although the reasons for this are unknown (to the author of this report) and generally were implemented prior to introduction of the Floodplain Development Manual.

It is probably impossible to provide a sound argument for nil freeboard as there will always be uncertainty in selecting a particular flood level. However, it might be argued that a larger freeboard than 0.5m is necessary where wave action is severe (say adjacent to a large water body) or the PMF is much greater than the 100 year ARI level (say several metres) and a large change in flood level occurs in a slightly greater ARI event. The opposite argument would apply if there is say minimal wave action or (as in overland flow areas) the 100 year ARI level and the PMF may be less than 0.5m apart.

A 0.5m freeboard is also probably not justified with a shallow depth of inundation (across a large area and not just at the perimeter of the floodplain) and one approach is to adopt a freeboard the same as the "general" water depth for areas with water depths < 0.5m with a minimum of 0.3m. Typically this would only apply in overland flow areas (inundation as a result of runoff before entering a watercourse rather than escaping from a watercourse) and not with mainstream flooding.

River Road, Sussex Inlet - June 1991 Flood

One important feature that is often neglected is the wave action of vehicles (SES vehicles, residents or boats) moving through flood waters as this is known to produce a wave sometimes greater than 0.5m and would typically occur in an area such as Sussex Inlet (refer photograph). This type of wave action would occur in all existing developed areas.

Of issue with incorporating different freeboards is determining which areas they should be applied and what to have at the boundary of the different areas.

In conclusion a freeboard of 0.5m is recommended unless it can be demonstrated with robust reasoning that adequate safeguards are incorporated with a smaller freeboard.

The effect of having nil, 0.3m and 0.5m freeboard above the 100 year ARI flood level for a new house to be built at Sussex Inlet has been evaluated through a change in AAD. In order to undertake this analysis assumptions were made regarding the assessment of flood damages and derivation of the 200 year and 500 year ARI events. These are explained below.

Freeboard is provided above the design flood level (in this case the 100 year ARI) to provide certainty that no inundation will occur in that event. For a flood damages assessment the floor level used to compare against the flood level from the hydraulic model can be taken as either the actual floor level minus the freeboard (i.e 0.5m below the actual floor level) or just the actual floor level and the freeboard is ignored. The latter approach has been adopted in this study as this approach eliminates issues such as how to address "slab on ground" floors (the floors would assumed to be inundated if the nearby flood level was within 0.5m of the floor) and the estimation of external damages. The adopted approach might slightly underestimate the number of floors inundated as wave action and other factors included in the freeboard would mean that whilst the hydraulic model indicates the floor is not inundated in reality it is due to a slightly higher actual flood level.

The above approach means that for a new house built with the nil, 0.3m and 0.5m freeboard above the 100 year ARI flood level there will be no above floor damages in the 100 year ARI event. The effect of different freeboards in AAD calculations will be most acutely felt in events just greater than the 100 year ARI when the floor becomes just inundated (say the 200 year and 500 year ARI events).

As the St Georges Basin Flood Study (Reference 1) did not provide a 200 year or 500 year ARI event it was assumed that the 10% and 30% increase in rainfall intensities (as derived as part of this study) approximate these events respectively. This assumption is based on comparison of the design rainfall intensities as provided in the St Georges Basin Flood Study (refer Table 7).

Table 7: Design Rainfall Depths (mm) and % Increase from 100 year ARIs

	Rainfall depth (mm) for ARI			**% Increase**	
Duration (h)	100 year	200 year	500 year	to 200 year	to 500 year
2	145	162	184	12%	27%
9	261	293	336	12%	29%
48	501	561	641	12%	28%

For the 10% and 30% rainfall increase scenarios no change was made to the ocean level assumptions (i.e it was taken the same as for the 100 year ARI). This assumption is slightly incorrect as the 200 year and 500 year ARI events would be expected to coincide with a slightly higher ocean level than for the 100 year ARI event.

The percentage reduction in AAD for a new house constructed with a 0.3m and 0.5m freeboard above the 100 year ARI flood level in Sussex Inlet compared to nil freeboard with the above assumptions is provided below. The above floor damages (no external damages) for the design events above the 100 year ARI flood (RL 2.4 mAHD) is:

- 200 year ARI (RL 2.5 mAHD) $20,000,
- 500 year ARI (RL 2.8 mAHD) $64,000,
- Extreme (RL 5.1 mAHD) $100,000.

The AAD assuming nil freeboard is only $340 and the % reduction in AAD with a 0.3m freeboard is 55% and 70% for a 0.5m freeboard.

The calculation of AAD is very sensitive to the magnitude of the event that first inundates the building floor. Thus a significantly greater value for AAD would be obtained if it was assumed for the flood damages assessment that the floor level was the actual floor level minus the freeboard (i.e 0.5m below the actual floor level).

The effect of reducing the freeboard is also likely to affect SES or domestic decisions to evacuate buildings as the flood waters will reach a higher depth within a house. The cost and implications of this cannot be accurately assessed but will likely increase the risk to life and need for evacuation.

5.4.3. Is Safe Sustainable Redevelopment viable in High Hazard Areas?

A climate change induced sea level rise will mean that many localities in the St Georges Basin study area (and elsewhere along the NSW coastline) will move from being defined as provisional (based on depth and velocity) low hazard in the year 2012 to high hazard (due to an increase in depth). If the land has no existing development on it and a re-zoning is required then residential development would likely not be permitted due to the high hazard categorisation. However in many of these localities there is existing development such as at Sussex Inlet or surrounding Lake Illawarra, Tuggerah Lakes or Lake Macquarie. Should redevelopment be permitted in these areas?

Each area is different and should be looked at individually, thus it is not possible to provide guidelines that can be applied without further consideration of the local area. It is suggested that a local area study be undertaken to investigate these local issues and this is proposed in Section 5.7.

The main driver to allow redevelopment is that there has been a significant investment by the public and private sector and this would effectively be lost if the area is abandoned. In the past communities have been abandoned for flooding reasons (Terara on the Shoalhaven River) or not permitted to be redeveloped (parts of Maitland on the Hunter River) but such approaches are unlikely to be supported by the community today. The main issue with redevelopment is that this will continue to place (or slightly increase) the residents' lives at risk during a flood (it is presumed that building floors will be raised to an appropriate level to take account of climate change and so the damage to property will be exposed to the same level of risk as with 2012 conditions).

There is also the question whether this type of development is sustainable? If sea levels continue to rise (beyond 2100) then it is unlikely that redevelopment is sustainable and at some point the land will be unsuitable for any form of development. However in the short term (say < 100 years) it may be sustainable.

In some cases it may be possible to provide high level access out of the area and so this will minimise but not eliminate the risk to life. However this is unviable (cost and practical consideration) for most of these areas including the majority of Sussex Inlet.

An alternative is to only approve developments that contain a safe refuge to the PMF (in the year 2100). This approach is termed "shelter in place" and has been considered for some flood prone areas (Newcastle) where it is impossible to provide protection or voluntary purchase for all existing houses in the floodplain. For floods that last for say less than 4 hours (June 2007 flood at Newcastle) this approach may be the only practical alternative as self help evacuation through floodwaters provides a greater risk to life. However at Sussex Inlet and many of these other areas the floodwaters inundate access for much longer (two days at Tuggerah Lakes). Shelter in place is therefore not viable for these areas as many residents will be effectively forced to leave through floodwaters due to lack of food, a power failure, a sewerage failure, the need to access relatives, a medical emergency or for some other reason.

Another approach is "planned retreat" where approval is only given on condition that once a certain climate change induced sea level rise has actually occurred (and can be demonstrated by historical records) then the residents must abandon their property. This means that the existing development continues if sea level rise does not occur or continues for a longer period if sea level occurs at a slower rate than estimated by the IPCC. There are many complex issues that would need to be resolved with adopting this approach and these should be explored by other experts.

In summary an approach needs to be found to support redevelopment in areas that become high hazard as a result of a climate change induced sea level rise to ensure that the risk to life is not increased (assuming that the damage to property is exposed to the same level of risk as with 2012 conditions). If this does not occur the likelihood of lives lost during floods in these areas will increase. The magnitude of the increase is impossible to evaluate but will place residents and rescuers (SES) lives at risk.

The question must then be asked whether this increase is risk to life due to a natural hazard is acceptable to the community for the advantage of continuing to live in these areas? The Australian Geographic (http://www.australiangeographic.com.au/journal/the-worst-floods-in-australian-history.htm) summarised the ten deadliest floods in Australian history as:

1. June 1852 - Gundagai, NSW
89 deaths, entire settlement of 250 people destroyed
2. December 2010 to January 2011 - Brisbane and south-east QLD
35 confirmed deaths, $2.38 billion in damage
3. 27 December 1916 - Clermont and Peak Downs, QLD
65 deaths, 10 homes destroyed, 50 buildings damaged and 10,000 livestock killed
4. 29 November 1934 - Melbourne, VIC
36 deaths, 6000 homeless and over 400 buildings damaged
5. 15 February 1893 - Ipswich, QLD
35 deaths, 300 people injured and two bridges destroyed
6. 9-17 February 1927 - Brisbane, Cairns and Townsville, QLD
47 deaths, 16 homes destroyed, an estimated £300,000 in damages.
7. April 1929 - Northern Tasmania
22 deaths, 1000 homes damaged, 25 bridges destroyed
8. February 1955 - Hunter Valley, NSW
24 deaths, 59 homes destroyed, 5200 homes flooded and more than 40,000 people evacuated
9. 25 January - 1 April 1974 - Brisbane, QLD - also NSW, TAS
14 deaths, 300 injured, 56 homes destroyed, an estimated $68 million in damages
10. August 1986 - Hawkesbury and Georges River Flood NSW
6 dead, 10,000 homes damaged, an estimated $35M in damages.

A comparable statistic for bush fires which is the other common life threatening natural disaster in Australia (http://www.ema.gov.au/www/ema/schools.nsf/Page/Get_The_FactsBushfires) is provided below:

- Victoria, 2009 in which 173 lives were lost and is now referred to as Black Saturday
- South Australia and Victoria in 1983, which claimed 76 lives and was named Ash Wednesday
- Southern Victoria, 1969 when 23 passed away

- New South Wales, 1968 in the Blue Mountains and coastal region, where 14 lives were lost during this fire
- Hobart and Southern Tasmania, 1967, which left 62 dead, and
- Victoria, 1939 and was named Black Friday, when 71 lives were lost.

Whilst both bush fires and floods have caused a significant loss of life in recorded Australian history a major difference between the two natural disasters is that flood extents can be accurately mapped and thus if development is prevented from these areas the loss of life will be largely eliminated. From a practical perspective (unless all the vegetative cover for a large radius surrounding developments is removed) it is impossible to eliminate the risk of loss of life due to bush fires in Australia. Cyclones have also caused significant loss of life but the risk today has been significantly reduced due to improved warning and awareness.

If redevelopment is permitted in these high hazard areas with lower standards of access than currently accepted, this may set a precedent in other flood liable areas not affected by sea level rise to allow development that previously may have been rejected. This would need to be investigated.

The issue of redevelopment and/or continued habitation in existing areas subject to sea level rise presents many issues for every coastal community in NSW and throughout the world. There is no simple viable solution and it will take time for residents and all levels of government to determine an equitable way forward.

5.4.4. The Same Mitigation/Adaptation Measures Suggested to Protect Existing Developments

The flood modification, levees and house raising measures suggested to protect existing developments can also be employed to protect future development. These measures may become viable as the only means of providing protection if they are considered appropriate by the community.

Generally levees are viewed as a means of protecting existing developments and not for providing protection for new developments. However a future sub division could be constructed such that a future levee would be able to be constructed if required. The success of this measure will depend on how the residents at the time accept the adverse consequences of levee construction, such as loss of view or loss of access.

House raising is a means by which a new house can be built at the existing FPL but is constructed in such a manner that it can be raised in the future as climate change impacts occur. This type of modular/adaptive housing construction is not common in NSW but is employed in the USA where the habitable floor may be several metres above the ground. A concern with this approach is that the surrounding ground in the property may remain saturated due to rising water tables and will also become more frequently inundated. Also of concern is the increase in maintenance required to ensure the condition of the roads remains acceptable and evacuation routes are maintained. These issues will need to be addressed if this type of housing construction is permitted.

5.4.5. Filling of the Floodplain

The filling of the floodplain is generally not considered an acceptable means of permitting future development as it “destroys” the ecology of the floodplain and also raises flood levels by eliminating temporary floodplain storage (and in some cases reduces the hydraulic conveyance). In the St Georges Basin waterway floodplain the effect on flood levels will be negligible given the size of the existing floodplain and the likely quantity of fill. If the ecological issues can be overcome this will provide a means of permitting future development.

This approach could also be adopted for infill development as long as care is taken to ensure local drainage issues (change in flood levels, velocities or flow paths occurring during localised rainfall events) are not exacerbated and services (roads, sewer, water) can be accommodated. Possibly a staged approach can be undertaken where the new buildings and garages are constructed on elevated pads and in time the remainder of the property and the roads are raised. This piece-meal approach can lead to dis-harmony within the community when there are some filled and some non filled properties.

5.4.6. Planned Retreat

As the predicted sea level rise occurs some developed parts of the St Georges Basin waterway may have to be resumed as park land or similar. However there is no certainty regarding the predicted sea level rise or the exact timeframe. Thus it may be possible to permit new development in these areas with the proviso that if sea level rise eventuates then the development must retreat according to a planned retreat strategy. This strategy could be based on a suite of conditions, or thresholds including groundwater levels, inundation in non flood times or availability of access allowing residents to stay until site conditions are considered unsuitable. This approach is more suited to commercial developments (tourist parks) than residential developments but should be considered.

5.4.7. Limit the Extent of Development

It is preferable if future residential development in low lying areas could be restricted to the “lowest residential” zoning (i.e no unit developments or sub-division). Thus any development that will increase the present residential density would not be permitted. However this may not be possible with the existing LEP zonings. This might be examined in the local area study proposed in Section 5.7.

5.5. Related Issues that may Threaten the Long Term Viability of Areas

5.5.1. Evacuation Requirements

For many of the existing flood liable areas (Sussex Inlet), even if house raising or construction of a levee was undertaken and the services (roads, sewerage) issues resolved there is still no safe access out of the area to high ground in flood. Whilst in a medical emergency a helicopter or flood boat could access the area many residents may attempt to cross the floodwaters (leave the area). This represents a burden on the SES to “rescue” residents and a risk to life to the residents who cross floodwaters unprepared.

At present many locations do not have adequate flood access and this will be exacerbated with climate change. The lack of adequate access may mean that some areas should not be further developed.

5.5.2. Frequency of Inundation of Land in Non Flood Times

Some private properties have land at or below 1 mAHD and during non flood times this land is never inundated by the range of “normal” river levels.

With sea level rise then the range of “normal” river levels in the basin and estuary will rise by a similar amount to the sea level rise. This will mean that low lying land will be more frequently inundated and with a 0.9m sea level rise all land below 1 mAHD will be permanently inundated. Consideration needs to be given to when the land becomes unsuitable for habitation due to frequent inundation.

5.5.3. Maintenance of Services

A rise in the range of “normal” water levels in the estuary and more frequent inundation during floods, as a consequence of a sea level rise, will impact on the maintenance of services (mainly roads but presumably many other services as well, such as sewer, gas and electricity). This will add to the maintenance budget of Shoalhaven City Council or the supply authority and may mean that, for example, the road standard will need to be reduced in order to maintain a level of service. This reduction in service supply may have ongoing ramifications for public safety or such like.

When the predicted sea level rise benchmarks are considered with regard to the existing service levels of the sewerage system, such as sewer outlets and manhole levels, significant works and costs may be required to maintain the service at working condition.

5.6. Review of Management Measures in Floodplain Risk Management Plan

Table 8 provides a listing of all the management measures proposed in the St Georges Basin Floodplain Risk Management Plan (Reference 3) and how climate change may affect these measures.

Table 8: Summary of Proposed Floodplain Risk Management Measures

	MEASURE	COMMENT	PRIORITY	CLIMATE CHANGE IMPLICATIONS
		FLOOD MODIFICATION		
F1	IMPLEMENT RECOMMENDATIONS OF STORMWATER MANAGEMENT PLAN TO DEAL WITH LOCAL FLOODING ISSUES	Local flooding problems generally do not result in houses being inundated. The Shoalhaven City Council Stormwater Management Plan identified and made recommendations for areas affected by local flooding. These recommendations should continue to be implemented to assist local flooding and drainage problems overall.	HIGH	Need to consider climate change.
F2	INVESTIGATE FEASIBILITY OF FAIRVIEW CRESCENT LEVEE	Raising Fairview Crescent to form a levee will reduce the inconvenience and damage caused by frequent flood events up to the 1% AEP but will also increase evacuation time for larger events.	MEDIUM	Will be impacted by sea level rise, however should be able to be accommodated with a modified design.
		PROPERTY MODIFICATION		
P1	ALLOW HOUSE RAISING FOR SUITABLE PROPERTIES	Six (6) houses have been identified as being suitable for house raising. Raising these houses will reduce flood damages but it will not change the hazard categorisation for the property.	MEDIUM	Will be impacted by sea level rise, however should be able to be accommodated with a modified design.
P2	ALLOW FLOOD PROOFING	Flood proofing should be encouraged for existing flood affected commercial properties. Generally it is not viable for residential properties but if applicable it can be considered.	LOW	Will be impacted by sea level rise, however should be able to be accommodated with a modified design.
P3	REVIEW AND UPDATE SCC INTERIM FLOOD POLICY (now replaced by DCP106 Amendment 1)	Formalise Council policy documentation to include findings from Floodplain Risk Management Process.	HIGH	Need to consider climate change.
P4	ADOPT APPROPRIATE FLOOD PLANNING LEVEL	Adopt a flood planning level which is consistent for different types of development (based on risks) across the floodplain. The Flood Planning Level should incorporate the appropriate design flood level, a freeboard allowance and consideration of wind waves (where appropriate).	HIGH	Need to consider and possibly include an increase for climate change.
P5	ADOPT A CONSISTENT FREEBOARD OF 0.5 m	A consistent freeboard of 0.5 m shall apply for all new development in flood liable areas.	HIGH	An increase for climate change is independent of the freeboard.
P6	MONITOR FLOOD IMPLICATIONS OF THE GREENHOUSE EFFECTS	Council to keep up to date with the latest research on climatic change pertaining to the Greenhouse effect and its impact on water levels. The increase is predicted to be relatively minor but must be closely monitored.	LOW	None
P7	APPLY MINIMUM SET BACK FROM FORESHORE	A minimum set back shall apply for new development in areas where erosion is potentially an issue. A detailed geomorphic assessment is required to determine the setback.	HIGH	Need to consider climate change.
P8	MONITOR THE EXTENT OF FILLING OF FLOOD PRONE LAND	Council to monitor the cumulative extent of filling on flood prone areas with the aid of GIS. Minor filling is unlikely to have any significant impact on flood levels. Ensure local flood behaviour is not altered by affects of filling associated with individual and cumulative development.	MEDIUM	Need to consider climate change but is unlikely to have significant implications.
P9	REVIEW AND UPDATE SECTION 149 CERTIFICATES (awaiting legal advice)	Updated flood information and the floor level survey need to be included on Section 149 certificates.	HIGH	Need to consider and possibly include information regarding climate change.
P10	MAINTAIN FLOOR/GROUND LEVEL DATABASE	Details of floor and ground levels for all properties within the floodplain should be updated with any new proposals or re-development.	MEDIUM	None
P11	NOTIFY EXISTING PROPERTY OWNERS OF CURRENT S149 CERTIFICATE DETAILS (awaiting legal advice)	As part of a flood awareness/education program and to ensure all existing property owners are made aware of any potential flood affectation encoded as a result of this floodplain risk management process, notifications should be mailed to all flood prone property owners.	MEDIUM	Need to consider climate change but is unlikely to have significant implications.
P12	REVIEW AND UPDATE LEP	Council are currently in the process of updating the LEP to incorporate the latest flood terminology and policies.	HIGH	LEP review does not presently include climate change. In order to manage this issue it should be included but it would need approval from the State Government.
P13	ADOPT & IMPLEMENT UPDATED DEVELOPMENT CONTROLS FOR FLOOD PRONE LAND	Council should adopt and implement a generic Flood DCP with reference to a specific planning matrix tailored to assist with development planning of flood prone lands on the St Georges Basin floodplain.	HIGH	Need to consider climate change.
P14	ADOPT UPDATED DEVELOPMENT CONTROLS FOR CARAVAN PARKS	Council should adopt and implement a caravan park planning matrix with graded development controls applying to different types of developments/improvements in caravan parks on flood prone lands.	HIGH	Need to consider climate change and may have significant implications for low lying parks.
P15	REVIEW AND ASSESS HAZARDS AND RISKS FOR ALL CARAVAN PARKS (Draft on Public Exhibition)	Some 15 caravan parks exist in low lying and potentially High Hazard areas of the floodplain. Each park should be inspected in detail to accurately identify the risks and any specific needs.	HIGH	Need to consider climate change and may have significant implications for low lying parks.
P16	ENFORCE CARAVAN PARK GUIDELINES (generally only through redevelopment applications)	The proposed caravan park development guidelines should be enforced for all existing and future development to ensure minimal damages are incurred.	MEDIUM	Need to consider climate change and may have significant implications for low lying parks.
		RESPONSE MODIFICATION		
R1	IDENTIFY SUITABLE RAINFALL/WATER LEVEL GAUGE SITES, COLLECT AND ANALYSE DATA	Automatic rainfall/water level gauges should be installed at appropriate locations across the catchment to facilitate the collection of data to assist in the establishment of a flood warning system.	HIGH	None
R2	DEVELOP A FLOOD WARNING SYSTEM	Develop a Flood Warning System in consultation with BOM and SES. Likely to be most effective for Sussex Inlet and Basin foreshore areas.	HIGH	Minor implications that can be accommodated.
R3	REVIEW AND UPDATE LOCAL FLOOD PLAN	The SES Local Flood Plan should be regularly reviewed and updated. This could include more detail on the particular problems at caravan parks on the Basin foreshores and in Sussex Inlet area and evacuation routes.	HIGH	Minor implications that can be accommodated.
R4	MONITOR CHANGES TO THE FLOODPLAIN	Changes to the floodplain (such as filling, new development or re-development) occur on an ongoing basis. Such changes can alter (increase or decrease) the number of people at risk, the level of risk or evacuation needs and this information may require the Local Flood Plan to be updated.	MEDIUM	Minor implications that can be accommodated.
R5	RAISE JACOBS DRIVE FOR 600 TO 800 METRES FROM WESTERN END	There may be some scope to raise part of Jacobs Drive to improve evacuation access times and reduce the number of properties cut off in up to a 1% AEP event by almost half.	MEDIUM	Need to consider climate change in any proposed design.
R6	INVESTIGATE ALTERNATIVE EVACUATION ROUTE FOR SUSSEX INLET PROPERTIES	There is currently only one route leading out of Sussex Inlet and the properties on high ground north of Badgee Lagoon are easily isolated in small/frequent flood events. A second alternative route would improve trafficability early in an evacuation and ensure nearly 400 properties are not completely isolated.	MEDIUM	Climate change will further reduce the accessibility and any proposed design needs to consider climate change.
R7	DEVELOP AND IMPLEMENT A FLOOD EDUCATION PROGRAM	An ongoing Flood Education program will help to maintain/enhance the awareness of the community, particularly, the transient non-permanent "holiday makers".	HIGH	Should include information on the potential implications of climate change.

5.7. Summary

According to the world's experts a climate change induced sea level rise is inevitable and the NSW Government's benchmark for the rise is 0.4m by the year 2050 and 0.9m by the year 2100. As such Shoalhaven City Council must include the effects of climate change in their flood related development controls and in conjunction develop a climate change adaptation strategy for both existing and future developments. This strategy would examine each of the floodplain management areas within the St Georges Basin waterway, consider each of the possible adaptation measures and propose a preferred approach.

It is possible that different approaches will be undertaken in different areas and consideration given to the increases by the year 2050 and 2100 and the nature of the development. For example a development with a short life span (tourist development) may be approved assuming only a 0.4m sea level rise by the year 2050 on the basis that after that time it would be re-developed. This approach would generally only be applicable for non-residential developments.

Development of this local area sea level rise adaptation strategy may take two years and involve input from a range of disciplines as well as extensive community consultation. As an interim measure the following should be employed.

- All new building approvals that do not involve sub-divisions or re-zoning must include the impacts of a 0.4m sea level rise in the determination of Flood Planning Levels (the actual amount will vary depending upon the locality – refer Figures 4 to 11),
- All new sub-divisions, re-zoning or flood mitigation works must include the impacts of a 0.9m sea level rise in the determination of Flood Planning Levels (the actual amount will vary depending upon the locality – refer Figures 4 to 11),
- At this time the effect of climate induced rainfall increases have not been applied. This is because as yet there is no scientific evidence acceptable to the Bureau of Meteorology that confirms that climate change will increase design storm rainfall intensities. If and when this information becomes available (this issue is under constant review by the Bureau of Meteorology) any changes to design rainfall intensities should be applied. It should be noted that most NSW Councils have not included a rainfall increase in their climate change policy at this time, however Pittwater Council has done so,
- The Section 149 certificates should be modified to include text on the potential implications of climate change,
- There should be no increase in the current density of residential development unless there is flood free access to suitable high ground in the 100 year ARI event plus the 0.9m sea level rise scenario.

<u>The main outcome from this review is that a sea level rise adaptation strategy must be undertaken for each local area in a future Floodplain Risk Management Plan to take account of climate change.</u>

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Figures

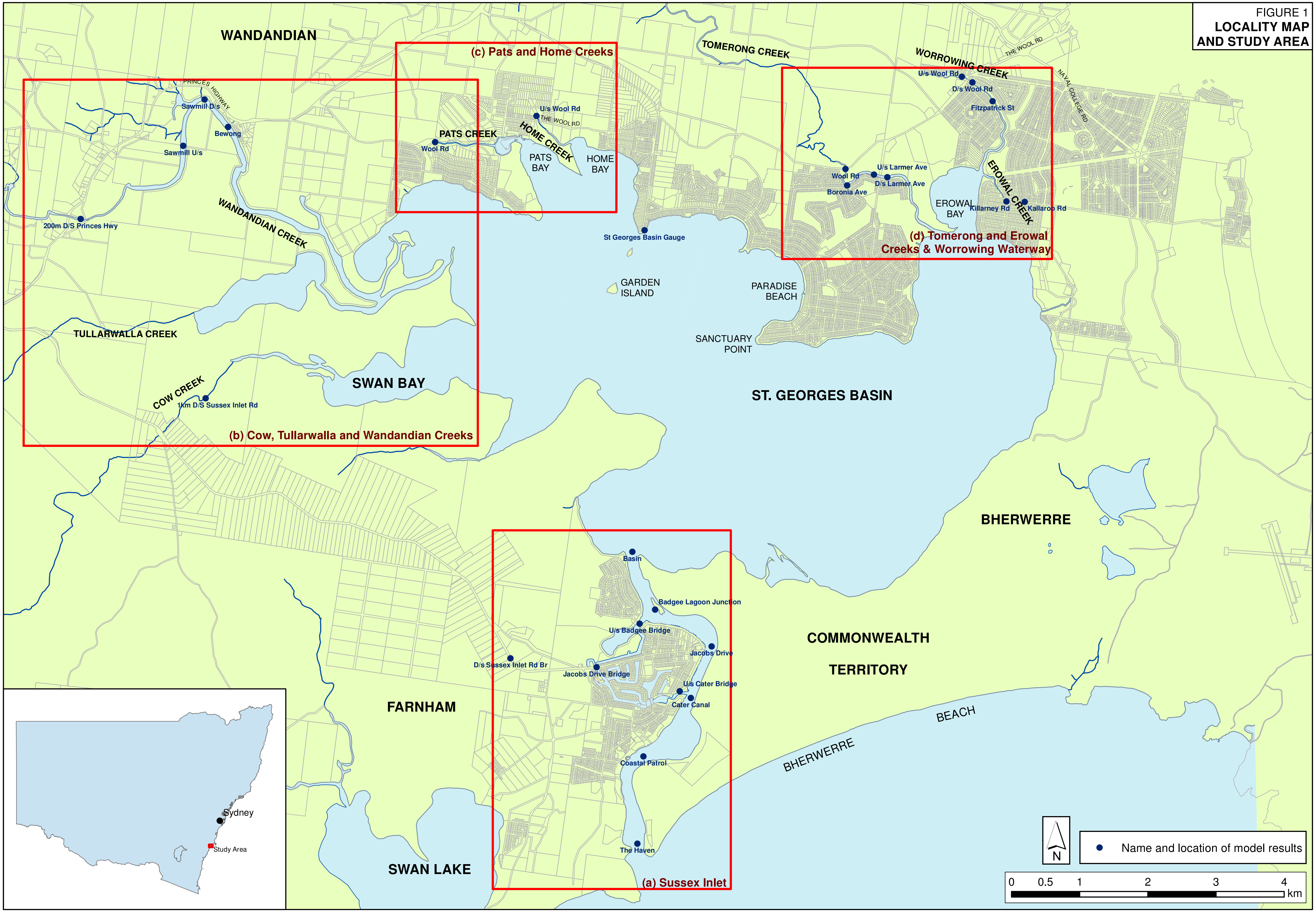

FIGURE 1
LOCALITY MAP AND STUDY AREA

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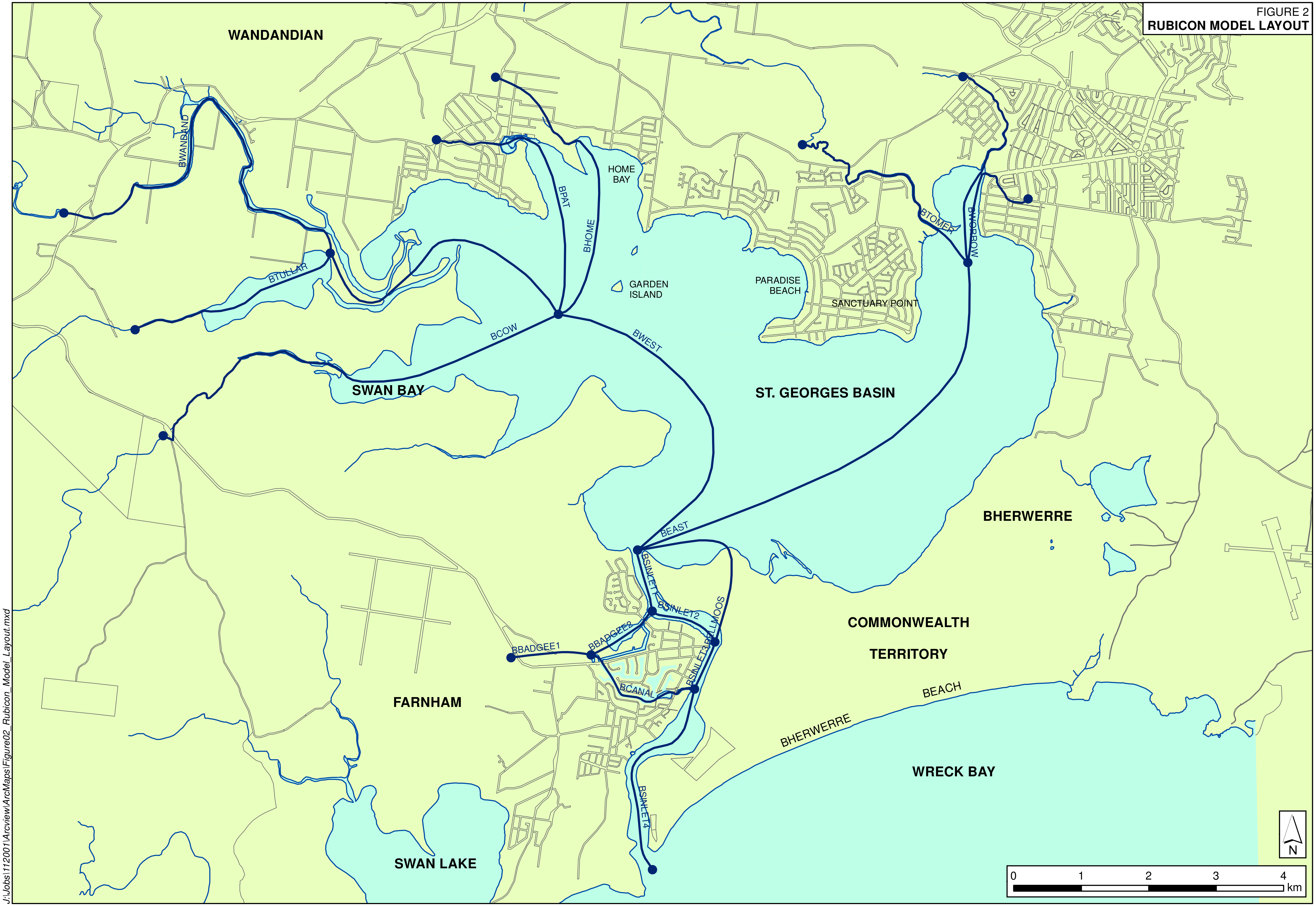
FIGURE 2
RUBICON MODEL LAYOUT
WANDANDIAN
BWANDAND
BTULLAR
BCOW
BPAT
BHOME
HOME BAY
GARDEN ISLAND
BWEST
PARADISE BEACH
SANCTUARY POINT
BTOMER
BWORROW
SWAN BAY
ST. GEORGES BASIN
BEAST
BHERWERRE
BSINLET1
BSINLET2
BSINLET3
BPILLWOOS
BBADGEE1
BBADGEE2
BCANAL
COMMONWEALTH
TERRITORY
FARNHAM
BHERWERRE BEACH
WRECK BAY
BSINLET4
SWAN LAKE
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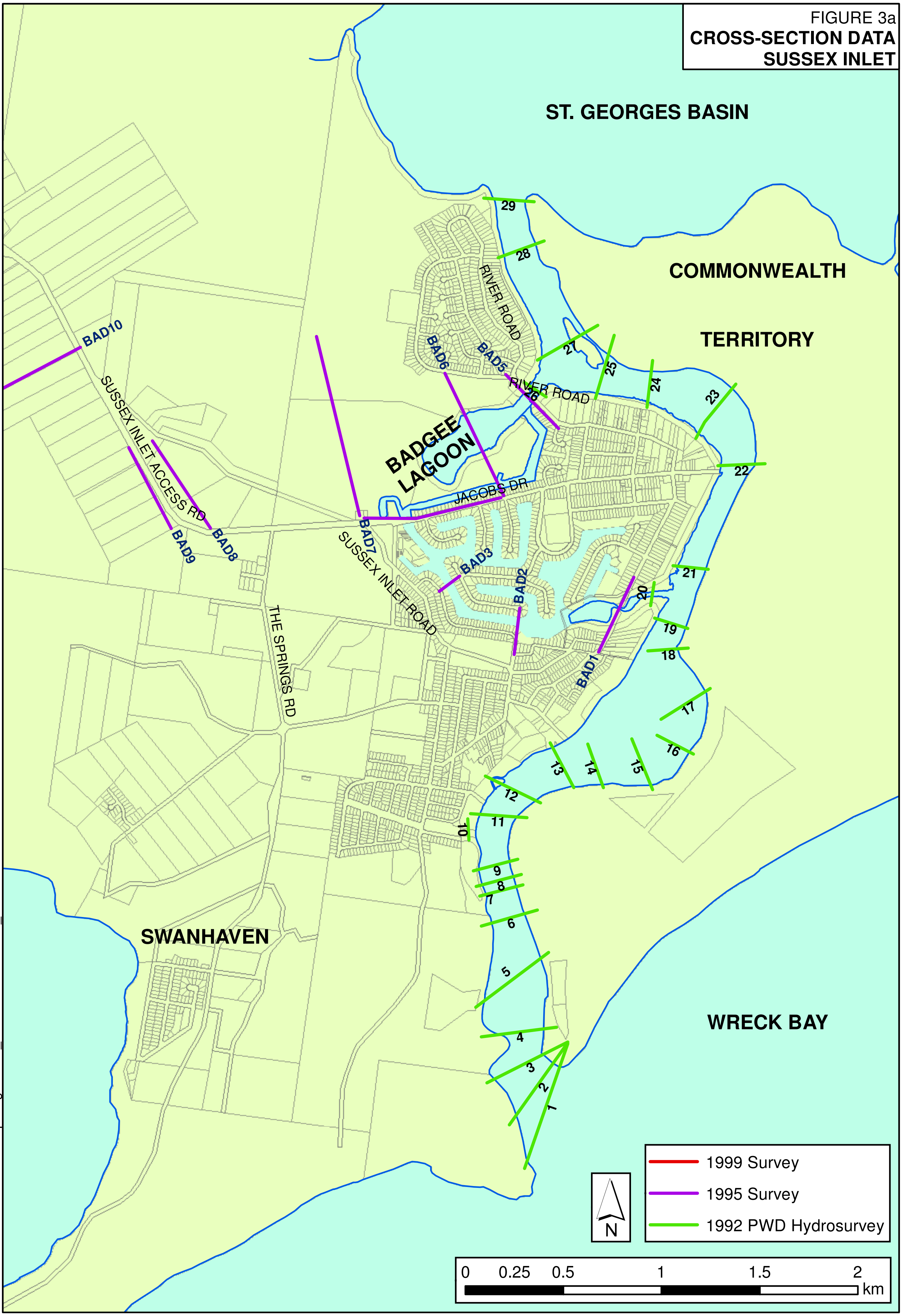
FIGURE 3a
CROSS-SECTION DATA
SUSSEX INLET
ST. GEORGES BASIN
COMMONWEALTH
TERRITORY
BADGEE
LAGOON
SWANHAVEN
WRECK BAY
RIVER ROAD
JACOBS DR
SUSSEX INLET ACCESS RD
SUSSEX INLET ROAD
THE SPRINGS RD
BAD1
BAD2
BAD3
BAD5
BAD6
BAD7
BAD8
BAD9
BAD10
1999 Survey
1995 Survey
1992 PWD Hydrosurvey
N
0
0.25
0.5
1
1.5
2
km
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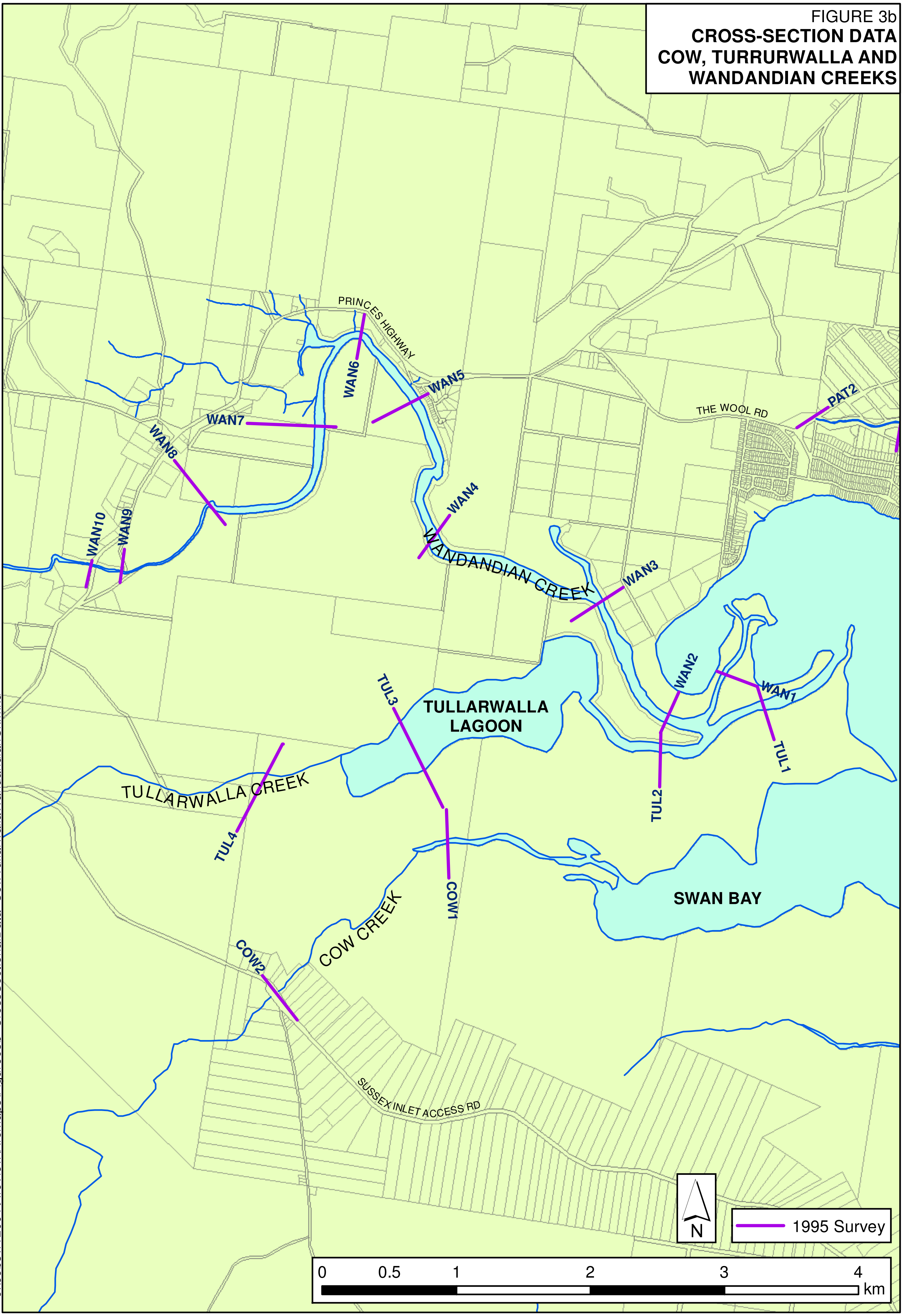

FIGURE 3b
CROSS-SECTION DATA
COW, TURRURWALLA AND
WANDANDIAN CREEKS
PRINCES HIGHWAY
THE WOOL RD
SUSSEX INLET ACCESS RD
WANDANDIAN CREEK
TULLARWALLA LAGOON
TULLARWALLA CREEK
COW CREEK
SWAN BAY
WAN1
WAN2
WAN3
WAN4
WAN5
WAN6
WAN7
WAN8
WAN9
WAN10
PAT2
TUL1
TUL2
TUL3
TUL4
COW1
COW2
N
1995 Survey
0
0.5
1
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3
4
km
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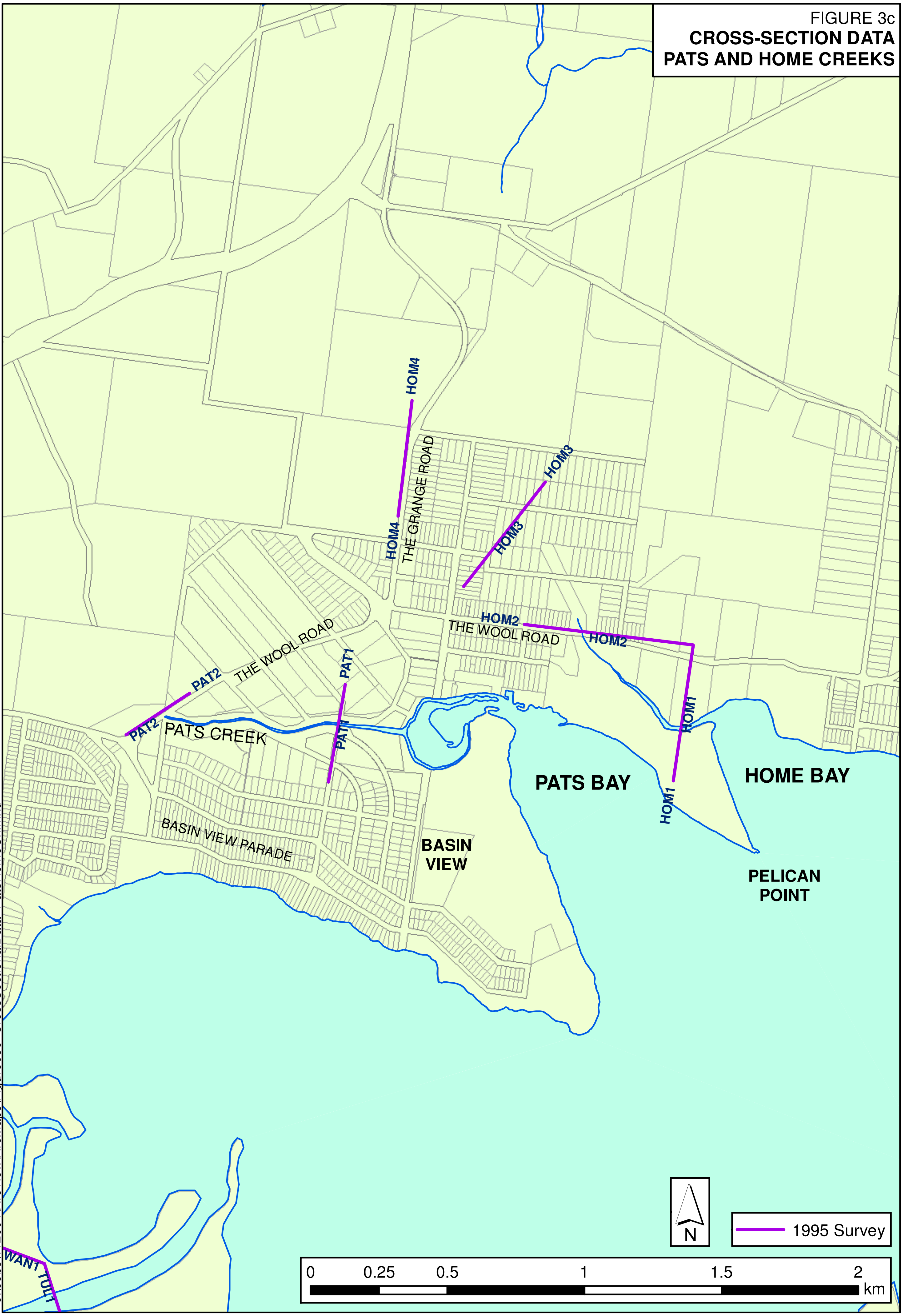
FIGURE 3c
CROSS-SECTION DATA
PATS AND HOME CREEKS



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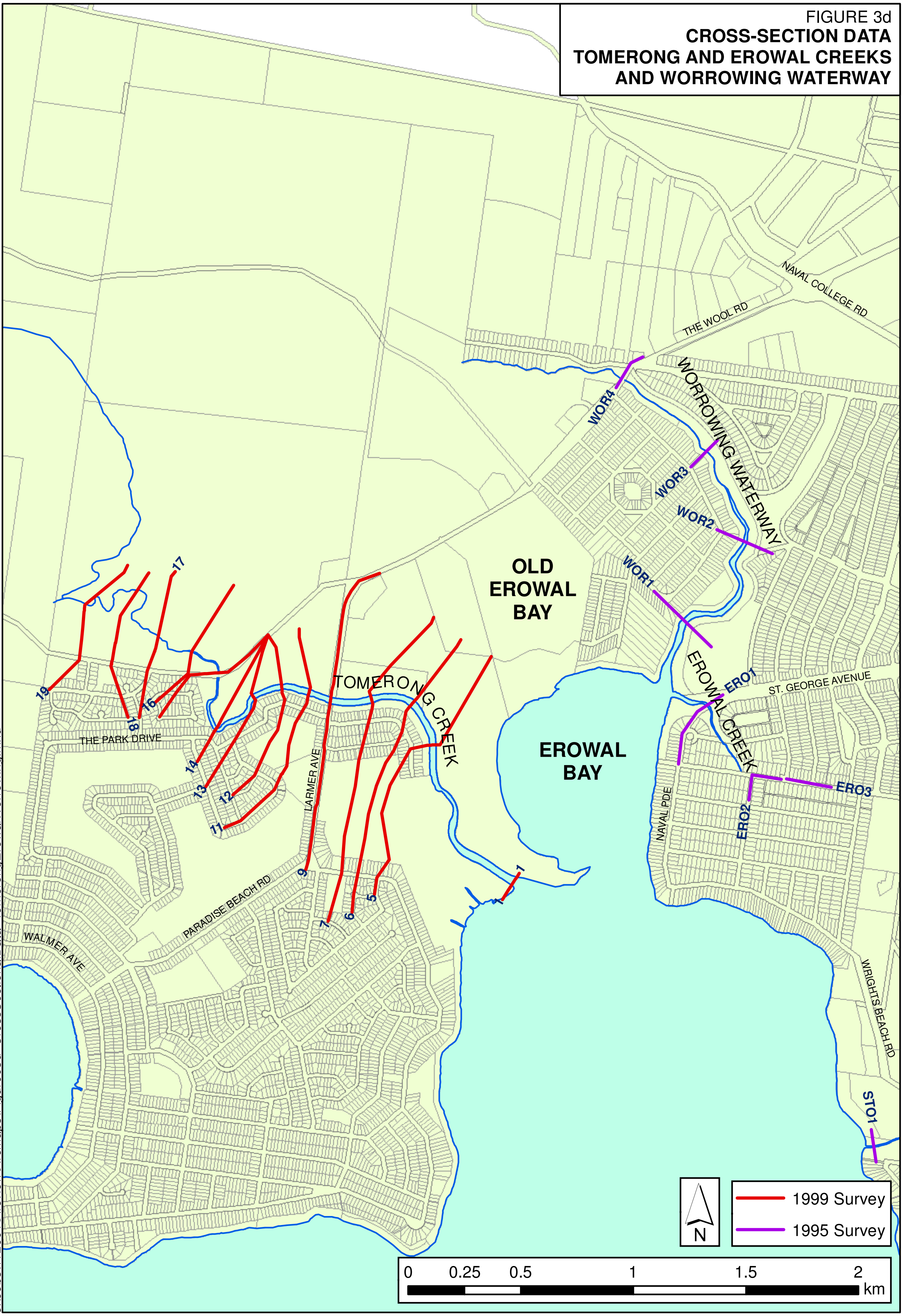
FIGURE 3d
CROSS-SECTION DATA
TOMERONG AND EROWAL CREEKS
AND WORROWING WATERWAY
NAVAL COLLEGE RD
THE WOOL RD
WORROWING WATERWAY
WOR4
WOR3
WOR2
WOR1
OLD
EROWAL
BAY
EROWAL
BAY
TOMERONG CREEK
EROWAL CREEK
ERO1
ERO2
ERO3
ST. GEORGE AVENUE
NAVAL PDE
THE PARK DRIVE
LARMER AVE
PARADISE BEACH RD
WALMER AVE
WRIGHTS BEACH RD
STO1
1
5
6
7
9
11
12
13
14
16
17
18
19
N
1999 Survey
1995 Survey
0
0.25
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1
1.5
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km
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FIGURE 4a
PEAK HEIGHT PROFILES
EXISTING CONDITIONS
ENTRANCE CHANNEL

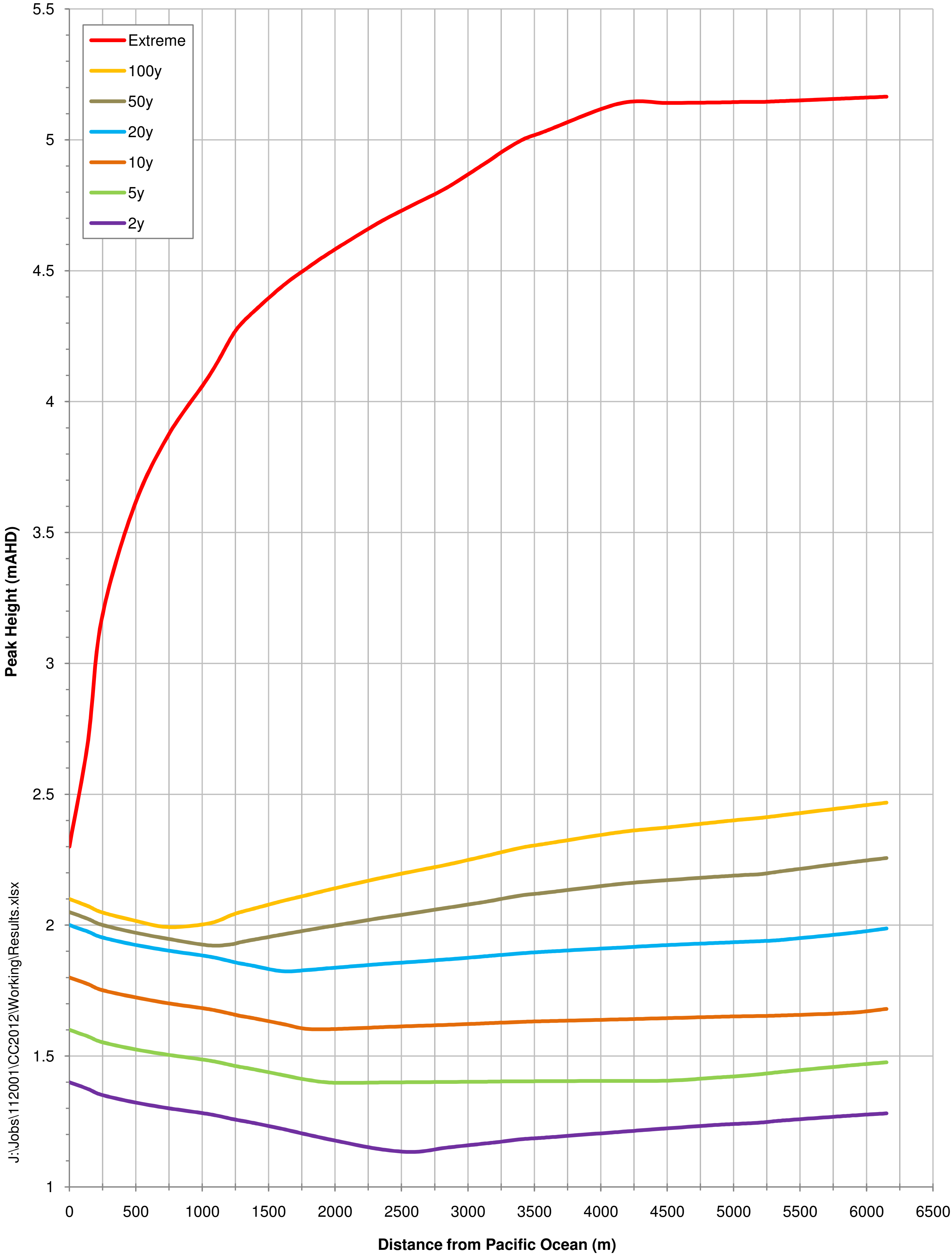
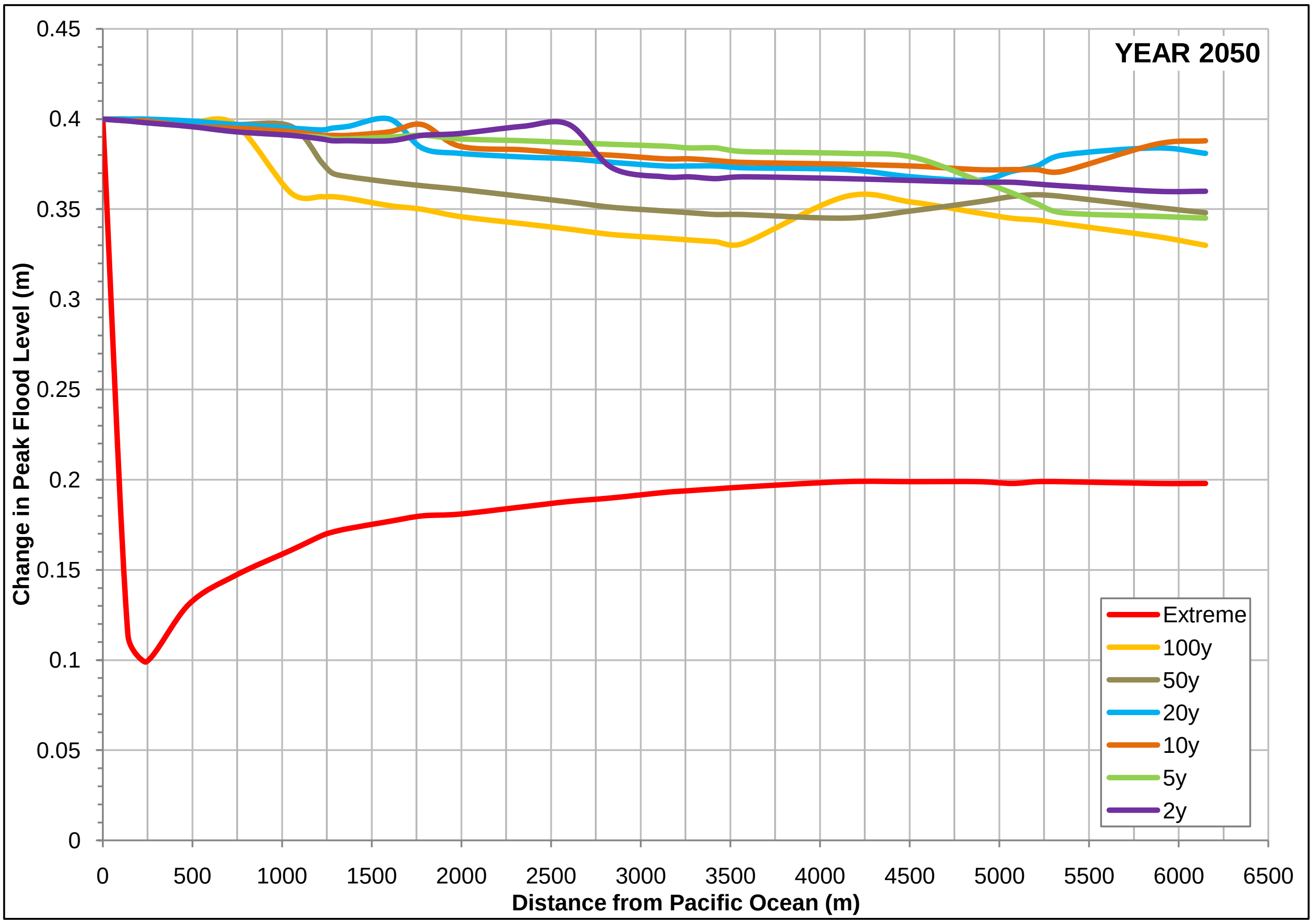


FIGURE 4b
CHANGE IN PEAK FLOOD LEVEL
ENTRANCE CHANNEL



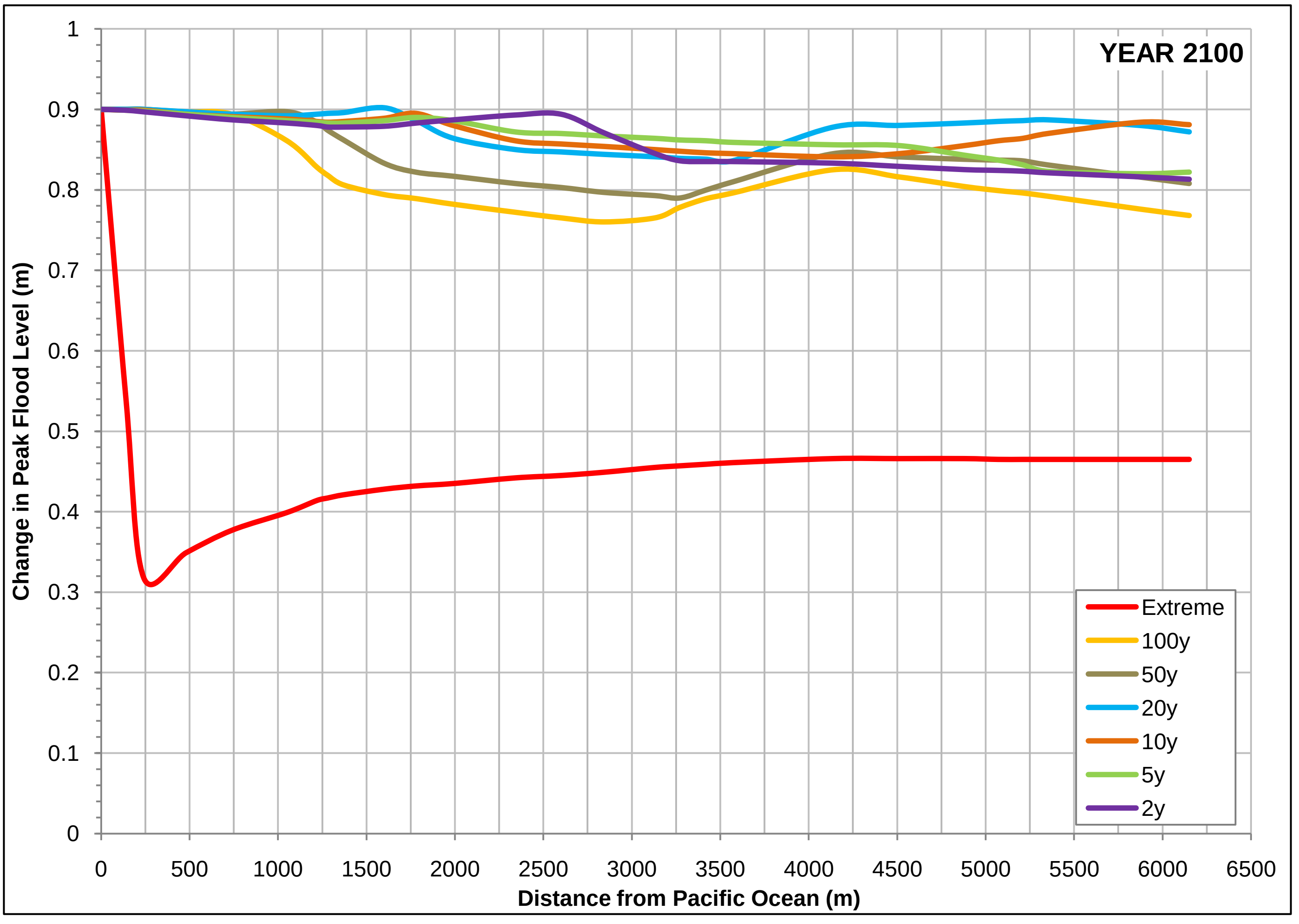


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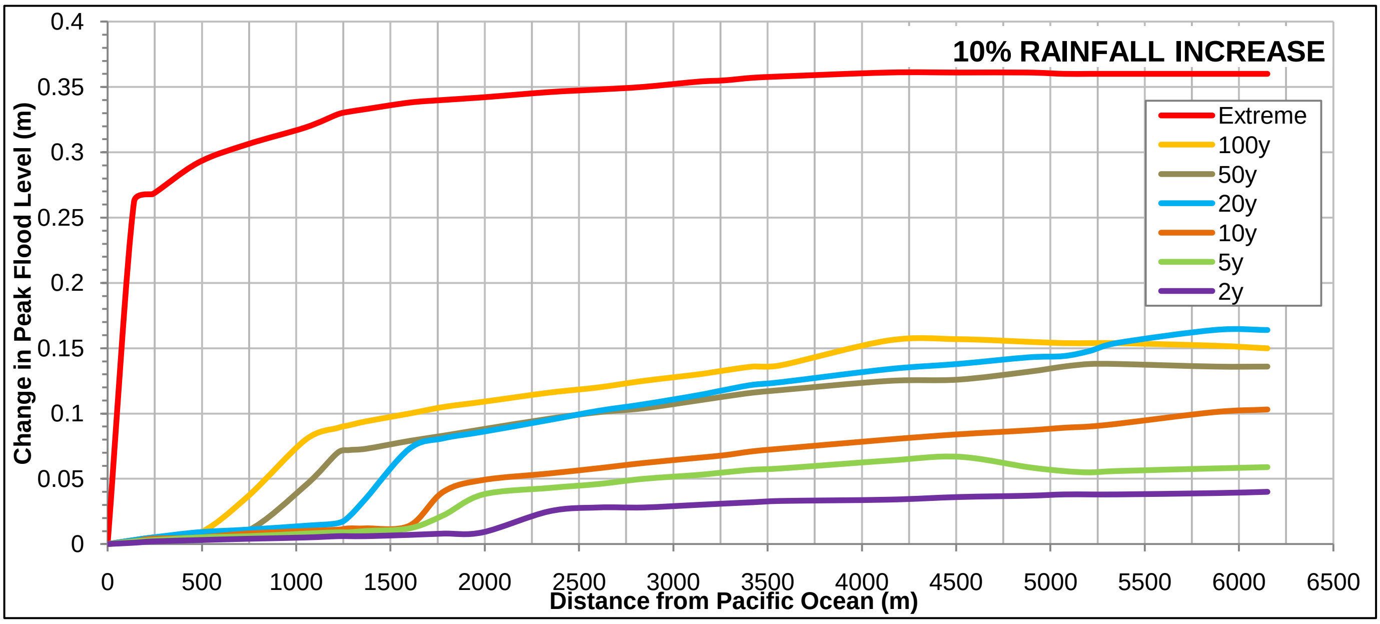
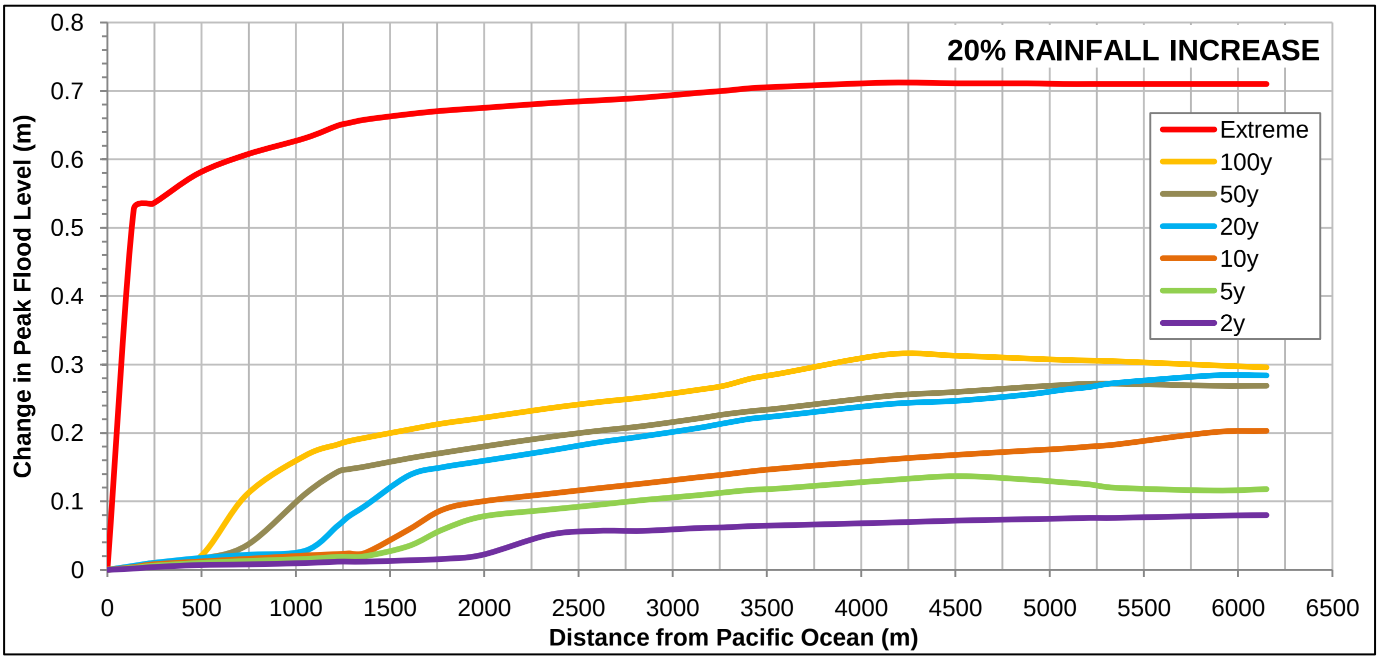
FIGURE 4c
CHANGE IN PEAK FLOOD LEVEL
ENTRANCE CHANNEL





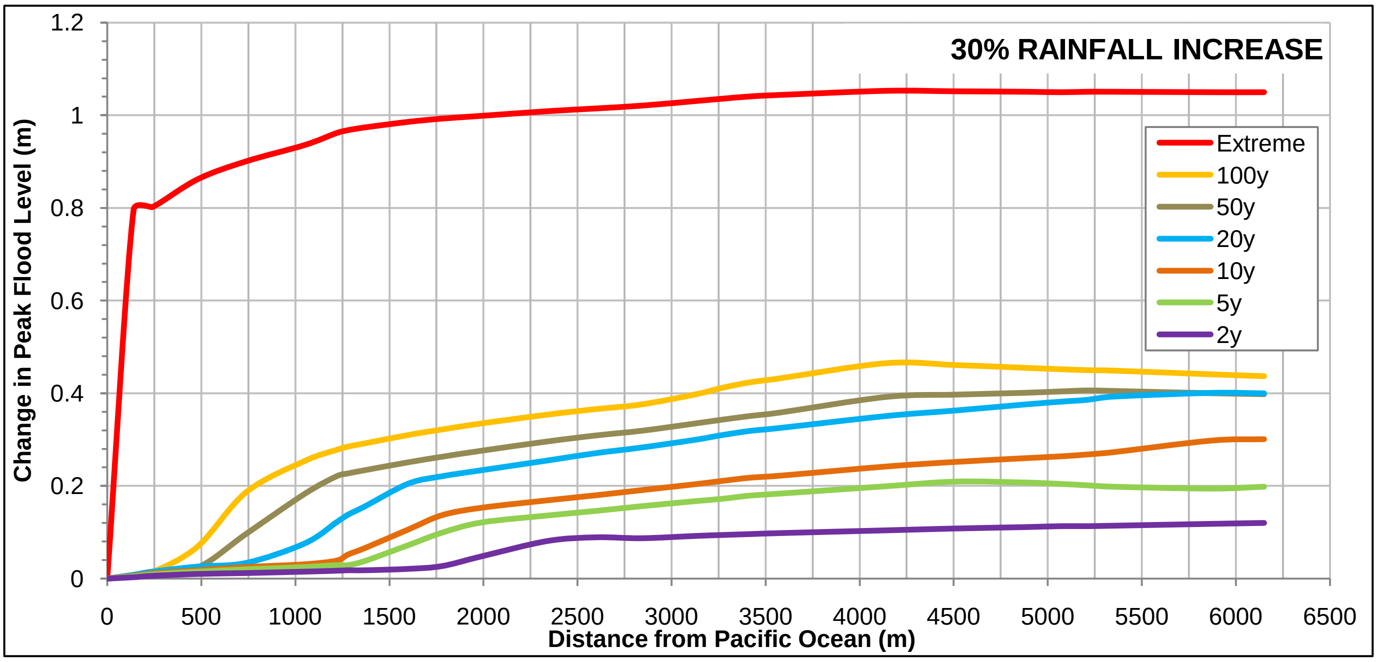


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FIGURE 5a
PEAK HEIGHT PROFILES
EXISTING CONDITIONS
EROWAL CREEK

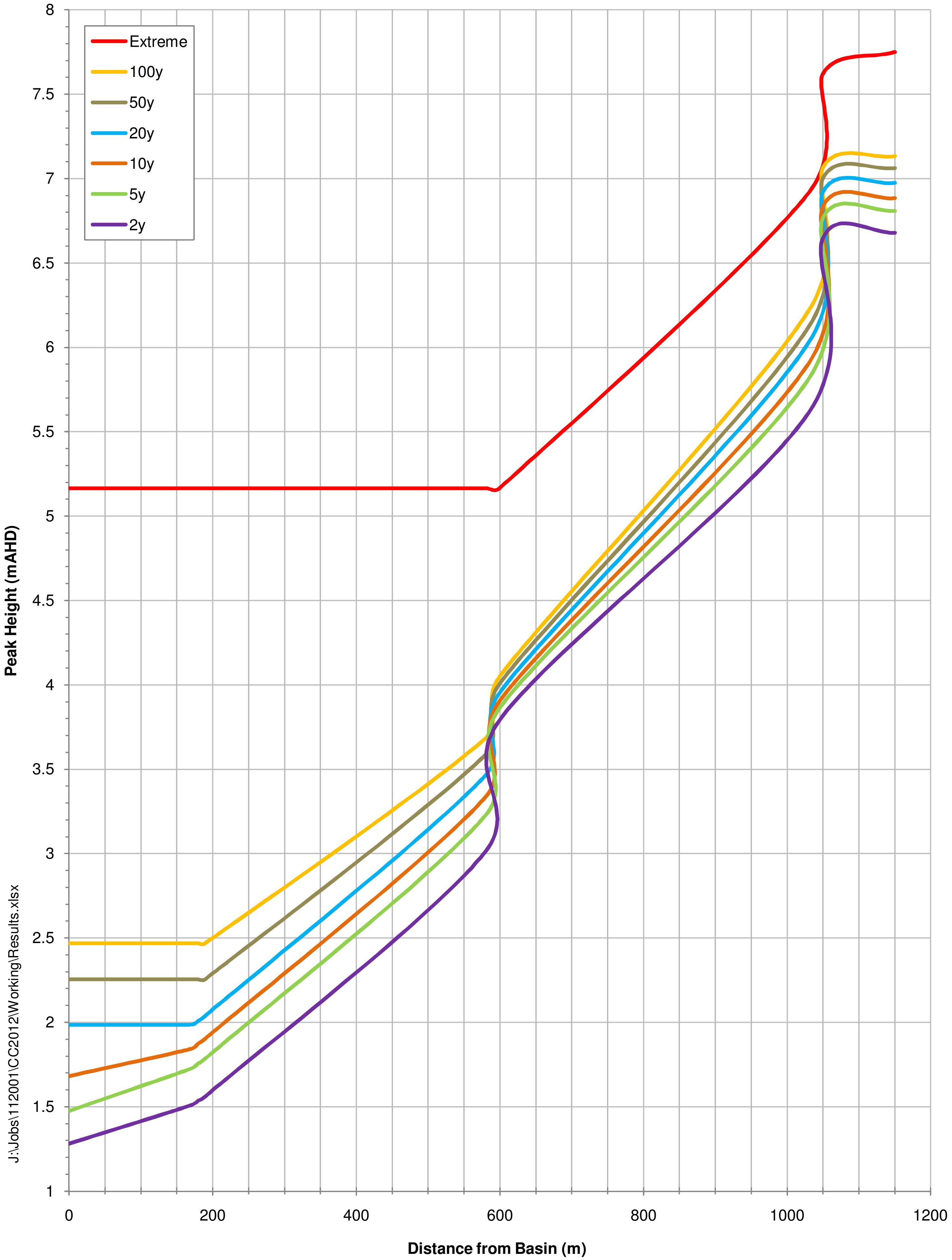

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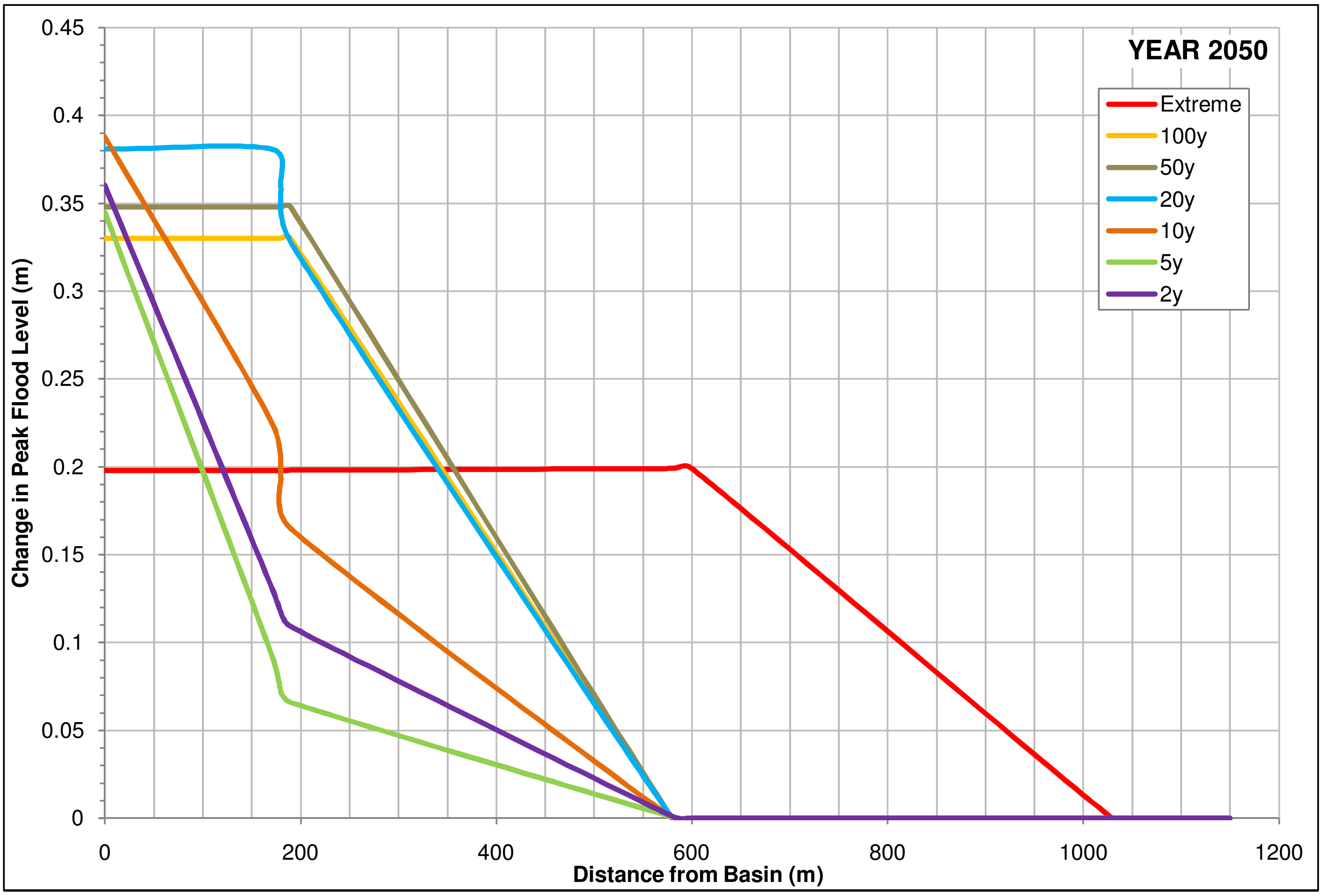
FIGURE 5b
CHANGE IN PEAK FLOOD LEVEL
EROWAL CREEK



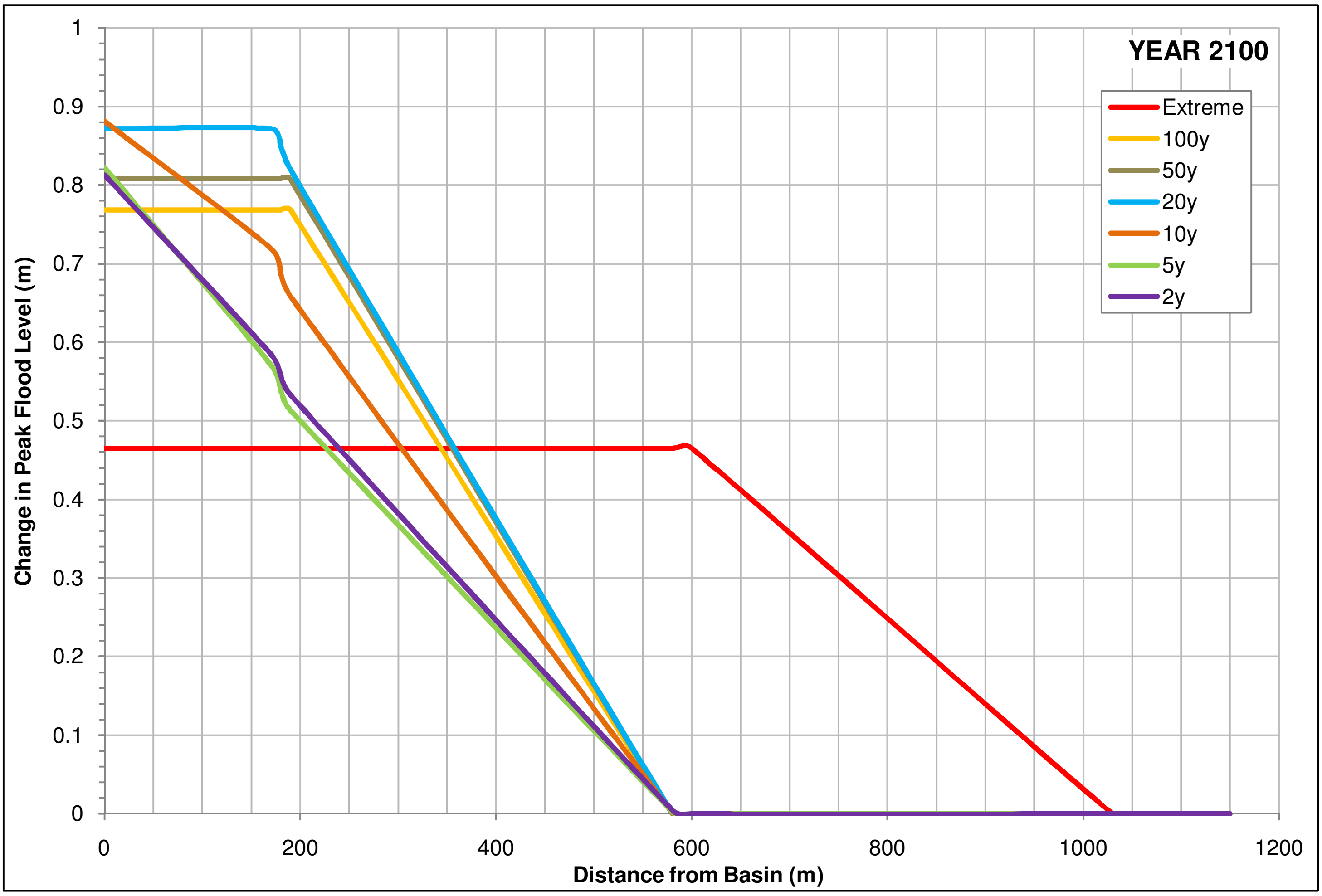


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FIGURE 5c

CHANGE IN PEAK FLOOD LEVEL
EROWAL CREEK

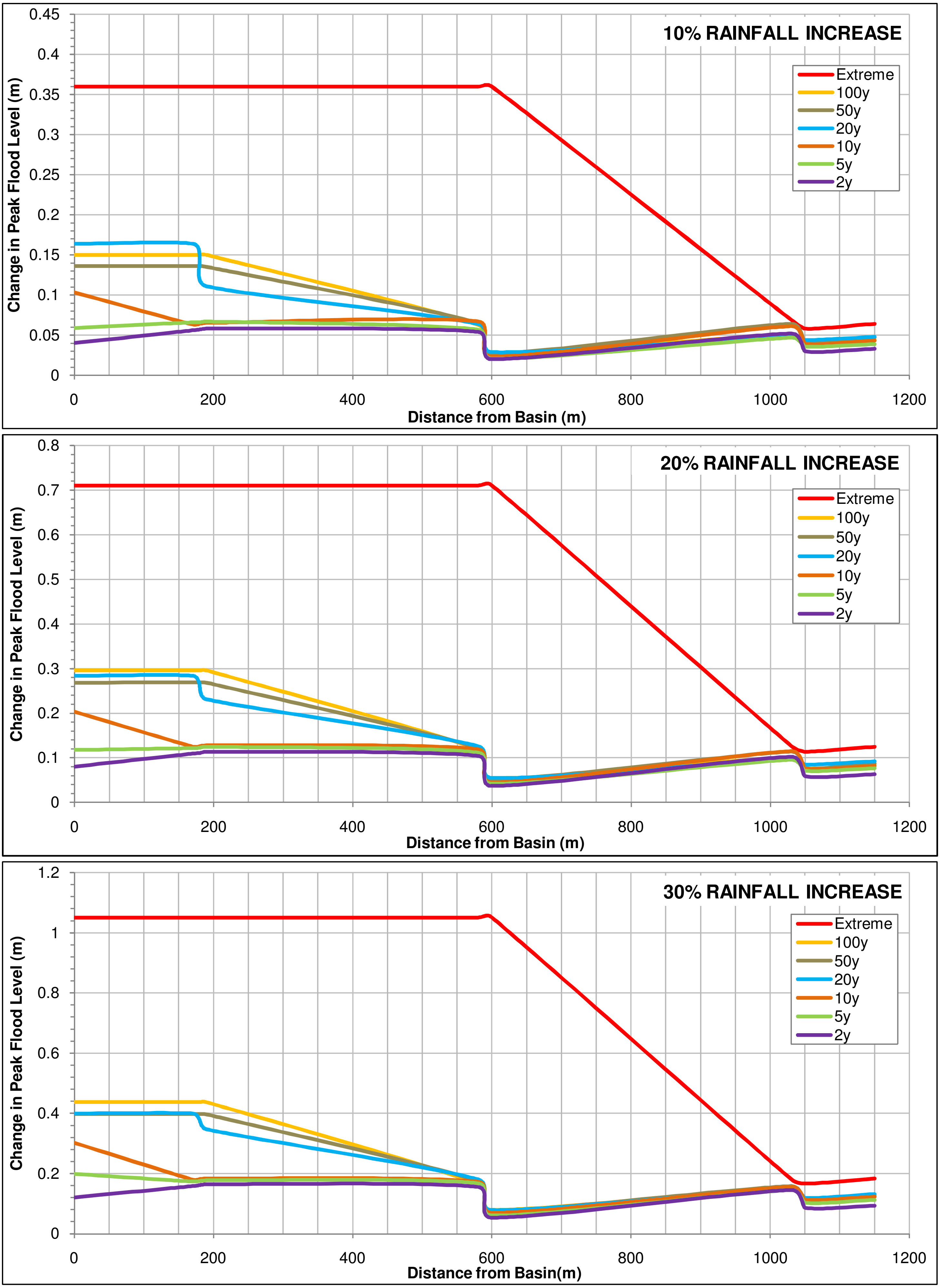

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FIGURE 6a
PEAK HEIGHT PROFILES
EXISTING CONDITIONS
WORROWING WATERWAY

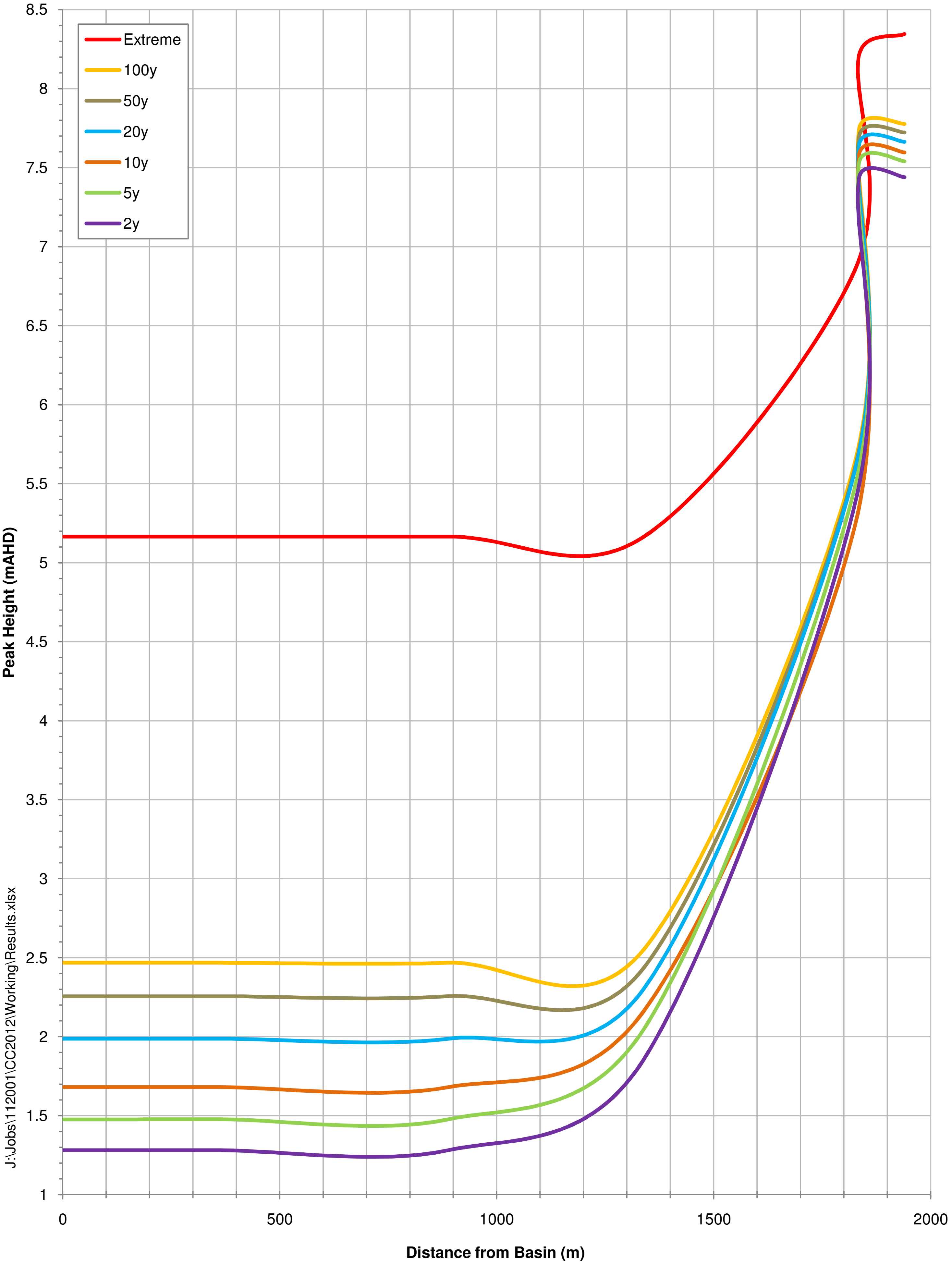
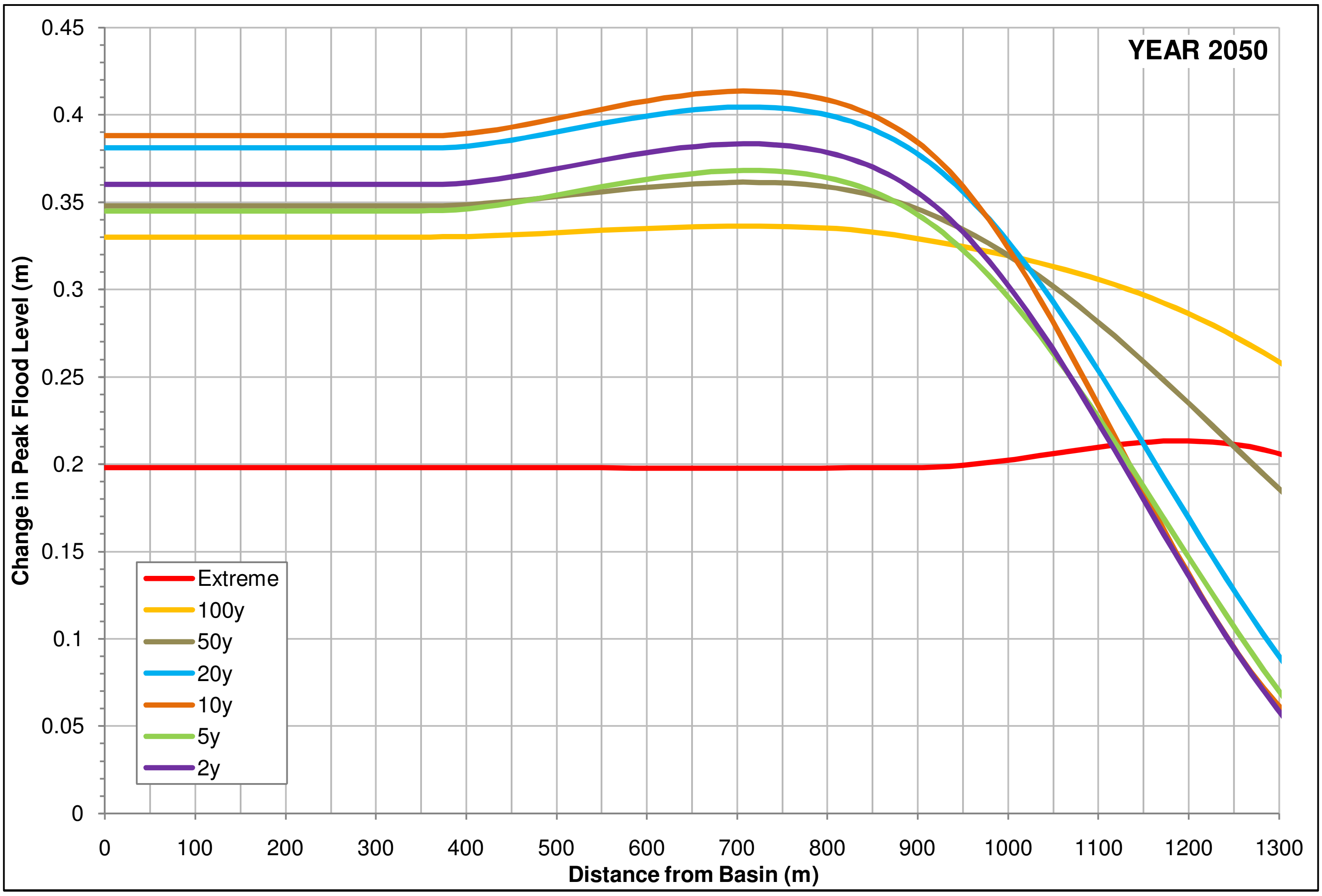


FIGURE 6b
CHANGE IN PEAK FLOOD LEVEL
WORROWING WATERWAY



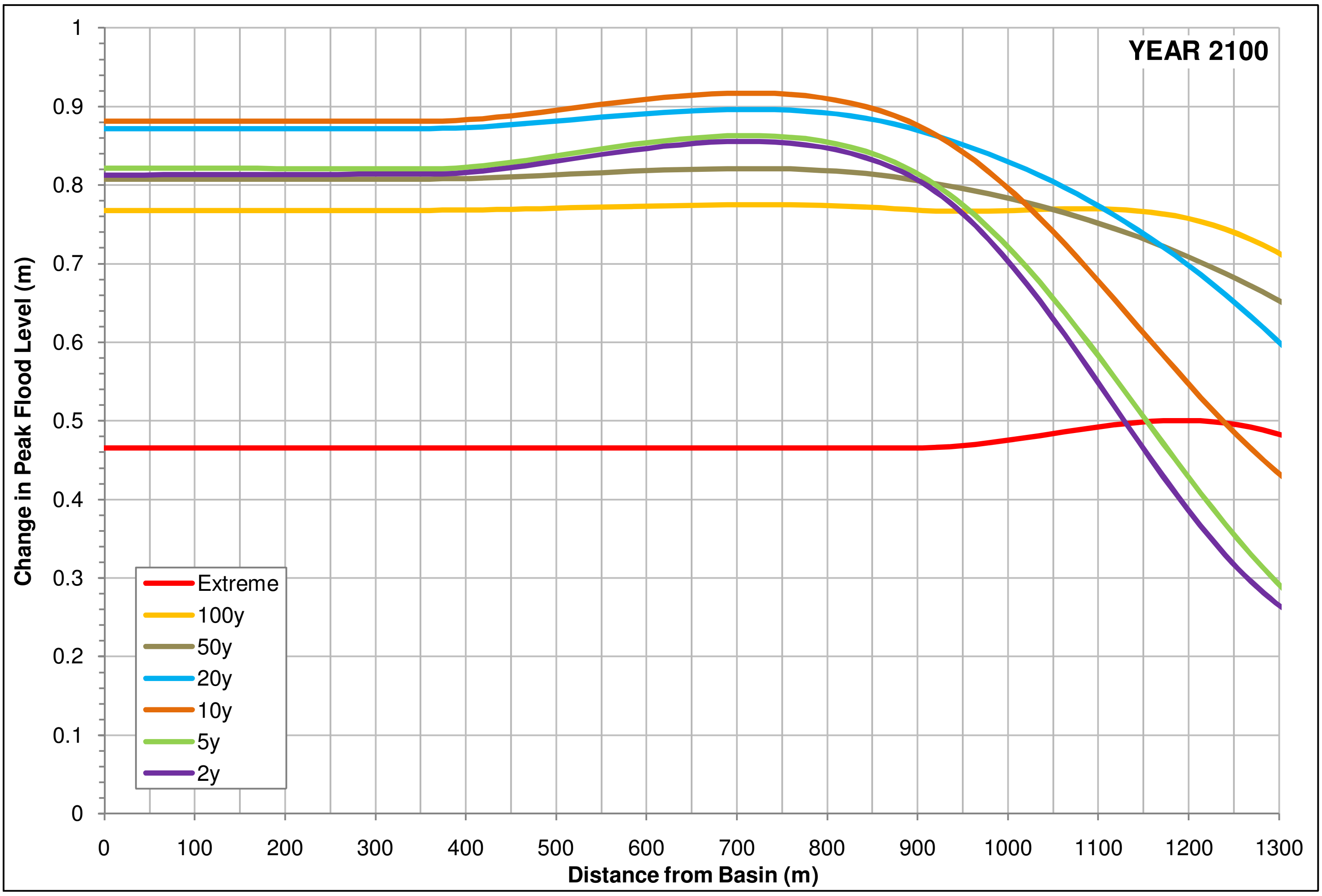


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FIGURE 6c

CHANGE IN PEAK FLOOD LEVEL
WORROWING WATERWAY

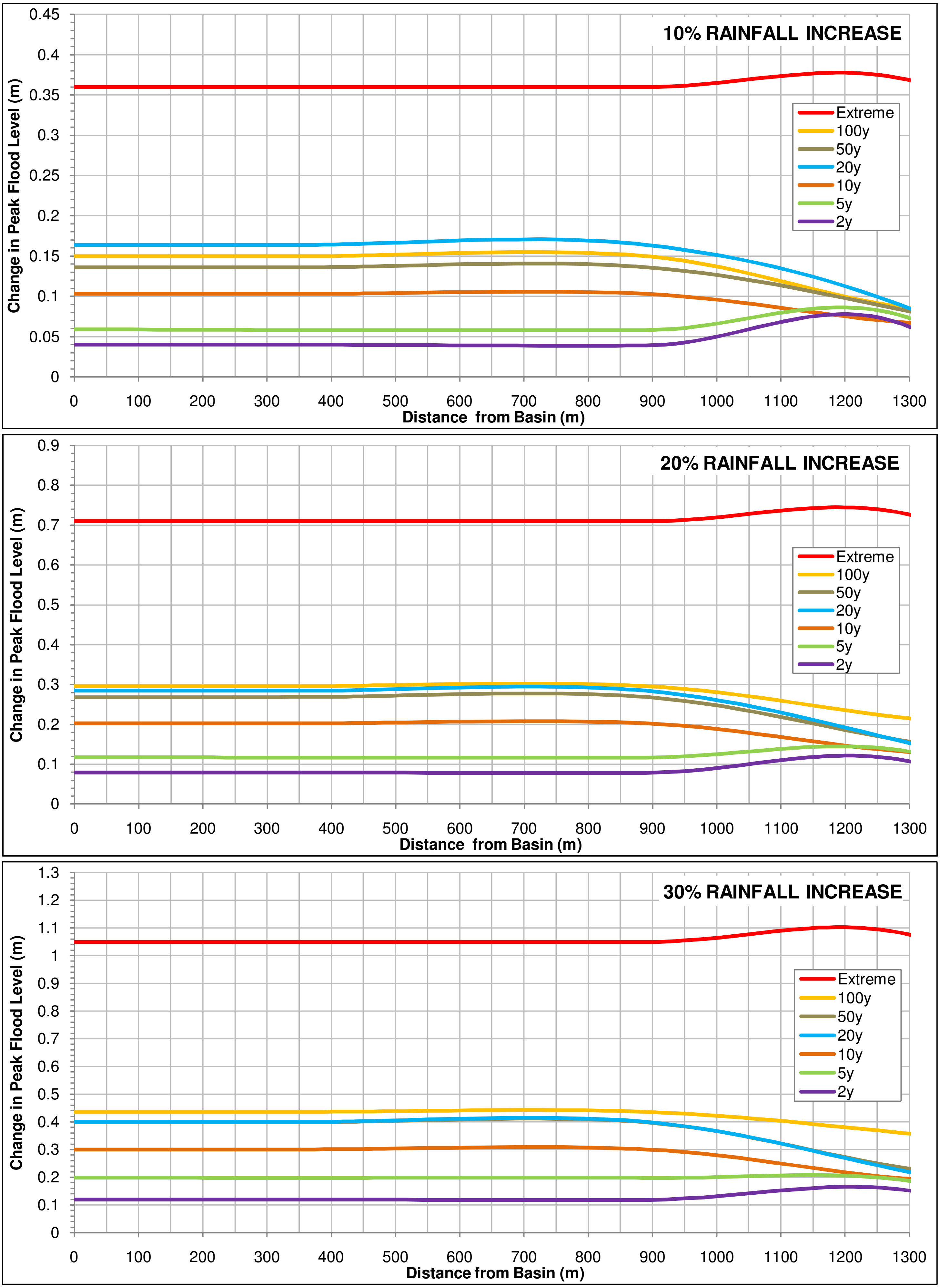

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FIGURE 7a

PEAK HEIGHT PROFILES
EXISTING CONDITIONS
TOMERONG CREEK

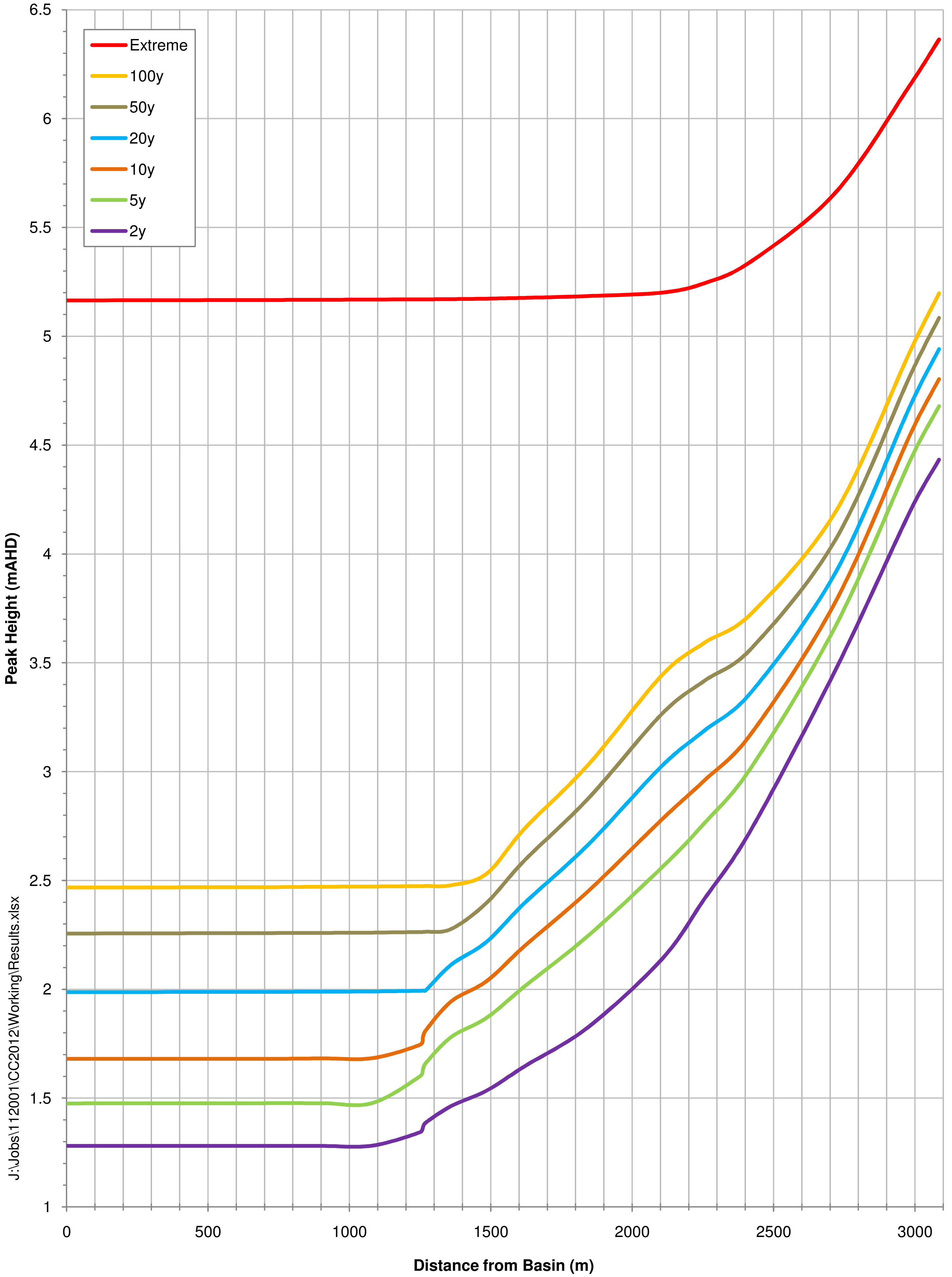
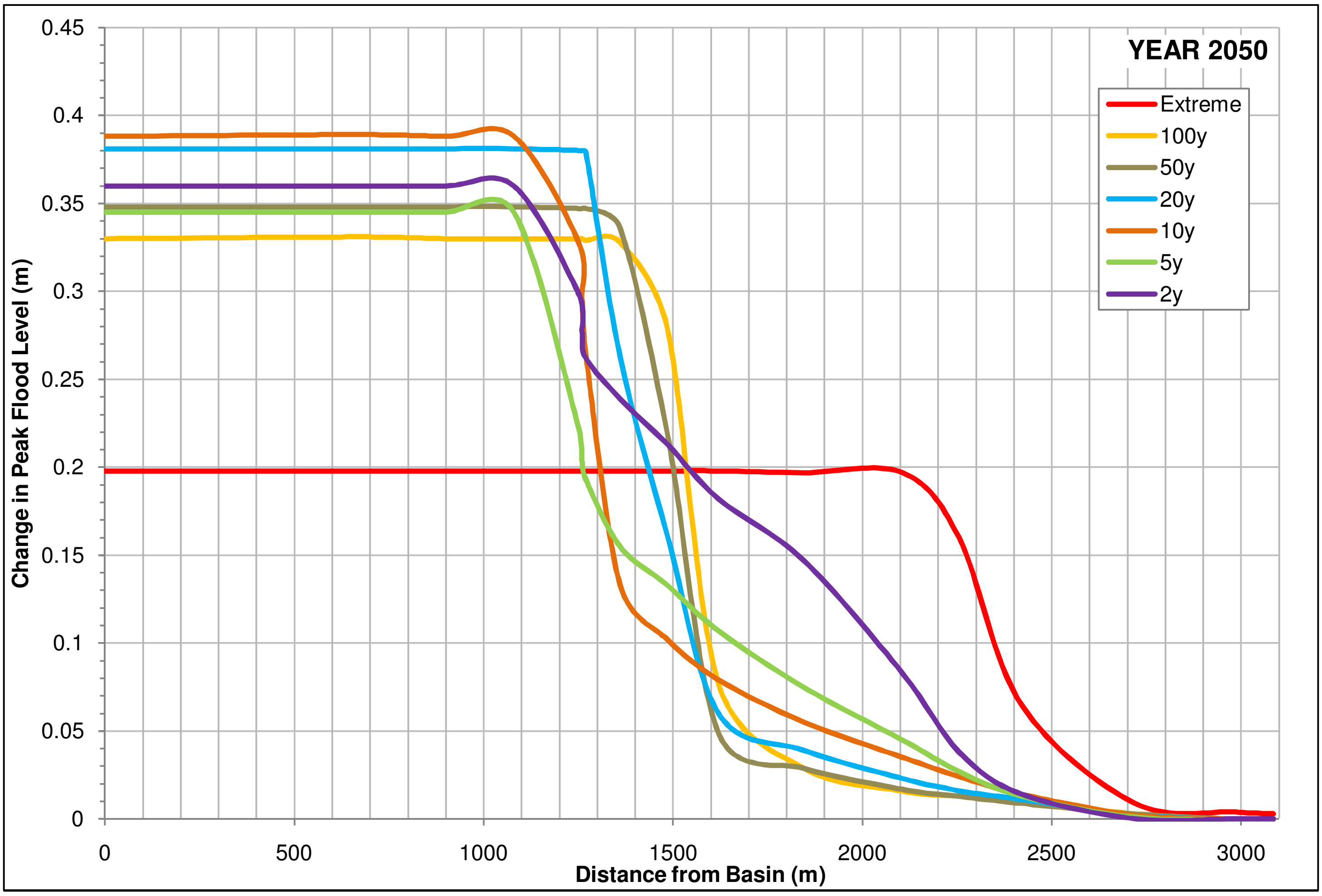


FIGURE 7b
CHANGE IN PEAK FLOOD LEVEL
TOMERONG CREEK



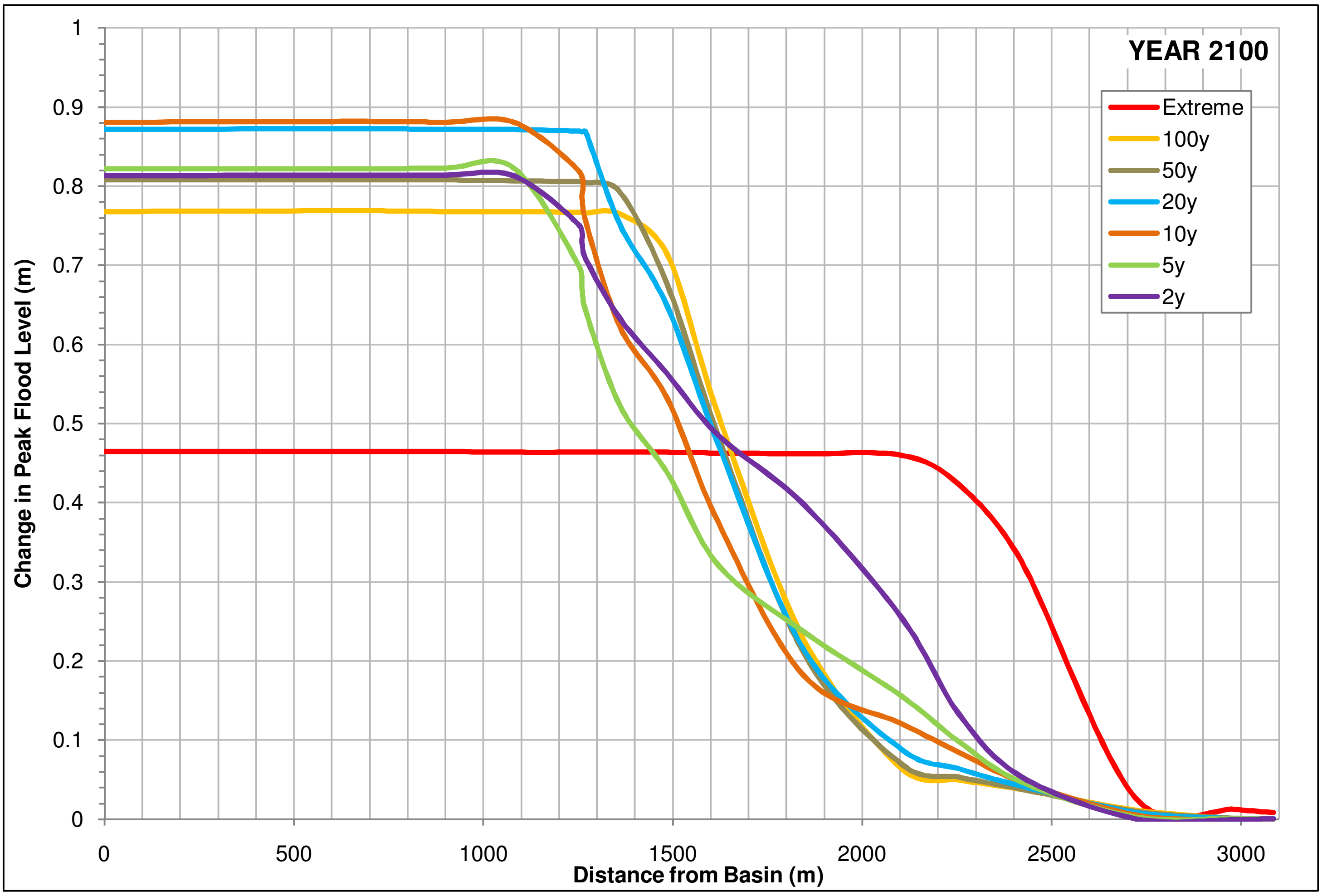


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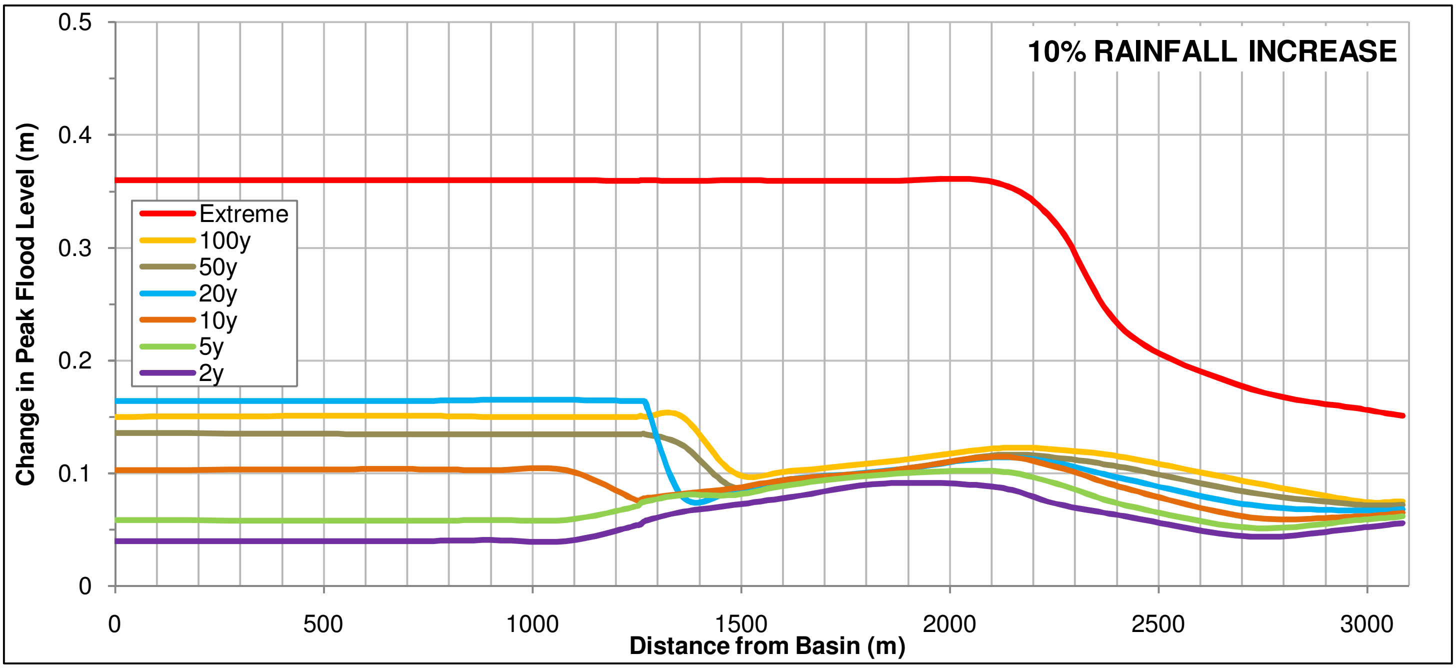
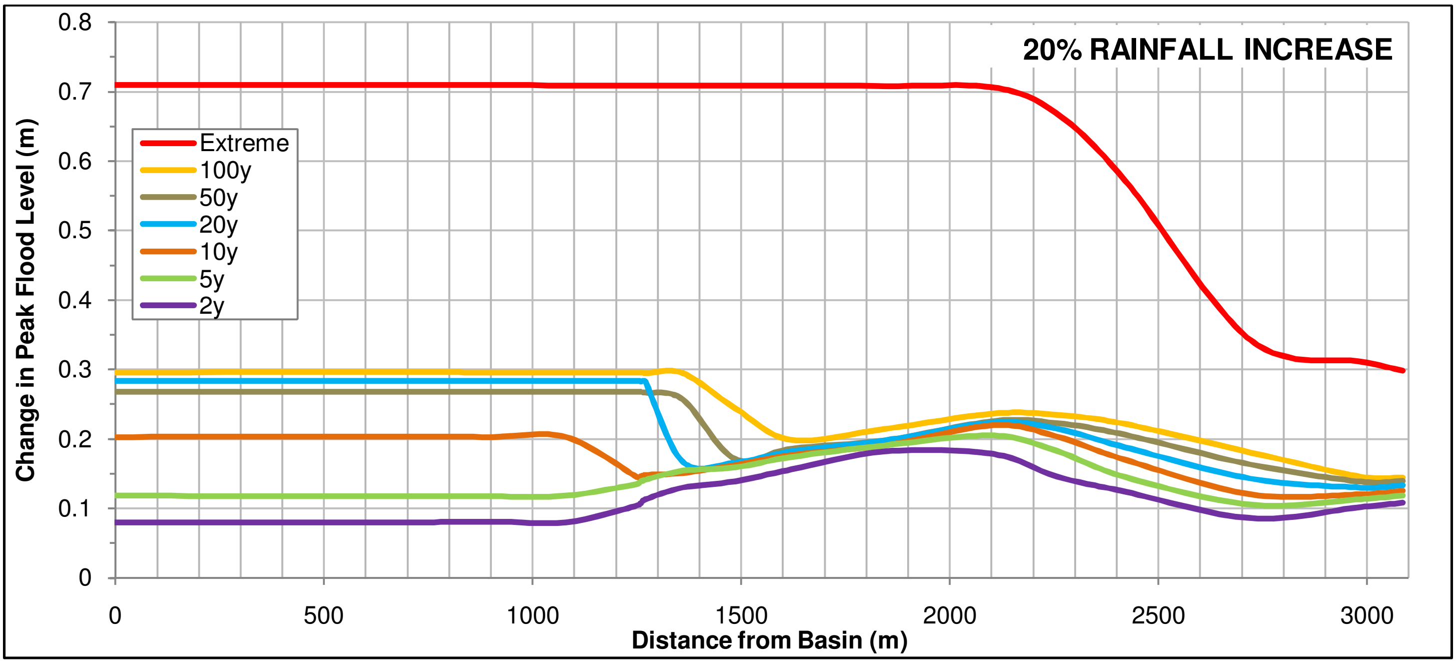
FIGURE 7c

CHANGE IN PEAK FLOOD LEVEL
TOMERONG CREEK





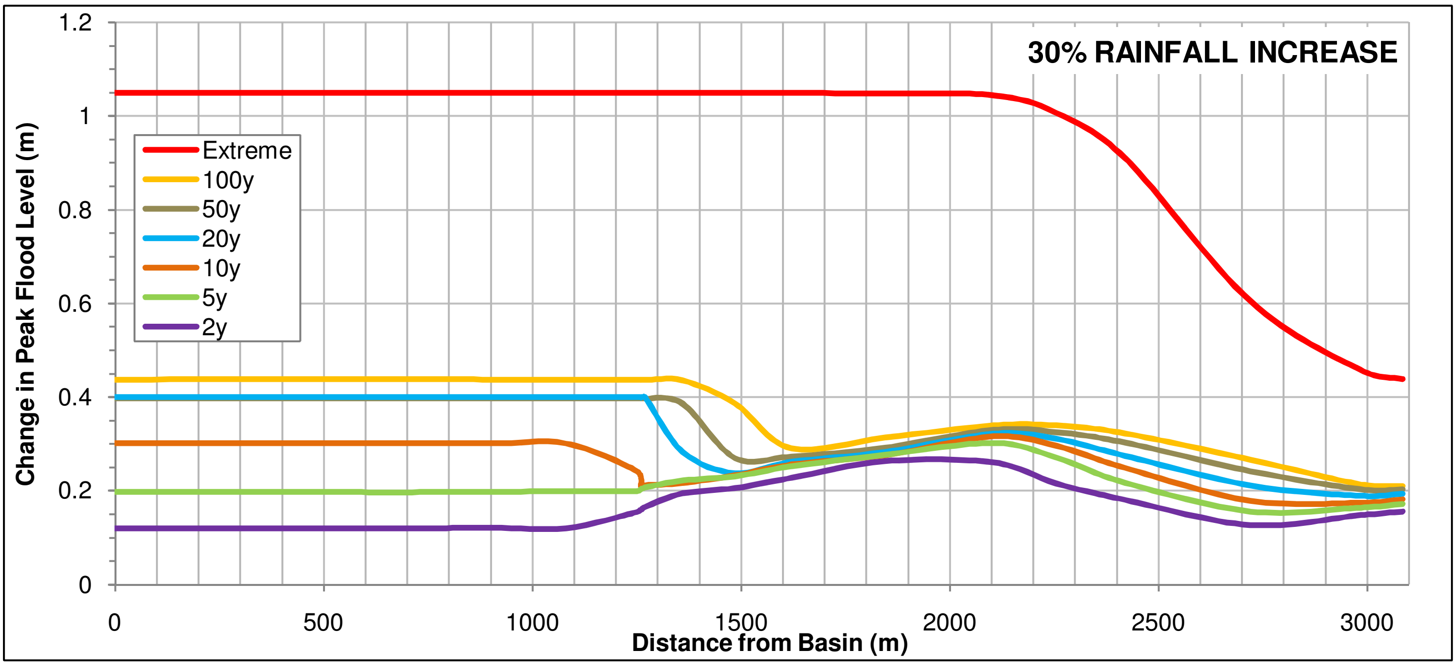


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FIGURE 8a
PEAK HEIGHT PROFILES
EXISTING CONDITIONS
HOME CREEK

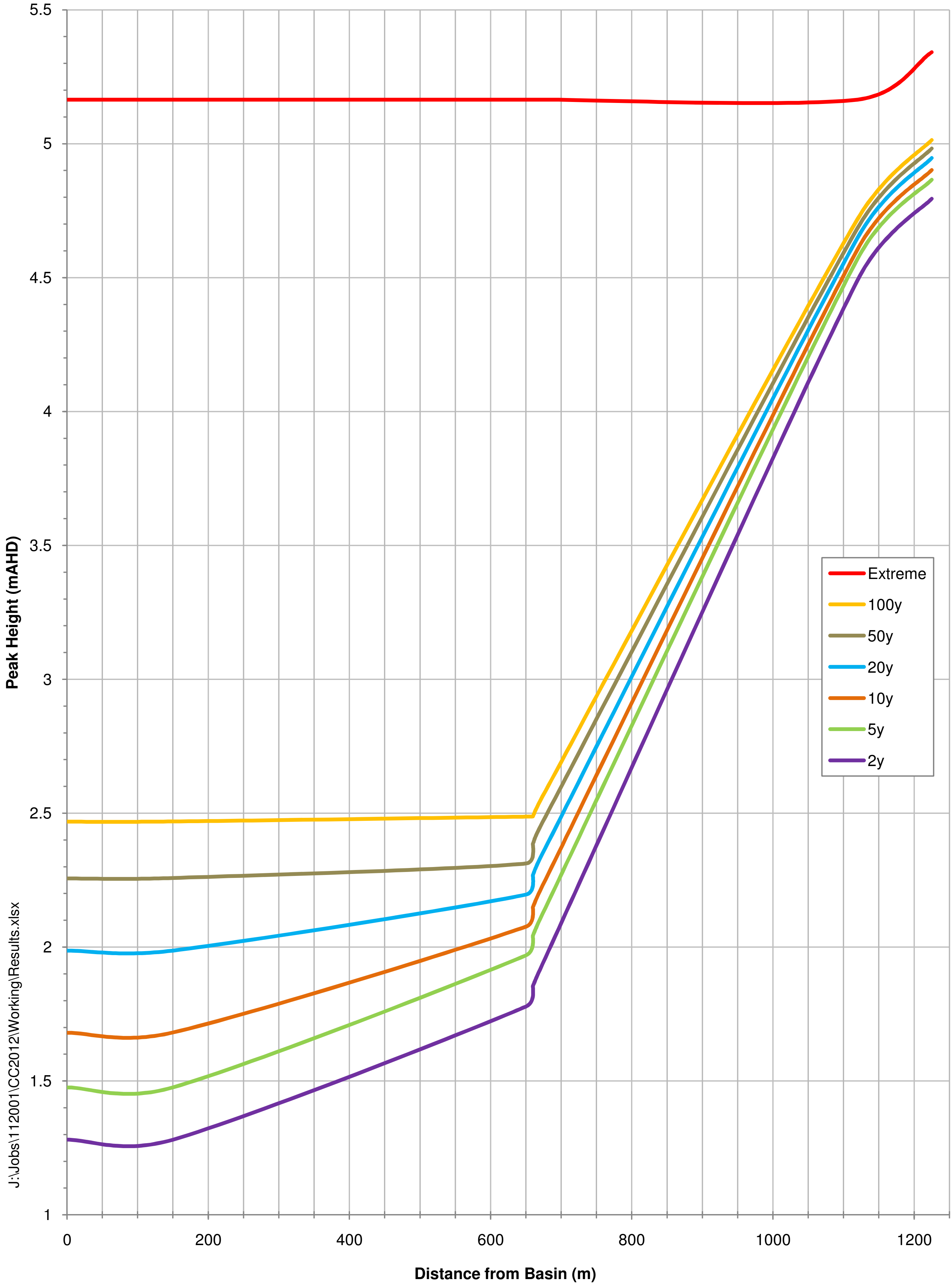

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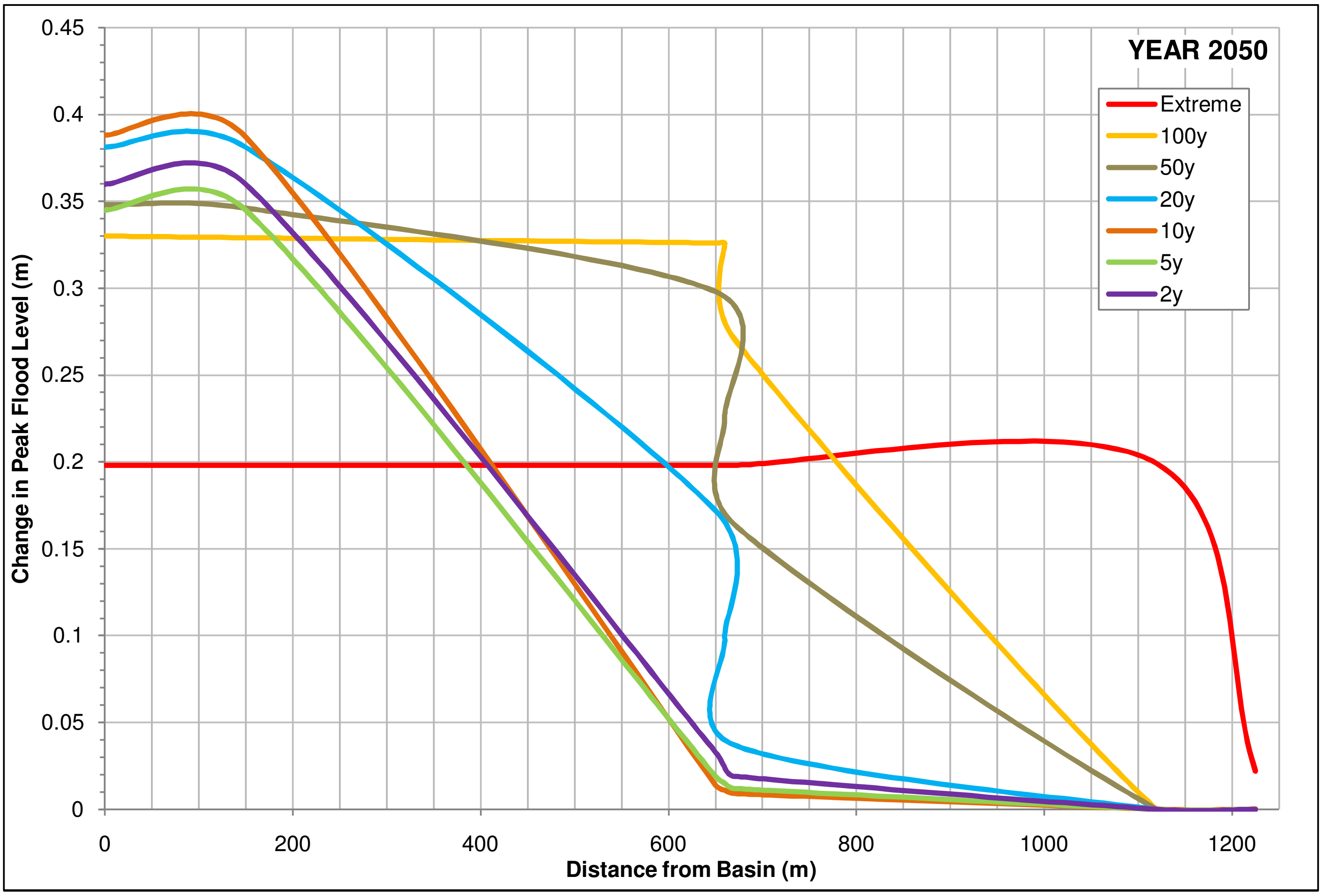
FIGURE 8b
CHANGE IN PEAK FLOOD LEVEL
HOME CREEK



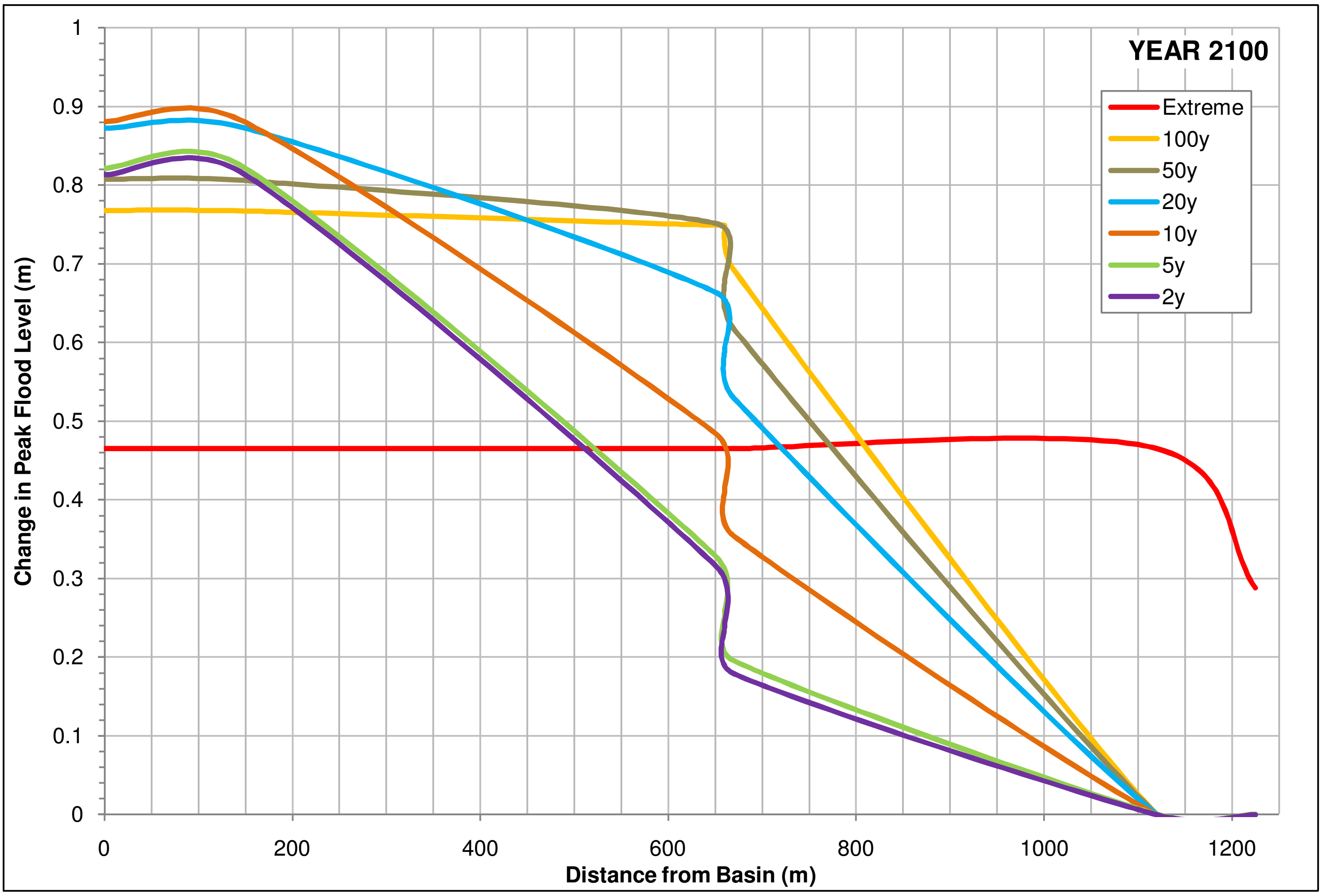


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FIGURE 8c

CHANGE IN PEAK FLOOD LEVEL
HOME CREEK

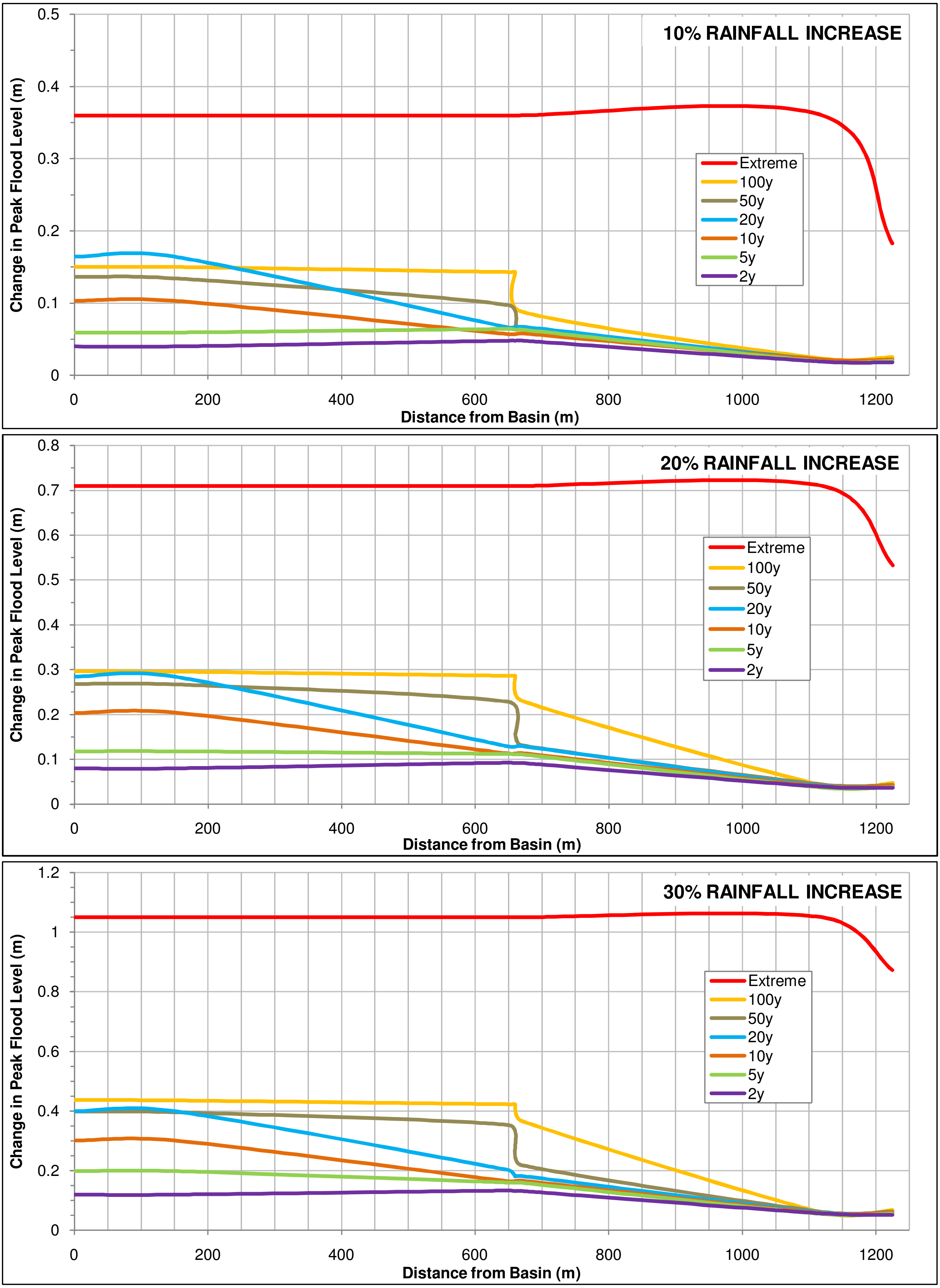

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FIGURE 9a
PEAK HEIGHT PROFILES
EXISTING CONDITIONS
PATS CREEK

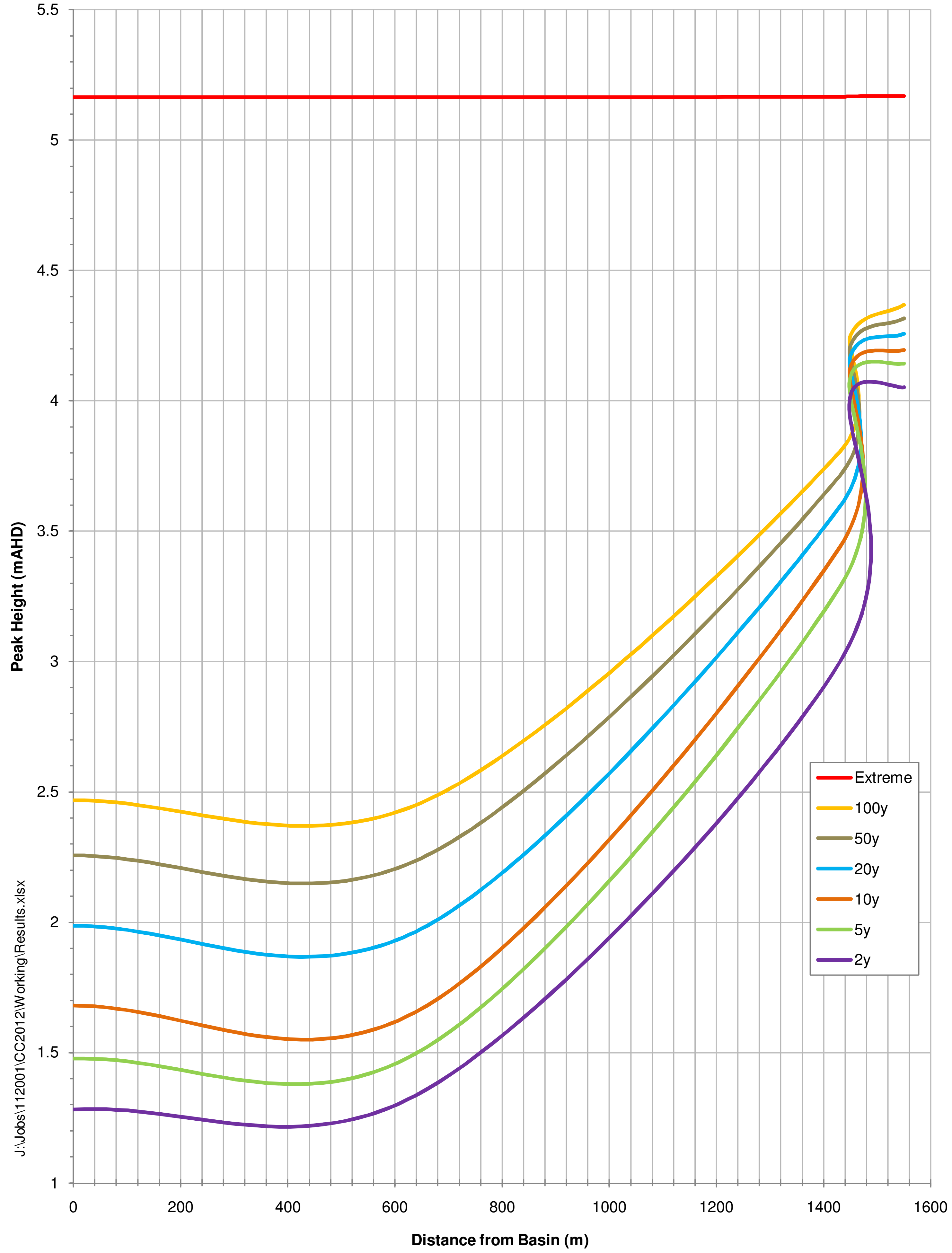
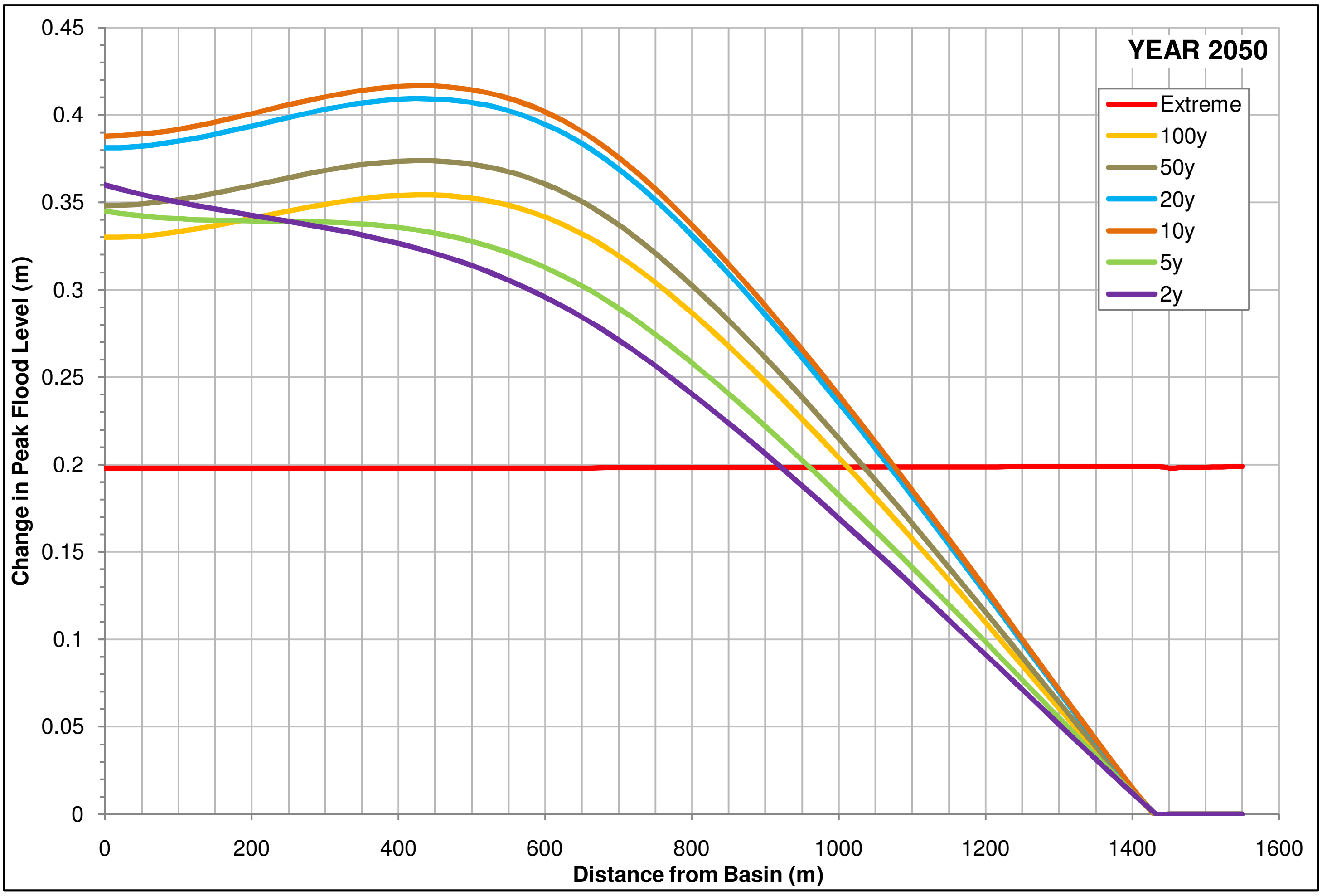


FIGURE 9b
CHANGE IN PEAK FLOOD LEVEL
PATS CREEK



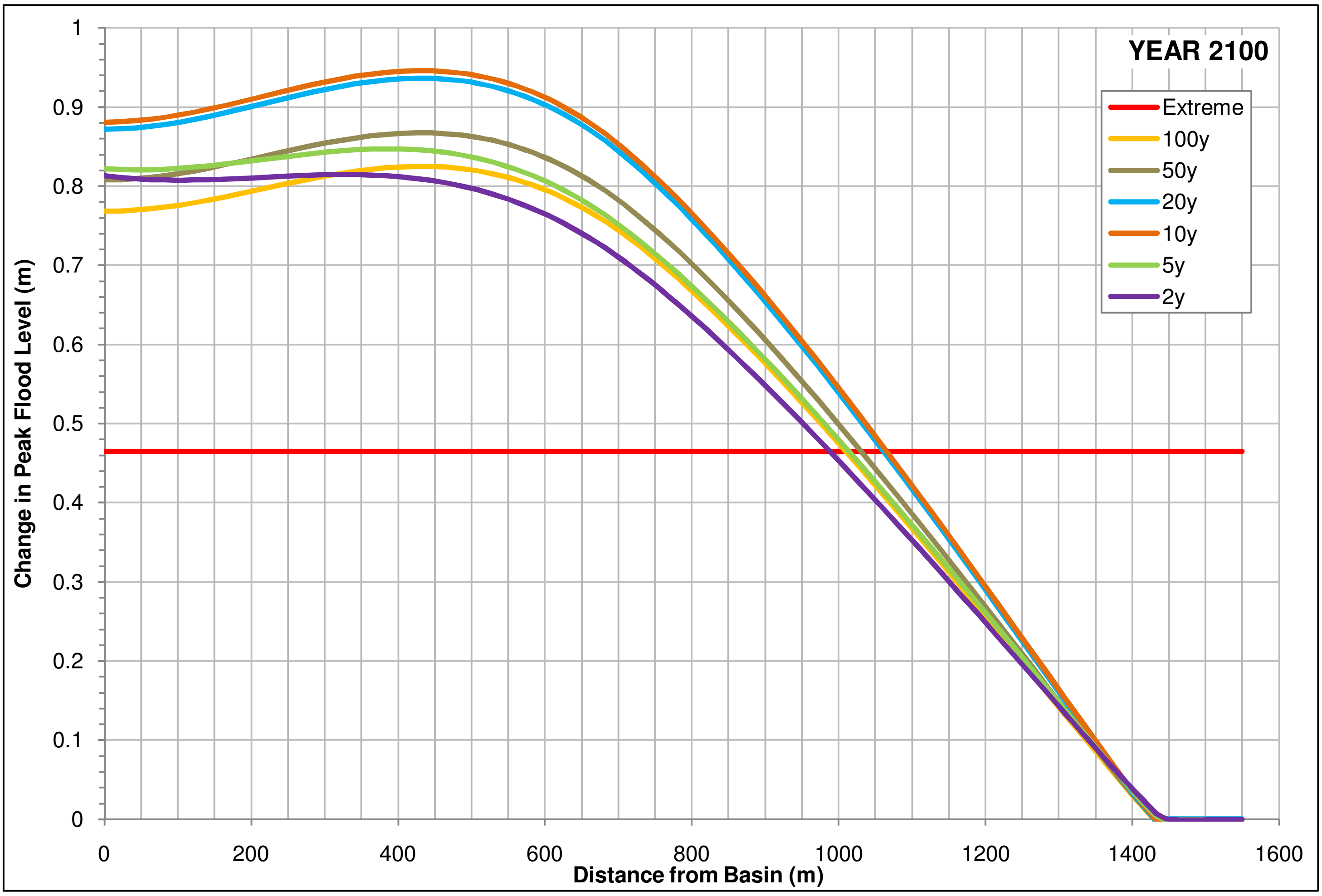


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FIGURE 9c

CHANGE IN PEAK FLOOD LEVEL

PATS CREEK

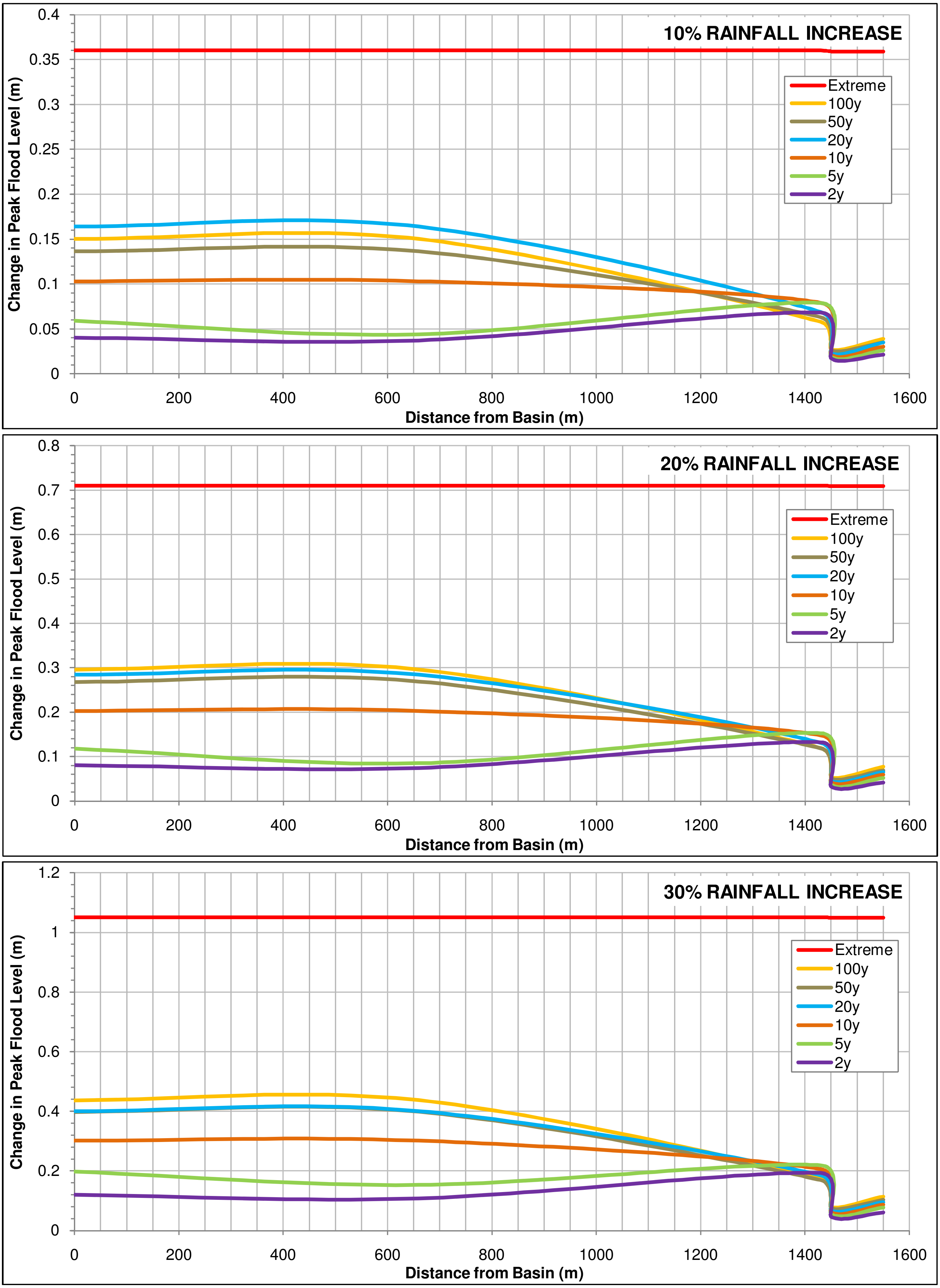

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FIGURE 10a
PEAK HEIGHT PROFILES
EXISTING CONDITIONS
WANDANDIAN CREEK

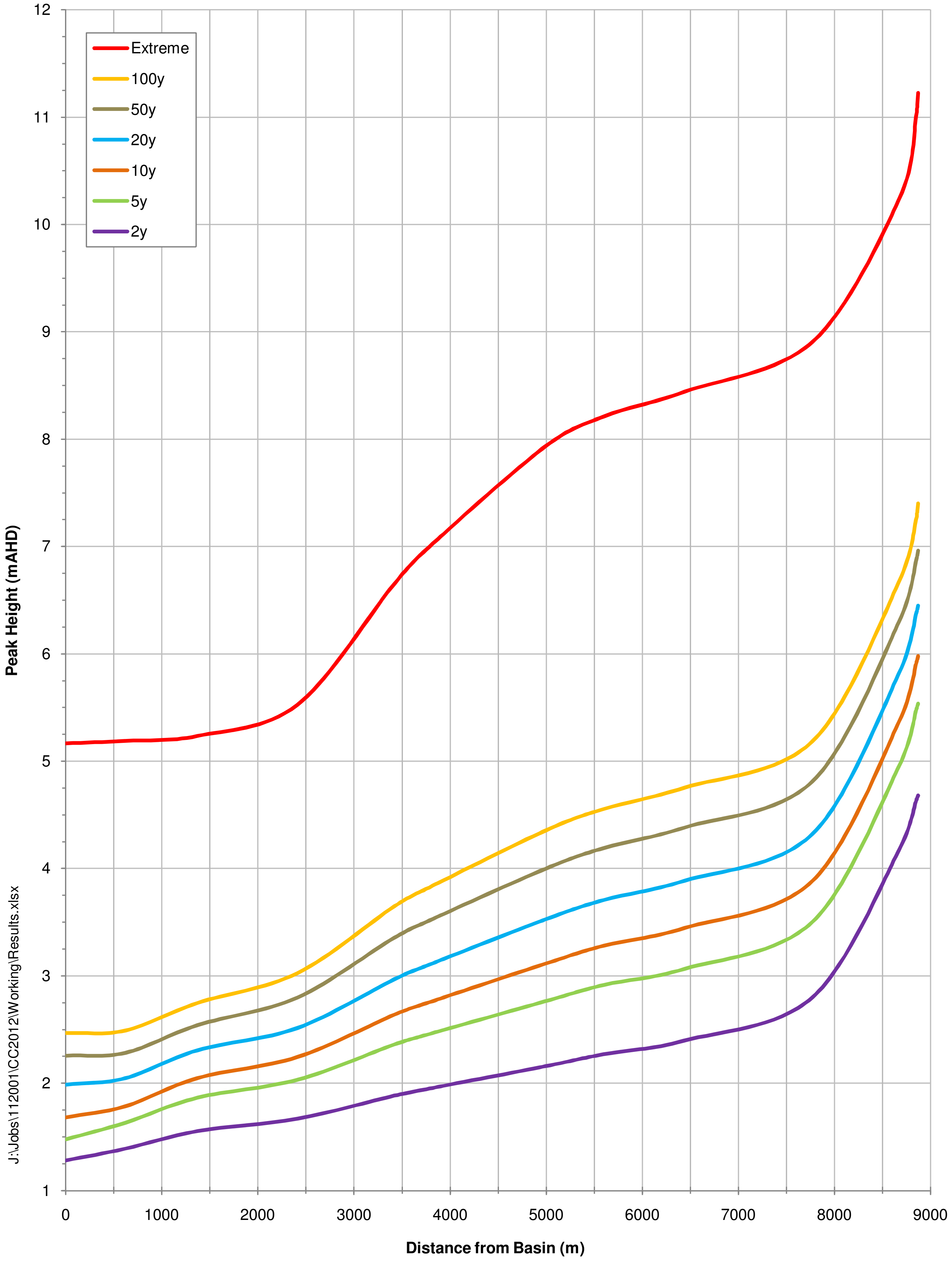
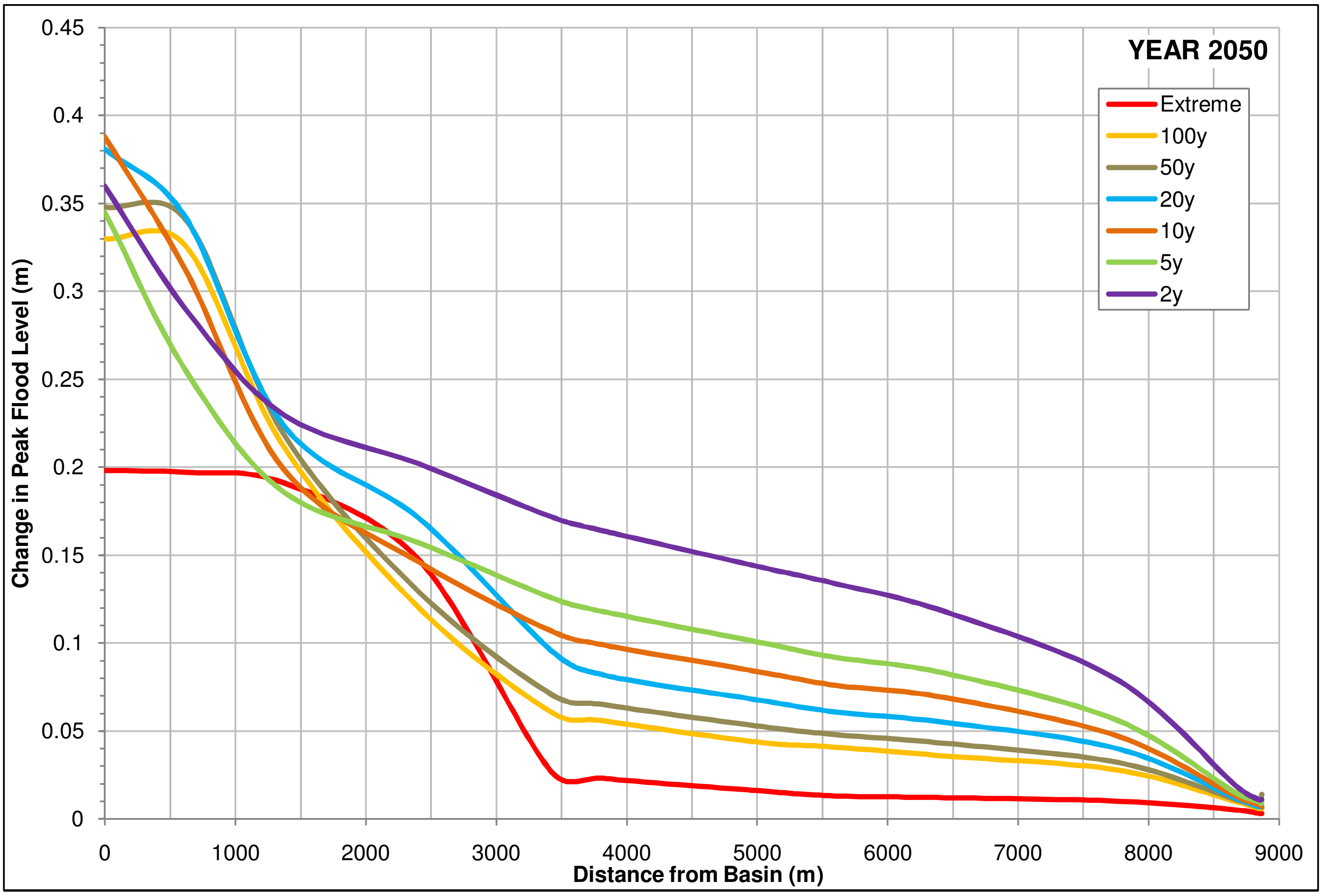


FIGURE 10b
CHANGE IN PEAK FLOOD LEVEL
WANDANDIAN CREEK



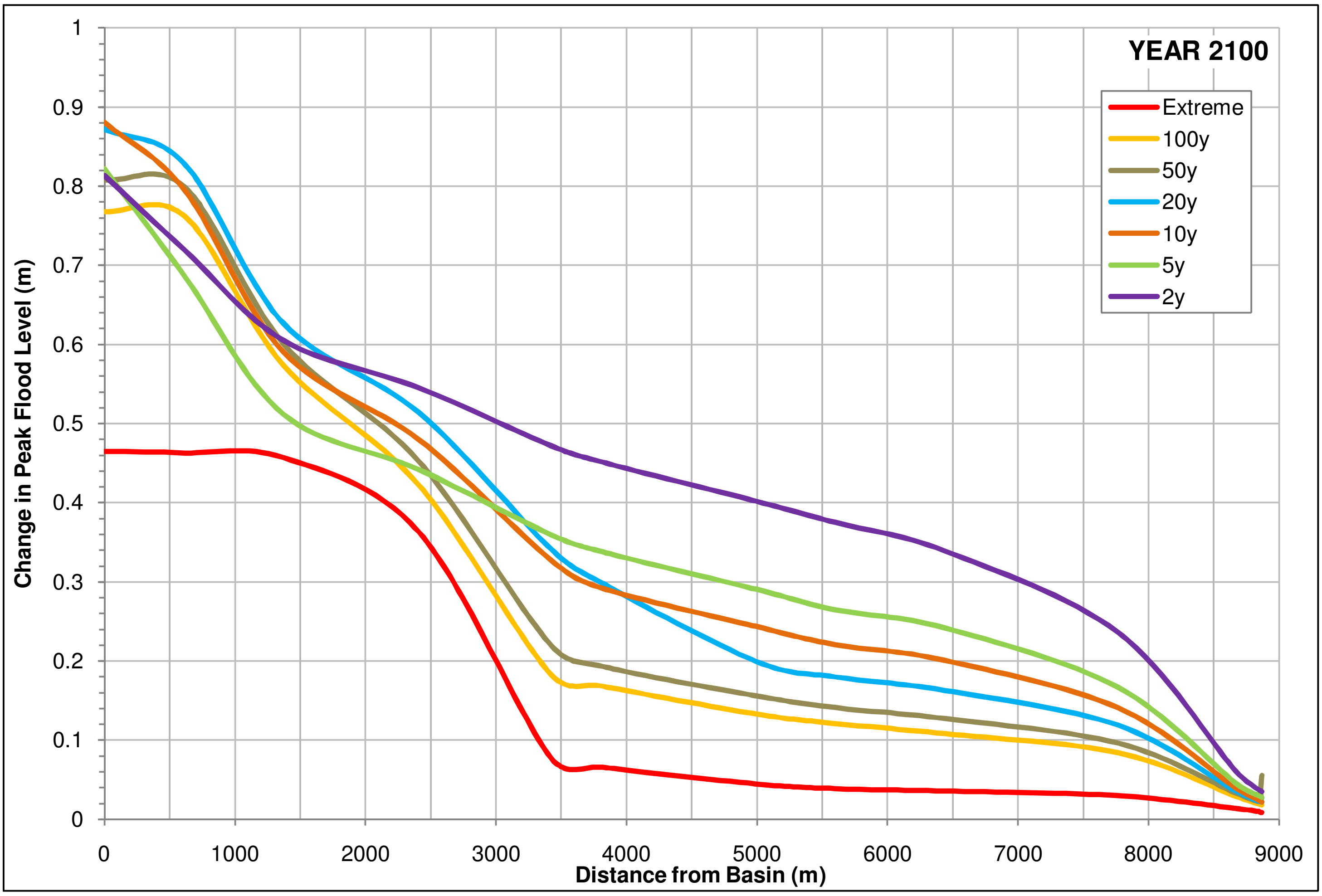


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FIGURE 10c

CHANGE IN PEAK FLOOD LEVEL
WANDANDIAN CREEK

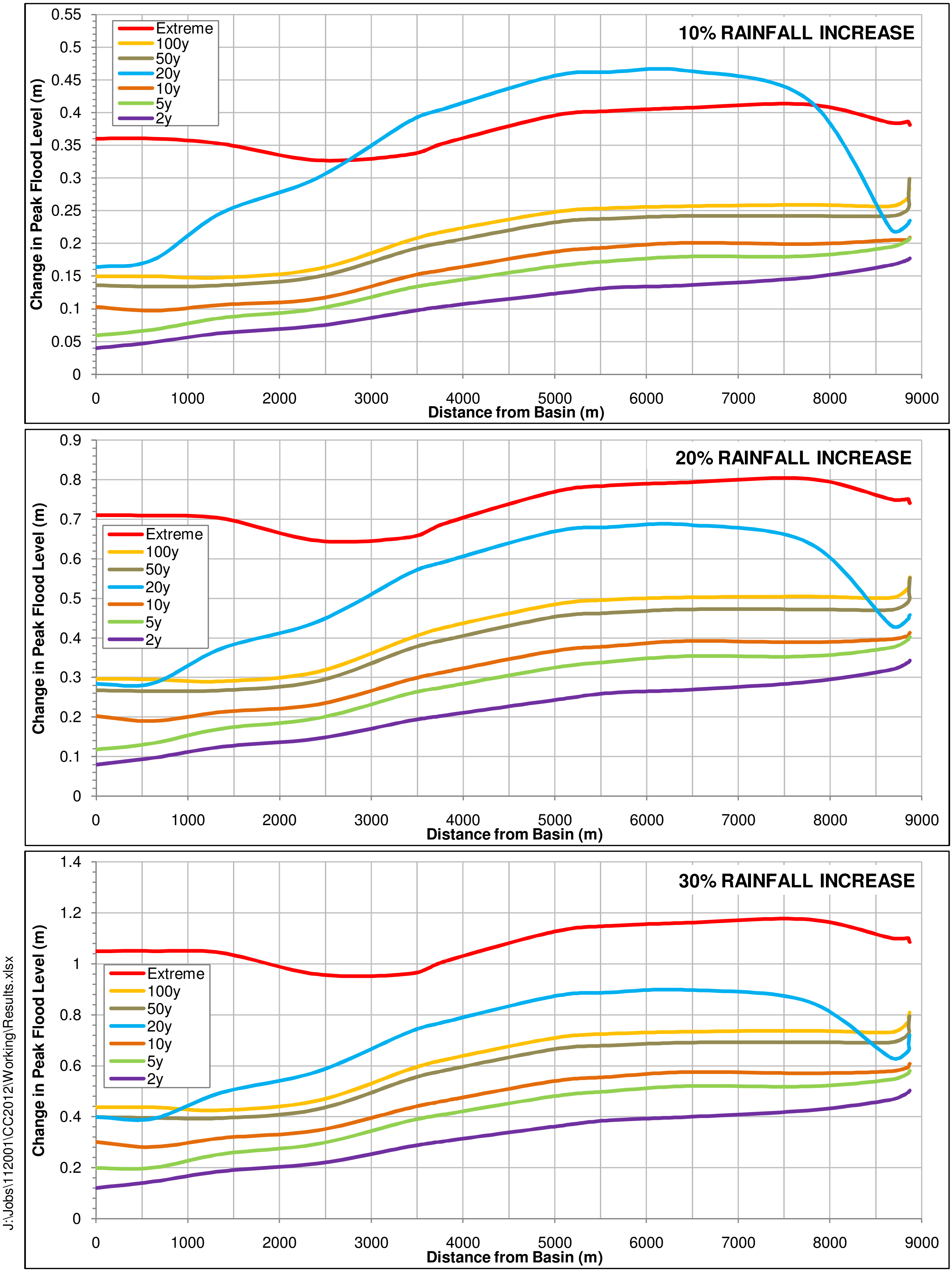


FIGURE 11a
**PEAK HEIGHT PROFILES
EXISTING CONDITIONS
COW CREEK**

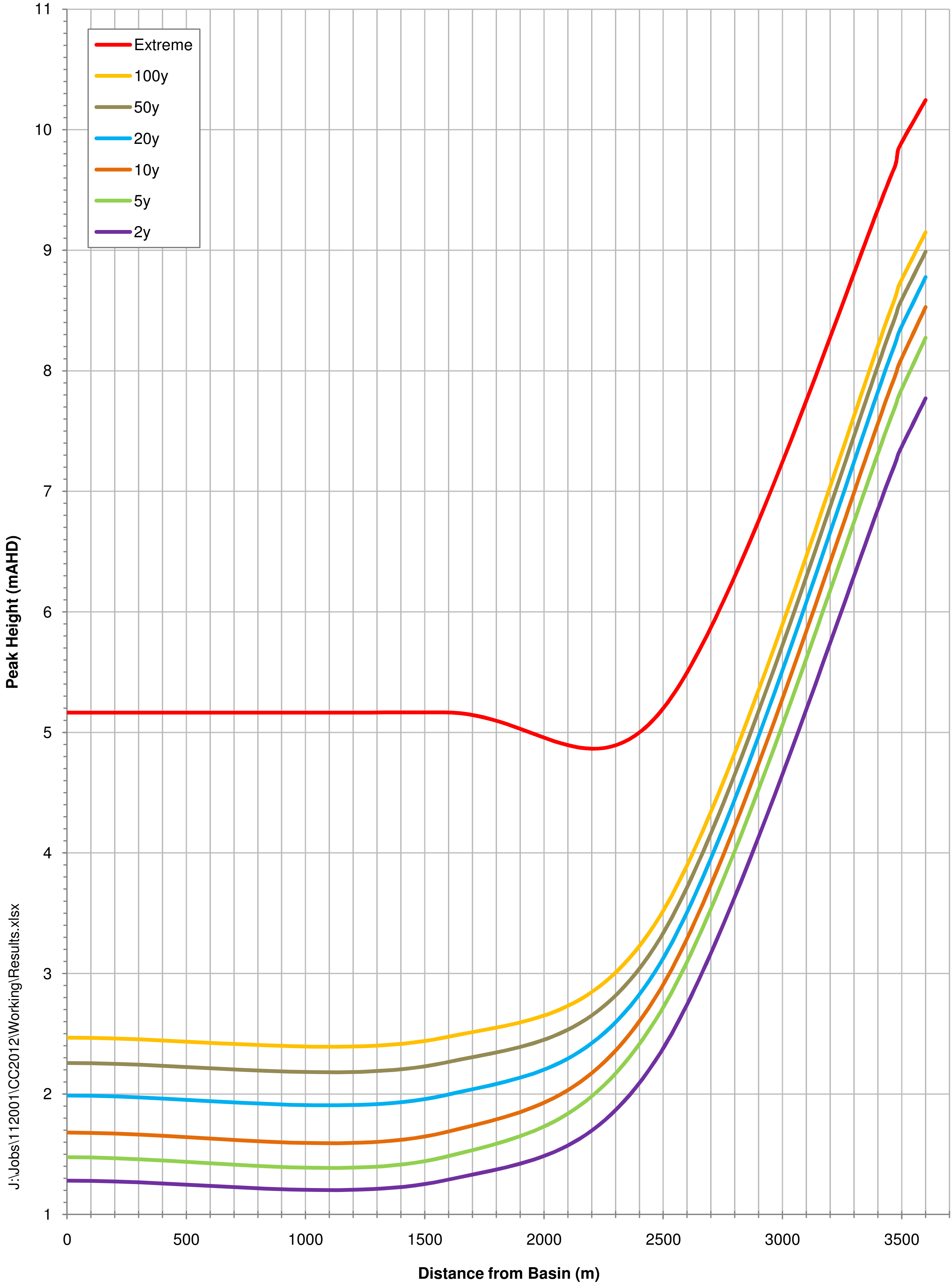
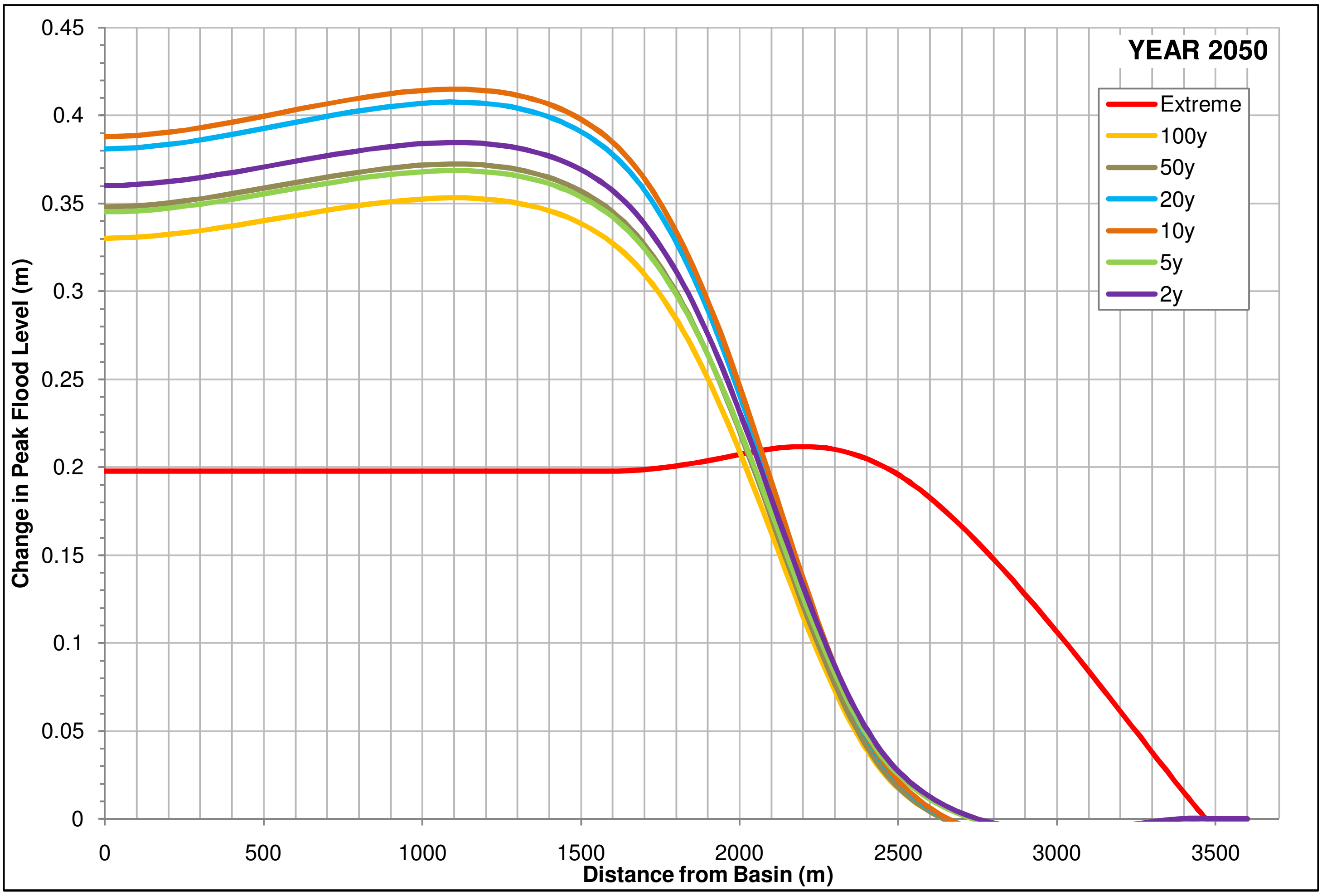


FIGURE 11b

CHANGE IN PEAK FLOOD LEVEL

COW CREEK



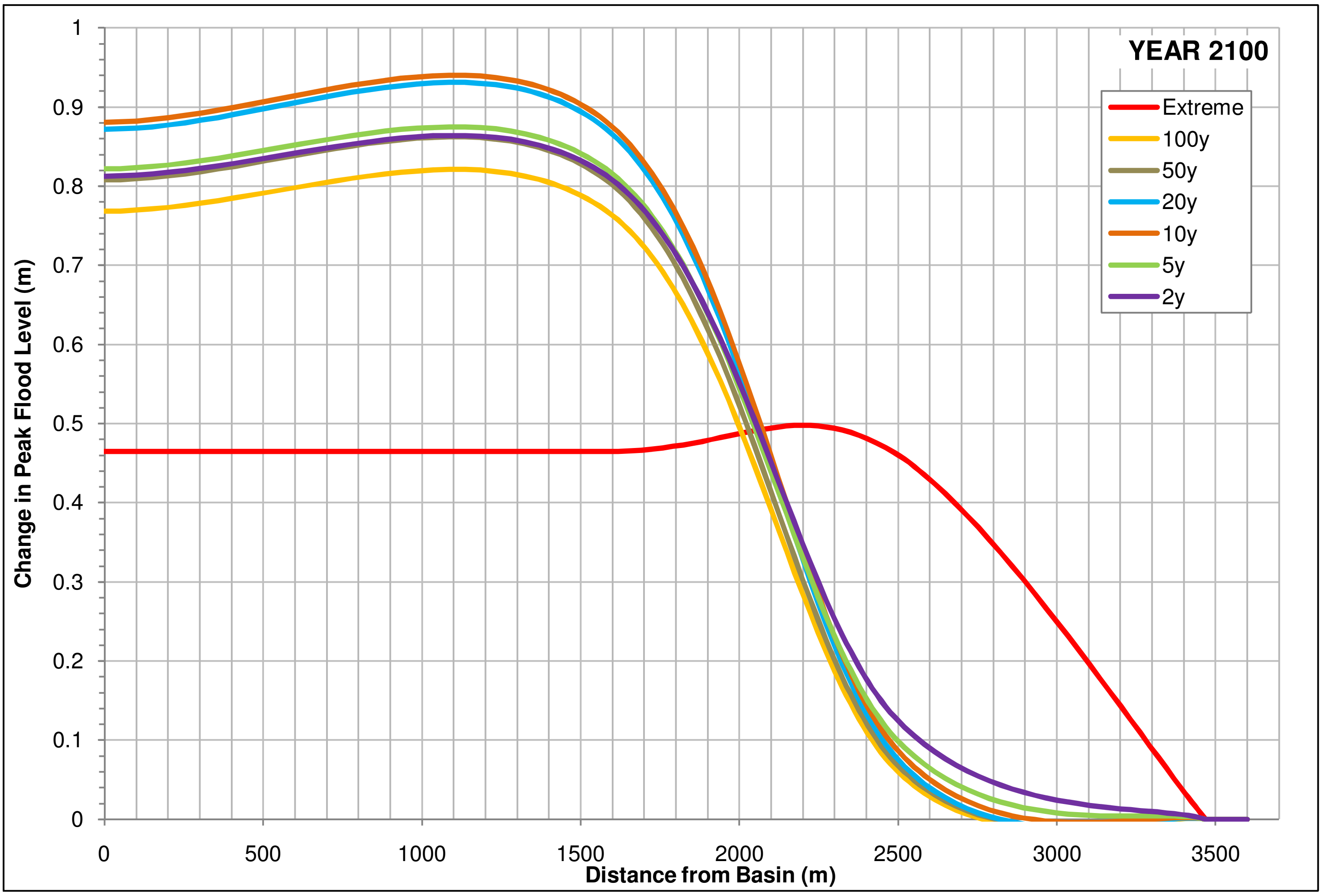


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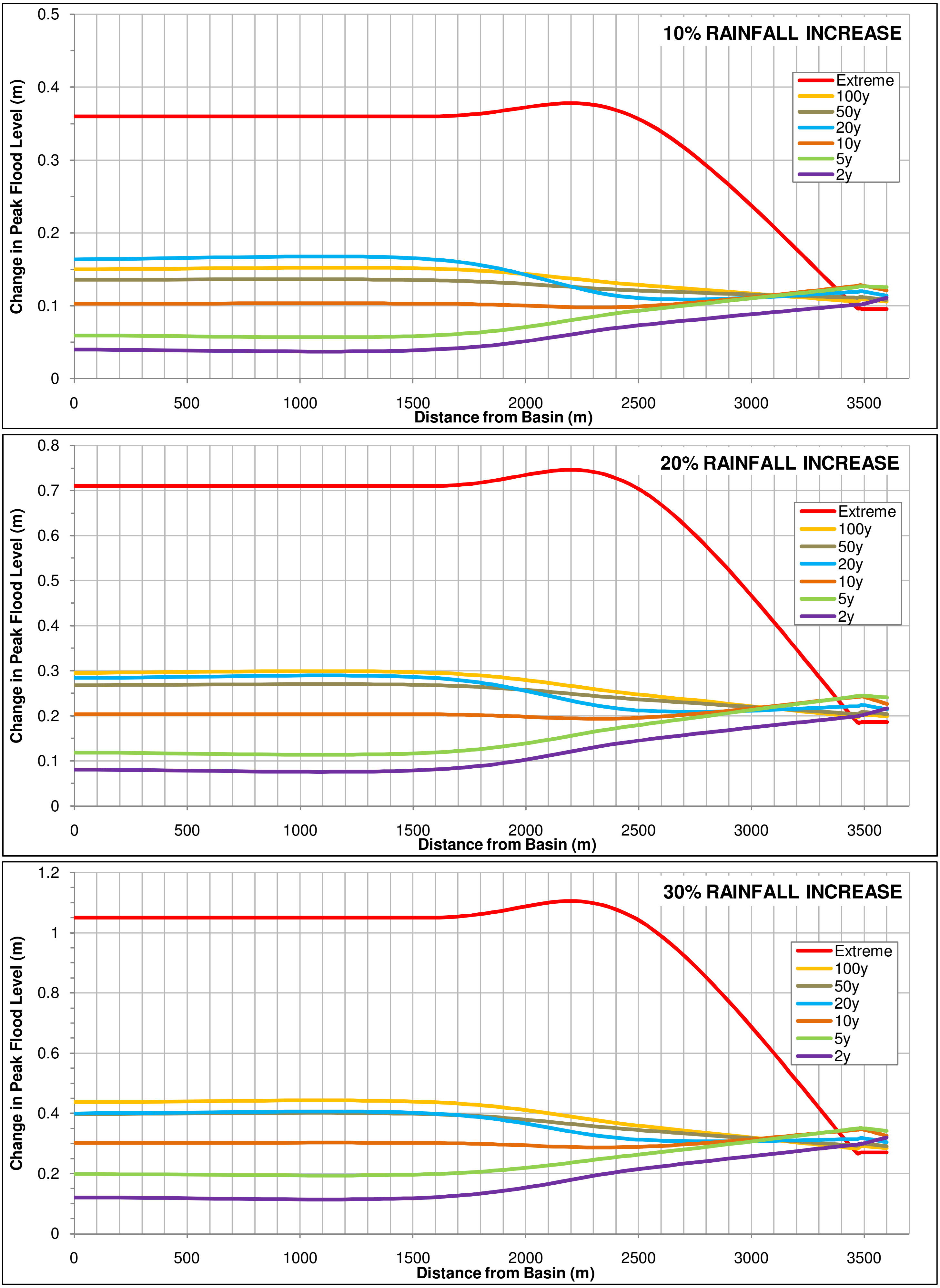
FIGURE 11c
CHANGE IN PEAK FLOOD LEVEL
COW CREEK



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Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning

	or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.

freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the

	consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to “water level”. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.

water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

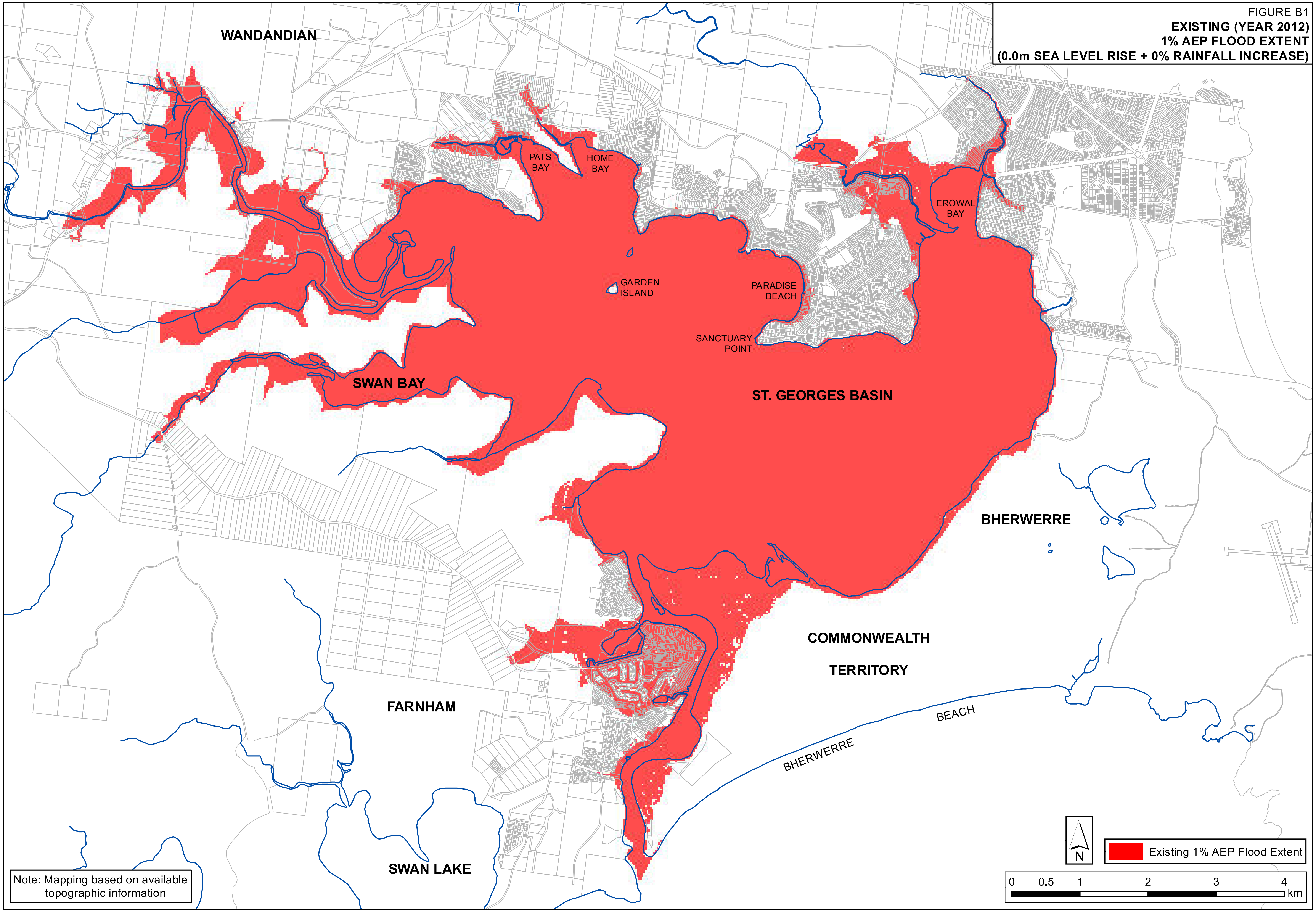

FIGURE B1
EXISTING (YEAR 2012)
1% AEP FLOOD EXTENT
(0.0m SEA LEVEL RISE + 0% RAINFALL INCREASE)

Note: Mapping based on available topographic information

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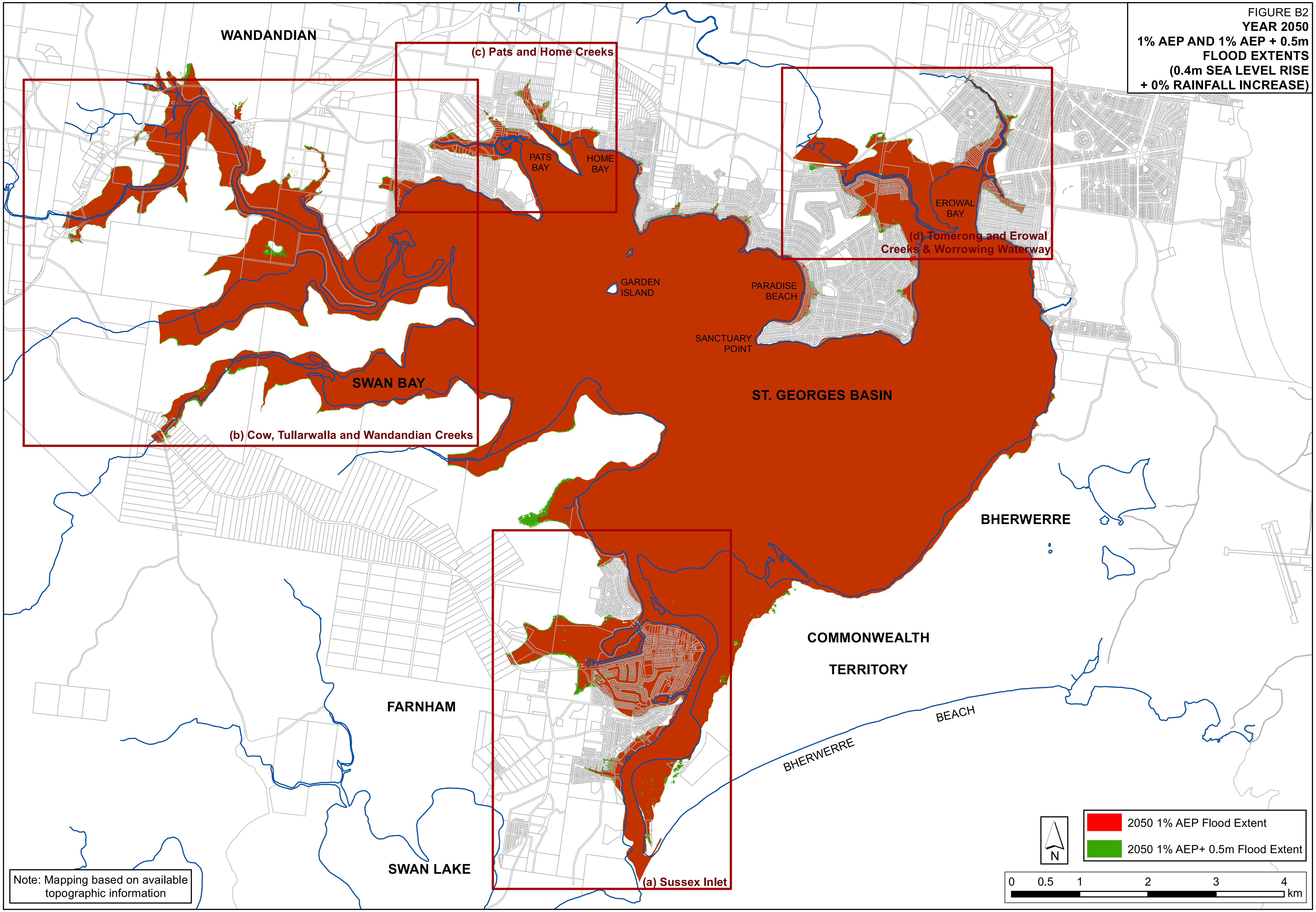


FIGURE B2
YEAR 2050
1% AEP AND 1% AEP + 0.5m
FLOOD EXTENTS
(0.4m SEA LEVEL RISE
+ 0% RAINFALL INCREASE)
WANDANDIAN
(c) Pats and Home Creeks
PATS BAY
HOME BAY
EROWAL BAY
(d) Tomerong and Erowal Creeks & Worrowing Waterway
GARDEN ISLAND
PARADISE BEACH
SANCTUARY POINT
SWAN BAY
ST. GEORGES BASIN
(b) Cow, Tullarwalla and Wandandian Creeks
BHERWERRE
COMMONWEALTH
TERRITORY
FARNHAM
BEACH
BHERWERRE
SWAN LAKE
(a) Sussex Inlet
2050 1% AEP Flood Extent
2050 1% AEP+ 0.5m Flood Extent
N
0 0.5 1 2 3 4 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureB2_2050_100y_and_FPL_extents.mxd

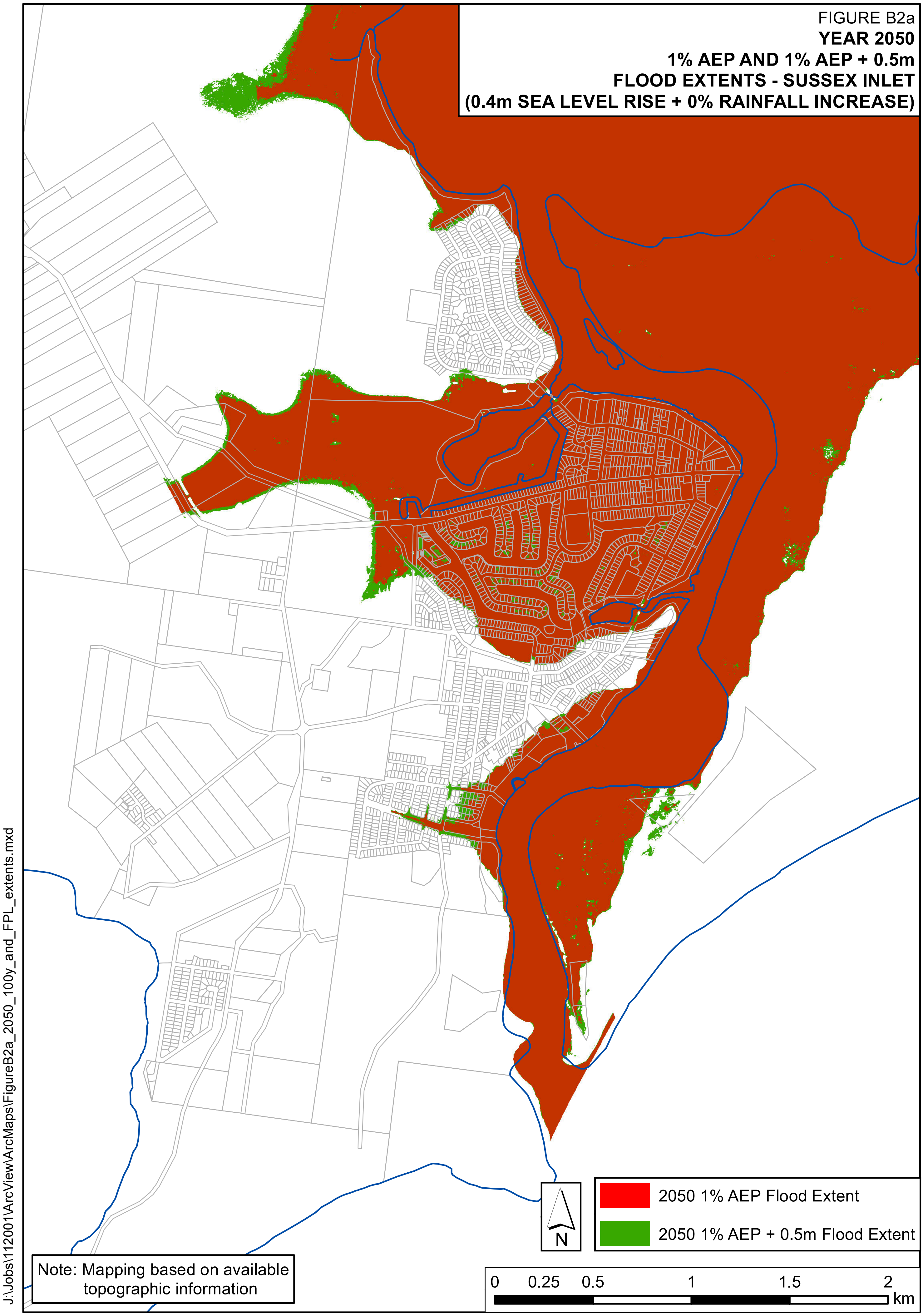


FIGURE B2a
YEAR 2050
1% AEP AND 1% AEP + 0.5m
FLOOD EXTENTS - SUSSEX INLET
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
2050 1% AEP Flood Extent
2050 1% AEP + 0.5m Flood Extent
N
0 0.25 0.5 1 1.5 2 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureB2a_2050_100y_and_FPL_extents.mxd

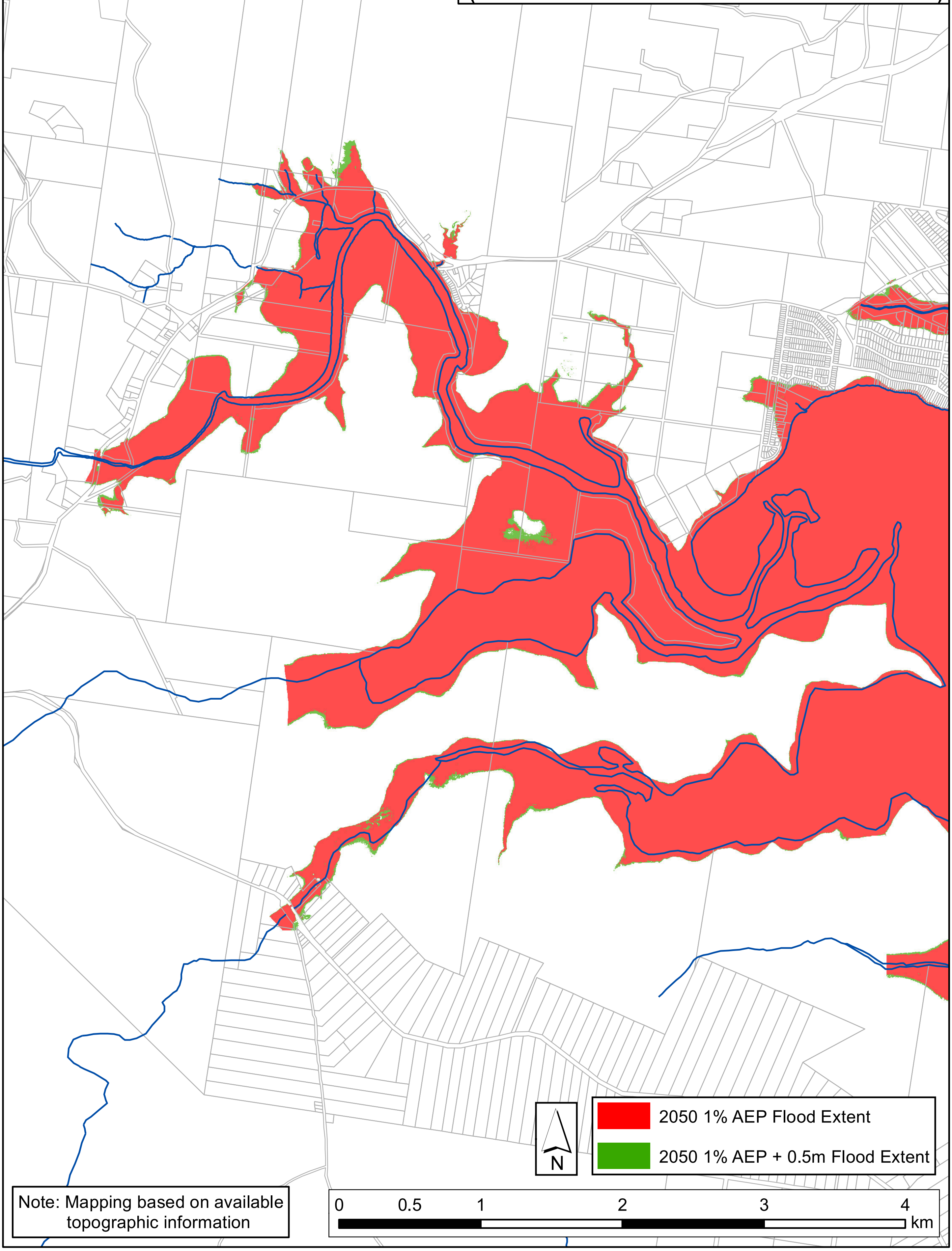
FIGURE B2b

YEAR 2050

1% AEP AND 1% AEP + 0.5m

FLOOD EXTENTS - COW, TULLARWALLA AND WANDANDIAN CREEKS

(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



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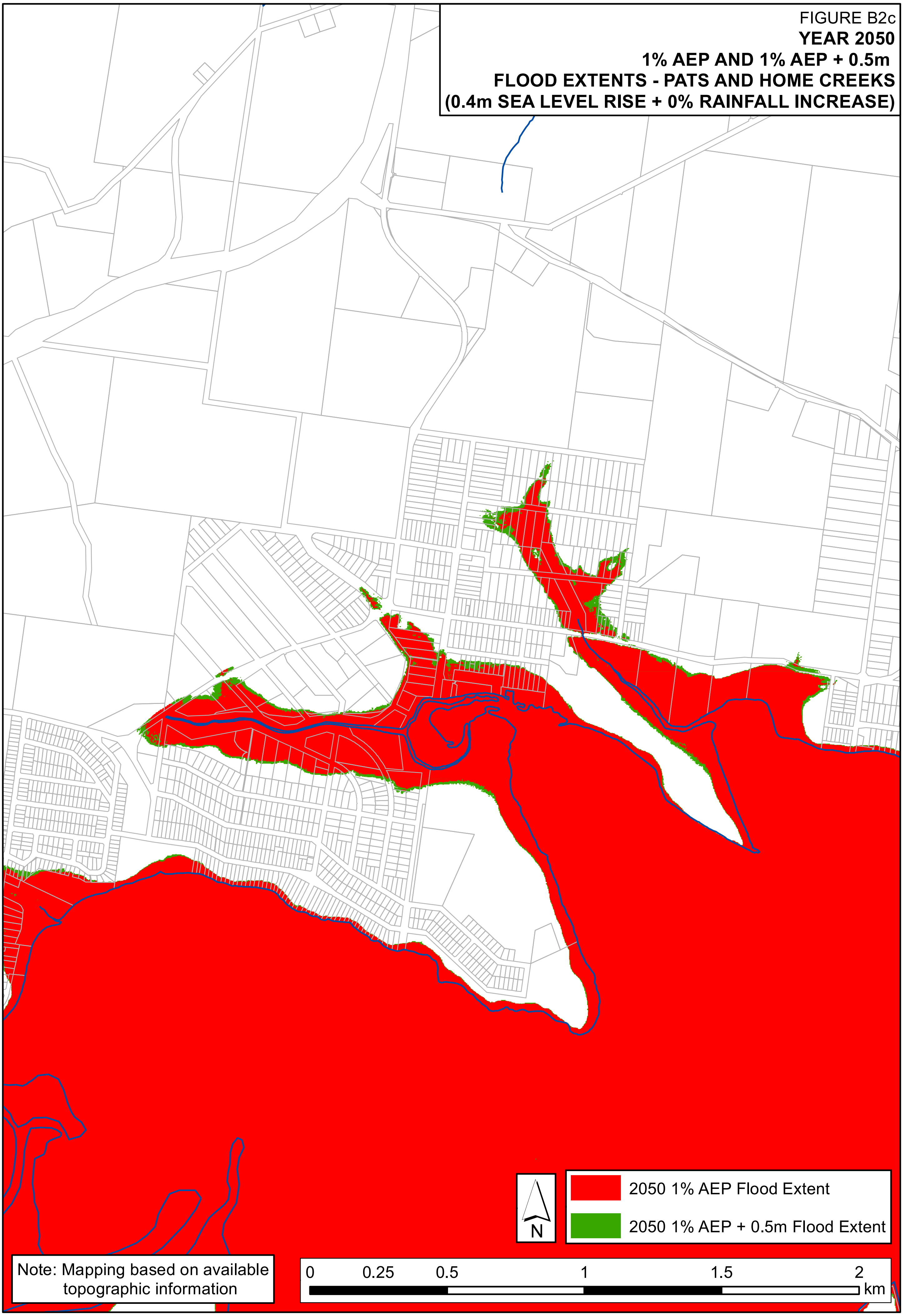

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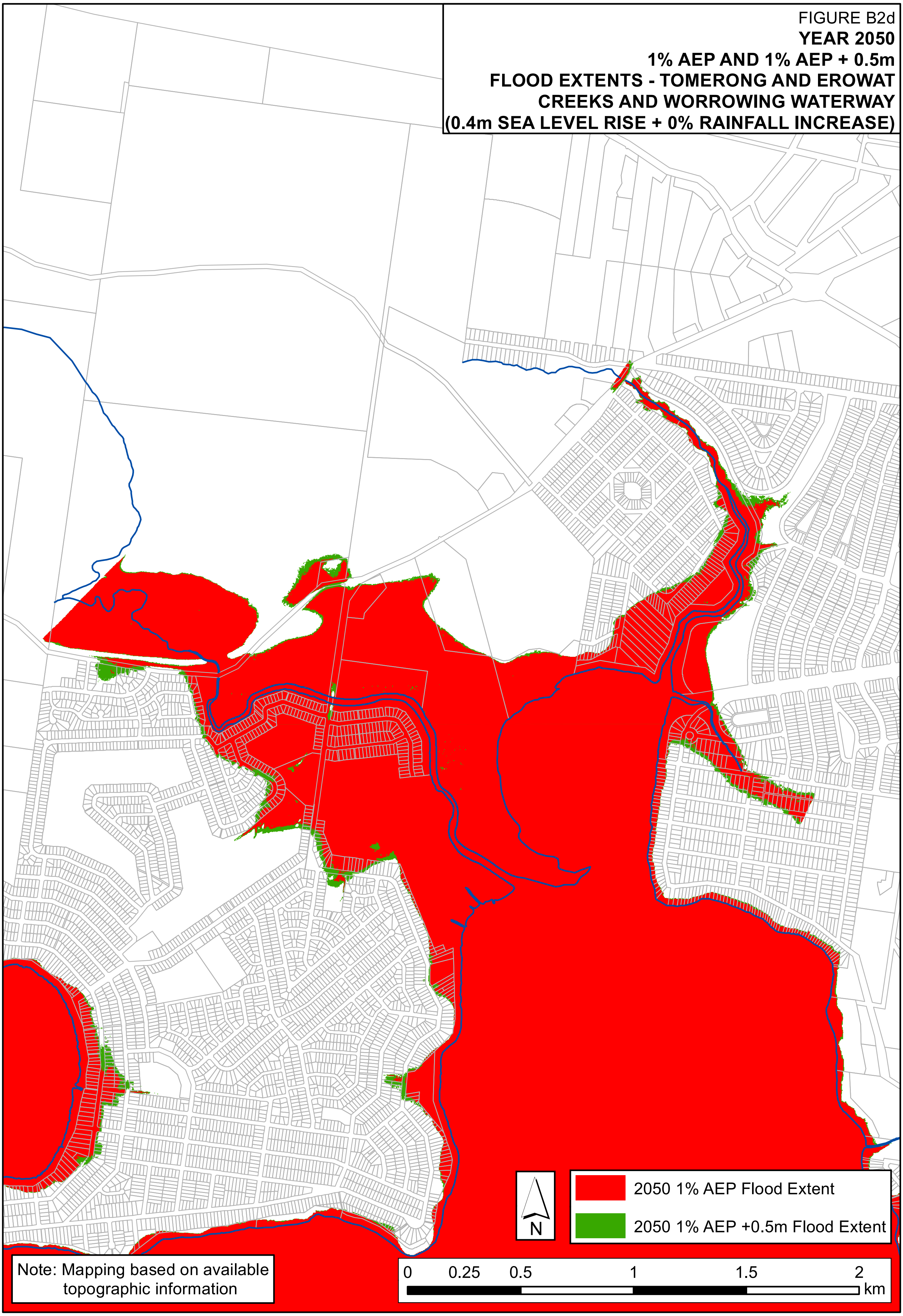

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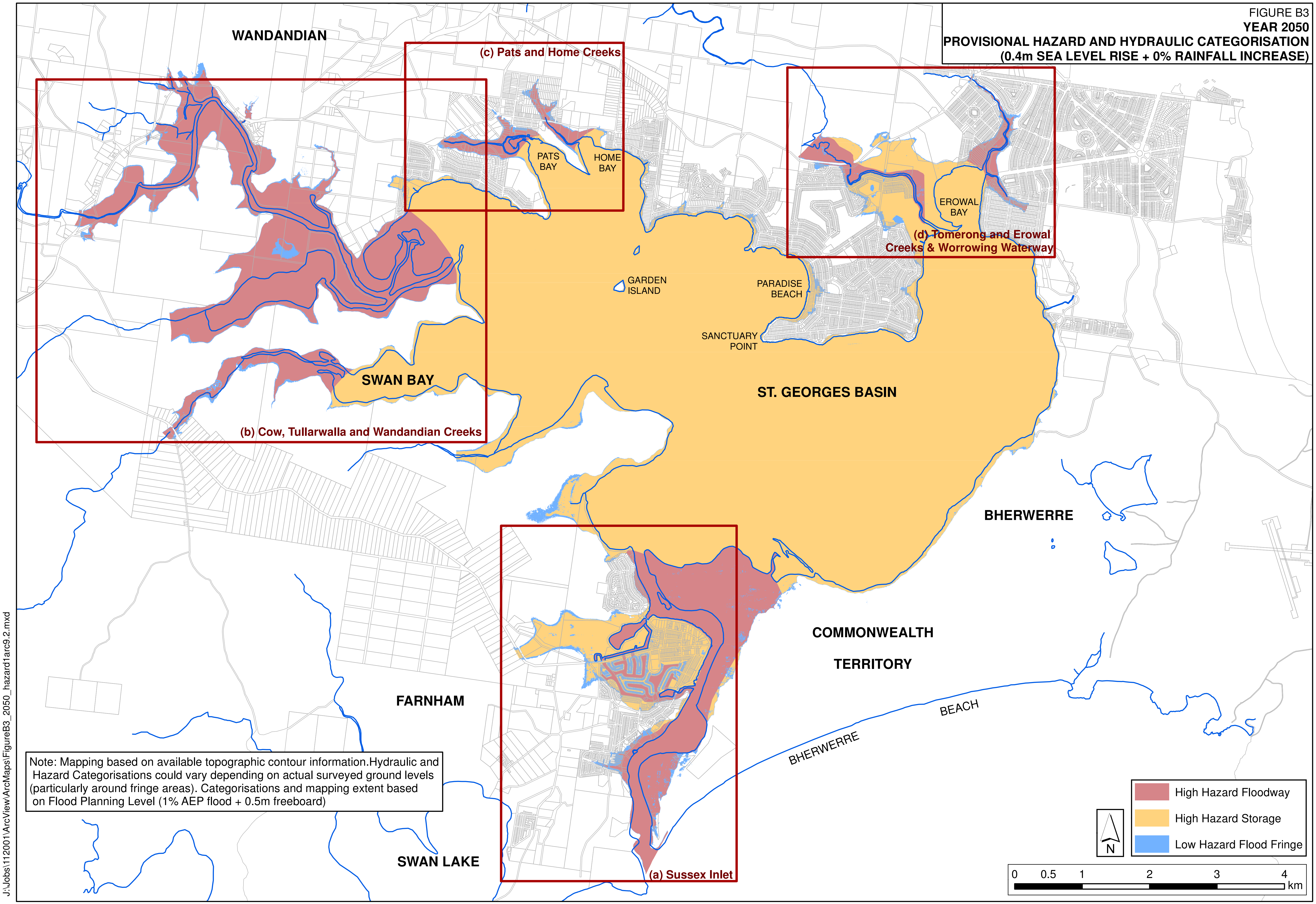


FIGURE B3
YEAR 2050
PROVISIONAL HAZARD AND HYDRAULIC CATEGORISATION
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
WANDANDIAN
(c) Pats and Home Creeks
PATS BAY
HOME BAY
EROWAL BAY
(d) Tomerong and Erowal Creeks & Worrowing Waterway
GARDEN ISLAND
PARADISE BEACH
SANCTUARY POINT
SWAN BAY
ST. GEORGES BASIN
(b) Cow, Tullarwalla and Wandandian Creeks
BHERWERRE
COMMONWEALTH
TERRITORY
FARNHAM
BEACH
BHERWERRE
SWAN LAKE
(a) Sussex Inlet
Note: Mapping based on available topographic contour information.Hydraulic and Hazard Categorisations could vary depending on actual surveyed ground levels (particularly around fringe areas). Categorisations and mapping extent based on Flood Planning Level (1% AEP flood + 0.5m freeboard)
High Hazard Floodway
High Hazard Storage
Low Hazard Flood Fringe
N
0 0.5 1 2 3 4 km
J:\Jobs\112001\ArcView\ArcMaps\FigureB3_2050_hazard1arc9.2.mxd

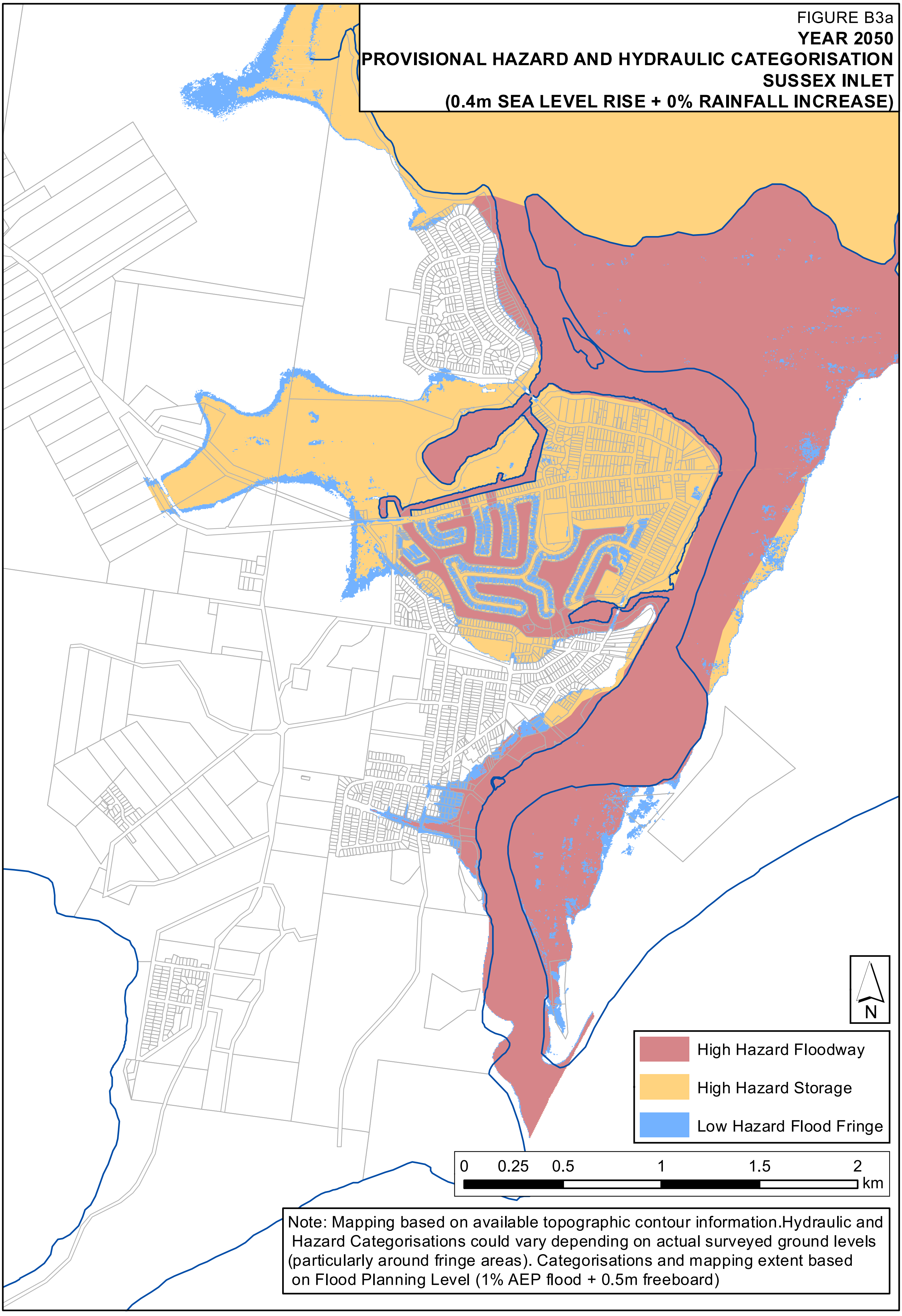
FIGURE B3a

YEAR 2050

PROVISIONAL HAZARD AND HYDRAULIC CATEGORISATION

SUSSEX INLET

(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic contour information.Hydraulic and Hazard Categorisations could vary depending on actual surveyed ground levels (particularly around fringe areas). Categorisations and mapping extent based on Flood Planning Level (1% AEP flood + 0.5m freeboard)

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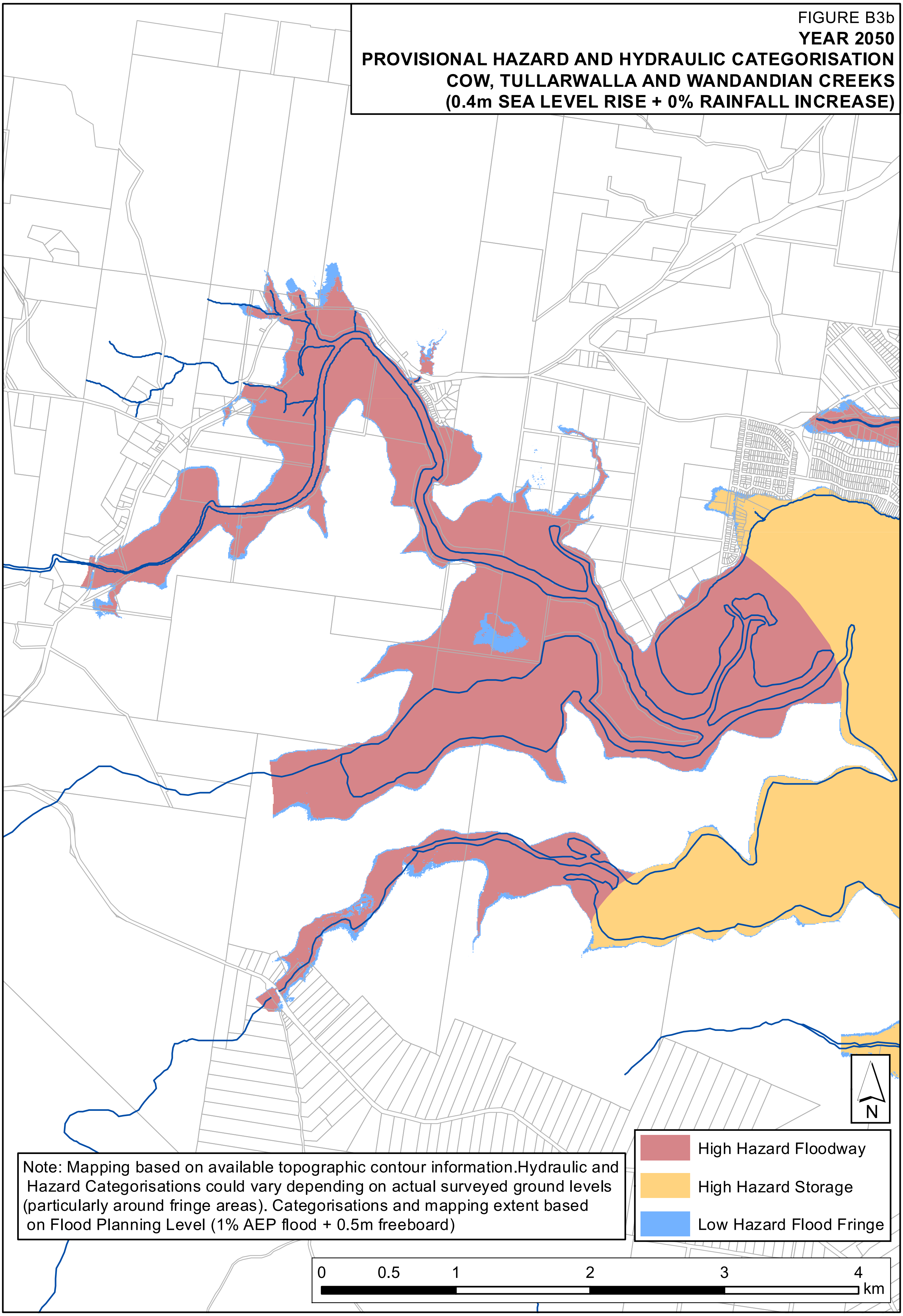
FIGURE B3b

YEAR 2050
PROVISIONAL HAZARD AND HYDRAULIC CATEGORISATION
COW, TULLARWALLA AND WANDANDIAN CREEKS
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic contour information.Hydraulic and Hazard Categorisations could vary depending on actual surveyed ground levels (particularly around fringe areas). Categorisations and mapping extent based on Flood Planning Level (1% AEP flood + 0.5m freeboard)

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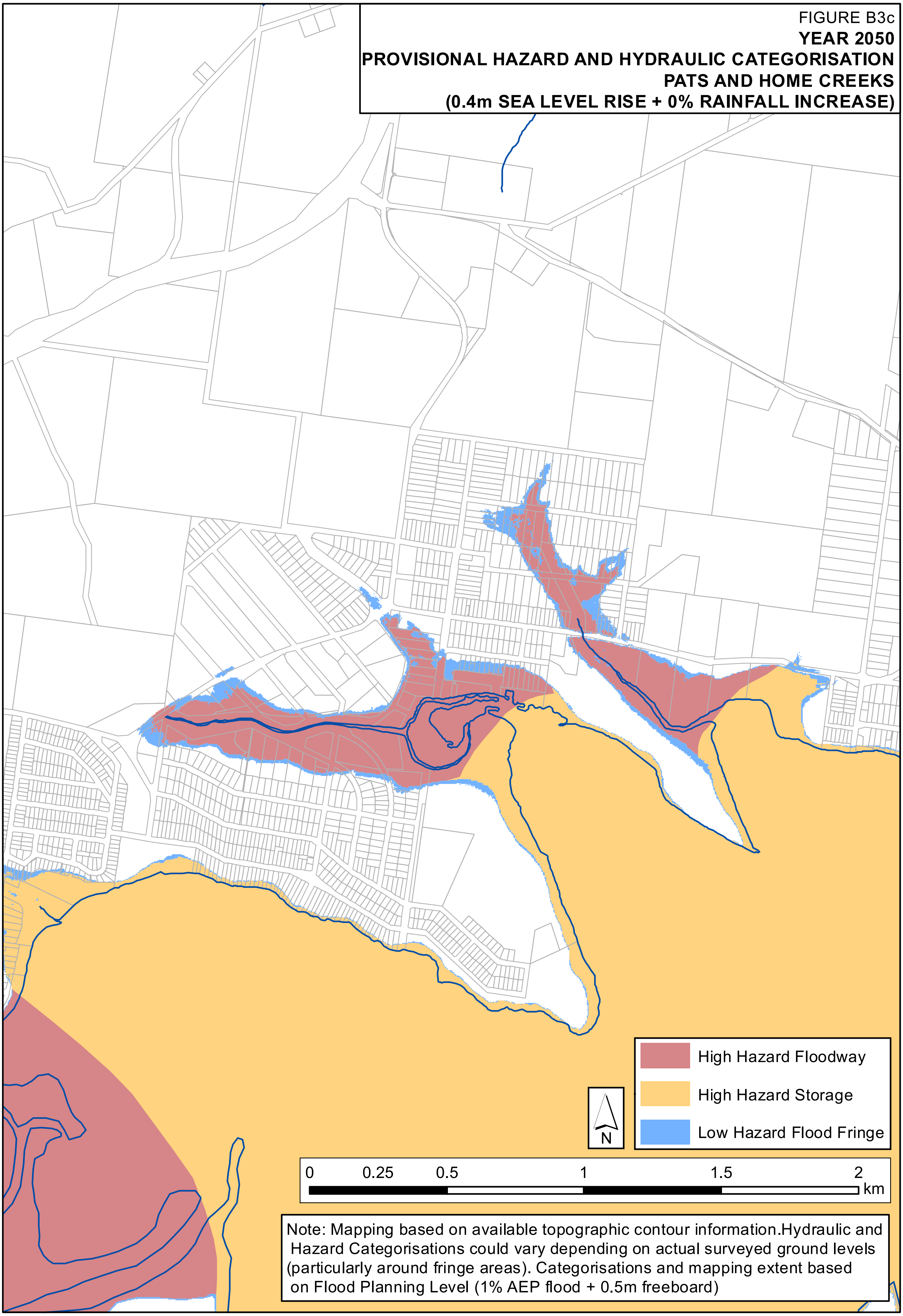
FIGURE B3c

YEAR 2050

PROVISIONAL HAZARD AND HYDRAULIC CATEGORISATION

PATS AND HOME CREEKS

(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic contour information.Hydraulic and Hazard Categorisations could vary depending on actual surveyed ground levels (particularly around fringe areas). Categorisations and mapping extent based on Flood Planning Level (1% AEP flood + 0.5m freeboard)

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FIGURE B3d
YEAR 2050
PROVISIONAL HAZARD AND HYDRAULIC CATEGORISATION
TOMERONG AND EROWAT CREEKS
AND WORROWING WATERWAY
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)

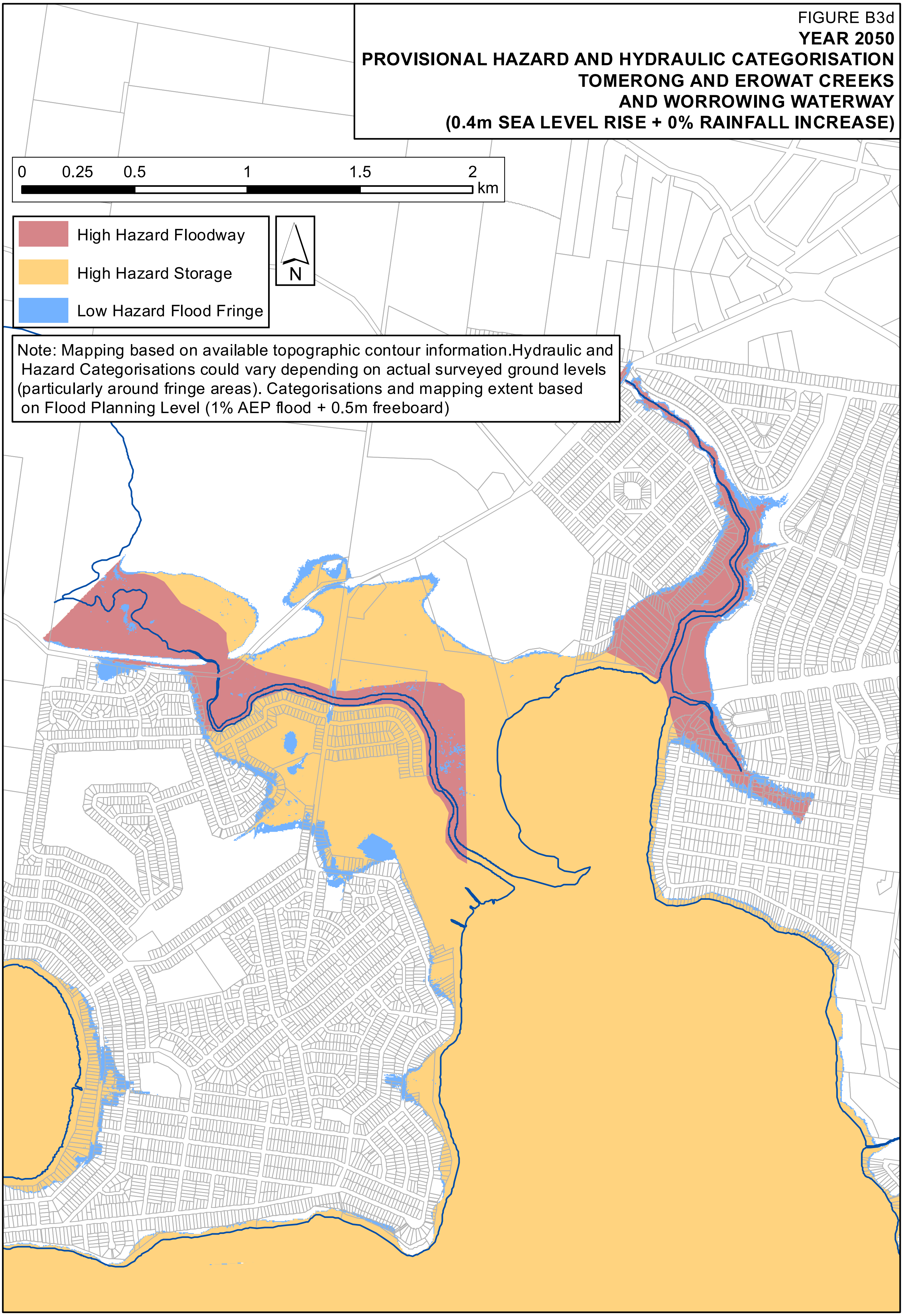

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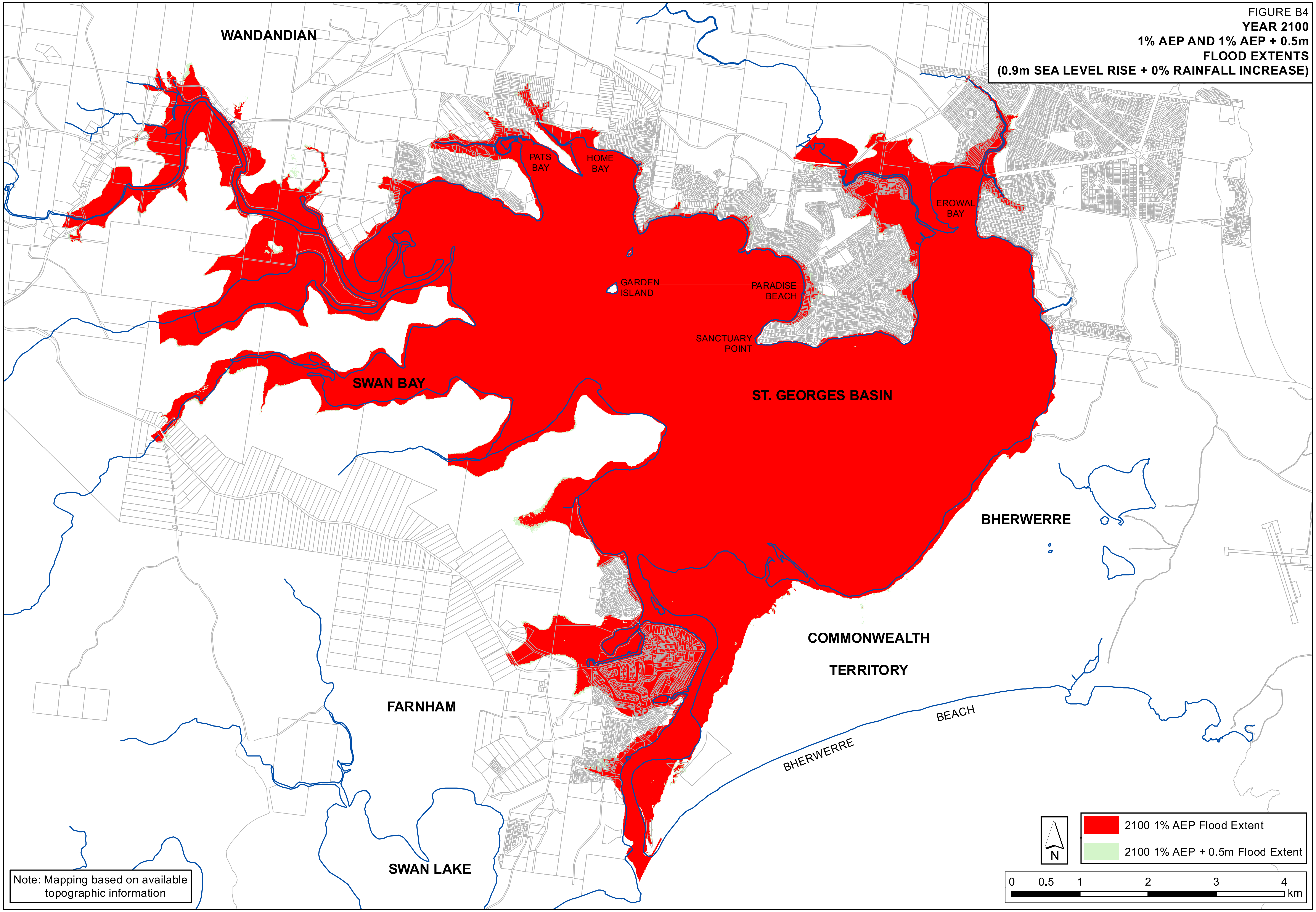
FIGURE B4
YEAR 2100
1% AEP AND 1% AEP + 0.5m
FLOOD EXTENTS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)



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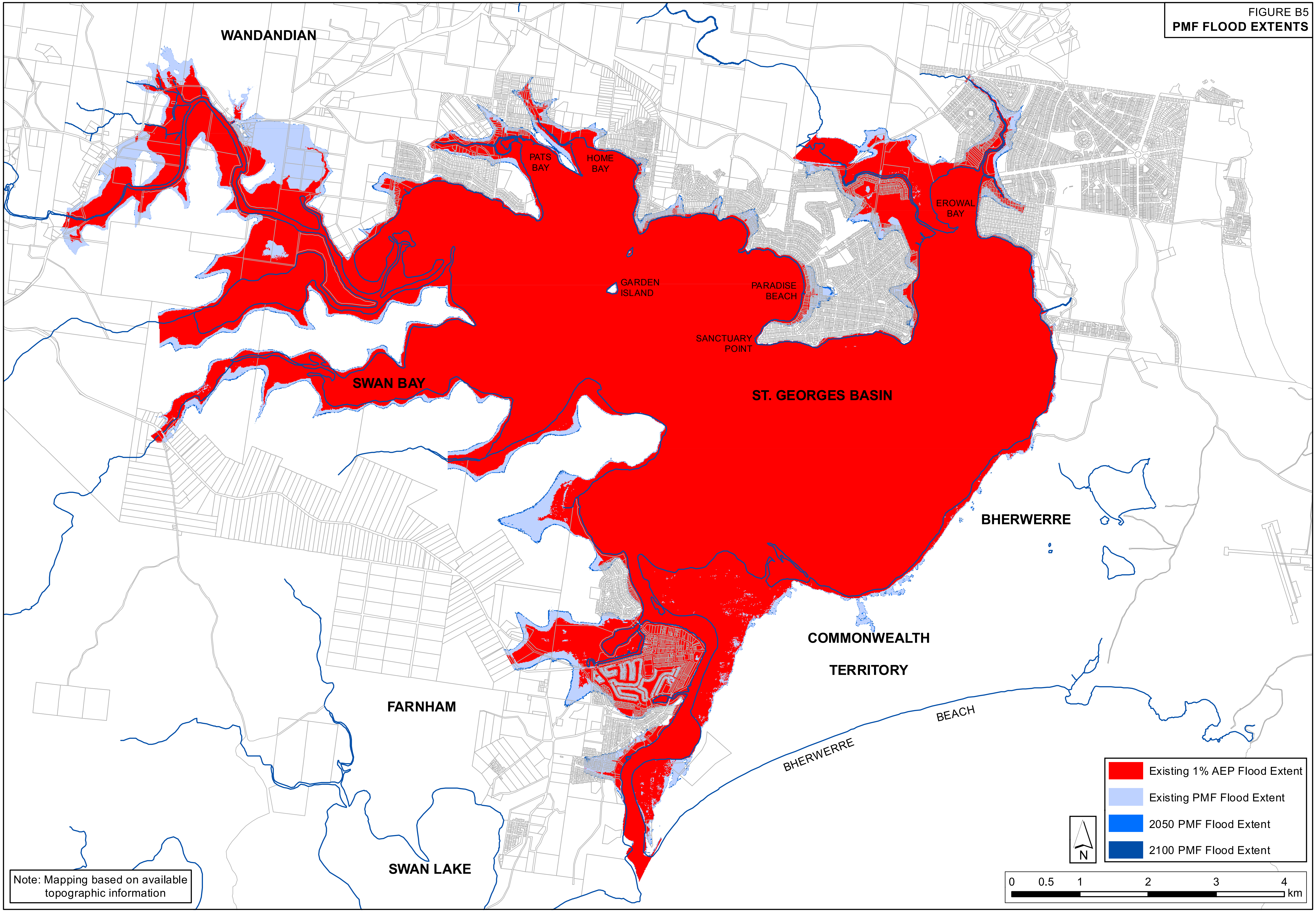
FIGURE B5
PMF FLOOD EXTENTS
WANDANDIAN
PATS
BAY
HOME
BAY
EROWAL
BAY
GARDEN
ISLAND
PARADISE
BEACH
SANCTUARY
POINT
SWAN BAY
ST. GEORGES BASIN
BHERWERRE
COMMONWEALTH
TERRITORY
FARNHAM
BHERWERRE
BEACH
SWAN LAKE
Existing 1% AEP Flood Extent
Existing PMF Flood Extent
2050 PMF Flood Extent
2100 PMF Flood Extent
N
0 0.5 1 2 3 4
km
Note: Mapping based on available topographic information
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Appendix C

FIGURE C1
RIVER CROSS SECTION LOCATIONS

Note: Mapping based on available topographic information

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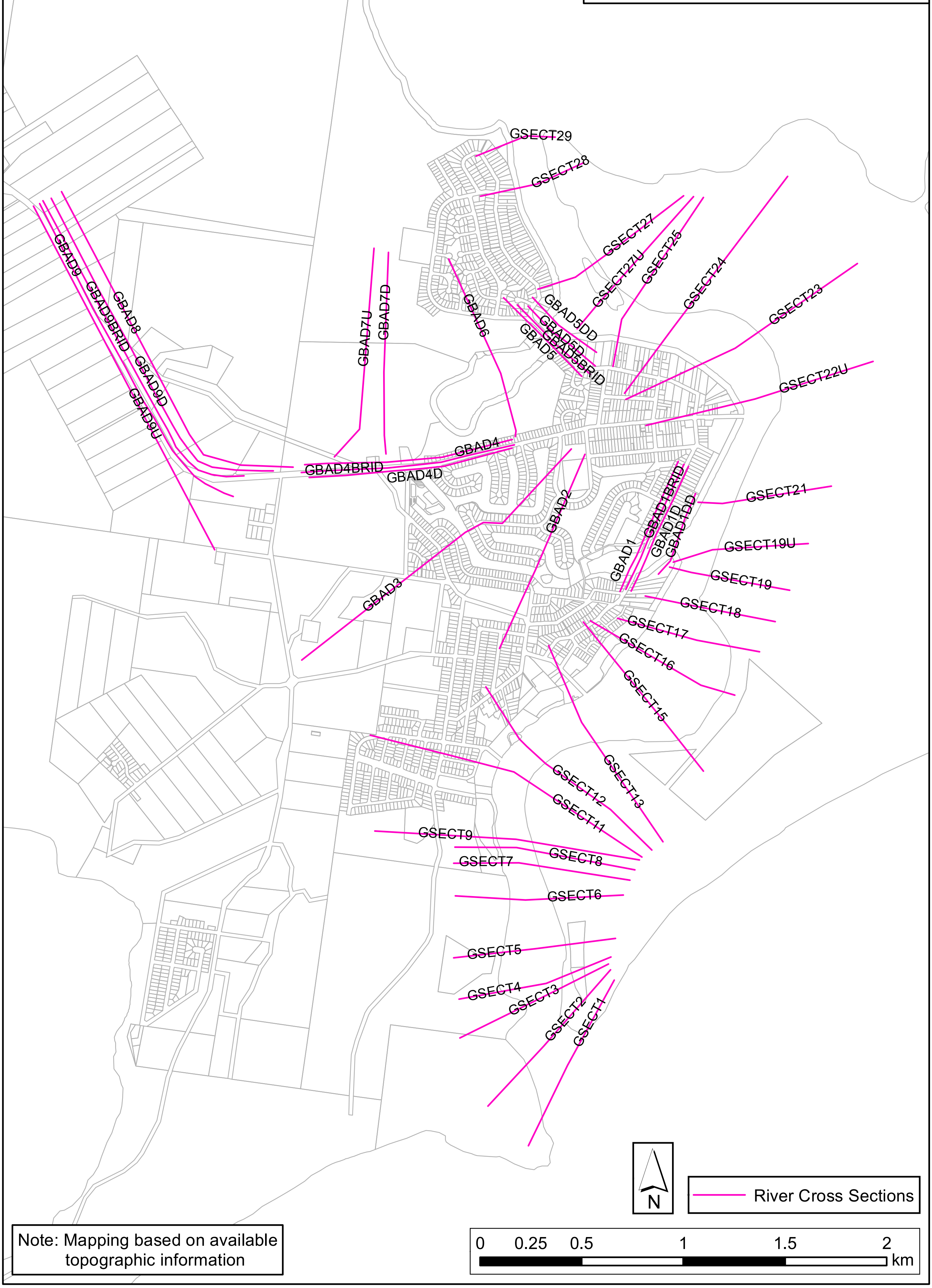
FIGURE C1a

RIVER CROSS SECTION LOCATIONS SUSSEX INLET



Note: Mapping based on available topographic information

J:\Jobs\112001\ArcView\ArcMaps\FigureC1a_RiverCrossSectionLocations.mxd

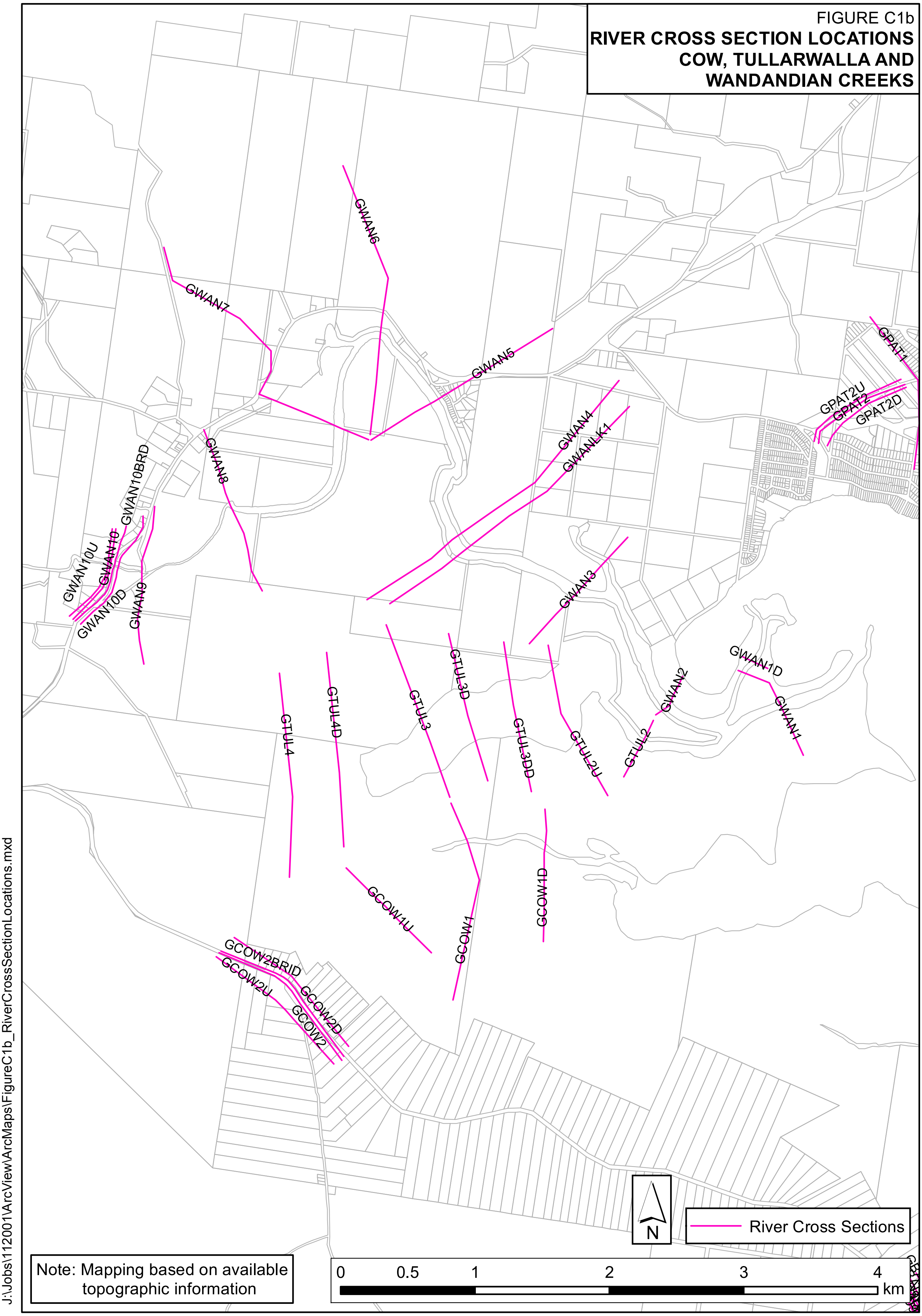


FIGURE C1b
RIVER CROSS SECTION LOCATIONS
COW, TULLARWALLA AND
WANDANDIAN CREEKS
GWAN6
GWAN7
GWAN5
GWAN4
GWANLK1
GWAN8
GWAN10BRD
GWAN10
GWAN10U
GWAN10D
GWAN9
GWAN3
GWAN2
GWAN1D
GWAN1
GPAT1
GPAT2U
GPAT2
GPAT2D
GTUL4
GTUL4D
GTUL3
GTUL3D
GTUL3DD
GTUL2U
GTUL2
GCOW1U
GCOW1
GCOW1D
GCOW2BRID
GCOW2U
GCOW2D
GCOW2
River Cross Sections
N
0
0.5
1
2
3
4
km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureC1b_RiverCrossSectionLocations.mxd

FIGURE C1c
RIVER CROSS SECTION LOCATIONS
PATS AND HOME CREEKS

Note: Mapping based on available topographic information

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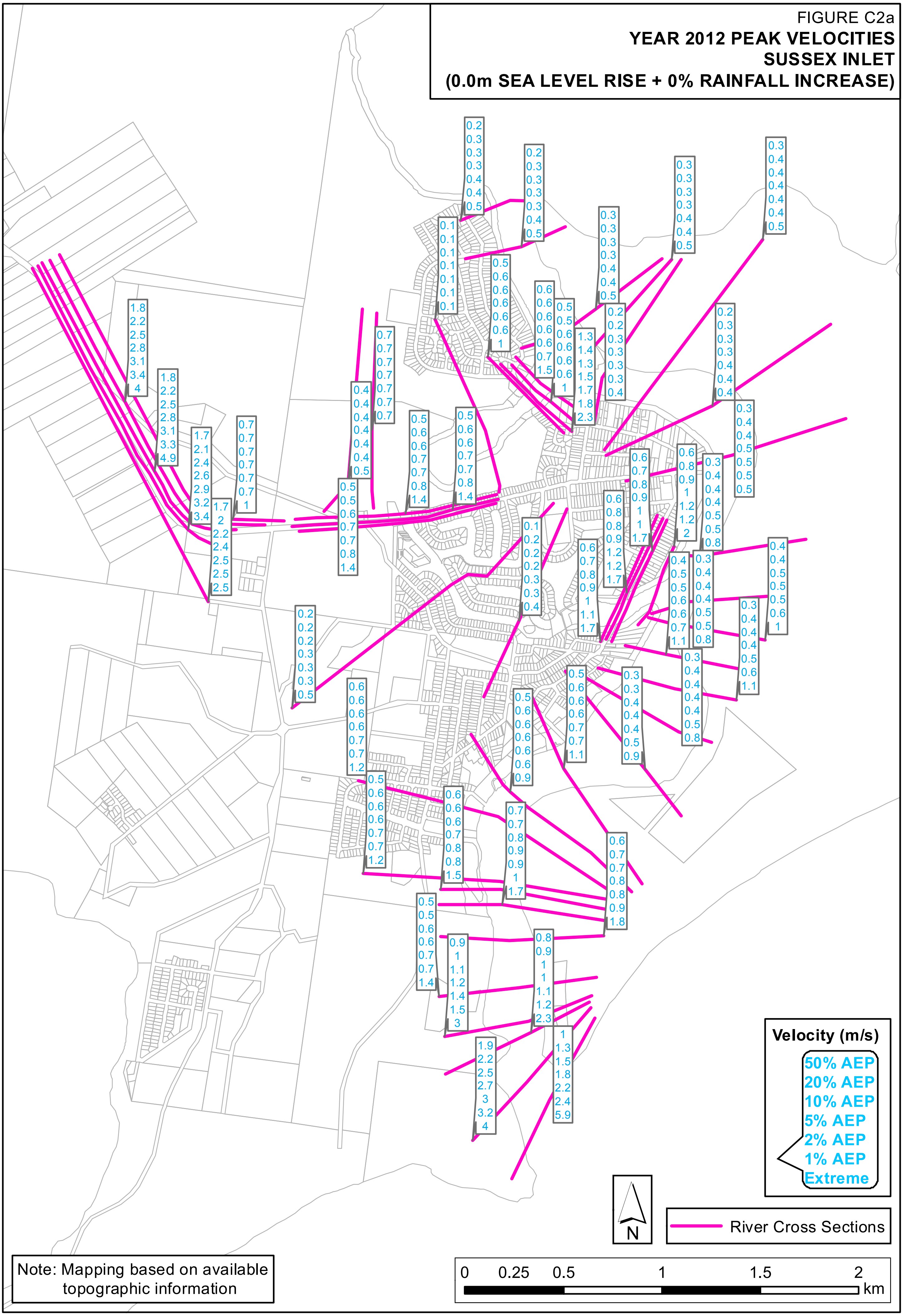
FIGURE C1d

RIVER CROSS SECTION LOCATIONS TOMERONG AND EROWAT CREEKS AND WORROWING WATERWAY

Note: Mapping based on available topographic information

J:\Jobs\112001\ArcView\ArcMaps\FigureC1d_RiverCrossSectionLocations.mxd

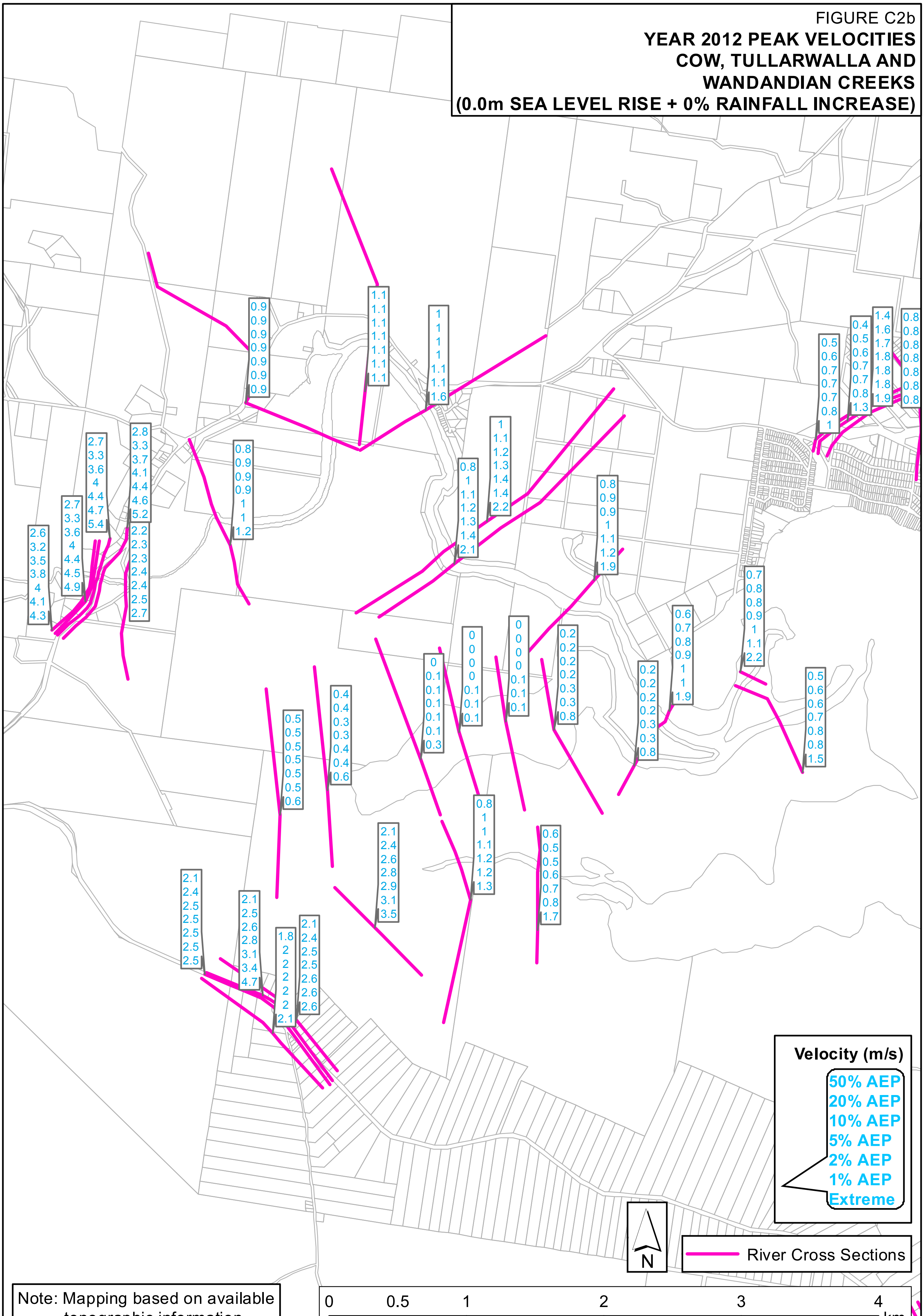
J:\Jobs\112001\ArcView\ArcMaps\FigureC2_2012_Peak_Velocities.mxd



J:\Jobs\112001\ArcView\ArcMaps\FigureC2a_2012_Peak_ Velocities.mxd

FIGURE C2b

YEAR 2012 PEAK VELOCITIES COW, TULLARWALLA AND WANDANDIAN CREEKS (0.0m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

J:\Jobs\112001\ArcView\ArcMaps\FigureC2b_2012_Peak_Velocities.mxd

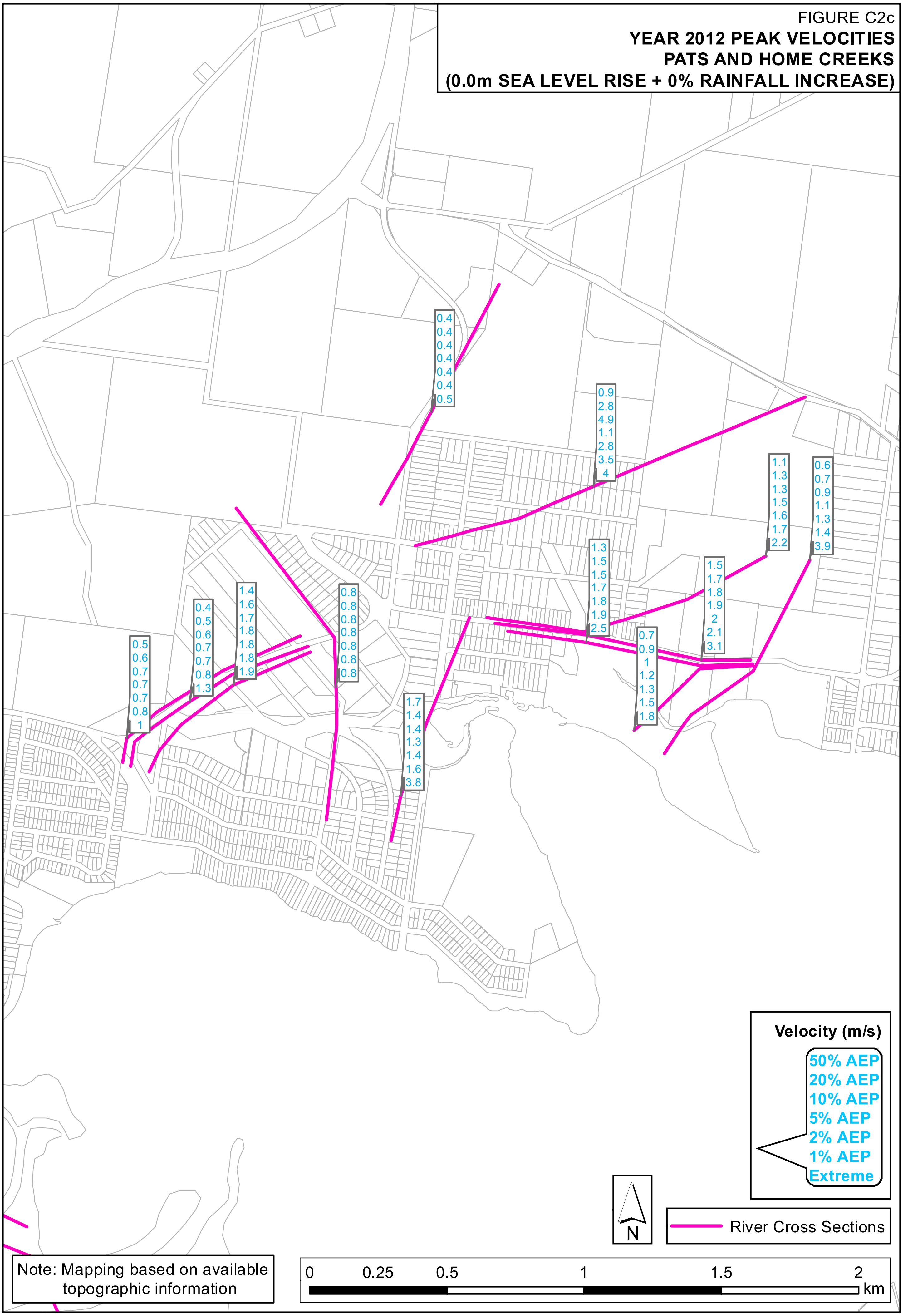
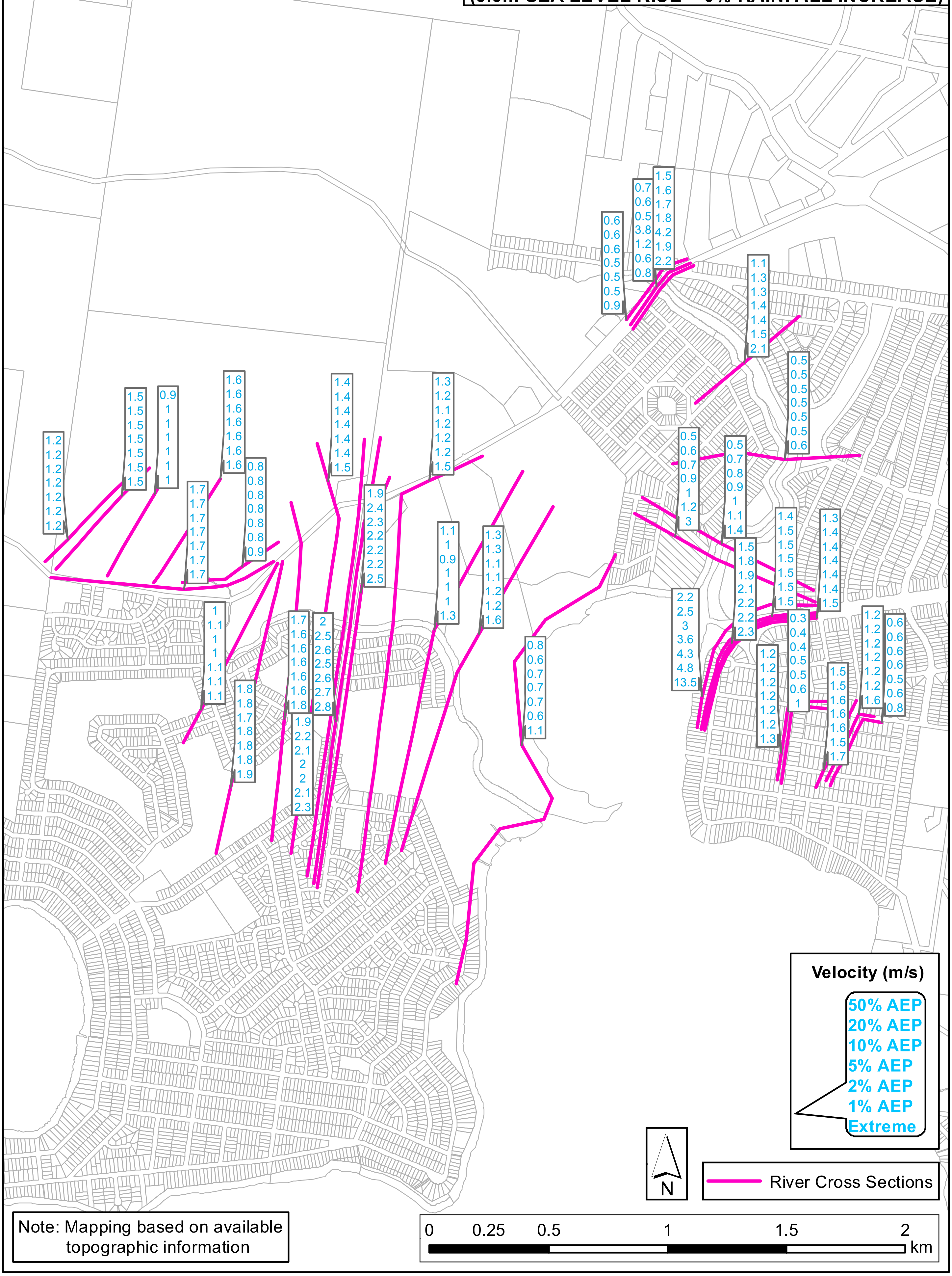


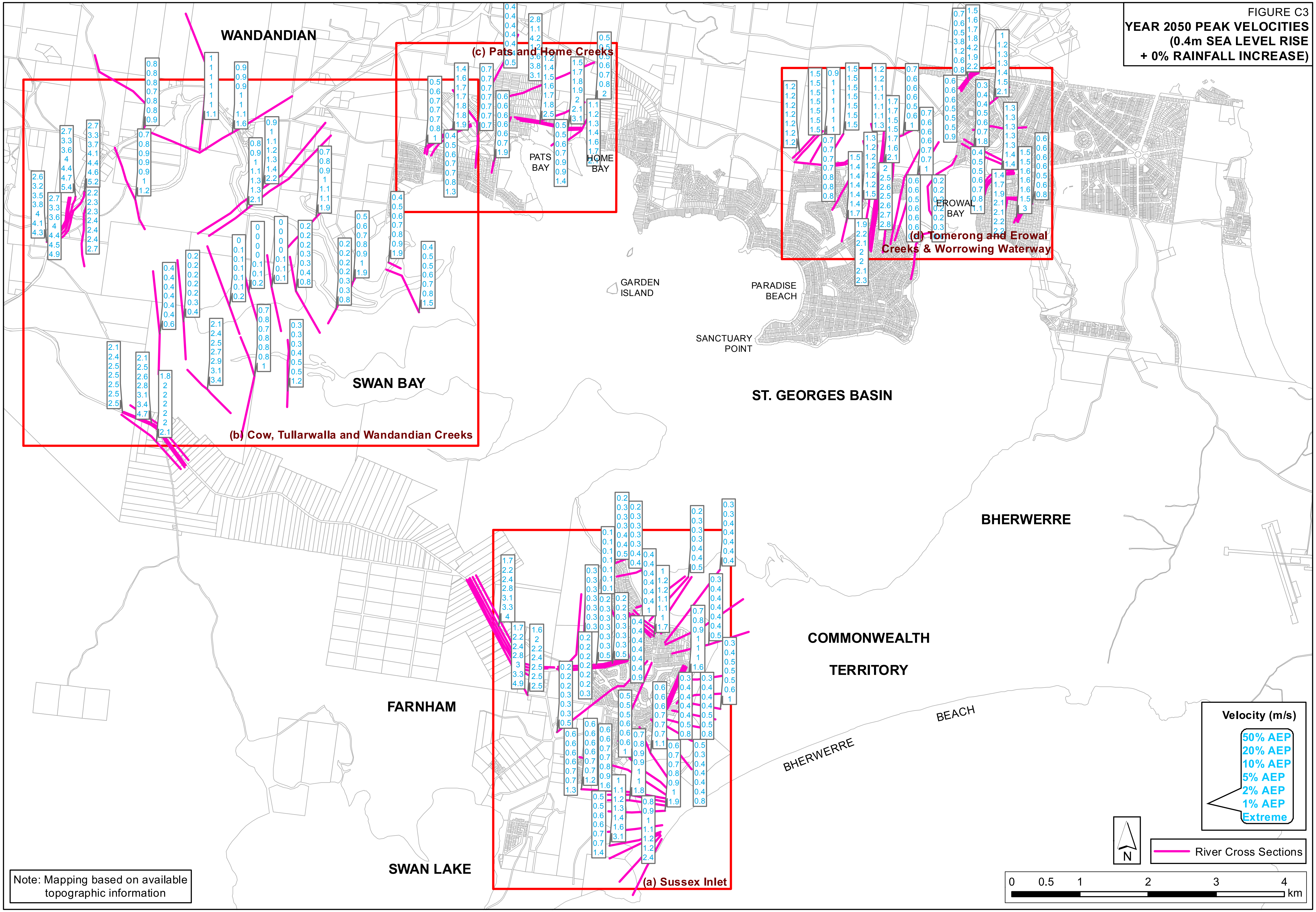
FIGURE C2c
YEAR 2012 PEAK VELOCITIES
PATS AND HOME CREEKS
(0.0m SEA LEVEL RISE + 0% RAINFALL INCREASE)

J:\Jobs\112001\ArcView\ArcMaps\FigureC2c_2012_Peak_Velocities.mxd

FIGURE C2d

YEAR 2012 PEAK VELOCITIES TOMERONG AND EROWAT CREEKS AND WORROWING WATERWAY (0.0m SEA LEVEL RISE + 0% RAINFALL INCREASE)

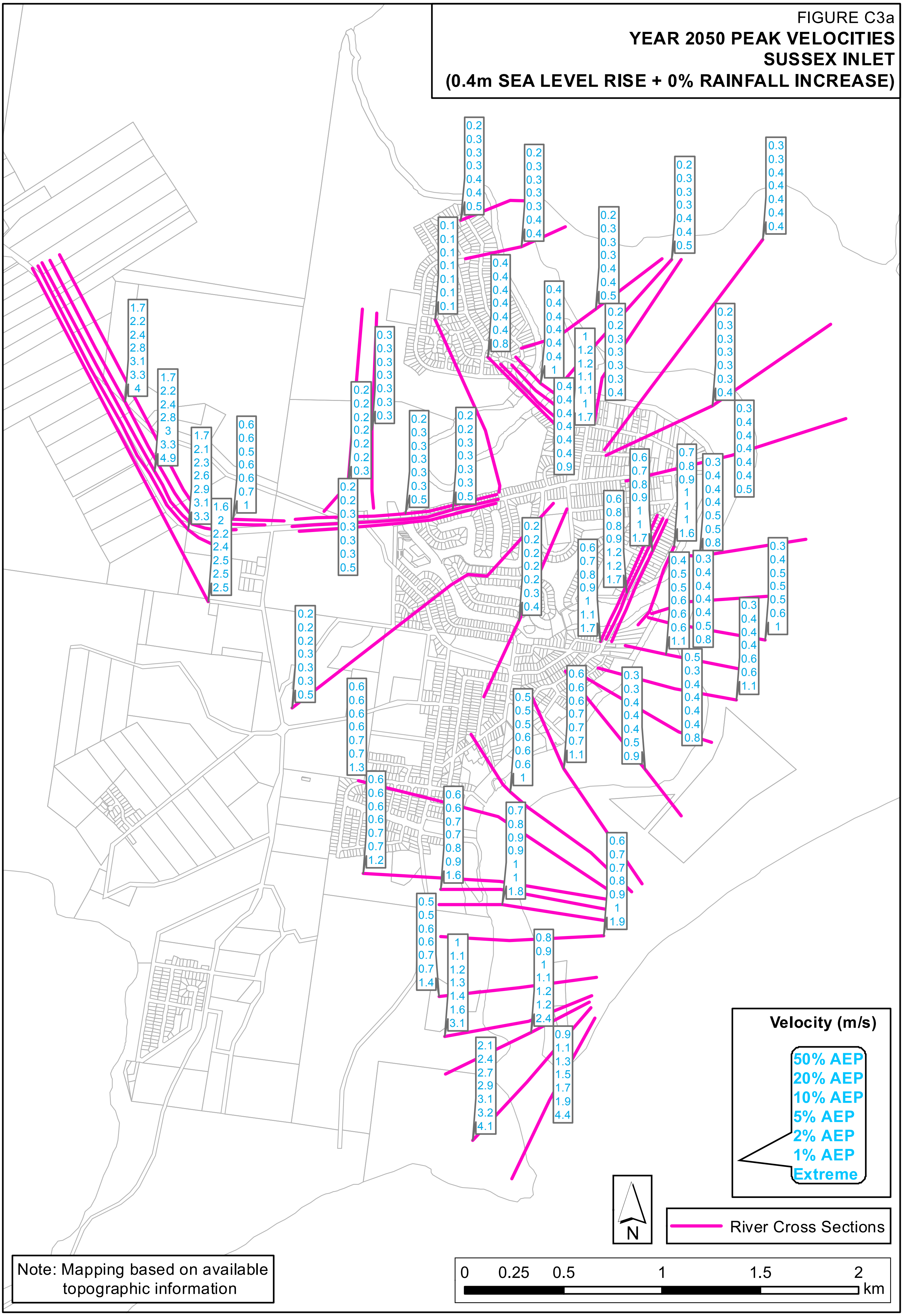




J:\Jobs\112001\ArcView\ArcMaps\FigureC3_2050_Peak_Velocities.mxd

FIGURE C3a

YEAR 2050 PEAK VELOCITIES SUSSEX INLET (0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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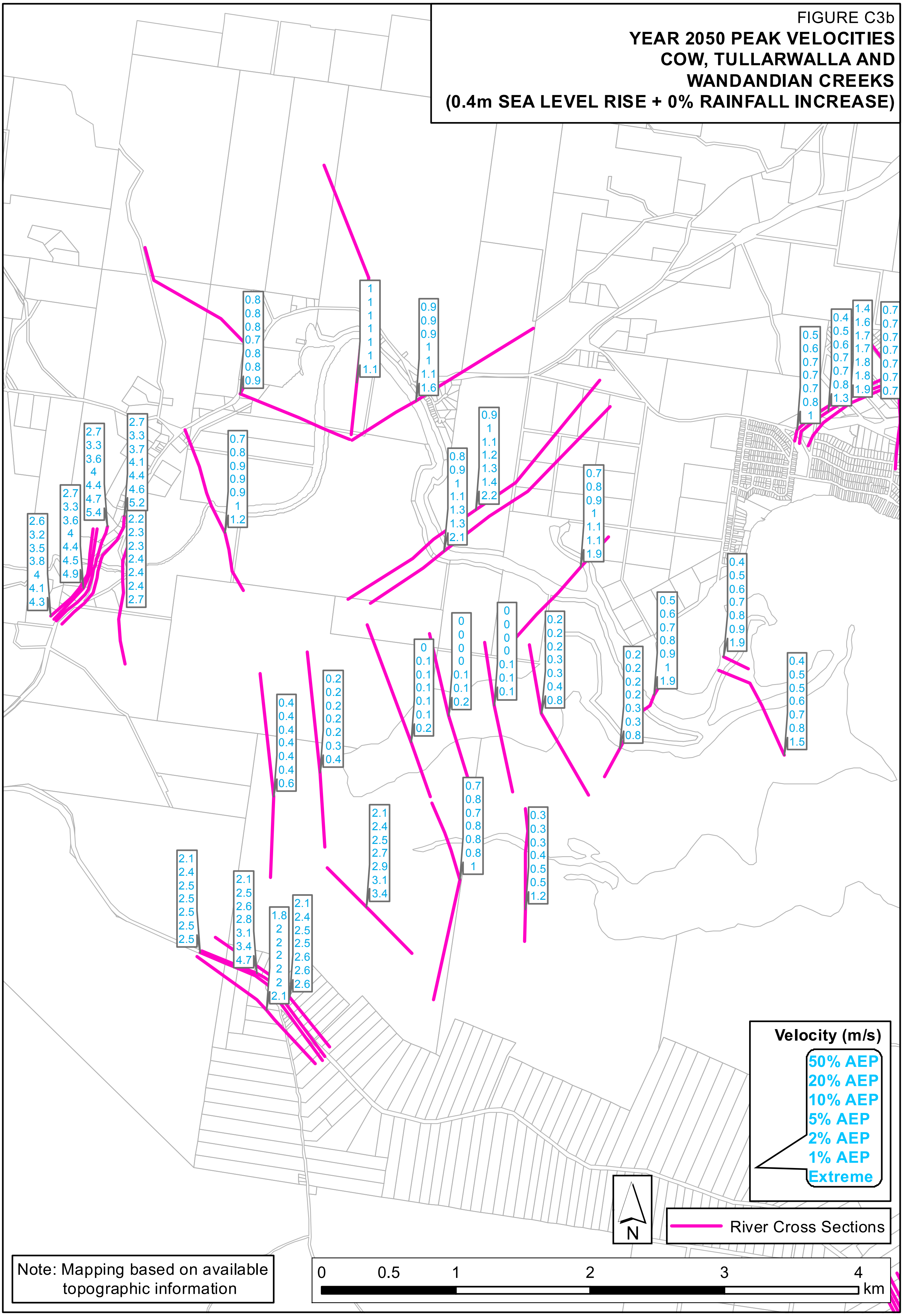
FIGURE C3b

YEAR 2050 PEAK VELOCITIES COW, TULLARWALLA AND WANDANDIAN CREEKS (0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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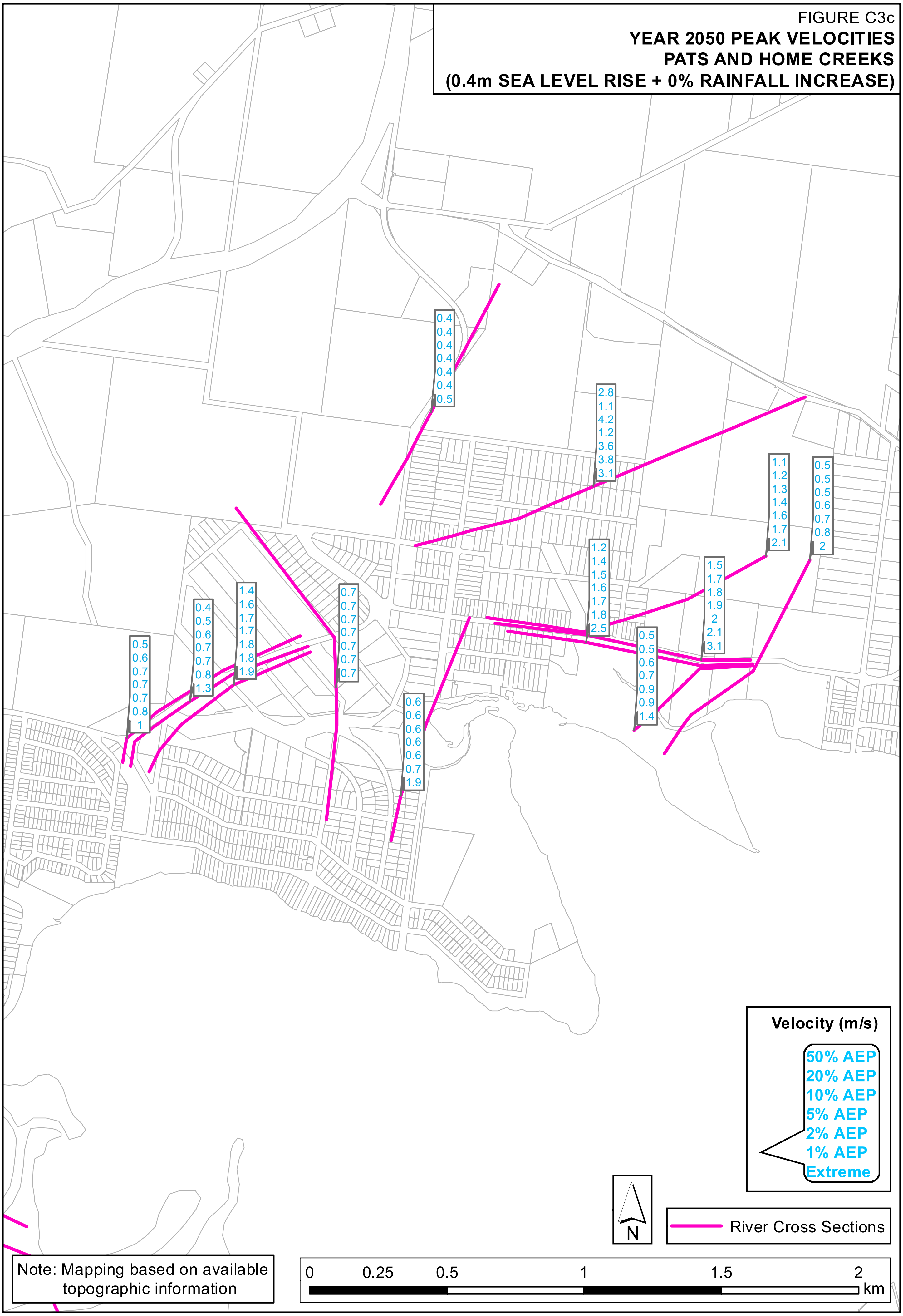

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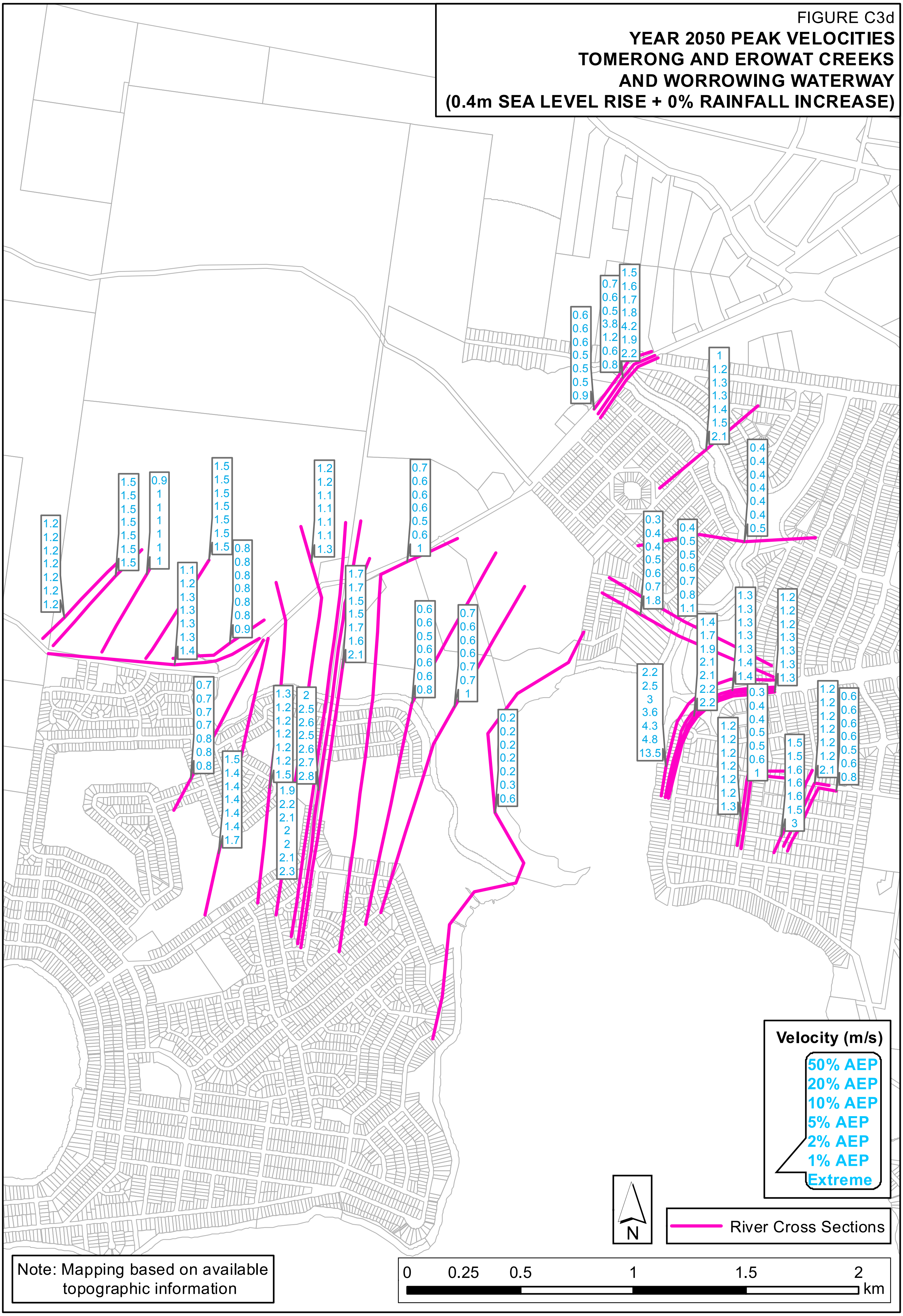

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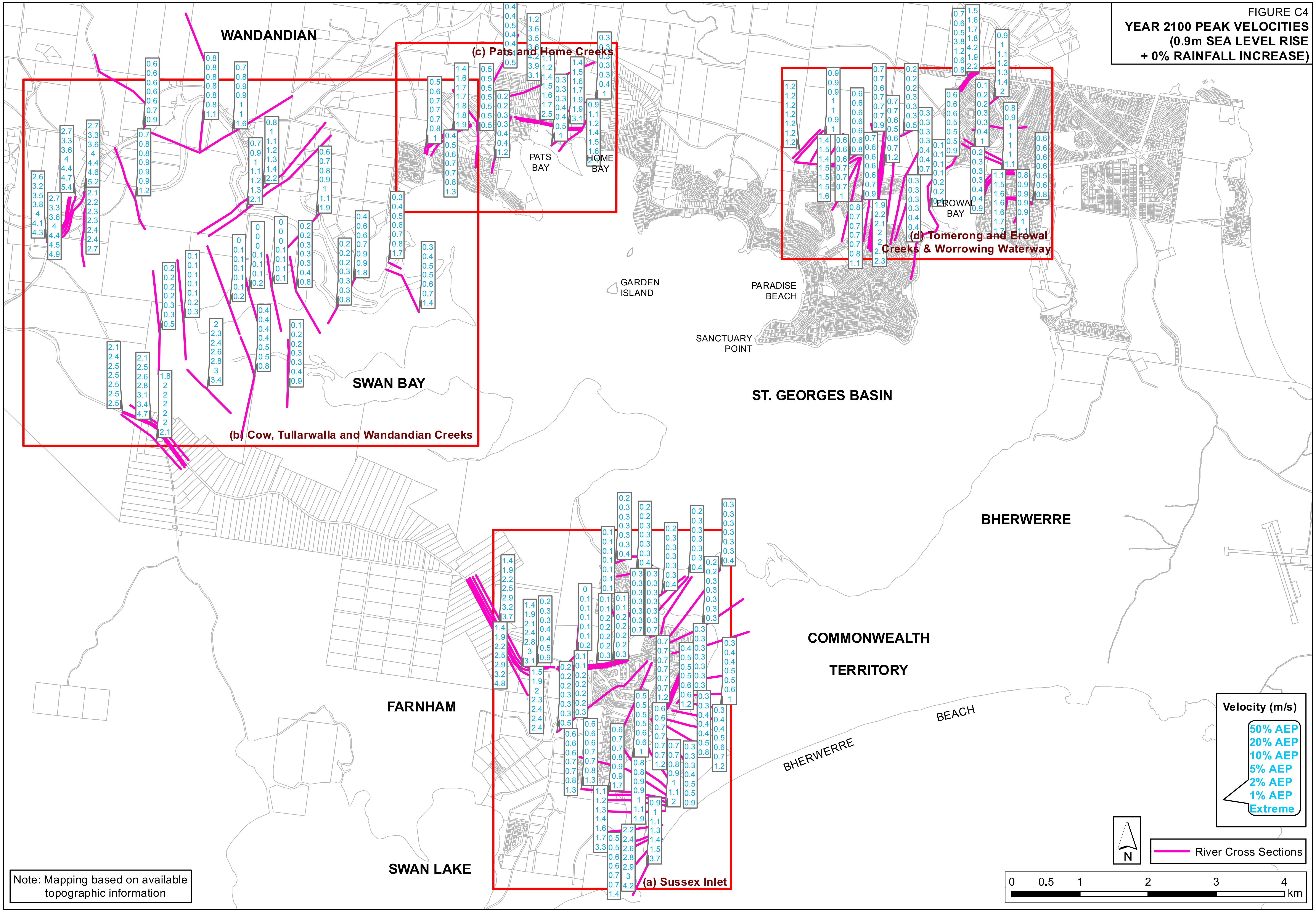

J:\Jobs\112001\ArcView\ArcMaps\FigureC4_2100_Peak_Velocities.mxd

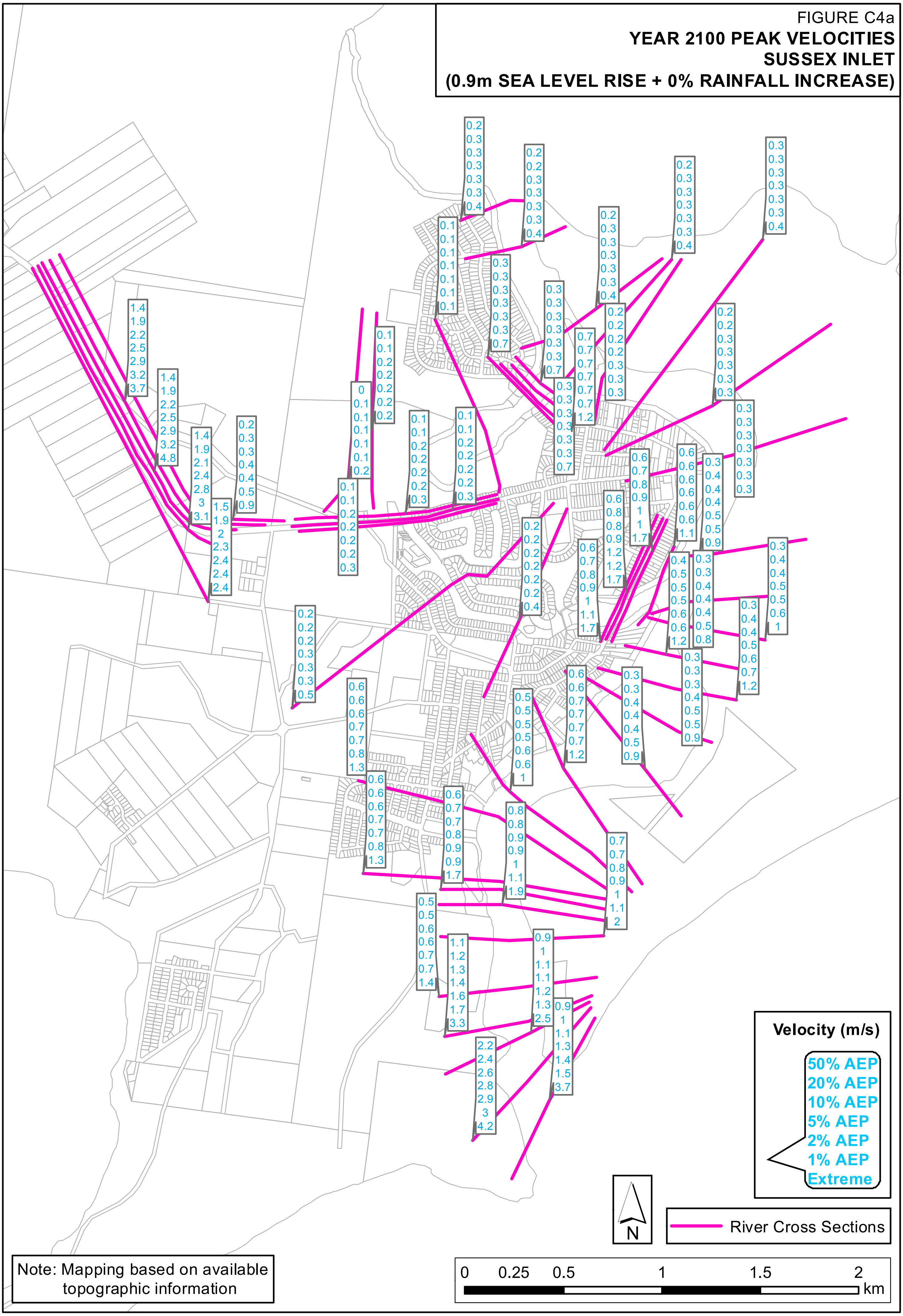

FIGURE C4a
YEAR 2100 PEAK VELOCITIES SUSSEX INLET (0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)

FIGURE C4b

YEAR 2100 PEAK VELOCITIES COW, TULLARWALLA AND WANDANDIAN CREEKS (0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)

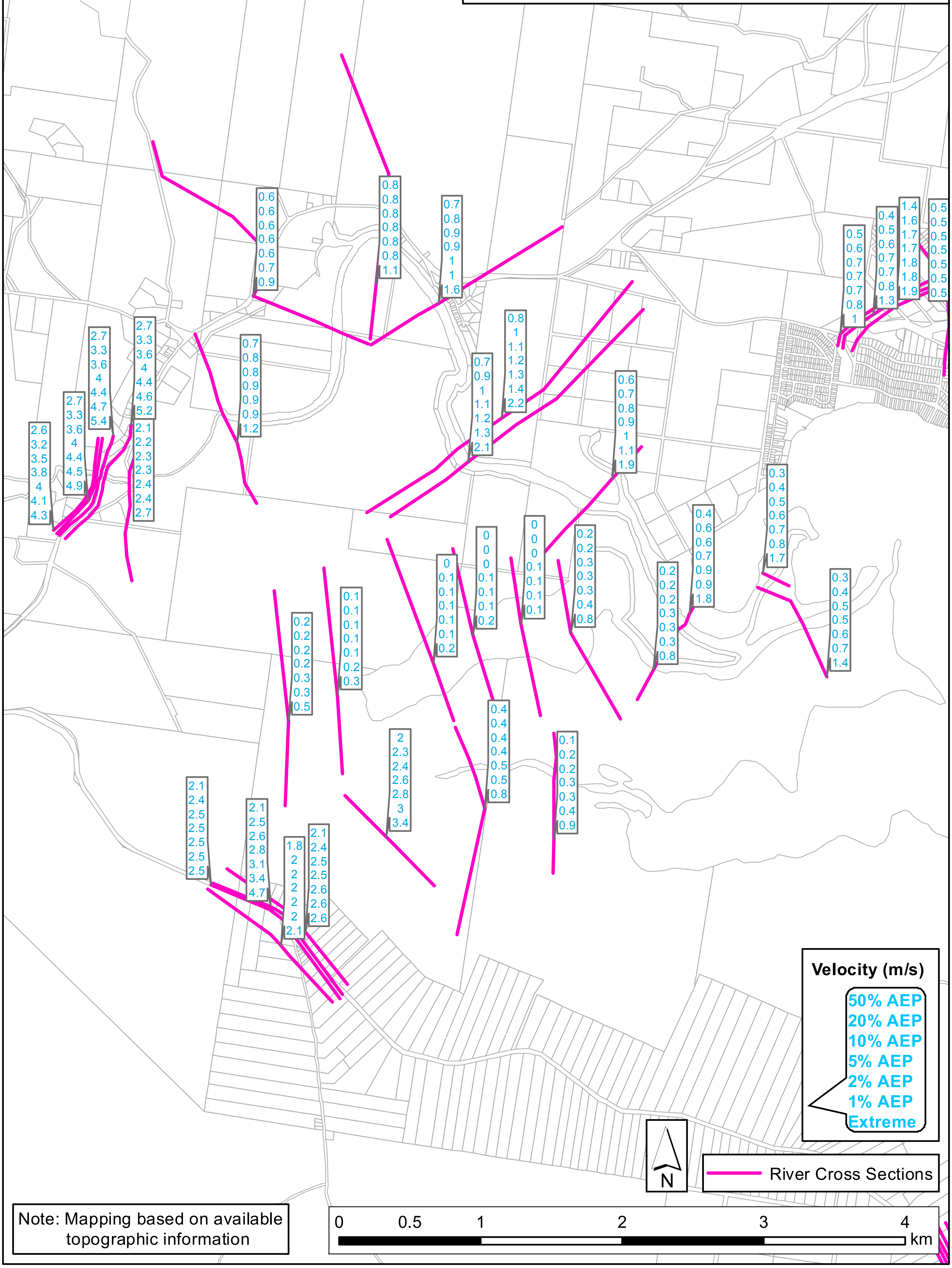

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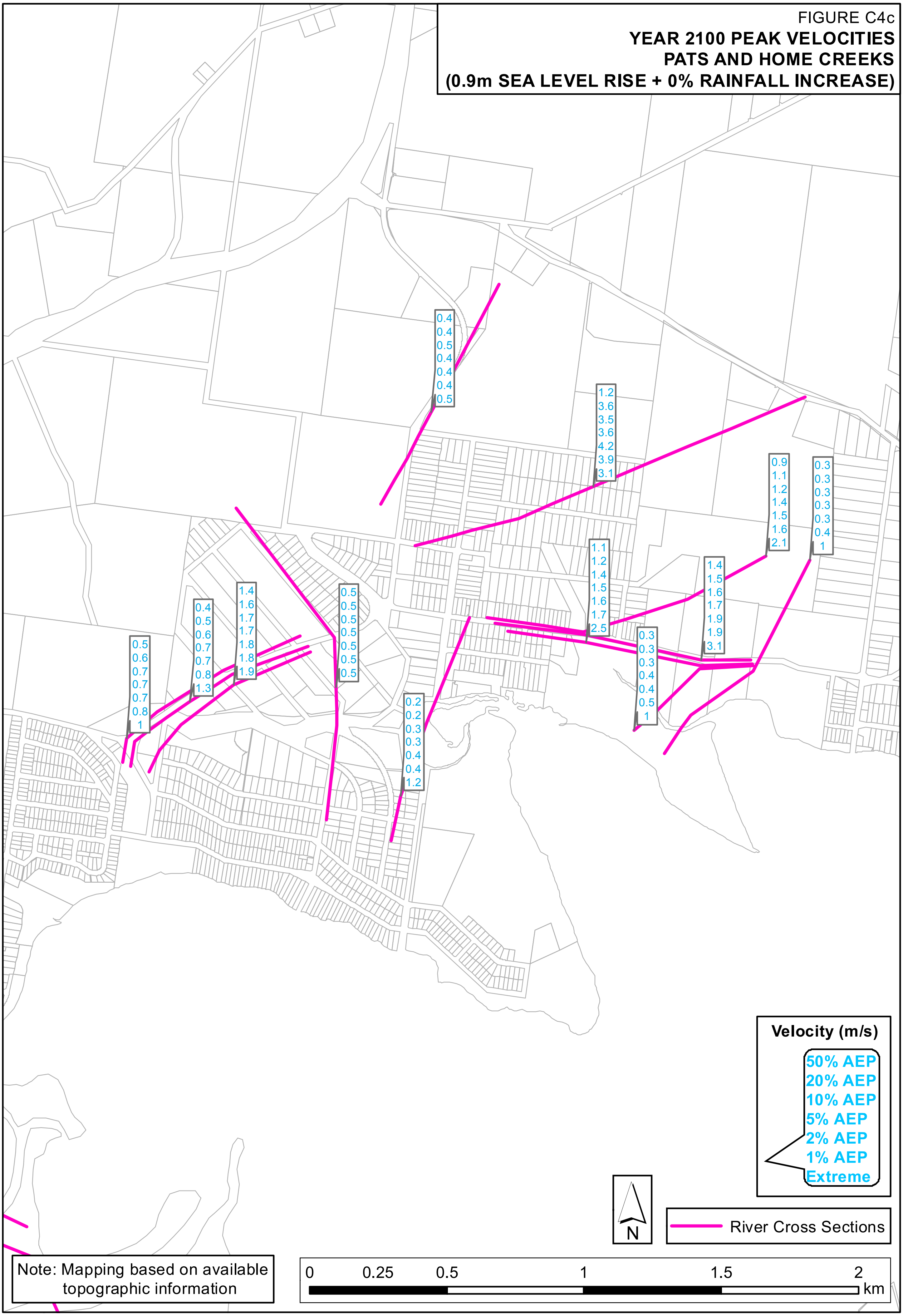
FIGURE C4c
YEAR 2100 PEAK VELOCITIES
PATS AND HOME CREEKS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)

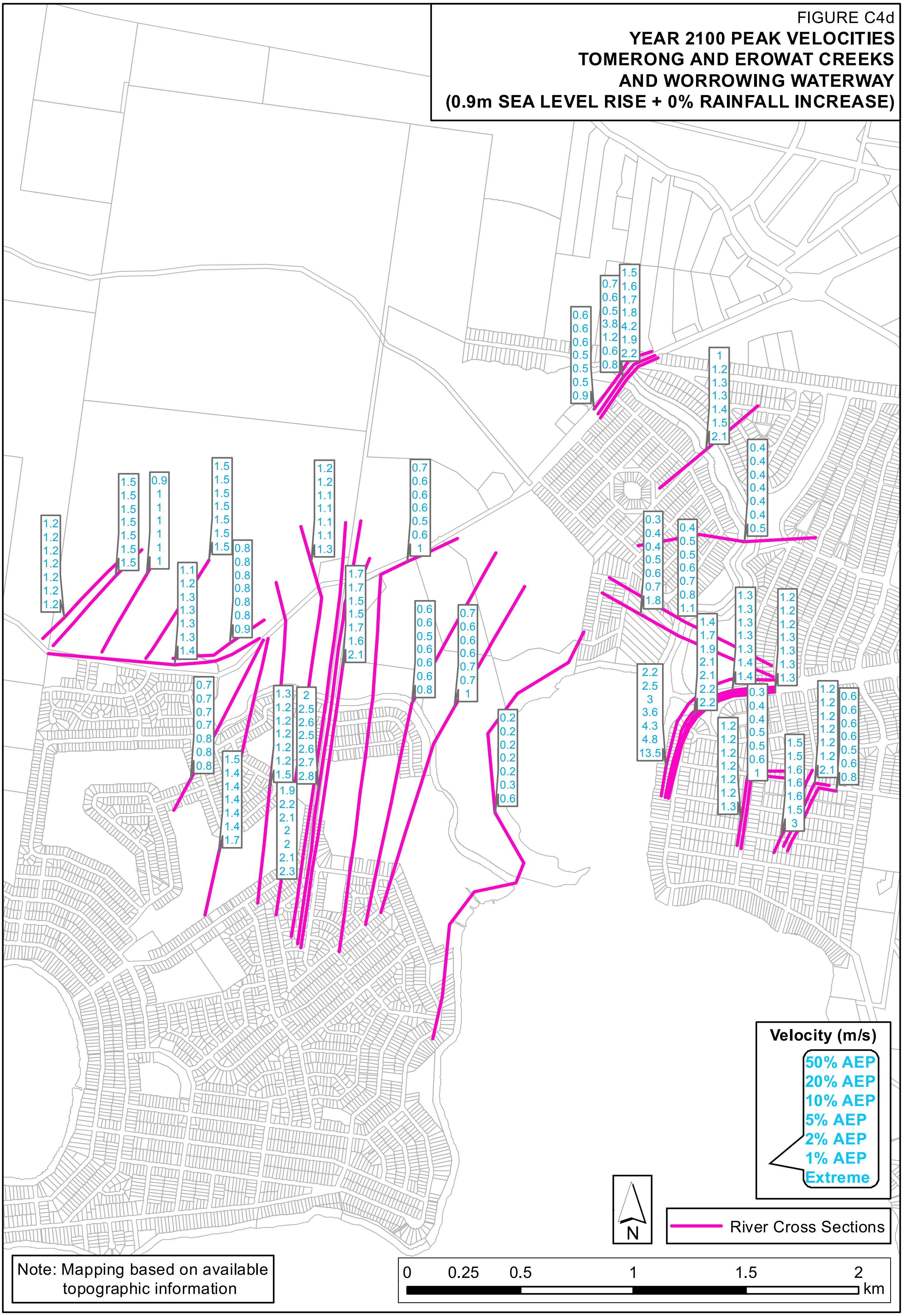


Note: Mapping based on available topographic information

J:\Jobs\112001\ArcView\ArcMaps\FigureC4c_2100_Peak_Velocities.mxd

FIGURE C4d

YEAR 2100 PEAK VELOCITIES TOMERONG AND EROWAT CREEKS AND WORROWING WATERWAY (0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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Appendix D

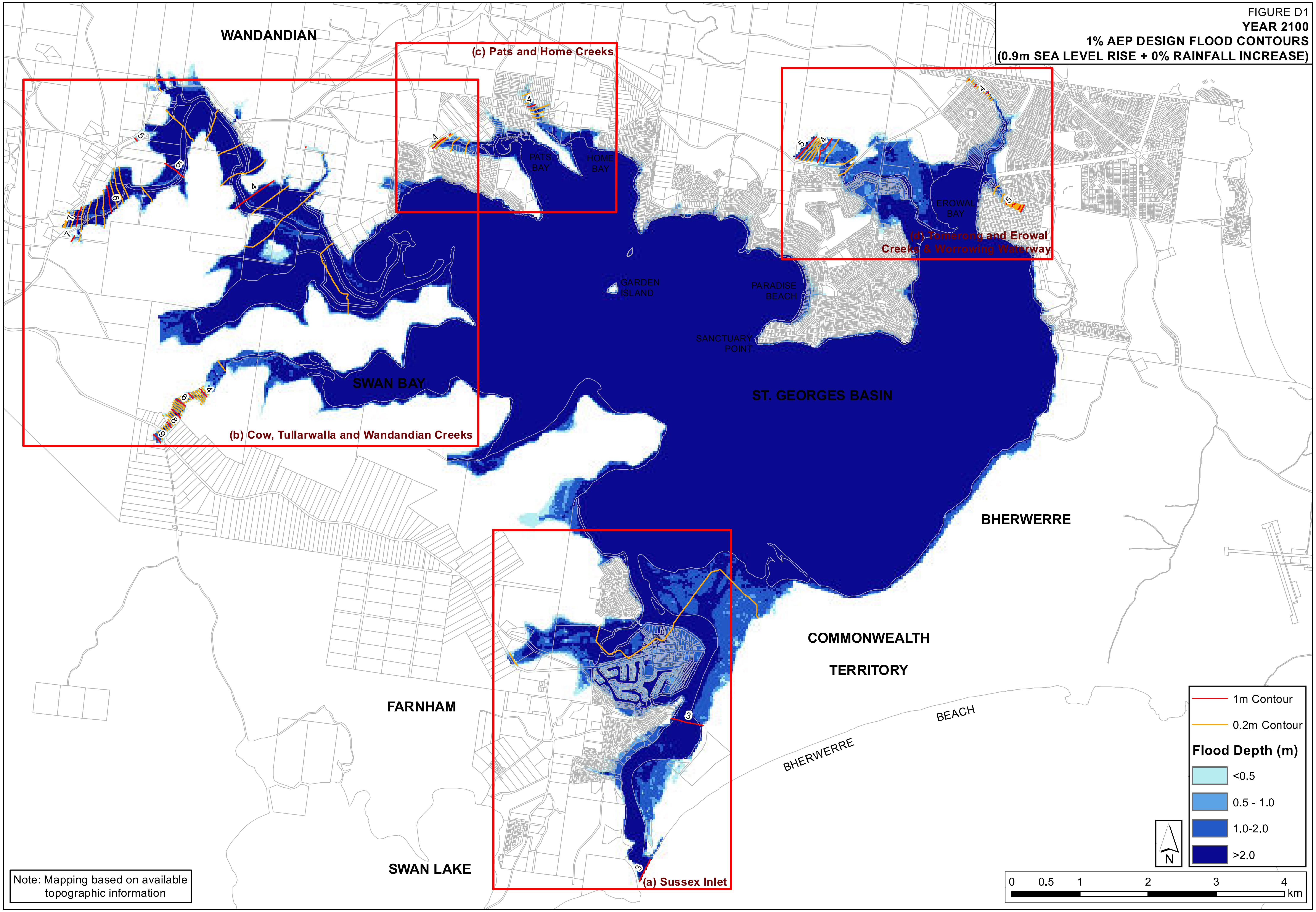
FIGURE D1
YEAR 2100
1% AEP DESIGN FLOOD CONTOURS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)
WANDANDIAN
(c) Pats and Home Creeks
PATS BAY
HOME BAY
(d) Tomerong and Erowal Creeks & Worrowing Waterway
EROWAL BAY
GARDEN ISLAND
PARADISE BEACH
SANCTUARY POINT
ST. GEORGES BASIN
SWAN BAY
(b) Cow, Tullarwalla and Wandandian Creeks
BHERWERRE
COMMONWEALTH
TERRITORY
FARNHAM
SWAN LAKE
(a) Sussex Inlet
BHERWERRE BEACH
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0 0.5 1 2 3 4 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD1_2100_100Y_Contours.mxd

FIGURE D1a
YEAR 2100
1% AEP DESIGN FLOOD CONTOURS
SUSSEX INLET
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)

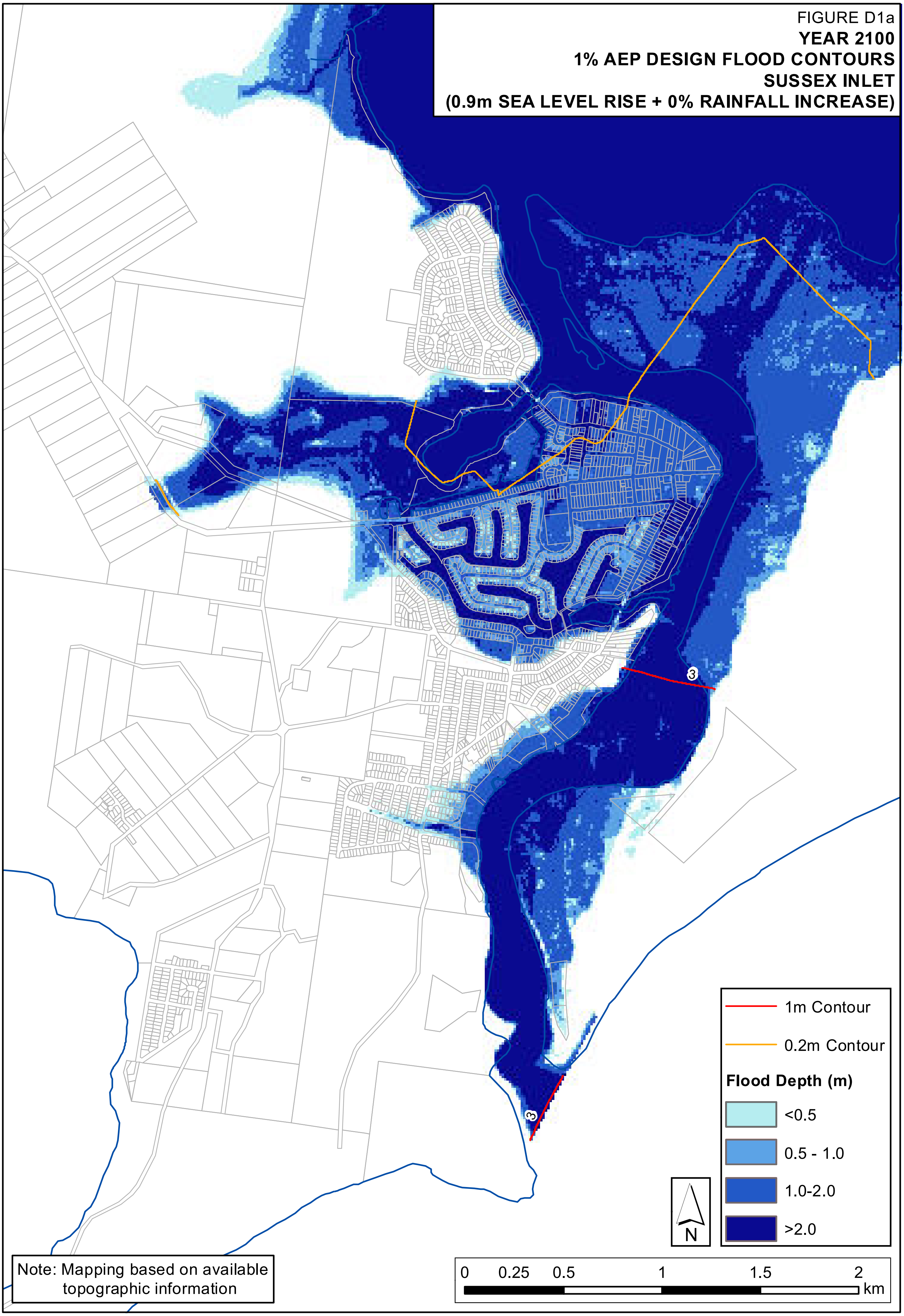

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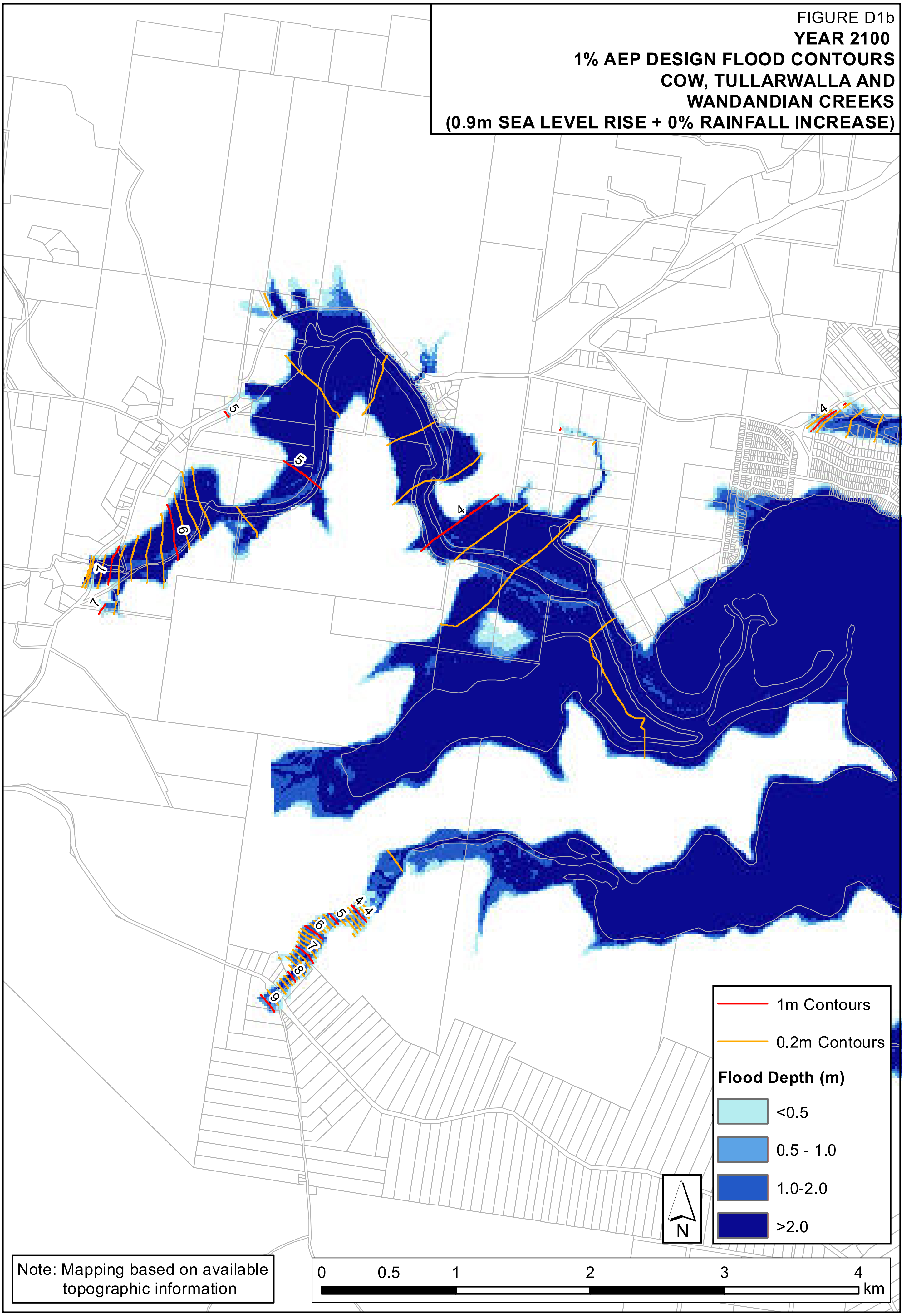
FIGURE D1b

YEAR 2100
1% AEP DESIGN FLOOD CONTOURS
COW, TULLARWALLA AND
WANDANDIAN CREEKS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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FIGURE D1c

YEAR 2100

1% AEP DESIGN FLOOD CONTOURS

PATS AND HOME CREEKS

(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)

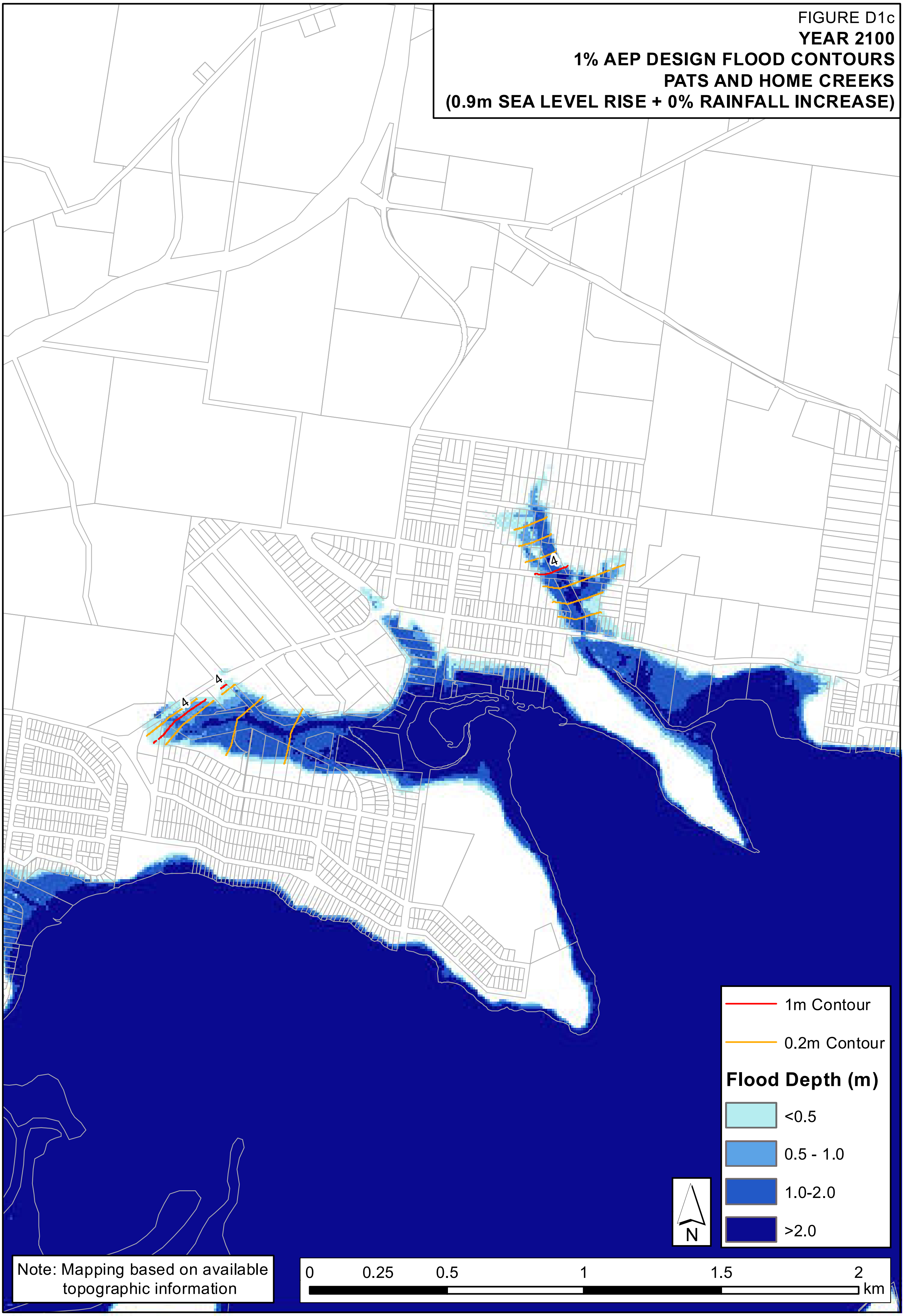

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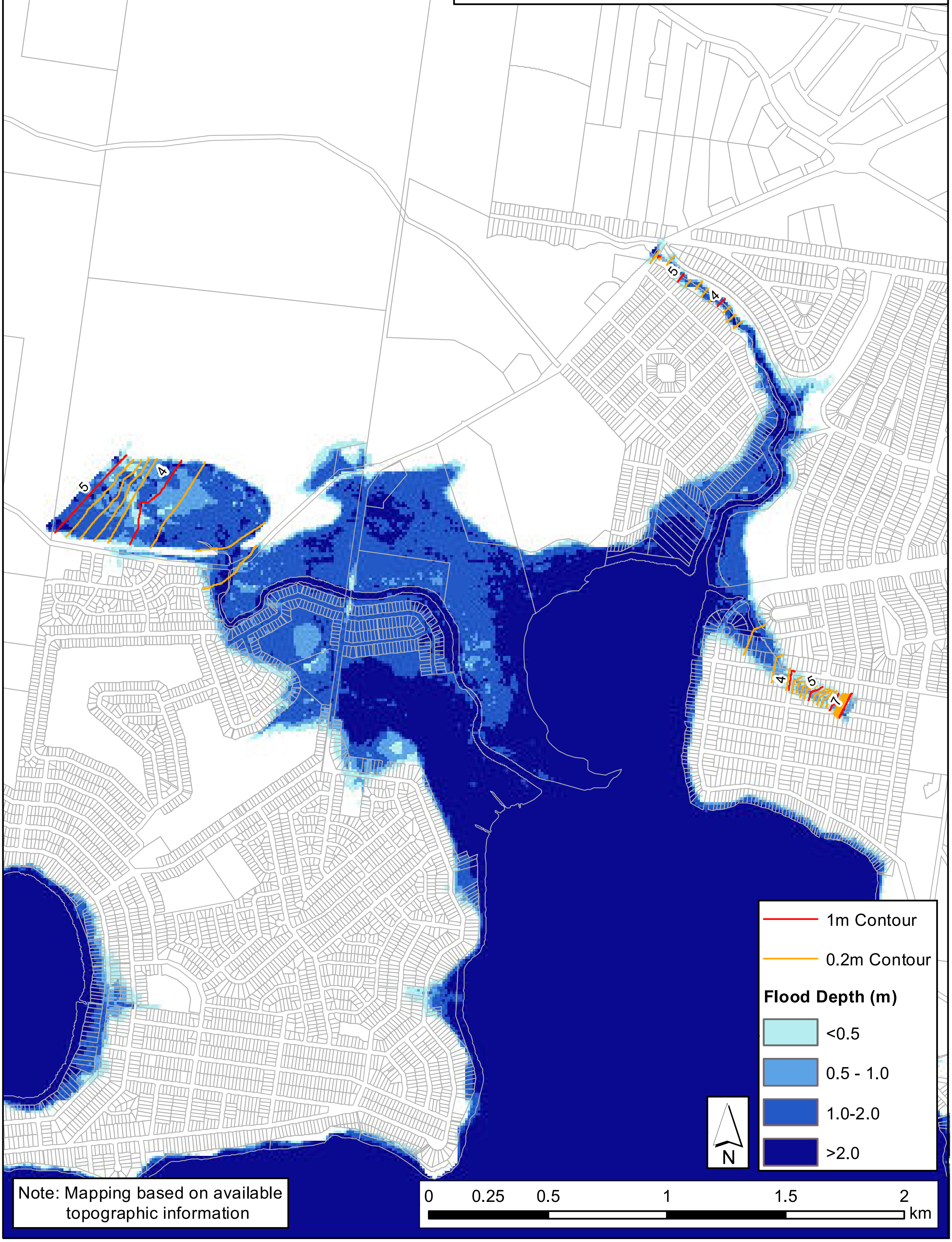
FIGURE D1d

YEAR 2100
1% AEP DESIGN FLOOD CONTOURS
TOMERONG AND EROWAL CREEKS
AND WORROWING WATERWAY
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)



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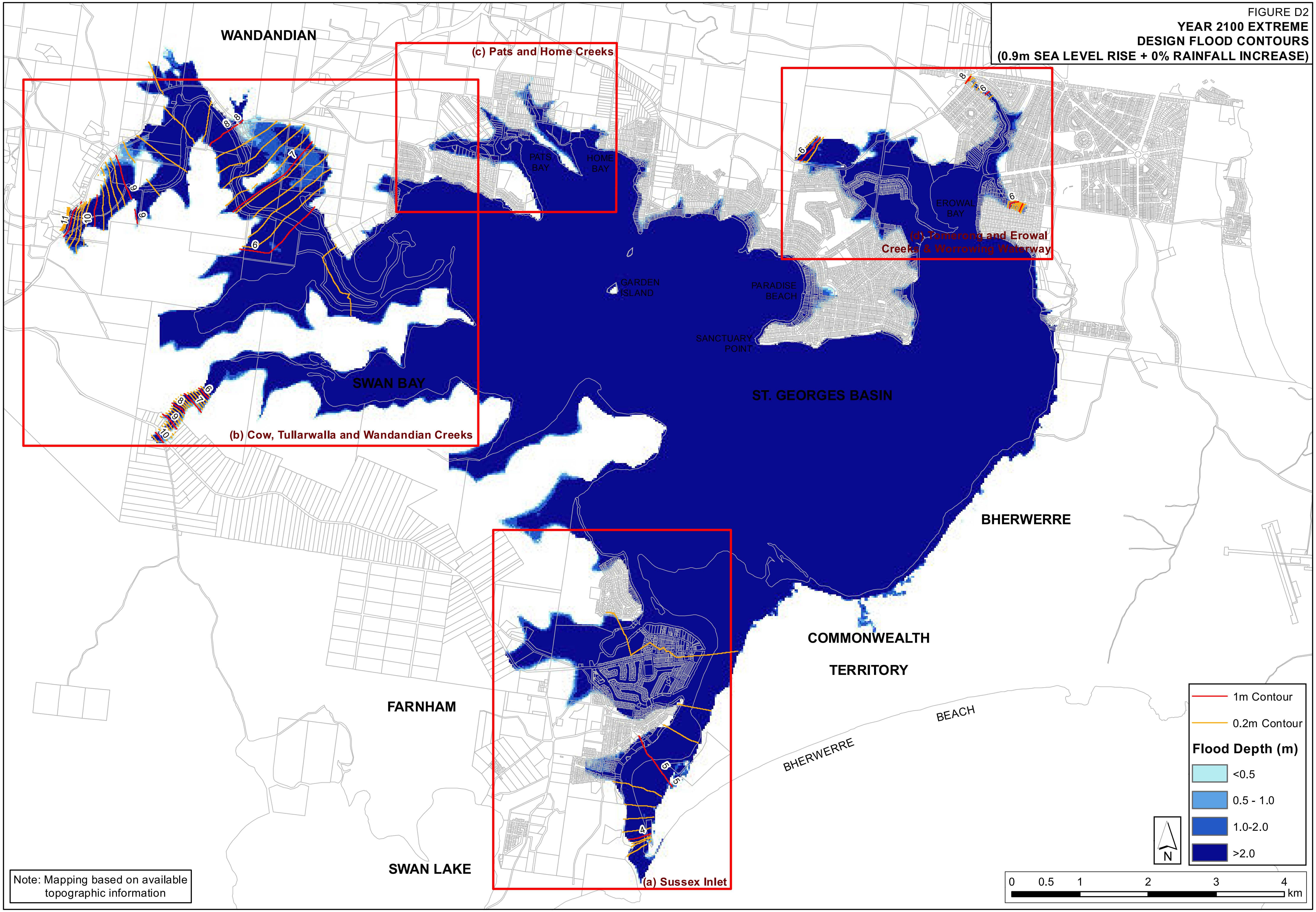


FIGURE D2
YEAR 2100 EXTREME
DESIGN FLOOD CONTOURS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)
WANDANDIAN
(c) Pats and Home Creeks
PATS BAY
HOME BAY
(b) Cow, Tullarwalla and Wandandian Creeks
SWAN BAY
GARDEN ISLAND
PARADISE BEACH
SANCTUARY POINT
ST. GEORGES BASIN
EROWAL BAY
(d) Tomerong and Erowal Creeks & Worrowing Waterway
BHERWERRE
COMMONWEALTH TERRITORY
FARNHAM
SWAN LAKE
(a) Sussex Inlet
BHERWERRE BEACH
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0 0.5 1 2 3 4 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD2_2100_Ext_Contours.mxd

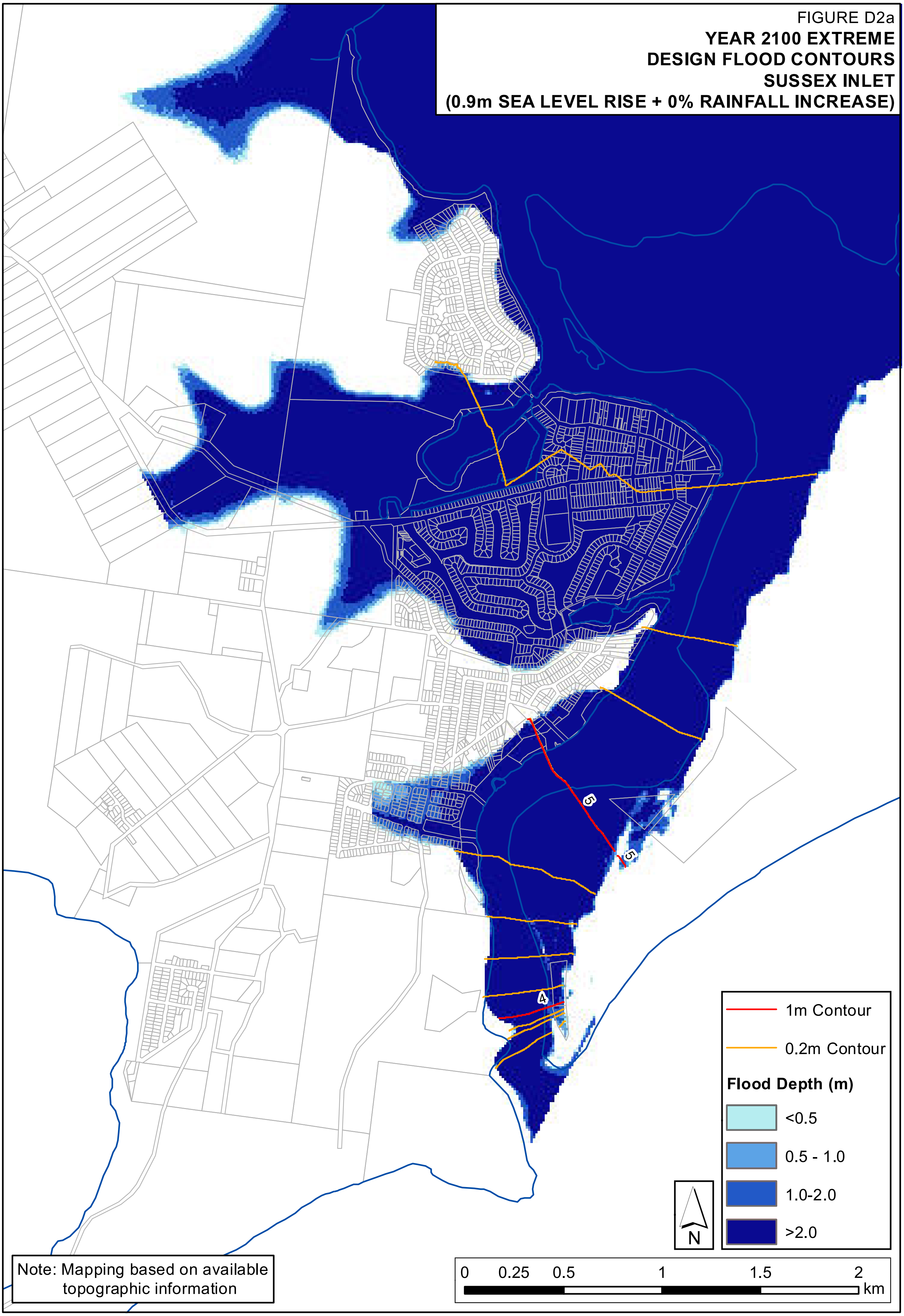


FIGURE D2a
YEAR 2100 EXTREME
DESIGN FLOOD CONTOURS
SUSSEX INLET
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0 0.25 0.5 1 1.5 2
km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD2a_2100_Ext_Contours.mxd

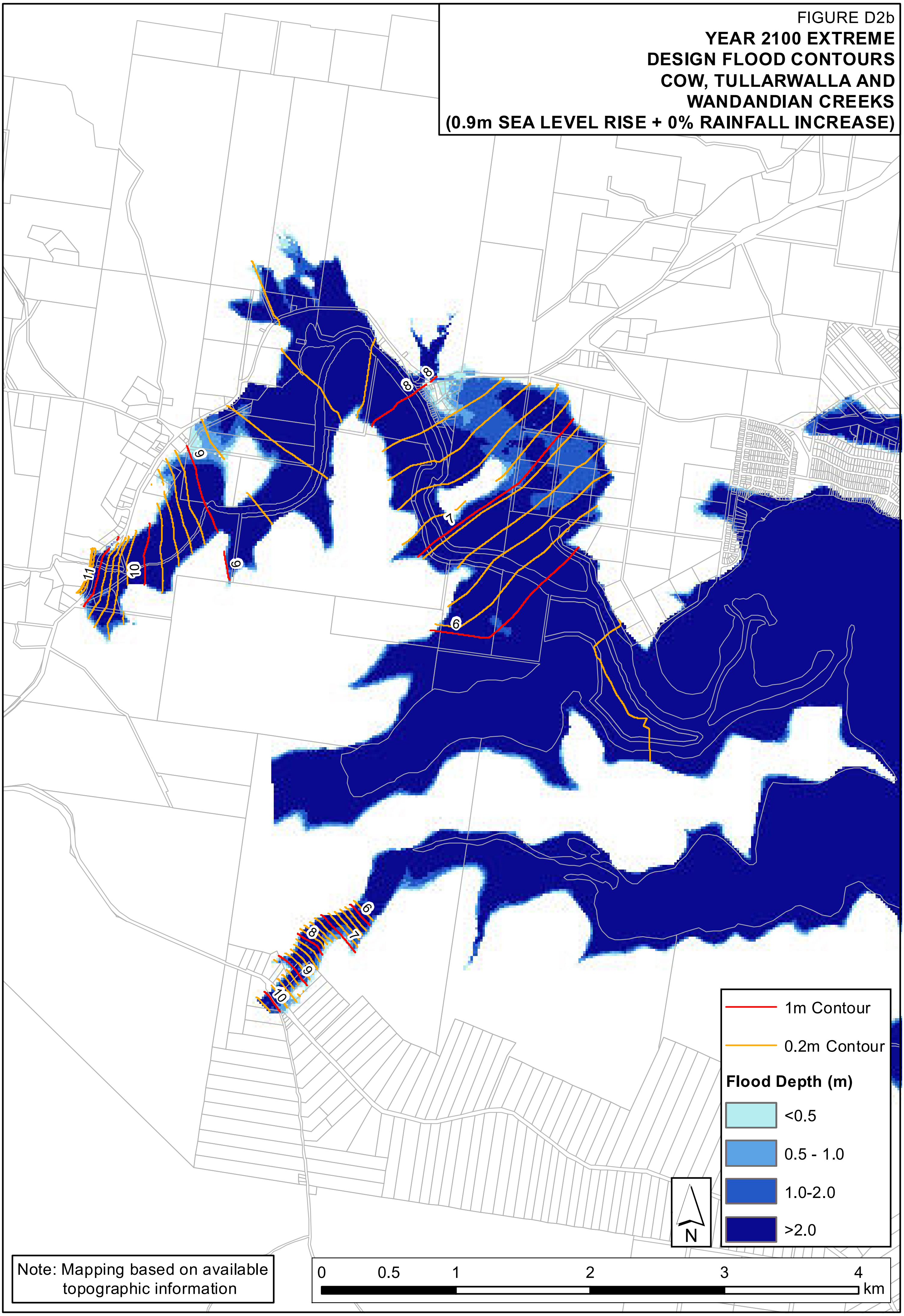


FIGURE D2b
YEAR 2100 EXTREME
DESIGN FLOOD CONTOURS
COW, TULLARWALLA AND
WANDANDIAN CREEKS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0
0.5
1
2
3
4
km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD2b_2100_Ext_Contours.mxd

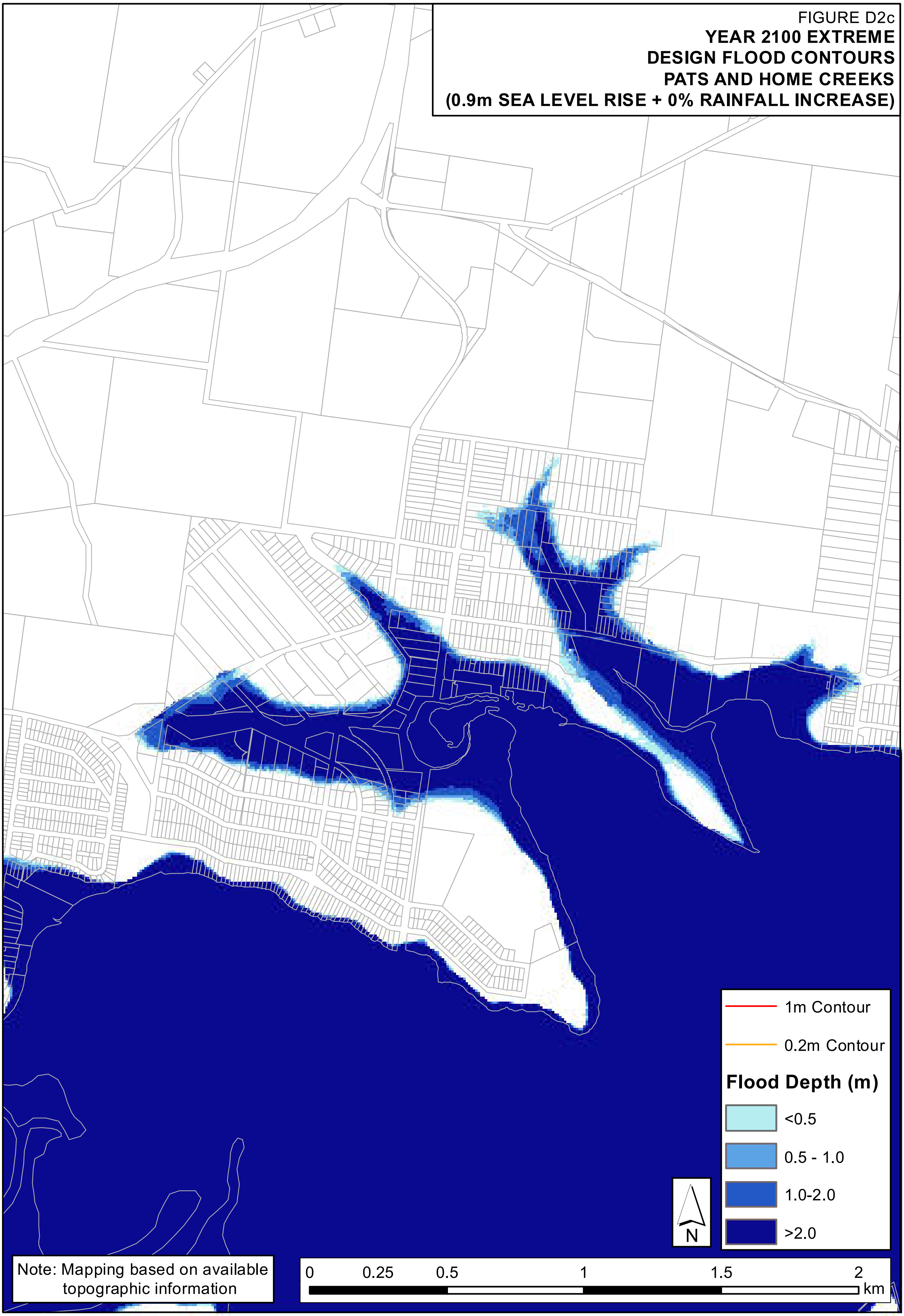
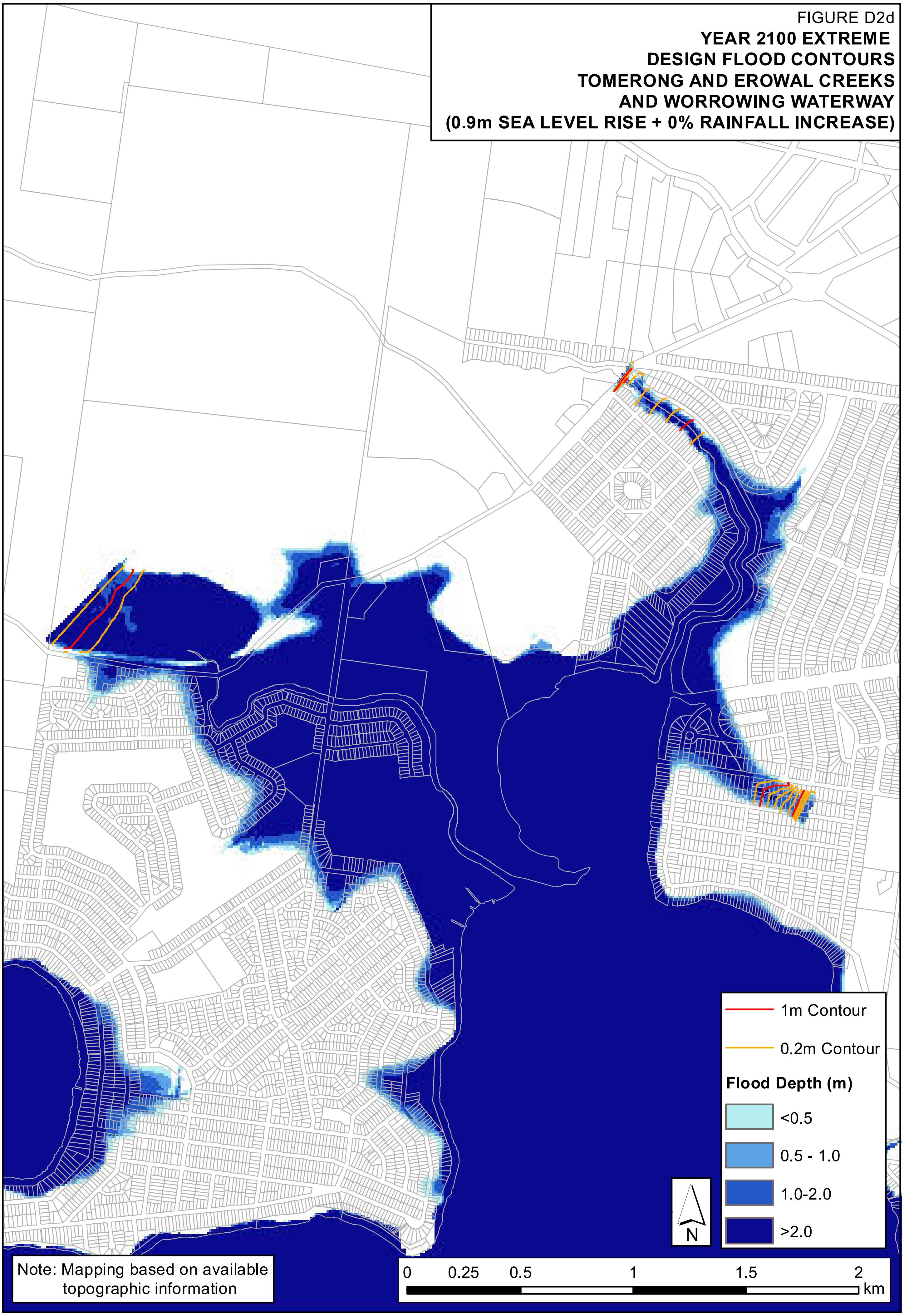


FIGURE D2c
YEAR 2100 EXTREME
DESIGN FLOOD CONTOURS
PATS AND HOME CREEKS
(0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0
0.25
0.5
1
1.5
2
km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD2c_2100_Ext_Contours.mxd

FIGURE D2d

YEAR 2100 EXTREME DESIGN FLOOD CONTOURS TOMERONG AND EROWAL CREEKS AND WORROWING WATERWAY (0.9m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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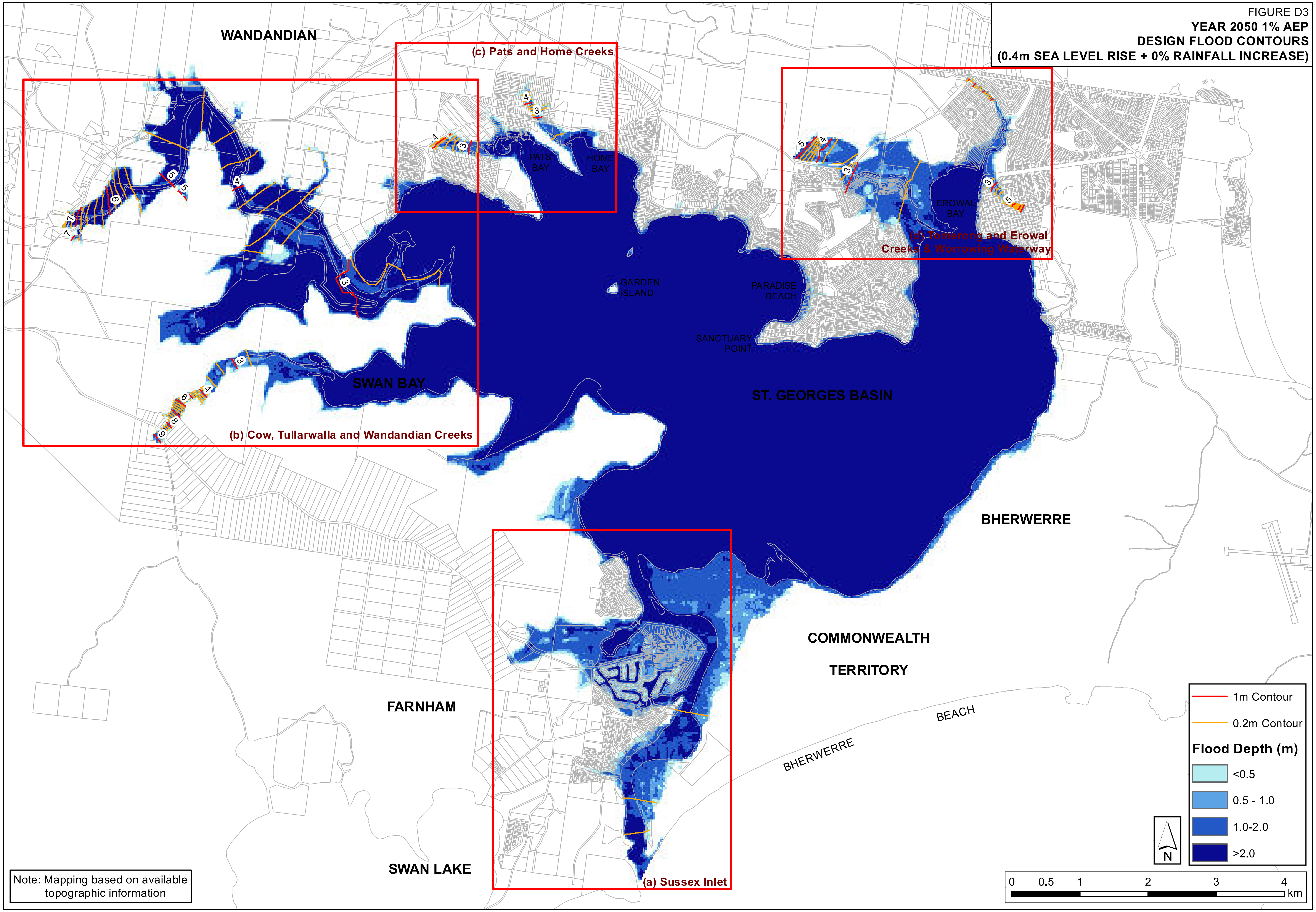
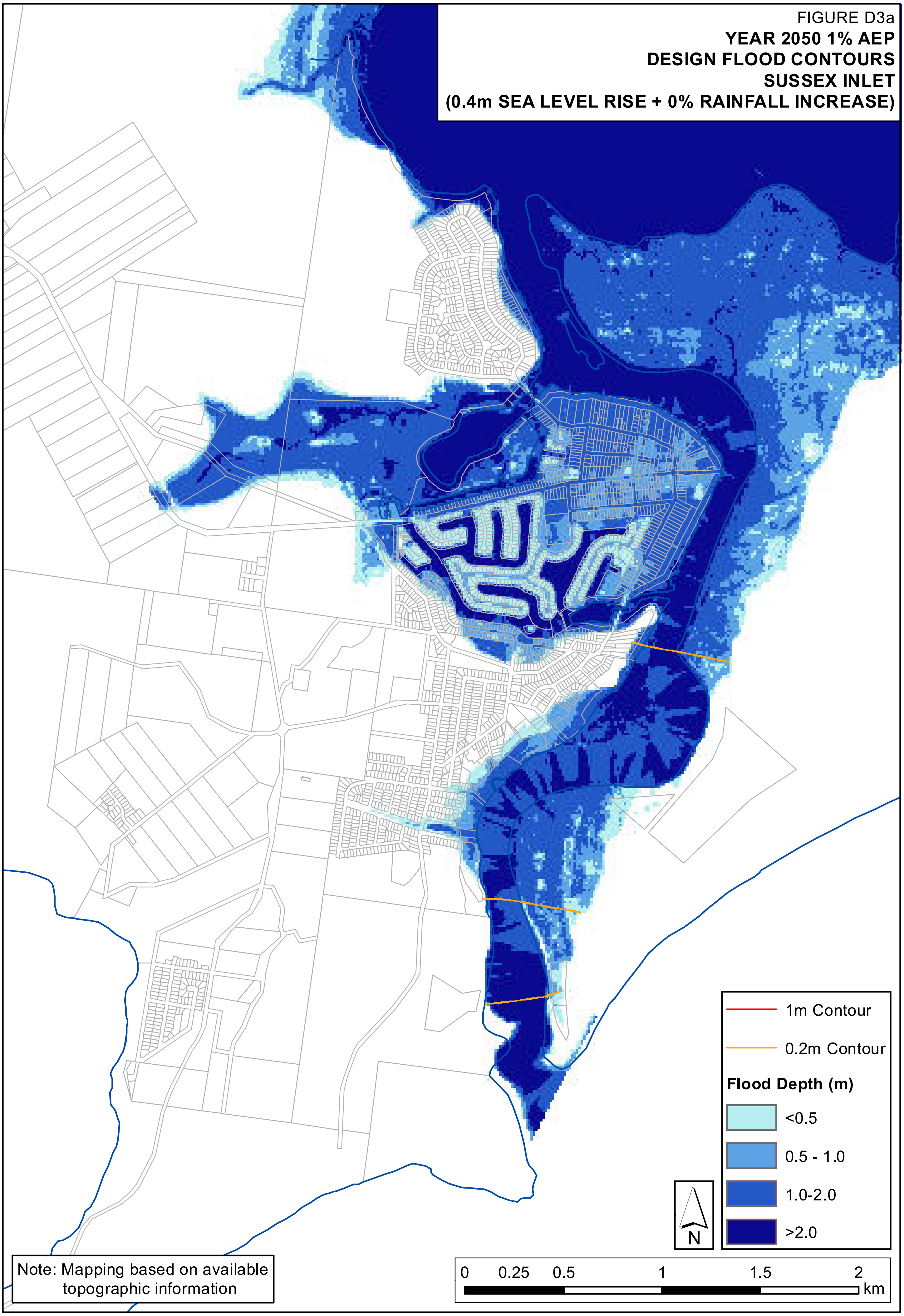


FIGURE D3
YEAR 2050 1% AEP
DESIGN FLOOD CONTOURS
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
WANDANDIAN
(c) Pats and Home Creeks
PATS BAY
HOME BAY
(d) Tomerong and Erowal Creeks & Worrowing Waterway
EROWAL BAY
GARDEN ISLAND
PARADISE BEACH
SANCTUARY POINT
SWAN BAY
ST. GEORGES BASIN
(b) Cow, Tullarwalla and Wandandian Creeks
BHERWERRE
COMMONWEALTH
TERRITORY
FARNHAM
SWAN LAKE
(a) Sussex Inlet
BHERWERRE
BEACH
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0 0.5 1 2 3 4 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD3_2050_100y_Contours.mxd

FIGURE D3a

YEAR 2050 1% AEP DESIGN FLOOD CONTOURS SUSSEX INLET (0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

J:\Jobs\112001\ArcView\ArcMaps\FigureD3a_2050_100y_Contours.mxd

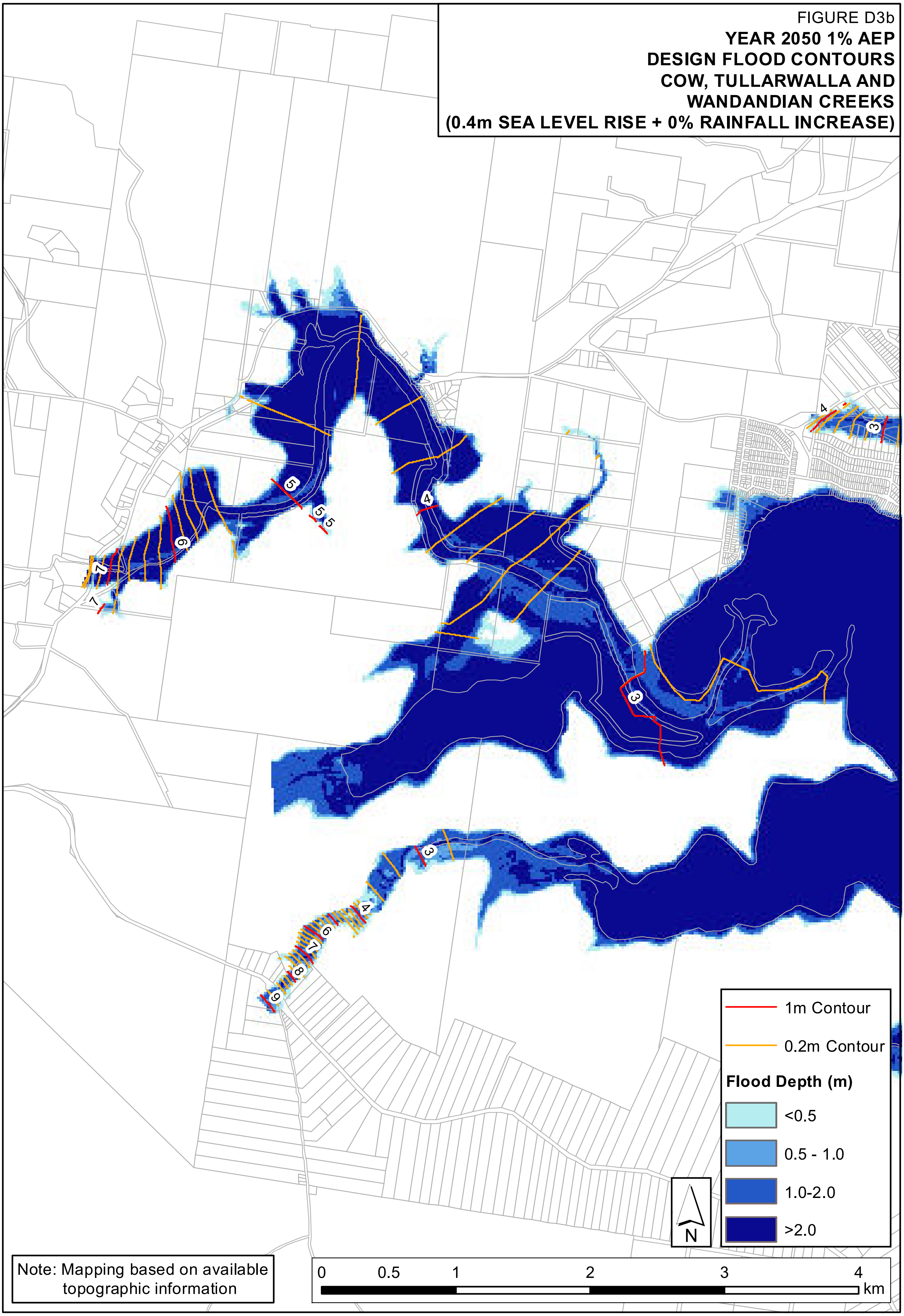
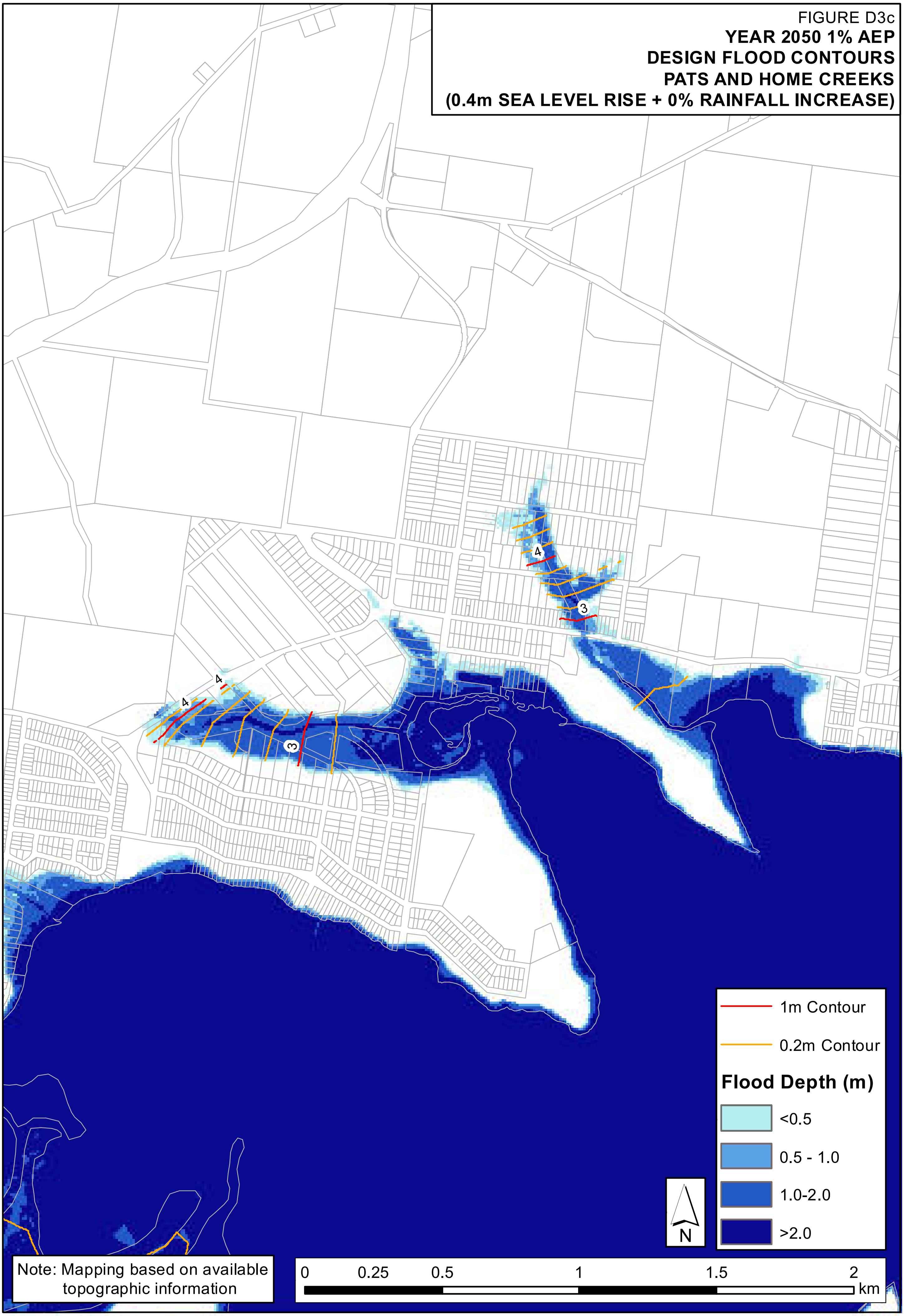


FIGURE D3b
YEAR 2050 1% AEP
DESIGN FLOOD CONTOURS
COW, TULLARWALLA AND
WANDANDIAN CREEKS
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
1m Contour
0.2m Contour
Flood Depth (m)
<0.5
0.5 - 1.0
1.0-2.0
>2.0
N
0
0.5
1
2
3
4
km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD3b_2050_100y_Contours.mxd

FIGURE D3c
YEAR 2050 1% AEP
DESIGN FLOOD CONTOURS
PATS AND HOME CREEKS
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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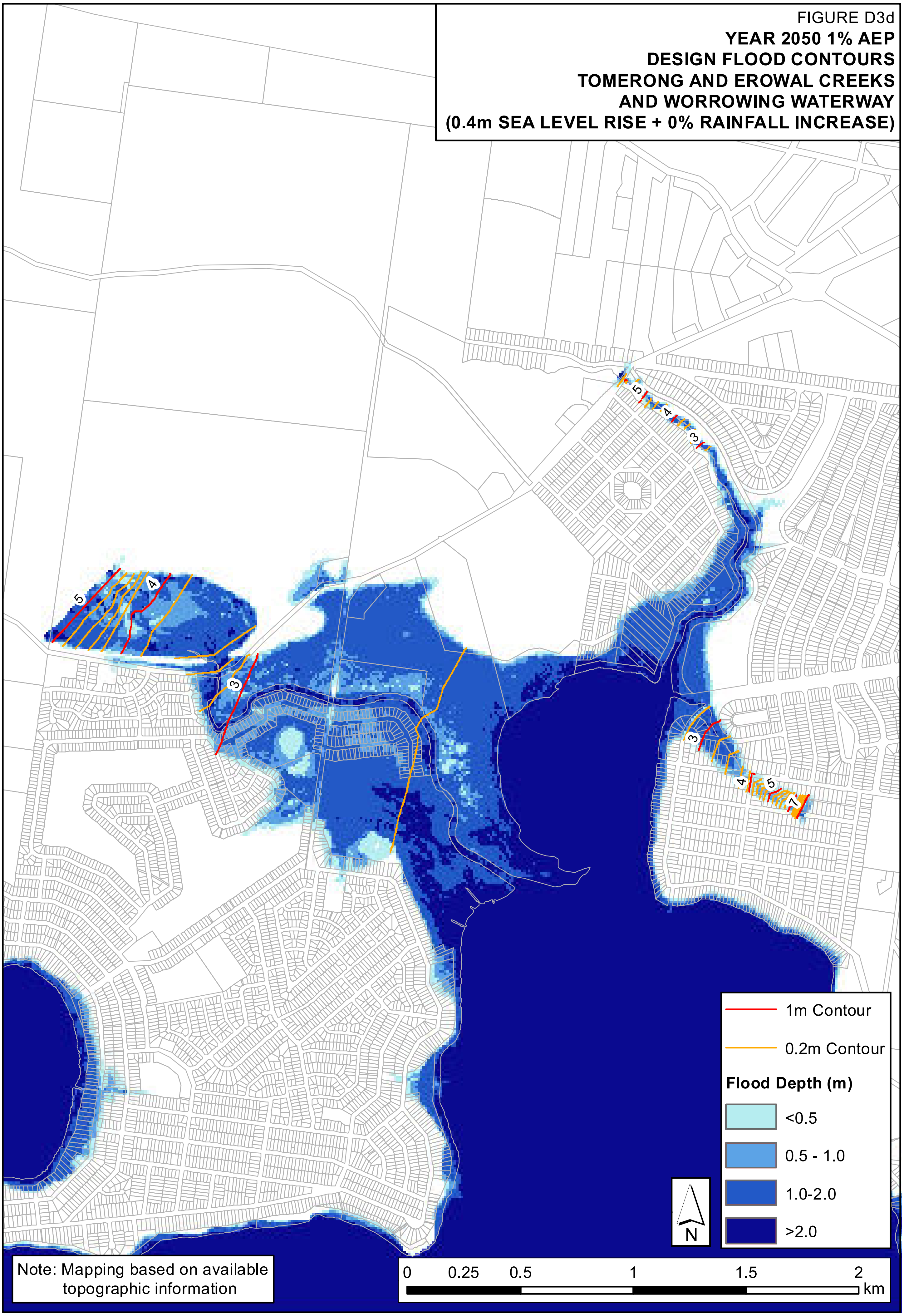
FIGURE D3d

YEAR 2050 1% AEP DESIGN FLOOD CONTOURS TOMERONG AND EROWAL CREEKS AND WORROWING WATERWAY (0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



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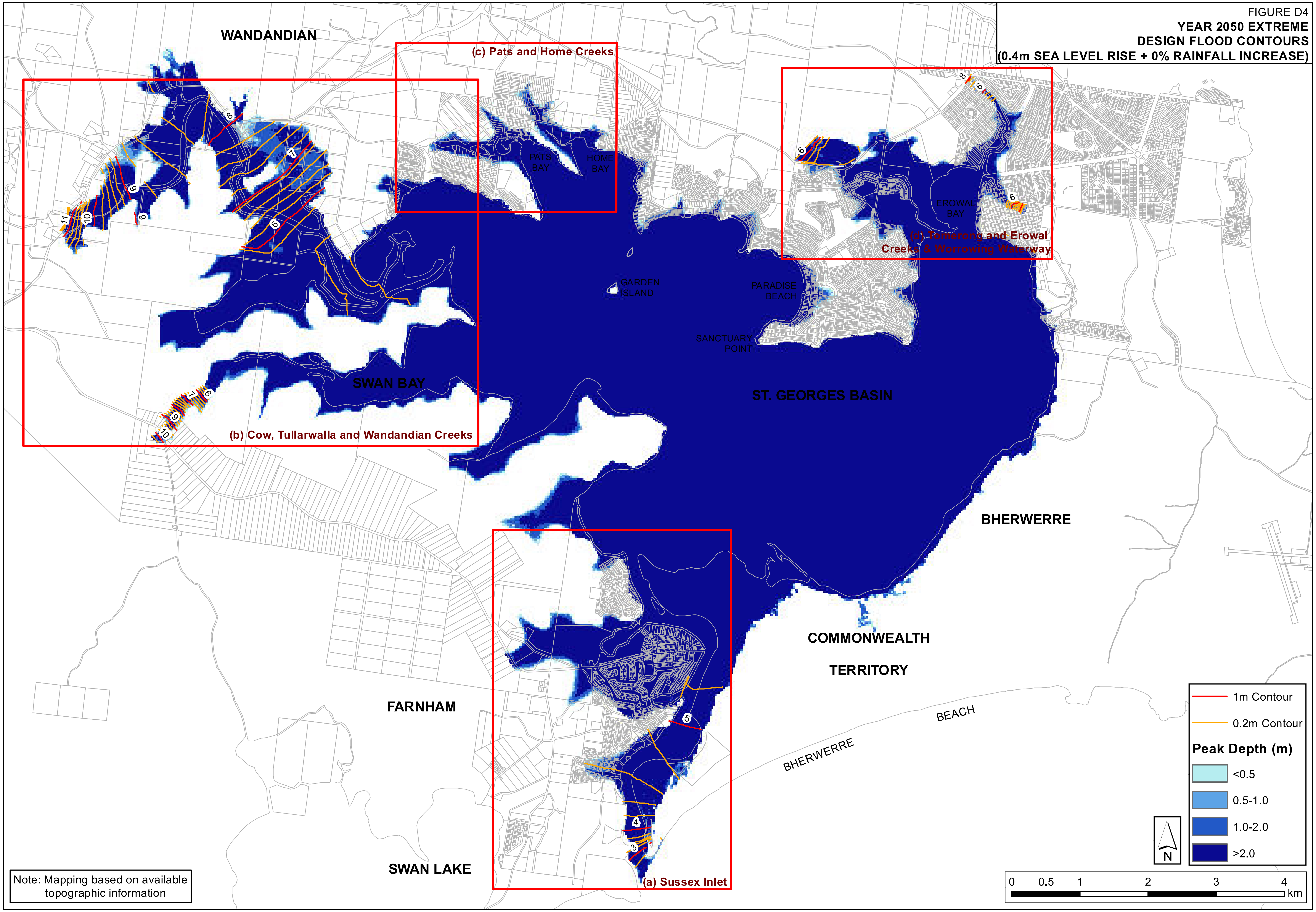
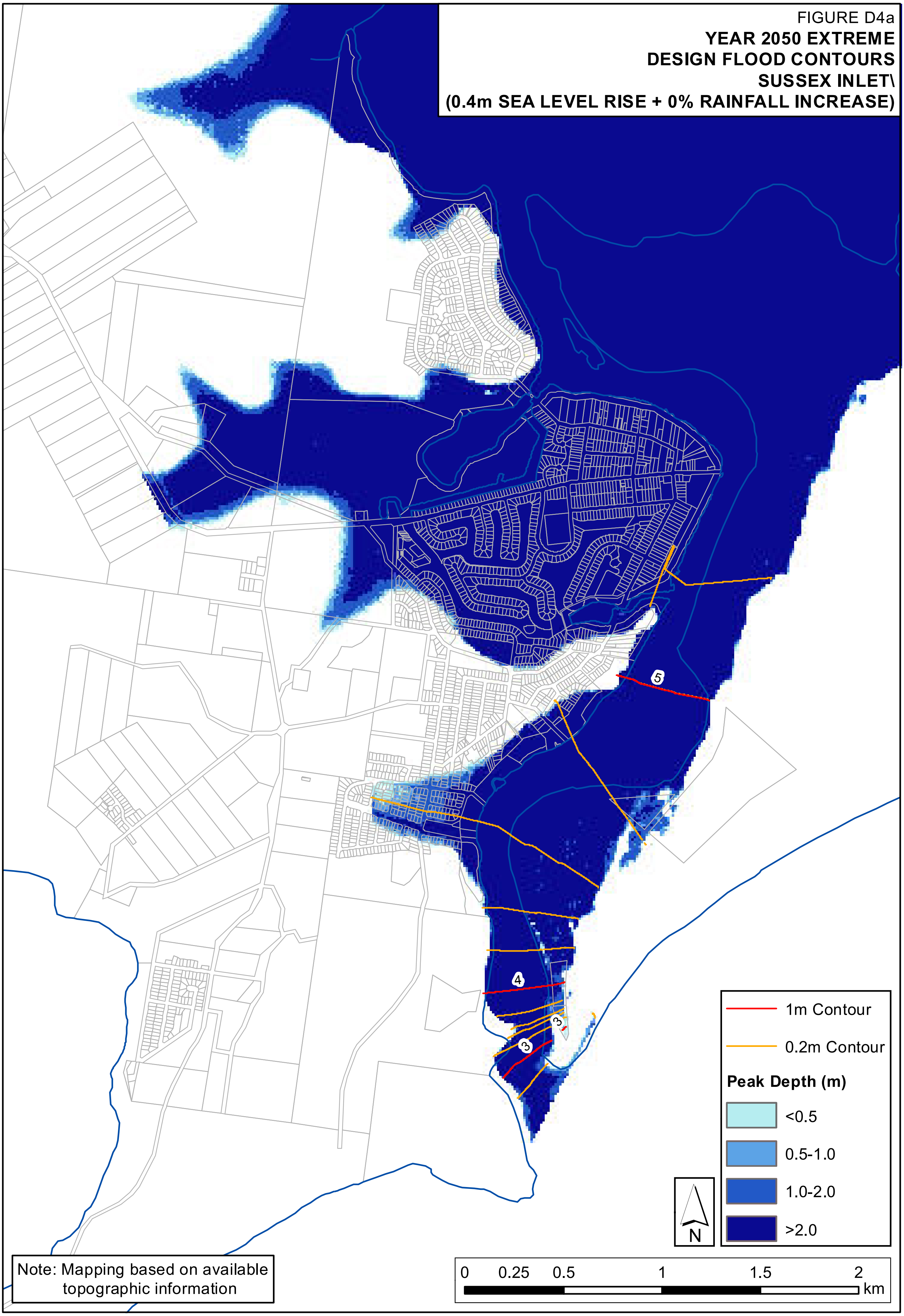


FIGURE D4
YEAR 2050 EXTREME
DESIGN FLOOD CONTOURS
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
WANDANDIAN
(c) Pats and Home Creeks
PATS BAY
HOME BAY
EROWAL BAY
(d) Tomerong and Erowal Creeks & Worrowing Waterway
GARDEN ISLAND
PARADISE BEACH
SANCTUARY POINT
SWAN BAY
ST. GEORGES BASIN
(b) Cow, Tullarwalla and Wandandian Creeks
BHERWERRE
COMMONWEALTH
TERRITORY
FARNHAM
SWAN LAKE
(a) Sussex Inlet
BHERWERRE
BEACH
1m Contour
0.2m Contour
Peak Depth (m)
<0.5
0.5-1.0
1.0-2.0
>2.0
N
0 0.5 1 2 3 4 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD4_2050_Ext_Contours.mxd

FIGURE D4a
YEAR 2050 EXTREME DESIGN FLOOD CONTOURS SUSSEX INLET\ (0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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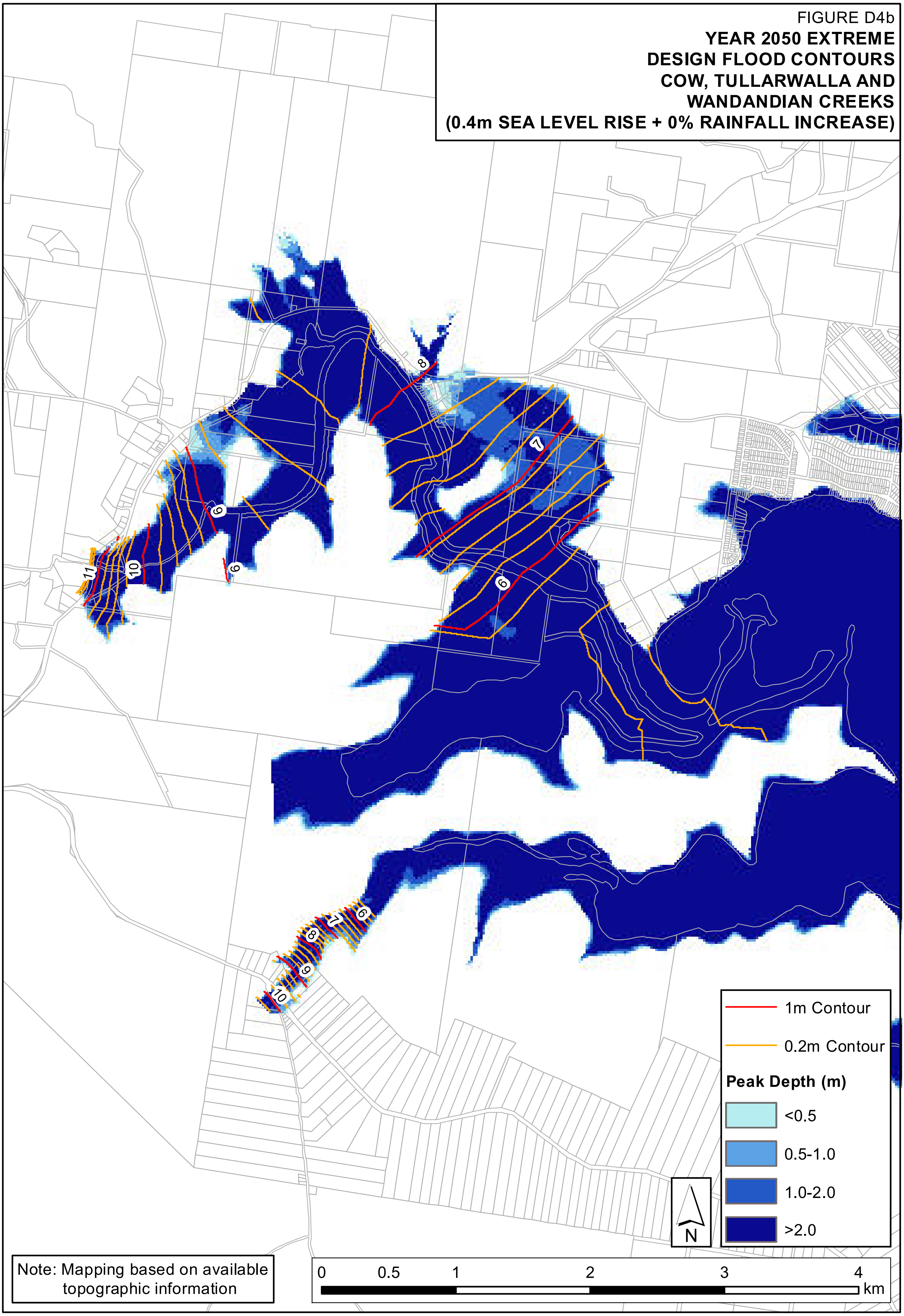
FIGURE D4b

YEAR 2050 EXTREME DESIGN FLOOD CONTOURS COW, TULLARWALLA AND WANDANDIAN CREEKS (0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)



Note: Mapping based on available topographic information

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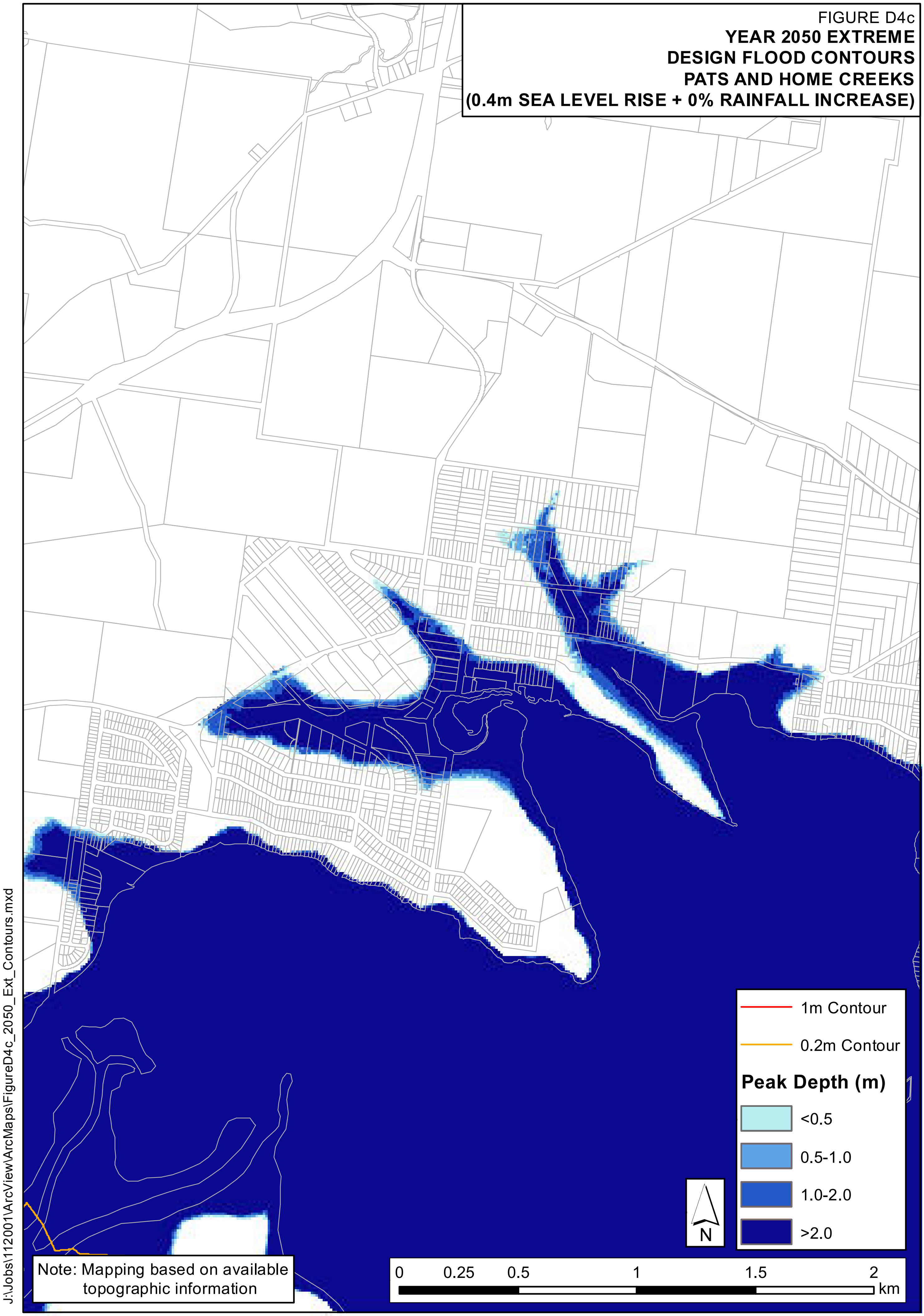
FIGURE D4c
YEAR 2050 EXTREME
DESIGN FLOOD CONTOURS
PATS AND HOME CREEKS
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
1m Contour
0.2m Contour
Peak Depth (m)
<0.5
0.5-1.0
1.0-2.0
>2.0
N
0
0.25
0.5
1
1.5
2
km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD4c_2050_Ext_Contours.mxd

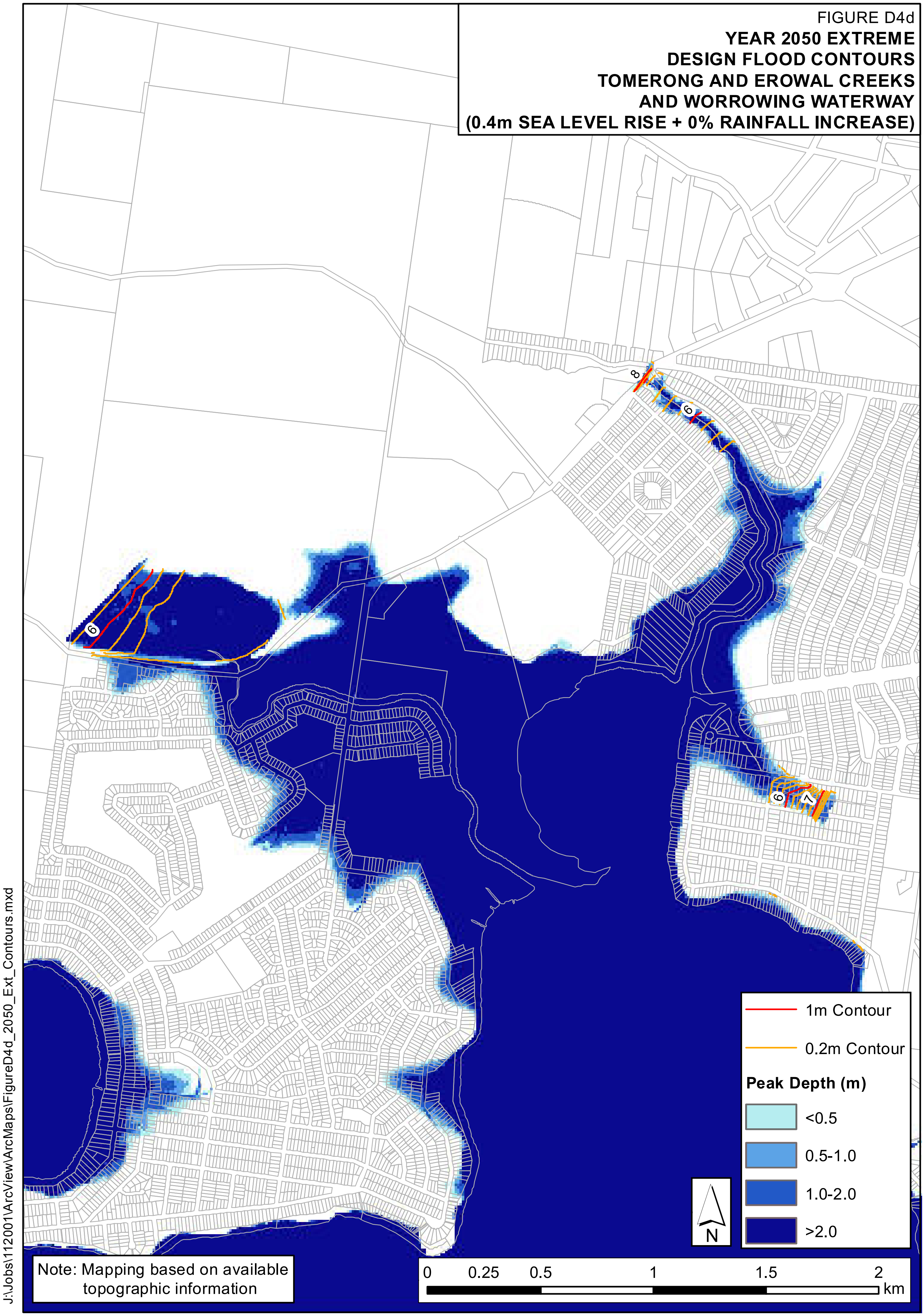
FIGURE D4d
YEAR 2050 EXTREME
DESIGN FLOOD CONTOURS
TOMERONG AND EROWAL CREEKS
AND WORROWING WATERWAY
(0.4m SEA LEVEL RISE + 0% RAINFALL INCREASE)
1m Contour
0.2m Contour
Peak Depth (m)
<0.5
0.5-1.0
1.0-2.0
>2.0
N
0 0.25 0.5 1 1.5 2 km
Note: Mapping based on available topographic information
J:\Jobs\112001\ArcView\ArcMaps\FigureD4d_2050_Ext_Contours.mxd