SHOALHAVEN CITY COUNCIL

LOWER SHOALHAVEN RIVER FLOODPLAIN MANAGEMENT STUDY & PLAN

CLIMATE CHANGE ASSESSMENT

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LOWER SHOALHAVEN RIVER FLOODPLAIN RISK MANAGEMENT STUDY & PLAN – CLIMATE CHANGE ASSESSMENT

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1. INTRODUCTION

1.1. Background

The main objective of this study is to amend the existing Lower Shoalhaven River Floodplain Risk Management Study and Plan (study area shown on Figure 1) to incorporate the predicted impacts of climate change.

In April, 1990 the Public Works Department (Consultant: Webb, McKeown & Associates) prepared the *"Lower Shoalhaven River – Flood Study"* (Reference 1) report which constitutes the first stage of the management process for the Lower Shoalhaven River Catchment. This Climate Change Assessment report provides an in depth response to Council's advice regarding climate change and builds on the April 1990 Flood Study.

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.

1.1.1. 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 flood 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 (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.

1.2. Climate Change

The *2005 Floodplain Development Manual* 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 (ocean 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 2), which updated the Third IPCC Assessment Report of 2001 (Reference 3);
- the preparation of *Climate Change Adaptation Actions for Local Government* by SMEC Australia for the Australian Greenhouse Office in mid 2007 (Reference 4);
- the preparation of *Climate Change in Australia* by CSIRO in late 2007 (Reference 5), which provides an Australian focus on Reference 2;
- 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 6 - referred to as the DECC Guideline 2007);
- Hunter, Central and Lower North Coast Regional Climate Change Project — Report 3: Climate Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW (Hunter and Central Coast Regional Environmental Strategy, 2009 (Reference 7);
- NSW Policy Statement on Sea Level Rise (October 2009) (Reference 8) 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 9): Incorporating sea level rise benchmarks in flood risk assessments*,
  - *Coastal Risk Management Guide (Reference 10): 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 11).*

1.3. Approach

As a result of the information provided in the above 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 above reports and at this time there is no absolute value that has been adopted by all experts.

The DECC Guideline 2007 indicated as below:

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

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

The NSW Policy Statement on Sea Level Rise (Reference 8 - October 2009) provided guidelines as indicated below:

- ***ocean 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.

1.4. Staging of Report

This project was sub-divided into two stages. Stage 1 included derivation of a climate change approach, the modelling of this approach using the available models and subsequent reporting (a Stage 1 report was produced and from this the scope for Stage 2 developed).

Stage 2 was intended to include the modelling of additional flood events, however the majority of these were already included within Stage 1. The only remaining hydraulic modelling that could be undertaken was the Extreme Flood and varying the entrance assumptions for Shoalhaven Heads (the crest of the berm).

Stage 1 recommended that the effect of ocean level rise be modelled for the Extreme Event but NOT rainfall increase as there is no scientific data available that suggests that this is likely to occur in this event. Modelling the effect of raising the entrance crest at Shoalhaven Heads was recommended for the 10, 20, 50 and 100 year ARI events. Recommended increases in the berm level at Shoalhaven Heads were + 0.4m and + 0.9m (to coincide with the ocean level increase).

The final outcomes from Stage 2 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,

- include the final findings from the investigation works under this brief into the Lower Shoalhaven River 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 Lower Shoalhaven River 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 Lower Shoalhaven River floodplain as a result of:

1. Increased ocean level rise,
2. Increased design rainfall intensities,
3. Changes to the "breakout" mechanism at Shoalhaven Heads (although this is to some extent dependant upon Council's Entrance Management policy (Reference 12) – this could be modified to mitigate the potential impacts due to sea level rise and rainfall increase),
4. Changes to the morphologic regime of the Lower Shoalhaven River. For example; "will climate change affect the dimensions of Berry's Canal or the build up (or erosion) of sediments?"
5. Changes to the wind wave action on the coast may influence the morphology of the two entrances and potentially the storm surge and wave setup component adopted in the design flood analysis.

The methodology addresses the Issues 1 and 2 identified above and to some extent Issue 3. Issues 4 and 5 are outside the scope of the present study. The following sections present detailed discussion of the various tasks involved in this study.

2.2. Modelling Approach

The existing flood levels in the Lower Shoalhaven River Flood Study are based on a WBNM and CELLS model undertaken in the late 1980's (Reference 1). 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 1990 Flood Study and therefore the change in flood level along the river (where calibration data is available) would probably not change significantly. Our experience is that there would be large 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 CELLS model). However the extent of the floodplain as defined in Reference 13 would not change as it was based on ALS, although if the flood levels change the floodplain extent will change (only slightly given the grade of the land at the perimeter of the floodplain).

The main issue with the use of a 2D model is the entrance breakout at Shoalhaven Heads. The procedure used in the CELLS model is crude but has at least been verified against past data (albeit limited). Some sort of approach would have to be incorporated and then tested with a 2D model. With no doubt this could be achieved but it will significantly extend the timeframe and may introduce many other problems.

The present approach is to use the existing hydrologic and hydraulic models as this permits a cost effective and "quick" response to the task. However as advised previously to Council, an updating of the Lower Shoalhaven River Flood Study is recommended. This should be a priority if a 10 year ARI or greater event occurred on the Shoalhaven River as this would significantly enhance the hydrologic/hydraulic model calibration.

2.3. Hydrologic and Hydraulic Modelling

Combinations of all the following design scenarios have been evaluated, with the exception of the % rainfall increases for the Extreme (this event is comparable to the Probable Maximum Flood (PMF) but was not derived according to current PMF procedures) but and 500y and 200y ARI events as these scenarios cannot be accommodated within the hydraulic model entrance breakout procedure at Shoalhaven Heads. Raising of the berm level at Shoalhaven Heads was also not evaluated for events greater than the 100y ARI.

Rainfall Design Events	Extreme Flood, 500y, 200y, 100y, 50y, 20y, 10y ARI,
Ocean Level Increases	+0.9m, +0.4m,
Rainfall Increases	+10%, +20%, +30%,
Berm level at Shoalhaven Heads	2m AHD (current scenario), 2.4m AHD, 2.9m AHD.

2.4. Existing Design Conditions

The design flood conditions for the Shoalhaven River (Lower Shoalhaven River Flood Study – 1990 – Reference 1 and adopted for the Shoalhaven River Floodplain Risk Management Study – Reference 13) include:

- The design inflows calculated using a rainfall-runoff hydrologic model (WBNM),
- A closed entrance berm (crest at 2m AHD) at Shoalhaven Heads which becomes overtopped and is scoured out during the course of the flood. The berm at Shoalhaven Heads is managed by Shoalhaven City Council in accordance with the *Shoalhaven River Entrance Management Plan for Flood Mitigation – 2006* (Reference 12),
- Design ocean hydrographs derived as part of the Lower Shoalhaven River Flood Study (Reference 1). The ocean hydrographs (*PWD Report: Elevated Ocean Stage Hydrographs – Shoalhaven River, Lawson & Treloar Pty Ltd, November 1987*) are different for the Shoalhaven River and Crookhaven River entrances to reflect the different wave setup conditions.

The effect of climate change (ocean level rise or rainfall increase) can be analysed by varying the boundary conditions of the hydraulic model (inflows and ocean level) and the assumed berm level at the Shoalhaven Heads entrance.

2.5. Climate Change Assumptions

2.5.1. Ocean Level Rise

To assess the effects of ocean level rise each ordinate of the ocean level hydrograph at the Shoalhaven River and Crookhaven River entrances was increased by the assumed ocean level rise (0.4m or 0.9m). A comparison of the adopted peak ocean levels is provided in Table 1. In the absence of any other data the 100y ARI ocean conditions have been adopted for all events greater than the 100y ARI.

Table 1: Comparison of Peak Ocean Levels (mAHD)

Flood (ARI)	100y/200y/ 500y/Extreme	50y	20y	10y
EXISTING				
Shoalhaven River	2.40	2.20	2.10	2.10
Crookhaven River	1.98	1.90	1.80	1.80
+0.4m OCEAN LEVEL RISE				
Shoalhaven River	2.80	2.60	2.50	2.50
Crookhaven River	2.38	2.30	2.20	2.20
+0.9m OCEAN LEVEL RISE				
Shoalhaven River	3.30	3.10	3.00	3.00
Crookhaven River	2.88	2.80	2.70	2.70

An ocean level rise of 0.4m equates to approximately twice the difference between the 20y and the 100y ARI design flood levels at the entrance to the Crookhaven River but this reduces to approximately the difference between the 50y and the 100y ARI design flood levels at Greenwell Point. For the Shoalhaven River the difference equates to 1.3 times the difference between the 50y and the 100y ARI design flood levels at the entrance. Thus an ocean level rise of 0.9 m represents a significant increase in the design ocean levels. 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 astronomic tide (1.1 mAHD) and the 100y ARI level (1.5 mAHD).

2.5.2. 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.

The adopted peak flows are provided in Table 2.

Table 2: Comparison of Peak Inflows at Nowra Bridge (m^3/s)

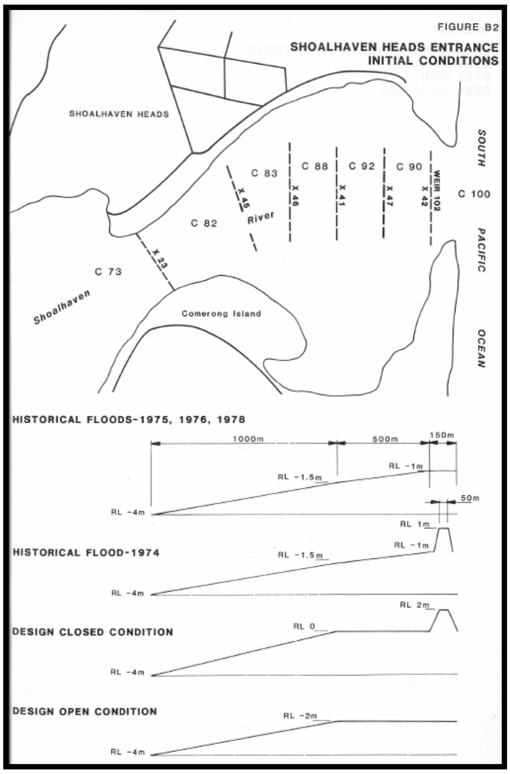
Flood (ARI)	10y	20y	50y	100y	200y	500y	Extreme
Existing	7380	9466	12196	15410	18171	21368	34105
+10% increase	8118	10413	13416	16951	Not obtained		
+20% increase	8856	11359	14635	18492			
+30% increase	9594	12306	15855	20033			

Whilst it is generally regarded that ocean 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 a 10% increase.

It should be noted that the increase in the existing peak flow from a 20y to a 50y ARI event is approximately 30% and from a 20y to the 100y ARI event is approximately 60%. Thus a 30% increase in flow would mean that the existing 50y ARI flood level would be reached or exceeded on average once in 20 years as opposed to once in 50 years.

2.5.3. Rise in Berm Level at Shoalhaven Heads

The design flood levels adopted in the Shoalhaven River (Lower Shoalhaven River Flood Study – 1990 – Reference 1) assume that the entrance berm at Shoalhaven Heads is at 2m AHD (see diagram below).



Climate change has the potential to alter the entrance conditions at Shoalhaven Heads and to a lesser extent at the mouth of the Crookhaven River. For this assessment only a change in the entrance conditions at Shoalhaven Heads has been evaluated. The entrance conditions at Shoalhaven Heads change as a result of floods eroding the berm and then taking the sand out to the ocean. After a major flood there is a sand plume into the ocean (see above photograph taken in June 1991 flood).

During non flood times the entrance berm gets re-established and builds up as a result of wave and wind action. These actions re-form the sand berm along the dune front but also wind action and sediment deposition from the river causes the river bed upstream of the berm to infill. Thus during a flood the flood waters must overtop the beach berm to initiate flow out to the ocean and the start of the erosion process. However it is not just the sand at the beach berm that must be removed but also the sand upstream (refer Figure B2 on the previous page showing the bed profile at Shoalhaven Heads).

Further details on the entrance processes are provided in *Shoalhaven River Entrance Management Plan for Flood Mitigation – 2006* (Reference 12). Reference 12 also describes the management plan for the entrance which in summary includes the lowering of the entrance berm to 2 mAHD (as indicated in Figure B2 on the previous page).

The effect of ocean level rise on the entrance conditions at Shoalhaven Heads is likely to be complex and cannot be accurately determined at this time. However it is generally acknowledged that an increase in ocean level will raise the height of the sand berm (if not lowered as part of Council's entrance management plan) by a similar amount to the increase in ocean level. Therefore as part of this assessment the effect of raising the entrance berm by 0.4m (to 2.4 mAHD) and 0.9m (to 2.9 mAHD) was simulated.

3. IMPACT OF CLIMATE CHANGE ON FLOOD LEVELS

3.1. Overview

The boundary conditions of the hydraulic model adopted in the Lower Shoalhaven River Flood Study to determine design flood levels were adjusted to reflect the adopted ocean level rise and increase in rainfall climate change scenarios as discussed in the previous section. The results have been taken at cell locations (refer to Figure 1) along the Crookhaven and Shoalhaven Rivers.

The results for the various scenarios modelled are provided on Figures 2 to 10.

The results have been provided as peak height profiles along the river based on the modelled river level at the centre of the cell. It should be noted that this hydraulic model (Cell Model) was established prior to geo-referencing of cross section locations and the use of GIS etc. Thus the centre of each cell and the river chainages are approximate and this data should not be used for any purpose where a precise location is required.

3.2. Discussion of Results

3.2.1. Figures 2 to 12

The following provides a brief description of each figure.

Figures 2 and 2a indicates the peak height profiles for the range of design flood events under existing conditions. The profiles can be divided into 3 different grades, between Cell 89 and Cell 56, between Cell 56 and Cell 7 and between Cell 7 and Cell 5. There is approximately a 0.7m difference between the 20y and the 100y ARI profiles and a 0.4m difference between the 50y and the 100y ARI profiles up to Cell 7. Further upstream the differences increase significantly as the Shoalhaven River is confined within a relatively narrow gorge with no accompanying floodplain.

Figures 3 and 2a indicate the effect of a 0.4m and a 0.9m increase in ocean level. The increase diminishes the further upstream from the ocean with the effect of a 0.4m ocean level rise decreasing to less than a 0.1m increase by Cell 56, while a 0.9m increase decreases to less than a 0.1m increase by Cell 42 (for events up to the 100y ARI).

Figure 4 shows the increases in flood levels due to the percentage rainfall increases (as indicated in the DECC Guideline 2007 - Reference 6). Within the Crookhaven/Shoalhaven Rivers the 10%, 20% and 30% rainfall increases all show similar trends between Cell 89 and Cell 27 within more significant increases upstream.

Figures 5 and 6 indicate the increases in flood levels due to the combination of rainfall increase and ocean level rise. The results are largely an “addition” of the impacts from each individual scenario.

Figures 7 to 10 indicates the increases in flood levels for each climate change scenario at:

- Nowra Bridge,
- Shoalhaven Heads,
- Terara and
- Greenwell Point.

Of interest in the above figures is how the effect of an ocean level rise varies with distance upstream from the Pacific Ocean and between Crookhaven Heads (Greenwell Point) and Shoalhaven Heads.

Figure 3 shows that in smaller events (10 year ARI) the impact of a 0.4m ocean level rise results in approximately a 0.26m rise in flood level at Greenwell Point (Cell 81). However the effect reduces with magnitude of the flood so the 100 year ARI event results in only a 0.18m rise and in a 500 year ARI event only a 0.15m rise. With a 0.9m ocean level rise the increase reduces from 0.66m (10 year) to 0.44m (100 year). Thus the larger the flood the less the impact of ocean level rise is on flood levels. This is to be expected as in larger events the greater peak flow means that the ocean level is a lesser factor in determining the peak water levels.

The effect of ocean level rise reduces with distance upstream from the Pacific Ocean, as would be expected. However it is noted that the effect reduces within a shorter distance upstream in the smaller events (10 year) than in the larger events (100 year).

At Shoalhaven Heads the impacts of an ocean level rise is complicated with the effect of the beach berm, its elevation and rate of scour. Figure 2a shows the opposite trend to that at Greenwell Point as at Shoalhaven Heads there is only a 0.04m rise (Cell 90) in the 10 year ARI compared to a 0.27m rise in the 100 year ARI event with a 0.4m ocean level rise. A similar trend is shown with a 0.9m ocean level rise.

3.2.2. Appendix A – Rise in Beach Berm

As discussed in Section 2.5.3 the effect of a 0.4m and 0.9m rise in level of the beach berm at Shoalhaven Heads has been determined for the following scenarios.

Rainfall Design Events	100y, 50y, 20y, 10y ARI,
Ocean Level Increases	+0.9m, +0.4m,
Rainfall Increases	+10%,
Rise in Berm level at Shoalhaven Heads	by 0.4m to 2.4m AHD, by 0.9m to 2.9m AHD.

Current guidelines (Reference 6) suggest that a likely outcome of future climatic change will be an increase in extreme rainfall intensities. This reference provides projected increases in annual extreme rainfall intensities for south-east NSW of 7% and 5%, for the years 2030 and 2070 respectively. The summer extreme rainfall intensities are projected to increase by 12% and 10% for the years 2030 and 2070 respectively. These figures are based on a 2.5% AEP (40-year ARI) 24h duration rainfall event. Based on these guidelines a design rainfall intensity increase of 10% was selected as being appropriate for assessing the potential impact of climate change on design rainfall in conjunction with a rise in the berm level. Results for the full range of rainfall increases are provided in Section 3.2.1.

The results are shown in the following figures (Appendix A) for the Shoalhaven River mouth.
Figure A1 shows the effect of a rise in berm level compared to the base. Thus raising the berm by 0.4m will increase the 100y ARI flood level at Shoalhaven Heads by approximately 0.09m (Cell 90), raising the berm by 0.9m will increase the 100y ARI flood level at Shoalhaven Heads by approximately 0.5m (Cell 90). However in both instances the impact rapidly decreases upstream. For both the 0.4m and 0.9m scenarios the greatest impact was in the 50y ARI event.

Figure A2 shows the effect of a berm level rise compared to the 0.4m and 0.9m ocean level rise. For all events the maximum impact is less than 0.2m for a 0.4m berm increase. For a 0.9m rise in berm level the impact is less than 0.1m for the 100y ARI but over 0.4m for the 20y ARI event. Thus a 0.9m ocean level rise plus a 0.9m berm rise will increase the 20y ARI flood level by approximately 0.8m at Shoalhaven Heads (Cell 90) (0.4m rise due to the 0.9m ocean level rise and an additional 0.4m rise due to the berm rise by 0.9m).

Figure A3 shows the effect of a berm level rise compared to the 10% rainfall increase scenario. The results indicate a similar magnitude in increase in flood levels to Figure A2 for a 0.4m increase. However for a 0.9m increase the relative impacts are much greater than for a similar berm rise as shown on Figure A2.

Figure A4 shows the effect of a berm level rise compared to the 10% rainfall increase plus ocean level scenario. The results indicate a similar magnitude in increase in flood levels to Figure A2.

The results are shown in the following figures (Appendix A) for the Crookhaven River.
Figure A5 shows the effect of a rise in berm level compared to the base. Thus raising the berm by 0.4m will increase the flood levels at the mouth of the Crookhaven River by approximately 0.1m, raising the berm by 0.9m will increase the flood levels at the mouth of the Crookhaven River by a maximum of approximately 0.4m. For the 0.4m and 0.9m scenarios the greatest impact was in the 10y and 20y ARI events respectively.

Figure A6 shows the effect of a berm level rise compared to the 0.4m and 0.9m ocean level rise. For all events the maximum impact is less than 0.1m for a 0.4m berm increase. For a 0.9m rise in berm level the impact is less than 0.1m for the 100y ARI but up to 0.25m for the 20y ARI event.

Figure A7 shows the effect of a berm level rise compared to the 10% rainfall increase scenario. The results indicate a similar magnitude in increase in flood levels to Figure A5 for the respective ocean level increases.

Figure A8 shows the effect of a berm level rise compared to the 10% rainfall increase plus ocean level scenario. The results indicate a similar magnitude in increase in flood levels to

Figure A6.

Figures A9 to A12 indicates the results for the berm level rise at:

- Nowra Bridge,
- Shoalhaven Heads,
- Terara and
- Greenwell Point.

The results indicate that any rise in berm level has little impact at Nowra Bridge. At Terara the maximum impact of a berm rise is 0.1m. At Greenwell Point there is up to a 0.4m increase (0.9m berm rise) for the base in the 20y ARI. In the 100y ARI the impact of a berm rise is less than 0.2m. The greatest impact of a berm rise is at Shoalhaven Heads (0.5m in the 100y ARI) for the base.

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

4.1. Overall

A climate change ocean level rise and a rainfall increase will affect flood levels along the Crookhaven and Shoalhaven River systems. Current (September 2010) NSW guidelines indicate that a 0.4m and a 0.9m ocean 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 ocean level rise) on flooding is the impact on the opening/closure regime at Shoalhaven Heads. Undoubtedly climate change will impact on this regime, though as yet the mechanisms and resulting impacts cannot be determine. To some extent the consequences of changes to this regime could be mitigated through adjustments to Shoalhaven City Council's Shoalhaven River Entrance Management Plan for Flood Mitigation. This would obviously be required if the community at Shoalhaven Heads becomes threatened. The impacts of a rise in the berm level have been investigated as part of this study (Appendix A).

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

- **Section 4.2** provides a general discussion of the impacts on water levels,
- **Section 4.3** provides a general discussion mitigation/adaptation measures to protect existing development,
- **Section 4.4** provides a general discussion mitigation/adaptation measures to protect future development,
- **Section 4.5** provides a general discussion of the issues that may threaten the long term viability of areas,
- **Section 4.6** provides comments on the implications of climate change for all floodplain management measures outlined in the Shoalhaven River (Reference 14), Riverview Road Area – Nowra (Reference 15) and Terara Village (Reference 16) Floodplain Management Plans,
- **Section 4.7** provides a summary and recommendations regarding inclusion of climate change impacts in flood related development controls.

4.2. How will Climate Change Affect Water Levels?

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

4.2.1. During Non Flood Times

The main impacts in non flood times will be:

- The range of "normal" water levels in the Shoalhaven and Crookhaven Rivers will rise.

An indicative increase is the same as the expected sea level rise (by 0.4m in 2050 and 0.9m in 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 in the Shoalhaven and Crookhaven Rivers in “non flood” times may result in increased maintenance costs and/or modifications costs for existing developments and infrastructure due to more frequent inundation in non flood times. For example, low lying roads will be more frequently inundated during elevated water levels. Inflows of water from the rivers to sewer surcharge vents in backyards may also 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.

A general raising of the river levels through an ocean level rise will also potentially impact on the erosional/sedimentation regime along the river bank. The existing bank protection works are designed to mitigate the effects of erosion within a certain water level band and thus the upper limit may have to be increased to compensate for raised river levels. Should this scenario eventuate (it will occur gradually) this issue can be addressed before significant damage is done.

It should also be noted that the floodplain of a river such as the Shoalhaven River is dynamic and is continually adapting to changing conditions. We also know that massive bank changes have occurred in the past (Terara in 1860 and 1870) and will undoubtedly occur again. Unfortunately there is no way of predicting where and when they will occur or if they will be exacerbated or not by climate change.

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

4.2.2. During Flood Times

There are several broad ways in which climate change will affect water levels in the Shoalhaven and Crookhaven Rivers during floods, namely:

1. *The increase in ocean level* will raise the “normal” water level in the Shoalhaven and Crookhaven Rivers as well as the assumed ocean level adopted for design flood analysis (Reference 1) as shown on Table 1. The impacts of ocean level have been quantified for various design scenarios with the results shown on Figures 2 to 10.
2. *The increase in peak rainfall intensity and storm volume* will increase design flood levels along the Shoalhaven and Crookhaven Rivers. The impacts of ocean level

have been quantified for various design scenarios with the results shown on Figures 2 to 10.

3. *The height of the sand berm at Shoalhaven Heads* may be affected by an increase in ocean 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 open more often and so the entrance berm might be assumed to be lower at the start of the design storm. At this time the impact on the entrance berm is unknown. The effect of a 0.4m and 0.9m increase in the level of the berm (assumed that a rise in ocean level will produce a similar rise in berm level) is provided in Appendix A and discussed in Section 3.2.2.
4. *A change in wind activity* may affect wind wave activity along the ocean foreshore or along the banks of the Crookhaven and Shoalhaven Rivers. At this time the impact of this effect is unknown.

According to the best available advice from the IPCC and NSW Government experts (summarised in Reference 9) it is likely that design flood levels will increase due to a climate induced ocean level rise. Any ocean level rise increase may be exacerbated by a further 0.1m+ if the increase in rainfall intensity and volume occurs concurrently.

4.2.3. Flood Damages

Flood damages assessments have been undertaken as part of the Lower Shoalhaven River Floodplain Risk Management Studies/Plans (Reference 14) and Terara and Riverview Road Floodplain Management Studies (References 15 and 16). These flood damages databases have been combined together and 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 2011. Details of the damages assessment approach can be found in the above references.

The following points are made regarding the approach:

- Residential buildings are separated in the 7 geographic regions with Industrial and Commercial buildings from each of these areas amalgamated together,
- The floor level database was accurate as at the year 2000 and it is likely that some developments will have changed since then, particularly for the commercial and industrial buildings,
- Pumping stations and caravan parks in each area have been amalgamated as a separate group. The damages to caravan parks 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 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 are provided in Table 3. The Average Annual Damages (AAD) for existing conditions is estimated as $4.7 million (year $2011).

The number of flood liable buildings and flood damages assessment for a 0.4m and 0.9m ocean level rise are shown on Tables 4 and 5 respectively. The AAD increases to $7.5 million for a 0.4m ocean level rise and to $12.3 million for a 0.9m rise.

Tables 6, 7 and 8 show the number of flood liable buildings and flood damages assessment for a 10%, 20% and 30% rainfall increase for the 100, 50, 20 and 10 year ARI events.

Table 9 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,
- An increase from a base of $0 is indicated by a **-** ,
- Overall the ocean level rise results shown on Table 9 indicate a greater % increase in damages for the smaller events than the larger events (this is to be expected with ocean level rise as in larger events there is less increase in flood level - refer Figure 3).

Figure11a and b indicates the number of building floors inundated at each of the 7 geographic regions together with the Commercial buildings group.

Table 3: Existing Flood Damages

FLOODPLAIN AREA	EXTREME			500y			200y			100y			50y			20y			10y		
	Damages	**Bd**	**Yd**	**Damages**	**Bd**	**Yd**	**Damages**	**Bd**	**Yd**	**Damages**	**Bd**	**Yd**	**Damages**	**Bd**	**Yd**	**Damages**	**Bd**	**Yd**	**Damages**	**Bd**	**Yd**
Nowra	$4,498,000	80	75	$3,577,000	73	69	$1,636,000	59	54	$452,000	16	35	$67,000	2	19	$3,000	0	1	$1,000	0	1
Bomaderry	$1,789,000	33	41	$734,000	19	32	$517,000	12	25	$438,000	8	21	$362,000	7	15	$287,000	7	14	$43,000	2	11
Shoalhaven Heads	$9,373,000	179	193	$8,759,000	175	188	$6,269,000	163	177	$4,548,000	124	170	$2,601,000	80	140	$1,237,000	50	112	$738,000	31	101
Greenwell Point	$21,653,000	372	374	$20,048,000	357	368	$17,934,000	354	367	$15,276,000	340	362	$12,006,000	265	355	$6,929,000	206	313	$2,883,000	137	289
Orient Point	$11,154,000	201	207	$8,320,000	164	189	$6,657,000	147	176	$5,259,000	127	158	$3,622,000	86	137	$1,602,000	62	98	$416,000	28	73
Riverview Rd	$18,381,000	193	197	$15,583,000	181	184	$4,294,000	131	170	$955,000	11	53	$80,000	2	7	$61,000	1	3	$60,000	1	3
Terara	$3,268,000	55	55	$3,010,000	52	55	$2,516,000	51	55	$1,544,000	44	55	$151,000	9	31	$0	0	0	$0	0	0
Commercial	$2,091,000	36	36	$1,859,000	33	35	$1,569,000	31	35	$1,381,000	28	32	$979,000	22	27	$626,000	17	20	$279,000	8	15
Industrial	$26,669,000	5	5	$26,203,000	5	5	$23,810,000	3	4	$21,332,000	3	3	$16,567,000	2	3	$3,939,000	0	2	$0	0	1
Pumping Stations	$137,000	24	25	$127,000	22	25	$120,000	21	25	$102,000	20	25	$80,000	15	25	$21,000	12	25	$8,000	2	25
Caravan Parks	$3,452,000	20	23	$3,243,000	19	23	$2,875,000	16	22	$2,344,000	16	21	$1,485,000	16	20	$775,000	12	19	$452,000	10	18
TOTALS	**$102,465,000**	**1,198**	**1,231**	**$91,463,000**	**1,100**	**1,173**	**$68,197,000**	**988**	**1,110**	**$53,631,000**	**737**	**935**	**$38,000,000**	**506**	**779**	**$15,480,000**	**367**	**607**	**$4,880,000**	**219**	**537**

Note: Bd = Building inundated, Yd = Yard inundated

Table 4: Flood Damages with 0.4m Ocean Level Rise

FLOODPLAIN AREA	EXTREME			500y			200y			100y			50y			20y			10y		
	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd
Nowra	$4,503,000	80	77	$3,683,000	74	70	$1,807,000	65	56	$492,000	18	36	$72,000	3	22	$3,000	0	1	$1,000	0	1
Bomaderry	$1,793,000	33	41	$736,000	20	32	$511,000	11	24	$436,000	8	20	$361,000	7	15	$239,000	7	14	$63,000	2	13
Shoalhaven Heads	$9,998,000	191	195	$9,187,000	179	193	$7,514,000	172	181	$5,749,000	155	176	$3,517,000	95	156	$1,891,000	69	125	$1,027,000	44	109
Greenwell Point	$21,704,000	374	374	$20,440,000	363	369	$19,083,000	355	368	$16,889,000	352	365	$13,686,000	277	359	$10,107,000	249	344	$6,462,000	197	312
Orient Point	$11,212,000	201	207	$8,857,000	173	191	$7,390,000	155	181	$5,993,000	137	167	$4,342,000	94	150	$2,858,000	77	124	$1,486,000	59	96
Riverview Rd	$18,383,000	193	197	$15,762,000	182	185	$4,635,000	131	171	$1,009,000	26	66	$89,000	3	7	$61,000	1	3	$60,000	1	3
Terara	$3,268,000	55	55	$3,017,000	52	55	$2,547,000	51	55	$1,618,000	46	55	$248,000	12	37	$0	0	0	$0	0	0
Commercial	$2,095,000	36	36	$1,868,000	33	35	$1,577,000	32	35	$1,418,000	28	33	$1,033,000	23	28	$574,000	18	21	$331,000	10	16
Industrial	$26,672,000	5	5	$26,229,000	5	5	$23,810,000	4	4	$21,636,000	3	3	$16,567,000	3	3	$3,939,000	1	2	$0	0	1
Pumping Stations	$137,000	24	25	$129,000	22	25	$122,000	22	25	$104,000	21	25	$84,000	15	25	$48,000	14	25	$9,000	5	25
Caravan Parks	$3,454,000	20	23	$3,290,000	19	23	$3,132,000	16	22	$2,632,000	16	21	$1,773,000	16	20	$1,089,000	12	19	$720,000	11	18
TOTALS	**$103,219,000**	**1,212**	**1,235**	**$93,198,000**	**1,122**	**1,183**	**$72,128,000**	**1,014**	**1,122**	**$57,976,000**	**810**	**967**	**$41,772,000**	**548**	**822**	**$20,809,000**	**448**	**678**	**$10,159,000**	**329**	**594**

Note: Bd = Building inundated, Yd = Yard inundated

Table 5: Flood Damages with 0.9m Ocean Level Rise

FLOODPLAIN AREA	EXTREME			500y			200y			100y			50y			20y			10y		
	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd
Nowra	$4,513,000	80	77	$3,815,000	74	71	$2,133,000	69	59	$597,000	24	38	$91,000	6	24	$3,000	0	2	$1,000	0	1
Bomaderry	$1,796,000	33	41	$739,000	20	32	$673,000	15	28	$438,000	8	21	$362,000	7	15	$247,000	7	14	$63,000	2	13
Shoalhaven Heads	$10,687,000	195	195	$10,159,000	195	195	$8,671,000	175	188	$7,292,000	169	181	$4,930,000	139	172	$3,263,000	93	151	$2,224,000	73	134
Greenwell Point	$21,767,000	374	374	$20,971,000	365	371	$19,952,000	357	368	$18,854,000	354	368	$15,979,000	346	362	$13,357,000	274	357	$11,573,000	264	353
Orient Point	$11,307,000	201	208	$9,641,000	184	203	$8,213,000	164	189	$7,186,000	154	177	$5,522,000	129	160	$4,214,000	91	147	$3,449,000	84	134
Riverview Rd	$18,398,000	193	197	$15,941,000	182	185	$5,239,000	140	171	$1,058,000	14	65	$111,000	4	9	$61,000	1	3	$60,000	1	3
Terara	$3,268,000	55	55	$3,030,000	52	55	$2,628,000	51	55	$1,800,000	48	55	$298,000	15	39	$0	0	0	$0	0	0
Commercial	$2,099,000	36	36	$1,886,000	33	35	$1,648,000	32	35	$1,458,000	28	33	$1,126,000	23	28	$613,000	20	22	$371,000	11	17
Industrial	$26,672,000	5	5	$26,425,000	5	5	$23,828,000	5	5	$21,641,000	3	3	$17,309,000	3	3	$5,951,000	1	2	$0	0	1
Pumping Stations	$138,000	24	25	$129,000	22	25	$125,000	22	25	$110,000	21	25	$86,000	17	25	$69,000	14	25	$48,000	11	25
Caravan Parks	$3,455,000	20	23	$3,339,000	19	23	$3,180,000	16	22	$2,916,000	16	21	$2,207,000	16	20	$1,556,000	12	19	$1,238,000	11	18
TOTALS	**$104,100,000**	**1,216**	**1,236**	**$96,075,000**	**1,151**	**1,200**	**$76,290,000**	**1046**	**1,145**	**$63,350,000**	**839**	**987**	**$48,021,000**	**705**	**857**	**$29,334,000**	**513**	**742**	**$19,027,000**	**457**	**699**

Note: Bd = Building inundated, Yd = Yard inundated

Table 6: Flood Damages with 10% Rainfall Increase

FLOODPLAIN AREA	100y			50y			20y			10y		
	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd
Nowra	$943,000	45	48	$156,000	7	31	$14,000	1	1	$2,000	0	1
Bomaderry	$478,000	9	24	$391,000	8	15	$322,000	7	15	$107,000	3	13
Shoalhaven Heads	$5,597,000	151	174	$3,384,000	94	153	$1,626,000	59	121	$855,000	37	103
Greenwell Point	$16,895,000	352	365	$13,924,000	284	360	$8,859,000	234	328	$4,126,000	171	297
Orient Point	$6,102,000	138	168	$4,324,000	94	150	$2,401,000	71	110	$696,000	39	79
Riverview Rd	$1,427,000	30	99	$455,000	8	33	$61,000	1	3	$61,000	1	3
Terara	$2,219,000	48	55	$673,000	23	51	$15,000	1	13	$0	0	0
Commercial	$1,520,000	28	34	$1,104,000	27	30	$784,000	17	20	$394,000	11	17
Industrial	$22,680,000	3	3	$18,894,000	3	3	$9,482,000	1	2	$0	0	1
Pumping Stations	$113,000	21	25	$86,000	17	25	$43,000	14	25	$10,000	2	25
Caravan Parks	$2,634,000	16	21	$1,824,000	16	20	$961,000	13	19	$492,000	11	18
TOTALS	**$60,608,000**	**841**	**1016**	**$45,215,000**	**581**	**871**	**$24,568,000**	**419**	**657**	**$6,743,000**	**275**	**557**

Note: Bd = Building inundated, Yd = Yard inundated

Table 7: Flood Damages with 20% Rainfall Increase

FLOODPLAIN AREA	100y			50y			20y			10y		
	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd
Nowra	$2,021,000	67	58	$319,000	13	34	$35,000	1	7	$3,000	0	1
Bomaderry	$517,000	12	25	$421,000	8	17	$347,000	7	15	$304,000	7	15
Shoalhaven Heads	$6,523,000	164	180	$3,894,000	106	165	$2,034,000	69	128	$1,031,000	45	110
Greenwell Point	$18,277,000	354	368	$14,328,000	307	360	$10,421,000	253	347	$5,837,000	194	304
Orient Point	$6,934,000	151	176	$4,727,000	115	155	$2,982,000	78	126	$1,186,000	55	91
Riverview Rd	$5,860,000	144	171	$789,000	10	40	$61,000	1	4	$61,000	1	3
Terara	$2,610,000	51	55	$1,126,000	39	54	$286,000	14	34	$0	0	0
Commercial	$1,580,000	33	35	$1,280,000	28	31	$858,000	19	22	$689,000	17	20
Industrial	$23,814,000	4	4	$20,803,000	3	3	$13,629,000	2	3	$3,000	0	2
Pumping Stations	$123,000	21	25	$94,000	18	25	$58,000	14	25	$18,000	7	25
Caravan Parks	$2,863,000	16	21	$1,966,000	16	20	$1,090,000	13	19	$584,000	11	18
TOTALS	**$71,122,000**	**1,017**	**1,118**	**$49,747,000**	**663**	**904**	**$31,801,000**	**471**	**730**	**$9,716,000**	**337**	**589**

Note: Bd = Building inundated, Yd = Yard inundated

Table 8: Flood Damages with 30% Rainfall Increase

FLOODPLAIN AREA	100y			50y			20y			10y		
	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd	Damages	Bd	Yd
Nowra	$2,991,000	69	63	$559,000	23	38	$66,000	2	18	$3,000	0	1
Bomaderry	$608,000	15	26	$453,000	9	23	$366,000	7	15	$277,000	7	14
Shoalhaven Heads	$7,627,000	172	182	$4,548,000	124	170	$2,360,000	74	135	$1,323,000	51	112
Greenwell Point	$19,336,000	356	368	$15,497,000	344	362	$11,590,000	261	352	$7,359,000	216	316
Orient Point	$7,655,000	156	183	$5,426,000	130	160	$3,488,000	84	135	$1,783,000	67	100
Riverview Rd	$13,119,000	171	177	$1,058,000	14	65	$79,000	2	7	$61,000	1	3
Terara	$2,842,000	52	55	$1,841,000	48	55	$151,000	9	30	$0	0	0
Commercial	$1,743,000	33	35	$1,421,000	28	33	$978,000	22	28	$628,000	17	20
Industrial	$25,072,000	4	4	$21,646,000	3	3	$16,581,000	2	3	$3,939,000	1	2
Pumping Stations	$124,000	22	25	$106,000	21	25	$74,000	15	25	$22,000	12	25
Caravan Parks	$3,045,000	16	21	$2,195,000	16	20	$1,219,000	13	19	$727,000	12	18
TOTALS	**$84,162,000**	**1,066**	**1,139**	**$54,750,000**	**760**	**954**	**$36,952,000**	**491**	**767**	**$16,122,000**	**384**	**611**

Note: Bd = Building inundated, Yd = Yard inundated

Table 9: % Increase in Flood Damages for Various Scenarios

Scenario (Refer end of Table)	1	2	3	4	5	6	7	8	9
AREA					**100y**				
Nowra	9%	32%	109%	347%	562%	137%	158%	200%	245%
Bomaderry	0%	0%	9%	18%	39%	9%	9%	9%	10%
Shoalhaven Heads	26%	60%	23%	43%	68%	50%	56%	79%	88%
Greenwell Point	11%	23%	11%	20%	27%	20%	21%	28%	30%
Orient Point	14%	37%	16%	32%	46%	31%	33%	49%	54%
Riverview Rd	6%	11%	49%	514%	1274%	74%	93%	102%	109%
Terara	5%	17%	44%	69%	84%	47%	49%	54%	58%
Commercial	3%	6%	10%	14%	26%	11%	12%	13%	14%
Industrial	1%	1%	6%	12%	18%	8%	8%	8%	8%
Pumping Stations	2%	8%	11%	21%	22%	14%	16%	19%	20%
Caravan Parks	12%	24%	12%	22%	30%	22%	24%	31%	32%
TOTALS	8%	18%	13%	33%	57%	21%	23%	30%	32%
					50y				
Nowra	7%	36%	133%	376%	734%	172%	173%	284%	327%
Bomaderry	0%	0%	8%	16%	25%	8%	8%	8%	6%
Shoalhaven Heads	35%	90%	30%	50%	75%	65%	72%	122%	146%
Greenwell Point	14%	33%	16%	19%	29%	22%	25%	43%	48%
Orient Point	20%	52%	19%	31%	50%	36%	39%	70%	78%
Riverview Rd	11%	39%	469%	886%	1223%	493%	468%	486%	494%
Terara	64%	97%	346%	646%	1119%	401%	417%	474%	543%
Commercial	6%	15%	13%	31%	45%	19%	20%	25%	28%
Industrial	0%	4%	14%	26%	31%	14%	14%	18%	18%
Pumping Stations	5%	8%	8%	18%	33%	10%	10%	16%	20%
Caravan Parks	19%	49%	23%	32%	48%	37%	41%	61%	71%
TOTALS	10%	26%	19%	31%	44%	26%	28%	43%	48%
					20y				
Nowra	0%	0%	367%	1067%	2100%	367%	367%	400%	567%
Bomaderry	0%	0%	12%	21%	28%	9%	0%	0%	0%
Shoalhaven Heads	53%	164%	31%	64%	91%	99%	117%	207%	296%
Greenwell Point	46%	93%	28%	50%	67%	66%	71%	104%	123%
Orient Point	78%	163%	50%	86%	118%	113%	123%	185%	230%
Riverview Rd	0%	0%	0%	0%	30%	0%	0%	0%	0%
Terara	0%	0%	-	-	-	-	-	-	-
Commercial	0%	0%	25%	37%	56%	27%	7%	15%	42%
Industrial	0%	51%	141%	246%	321%	173%	173%	173%	226%

Pumping Stations	129%	229%	105%	176%	252%	210%	214%	257%	262%
Caravan Parks	41%	101%	24%	41%	57%	60%	73%	119%	148%
TOTALS	34%	89%	59%	105%	139%	98%	102%	133%	170%
	10y								
Nowra	0%	0%	100%	200%	200%	100%	100%	100%	200%
Bomaderry	47%	47%	149%	607%	544%	149%	151%	149%	121%
Shoalhaven Heads	39%	201%	16%	40%	79%	80%	115%	252%	419%
Greenwell Point	124%	301%	43%	102%	155%	171%	202%	326%	375%
Orient Point	257%	729%	67%	185%	329%	378%	458%	799%	942%
Riverview Rd	0%	0%	2%	2%	2%	2%	2%	2%	2%
Terara	0%	0%	0%	0%	0%	0%	0%	0%	0%
Commercial	19%	33%	41%	147%	125%	54%	57%	71%	87%
Industrial	0%	0%	0%	-	-	0%	0%	0%	0%
Pumping Stations	13%	500%	25%	125%	175%	125%	175%	613%	650%
Caravan Parks	59%	174%	9%	29%	61%	89%	90%	186%	249%
TOTALS	108%	290%	38%	99%	230%	158%	189%	323%	396%

1	0.4m Ocean Level Rise	
2	0.9m Ocean Level Rise	
3	10% Rainfall Increase	
4	20% Rainfall Increase	
5	30% Rainfall Increase	
6	10% rainfall +0.4m ocean rise	
7	10% rainfall +0.4m ocean rise + 0.4m berm rise	
8	10% rainfall +0.9m ocean rise	
9	10% rainfall +0.9m ocean rise + 0.9m berm rise	

4.2.4. Flood Extent and Hazard Mapping

A digital terrain model (DTM) of the Shoalhaven River floodplain has been created based on the airborne laser scanning (ALS) survey provided by Shoalhaven City Council. This DTM covers the entire floodplain from approximately 2 kilometres upstream of Nowra Bridge to the Pacific Ocean with the exception of the Shoalhaven Heads area (no ALS or other survey available).

The CELLS model (Section 2.2) is a one dimensional model that represents the river and floodplain as a series of cells with the flood level calculated at the centre of each cell. Flood extent and hazard mapping has been undertaken based on the results of the CELLS model and with the use of the DTM. <u>It should be noted that the accuracy of the mapping is limited by the nature of the output from the CELLS model.</u> As noted above the results are only available at the centre of each cell and thus interpolation is required to extend the flood extent to the perimeter of the floodplain and between cells. Also the available velocity data is of limited use and generally only applicable in the river channel.

The following maps have been provided:

LIST OF MAPPING FIGURES
Note: Assumes 1978 Riverview Road Levee rather than current Levee

4.2.5. Are the Implications of Climate Change Significant?

At some localities in NSW an increase in flood level (due to ocean 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 Shoalhaven River floodplain the impact on the "normal" water level will generally not have a significant impact but climate change will have significant implications on design flood levels and flood damages for the area and needs to be addressed.

4.3. Mitigation/Adaptation Measures to Protect Existing Developments

4.3.1. 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.

4.3.2. Flood Modification Measures

Flood modification measures such as dredging the Shoalhaven River 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 on the Shoalhaven River.

4.3.3. Levees

Levees are one such measure that could be used to protect existing development (as they do already at Riverview Road, Nowra and at Terara). 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,
- 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.

The existing levees at Riverview Road and Terara could be raised to mitigate the effects of flood level increases due to sea level rise but due to the relatively small increases in flood level (less than 0.1m) these works cannot be justified at this time on economic grounds. However if climate change rainfall increases are predicted to occur (there is no current scientific advice in this regard) raising could be considered at the time.

The levees proposed in Reference 14 at Greenwell Point could be constructed to account for ocean level rise. Levees at other localities such as Shoalhaven Heads could also be considered if there is sufficient justification.

4.3.4. 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 houses raising is a viable solution if the area remains serviceable with climate change (adequate sewer and roads).

4.3.5. 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.

4.4. Mitigation/Adaptation Measures to Protect Future Developments

4.4.1. 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.

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 17) 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 9) 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 ocean 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 ocean level rise (Figure 3). The climate change component in the 0.5m freeboard allowance accounts for any uncertainty regarding the 0.9m ocean level rise (in reality the true rise may be less or more).

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).

4.4.2. 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.

4.4.3. 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). On the Shoalhaven River 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 that do not cause major Shoalhaven River flooding) 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.

4.4.4. Planned Retreat

As the predicted sea level rise occurs some developed parts of the Shoalhaven River 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.

4.4.5. Limit the Extent of Development

Future residential development in low lying areas could be restricted to the “lowest residential” zoning. Thus any development that will increase the present residential density would not be permitted. Thus dual occupancy, sub division or increasing the % site coverage (increasing the size of the building) would not be permitted. These controls could be further refined through a site specific DCP.

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

4.5.1. Evacuation Requirements

For many of the existing flood liable areas (Greenwell Point), 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.

4.5.2. 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 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.

4.5.3. 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 presumable 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.

4.6. Review of Management Measures in Floodplain Management Plans

This section provides a listing of all the management measures proposed in the Shoalhaven River (Reference 14), Riverview Road Area – Nowra (Reference 15) and Terara Village (Reference 16) Floodplain Management Plans.

Table 10: Shoalhaven River Summary of Proposed Floodplain Management Measures

MEASURE		COMMENT	PRIORITY	CLIMATE CHANGE IMPLICATIONS
FLOOD MODIFICATION				
F1	IMPLEMENT RECOMMENDATIONS OF STORMWATER MANAGEMENT PLAN TO DEAL WITH LOCAL FLOODING ISSUES	These recommendations should continue to be implemented to assist local flooding and drainage problems overall.	HIGH	Nil
F2	INVESTIGATE FEASIBILITY OF GREENWELL POINT LEVEES	While there are a number of issues which may limit the feasibility or viability of levee protection for these properties, further detailed investigation of the possible levee solutions is warranted.	MEDIUM	Must be considered to determine the viability of any proposed levee
F3	FINALISE, IMPLEMENT AND UNDERTAKE REGULAR REVIEW OF COUNCIL'S SHOALHAVEN RIVER ENTRANCE MANAGEMENT PLAN FOR FLOOD MITIGATION	This Plan will ensure that the optimal flood mitigation benefit is achieved through management of the Shoalhaven Heads Entrance in an ecologically sustainable manner.	HIGH	Must be considered
PROPERTY MODIFICATION				
P1	ALLOW HOUSE RAISING FOR SUITABLE PROPERTIES	Sixteen houses have been identified as being suitable for house raising.	MEDIUM	May increase number of houses included but in the long term re-development is the preferred approach
P2	ALLOW FLOOD PROOFING	Flood proofing should be encouraged for existing flood affected commercial properties.	LOW	This measure may be considered for other developments
P3	REVIEW AND UPDATE FLOOD POLICY	Formalise Council's Flood Policy documentation to include findings from Floodplain Risk Management Process.	HIGH	Must be considered and Policy updated
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.	HIGH	Must be considered and FPLs updated
P5	ADOPT A CONSISTENT FREEBOARD OF 0.5 m	A consistent freeboard of 0.5 m shall apply for all new development in flood planning areas.	HIGH	Nil the freeboard is not affected
P6	MONITOR FLOOD IMPLICATIONS OF CLIMATE CHANGE	Council to keep up to date with the latest research on climatic change and its impact on water levels.	LOW	Nil
P7	APPLY MINIMUM SET BACK FROM FORESHORE	A minimum set back shall apply for new development in areas where erosion is potentially an issue.	HIGH	May need to be updated for 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.	MEDIUM	Nil
P9	REVIEW AND UPDATE SECTION 149 CERTIFICATES	Updated flood information and the floor level survey need to be included on Section 149 certificates.	HIGH	Must be considered and S149s updated
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	Nil
P11	NOTIFY EXISTING PROPERTY OWNERS OF CURRENT S149 CERTIFICATE DETAILS	As part of a flood awareness/education program and to ensure all existing property owners are made aware of any potential flood affectation, notifications should be mailed to all flood prone property owners.	MEDIUM	May add additional properties
P12	REVIEW AND UPDATE LEP	Council are currently in the process of updating the LEP to incorporate the latest flood terminology and policies.	HIGH	May have significant implications
P13	ADOPT & IMPLEMENT UPDATED	Council should adopt and implement the generic Flood DCP No. 106.	HIGH	May require updating to include

	DEVELOPMENT CONTROLS FOR FLOOD PRONE LAND			climate change
P14	ADOPT UPDATED DEVELOPMENT CONTROLS FOR CARAVAN PARKS	Council should adopt and implement a caravan park planning matrix ds.	HIGH	May require updating to include climate change
P15	REVIEW AND ASSESS HAZARDS AND RISKS FOR ALL CARAVAN PARKS	Each park should be inspected in detail to accurately identify the risks and any specific needs.	HIGH	Unlikely to significantly increase the number affected
P16	ENFORCE CARAVAN PARK GUIDELINES	The proposed caravan park development guidelines should be enforced for all existing and future development to ensure minimal damages are incurred.	MEDIUM	Nil
RESPONSE MODIFICATION				
R1	INSTALL ADDITIONAL TELEMETERED WATER LEVEL GAUGES, COLLECT AND ANALYSE DATA	Additional automatic water level gauges should be installed at appropriate locations to assist with the collection of flood warning/evacuation information.	HIGH	Nil
R2	IMPROVE PUBLIC ACCESS TO FLOOD WARNING INFORMATION	Develop a Warning Information System in consultation with BOM and SES.	HIGH	Nil
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 in the Shoalhaven Heads area.	HIGH	May require updating to include climate change
R4	MONITOR CHANGES TO THE FLOODPLAIN	Changes to the floodplain 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	Nil
R5	INVESTIGATE RAISING OF GREENWELL POINT ROAD	There may be some scope to raise part of Greenwell Point Road to improve evacuation access times and reduce the number of properties isolated.	HIGH	May require updating to include climate change
R6	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	Nil

Table 11: Riverview Road Area Summary of Proposed Floodplain Management Measures

MEASURE	RECOMMENDATION	PRIORITY	CLIMATE CHANGE IMPLICATIONS
FLOOD MODIFICATION:			
LEVEE AUDIT	A management and maintenance audit of the levee should be undertaken.	Medium	Nil
IMPROVING LOCAL DRAINAGE	The local residents' association and Council should address the problem and seek solutions.	Medium	Nil
OPENING THE ENTRANCE AT SHOALHAVEN HEADS	Council should formalise its entrance opening policy.	Medium	Must be considered
FLOOD MITIGATION DAMS	Inclusion of some flood storage should be considered on a catchment wide basis when new dams (or upgrading works) are proposed.	Low	Nil
CATCHMENT TREATMENT	As a general policy Council policies should encourage the use of appropriate and targeted catchment treatments.	Low	Nil
PROPERTY MODIFICATION:			
PLANNING	Council needs to clarify its conditions regarding future development in this area.	High	Must be considered
FLOOD PROOFING OF BUILDINGS AND HOUSE RAISING	Further investigation of these measures and discussions with the property owners are required.	Low	May have a minor impact
RESPONSE MODIFICATION:			
IMPROVE FLOOD WARNING SYSTEM	Install river and rainfall gauges and undertake minor system upgrades, and prepare a Flood Warning Manual.	High	Nil
UPDATE THE EVACUATION PLANNING SYSTEM	Update the Local Flood Plan to include the latest information as provided in the Floodplain Management Study.	High	Nil
IMPROVE FLOOD AWARENESS AND PREPAREDNESS	A flood awareness program should be initiated.	High	Some implications
OTHER ISSUES			
MONITOR THE EFFECTS OF BANK EROSION.	The situation should be closely monitored by Council as part of the Estuary Management Program. .	Medium	Some implications
DEVELOPMENT MEASURES			
CARAVAN PARKS	Council needs to ensure (say annually) that existing caravan park owners are complying with Council's Caravan Parks on Flood Prone Land Interim Flood Policy (August 1995).	High	Nil
GREENHOUSE EFFECT	Council should monitor the available literature and reassess Council's Flood Policy annually.	Low	Nil
CONTROL OF DEVELOPMENT OUTSIDE THE STUDY AREA	This issue is already addressed under Council's existing development controls.	No action required	Nil

Table 12: Terara Village Summary of Proposed Floodplain Management Measures

MEASURE	RECOMMENDATION	PRIORITY	CLIMATE CHANGE IMPLICATIONS
FLOOD MODIFICATION			
LEVEE AUDIT	A full levee audit should be undertaken and the outcomes considered.	High - 1	Nil
IMPROVING LOCAL DRAINAGE	The local residents association and Council should address the problem and seek solutions.	High - 2	Nil
UPGRADING OF THE LEVEE	The upgrading works may cost up to $50 000.	High - 3	Nil
OPENING THE ENTRANCE AT SHOALHAVEN HEADS	Council should formalise its entrance opening policy.	Medium	Must be considered
FLOOD MITIGATION DAMS	Inclusion of some flood storage should be considered on a catchment wide basis when new dams (or upgrading works) are proposed.	Low	Nil
CATCHMENT TREATMENT	As a general policy Council should encourage the use of appropriate and targeted catchment treatments.	Low	Nil
PROPERTY MODIFICATION			
PLANNING	Council needs to clarify its conditions regarding future development in this area in an updated Flood Policy.	High	Nil
FLOOD PROOFING OF BUILDINGS	Further investigation of this measure and discussion with the eight property owners are required.	Medium	Nil
VOLUNTARY PURCHASE	Consider opportunities as and when required.	Low	Minor
HOUSE RAISING	Council should inform residents that grants are available for house raising and consider any applications.	Low	Nil
RESPONSE MODIFICATION			
IMPROVE THE FLOOD WARNING SYSTEM	Install river and rainfall gauges and undertake the minor system upgrades, and prepare a Flood Warning Manual.	High	Nil
UPDATE THE EVACUATION PLANNING SYSTEM	Update the Local Flood Plan to include the latest information.	High	Nil
IMPROVE FLOOD AWARENESS AND PREPAREDNESS	A flood awareness program should be initiated.	High	Nil
OTHER ISSUES			
ASSESS AND CONTROL EXTENT OF RIVER BANK EROSION	Council should assess the extent of the problem and suggest appropriate works as part of the Estuary Management Program.	High	Some implications
RAISING OF TERARA ROAD FOR FLOOD EVACUATION	Terara Road should be raised and flood depth indicators should be installed.	High	Nil
DEVELOPMENT MEASURES			

DEPOSITION OF SILT ON PIG ISLAND	Council needs to address this issue, resolve it and implement a program of communication.	High	Nil
THE GREENHOUSE EFFECT	Council should monitor the available literature and reassess Council's Flood Policy annually.	Low	Nil
CONTROL OF DEVELOPMENT OUTSIDE THE STUDY AREA	This issue is already addressed under Council's existing development controls.	No action required	Nil

4.7. 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 0.9 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, 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.

Consideration also needs to be given to whether the corresponding rise in the Shoalhaven Heads berm level should be included together with the ocean level rise (this could be partially negated by a change in the entrance management strategies – Reference 12).

Development of this 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 ocean level rise in the determination of Flood Planning Levels (the actual amount will vary depending upon the locality – refer Figure 3),
- All new sub-divisions, re-zoning or flood mitigation works must include the impacts of a 0.9m ocean level rise in the determination of Flood Planning Levels (the actual amount will vary depending upon the locality – refer Figure 3),
- 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 0.9m ocean level rise scenario.

5. REFERENCES

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   Climate Change Adaptation Actions for Local Government
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5. **Climate Change in Australia – Technical Report 2007**
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6. **Floodplain Risk Management Guideline - *Practical Consideration on Climate Change***
   NSW Department of Environment and Climate Change (DECC), October 2007

7. **Hunter, Central and Lower North Coast Regional Climate Change Project 2009 Report *3, Climatic Change Impact for the Hunter, Lower North Coast and* Central *Coast Region of NSW***
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10. **Coastal Risk Management Guide**
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11. **NSW Coastal Planning Guideline: Adapting to Sea Level Rise**
    NSW Government Planning, August 2010

12. **Shoalhaven City Council**
    Shoalhaven River Entrance Management Plan for Flood Mitigation
    November 2006

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Lower Shoalhaven River Floodplain Risk Management Study
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14. **Shoalhaven City Council**
Lower Shoalhaven River Floodplain Risk Management Plan
Webb McKeown & Associates, Nexus, May 2008

15. **Shoalhaven City Council**
Riverview Road Area - Nowra Floodplain Management Plan
Webb McKeown & Associates, February 2002

16. **Shoalhaven City Council**
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17. **NSW Government**
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April 2005

Figures

FIGURE 1
CELL MODEL LAYOUT

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PEAK HEIGHT PROFILES
EXISTING CONDITIONS
CROOKHAVEN / SHOALHAVEN RIVERS

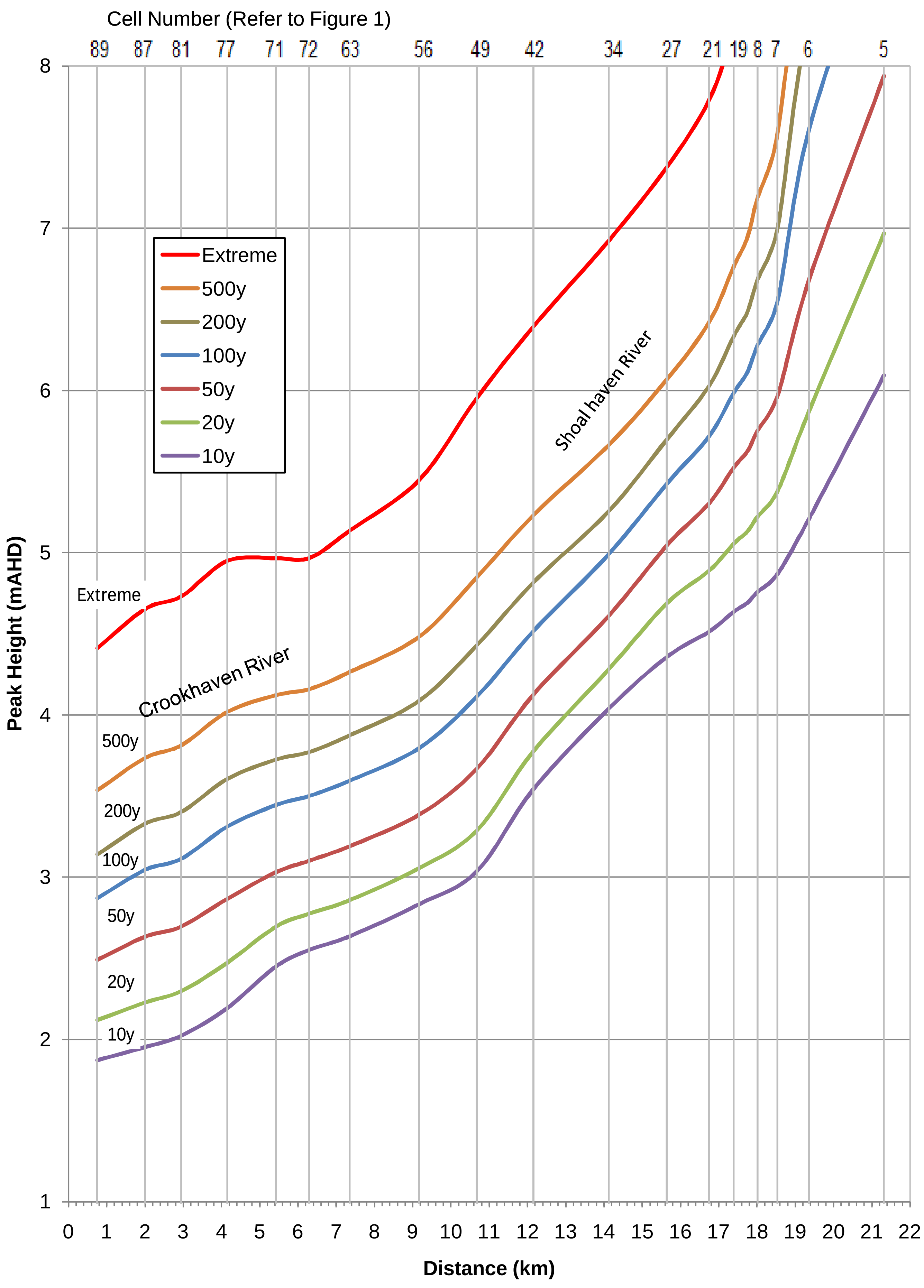

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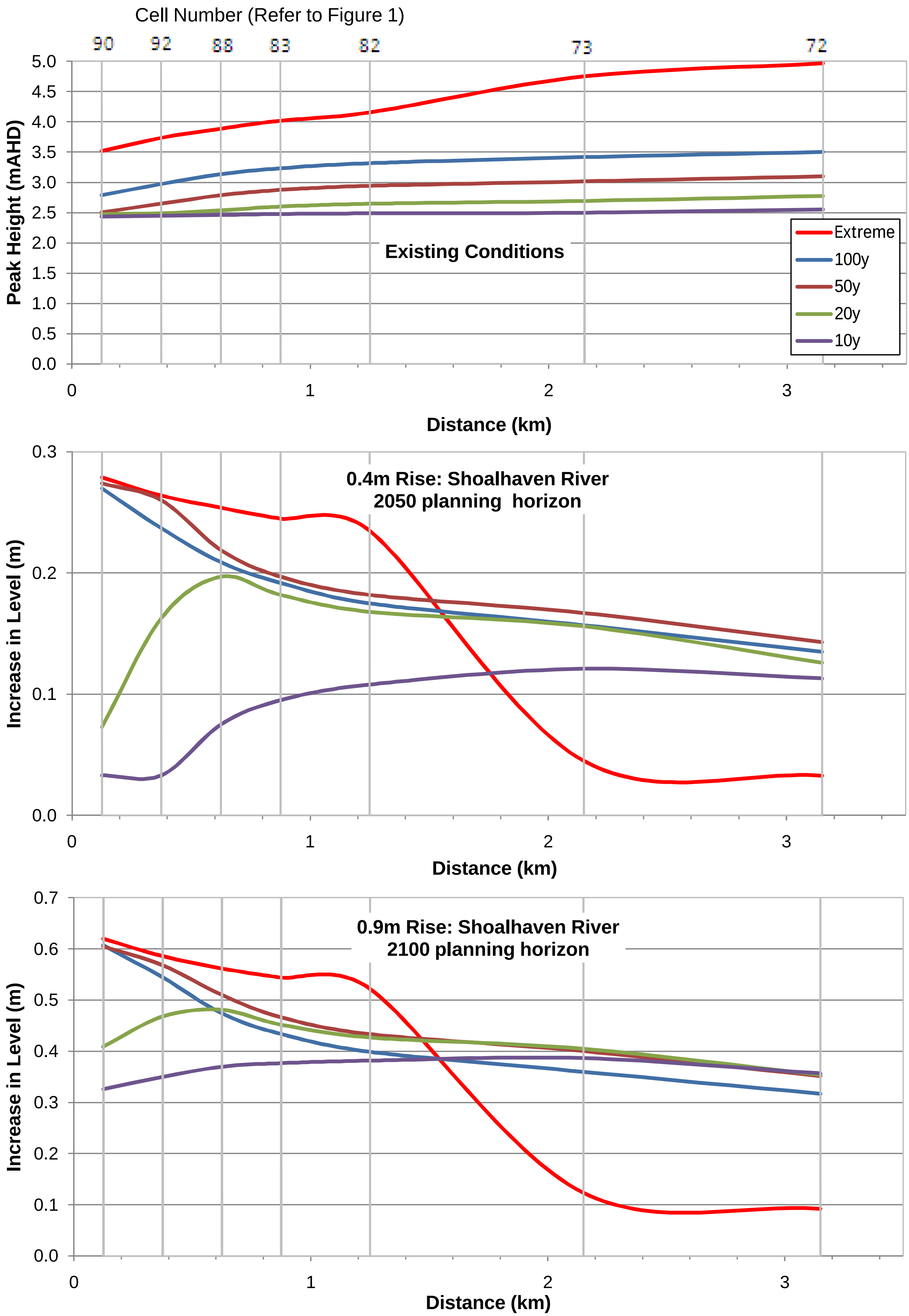
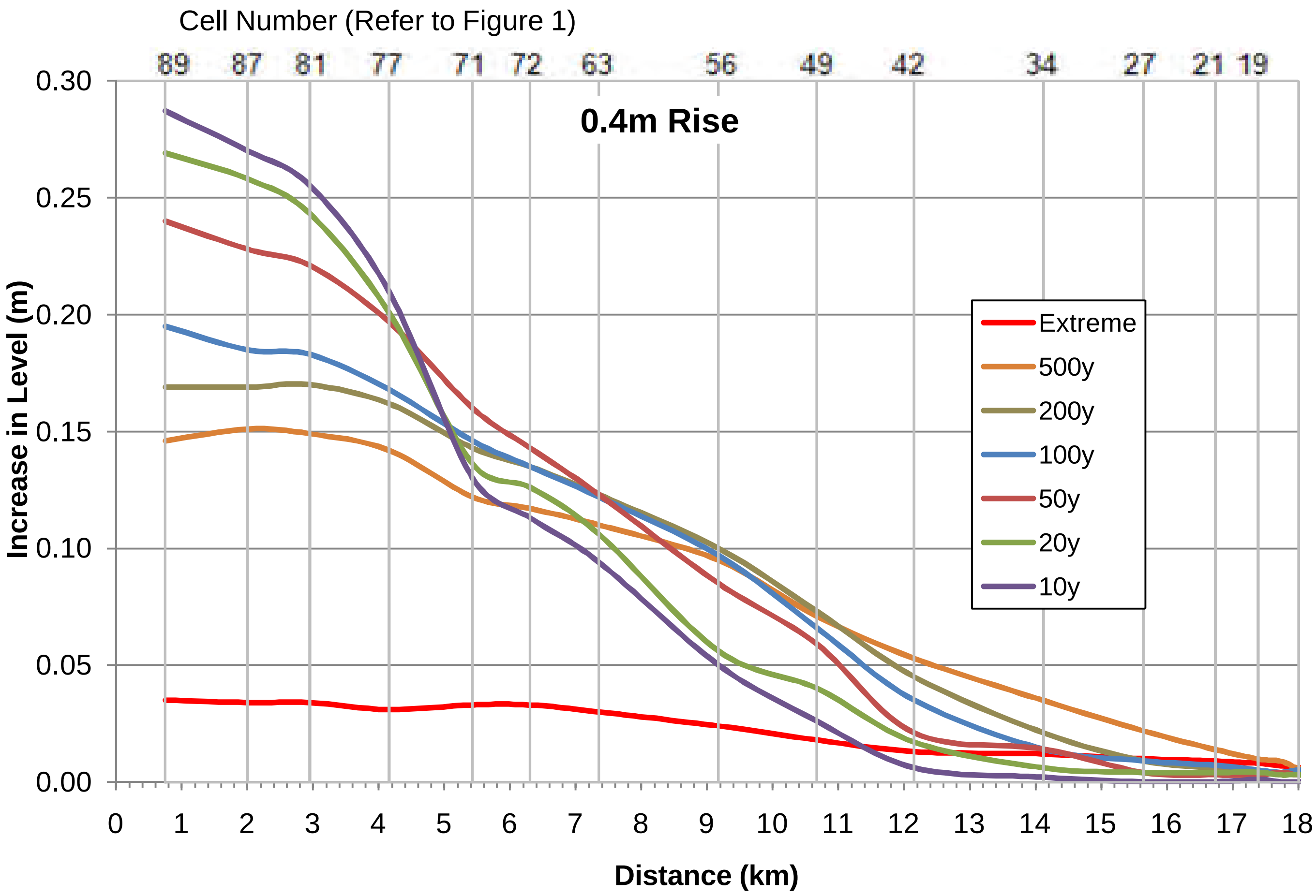
FIGURE 2a
PEAK HEIGHT PROFILES
SHOALHAVEN RIVER




Cell Number (Refer to Figure 1)
89 87 81 77 71 72 63 56 49 42 34 27 21 19
0.4m Rise
Increase in Level (m)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Distance (km)
Extreme
500y
200y
100y
50y
20y
10y

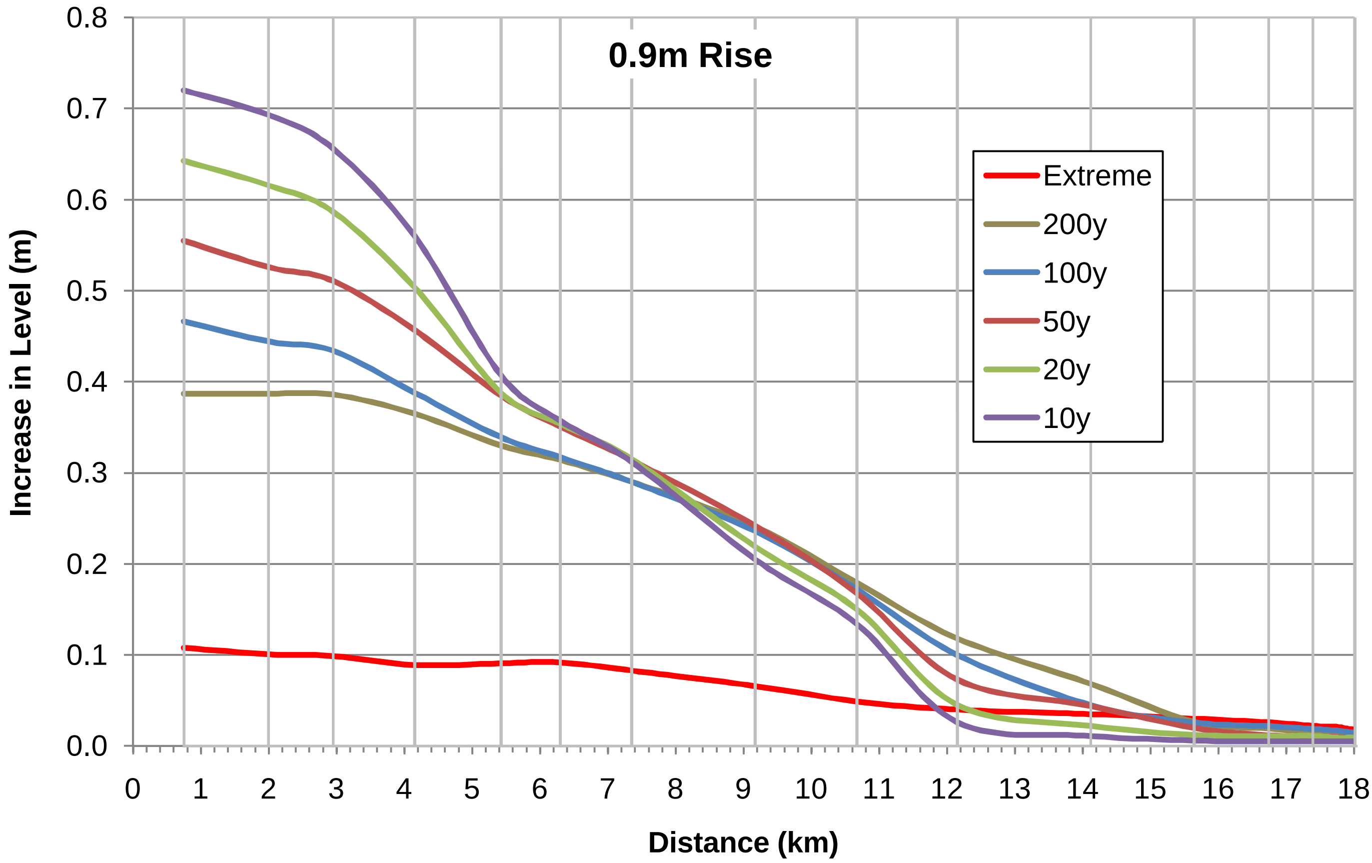
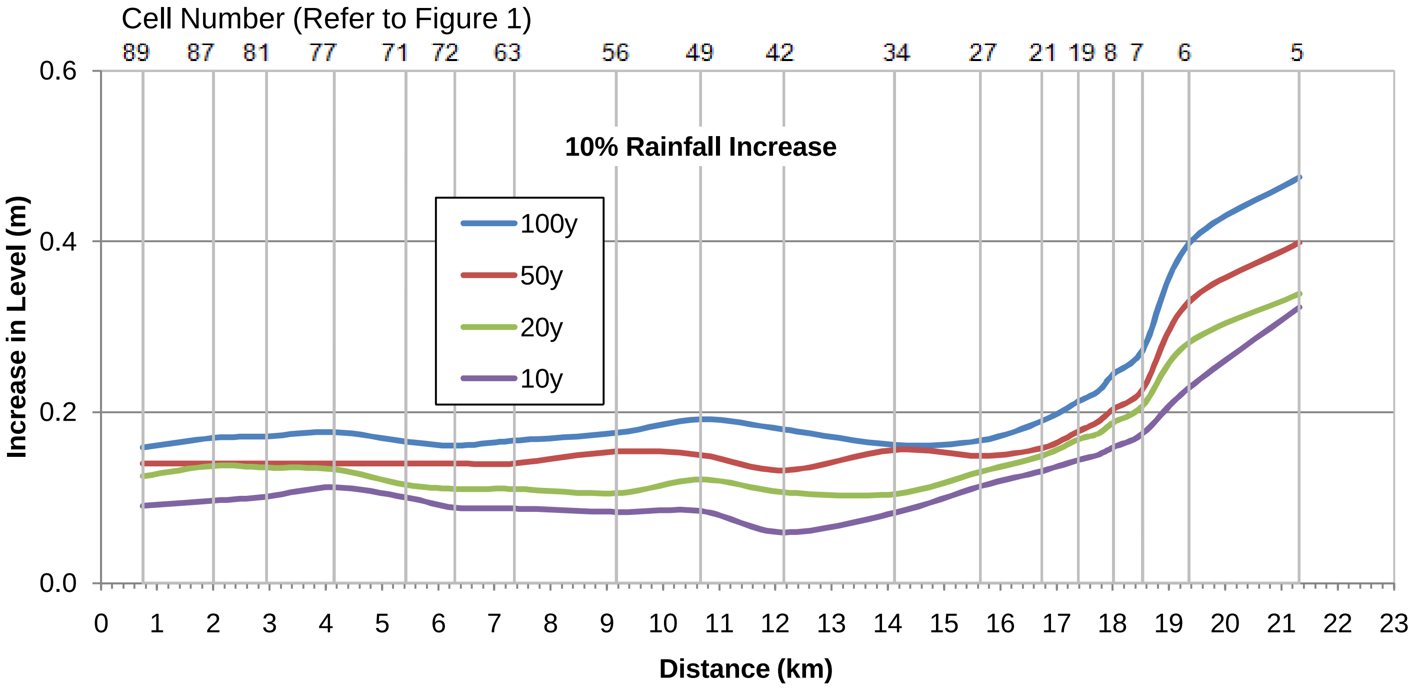
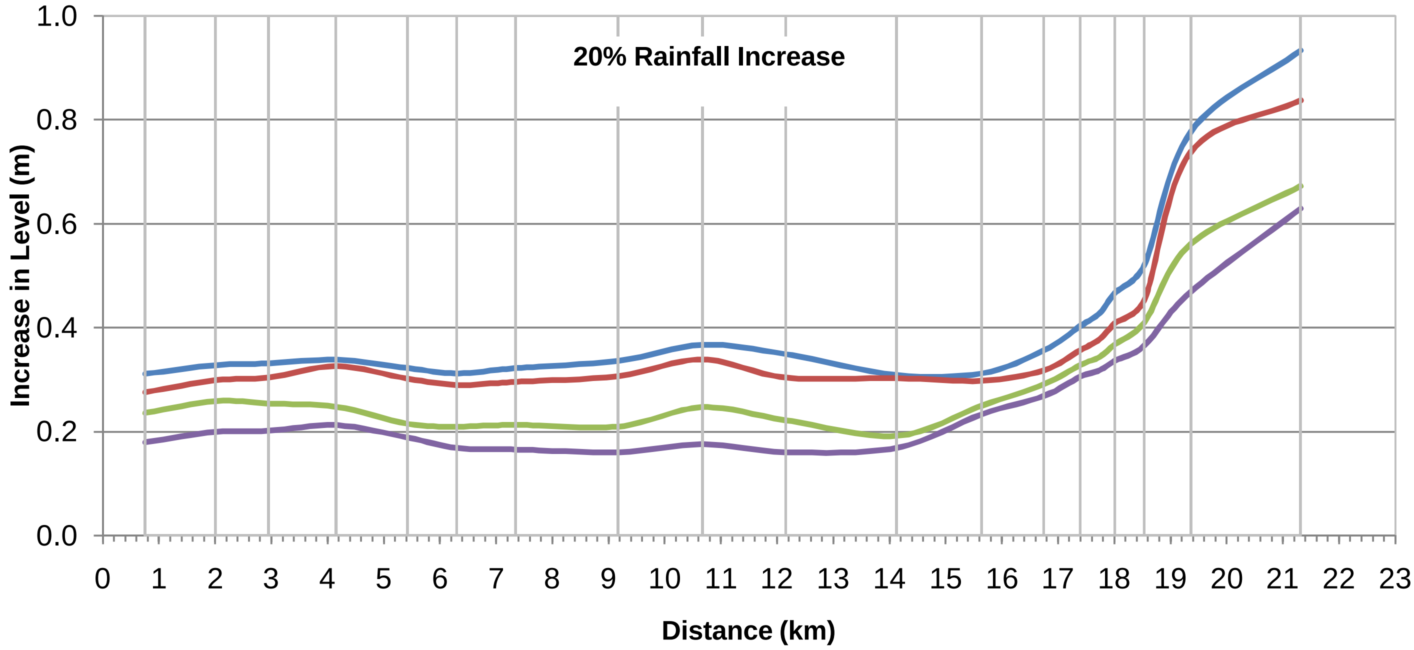

0.9m Rise
Increase in Level (m)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Distance (km)
Extreme
200y
100y
50y
20y
10y

FIGURE 4
PERCENTAGE RAINFALL INCREASE





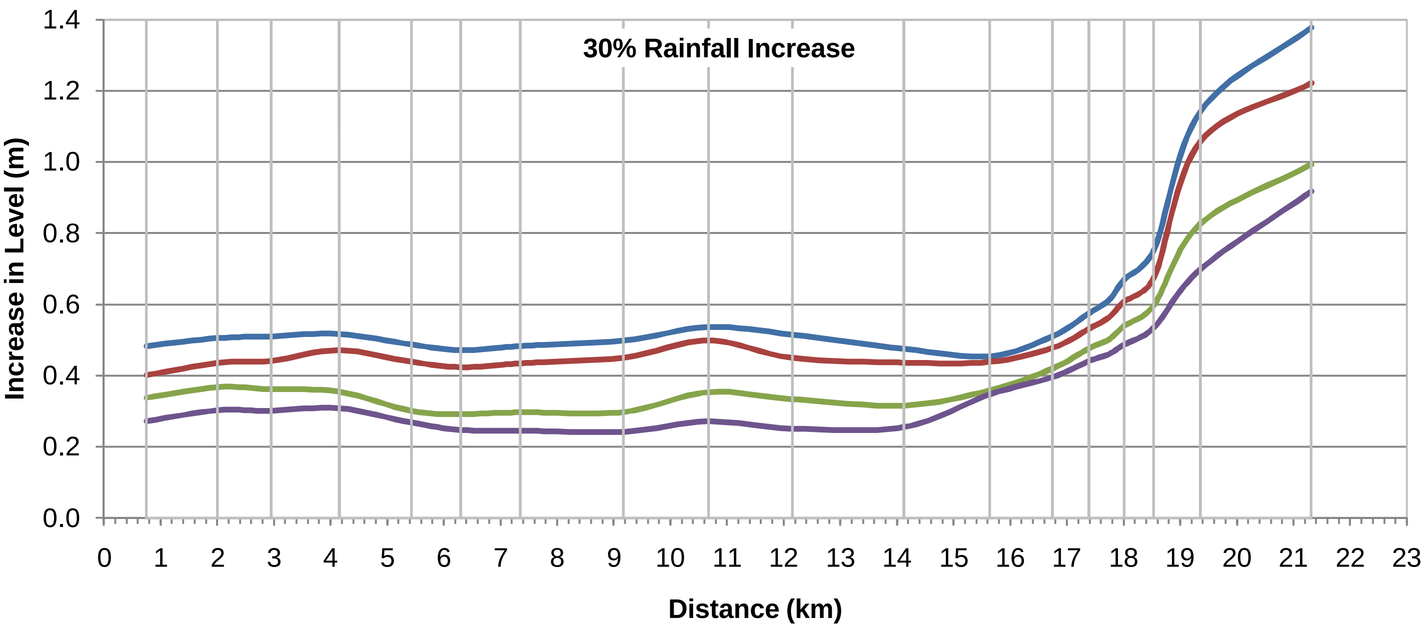
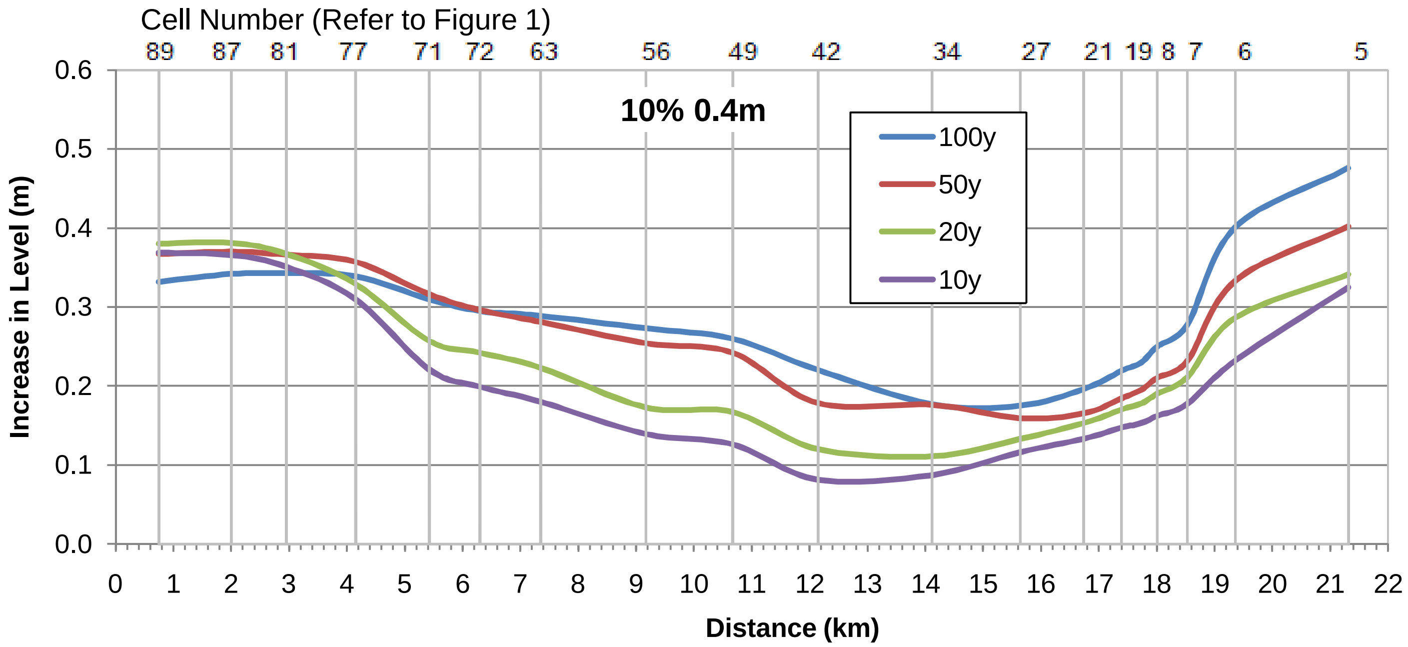
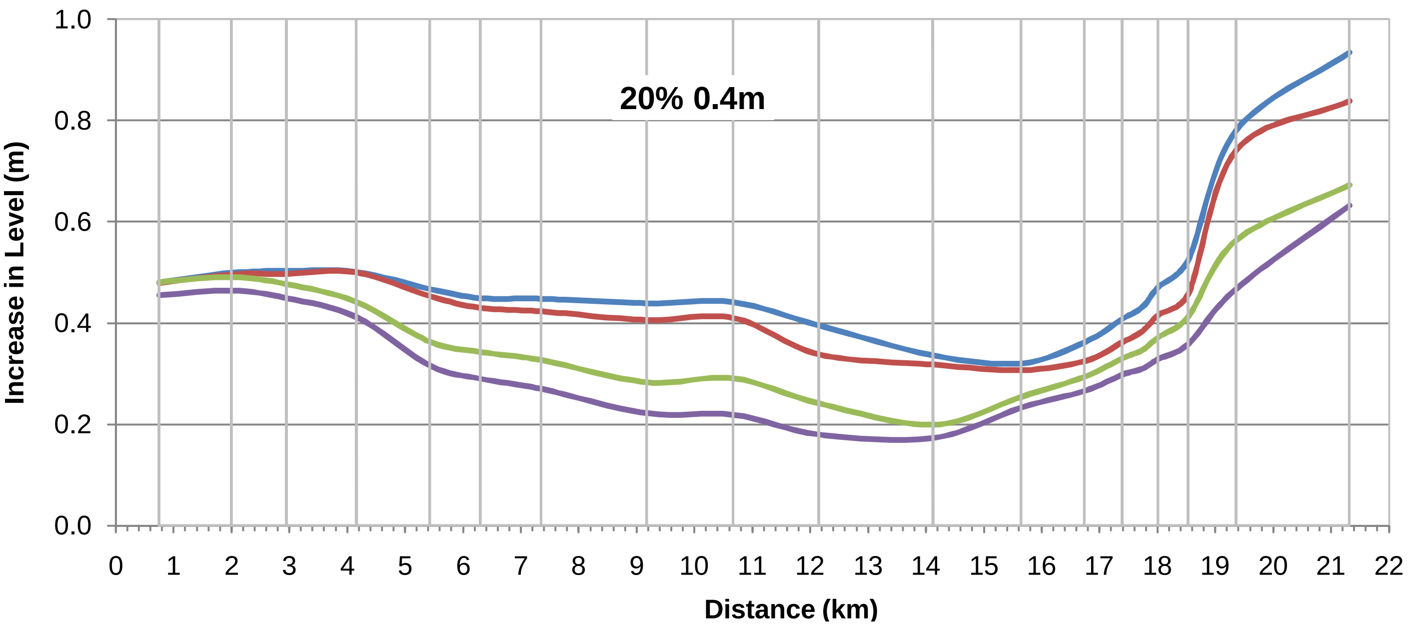


FIGURE 5
PERCENTAGE RAINFALL INCREASE PLUS 0.4m OCEAN LEVEL RISE





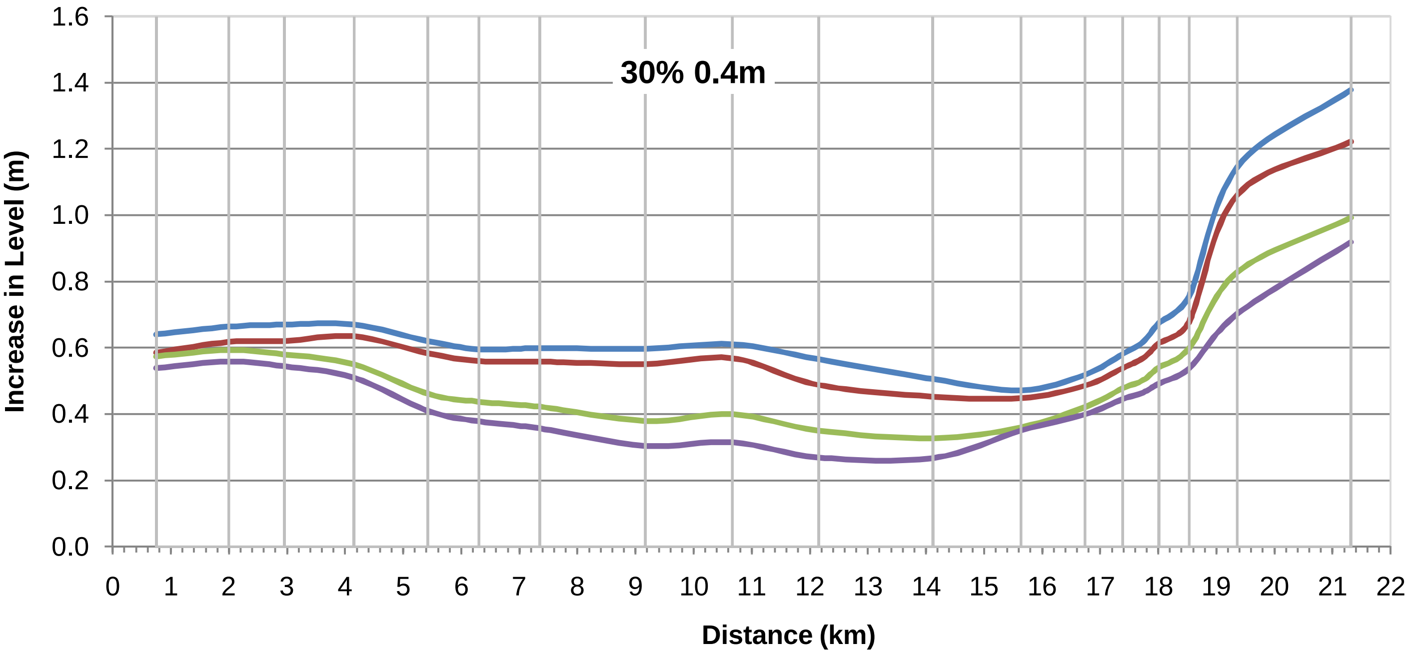


FIGURE 6

PERCENTAGE RAINFALL INCREASE
PLUS 0.9m OCEAN LEVEL RISE

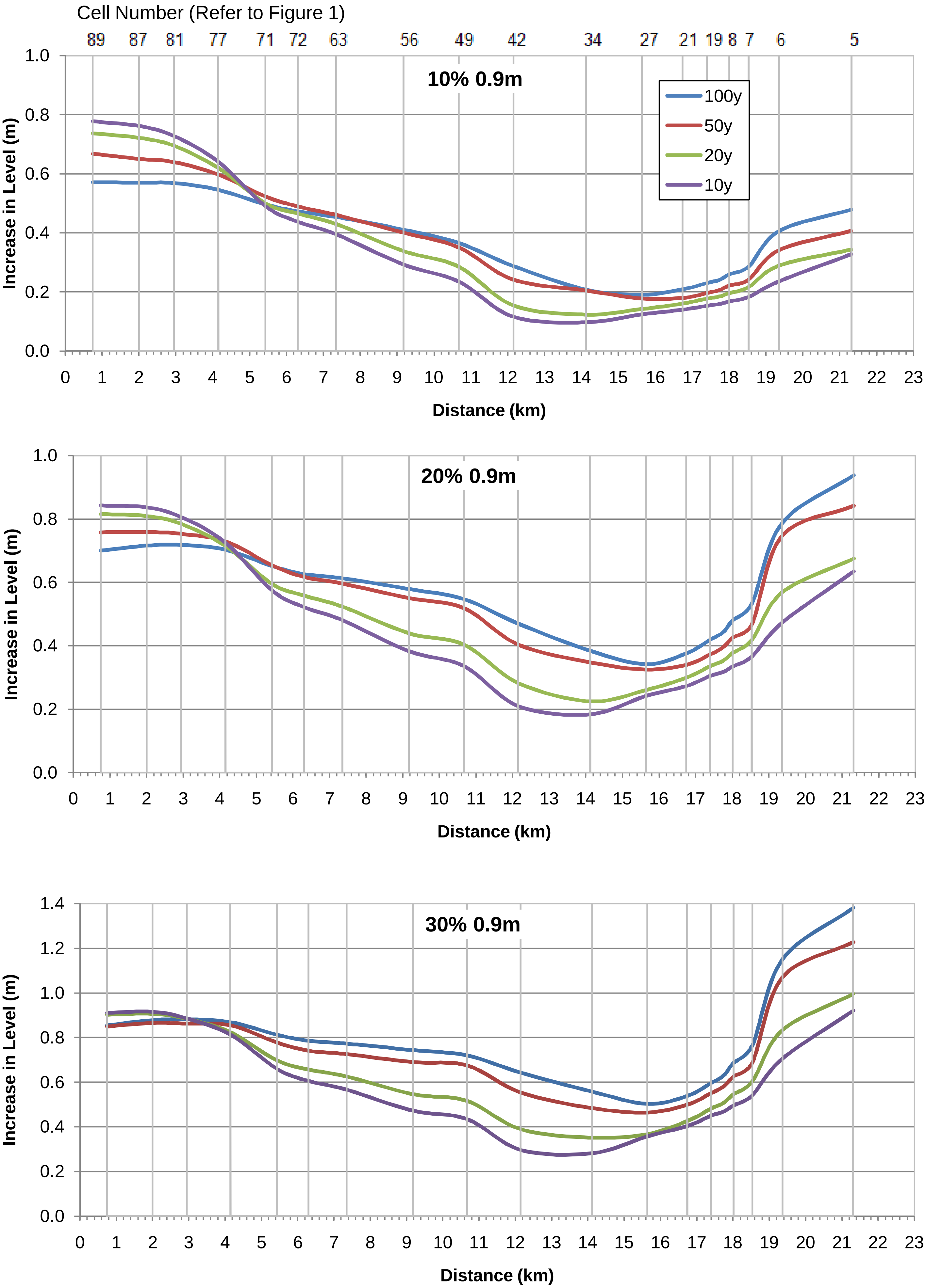


FIGURE 7
NOWRA BRIDGE

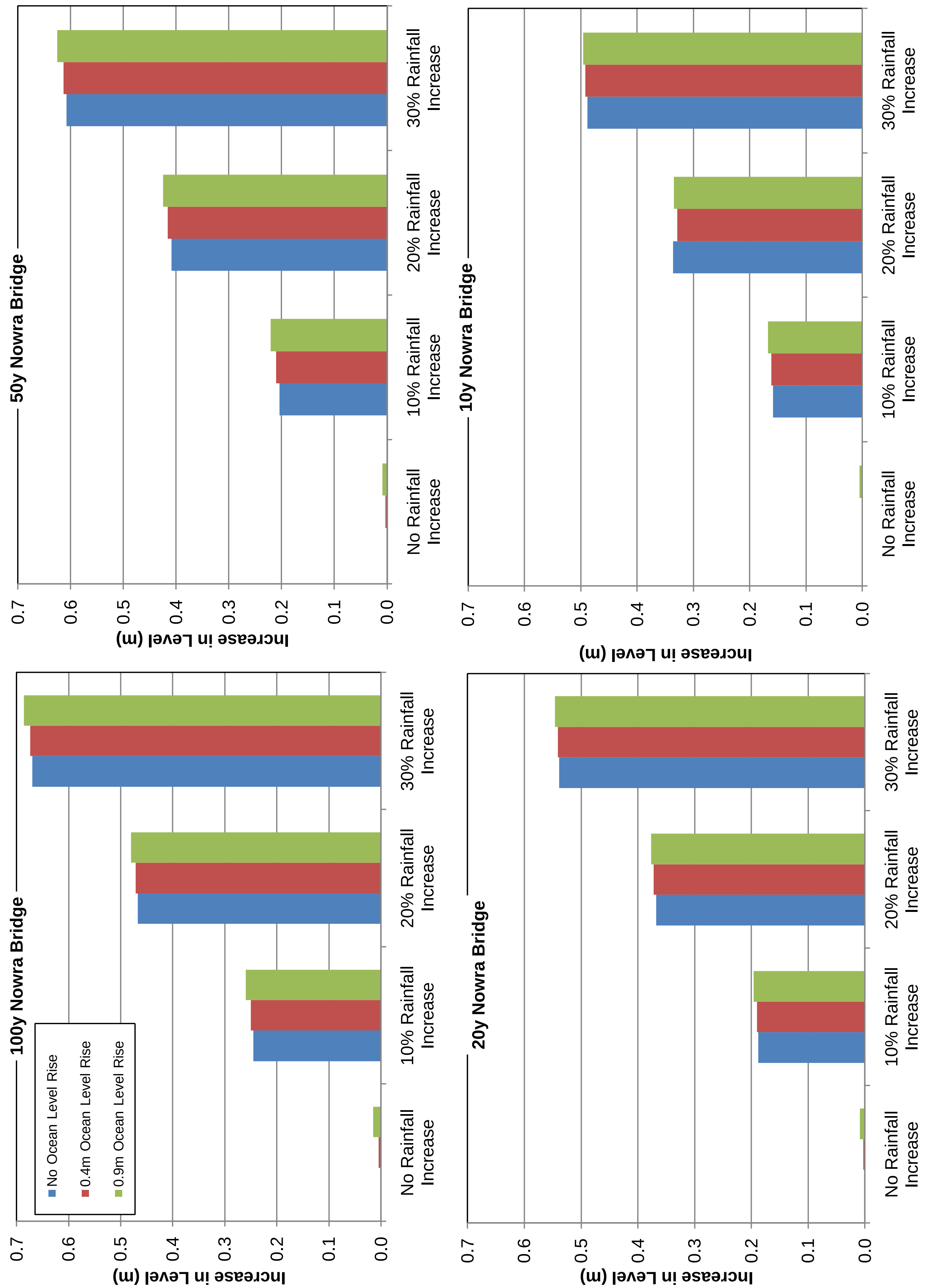


FIGURE 8
SHOALHAVEN HEADS

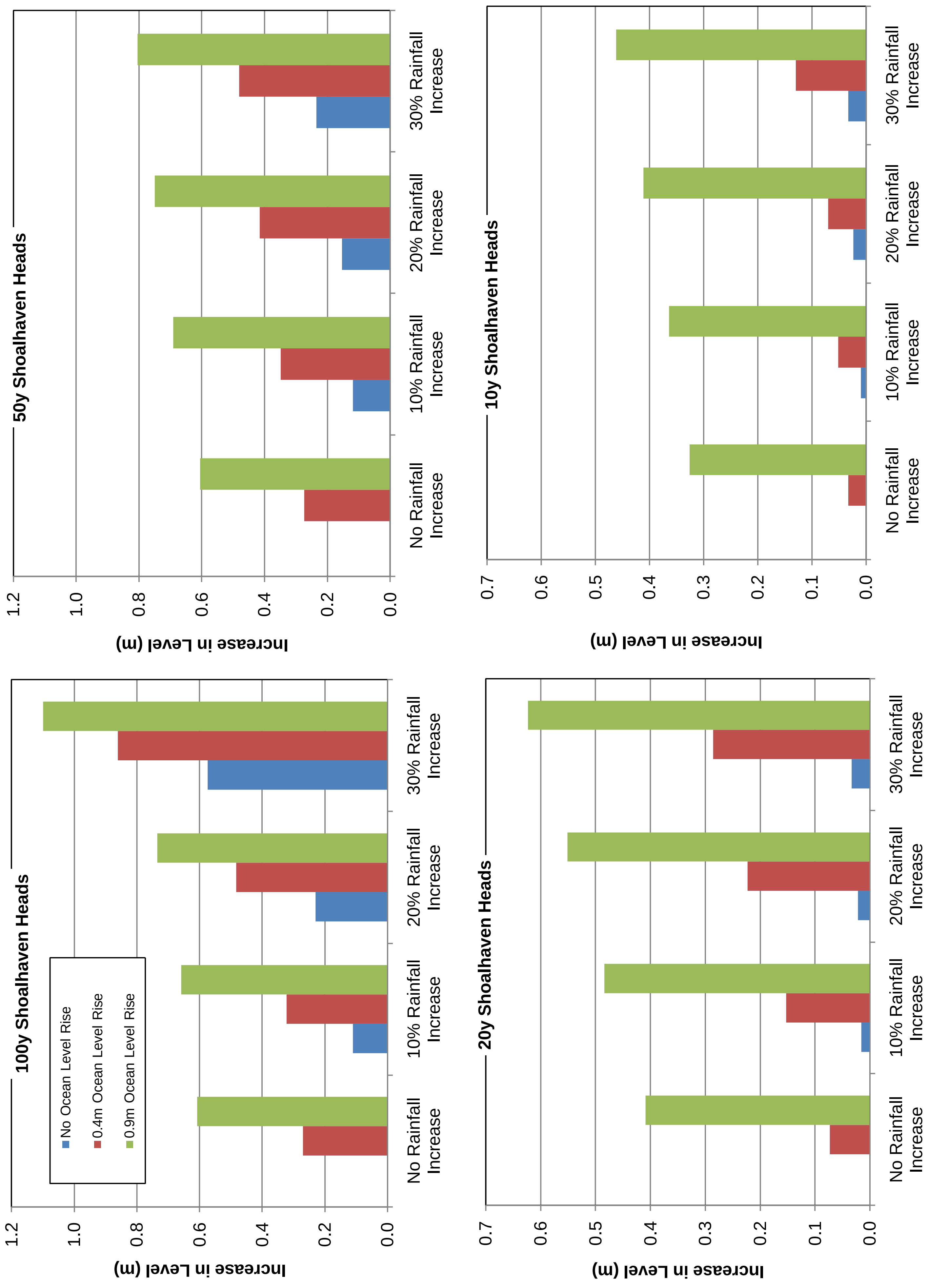


FIGURE 9
TERARA

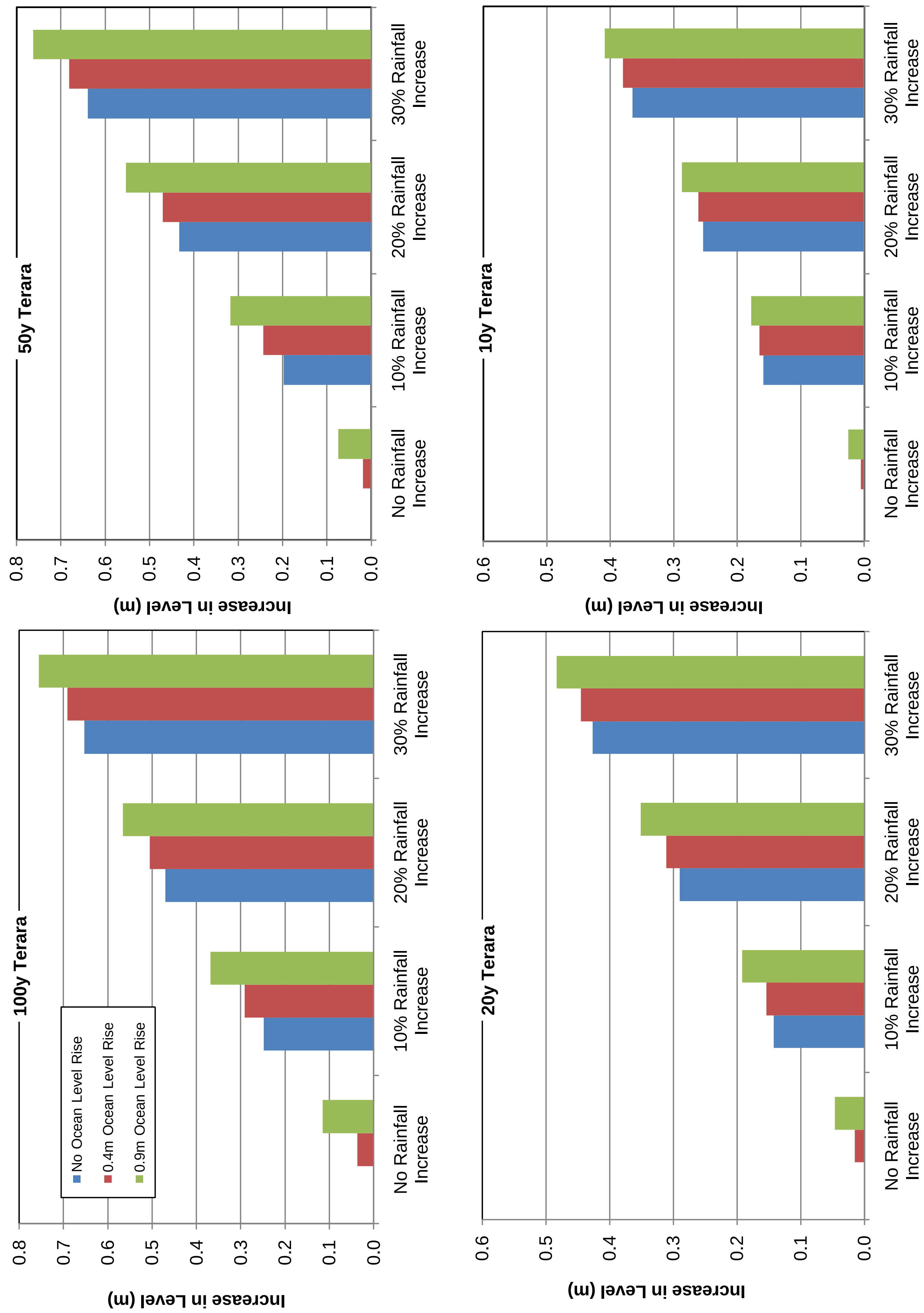


FIGURE 10
GREENWELL POINT

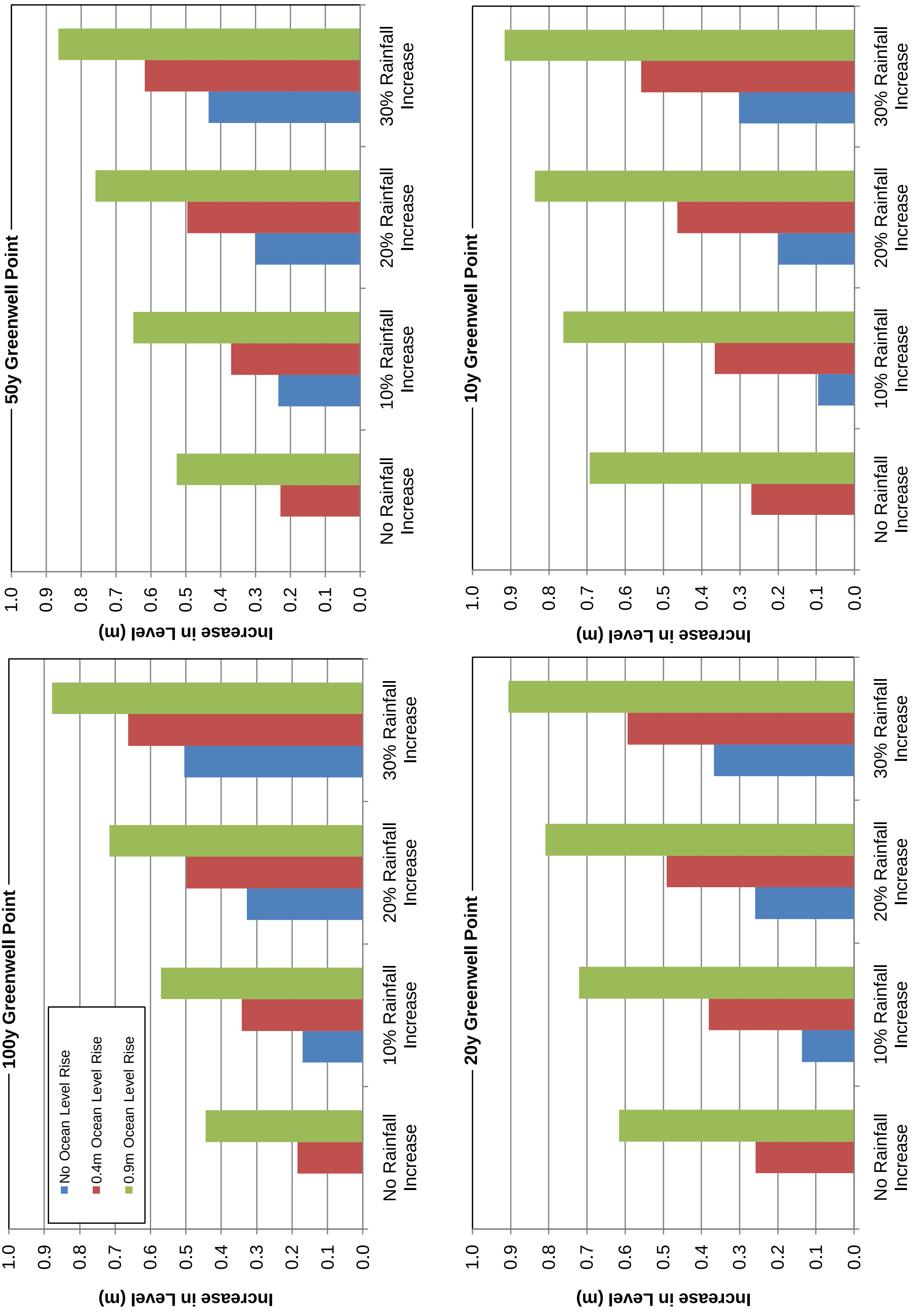


FIGURE 11a
BUILDING FLOORS INUNDATED

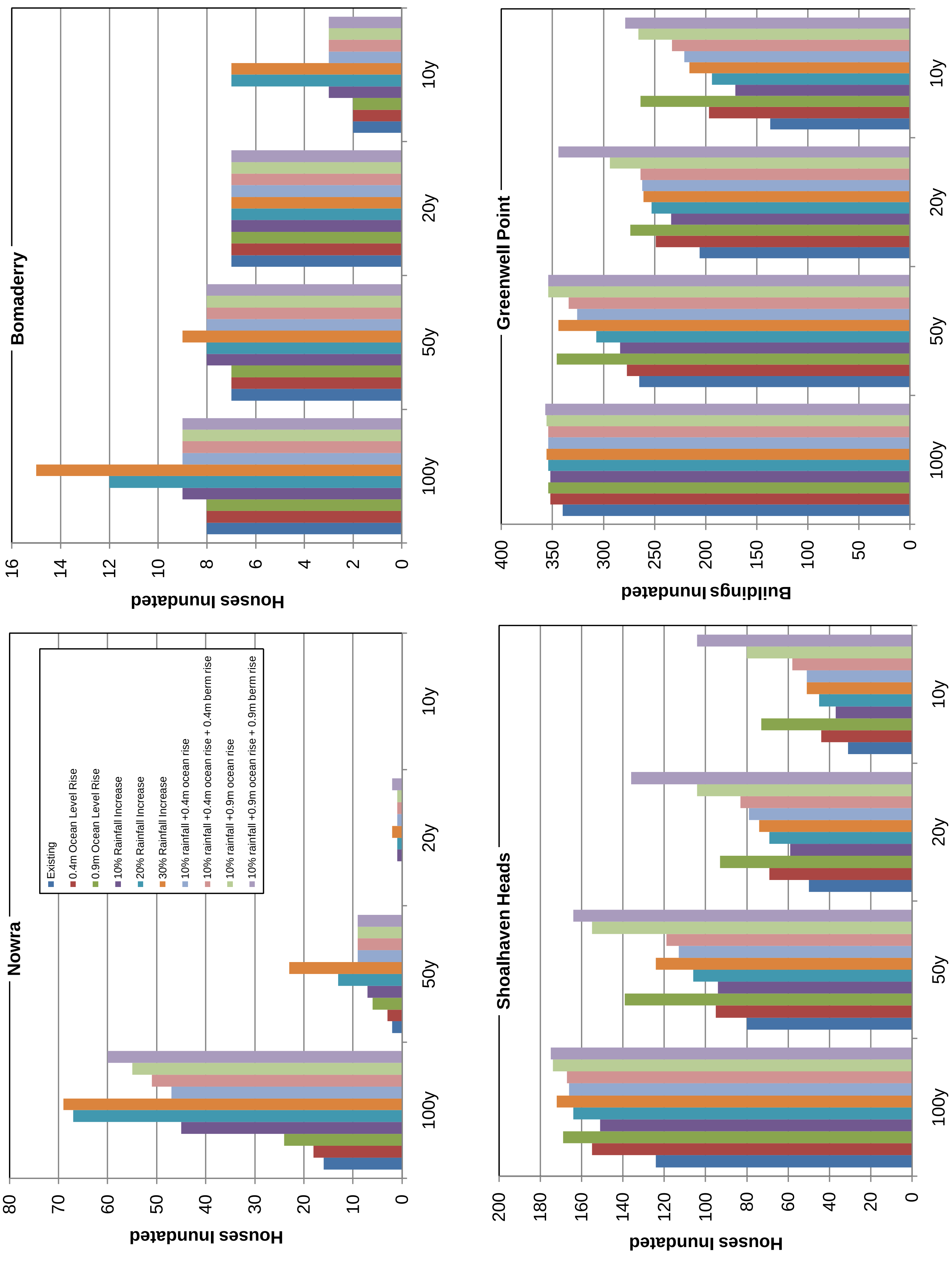
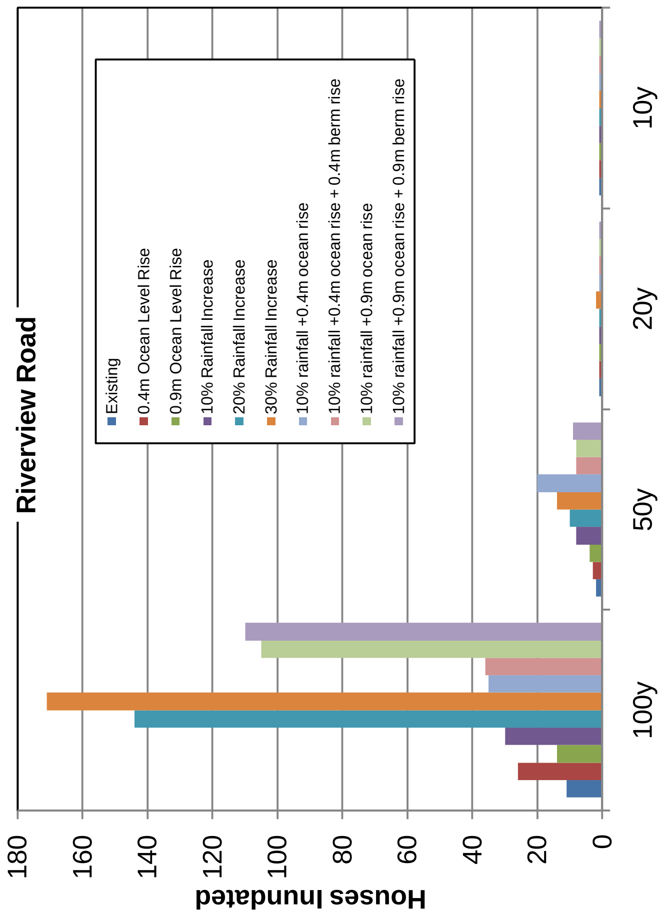
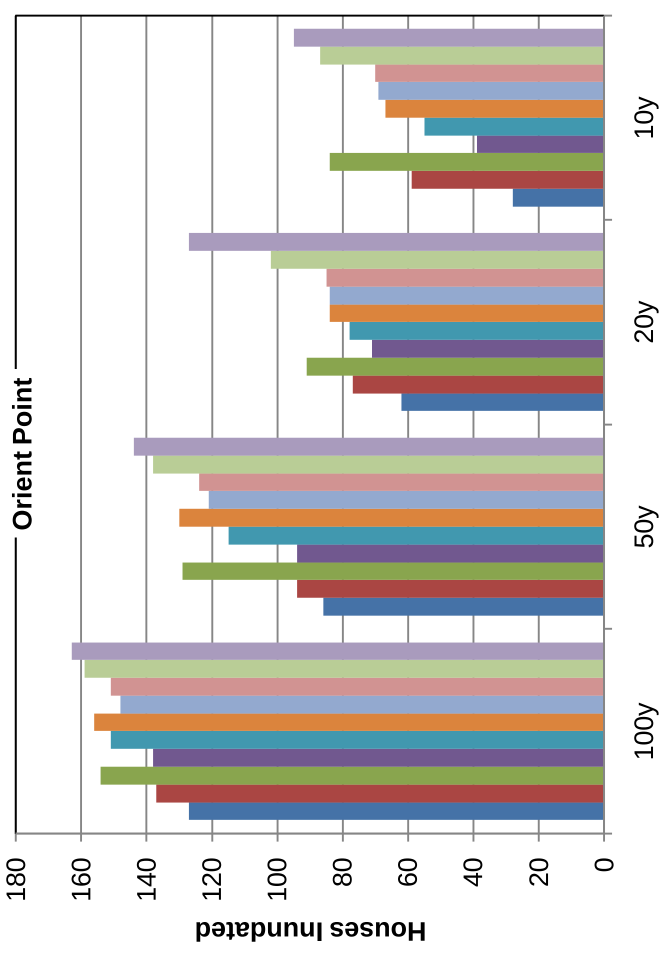
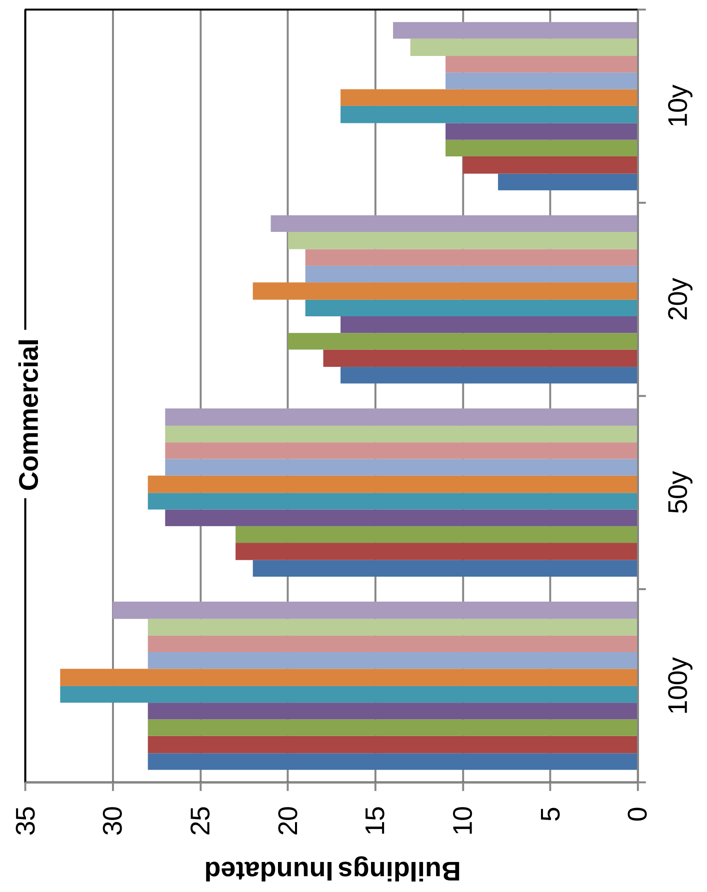
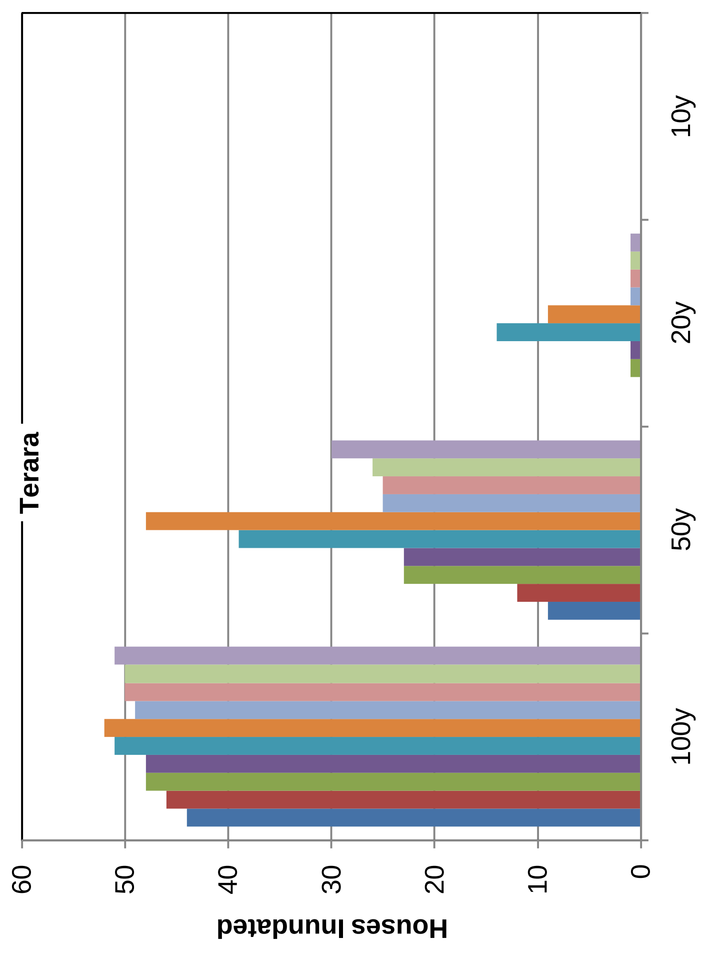


FIGURE 11b
BUILDING FLOORS INUNDATED



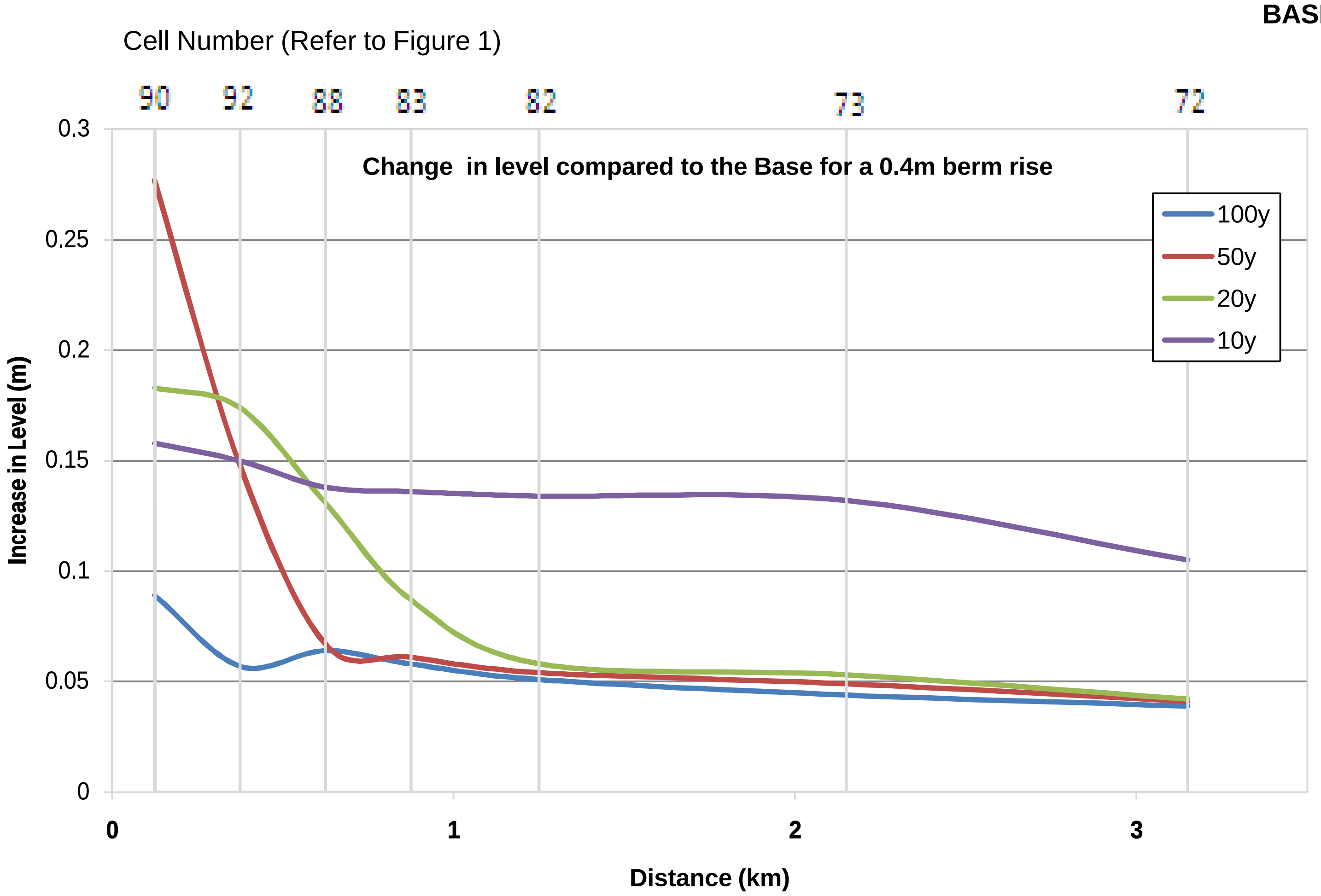






Appendix A

FIGURE A1
PEAK HEIGHT PROFILES WITH BERM LEVEL RISE SHOALHAVEN RIVER BASE



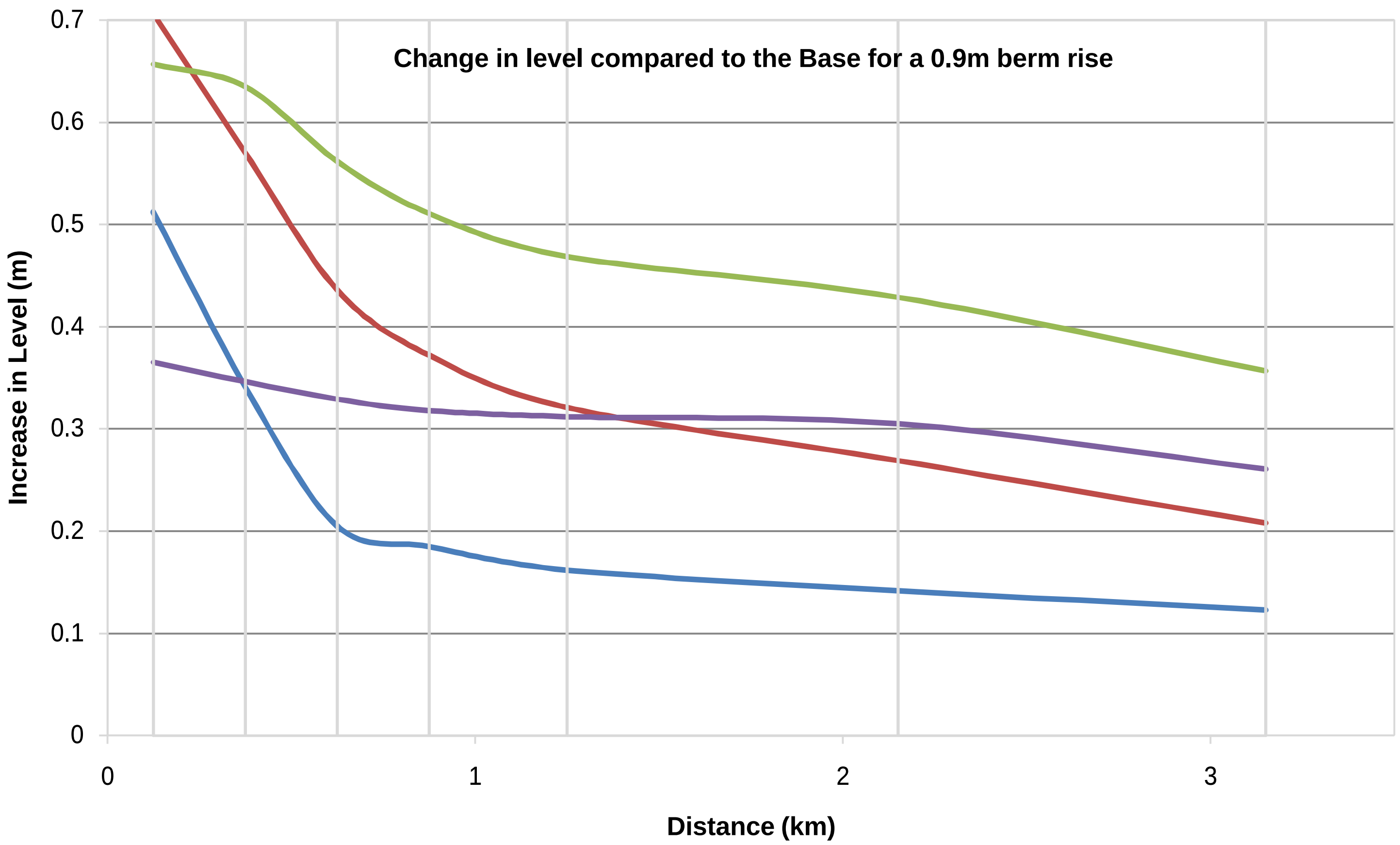
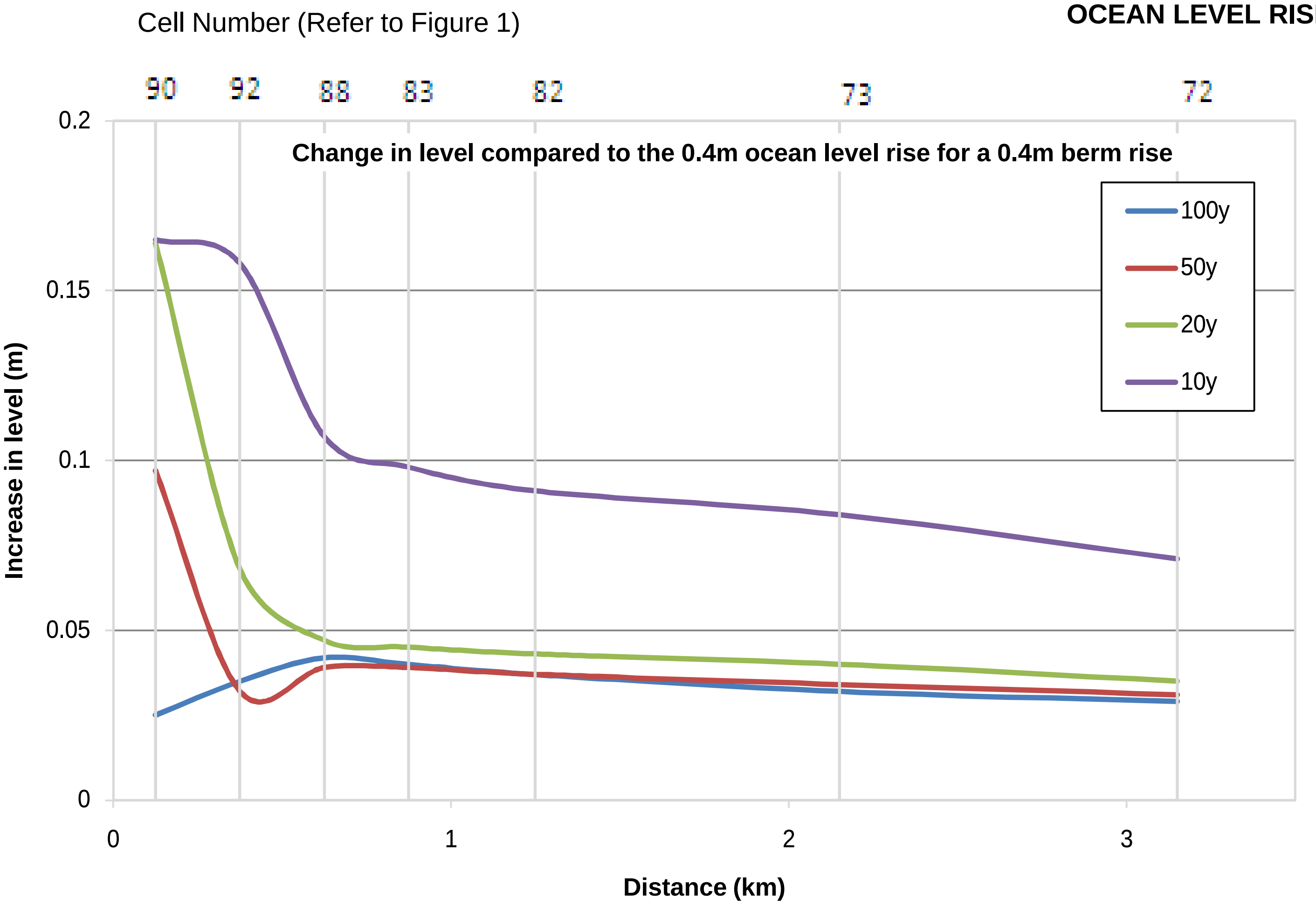


FIGURE A2

PEAK HEIGHT PROFILES WITH BERM LEVEL RISE SHOALHAVEN RIVER OCEAN LEVEL RISE



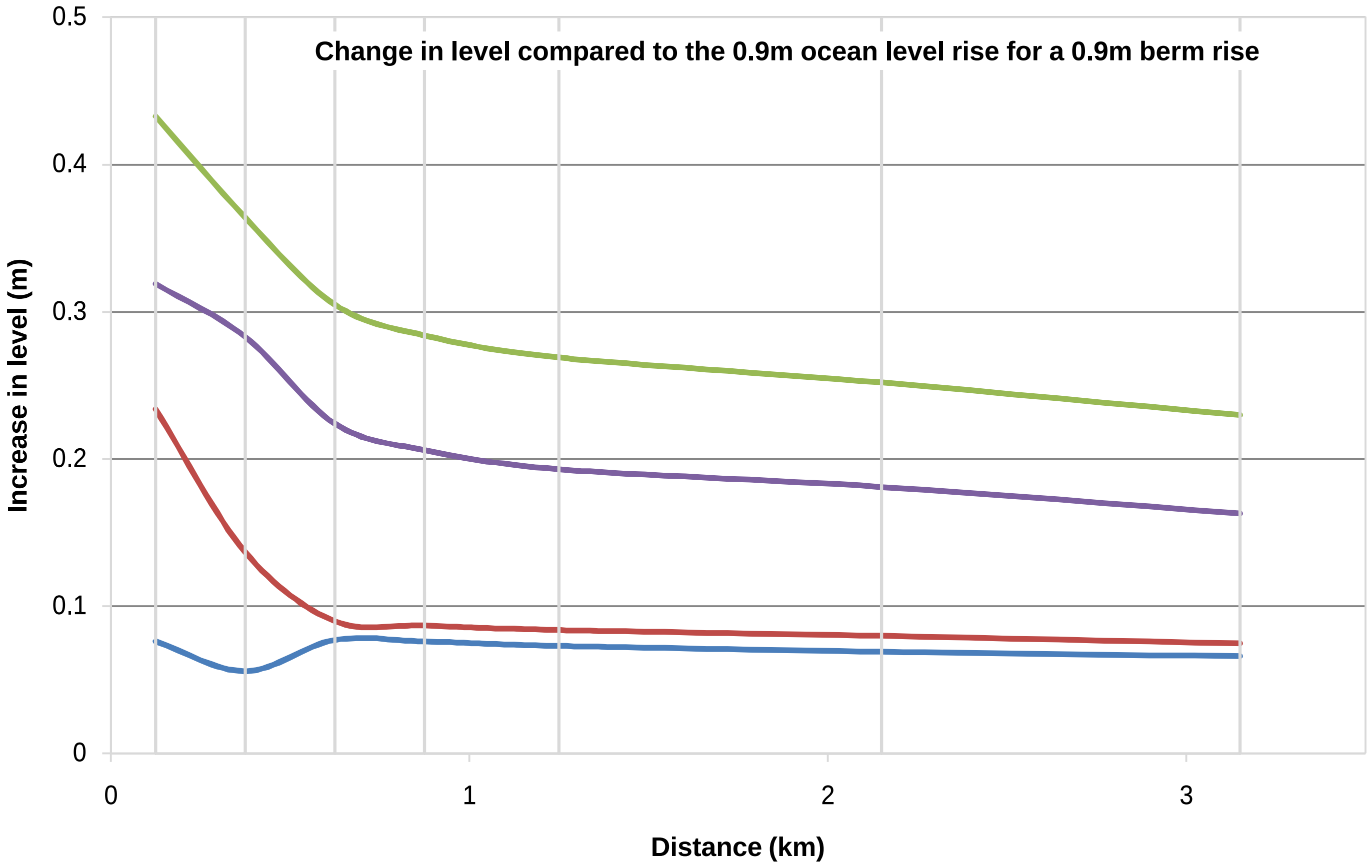
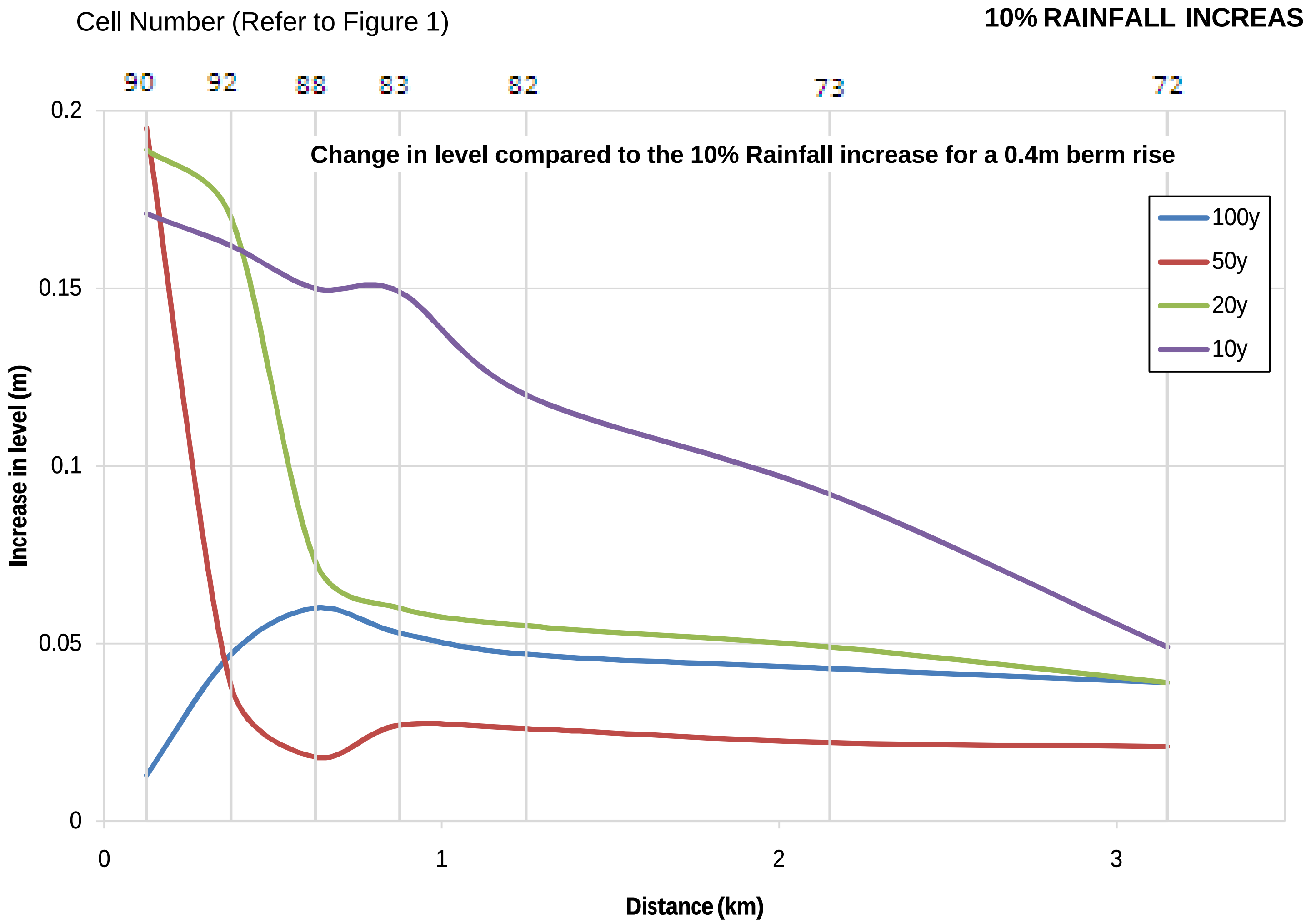


FIGURE A3

PEAK HEIGHT PROFILES WITH BERM LEVEL RISE SHOALHAVEN RIVER 10% RAINFALL INCREASE



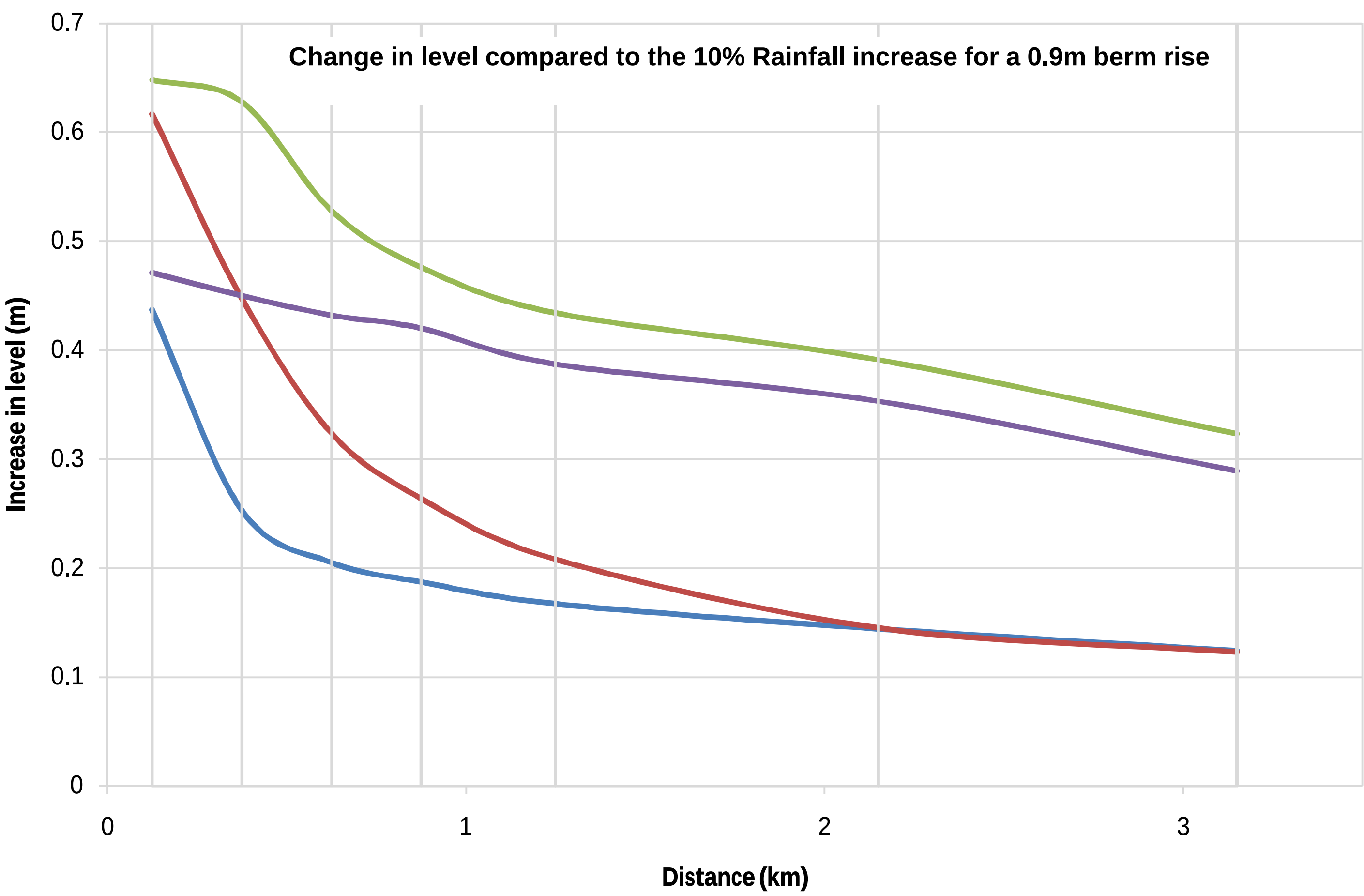
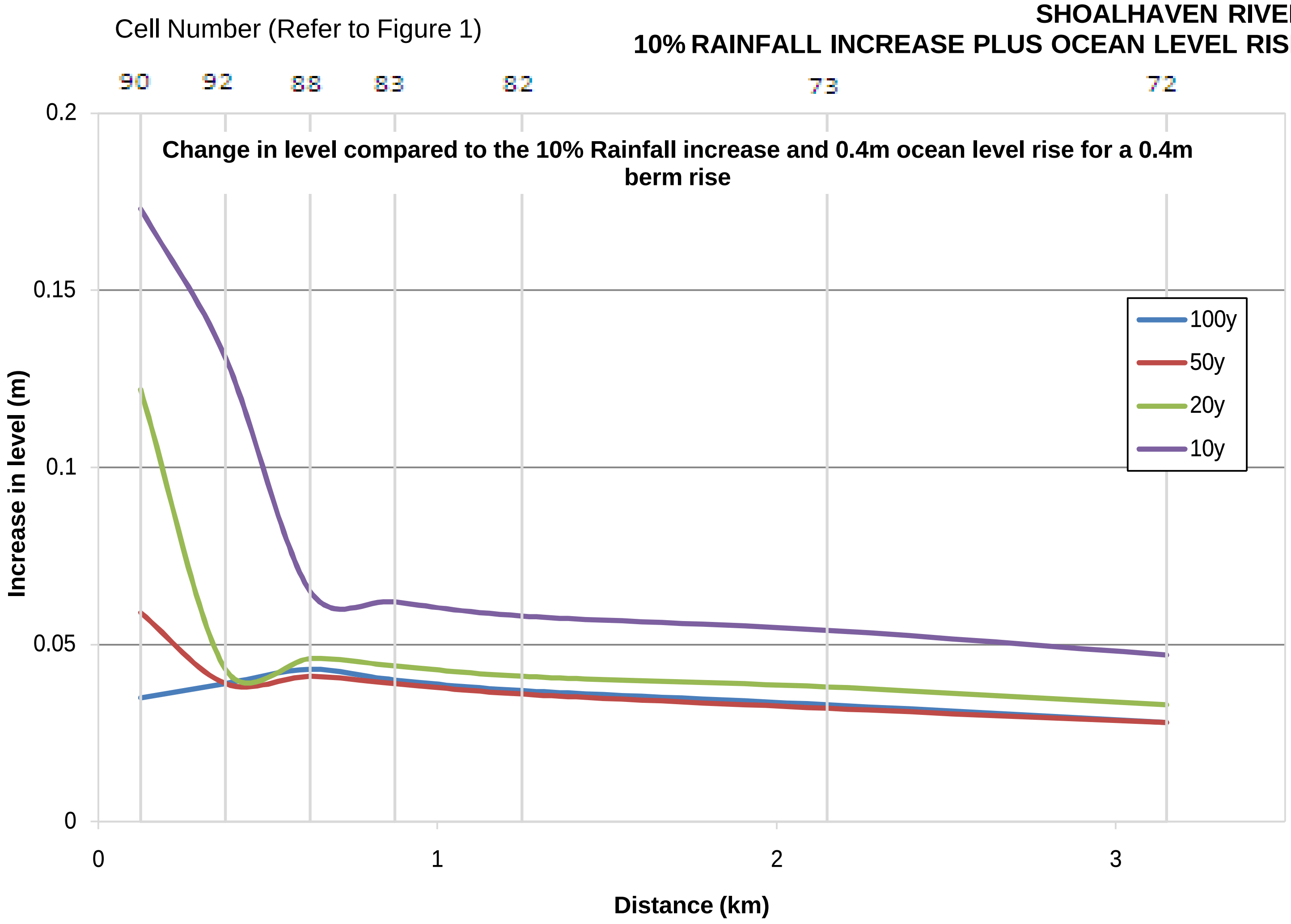


FIGURE A4
PEAK HEIGHT PROFILES
WITH BERM LEVEL RISE
SHOALHAVEN RIVER
10% RAINFALL INCREASE PLUS OCEAN LEVEL RISE



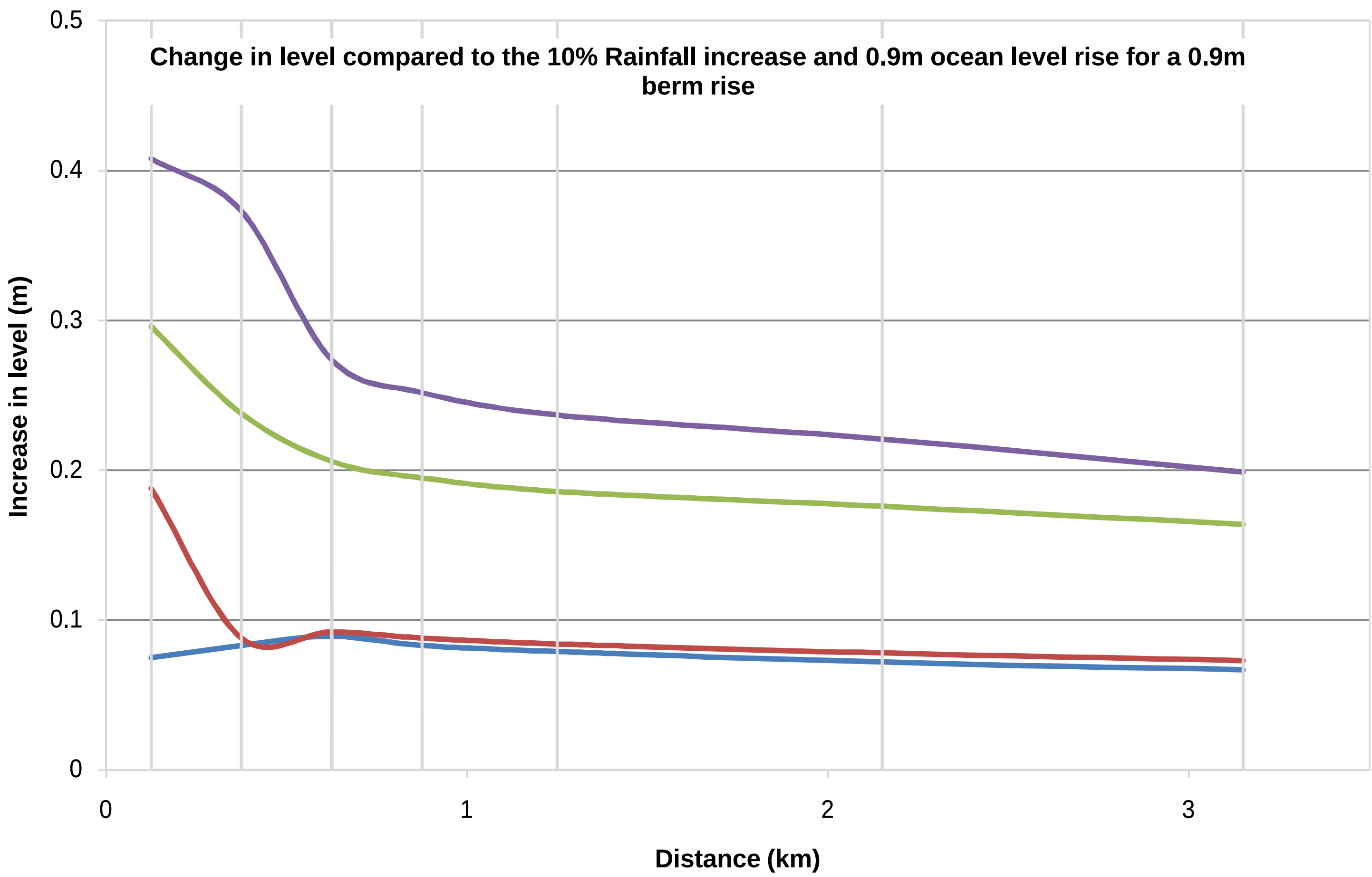
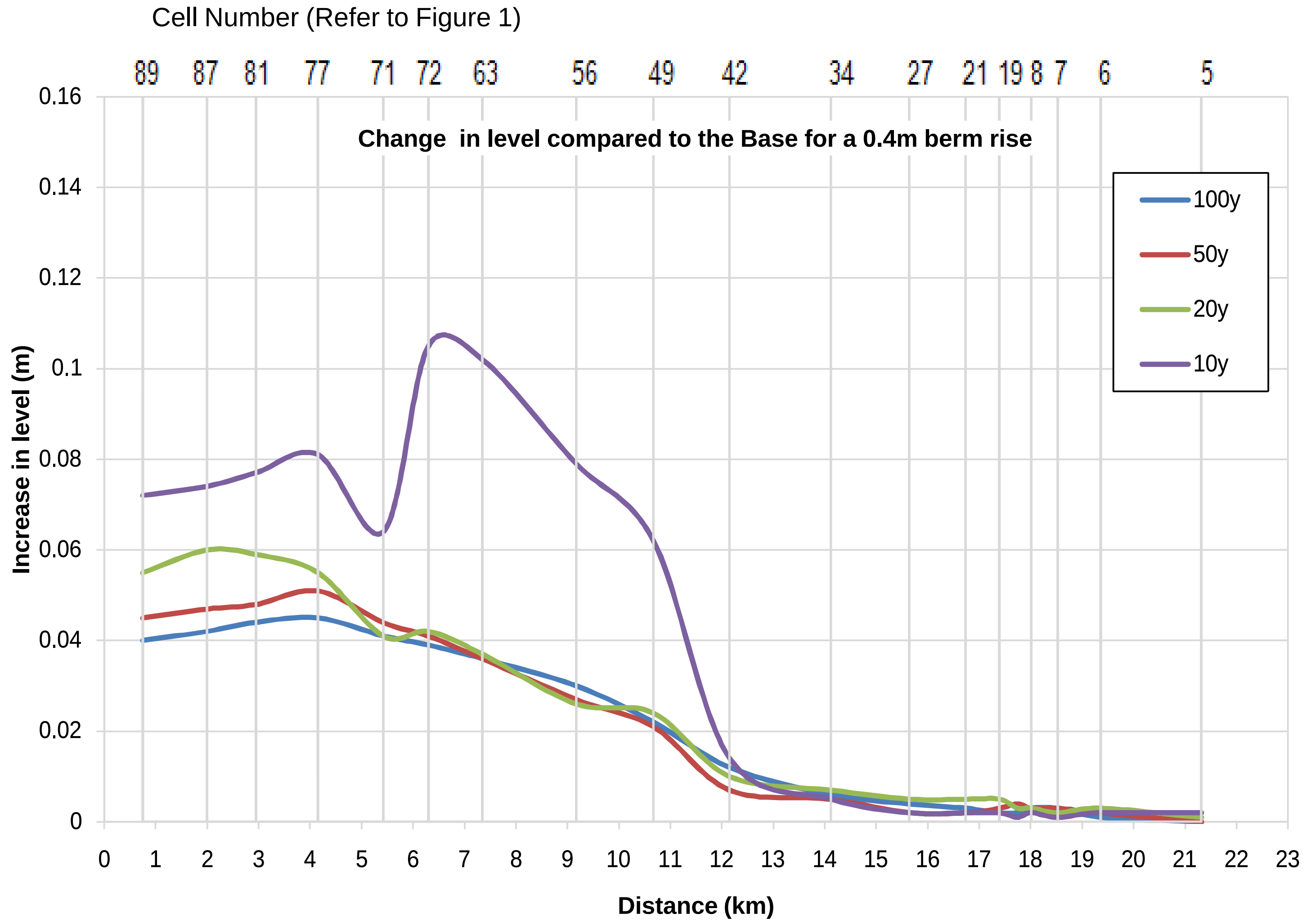


FIGURE A5

PEAK HEIGHT PROFILES WITH BERM LEVEL RISE CROOKHAVEN RIVER BASE



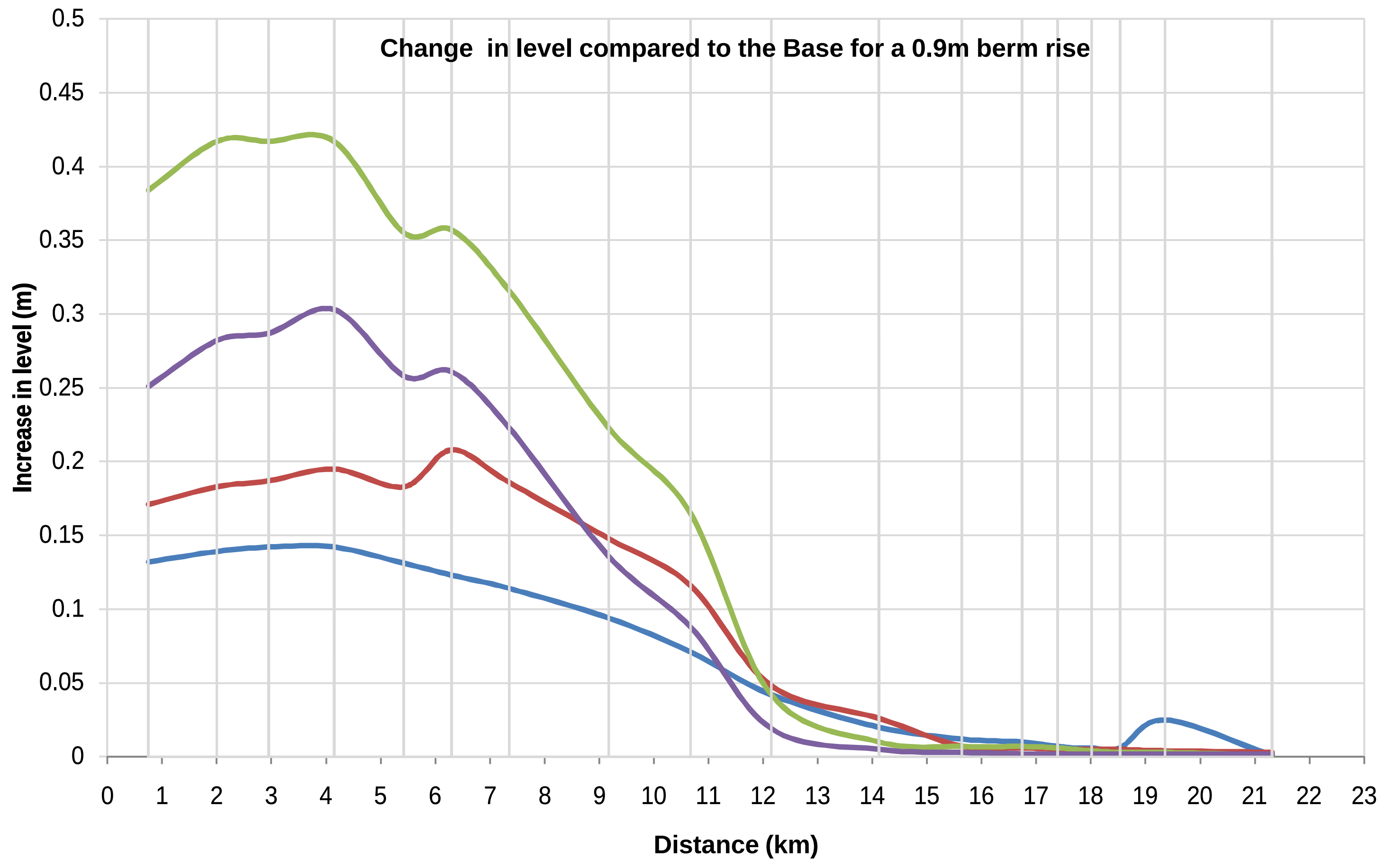
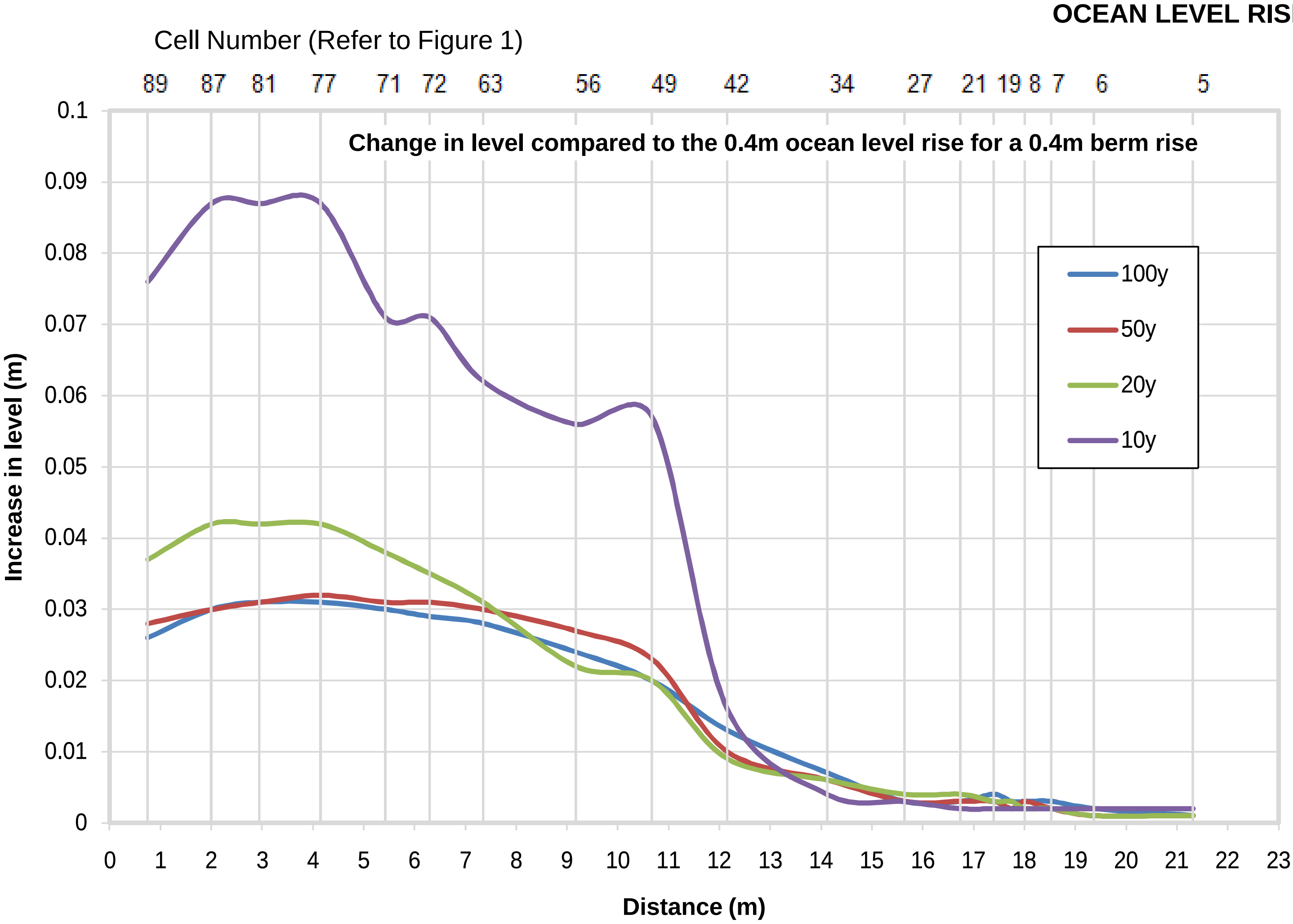


FIGURE A6

PEAK HEIGHT PROFILES WITH BERM LEVEL RISE CROOKHAVEN RIVER OCEAN LEVEL RISE



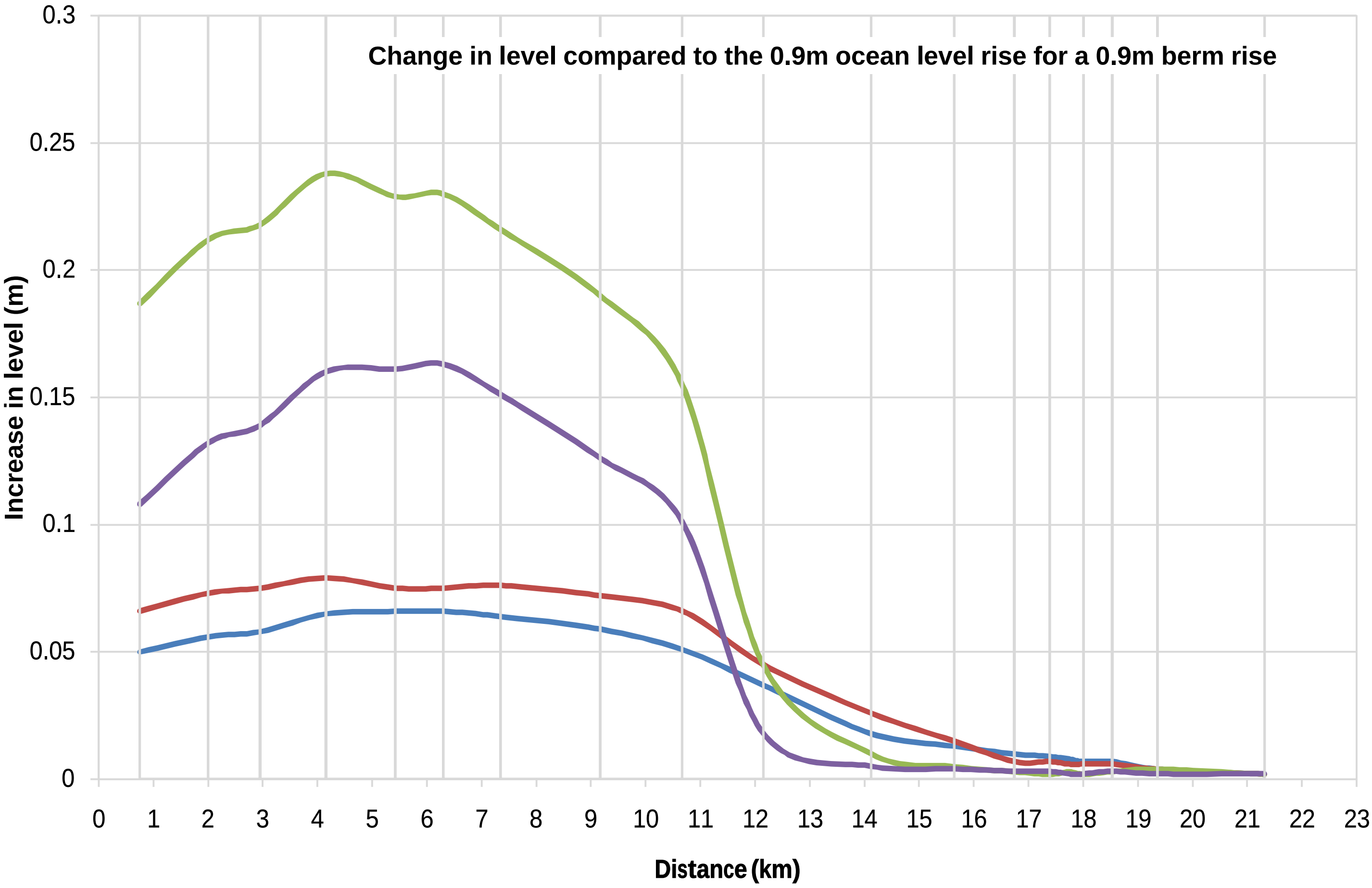
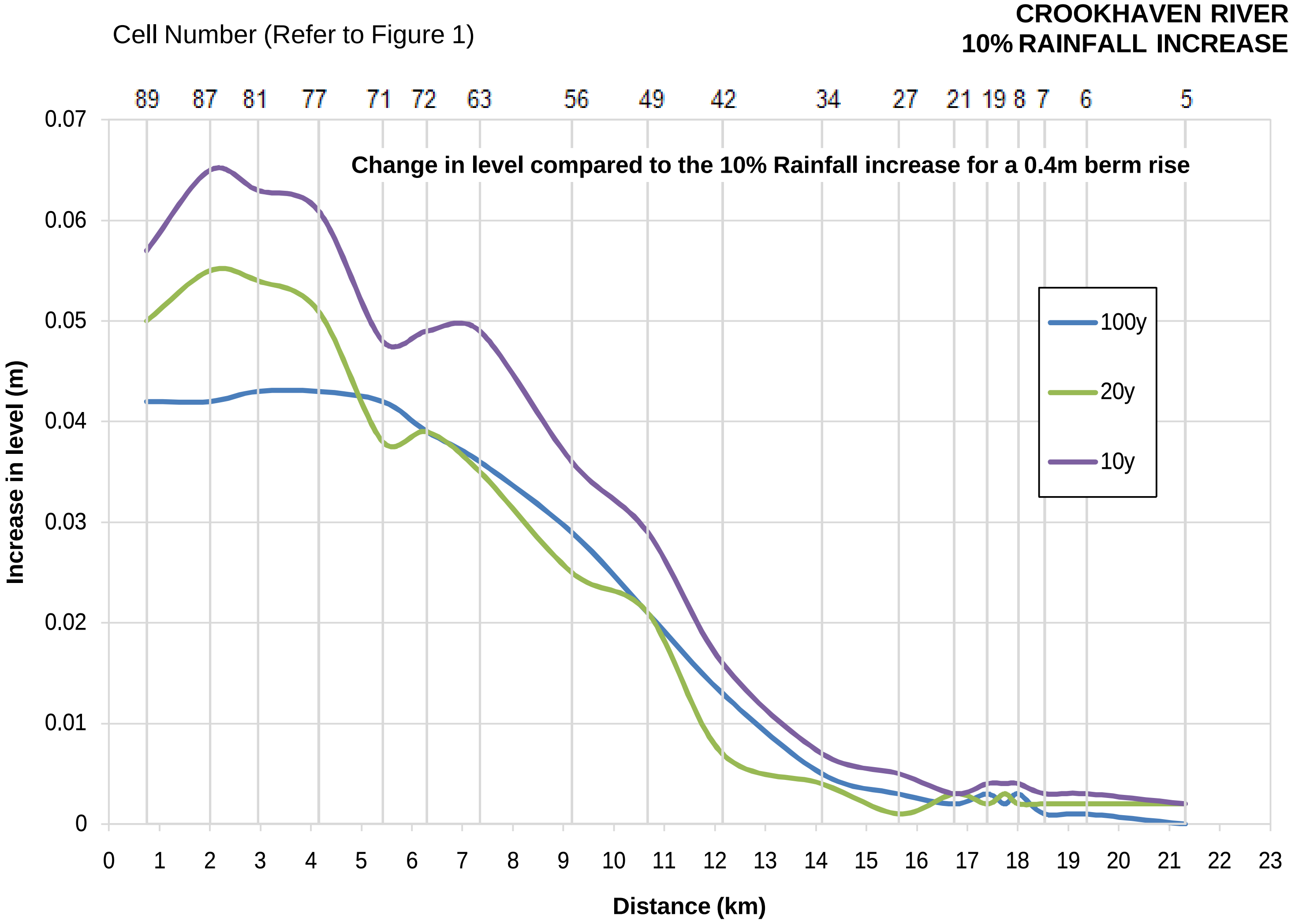


FIGURE A7
PEAK HEIGHT PROFILES WITH BERM LEVEL RISE CROOKHAVEN RIVER 10% RAINFALL INCREASE



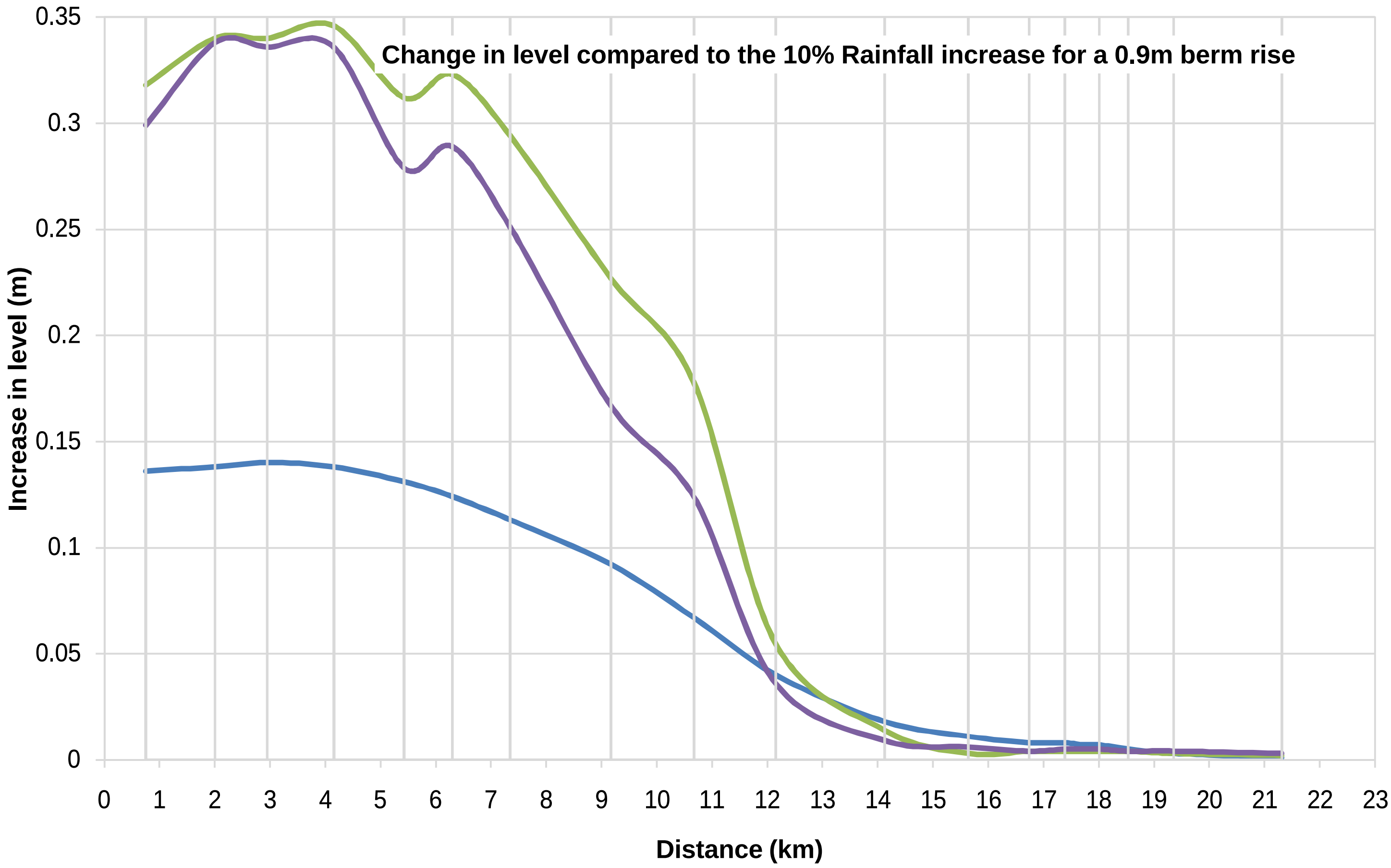
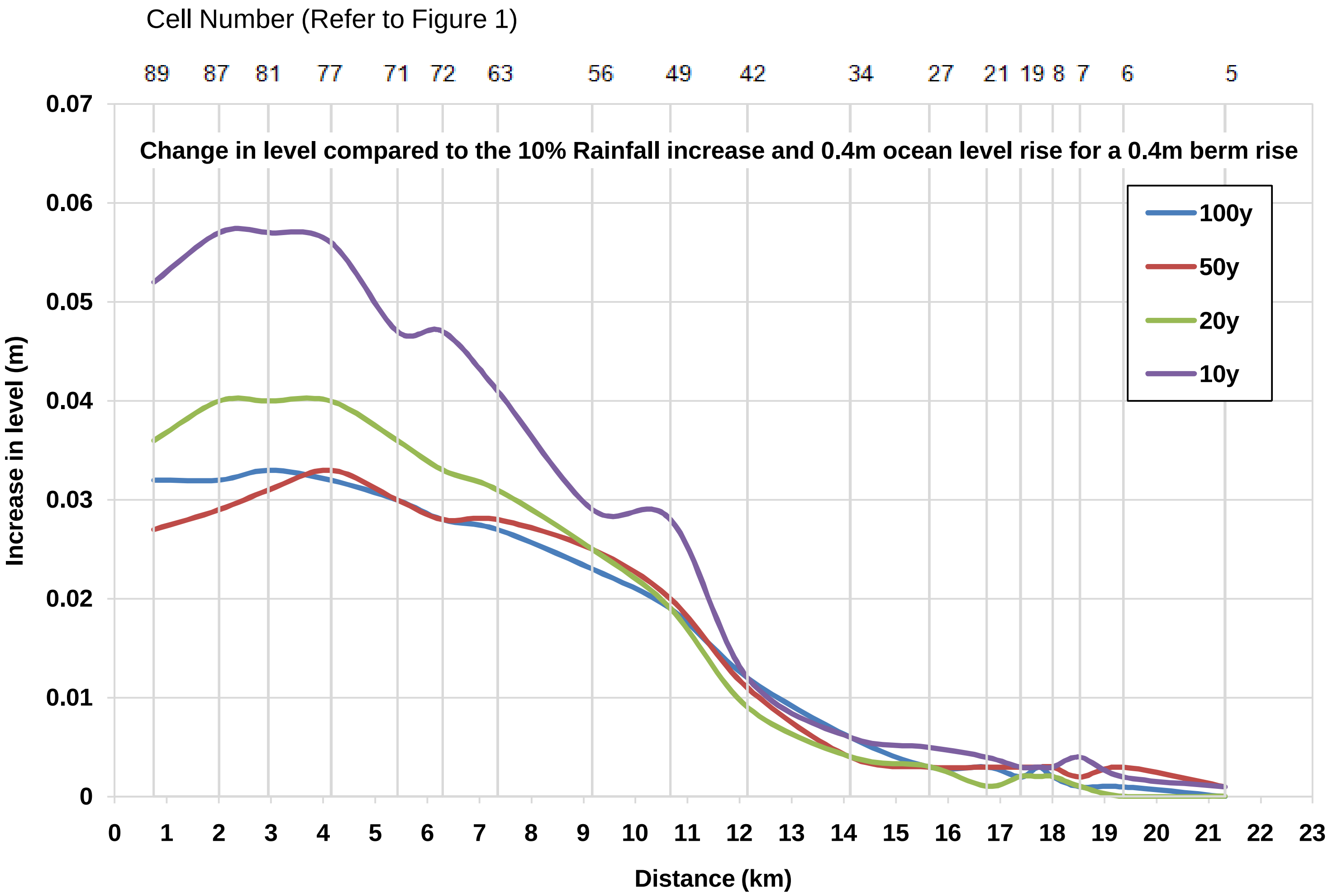


FIGURE A8

PEAK HEIGHT PROFILES
WITH BERM LEVEL RISE
CROOKHAVEN RIVER
10% RAINFALL INCREASE PLUS OCEAN LEVEL RISE



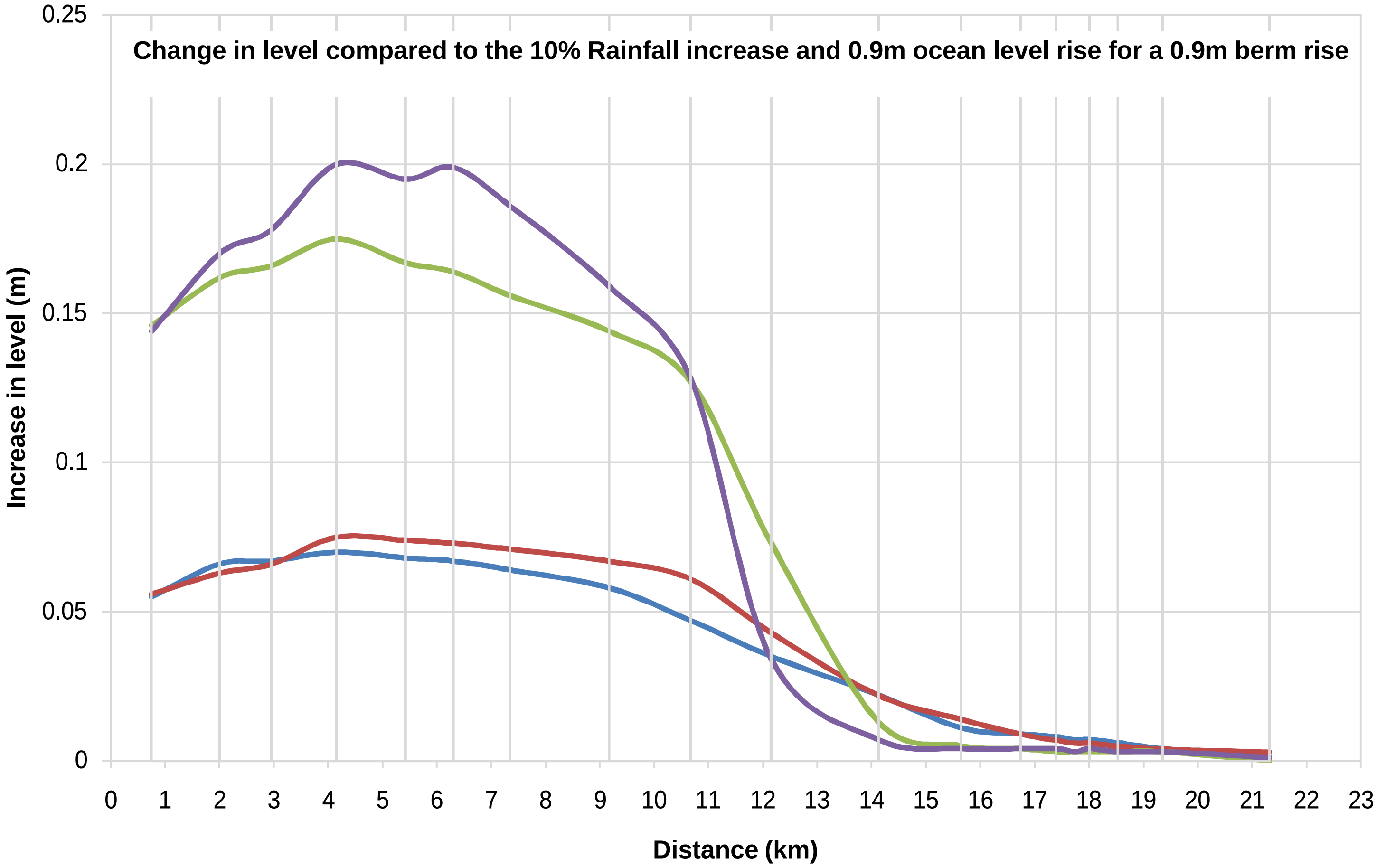


FIGURE A9
NOWRA BRIDGE
WITH BERM LEVEL RISE

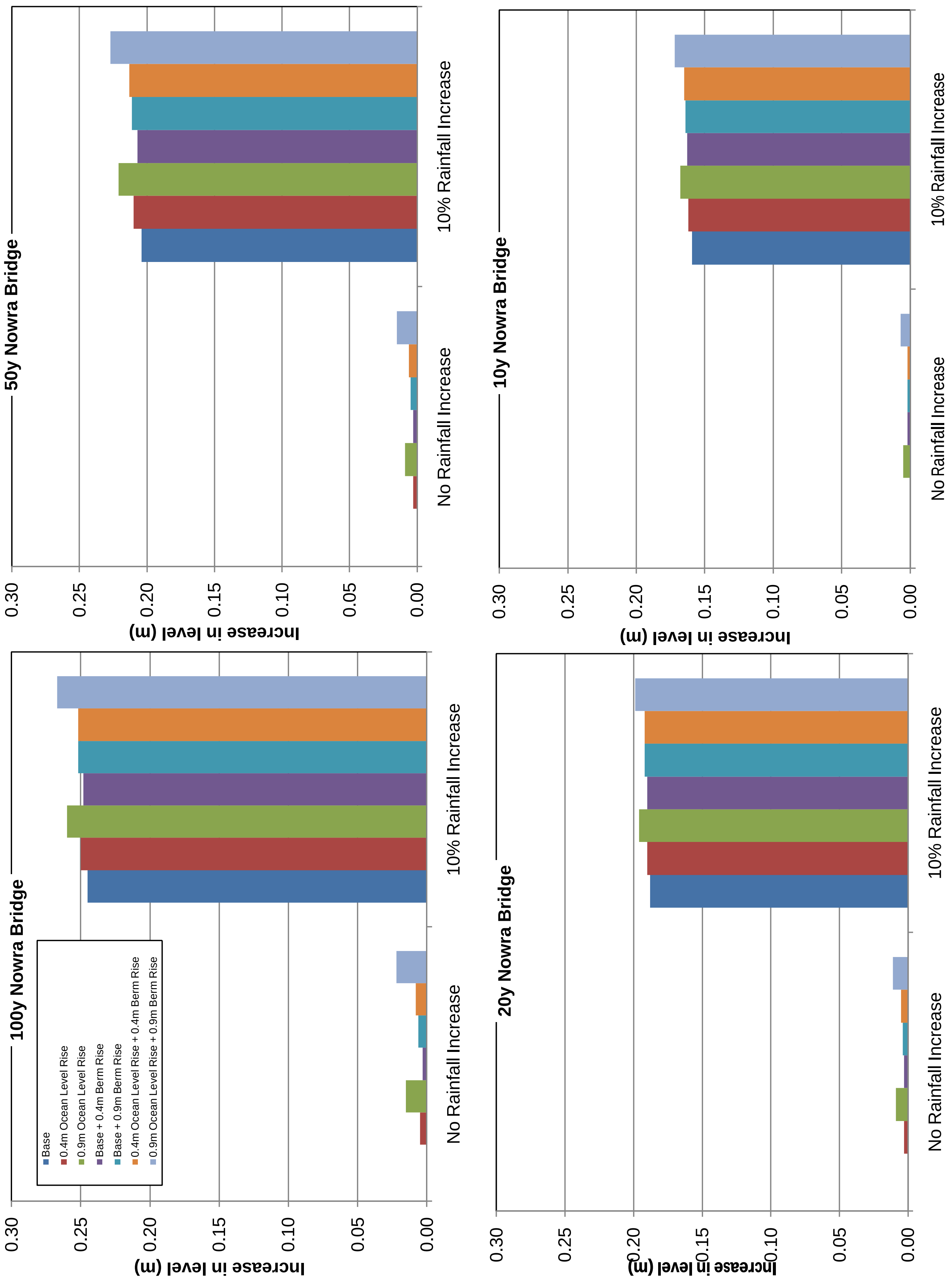


FIGURE A10
SHOALHAVEN HEADS
WITH BERM LEVEL RISE

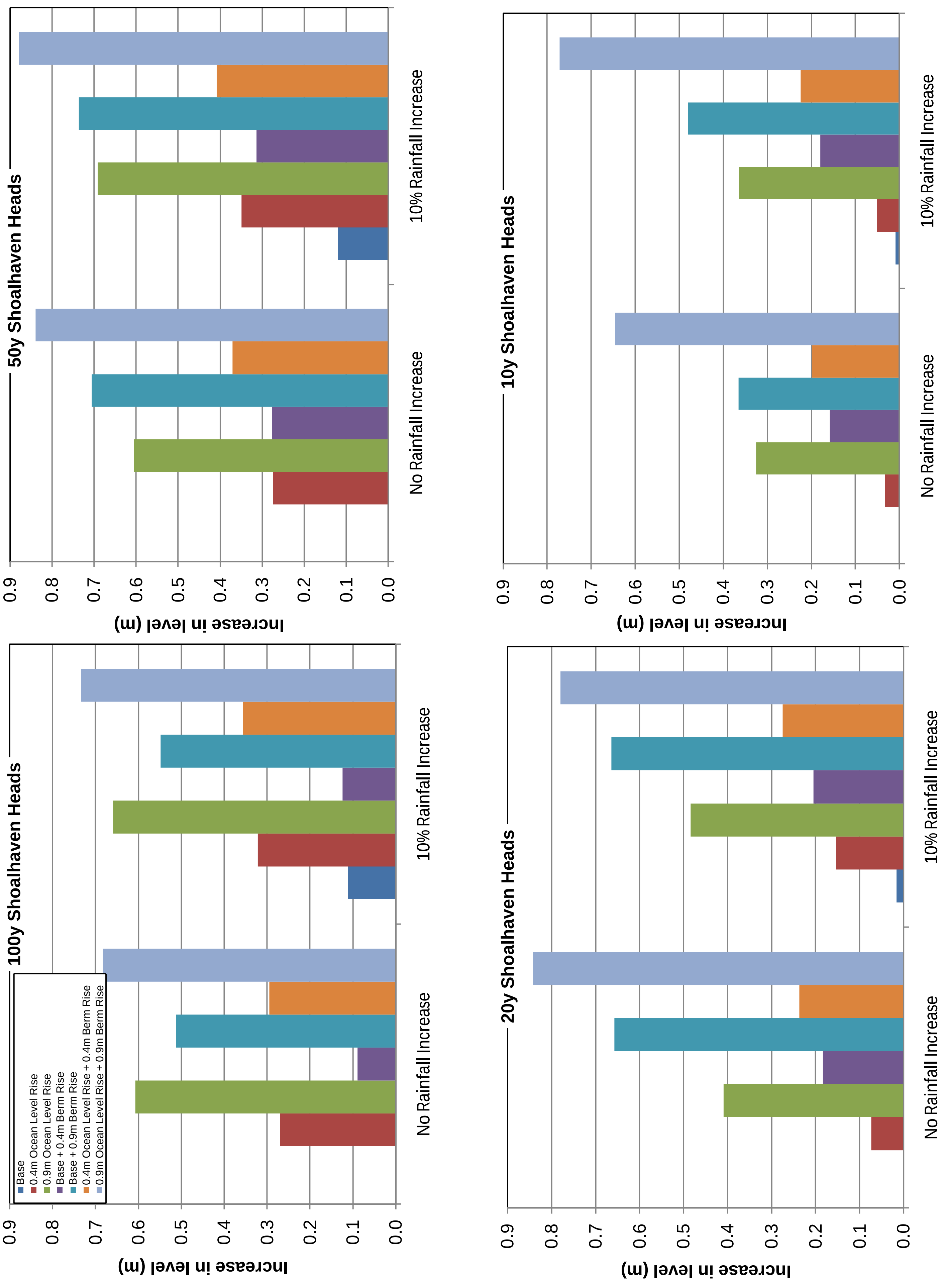


FIGURE A11
TERARA
WITH BERM LEVEL RISE

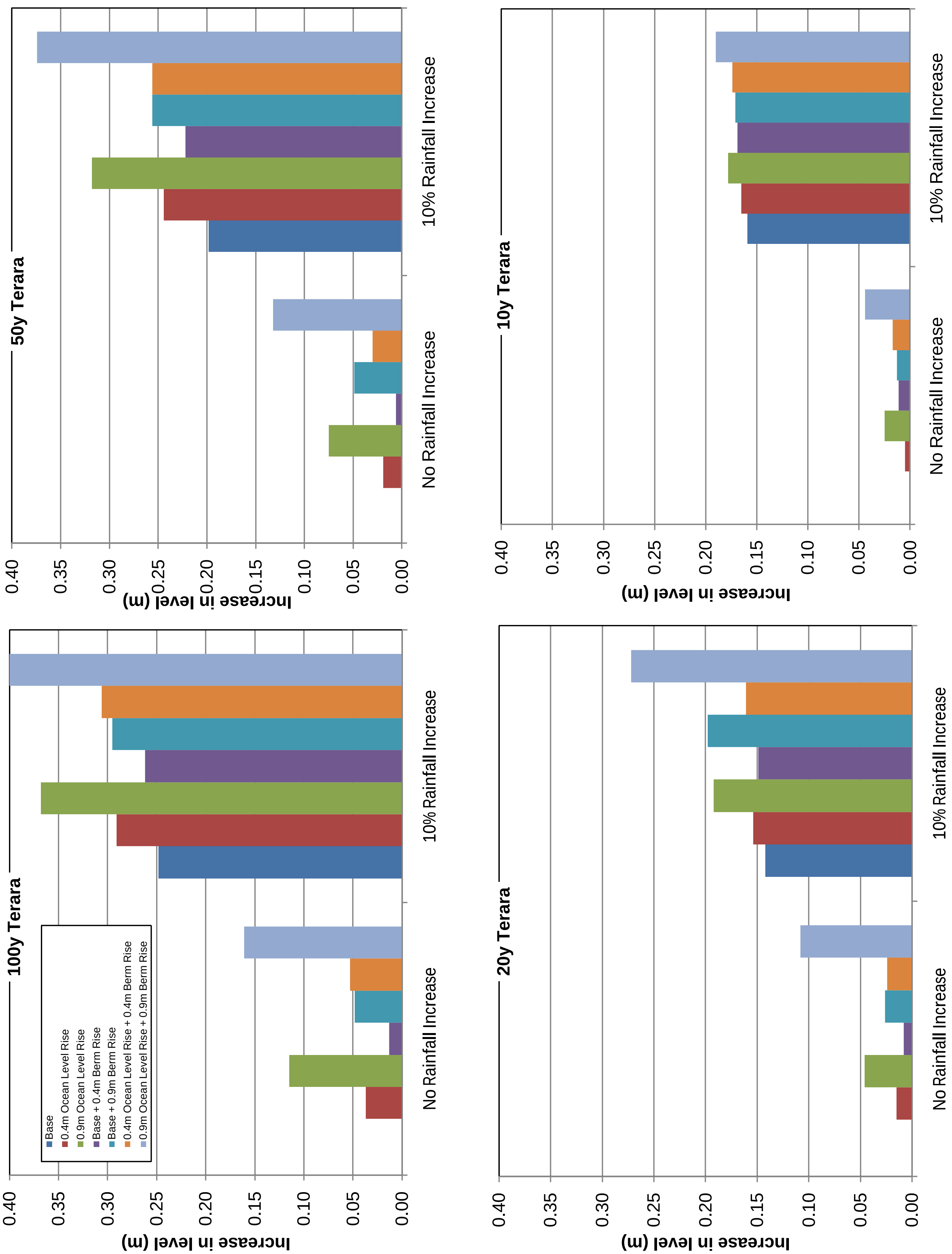
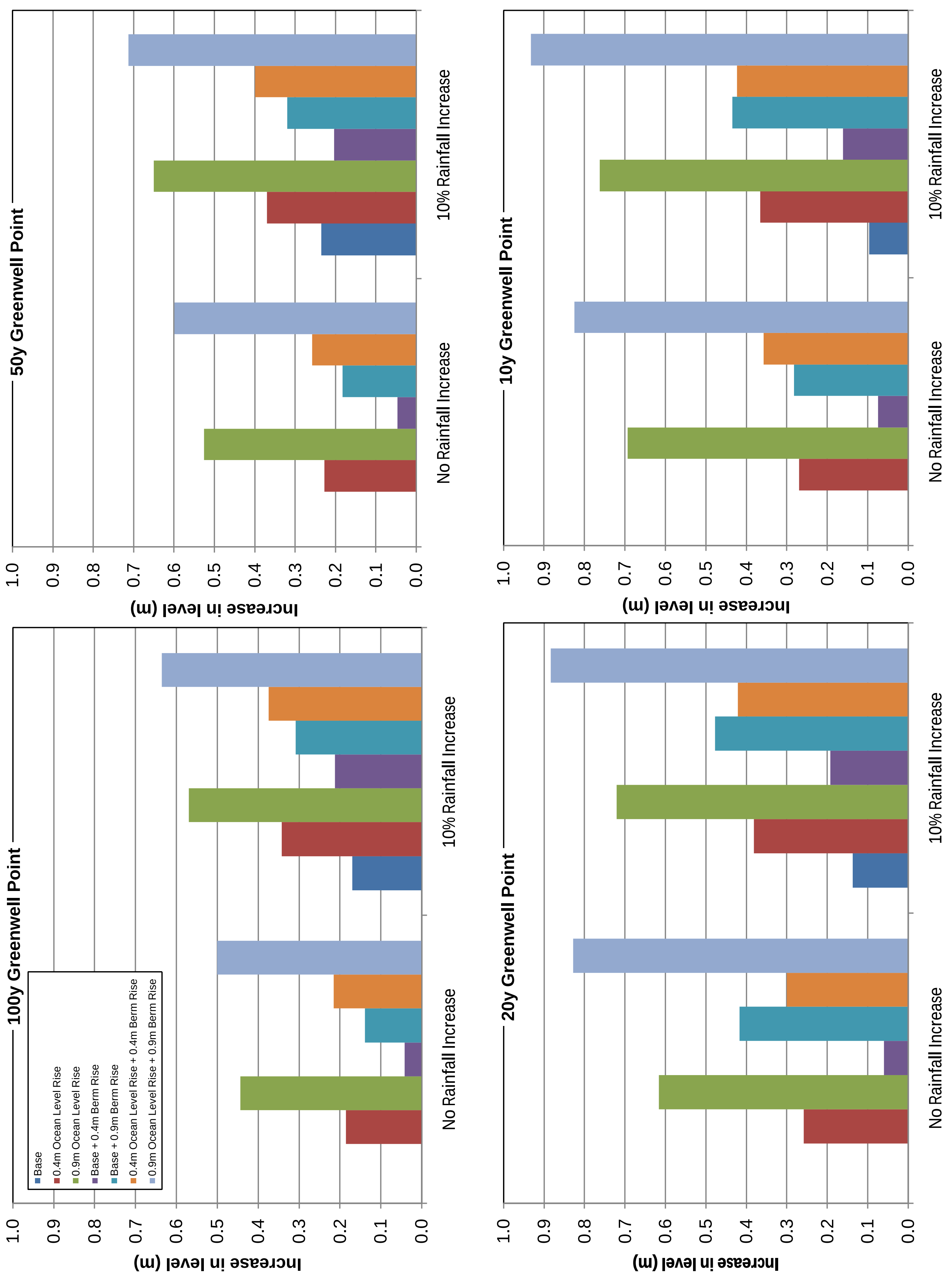


FIGURE A12
GREENWELL POINT
WITH BERM LEVEL RISE



Mapping Figures

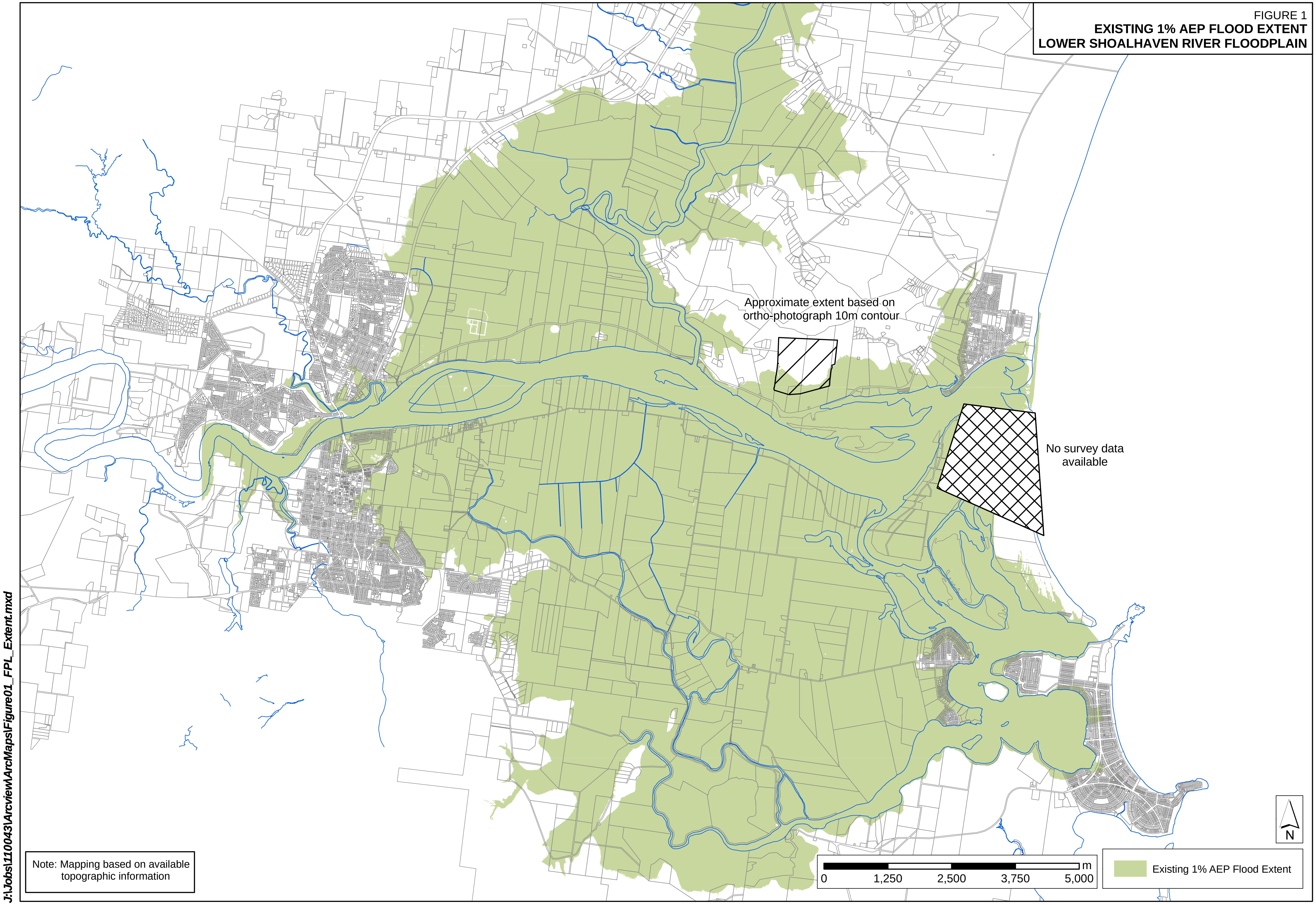
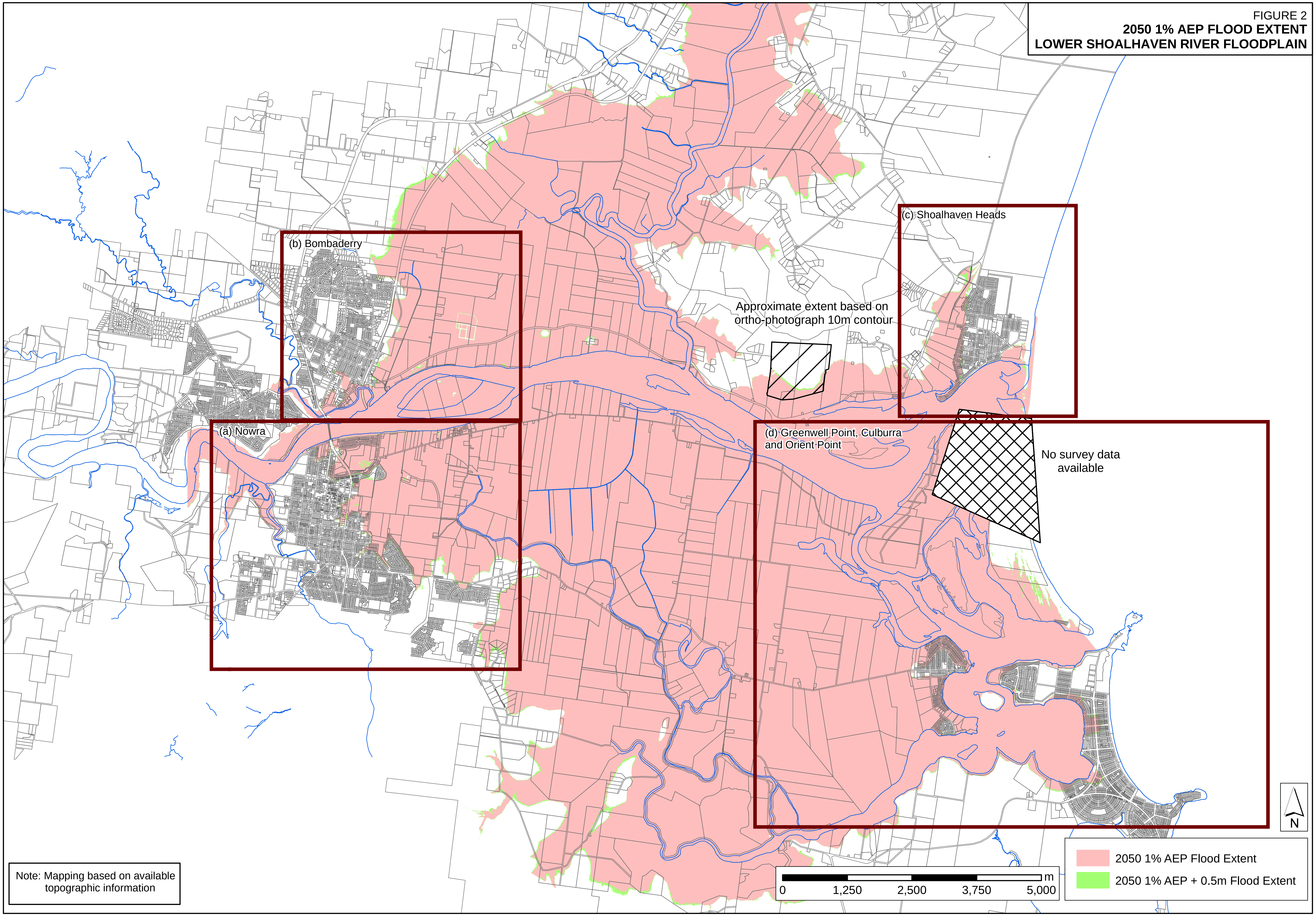


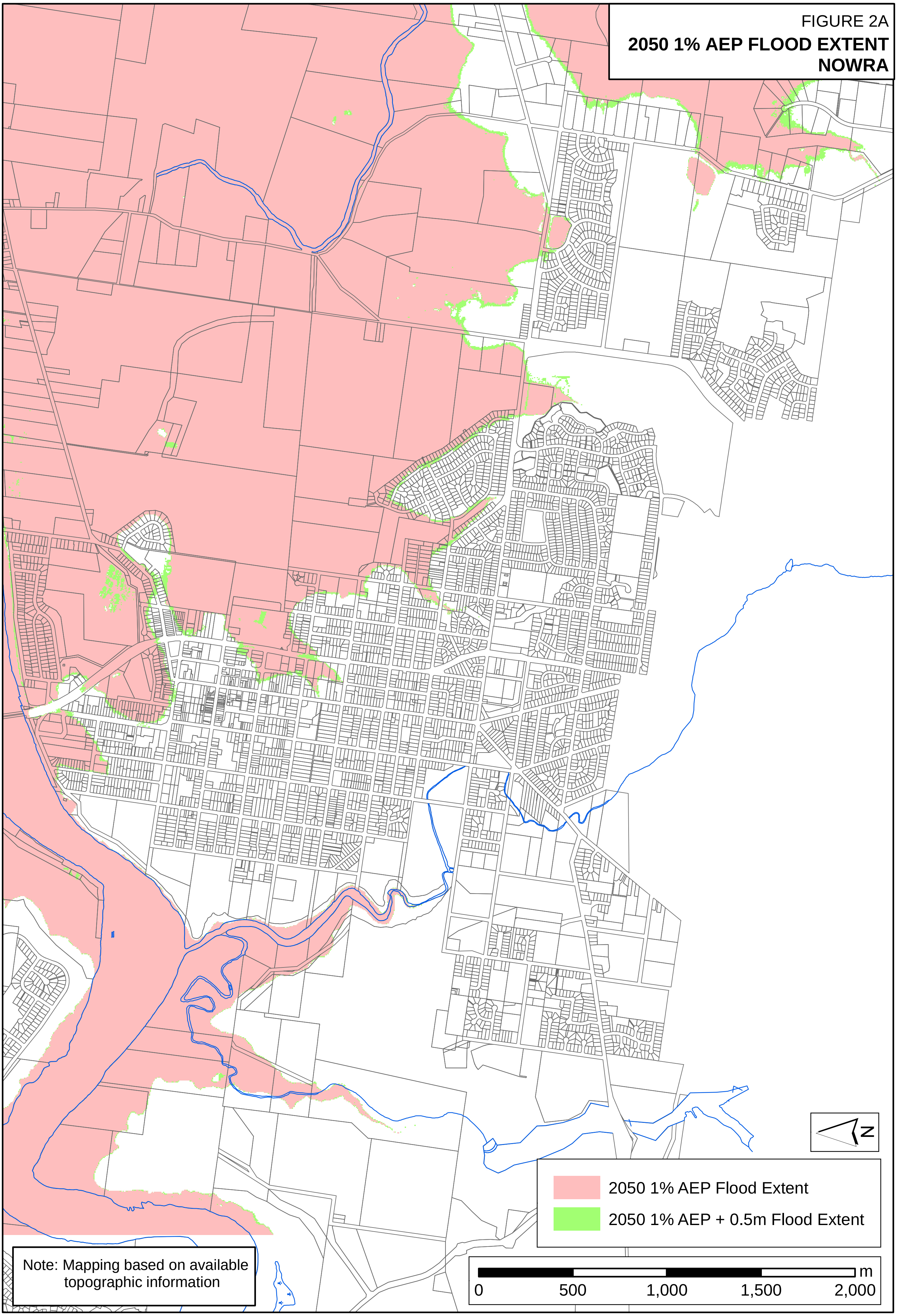
FIGURE 1
EXISTING 1% AEP FLOOD EXTENT
LOWER SHOALHAVEN RIVER FLOODPLAIN
Approximate extent based on ortho-photograph 10m contour
No survey data available
N
m
0
1,250
2,500
3,750
5,000
Existing 1% AEP Flood Extent
Note: Mapping based on available topographic information
J:\Jobs\110043\Arcview\ArcMaps\Figure01_FPL_Extent.mxd



J:\Jobs\110043\Arcview\ArcMaps\Figure02_2050_FPL_Extent.mxd

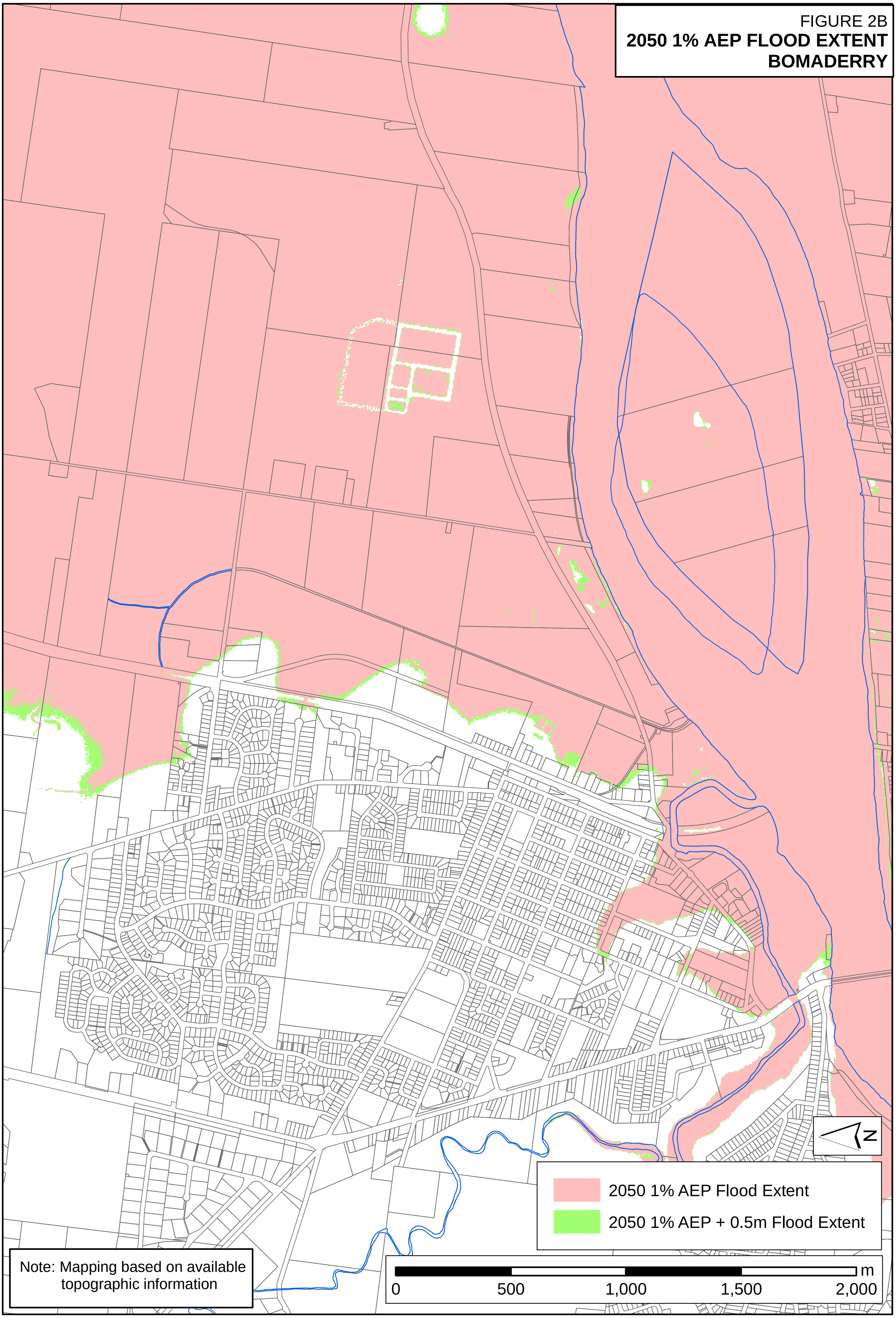
FIGURE 2A

2050 1% AEP FLOOD EXTENT NOWRA



Note: Mapping based on available topographic information

J:\Jobs\110043\Arcview\ArcMaps\Figure02a_2050_FPL_Extent_Nowra.mxd



J:\Jobs\110043\Arcview\ArcMaps\Figure02b_2050_FPL_Extent_Bomaderry.mxd

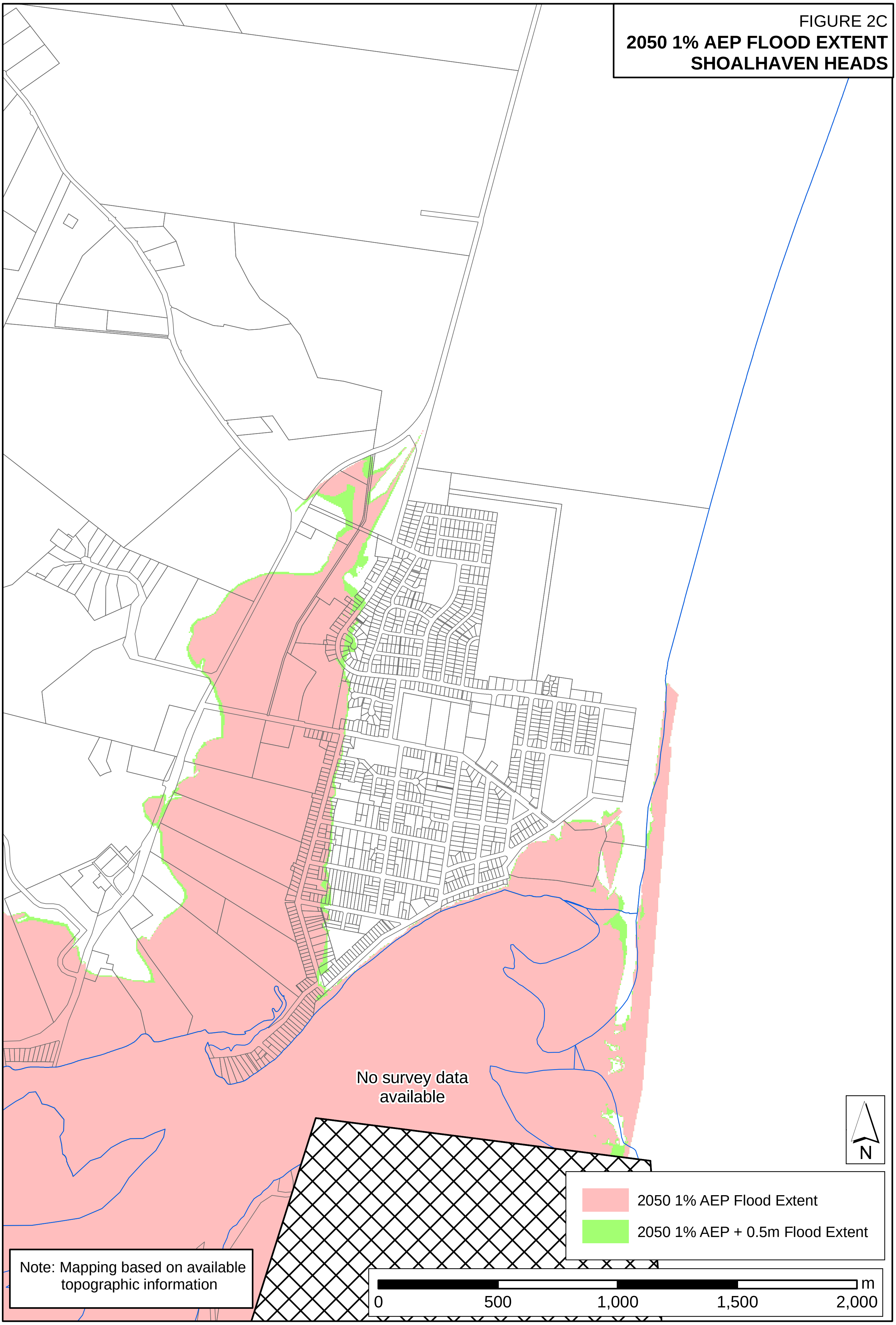


FIGURE 2C
2050 1% AEP FLOOD EXTENT SHOALHAVEN HEADS

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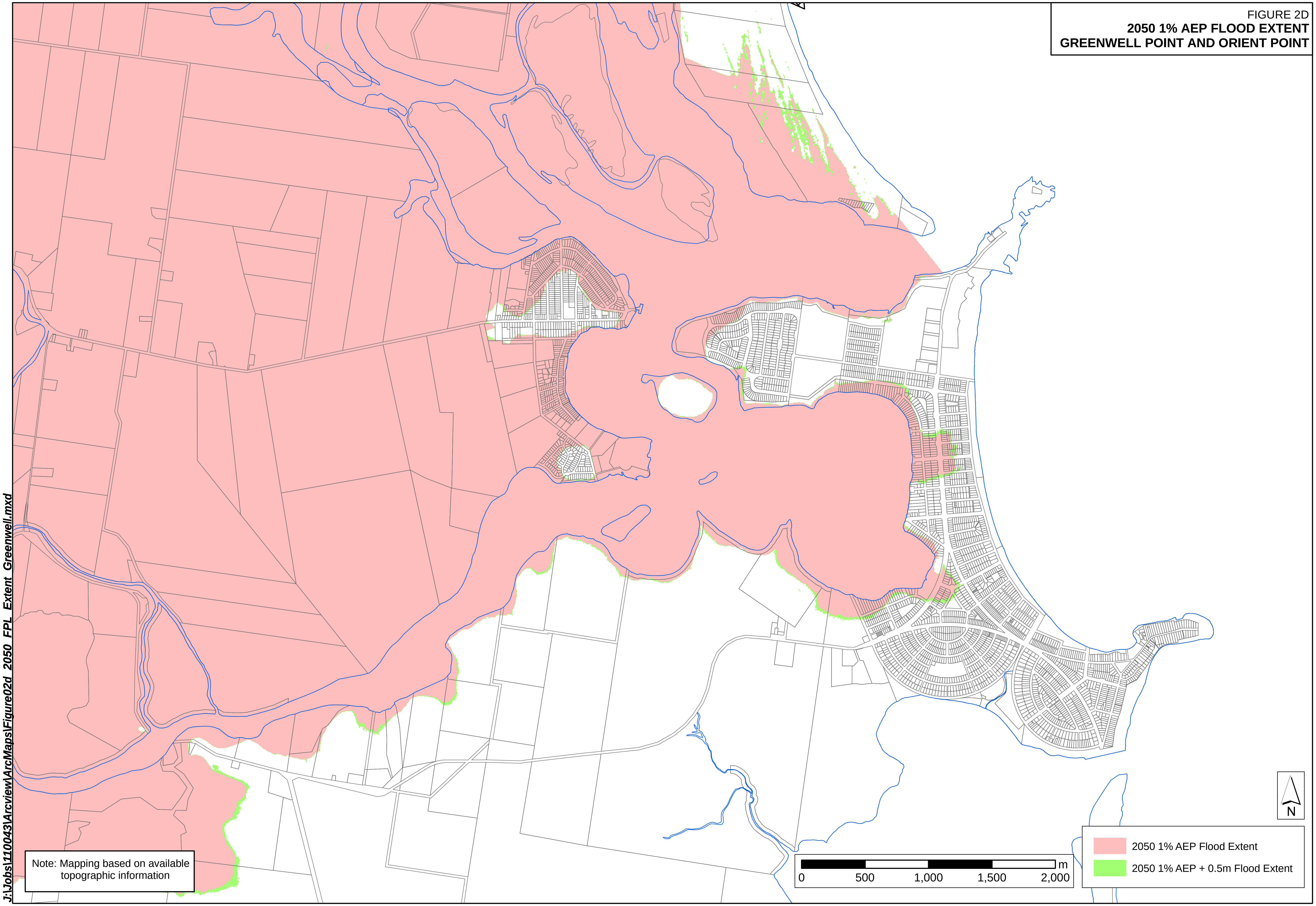
FIGURE 2D
2050 1% AEP FLOOD EXTENT
GREENWELL POINT AND ORIENT POINT



Note: Mapping based on available topographic information

J:\Jobs\110043\Arcview\ArcMaps\Figure02d_2050_FPL_Extent_Greenwell.mxd

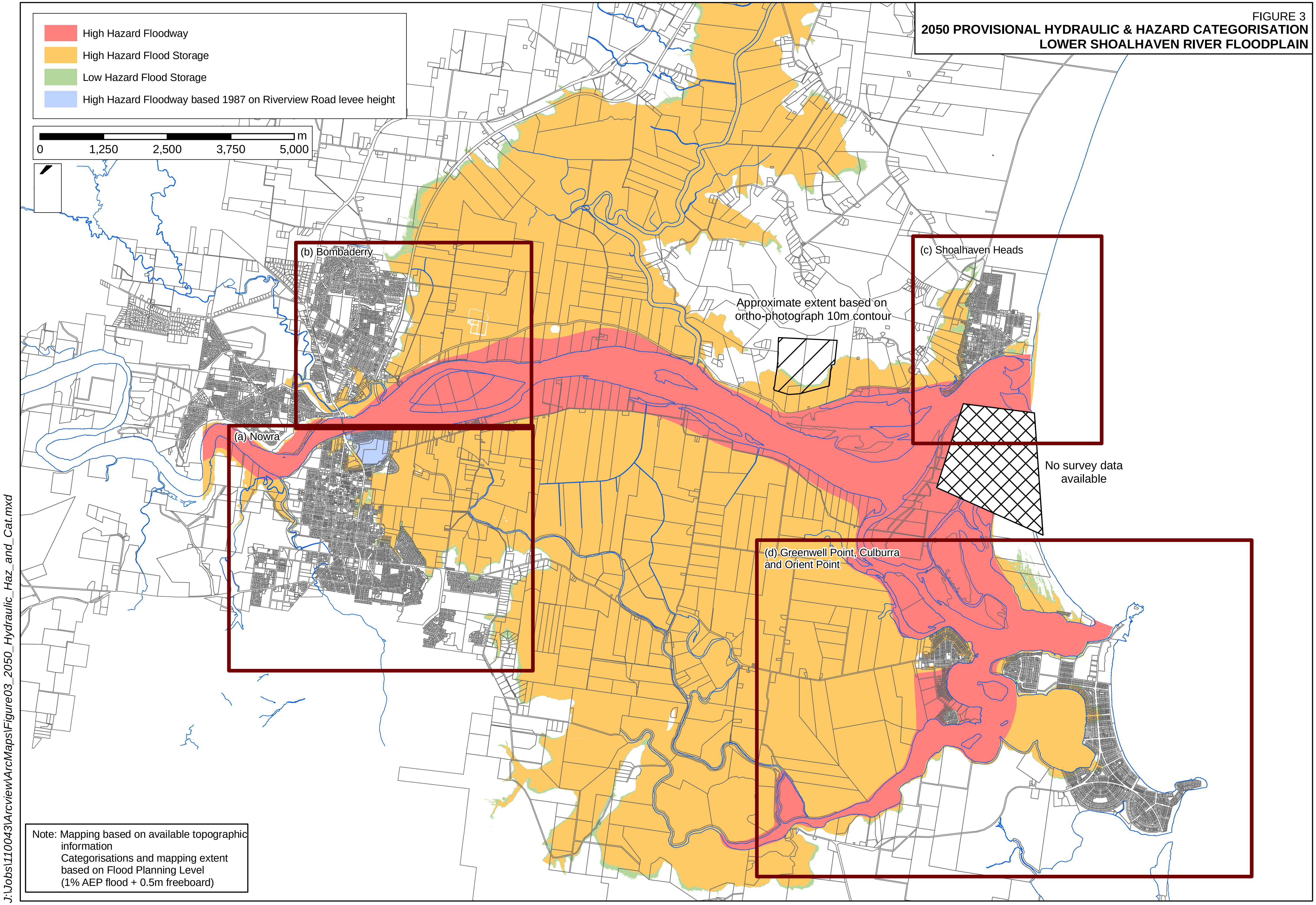
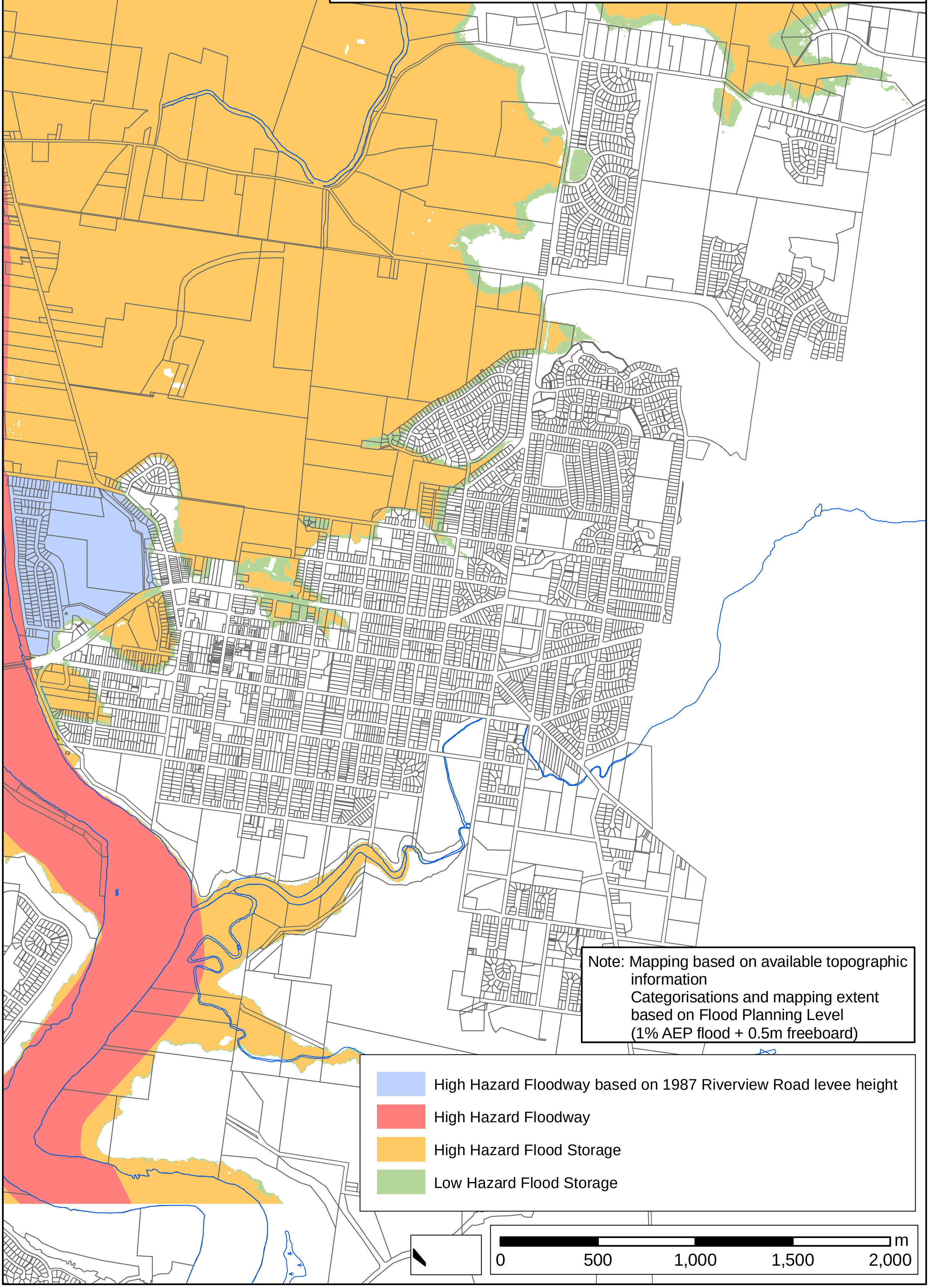


FIGURE 3
2050 PROVISIONAL HYDRAULIC & HAZARD CATEGORISATION
LOWER SHOALHAVEN RIVER FLOODPLAIN
High Hazard Floodway
High Hazard Flood Storage
Low Hazard Flood Storage
High Hazard Floodway based 1987 on Riverview Road levee height
0
1,250
2,500
3,750
5,000
m
(a) Nowra
(b) Bombaderry
(c) Shoalhaven Heads
(d) Greenwell Point, Culburra and Orient Point
Approximate extent based on ortho-photograph 10m contour
No survey data available
Note: Mapping based on available topographic information
Categorisations and mapping extent based on Flood Planning Level
(1% AEP flood + 0.5m freeboard)
J:\Jobs\110043\Arcview\ArcMaps\Figure03_2050_Hydraulic_Haz_and_Cat.mxd

FIGURE 3A

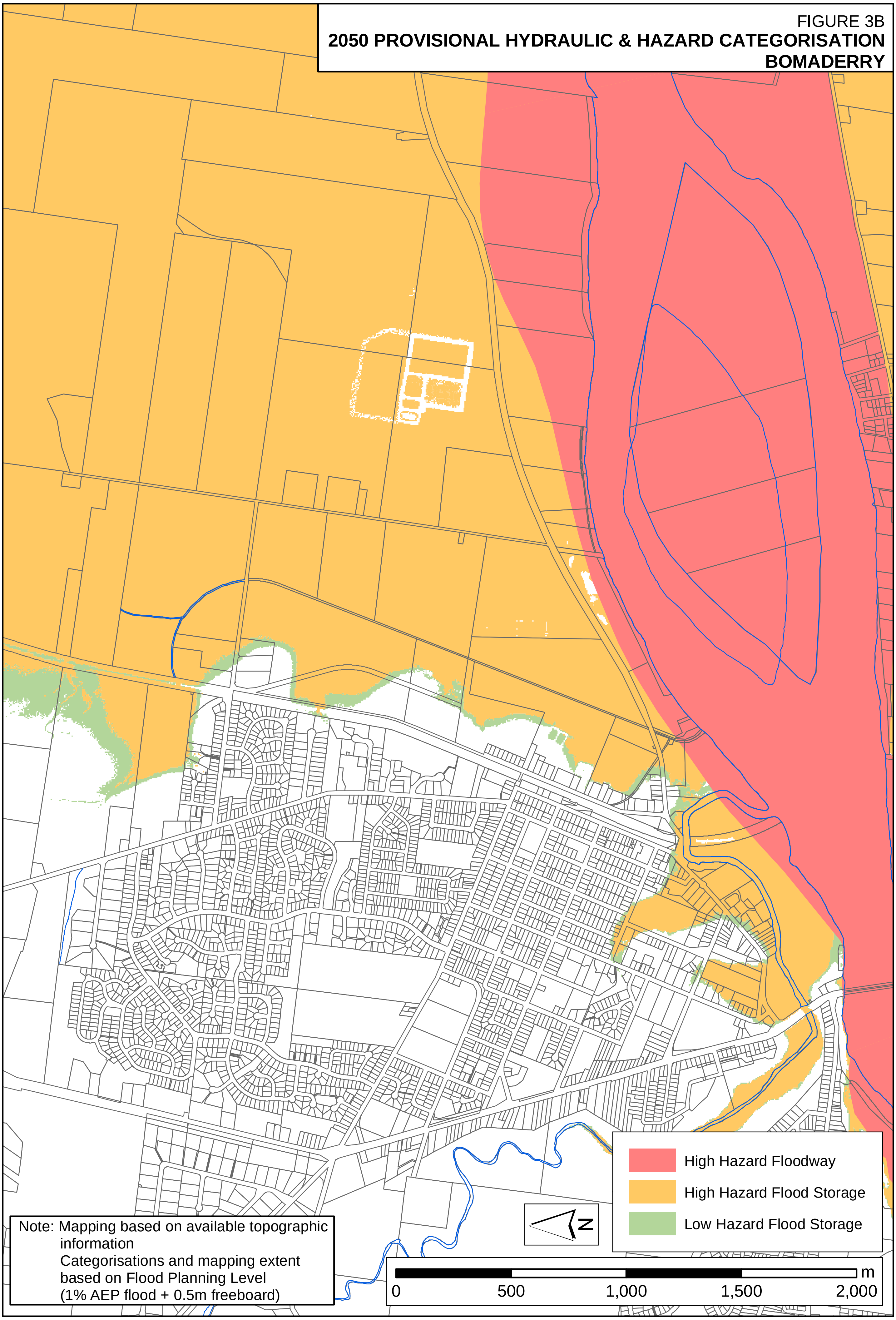
2050 PROVISIONAL HYDRAULIC & HAZARD CATEGORISATION NOWRA



J:\Jobs\110043\Arcview\ArcMaps\Figure03a_2050_HydHaz_Categorisation_Nowra.mxd

FIGURE 3B

2050 PROVISIONAL HYDRAULIC & HAZARD CATEGORISATION BOMADERRY



Note: Mapping based on available topographic information
Categorisations and mapping extent based on Flood Planning Level (1% AEP flood + 0.5m freeboard)

J:\Jobs\110043\Arcview\ArcMaps\Figure03b_2050_HydHaz_Categorisation_Bomaderry.mxd

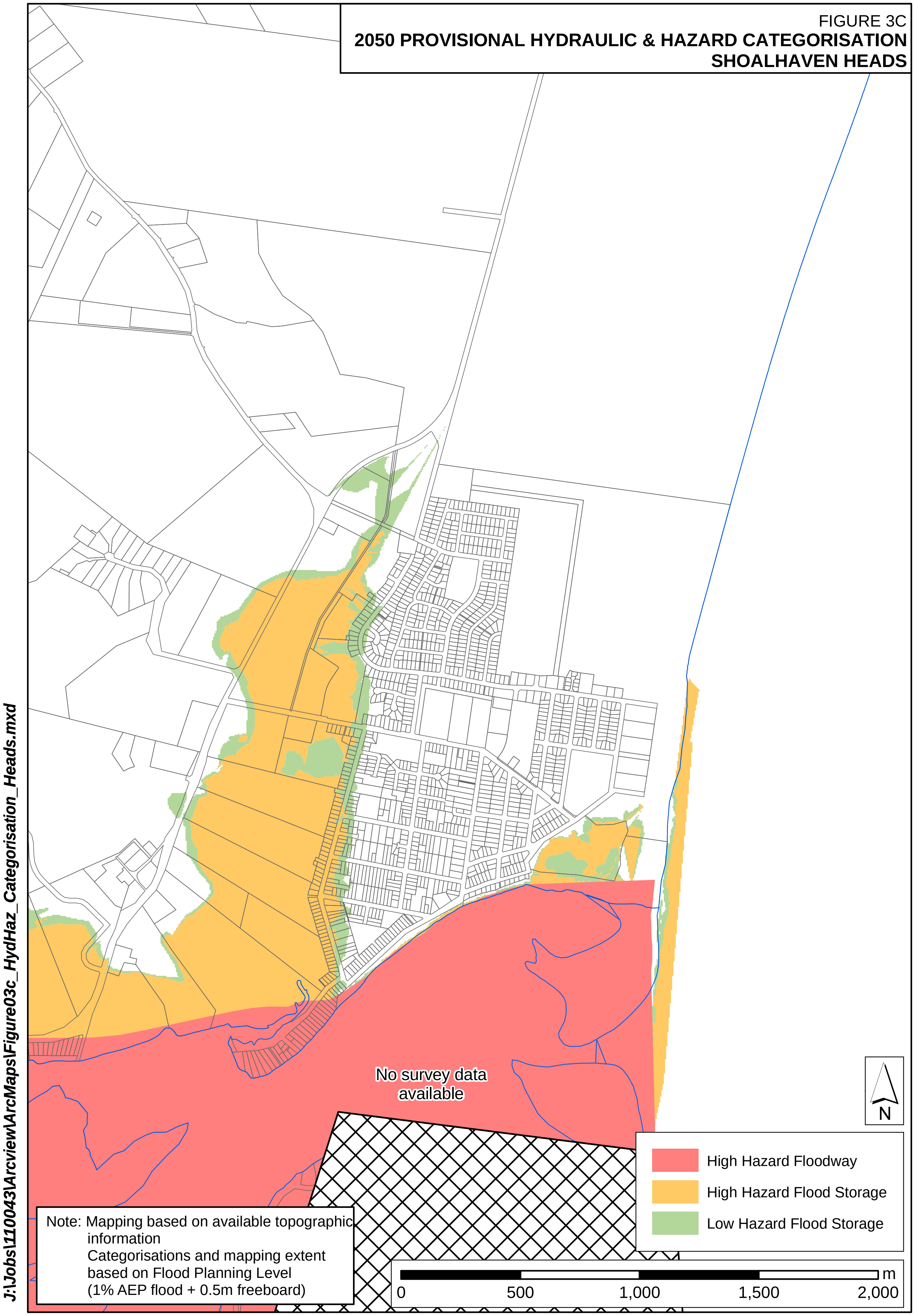


FIGURE 3C
2050 PROVISIONAL HYDRAULIC & HAZARD CATEGORISATION
SHOALHAVEN HEADS
No survey data available
High Hazard Floodway
High Hazard Flood Storage
Low Hazard Flood Storage
N
Note: Mapping based on available topographic information
Categorisations and mapping extent based on Flood Planning Level
(1% AEP flood + 0.5m freeboard)
0
500
1,000
1,500
2,000
m
J:\Jobs\110043\Arcview\ArcMaps\Figure03c_HydHaz_Categorisation_Heads.mxd

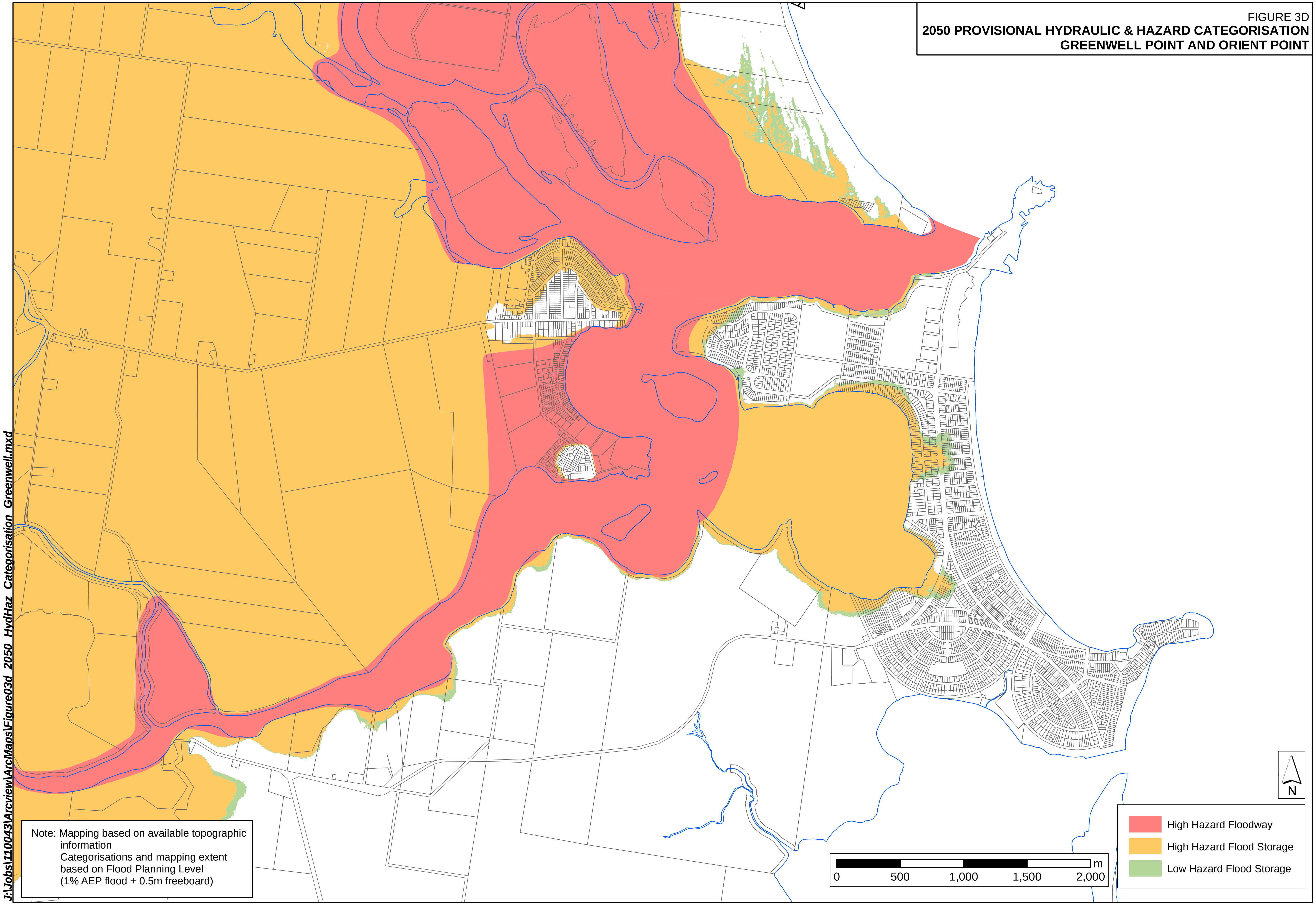


FIGURE 3D
2050 PROVISIONAL HYDRAULIC & HAZARD CATEGORISATION
GREENWELL POINT AND ORIENT POINT
High Hazard Floodway
High Hazard Flood Storage
Low Hazard Flood Storage
N
m
0
500
1,000
1,500
2,000
Note: Mapping based on available topographic information
Categorisations and mapping extent based on Flood Planning Level (1% AEP flood + 0.5m freeboard)
J:\Jobs\110043\Arcview\ArcMaps\Figure03d_2050_HydHaz_Categorisation_Greenwell.mxd

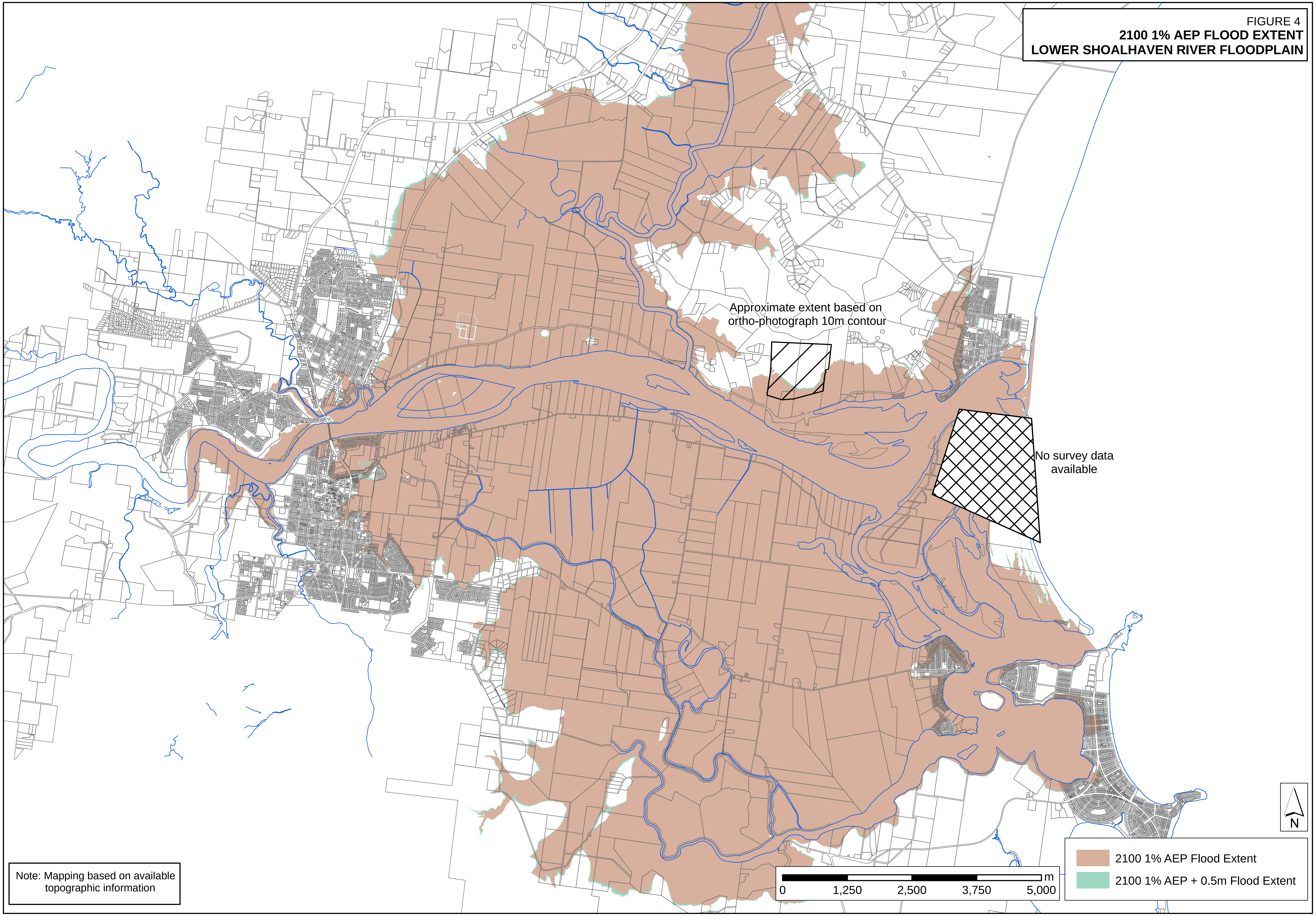
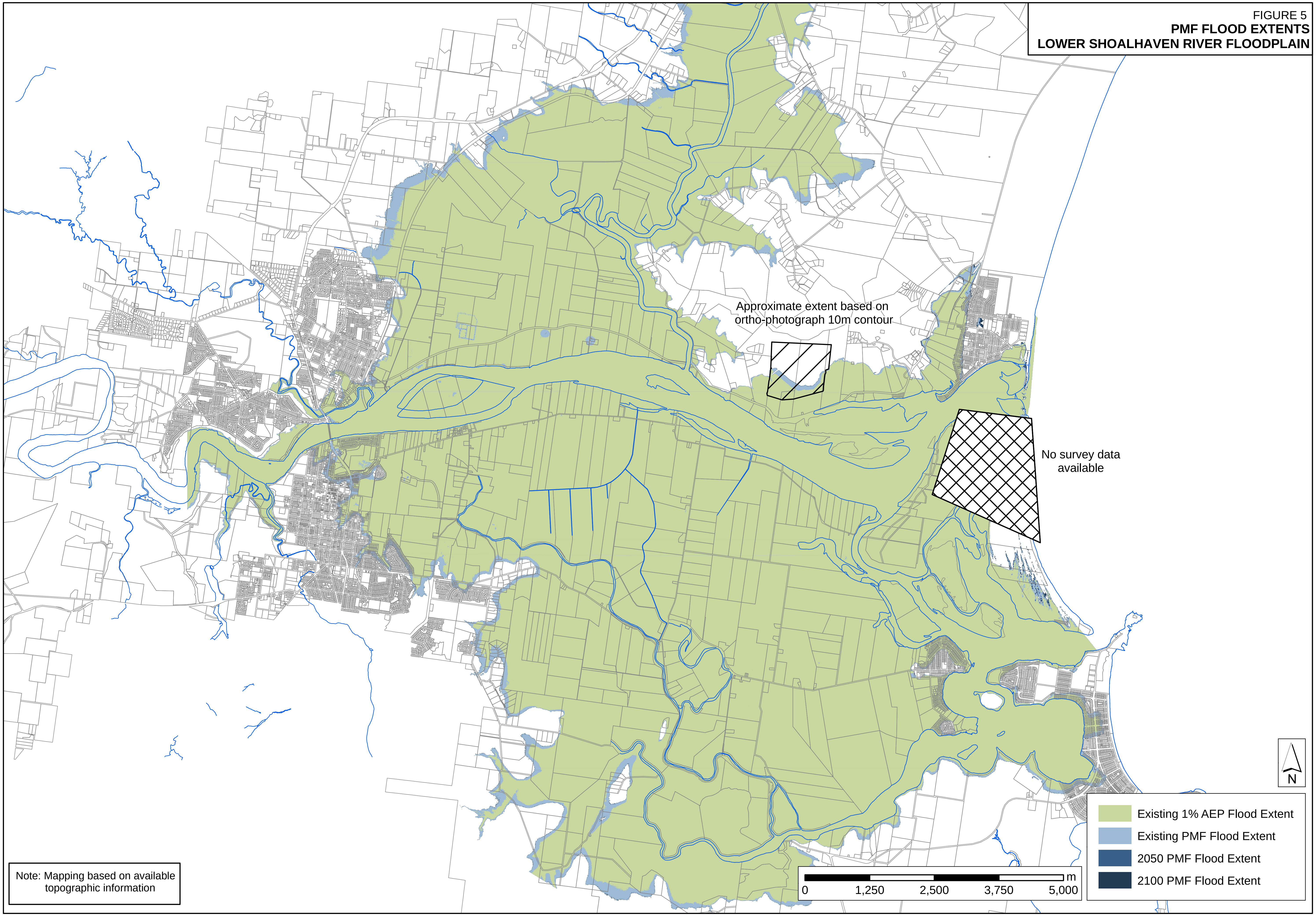


FIGURE 4

2100 1% AEP FLOOD EXTENT

LOWER SHOALHAVEN RIVER FLOODPLAIN

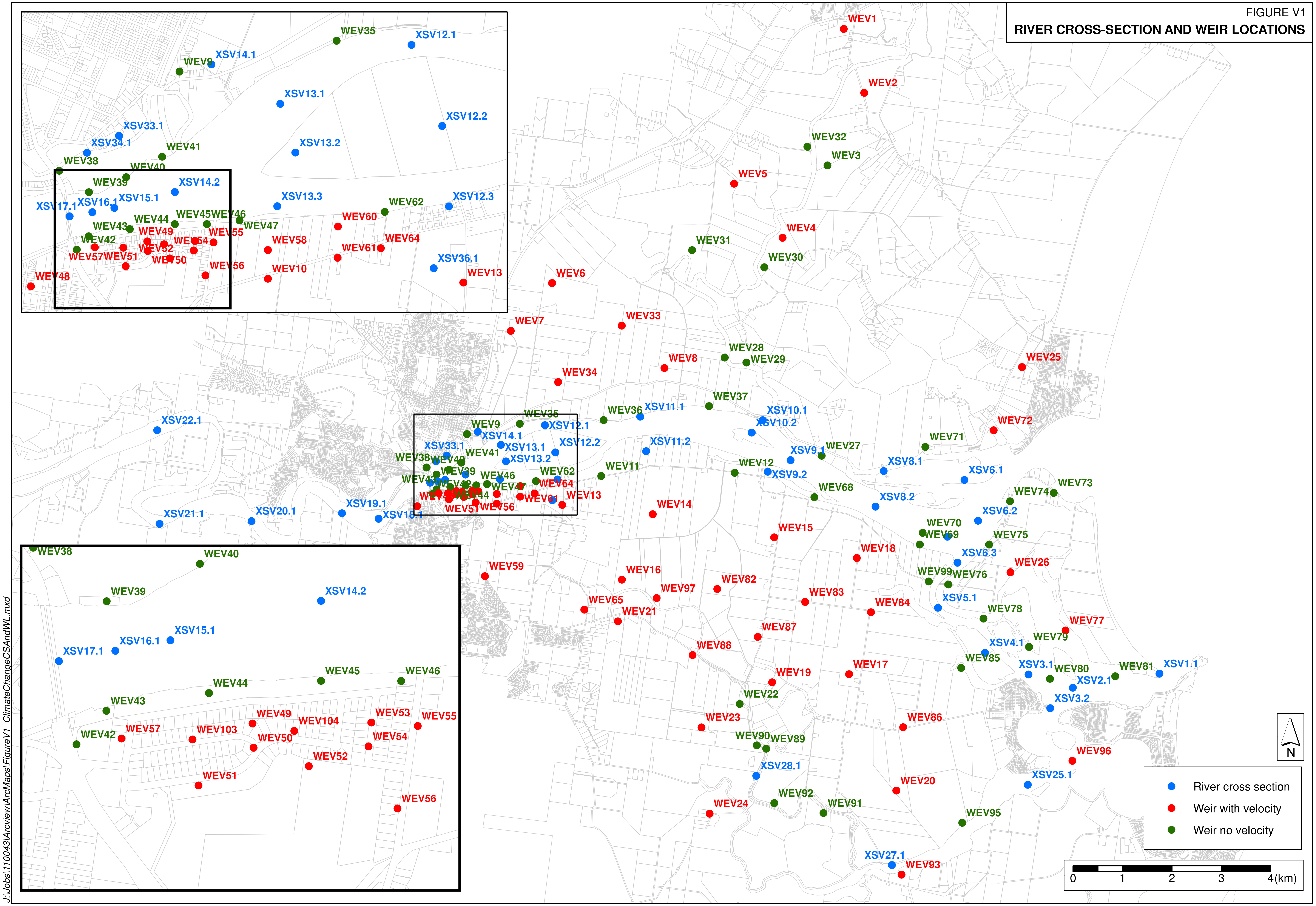
J:\Jobs\110043\Arcview\ArcMaps\Figure04_2100_FPL_Extent.mxd



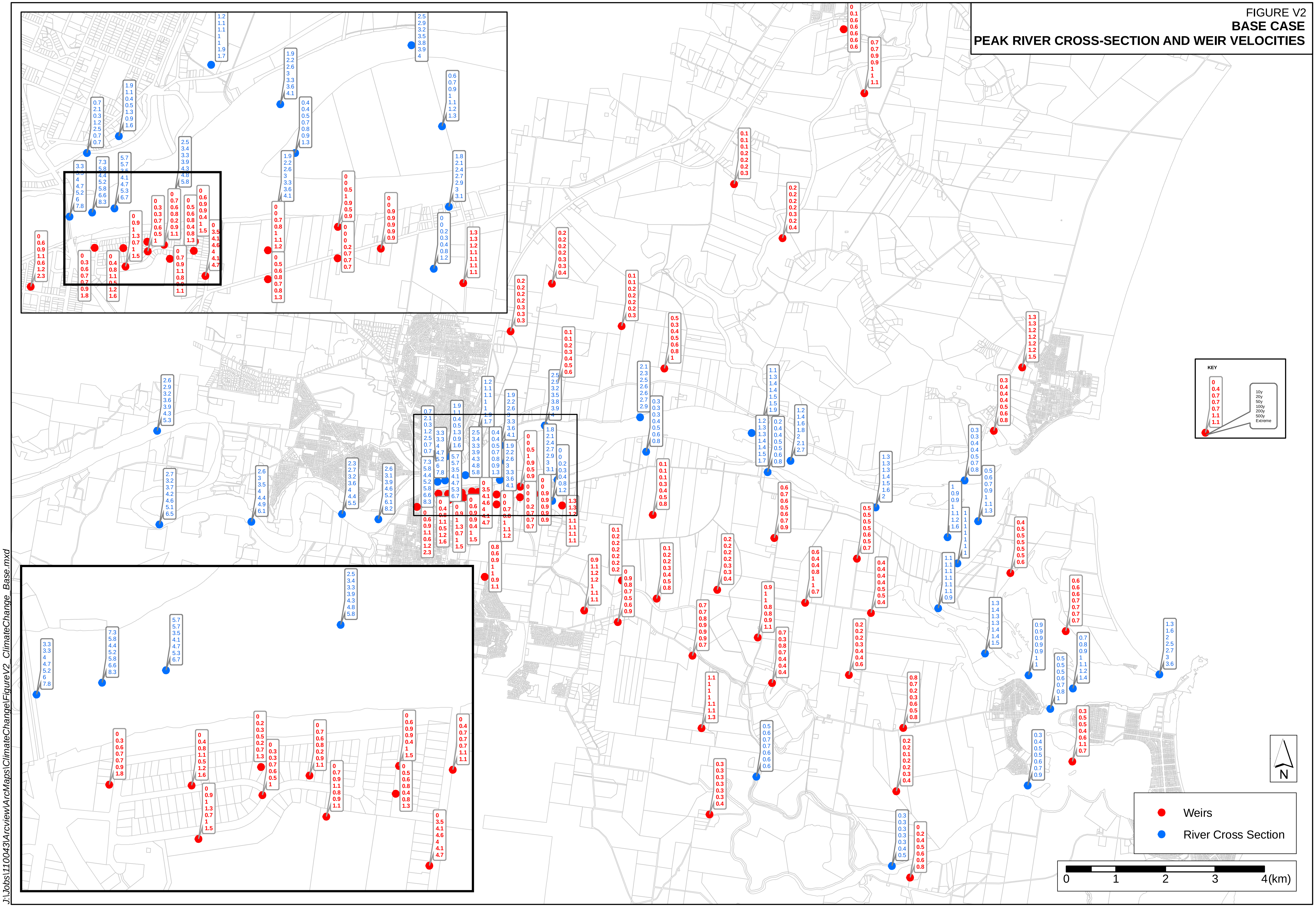
J:\Jobs\110043\Arcview\ArcMaps\Figure05_PMF_Extent.mxd

FIGURE V1

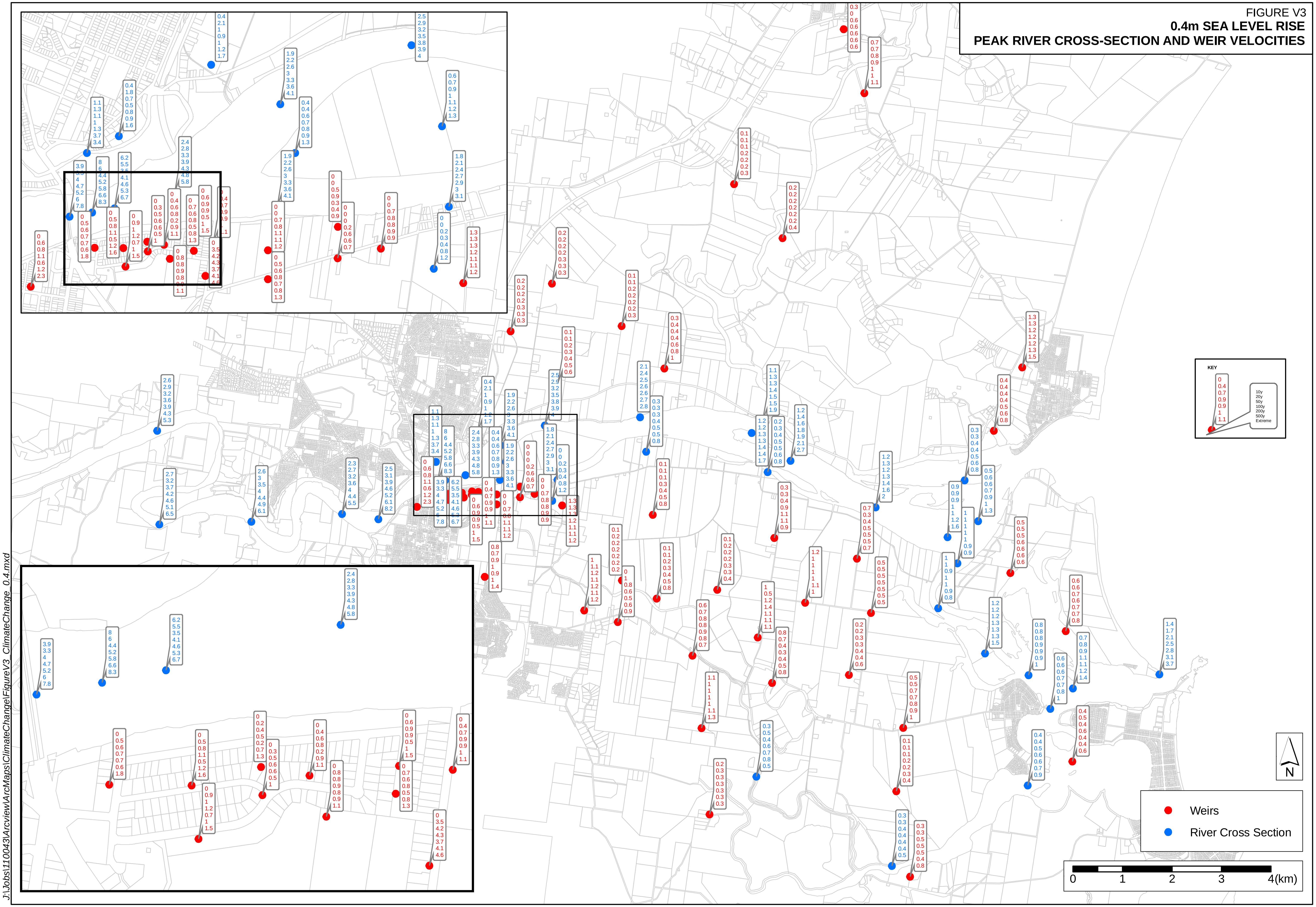
RIVER CROSS-SECTION AND WEIR LOCATIONS



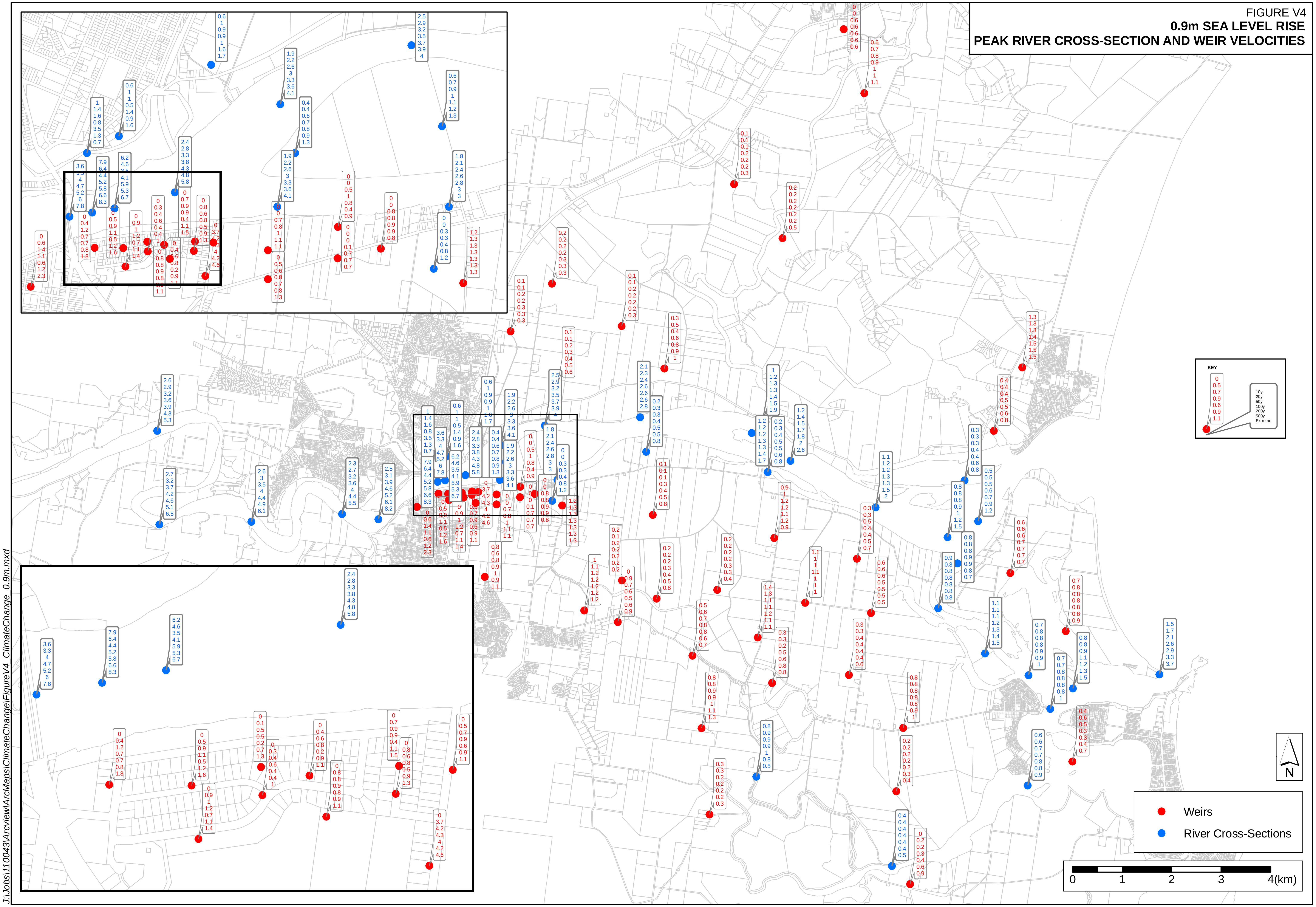
J:\Jobs\110043\Arcview\ArcMaps\FigureV1_ClimateChangeCSAndWL.mxd



J:\Jobs\110043\Arcview\ArcMaps\ClimateChange\FigureV2_ClimateChange_Base.mxd



J:\Jobs\110043\Arcview\ArcMaps\ClimateChange\FigureV3_ClimateChange_0.4.mxd



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