PATERSON RIVER FLOOD STUDY
VACY TO HINTON

FINAL REPORT

June 2017

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Project **Paterson River Flood Study**	**Project Number** **114084**
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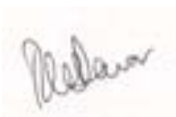
Date 19 June 2017	**Verified by** 

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AR&R	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CFERP	Community Flood Emergency Response Plan
DSC	Dungog Shire Council
DWR	Department of Water Resources
ERP	Emergency Response Classification
EY	Exceedances per Year
GEV	Generalised Extreme Value probability distribution
GSAM	General Southeast Australia Method
GSDM	Generalised Short Duration Method
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LiDAR	Light Detection and Ranging (also known as ALS)
LPI	Land and Property Information
LP3	Log Pearson III probability distribution
m	metre
MCC	Maitland City Council
MHL	Manly Hydraulics Laboratory
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
NOW	NSW Office of Water
OEH	Office of Environment and Heritage
PINNEENA	Database of water resources information
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PSC	Port Stephens Council
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
WBNM	Watershed Bounded Network Model (hydrologic computer model)
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

TERMINOLOGY USED IN REPORT

Australian Rainfall and Runoff have produced a set of draft guidelines for appropriate terminology when referring to the probability of floods. In the past, AEP has generally been used for those events with greater than 10% probability of occurring in any one year, and ARI used for events more frequent than this. However, the ARI terminology is to be replaced with a new term, EY.

Annual Exceedance Probability (AEP) is expressed using percentage probability. It expresses the probability that an event of a certain size or larger will occur in any one year, thus a 1% AEP event has a 1% chance of being equalled or exceeded in any one year. For events smaller than the 10% AEP event however, an annualised exceedance probability can be misleading, especially where strong seasonality is experienced. Consequently, events more frequent than the 10% AEP event are expressed as X Exceedances per Year (EY). Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month average recurrence interval where there is no seasonality, or an event that is likely to occur twice in one year.

While AEP has long been used for larger events, the use of EY is to replace the use of ARI, which has previously been used in smaller magnitude events. The use of ARI, the Average Recurrence Interval, which indicates the long term average number of years between events, is now discouraged. It can incorrectly lead people to believe that because a 100-year ARI (1% AEP) event occurred last year it will not happen for another 99 years. For example there are several instances of 1% AEP events occurring within a short period, for example the 1949 and 1950 events at Kempsey.

The PMF is a term also used in describing floods. This is the Probable Maximum Flood that is likely to occur. It is related to the PMP, the Probable Maximum Precipitation.

This report has adopted the approach of the ARR draft terminology guidelines and uses % AEP for all events greater than the 10% AEP and EY for all events smaller and more frequent than this.

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

1. Flood Study
- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management Study
- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

EXECUTIVE SUMMARY

BACKGROUND

The Paterson River catchment is located in the Hunter Valley, approximately 50 km west of Newcastle. The catchment lies within the Local Government Area (LGA) of Maitland City Council (MCC), Port Stephens Council (PSC) and Dungog Shire Council (DSC). The Paterson River has a total catchment area of approximately 1200 km^2. The area of interest for this study is the floodplain from Vacy (near of the confluence of the Paterson and Allyn Rivers) to the confluence with the Hunter River at Hinton. This portion of the catchment has an area of approximately 105 km^2.

The components of the study are to:

- collate available historical flood related data;
- analyse historical rainfall and flooding data;
- undertake a community consultation program;
- develop robust computational hydrologic and hydraulic models and calibrate them against multiple historical events;
- undertake a flood frequency analysis based on the historical record
- determine the flood behaviour including design flood levels, velocities and flood extents within the catchments;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increase in rainfall intensities
- to assess the floodplain categories in accordance with Council policy and undertake provisional hazard mapping; and
- to determine and map the flood planning area in accordance with the floodplain development manual

COMMUNITY CONSULTATION

In collaboration with Maitland City Council, Port Stephens Council and Dungog Council a questionnaire was distributed to residents in the study area. The purpose of the questionnaire was to identify what residents had experienced problems with flooding and to collate as much historical flood data as possible. From this, 175 responses were received. Of those that responded 90% are aware of flooding issues in the catchment, with 40 respondents having their properties affected by flooding with a further 7 properties flooded above floor level.

The questionnaire was distributed shortly before a major flood in April 2015. Subsequent to this flood, WMAwater personnel visited the catchment to collect flood observations, and spoke with community members about their flood observations. There is a relatively high level of flood awareness and preparedness generally in the Paterson Valley, as several major floods have occurred in the last ten years.

MODELLING SUMMARY

The study comprises two distinct modelling components:

- WBNM (Hydrologic) – The model was used to calculate the flow hydrographs for input into the TUFLOW model.
- TUFLOW (Hydraulic) – The 2D hydraulic model was used to assess the complex flow regimes of Paterson River and its tributaries and how these flows interact with the floodplain and levee system.

CALIBRATION

A joint calibration of the hydrologic and hydraulic model was chosen as the best approach for the study area for the following reasons:

- The only gauge with a rating curve inside the study area is Gostwyck PINNEENA (210079). This is the only gauge that the hydrologic model could be calibrated to inside the study area. The highest recent gauging was 10.53m recorded in March 2000. All the historical events that have been used for calibration have recorded stage heights greater than 10.53m. Therefore there is little confidence in the rating curve beyond this point.
- The Allyn River Flying Fox Lane (210043) gauge has only one gauging above 1.5m therefore the rating curve can't be confidently applied for calibration of flows.
- The Paterson River Lostock Dam (210021) gauge and the Allyn River Halton (210022) gauge are located approximately 25 km upstream of the Hydraulic model boundary. This distance was considered too great for an independent hydrologic model calibration.
- There are five gauges inside the study area that record water levels that the hydraulic model can be calibrated to. The only calibration event that does not have records for all five gauges is March 1978 which only has records for Gostwyck PINNEENA - 210079.

The approach to model calibration was to adjust the rainfall loss parameters and the stream routing parameter in the WBNM (hydrologic) model and adjust the Manning's 'n' roughness values in the TUFLOW hydraulic model. Multiple combinations of these parameters were investigated until the best fit to the recorded water levels in the study area could be achieved across the whole range of calibration events.

For most events, the adopted rainfall depths and temporal patterns were found to have the most influence on the calibration results. The levels obtained at the gauges were more sensitive to the rainfall assumptions than to the other model parameters available for tuning the model calibration. This indicates that it is unreasonable to try and obtain a perfect fit in the model calibration results, since the available rainfall data is inherently unable to reflect the true spatial and temporal rainfall distribution across the catchment for the floods investigated.

The models were calibrated to the March 1978, March 2001, June 2007, June 2001, March 2013, November 2013 and April 2015 events. The model produced a good match to the recorded historical flood behaviour.

DESIGN FLOOD ESTIMATION

Two approaches were investigated to determine design flood magnitude. Flood Frequency Analysis and design rainfall modelling were both undertaken with similar results for peak flow at key gauges. The design rainfall approach was adopted as it provides a more holistic result for the entire study area, especially in regard to flood mapping of the Paterson River floodplains and tributaries.

The study included modelling of the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF design flood events, with mapping provided for peak flood depths and levels, peak velocities, hydraulic hazard and hydraulic categories.

KEY OUTCOMES

The study has quantified flood behaviour in the study area and the modelling tools that have been developed will assist Maitland City Council, Port Stephens Council and Dungog Council to undertake flood related planning decisions for future and existing development. A summary of key outcomes is as follows:

- The April 2015 flood event was equivalent to between a 2% and 1% AEP event in the study area;
- Vacy Bridge is above the 1% AEP flood level but overtopped in the 0.5% AEP event;
- Gostwyck Bridge is above the 0.5% AEP level but overtopped in the 0.2% AEP event;
- Paterson Road Bridge is above the 0.5% AEP level but overtopped in the 0.2% AEP event;
- Webbers Creek Bridge is above the 10% AEP level but overtopped in the 5% AEP event;
- Dunmore Bridge is above the 0.2% AEP level;
- The Horns Crossing causeway on the Allyn River is impassable in all events modelled.
- Major roads throughout the catchment are cut in events beginning at the 20% AEP event. This has implications for emergency response planning as well as planning future development in the catchment;
- The primary damages resulting from flooding in the study area are likely to be infrastructure damage to roads, bridges and railway lines, damages to agricultural equipment (farm machinery, structures, fences, etc.), and loss of crops and livestock;
- Existing residential and commercial buildings are generally at a low risk from flooding.
- This flood study will provide planning tools for Council to mitigate flood risk to future development in the catchment.

The outcomes relating to road closures are expected to be mainly of interest to the SES in formulating flood response procedures.

Note that the results presented in this study are for Paterson River flooding, in combination with smaller coincident Hunter River flood events. In the lower Paterson River floodplain, the Hunter River design flood levels (from Reference 5) are often the critical level for flood planning and development control purposes. The results from both studies should be considered for floodplain management decision-making.

For areas downstream of Dunmore Bridge the 1% AEP flood levels from the Hunter River Flood Study (Reference 5) are to be used for developmental purposes.

PUBLIC EXHIBITION

A draft of this study was placed on public exhibition to invite feedback from the community. From the month long public exhibition period, two public submissions were received, which are attached in Appendix E. The submissions related to levee modification works undertaken by OEH on the Wallalong levee in early 2016.

In response to the public submissions received WMAwater notes the following:

- The modelling completed for this study does not include the levee modification works carried out in early 2016. The levee topography utilised in the study is based on pre-modification levels from aerial survey collected in 2012 and 2013. The results and mapping outputs reflect pre-modification conditions.
- A separate modelling analysis undertaken for OEH quantified the changes to peak flood levels resulting from the levee modifications, for both Hunter River flooding and Paterson River flooding (attached in Appendix E).
- OEH is currently investigating further modifications to the levee with the intention of minimising the changes in flood behaviour compared to pre-modification conditions (as mapped for this study). WMAwater understands this process will involve community consultation.

RECOMMENDATIONS

It is recommended that following the conclusion and adoption of the Paterson River Flood Study; combined flood level and DCP mapping be developed utilising results from the Paterson River Flood Study and the Hunter River Flood Study (Reference 5). The DCP mapping can be tailored to meet each Council's individual needs or developed after a consultation process with all stakeholders.

1. INTRODUCTION

1.1. Background

The Paterson River is located within the Hunter Valley of NSW, approximately 50 km north-west of Newcastle. The catchment lies within the Local Government Area (LGA) of Maitland City Council (MCC), Port Stephens Council (PSC) and Dungog Shire Council (DSC). The Paterson River has a total catchment area of approximately 1200 km^2 and is shown in Figure 1. The area of interest for this study is the floodplain from Vacy (near of the confluence of the Paterson and Allyn Rivers) to the confluence with the Hunter River at Hinton. This portion of the catchment has an area of approximately 105 km^2 and is shown in Figure 2.

1.2. Objectives

The primary objective of this Flood Study is to develop a robust hydrologic and hydraulic modelling system that defines flood behaviour for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and the Probable Maximum Flood design events on the Paterson River. This will be used to assist MCC, PSC and DSC in determining existing flood risk, peak flood levels and inundation extents within the study area. The system may subsequently be used within a Floodplain Risk Management Study and Plan to assess the effectiveness and suitability of potential flood risk mitigation measures.

This Flood Study includes:

- a description of the study area;
- a summary of available historical flood-related data;
- analysis of rainfall and river level data;
- outcomes of the community consultation program
- identification of suitable historical events for calibration and verification;
- the modelling methodology adopted
- description of the hydrological and hydraulic model set up;
- the calibration methodology and results.
- flood frequency analysis methodology and results
- design flood event results
- sensitivity analysis including climate change

2. BACKGROUND

2.1. Study Area

The Paterson River and its main tributary the Allyn River are significant features of the Hunter Valley. The river systems course through the fertile farming land of the Paterson and Allyn River Valleys. The Paterson and Allyn Rivers originate as mountainous streams in the Barrington Tops National Park and flow parallel in a general southerly direction until their confluence near Vacy. The Paterson River continues south through the rich Paterson Plains until its confluence with the Hunter River at Hinton.

The catchment has been mainly cleared for agriculture, but pockets of forest remain especially in the upper reaches of the catchment near Barrington Tops. The gradient of the Paterson River is quite steep with limited floodplain until it reaches the township of Paterson. Intermittent floodplain areas begin to form south of the town of Paterson but they are still separated by ridges and topographic features which influence overbank flood conveyance. At a point approximately 4km upstream of the town of Woodville the floodplain widens significantly, and the floodplain is relatively broad through to the confluence with the Hunter River.

A major levee system was constructed in the 1960s and 1970s by the Department of Public Works. The levee system is built on the major floodplains, beginning at the township of Tocal and continuing to the confluence of the Hunter River where it meets the Hunter River levee system. The levee system has a considerable influence on flood behaviour especially in smaller events, which are contained within the river by the levee system.

2.2. Historical Flooding

2.2.1. Flood Mechanisms

Flooding in the Paterson Valley is influenced by two flood mechanisms:

1. Paterson River Flooding – Flooding on the Paterson River can occur due to heavy rainfall over the Paterson and Allyn River catchments. This mechanism influences flooding the entire length of the Paterson Valley
2. Hunter River Flooding – Flooding on the Hunter River can be caused by rainfall over the broader Hunter River and Goulburn River catchments. This mechanism influences flooding on the lower reaches and floodplains of the Paterson River.

Flooding on the Paterson and Hunter Rivers can occur independently of one another or concurrently. Concurrent flooding has a significant influence on flood levels on the lower reaches of the Paterson River and floodplains.

2.2.1. Historical Events

The Paterson River has flooded historically on a regular basis with 16 floods above the "major" flood level classification since 1929. The flood classifications for the Paterson River at Gostwyck Bridge and Paterson Bridge as well as the Hunter River at Belmore Bridge are shown in Table 1. A summary of recorded major historical floods for the Paterson River is listed in Table 2 along with their recorded stage heights and classification for both the Paterson and Hunter Rivers.

Table 1 – BOM Flood Classifications

Station	Flood Classifications (Gauge Readings)		
	Minor	Moderate	Major
Paterson River Gostwyck	9.1	10.7	12.2
Paterson River Railway Bridge	6.1	7.6	9.1
Hunter River Belmore Bridge	5.9	8.9	10.5

Table 2 – Historical Flood Events

Event	Paterson River Gostwyck Bridge mAHD	Classification	Hunter River Belmore Bridge mAHD	Classification
1929	13.9	Major	8.5	Minor
1930	13.6	Major	11.2	Major
1946	14.3	Major	9.3	Moderate
1955	13.7	Major	12.1	Major
1963	14.5	Major	8.0	Minor
1967	14.1	Major	8.7	Minor
1972	13.6	Moderate	8.9	Moderate
1977	13.1	Major	10.8	Major
1978	15.5	Major	9.6	Moderate
1985	15.2	Major	9.3	Moderate
1990	14.7	Major	8.8	Minor
1995	10.3	Minor	2.6	Below Minor
2001	13.5	Major	7.2	Minor
2007	13.6	Major	10.7	Major
2011	13.9	Major	7.2	Minor
Mar 2013	12.9	Major	8.2	Minor
Nov 2013	12.0	Moderate	4.8	Below Minor
Apr 2015	16.1	Major	8.9	Moderate

3. AVAILABLE DATA

3.1. Topographic Data

Light Detection and Ranging (LiDAR) survey of the study area and its immediate surroundings was provided for the study by LPI (see Figure 3). LiDAR is aerial survey data that provides a detailed topographic representation of the ground with a survey mark approximately every square metre. The data for the Maitland area was collected in 2012 and the Raymond Terrace area in 2013. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The accuracy is typically ± 0.15 m for clear terrain. The accuracy within creek channels is typically much less, and the LiDAR must be supplemented with detail survey and bathymetric survey.

3.2. Bathymetric Survey

OEH provided detailed bathymetric survey of the tidal portions of the Paterson River and Hunter River. The Paterson River survey begins 5km upstream of Dunmore Bridge at Woodville and concludes at the confluence with the Hunter River. The Hunter River survey begins in between Oakhampton Railway Bridge and Belmore Bridge and concludes outside the study area at Hexham Bridge. The survey locations are shown in Figure 3.

The survey was undertaken in 2013 and river cross sections can vary over time especially after large flood event were erosion and sediment deposits can alter bathymetry. It should be noted that a change in river cross sections will generally have more influence in a smaller events, and will have less influence in the 1% AEP or similar events when 50% or more of the flow is in the overbank areas.

3.3. Levee Survey

OEH provided detailed survey of the Paterson River levee system. The levee survey begins at Tocal and continues through to the confluence with the Hunter River.

3.4. Flood Level Survey

In April 2015, after the study was already underway, there was a major flood on the Paterson River. The storm event of April 2015 affected much of the east coast of New South Wales, particularly along the coast from the Illawarra region to the Hunter Valley, causing widespread flooding and other storm damage.

WMAwater personnel undertook post-flood data collection in the Hunter Valley from Tuesday 28th April to Friday 1st May, approximately one week after the peak of the flooding. The focus was to collect photographs and flood marks that could be used for model calibration as part of the study. WMAwater personnel spoke with several residents about their observations of the flood behaviour.

The Paterson River flood marks identified during the data collection exercise were surveyed on 23 October 2015 by surveyors from MCC, to obtain accurate flood levels. The location of the flood levels obtained from the survey are shown on Figure 3, and a comparison with modelled flood levels is provided in Section 8.

3.5. Stream Gauges

In order to calibrate hydrologic and hydraulic models, water level recorders (stream gauges) are required in a river. For this study nine gauges are located in or adjacent to the study area and are listed in Table 3 with their locations shown in Figure 4.

Table 3 – Stream Gauges

Station No	Station Name	Opened	Closed
210022	AR - Halton	Dec-40	Current
210143	AR - Flying Fox Lane	May-06	Current
210021	PR - D/S Lostock Dam	Nov-40	Current
210102	PR - Lostock Dam (Storage)	Feb-71	Current
210079	PR - Gostwyck PINNEENA	May-28	Current
210402	PR - Gostwyck MHL	Oct-88	Current
210406	PR - Paterson Railway Bridge	Dec-84	Current
210409	PR - Dunmore	Nov-84	Current
210410	PR - Hinton Bridge	Mar-85	Current
210430	HR - Morpeth	Apr-85	Current
210432	HR - Green Rocks	Dec-84	Current
210455	HR - McKimms Corner	Mar-86	Current
210458	HR - Belmore Bridge	Jun-92	Current
210475	HR - Oakhampton Bridge	Dec-95	Current

The flow corresponding to a given water level is estimated from a rating curve which provides a relationship between the water level and flow at each gauge. This relationship is derived from velocity measurements (using a current meter) at a known water level and cross sectional water area (obtained by survey). Many of these velocity readings are taken over a period of years at different water levels (termed gaugings) and in this way a rating curve is developed as a "line of best fit" between the gaugings. For the region above the highest gauging measurement the rating curve must be extrapolated, and this portion of the curve is often subject to significant uncertainty and inaccuracy.

Four gauges in the Paterson River catchment controlled by the Office of Water from the Department of Primary Industries have available rating curves. The gauges are:

- 210022 – Allyn River Halton
- 210143 – Allyn River Flying Fox Lane
- 210021 – Paterson River D/S Lostock Dam
- 210079 – Paterson River Gostwyck

The rating curves and the recorded gaugings are shown in Figure 5 to Figure 8.

It is relatively easy to obtain “low flow” gaugings as small rises in water levels occur frequently and the gauging party has therefore ample opportunity to undertake them. It is much harder to obtain “high flow” gaugings as they can only be obtained during large floods (which occur infrequently) and it may be that the gauging party cannot get access to the site or are otherwise engaged. Safe access to the site can also be an issue. Thus all rating curves generally have few “high flow” gaugings, and there is considerable uncertainty about the flow estimates at high water levels. A graph of the gaugings indicates how many “high flow” gaugings were undertaken and the height at which they were taken, and from this an estimate of the accuracy of the high flows can be made. Generally there are few gaugings taken at the peak of a flood and thus the highest gaugings may be several metres below the highest recorded flood levels, and the rating curve must be extrapolated.

3.5.1. Analysis of Stream Gauge Records

The stream gauge records were analysed for the ten significant historical events. The recorded peak stage heights for each event are shown in Table 4 and the stage hydrographs are shown in Figure 9 to Figure 19.

Table 4 – Peak Stage Heights (m)

Station Name	Mar77	Mar78	Oct85	Feb90	Mar95	Mar01	Jun07	Jun11	Mar13	Nov13	Apr15
AR - Halton 210022	5.94	6.73	3.96	6.57	4.49	4.53	5.37	5.03	5.62	2.57	4.66
AR – Flying Fox Lane 210143	-	-	-	-	-	-	7.78	11.69	10.29	10.47	-
PR – Lostock Dam 210021	4.06	-	3.96	5.16	3.51	4.52	4.12	4.64	4.51	0.89	3.37
PR - Gostwyck 210079	12.99	14.37	13.60	13.37	9.13	12.16	12.57	13.12	11.70	11.05	15.50
PR - Gostwyck 210402	-	-		14.7	10.33	13.49	13.64	13.93	12.85	12.02	16.12
PR - Paterson Railway Bridge 210406	-	-	11.17	11.12	7.19	10.42	10.16	10.35	9.66	8.43	11.99
PR - Dunmore 210409	-	-	-	6.43	4.05	6.48	6.36	6.32	6.34	5.03	6.06
PR - Hinton Bridge 210410	-	-	-	5.67	2.57	5.44	5.78	5.35	5.49	3.77	5.76
HR - Morpeth 210430	-	-	-	6.12	2.49	5.64	6.52	5.52	5.7	3.75	6.11
HR - Green Rocks 210432	-	-	3.86	-	1.81	4	3.98	3.93	4.07	3.75	4.37
HR - McKimms Corner 210455	-	-	-	7.4	2.5	6.23	8.22	6.19	6.84	4.04	7.33
HR - Belmore Bridge 210458	-	-	-	-	2.63	7.22	10.47	7.23	8.18	4.83	8.92
HR - Oakhampton 210475	-	-	-	-	-	8.09	12.24	8.18	9.49	5.58	10.43

3.6. Rainfall Stations

3.6.1. General

There are a number of rainfall stations within a 50 km radius of the study area. These include daily read stations and continuous pluviometer stations.

The daily read stations record total rainfall for the 24 hours to 9:00 am of the day being recorded. For example the rainfall received for the period between 9:00 am on 3 February 2008 until 9:00 am on 4 February 2008 would be recorded on the 4 February 2008.

The continuous pluviometer stations record rainfall in sub-daily increments (with output typically reported every 5 or 6 minutes). These records were used to create detailed rainfall hyetographs, which form a model input for historical events against which the model is calibrated. Table 5 and Table 6 presents a summary of the continuous pluviometer and daily rainfall gauges available for use in this study. The locations of these gauges are shown in Figure 20 and Figure 21. These gauges are operated by Sydney Catchment Authority (SCA), Hunter Water (HWC), Manly Hydraulics Laboratory (MHL) and the Bureau of Meteorology (BOM).

Table 5 - Continuous read rainfall stations

Station No	Station Name	Opened	Closed
61158	Glendon Brook (Lilyvale)	1964	Current
61174	Millfield Composite	1958	1981
61183	Pokolbin (Mount Bright)	1962	1971
61237	Pokolbin (Kiera)	1962	1973
61238	Pokolbin (Somerset)	1962	Current
61250	Paterson (Tocal AWS)	1975	Current
61288	Lostock Dam	1969	Current
61314	Mount Bright (Mount View Range)	1972	1981
210022	Halton	1986	2009
210458	Belmore Bridge	1995	Current
210402	Gostwyck	1999	Current

Table 6 - Daily read rainfall stations

Station No	Station Name	Opened	Closed
60042	Craven (Longview)	1961	Current
60075	Gloucester (Upper Bowman)	1965	Current
60096	Cabbage Tree Mountain	2002	Current
60152	Cobark	2008	Current
60153	Moppy Lookout (Barrington Tops)	2008	Current
61010	Clarence Town (Prince St)	1895	Current
61014	Branxton (Dalwood Vineyard)	1863	Current
61017	Dungog Post Office	1897	Current
61024	Gresford Post Office	1895	Current
61031	Raymond Terrace (Kinross)	1894	Current
61071	Stroud Post Office	1889	Current

Station No	Station Name	Opened	Closed
61072	Tahlee (Carrington (Church St))	1887	Current
61078	Willamtown RAAF	1942	Current
61092	Elderslie	1927	Current
61095	Rouchel Brook (Albano)	1932	Current
61096	Paterson Post Office	1901	Current
61097	Moonan Flat (High St)	1897	Current
61100	Broke (Harrowby	1887	Current
61106	Dungog (Monkerai Hill (Urimbirra))	2001	Current
61135	Upper Rouchel (Mount View)	1961	Current
61143	Bulga (Downtown)	1960	Current
61146	Carrow Brook	1960	Current
61151	Chichester Dam	1942	Current
61158	Glendon Brook (Lilyvale)	1960	Current
61160	Hilldale (Sundance)	1960	2012
61170	Dungog - Main Creek (Yeranda)	1960	Current
61191	Bulga (South Wambo)	1959	Current
61241	Carrabolla (Woodbury)	1965	2011
61250	Paterson (Tocal AWS)	1967	Current
61260	Cessnock Airport AWS	1968	Current
61268	Maitland Belmore Bridge (Hunter River)	1906	Current
61270	Bowmans Creek (Grenell)	1969	Current
61288	Lostock Dam	1969	Current
61290	Upper Allyn Township	1969	Current
61311	Grahamstown (Hunter Water Board)	1971	2013
61315	Rouchel (Bonnie Doon)	1972	Current
61339	Clarencetown (Mill Dam Falls (Williams River))	1927	Current
61346	Hunter Springs (Wondecla)	1971	Current
61349	Gostwyck Bridge (Paterson River)	1929	Current
61350	Upper Chichester (Simmonds)	1981	Current
61364	Dungog (Leawood)	1981	Current
61388	Maitland Visitor Centre	1997	Current
61390	Newcastle University	2013	2013
61395	Tanilba Bay WWTP	2001	Current
61397	Singleton STP	2002	Current
61399	Moonan Brook (Pampas)	2003	Current
61405	Woodville (Clarence Town Rd)	2004	Current
61413	Careys Peak (Barrington Tops)	2008	Current
61414	Heddon Greta (Kurri Kurri Golf Club)	2007	Current
61415	Dungog (Upper Myall Creek(	2007	Current
61418	Barrington Tops (Mount Barrington)	2009	Current
61420	Mirannie (Maeranie Station)	2010	Current
61421	Cranky Corner (Tangory Moutain)	2010	Current
61422	Milbrodale School	2010	Current

3.6.2. Analysis of Daily Read Data

The daily rainfall gauges within 10 km of the catchment were analysed for each of the ten significant events identified in Section 3.5. Each event was analysed for the maximum 1-day, 2-day, 3-day and entire event totals. The results of the analysis are shown in Table 7 to Table 10.

The rainfall totals for each event at each available rain gauge were used to create rainfall isohyets for the entire catchment. These rainfall isohyets were used to determine the rainfall depths for each individual subcatchment in the hydrological model and are shown in Figure 30 to Figure 33. The rainfall isohyets were developed using the natural neighbour interpolation technique

Table 7 – Highest Daily Read Rainfall Readings (mm) for 1 day event.

Event	Station No	Station Name	Total Rainfall (mm)
1977	61031	Raymond Terrace (Kinross)	171
1978	61290	Upper Allyn Township	248
1985	61017	Dungog Post Office	187
1990	61311	Grahamstown	235
1995	61151	Chichester Dam	110
2001	61290	Upper Allyn Township	142
2007	61405	Woodville (Clarence Town Rd)	201
2011	61413	Careys Peak (Barrington Tops)	198
Mar 2013	61151	Chichester Dam	179
Nov 2013	61096	Paterson Post Office	215
April 2015	61096	Paterson Post Office	237

Table 8 – Highest Daily Read Rainfall Readings (mm) for 2 day event.

Event	Station No	Station Name	Total Rainfall (mm)
1977	61290	Upper Allyn Township	214
1978	61151	Chichester Dam	346
1985	61024	Gresford Post Office	244
1990	61311	Grahamstown	393
1995	61350	Upper Chichester (Simmonds)	158
2001	61290	Upper Allyn Township	227
2007	61405	Woodville (Clarence Town Rd)	320
2011	61413	Careys Peak (Barrington Tops)	278
Mar 2013	61413	Careys Peak (Barrington Tops)	238
Nov 2013	61096	Paterson Post Office	274
April 2015	61096	Paterson Post Office	223

Table 9 – Highest Daily Read Rainfall Readings (mm) for 3 day event.

Event	Station No	Station Name	Total Rainfall (mm)
1977	61290	Upper Allyn Township	278
1978	61290	Upper Allyn Township	460
1985	-	-	-
1990	61311	Grahamstown	456
1995	61350	Upper Chichester (Simmonds)	224
2001	61290	Upper Allyn Township	284
2007	61405	Woodville (Clarence Town Rd)	334
2011	61413	Careys Peak (Barrington Tops)	278
Mar 2013	61413	Careys Peak (Barrington Tops)	294
Nov 2013	61096	Paterson Post Office	288
April 2015	61096	Paterson Post Office	460

Table 10 – Highest Daily Read Rainfall Readings (mm) for entire event.

Event	Station No	Station Name	Duration	Total Rainfall (mm)
1977	61290	Upper Allyn Township	5	387
1978	61290	Upper Allyn Township	5	489
1985	61024	Gresford Post Office	2	244
1990	61311	Grahamstown	5	456
1995	61350	Upper Chichester (Simmonds)	6	299
2001	61290	Upper Allyn Township	7	320
2007	61405	Woodville (Clarence Town Rd)	4	341
2011	61413	Careys Peak (Barrington Tops)	5	459
Mar 2103	61413	Careys Peak (Barrington Tops)	12	658
Nov 2013	61096	Paterson Post Office	4	291
April 2015	61096	Paterson Post Office	3	460

3.6.3. Analysis of Pluviometer Data

The pluviometer gauges were analysed for the historical events that had corresponding rainfall data. This data was used to determine the temporal patterns of each storm event that were subsequently used in the model calibration process. The temporal patterns for the historical event are shown in Figure 22 to Figure 29.

3.7. Suitable Events for Calibration and Verification

In order to identify the most suitable events for model calibration on a catchment wide basis it is important that there is sufficient available water level data recorded on river gauges and sub-hourly rainfall data that is recorded on pluviometer gauges. Table 11 provides a matrix of the significant events and the available rainfall and water level data.

Table 11 – Available Rainfall and Water Level Records

Station Name	Mar77	Ma7r8	Oct85	Feb90	Mar95	Mar01	Jun07	Jun11	Mar13	Nov13	Apr15
Pluviograph Rain Gauges	3	4	1	0	0	6	5	6	4	5	5
Pluviograph Rain Gauges in Catchment	1	1	0	0	0	4	2	3	2	3	3
Daily Rain Gauges	27	26	30	26	26	31	35	40	43	40	38
Paterson River Stream Gauges	1	1	3	6	6	6	6	6	6	6	6
Hunter River Stream Gauges	0	0	2	2	4	5	5	5	5	5	6
Allyn River Stream Gauges	0	1	1	1	1	1	2	2	2	2	0

MARCH 1977 – Selected for calibration

- moderate size flood on the Paterson River
- water level data at Gostwyck Bridge
- good coverage of daily gauges and data for one pluviometer gauge in the catchment
- event was modelled in the Paterson River Flood Study 1997 (Reference 3) allowing for comparison
- Hunter River modelled in the Hunter River: Branxton to Green Rocks Flood Study (Reference 5)

MARCH 1978 – Selected for calibration

- major flood on the Paterson River
- water level data at Gostwyck Bridge
- good coverage of daily gauges and data for one pluviometer in the catchment
- event was modelled in the 1997 Paterson River Flood Study (Reference 3) allowing for comparison

OCTOBER 1985 – Not selected for calibration

- major flood on the Paterson River but slightly lower than 1978
- water level data at Gostwyck Bridge and Paterson Railway Bridge
- no pluviometer data in the catchment

FEBRUARY 1990 – Not selected for calibration

- major flood on the Paterson River
- water level data at four Paterson River gauges
- no pluviometer data in the catchment

MARCH 1995 – Not selected for calibration

- minor flood on the Paterson River with little influence on the Hunter River
- water level data at four Paterson River gauges
- water level data at four Hunter River gauges
- no pluviometer data in the catchment

MARCH 2001 – Selected for calibration

- major flood on the Paterson River and a minor flood on the Hunter River
- water level data at four Paterson River gauges
- water level data at five Hunter River gauges
- good coverage of daily gauges and data for four pluviometer gauges in the catchment

JUNE 2007 - Selected for calibration

- major flood on the Paterson River and a major flood on the Hunter River
- water level data at four Paterson River gauges
- water level data at five Hunter River gauges
- good coverage of daily gauges and data for two pluviometer gauges in the catchment
- Hunter River modelled in the Hunter River: Branxton to Green Rocks Flood Study (Reference 5)

JUNE 2011 – Selected for calibration

- major flood on the Paterson River and a minor flood on the Hunter River
- water level data at four Paterson River gauges
- water level data at five Hunter River gauges
- good coverage of daily gauges and data for three pluviometer gauges in the catchment

MARCH 2013 – Selected for calibration

- major flood on the Paterson River and a minor flood on the Hunter River
- water level data at four Paterson River gauges
- water level data at five Hunter River gauges
- good coverage of daily gauges and data for two pluviometer gauges in the catchment

NOVEMBER 2013 – Selected for calibration

- major flood on the Paterson River and a minor flood on the Hunter River
- water level data at four Paterson River gauges
- water level data at five Hunter River gauges
- good coverage of daily gauges and data for three pluviometer gauges in the catchment

APRIL 2015 – Selected for calibration

- major flood on the Paterson River and a minor flood on the Hunter River
- water level data at six Paterson River gauges
- water level data at six Hunter River gauges
- good coverage of daily gauges and data for four pluviometer gauges in the catchment

3.8. Design Rainfall

The design rainfall intensities for the catchment centroid are shown in Table 12.

Table 12 - IFD table for the catchment centroid

Storm Duration	1EY (1 in 1 year)	0.5EY (1 in 2 year)	0.2EY (1 in 5 year)	10% (1 in 10 year)	5% (1 in 20 year)	2% (1 in 50 year)	1% (1 in 100 year)
1 hour	22.2	28.8	37.5	42.8	49.7	58.9	65.9
2 hour	15	19.4	25.3	28.8	33.4	39.6	44.4
3 hour	11.9	15.4	20	22.8	26.5	31.3	35.1
6 hour	7.97	10.3	13.5	15.3	17.8	21.1	23.7
12 hour	5.34	6.93	9.08	10.4	12.1	14.3	16.1
24 hour	3.53	4.6	6.09	7	8.18	9.78	11
36 hour	2.73	3.57	4.78	5.52	6.49	7.79	8.81
48 hour	2.26	2.96	4	4.63	5.46	6.58	7.46
72 hour	1.7	2.24	3.05	3.55	4.22	5.09	5.8

3.9. Previous Studies

3.9.1. Paterson River Flood Study – WBM Oceanics 1997

The study defined flood behaviour for the Paterson River from the Gostwyck Bridge to the Hunter River, including the floodplains on both banks and those in common with the Hunter River east of Hinton. The purpose of the study was to develop suitable computer flood models in order to understand and quantify flood behaviour in the lower Paterson River and to assist Port Stephens, Maitland and Dungog Councils in the development of a Floodplain Risk Management Plan for the study area to consider both existing and future development.

A RAFTS-XP hydrological model was used to determine inflows for the Paterson River and its tributaries which were input into the MIKE-11 hydraulic model in order to determine flood behaviour in the catchment. A flood frequency analysis was carried out to provide an alternative assessment of peak design flows at Gostwyck Bridge, using an annual series approach.

The models were calibrated to the March 1977, March 1978 and March 1995 events and then used for design flood estimation.

3.9.2. Paterson River Floodplain Risk Management and Plan – Bewsher Consulting 2001

The study identified practical measures to minimise the impacts of floods on the community of the Paterson River Valley. A range of possible measures were examined to find the most suited based on economic, technical, social and environmental criteria and the likely level of community support. Floodplain Management Plans for the Paterson River floodplain within the Dungog and Port Stephens Council areas were prepared. Within the Dungog LGA the cost of the recommended measures totalled $100,000 and within the Port Stephens Council area the recommended measures were estimated to cost between $1.2 million to $2.4 million.

As part of the current floodplain management study, the flood study was updated to provide flood behaviour information upstream of Paterson town (extending to Vacy). Events modelled included the 20%, 10%, 2%, 1% and 0.2% annual exceedance probability (AEP) events and an extreme flood (EF).

The updated modelling was documented in Volume 3 of the 2001 study. Port Stephens Council indicated that these are the model results relied upon for design flood and planning control purposes.

3.9.3. Hunter River: Branxton to Green Rocks Flood Study – WMAwater 2010

The study covered the Hunter River and its floodplain from approximately 3 km upstream of the Black Creek tributary at Branxton to Green Rocks (approximately 8 km downstream of Morpeth at the Maitland LGA boundary). The purpose of the study was to develop a suitable hydraulic model that could be used to assist Maitland and Cessnock Councils in the development of an updated Floodplain Risk Management Plan for the study area to consider both existing and future development.

A flood frequency analysis was used to determine the peak flows for the Hunter River and WBNM models were used to determine the smaller tributary flows. These inflows were input into TUFLOW hydraulic models to determine flood behaviour in the study area.

Due to the size of the computer models, two separate TUFLOW models were established with an overlapping intermediate area at Oakhampton. The models were calibrated to historical flood height data (1955, 1971, 1977 and 2007) where data was available and then used for design flood estimation.

4. COMMUNITY CONSULTATION

4.1. Information Brochure and Survey

In collaboration with MCC, PSC and DSC an information brochure with survey was distributed to residents with the study area. The function of this was to describe the role of the Flood Study in the flood plain risk management process and to request records of historical flooding. 175 responses were received from the questionnaire. From the survey 90% of respondents are aware of flooding issues in the catchment, with 40 respondents having their properties affected by flooding with a further 7 properties being flooded above floor level.

4.2. Community Responses

Photo 1 – Phoenix Park Road 2015

Photo 2 – Morpeth Bridge 2015

Photo 3 - Dunmore Bridge 2015

Photo 4 - Dunmore Bridge 2015

Photo 5 – Martins Creek during 2015 flood

Photo 6 – Martins Creek after 2015 flood

The responses are summarised in graphs in Figure 36 and the flood affected properties are shown in Figure 37. The following issues were raised by the respondents:

- Residents on the Paterson River, especially the upper reaches, described the 2015 event as the biggest they have witnessed
- The majority of landowners are acutely aware of flooding risks and are generally prepared for flood events and the potential for isolation until the floodwaters recede. Even with this knowledge and preparedness some residents were caught off guard by the rapidly rising floodwaters of the April 2015 event which prevented them from buying additional supplies or implementing their flood plans in time.
- Although residents are prepared for isolation they feel that they are neglected by the SES and there is inadequate real-time flood information. Residents have suggested that there be more information provided on ABC radio and that the post office be provided with information so that there is someone they can contact for information.
- Many residents are concerned about the erosion of the river banks on both the Paterson and Hunter Rivers which they say is getting worse after every flood. Some residents have taken preventative action and planted trees along the banks including Hunter River Red Gums. In some cases these trees were destroyed in the April 2015 flood.
- Some residents feel that they levee system is being neglected by the government.
- Some residents believe that the release of waste from Hunter Valley mines is polluting and contaminating the Hunter and Paterson Rivers during flood events killing fish.
- Some residents are concerned about future development in areas that are isolated during flood events. They are concerned that this will be dangerous to new residents and stretch the resources of community and emergency services during flood events.

5. APPROACH

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). For the Paterson River, there are stream gauges with sufficient record length that flood frequency analysis can be used to estimate peak design flood flows. There is a thorough record of daily rainfall data for the catchment and some sub-hourly rainfall data from pluviometer gauges, which can be used for event-based model calibration. A diagrammatic representation of the flood study process undertaken in this manner is shown below.

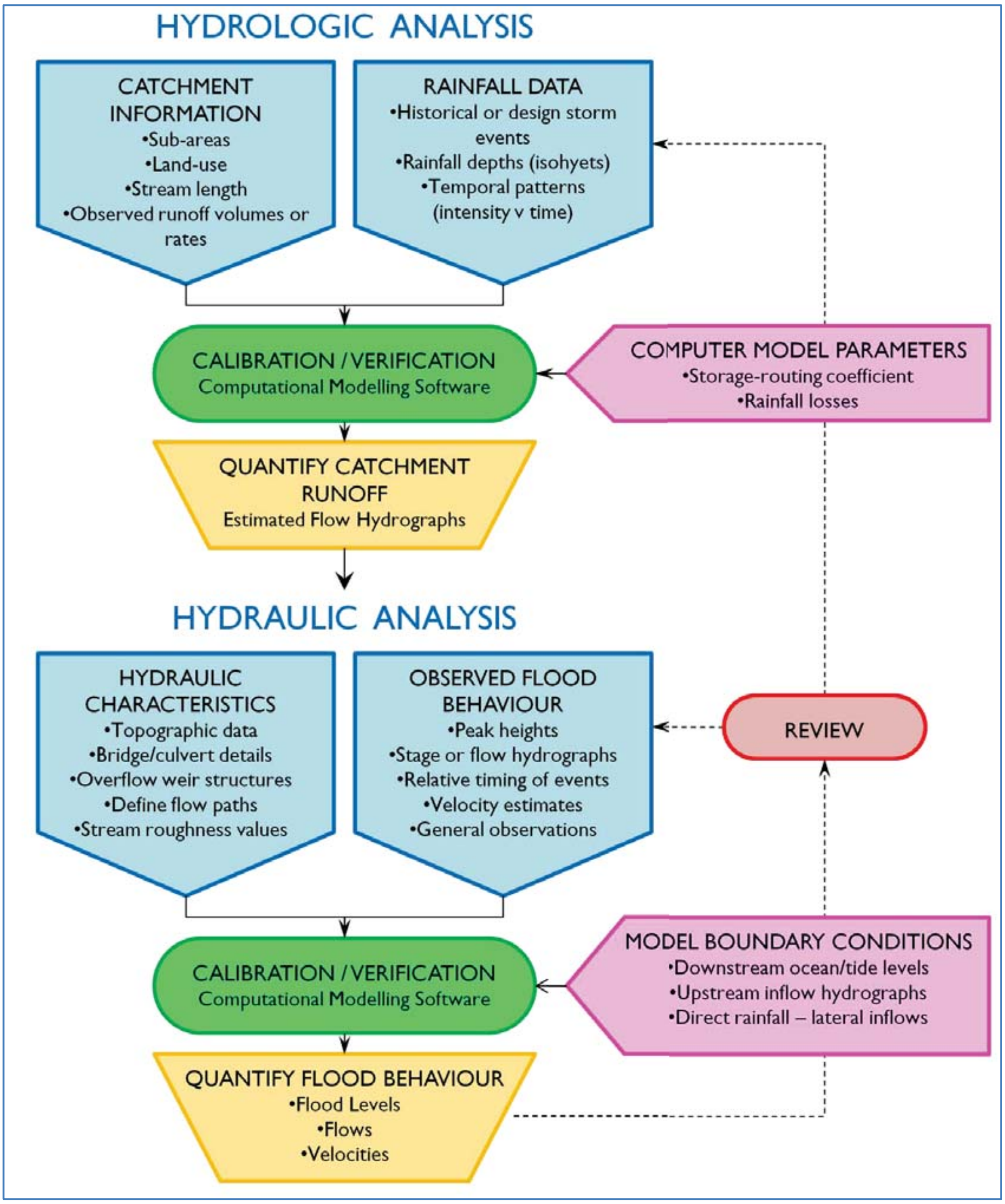


Diagram 1: Flood Study Process

6. HYDROLOGICAL MODEL

6.1. Introduction

Inflow hydrographs are required as inputs at the boundaries of the hydraulic model. Typically in flood studies a rainfall-runoff hydrologic model (converts rainfall to runoff) is used to provide these inflows. A range of runoff routing hydrologic models is available as described in AR&R 1987 (Reference 2). These models allow the rainfall depth to vary both spatially and temporarily over the catchment and readily lend themselves to calibration against recorded data.

The WBNM hydrologic run-off routing model was used to determine flows from each sub-catchment in the study area. The WBNM model has a relatively simple but well supported method. If flow data is available at a stream gauge, then the WBNM model can be calibrated to this data through adjustment of the model parameters including the stream lag factor, storage lag factor, and/or rainfall losses.

A hydrological model for the entire Paterson River catchment was created and used to:

- calibrate the Paterson River and Allyn River flows to hydrographs determined from the rating curves;
- calculate Paterson River an Allyn River flows for input into TUFLOW model at upstream boundary
- calculate the flows for each individual subcatchment and tributary creeks in the study area for inclusion in the TUFLOW model

6.2. Sub-catchment delineation

The total catchment represented by the WBNM model was 1186 km^2. This area was represented by a total of 63 catchments. The subcatchment delineation is shown in Figure 34. The subcatchment delineation was split into two zones.

1. The section of catchment upstream of the study area – 21 subcatchments
2. The section of catchment inside the study area – 42 subcatchments

This method was undertaken in order to further refine the subcatchments inside the study area so that the hydrological model could provide flow inputs for the hydraulic model that more accurately represent the topographic, riverine and floodplain conditions within the hydraulic model area. The subcatchments were derived from LiDAR topographic data and 1:25000 topographic maps of the region.

6.3. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occurs significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. This is less important in rural studies as they consist of very little impervious areas, and those areas are typically not hydraulically connected to the waterway (i.e. the water flows across pervious areas on the route between the impervious surface and the receiving waterway). Due to the rural nature and minimal consolidated urban development of the study area all subcatchments were modelled with 0% imperviousness.

6.4. Model Parameters

The model input parameters for each subcatchment are:

- A lag factor (termed C), which can be used to accelerate or delay the runoff response to rainfall;
- A stream flow routing factor, which can speed up or slowdown in-channel flows occurring through each subcatchment;
- An impervious area lag factor;
- An aerial reduction factor
- The percentage of catchment area with a pervious/impervious surface; and
- Rainfall losses calculated by initial and continuing losses to represent infiltration.

A typical regional value of 1.7 for the lag factor ‘C’ hydrologic model parameter was found to be appropriate. A value of 0.8 was used for the stream flow routing factor in order to speed up in-channel flows, relative to a typical value of 1.0 for natural channels. This was found to be required to correctly produce the rate of rise and time to peak of the historical flood hydrographs, and is considered reasonable due to the relatively steep gradient of the river and tributaries, and the incised nature of the channel. This stream flow routing factor was determined through the calibration process and is discussed in Section 8. The aerial reduction factor was determined based on catchment area and location. The model parameters adopted for use in the calibration and design events are summarised in Table 13.

Table 13 – WBNM model parameters

Parameter	Value
C (Catchment Routing)	1.7
Impervious Catchment Area	0%
Stream Routing Factor	0.8
Aerial Reduction Factor	0.84
Initial loss	Varies
Continuing loss	2 mm/hr

6.5. Rainfall Losses

Methods for modelling the proportion of rainfall that does not occur as runoff (i.e. “lost”) are outlined in AR&R (Reference 2). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the filling of localised depressions, and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues. The rainfall losses adopted as a result of the calibration process are discussed in Section 8 and the loss values used in design flood estimation are discussed in Section 10.

7. HYDRAULIC MODEL

7.1. Introduction

The availability of high quality LiDAR as well as detailed aerial photographic data enables the use of 2D hydraulic modelling for the study. Various 2D software packages are available (SOBEK, TUFLOW, RMA-2) and the TUFLOW package was adopted as it is the most widely used model of this type in Australia for riverine flood modelling.

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water equations in two dimensions. The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia and is capable of dynamically simulating complex overland flow regimes.

The TUFLOW model version used in this study was 2013-12-AE-w64 and further details regarding TUFLOW software can be found in the User Manual (Reference 9).

In TUFLOW the ground topography is represented as a uniform grid with a ground elevation and Manning's 'n' roughness value assigned to each grid cell. The size of grid is determined as a balance between the model result definition required and the computer processing time needed to run the simulations. The greater the definition i.e. the smaller the grid size the greater the processing time need to run the simulation. A cell size of 10 m by 10 m was adopted as it provided an appropriate balance between providing sufficient detail for the river channels and bridges, while still resulting in workable computational run times.

7.2. TUFLOW Hydraulic Model

The Digital Elevation Model (DEM) was generated from a triangulation of filtered ground points from the LiDAR dataset, discussed in Section 3.1. The DEM is shown in Figure 3. The model extent for the catchment was determined in conjunction with MCC and PSC. The upstream boundaries are the Paterson and Allyn Rivers upstream of the town of Vacy. The downstream boundaries are located on the Hunter River. The western boundary is located just downstream of McKimms Corner and the eastern boundary is located 1.5 km downstream of the confluence of the Hunter and Paterson Rivers. The model extent is shown in Figure 35.

7.3. Boundary Locations

7.3.1. Inflows

For sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the WBNM model (see Section 6). These were applied to the downstream end of the sub-catchments within the 2D domain of the Paterson River hydraulic model. The hydraulic model has three separate inflows:

- Paterson River upstream of Vacy
- Allyn River upstream of Vacy
- Hunter River at McKimms Corner

Paterson River Inflow

The inflow hydrographs from the WBNM hydrological model enter the upstream boundary of the model approximately 2.6 km upstream of the confluence of the Paterson and Allyn Rivers.

Allyn River Inflow

The inflow hydrographs from the WBNM hydrological model enter the upstream boundary of the model approximately 1 km upstream of the confluence of the Paterson and Allyn Rivers.

Hunter River Inflow

The Hunter River inflows are located 800m downstream of the McKimms Corner gauge. The Hunter River inflows were split into three sections:

1. Main channel inflow
2. Left overbank inflow
3. Right overbank inflow

The inflows hydrographs for the design events were taken from (Reference 5). In order to determine the inflow hydrographs for the historical events a relationship between each of the three inflows and the water level at McKimms Corner was identified from the design events in (Reference 5). This relationship was applied to the recorded water level at McKimms corner for each of the seven historical events used in calibration. The resulting inflows were applied at the three inflow boundaries for the modelled historical events

7.3.2. Downstream Boundary

The hydraulic model has two separate downstream boundary conditions;

- Hunter River
- McClymonts Swamp

Hunter River

Dynamic tailwater levels were applied as the downstream boundary condition for the Hunter River. The boundaries are located 1.5 km downstream of the confluence of the Hunter and Paterson Rivers. The Hunter River boundaries were split into two sections:

1. Main channel outflow
2. Right bank outflow

The dynamic tailwater levels for the design events were taken from (Reference 5). In order to determine the tailwater levels for the historical events a relationship between the water level at the boundaries and the water levels at Green Rocks and Hinton was identified for the design events. This relationship was applied to the recorded water levels at Green Rocks and Hinton for each of the seven historical events used in calibration. The resulting dynamic tailwater levels were applied at the two outflow boundaries for the modelled historical events

McClymonts Swamp

A water level vs flow curve was applied to the McClymonts Swamp boundary. This curve is generated by TUFLOW using the gradient and cross-section of the flow path. The flood gradient was assumed based on the topographic gradient of the DEM.

7.4. Mannings 'n' Roughness

Roughness, represented by the Manning's 'n' coefficient, is an influential parameter in hydraulic modelling. As part of the calibration process roughness values are adjusted within ranges defined in the literature so that the model may match observed peak flood levels at a variety of locations. The calibration process is discussed in Section 8. The manning's values chosen are justified by the following literature.

Chow (Reference 10) provides the definitive reference work in regards to the setting of the of the roughness values for hydraulic calculations. Chow presents a series of channel "scenarios" with varying characteristics and the derived roughness values for each. Chow also proposes a custom roughness calculation implementing the following equation (equation 5-12 from Reference 10).

$$n = (n0 + n1 + n2 + n3 + n4).m5$$

In this table various categories are assessed and a representative 'n' is aggregated from addition of different elements. Value ranges are defined in Table 5-5 (Chow, 1959) and for the case of Paterson River the following value ranges are obtained:

- Earth channel hence n_0 = 0.02 (only value appropriate for a natural channel);
- Irregularity is minor ("slightly eroded or scoured side slopes") n_1 = 0.005;
- Variation of channel cross-section is "gradual" (change in size or shape of cross section occurs gradually) n_2 = 0.00 (mid value);
- Relative effect of obstructions is negligible, refers to debris deposits, stumps, exposed roots, boulders and fallen and lodged logs) n_3 = 0.00;
- Vegetation is low (low is for conditions comparable to the following; dense growths of flexible turf grasses so n_4 = 0.005 to 0.01 (mid value); and
- Degree of meandering is minor (low value) and so m_5 = 1.0

Use of these values generates a Manning's n value ranging from 0.03 (lower end estimate) to 0.035 (upper end estimate). Henderson (Reference 11) also provides roughness values for various land use and flow conditions. Table 4-2 of Henderson (1966) states that for a natural channel, roughness may vary between 0.025 to 0.03 for a clean and straight channel, from 0.033 to 0.04 for a winding channel with pools and shoals, and from 0.075 to 0.15 for a very winding and overgrown channel.

The main channels of Paterson River, Allyn River and Hunter River are clean earth channels with very limited obstructions that meander gradually as they travel downstream. There are some riparian sections of dense weeds and shrubs on each river which is vastly different compared to the in-bank channel therefore separate values were chosen for the river channels and the riparian edge.

The in-bank section of each river was modelled using a Manning's 'n' value of 0.03 and the dense riparian vegetation was modelled using a Manning's 'n' value of 0.07, recognising that some of the reeds and grass on the banks will be knocked flat in a major flood event.

The Manning's 'n' values adopted are shown in Table 14.

Table 14 – Adopted Manning's *n* values – TUFLOW model

Surface	Manning's *n*
Rural farmland	0.04
Towns	0.04
River	0.03
Riparian Vegetation	0.07
Dense Vegetation	0.10

7.5. Rivers

The river channels were defined in the 2D grid domain. The DEM was modified to provide a continuous flow path with gradient determined from available data. The LiDAR was able to survey the river channels above the water level on the day of the survey. The bathymetric survey supplied by OEH, river gauge data from the Department of Water as well as the LiDAR survey upstream of the Gostwyck PINNEENA (210079) gauge was used to determine cross sectional data below the water level and an assumed river gradient. The subsequent data was used to carve out the river channels from the DEM.

7.6. Levees, Roads and Railway

The levees, roads and railway were all modelled using break lines which alter the topography of the DEM. The elevations of the levee system were determined using a combination of the levee survey supplied by OEH and the LiDAR survey. The elevations of the road and railway system were determined using the LiDAR survey.

7.7. Hydraulic Structures

7.7.1. Bridges

Photo 7 – Paterson Road Bridge

Photo 8 – Vacy Bridge

The bridges traversing Paterson River, Allyn River and Hunter River are shown in Figure 35. The bridges were modelled in the 2D domain for the purpose of maintaining continuity in the model. The modelling parameter values for the bridges were based on the geometrical properties of the structure, which were obtained from measurements and photographs taken during site inspections and previous experience modelling similar structures. Examples of bridges included in the model are shown in Photo 7 and Photo 8.

7.7.2. Culverts

Large road culverts were modelled in the 2D domain. The modelling parameter values for the culverts/bridges were based on the geometrical properties of the structure, which were obtained from measurements and photographs taken during site inspections and previous experience modelling similar structures. For several of the culverts, dimensions had to be estimated from topographic information due to lack of available detail survey data or plans. An example of a culvert included in the model is shown in Photo 9.

Photo 9 – Road Culverts Mindaribba

7.7.3. Buildings

Due to the rural nature of the study area and the limited development on the floodplain no buildings were included in the model as they were assumed to have a negligible effect on broader flood conveyance.

8. CALIBRATION

8.1. Objectives

The objective of the calibration process is to build a robust hydrologic and hydraulic modelling system that can replicate historical flood behaviour in the catchment being investigated. If the modelling system can replicate historical flood behaviour then it can more confidently be used to estimate design flood behaviour. The resulting outputs from design flood modelling are used for planning purposes and for infrastructure design. For this study, a wide range of historical events were available to use for calibration purposes. The historical events chosen for calibration were:

- March 1978
- March 2001
- June 2007
- June 2011
- March 2013
- November 2013
- April 2015

8.2. Methodology

A joint calibration of the hydrologic and hydraulic model was chosen as the best approach for the study area for the following reasons:

- The only gauge with a rating curve inside the study area is Gostwyck PINNEENA (210079). This is the only gauge that the hydrologic model can be calibrated to inside the study area. The highest recent gauging was 10.53 m recorded in March 2000. All the historical events that have been used for calibration have recorded stage heights greater than 10.53 m. Flow breakouts in the overbank area play a more significant role for events above this level, which are not accounted for in the rating curve extrapolation, and therefore there is little confidence in the rating curve beyond this point.
- The Allyn River Flying Fox Lane (210043) gauge has only one gauging above 1.5m therefore the rating curve could not be confidently applied for calibration of flows.
- There are five gauges inside the study area that record water levels that the hydraulic model can be calibrated to. The only calibration event that does not have records for all five gauges is March 1978 which only has records for Gostwyck PINNEENA - 210079.

The approach to model calibration was to adjust the rainfall loss parameters and the stream routing parameter in the WBNM (hydrologic) model and adjust the Manning's 'n' roughness values in the TUFLOW hydraulic model. Multiple combinations of these parameters were investigated until the best fit to the recorded water levels in the study area could be achieved across the whole range of calibration events.

For most events, the adopted rainfall depths and temporal patterns were found to have the most influence on the calibration results. The levels obtained at the gauges were more sensitive to the rainfall assumptions than to the other model parameters available for tuning the model calibration. This indicates that it is unreasonable to try and obtain a perfect fit in the model calibration results, since the available rainfall data is inherently unable to reflect the true spatial and temporal rainfall distribution across the catchment for the floods investigated.

8.3. Rainfall Losses (WBNM)

The initial loss / continuing loss model was used to estimate rainfall losses over the catchment. The approach taken was to vary the initial loss across the calibration events and to use an identical continuing loss for all the events in order to provide the best fit to recorded water levels. This can be justified as there would be different antecedent conditions in the catchment for the historical events. Antecedent conditions in the catchment may change but the rate of ongoing infiltration of water into the saturated soil (continuing loss) should theoretically be relatively consistent in the historical events.

A continuing loss that provided the best average fit for all the historical events was determined through multiple model runs. A better fit to recorded levels could have been achieved by changing the continuing loss values across the historical events but it was deemed to be an exercise in curve fitting rather an accurate representation of catchment conditions. The rainfall loss values applied to the historical events are shown in Table 15.

Table 15 – Calibration Event Rainfall Losses

Event	Initial Loss	Continuing Loss
March 1978	40mm	2mm/h
March 2001	20mm	2mm/h
June 2007	80mm	2mm/h
June 2011	30mm	2mm/h
March 2013	50mm	2mm/h
November 2013	80mm	2mm/h
April 2015	40mm	2mm/h

8.4. Stream Routing Parameter (WBNM)

The typical stream routing value in WBNM is 1.0 for natural channels. An increase to this parameter will reduce stream velocity and a decrease will increase stream velocity. A stream routing value of 0.8 was applied to provide to best fit to historical events. This value can be justified by the steep nature of the Paterson and Allyn River catchments upstream of Vacy, the relative lack of meanders in the river channels, and the relatively incised in-bank channel profiles.

8.5. Manning's 'n'

Multiple combinations of Manning's 'n' parameters were modelled in order to determine the values that provided the best fit to recorded water levels. The values modelled were justified in the literature discussed previously in Section 7.4. The Manning's 'n' values that provided the best fit are shown in Table 16.

Table 16 – Adopted Manning's *n* values – TUFLOW model

Surface	Manning's *n*
Rural farmland	0.04
Towns	0.04
River	0.03
Riparian Vegetation	0.07
Dense Vegetation	0.10

8.6. Calibration Results

The flow hydrographs for the Lostock Dam (210021) and Halton (210022) gauges from the calibration of the historical events are shown in

Figure B1 to Figure B6. The same rainfall loss and stream routing parameters that were used as part of the joint calibration were adopted. A better calibration for each event could have been achieved if they were calibrated independently but this would not have been consistent with the methodology adopted for the study.

The modelled flows at the Gostwyck PINNEENA (210079) gauge were consistently higher that the estimated flows determined from the rating curve, but a reasonable match was obtained for the flood levels. It was found that in order to force the models to produce flows matching the rating curve flows, the model parameters needed to be pushed beyond reasonable limits for those parameters. It is concluded that the official rating curve is not accurate for flood events above the 10.53 m gauging undertaken in 2000. An updated rating curve was therefore developed using the hydraulic model (see Figure 8 and Figure 38).

MARCH 1978

The March 1978 event was modelled over 5 days with a maximum total rainfall of 489 mm recorded at the Upper Allyn Township (61290) daily rainfall gauge. The temporal pattern from the Lostock Dam (61288) pluviometer produced the best fit to recorded levels. The results are shown in Figure B7 and Table 17.

Table 17 – Peak Flood Levels March 1978

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	17.69	17.42	-0.27	-1.5%	Good

MARCH 2001

The March 2001 event was modelled over 7 days with a maximum total rainfall of 320 mm recorded at the Upper Allyn Township (61290) daily rainfall gauge. The temporal pattern from the Halton (210022) pluviometer produced the best fit to recorded levels. The results are shown in Figure B8 to Figure B10 and Table 18.

Table 18 – Peak Flood Levels March 2001

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	15.83	14.64	-1.19	-7.5%	Fair
Gostwyck Bridge - 210402	13.49	12.67	-0.82	-6.1%	Fair
Paterson RB -210406	10.42	9.36	-1.06	-10.2%	Poor
Dunmore - 210409	6.48	6.33	-0.15	-2.3%	Good
Hinton Bridge - 210410	5.44	5.27	-0.17	-3.1%	Good

JUNE 2007

The June 2007 event was modelled over 4 days with a maximum total rainfall of 341 mm recorded at the Woodville – Clarence Town Road (61405) daily rainfall gauge. The temporal pattern from the Gostwyck (210402) pluviometer produced the best fit to recorded levels. The results are shown in Figure B11 to Figure B13 and Table 19.

Table 19 – Peak Flood Levels June 2007

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	15.78	16.44	0.66	4.2%	Good
Gostwyck Bridge - 210402	13.64	14.33	0.69	5.1%	Good
Paterson RB -210406	10.16	10.47	0.31	3.1%	Good
Dunmore - 210409	6.36	6.38	0.02	0.3%	Good
Hinton Bridge - 210410	5.78	4.9	-0.88	-15.2%	Poor

JUNE 2011

The June 2011 event was modelled over 5 days with a maximum total rainfall of 459 mm recorded at the Careys Peak – Barrington Tops (61413) daily rainfall gauge. A combination of the temporal patterns form the Halton (210022) and Gostwyck (210402) pluviometers produced the best fit to recorded levels. The results are shown Figure B14 and Figure B16 and Table 20.

Table 20 – Peak Flood Levels June 2011

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	16.34	16.26	-0.08	-0%	Good
Gostwyck Bridge - 210402	13.93	14.24	0.31	2%	Good
Paterson RB - 210406	10.35	10.55	0.2	2%	Good
Dunmore - 210409	6.32	6.39	0.07	1%	Good
Hinton Bridge - 210410	5.35	4.97	-0.38	-7%	Fair

MARCH 2013

The March 2013 event was modelled over 12 days with a maximum total rainfall of 658 mm recorded at the Careys Peak – Barrington Tops (61413) daily rainfall gauge. A combination of the temporal patterns form the Halton (210022) and Gostwyck (210402) pluviometers produced the best fit to recorded levels. The results are shown Figure B17 to Figure B19 and Table 21.

Table 21 – Peak Flood Levels March 2013

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	14.91	15.85	0.94	6.3%	Fair
Gostwyck Bridge - 210402	12.85	13.89	1.04	8.1%	Fair
Paterson RB -210406	9.66	10.28	0.62	6.4%	Fair
Dunmore - 210409	6.34	6.39	0.05	0.8%	Good
Hinton Bridge - 210410	5.49	5.26	-0.23	-4.2%	Good

NOVEMBER 2013

The November 2013 event was modelled over 4 days with a maximum total rainfall of 291 mm recorded at the Paterson Post Office (61096) daily rainfall gauge. The temporal pattern from the Gostwyck (210402) pluviometer produced the best fit to recorded levels. The results are shown in Figure B20 to Figure B22 and Table 22.

Table 22 – Peak Flood Levels November 2013

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	14.26	14.39	0.13	0.9%	Good
Gostwyck Bridge - 210402	12.02	12.42	0.4	3.3%	Good
Paterson RB -210406	8.43	8.87	0.44	5.2%	Fair
Dunmore - 210409	5.03	5.74	0.71	14.1%	Poor
Hinton Bridge - 210410	3.77	3.69	-0.08	-2.1%	Good

APRIL 2015

The April 2015 event was modelled over 3 days with a maximum total rainfall of 460 mm recorded at the Woodville – Clarence Town Road (61405) daily rainfall gauge. The temporal pattern from the Gostwyck (210402) pluviometer produced the best fit to recorded levels. The results are shown in Figure B23 and Table 23.

A flood level survey was undertaken for the April 2015 event. The flood marks were obtained by WMAwater personnel after the event and survey by Maitland Council surveyors. The locations of the surveyed points are shown in Figure B26 to Figure B28 and the results shown in Table 24.

A reasonable match is made to all the flood marks except for flood mark 16 which was considered to be of low accuracy due to poor visibility of the actual mark inside the culvert. A good match was made to the flood extent marks shown in Figure B27 at Bolwarra Heights and the levee on Phoenix Park Road. The flood mark recorded on the levee shows the levee did not overtop which was replicated in the model. The break out at Iona is shown Figure B28 with a good match to the flood extent recorded.

Table 23 – Peak Flood Levels April 2015

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	18.72	17.85	-0.87	-4.6%	Good
Gostwyck Bridge - 210402	16.12	15.75	-0.37	-2.3%	Good
Paterson RB -210406	11.99	11.66	-0.33	-2.8%	Good
Dunmore - 210409	6.06	6.45	0.39	6.4%	Fair
Hinton Bridge - 210410	5.76	5.68	-0.08	-1.4%	Good

Table 24 – Survey Flood Levels

ID	Location	Assessed Flood Mark Accuracy	Surveyed Level	Modelled Level	Difference
1	Paterson Railway Bridge Picnic Ground	High	12.24	11.83	-0.41
2	63 Maitland Road (Tocal Road) Paterson	Medium	10.57	10.69	0.12
3	88 Hinton Road Phoenix Park	Low	6.10	5.70	-0.4
4	Park on Old Punt Road Hinton across from Victoria Hotel downstream of Hinton Bridge	Medium	5.50	5.37	-0.13
5	Victoria Hotel - 2 Paterson Street Hinton	Medium	5.58	5.36	-0.22
6	Victoria Hotel - 2 Paterson Street Hinton	Medium	5.57	5.63	-0.21
7	Woodville General Store - 229 Clarence Town Road Woodville	High	6.30	6.05	-0.25
8	Woodville General Store Coffee Hut - 229 Clarence Town Road Woodville	High	6.06	6.05	-0.01
9	Paterson Road Iona	Medium	6.01	6.07	0.06
10	2 Iona Lane Dunns Creek	Low	6.68	6.88	0.2
11	Paterson Road Bridge	Medium	10.48	10.41	-0.07
12	63 Maitland Road (Tocal Road) Paterson	High	10.66	10.76	0.1
13	John Tucker Park Queen Street Paterson	High	10.99	11.07	0.08
14	Vacy Bridge Gresford Road	Medium	20.21	19.83	-0.38
15	27 Lang Drive Bolwarra Heights	High	Flood Extent		
16	Culverts Maitland Road Mindaribba	Low	5.28	6.86	1.49
17	Rail Underpass Mindaribba	Low	8.36	8.57	-0.11
18	Levee Phoenix Park Road	Medium	Flood Extent		

9. FLOOD FREQUENCY ANALYSIS

9.1. Overview

Flood Frequency Analysis (FFA) enables the magnitude of floods (5%, 1% AEP etc.) to be estimated based on statistical analysis of recorded floods. It can be undertaken graphically or using a mathematical distribution. This approach has the following advantages in design flood estimation:

- no assumptions are required regarding the relationship between probabilities of rainfall and runoff,
- all factors affecting flood magnitude are already integrated into the data,
- estimation of rainfall losses are not required,
- confidence limits can be estimated, and
- historic rainfall data are not required.

However this approach also has several limitations:

- The underlying distribution of flooding is not known for certain, thus different distributions will provide different answers.
- As most flood records are relatively short (compared to the design event for which a magnitude is required) there is considerable uncertainty (the broken record at Gostwyck is an example). With the use of rainfall data for design flood estimation there is less uncertainty as there are longer records and more spatial homogeneity of the data.
- The data cannot be adjusted to account for a change in catchment or climatic conditions.
- There are many issues with the accuracy of rating curves, especially at high flows. However this is less of an issue with the use of hydraulic models based on high quality survey (ALS) to obtain rating curves.

9.2. Gauges and Rating Curve

The stream flow gauge at Gostwyck (210079) has records for the period 1928 to 1946 and 1969 to 2016, a total of 67 years. During this time the gauge was situated at three different locations:

- Location 1: (1928 to 1946) – Gostwyck Bridge
- Location 2: (1969 to 1977) – 1.5 km upstream of Gostwyck Bridge
- Location 3: (1978 to present) – 4 km upstream of Gostwyck Bridge

As discussed previously, the official rating curve developed by the Department of Water is not accurate for the high flows that were of interest to this study. Rating curves for the high flow extrapolated area were developed from the calibrated TUFLOW hydraulic model at each location. The revised rating curve for the current Gostwyck gauge location (Location 3) is shown Figure 38.

9.3. Methodology

It would be desirable to have a continuous record at the same gauge location to undertake a FFA. This is not the case at Gostwyck with a broken record and gaugings at three different locations.

There is a continuous record of 38 years at the current location. After examining the results from the historical events used for calibration it was determined that there are no major overbank breakouts between the current gauge - Location 3 (4 km upstream of Gostwyck Bridge) and Location 1 (Gostwyck Bridge) for the events making up the dataset, and that the differences in flow due to attenuation are within an acceptable margin of error for the purpose of FFA. A continuous flow record was therefore developed by estimating flows at each of the separate gauging locations and combining the records together. The estimated flow rates using the developed rating curves at both locations for the calibration events are shown in Table 25.

Table 25 – Estimated Peak Flow (m^3/s) Historical Events

Historical Event	Gostwyck – 210079 Current Location	Gostwyck Bridge	% Difference
March 1978	1721	-	
March 2001	963	978	-1.6%
June 2007	1072	1014	5.4%
June 2011	1239	1083	12.6%
March 2013	851	833	2.1%
November 2013	719	683	5.0%
April 2015	2315	2030	12.3%

The annual series approach was adopted as recommended by AR&R. The maximum gauge height for each year was converted to a flow using the corresponding rating curve. The annual series is shown in Table 26.

Table 26 – Annual Series Paterson River Gostwyck (210079)

Year	Gauge (m)	Level (mAHD)	Flow (m^3/s)
Location 1 – Gostwyck Bridge			
1928	11.93	11.63	632
1929	14.16	13.86	1066
1930	13.86	13.56	994
1931	13.02	12.72	810
1932	8.05	7.75	239
1933	6.09	5.79	132
1934	8.53	8.23	275
1935	4.9	4.6	88
1936	8.21	7.91	249
1937	5.68	5.38	115
1938	9.21	8.91	332
1939	6.85	6.55	168
1940	3.35	3.05	46
1941	6.47	6.17	149
1942	12.63	12.33	739
1943	5.48	5.18	107
1944	4.59	4.29	79
1945	11.11	10.81	529

Year	Gauge (m)	Level (mAHD)	Flow (m³/s)
1946	14.62	14.32	1222
Location 2 – 1.5km Upstream Gostwyck Bridge			
1969	10.12	11.12	473
1970	8.52	9.52	322
1971	12.64	13.64	837
1972	13.4	14.4	1004
1973	7.2	8.2	224
1974	10.09	11.09	470
1975	9.79	10.79	439
1976	12.41	13.41	797
1977	12.99	13.99	898
Location 3 – 4km Upstream Gostwyck Bridge			
1978	14.37	17.66	1721
1979	9.05	12.34	428
1980	2.98	6.27	62
1981	5.25	8.54	155
1982	7.89	11.18	321
1983	3.78	7.07	89
1984	11.6	14.89	832
1985	13.6	16.89	1406
1986	7.66	10.95	304
1987	8.79	12.08	402
1988	10.49	13.78	621
1989	7.74	11.03	310
1990	13.37	16.66	1324
1991	2.37	5.66	45
1992	7.34	10.63	281
1993	4.95	8.24	140
1994	2.54	5.83	50
1995	9.13	12.42	436
1996	4.47	7.76	117
1997	4.54	7.83	120
1998	9.16	12.45	439
1999	9.62	12.91	494
2000	11.25	14.54	759
2001	12.16	15.45	963
2002	4.65	7.94	125
2003	5.76	9.05	182
2004	7.79	11.08	314
2005	6.5	9.79	225
2006	3.77	7.06	89
2007	12.55	15.84	1067
2008	11.77	15.06	870
2009	11.47	14.76	804
2010	6.34	9.63	216
2011	13.07	16.36	1223
2012	8.03	11.32	332
2013	11.68	14.97	849
2014	2.98	6.27	62

Year	Gauge (m)	Level (mAHD)	Flow (m^3/s)
2015	15.5	18.79	2316
2016	11.75	15.04	865

Various underlying distributions were tested, and a Log-Pearson III distribution was found to produce the best fit, with the results shown in Figure 39. The design flows as determined by the FFA are shown in Table 27.

Table 27 – Peak Flows Determined by FFA

Event	Peak Flow m^3/s
20% AEP	820
10% AEP	1190
5% AEP	1570
2% AEP	2100
1% AEP	2520
0.5% AEP	2950
0.2 % AEP	3520

10. DESIGN EVENT MODELLING

10.1. Overview

Design flood levels in the study area are a combination of inflows from the Paterson and Allyn Rivers upstream of Vacy, rainfall over the catchment downstream of Vacy and Hunter River inflows upstream of McKimms Corner (Reference 5). The design flows determined from the design rainfall approach were very similar to the flows determined from the FFA. Therefore the design rainfall approach has been used as it provides a more holistic result for the entire study area, especially in regard to flood mapping of the Paterson River floodplains and tributaries. A comparison of the flows at the Gostwyck PINEENA gauge (210079) for the design rainfall and FFA approach are shown in Table 28.

Table 28 – Comparison of Flows (m^3/s) – Design Rainfall vs FFA

Event	Design Rainfall (m^3/s)	FFA (m^3/s)
20% AEP	1000	820
10% AEP	1280	1190
5% AEP	1680	1570
2% AEP	2130	2100
1% AEP	2530	2520
0.5% AEP	2990	2950

10.2. Upstream Inflows

Design peak inflows from the Paterson River and Allyn River are shown in Table 29.

Table 29 – Paterson River and Allyn River Design Peak Inflows

Event	Paterson River (m^3/s)	Allyn River (m^3/s)
20% AEP	566	487
10% AEP	726	610
5% AEP	936	795
2% AEP	1172	1015
1% AEP	1403	1222
0.5% AEP	1647	1439
0.2 % AEP	1979	1736
PMF	4568	3855

10.3. Critical Duration

To determine the critical storm duration for the catchment (i.e. produce the highest flood level), modelling of the 1% AEP event was undertaken for a range of design storm durations from 6 hr to 72 hr using temporal patterns from AR&R (Reference 2). The peak flows at a number of locations throughout the study area were analysed and it was determined that the 36 hr event would be used for all design event up to the 0.2% AEP.

The same process was undertaken for the PMF and it was determined that the 72 hr duration was the critical duration for the PMF event.

10.4. Losses

Table 6.2 of AR&R (1987) recommends that for catchments east of the Great Dividing Range in New South Wales, an initial loss of between 10 mm and 30 mm is appropriate. An initial loss of 20mm was determined to be appropriate for the catchment. A continuing loss of 2mm/h was chosen based on the calibration results as it was shown to provide the best possible fit to recorded flood levels. The rainfall losses for the design event are shown in Table 30.

Table 30 – Design Event Rainfall Losses

Rainfall Losses	
Initial Loss	**Continuing Loss**
20 mm	2 mm/h

10.5. Coincident Hunter River Flooding

There is sufficient data to investigate the historical comparison of flooding on Paterson River and the Hunter River. The annual maximum gauge levels at Gostwyck and Belmore Bridge are plotted in Figure 40 in order to try and understand the historical correlation. The only floods plotted are those where there is a record available from both gauges. The observations from Figure 40 are:

- For all the Hunter River floods above the "Major" level at Belmore Bridge (10.5 m), there was also a "Major" flood on the Paterson (above 12.2 m). There are 5 of these floods in the record. Large Hunter River floods are usually associated with a large Paterson flood.
- The inverse is less true. For all the major floods on the Paterson River, only a small proportion coincided with the major Hunter River floods. This is partially to do with there being more floods above the "major flood level" specified the Bureau - 25 events above this level on the record. If we look at the largest 5 or 6 Paterson floods (above 14m), they all coincide with Hunter floods that were between the Minor and Major flood levels at Belmore Bridge.
- The major level of 10.5 m at Belmore is roughly a 10% AEP flood on the Hunter River. The 20% AEP level is about 9.8 m at Belmore Bridge. So when the largest floods on the Paterson have occurred, it has typically been in conjunction with a Hunter flood of 20% AEP or less.
- April 2015 is the largest Paterson flood on record (somewhere between a 2% AEP and

1% AEP based on the Flood Frequency Analysis). The corresponding flood on the Hunter was about 8.9 m, which is smaller than a 20% AEP flood.
- The next largest Paterson flood (1978) occurred in conjunction with about a 20% AEP Hunter River flood.

This is not a robust statistical analysis, but it does indicate that major floods on the Paterson are less likely to be accompanied by major floods on the Hunter, whereas major Hunter floods are more likely to involve significant Paterson flooding. There are some logical arguments to support this. The rainfall producing a large Hunter flood would need to be widespread and sustained over large parts of the Hunter valley, including the Paterson valley. However as observed in April 2015, the Paterson can be affected by more localised storm cells which do not extend over the upper Hunter Valley.

The above also does not consider timing. Given the relative size of the catchments, if flooding is produced by the same rainfall system, the Paterson flood would be expected to peak earlier than the Hunter in general. However for the purposes of modelling it is often assumed that the peaks coincide, which may overstate the Hunter tailwater influence on the Paterson design levels. Based on the above arguments, this study adopted a lower level of coincident flooding in the Hunter River than the previous Paterson River Flood Study (Reference 3). The coincident flood assumptions for the design flood events in this study are shown in Table 31.

Table 31 – Paterson River Design Events

Design Event	Paterson River	Hunter River
20% AEP	20% AEP	50% AEP
10% AEP	10% AEP	50% AEP
5% AEP	5% AEP	50% AEP
2% AEP	2% AEP	20% AEP
1% AEP	1% AEP	10% AEP
0.5% AEP	0.5% AEP	5% AEP
0.2% AEP	0.2% AEP	2% AEP
PMF	PMF	1% AEP

10.6. Hunter River Inflows and Tailwater

The dominant flood mechanism in the downstream reaches of the Paterson River is the Hunter River. That is, the flood level at Hinton from a 1% AEP Hunter River Flood is significantly higher that the levels from a 1% AEP flood on the Paterson (assuming some coincident flooding in both scenarios). Dynamic design flood inflows for the Hunter River were used for this study, they were based on model results from (Reference 5). The max flows at the three Hunter River inflow locations are shown in Table 32.

Table 32 – Hunter River Inflows (m^3/s)

Event	Hunter In-bank (m^3/s)	Hunter Left Over-bank (m^3/s)	Hunter Right Over-bank (m^3/s)
50% AEP	713	0	0
20% AEP	1345	0	290
10% AEP	1700	0	631
5% AEP	1781	325	851
2% AEP	1830	1047	1049
1% AEP	1851	1558	1331
0.5% AEP	2060	2653	2845
0.2 % AEP	2100	6274	4533
PMF	2096	9287	7356

Dynamic design tailwater levels for the Hunter River were modelled, based on model results from (Reference 5). The max tailwater levels at the two Hunter River outflow locations are shown in Table 33.

Table 33 – Hunter River Tailwater (mAHD)

Event	Hunter In-bank (mAHD)	Hunter Left Over-bank (mAHD)
50% AEP	3.7	Ground Level
20% AEP	5.0	2.6
10% AEP	5.2	4.3
5% AEP	5.4	4.9
2% AEP	5.7	5.7
1% AEP	5.9	5.9
0.5% AEP	6.3	6.3
0.2 % AEP	7.2	7.3
PMF	8.1	8.2

Note that the results presented below are for Paterson River flooding, in combination with smaller Hunter River flood events as outlined in Table 33. In the lower Paterson River floodplain, the Hunter River design flood levels (from Reference 5) are often the critical level for flood planning and development control purposes. The results from both studies should be considered for floodplain management decision-making.

10.7. Design Flood Modelling Results

The results for the study are presented as:

- Peak flood depth and level contours in Figure C1 to Figure C8

- Peak flood velocities in Figure C9 to Figure C16
- Provisional Hydraulic Hazard in Figure C17 to Figure C19
- Provisional Hydraulic Categorisation in Figure C20 Figure C22

10.7.1. Summary of Results

Peak flood levels, depths and flows at key location in the catchment are summarised below. These key locations coincide with those used for the sensitivity analysis discussed in Section 11. A tabulated summary of peak flood levels and depths at locations displayed in Figure 35 are shown in Table 34 and Table 35.

Table 34 – Peak Flood Levels (mAHD) at Key Locations

Point	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	Paterson River Upstream of Vacy	18.1	19.4	20.5	21.2	21.8	22.4	23.1	27
2	Vacy Bridge	16.9	18.2	19.2	19.9	20.7	21.3	22.2	26
3	Horns Crossing	16.8	18	19	19.7	20.3	21	21.9	25.9
4	Gostwyck PINEENA Gauge	15.3	16.4	17.5	18.4	19.3	20.1	21.1	25.2
5	Gostwyck Bridge	13.3	14.4	15.3	16.3	17.1	17.9	19.1	23.2
6	Paterson Rail Bridge	9.5	10.5	11.3	12.1	12.7	13.2	13.9	18.7
7	Paterson Road Bridge	8.8	9.6	10.1	10.6	11	11.4	11.9	14.8
8	Webbers Creek Bridge	8.4	9.2	9.7	10.2	10.6	11	11.5	14.4
9	Dunns Creek Floodplain	4.5	5.1	8.9	9.7	10.2	10.6	11.1	13.6
10	Mindaribba Floodplain	3.7	4.2	4.8	6.3	6.9	7.1	7.5	9
11	Iona Floodplain	1.9	2.6	4.2	6	6.6	7	7.5	8.9
12	Woodville Floodplain	1.4	2.9	3.7	5.5	6.9	7	7.4	8.8
13	Dunmore Bridge	6.2	6.3	6.3	6.5	6.6	6.9	7.3	8.6
14	Clarence Town Road Floodplain	1.3	1.7	1.9	5.9	6.4	6.8	7.2	8.2
15	Largs Floodplain	3.3	3.6	4.1	6.1	6.4	6.8	7.2	8.2
16	Hinton Floodplain	1.9	2	2	2.7	3.5	4	4.6	6.2
17	Hinton Bridge	4.2	4.3	4.4	5.6	6	6.3	6.6	7.3
18	Phoenix Park Floodplain	3.5	3.6	3.7	4.7	6.1	6.4	6.8	7.5
19	Morpeth Bridge	4.2	4.2	4.3	6	6.6	6.8	7.1	7.8

Table 35 – Peak Flood Depths (m) at Key Locations

Point	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	Paterson River Upstream of Vacy	9.2	10.5	11.6	12.3	12.9	13.5	14.2	18.1
2	Vacy Bridge	11.2	12.5	13.5	14.2	15	15.6	16.5	20.3
3	Horns Crossing	11.6	12.9	13.8	14.5	15.2	15.8	16.8	20.7
4	Gostwyck PINEENA Gauge	12	13.1	14.1	15.1	15.9	16.8	17.8	21.8
5	Gostwyck Bridge	12.5	13.6	14.6	15.5	16.3	17.2	18.3	22.4
6	Paterson Rail Bridge	12.9	13.9	14.7	15.4	16	16.6	17.3	22
7	Paterson Road Bridge	12.4	13.2	13.7	14.2	14.6	15	15.5	18.4
8	Webbers Creek Bridge	10.5	11.3	11.8	12.3	12.7	13.1	13.6	16.4
9	Dunns Creek Floodplain	1.9	2.5	6.4	7.1	7.6	8	8.5	11.1
10	Mindaribba Floodplain	2.6	3.1	3.8	5.3	5.8	6	6.5	7.9
11	Iona Floodplain	0.8	1.5	3	4.8	5.4	5.9	6.4	7.8
12	Woodville Floodplain	0.9	2.3	3.1	5	6.3	6.5	6.9	8.2
13	Dunmore Bridge	10.6	10.8	10.8	10.9	11	11.3	11.8	13.1
14	Clarence Town Road Floodplain	0.5	0.8	1.1	5.1	5.6	5.9	6.4	7.4
15	Largs Floodplain	0.7	1.1	1.5	3.6	3.9	4.2	4.7	5.6
16	Hinton Floodplain	0.5	0.5	0.6	1.3	2.1	2.6	3.1	4.7
17	Hinton Bridge	9.2	9.3	9.4	10.5	11	11.3	11.6	12.2
18	Phoenix Park Floodplain	0.9	1	1.2	2.2	3.6	3.9	4.3	5
19	Morpeth Bridge	8.7	8.8	8.8	10.5	11.1	11.4	11.6	12.3

The peak flows (m³/s) modelled at the bridges and gauge at locations displayed in Figure 35 are shown in Table 36.

Table 36 – Peak Flows (m³/s) at Bridge and Gauge Locations

Point	Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
2	PR – Vacy Bridge	560	710	920	1150	1380	1610	1930	4410
3	AR – Horns Crossing	470	610	800	1010	1220	1440	1730	3820
4	PR – Gostwyck PINEENA	1000	1280	1680	2120	2550	2990	3590	8370
5	PR – Gostwyck Bridge	970	1250	1650	2090	2510	2940	3520	8500
6	PR – Paterson Rail Bridge	930	1200	1590	2070	2500	2920	3500	8540
7	PR – Paterson Road Bridge	900	1170	1540	1860	2060	2200	2320	3280
13	PR - Dunmore Bridge	780	850	860	870	900	930	880	1310
17	PR - Hinton Bridge	790	850	860	760	450	340	250	620

10.7.2. Comparison with the 1997 Flood Study

A comparison flows with the Paterson River 1997 Flood Study by WBM (Reference 3) was undertaken at Gostwyck Bridge (see Table 37). The current study matches the flows within 2% for the 2% AEP and 1% AEP event. The flows for the PMF event and the more frequent events were consistent within 20% or less. The main reason for the discrepancies in the smaller events is the 1997 study based the model inflows on the FFA where the current study uses the design rainfall approach for the full range of flood events. This approach was considered reasonable as it matches the design flows from the FFA in the larger events and provides a more holistic approach with regard to catchment modelling and mapping. It is also noted that the updated FFA undertaken for this study produced higher flows for the more frequent flood events than the 1997 Flood Study.

Table 37 – Peak Flows (m³/s) Comparison 2016 and 1997 Flood Studies

Design Event	WMAwater (2016)	BMT WBM (1997)	Difference
10% AEP	1250	1050	16%
5% AEP	1650	1450	12%
2% AEP	2090	2050	2%
1% AEP	2500	2500	0%
PMF (Extreme)	8500	7500	12%

A comparison of peak flood levels from the previous study is provided in Table 38. The levels from this study are notably lower at the tabulated locations, typically by about 0.5 m to 1.5m for the range of events modelled. As discussed above, the peak design flows from Flood Frequency

Analysis for the two studies were very similar, particularly for the 1% AEP event. The main reason for the changes in peak flood levels are as follows:

- the change in the hydraulic modelling methodology from 1D (node and branch) model to 2D grid-based model with 10 m resolution;
- the availability of more comprehensive aerial survey data for the overbank floodplain (LIDAR on a 1 m grid compared to photogrammetry for the previous study);
- the reduced level of Hunter River flooding assumed to be coincident with the 1% AEP Paterson River flow (10% AEP Hunter River flow for this study, compared to 2% AEP Hunter River flow for the previous study).

Table 38 – Peak Levels (mAHD) Comparison 2016 and 1997 Flood Studies

Location	Studies	%5 AEP	2% AEP	1% AEP	PMF
Gostwyck Bridge	BMT WBM (1997)	15.4	17.1	18.1	25.6
	WMA (2016)	15.3	16.3	17.1	23.9
	Difference	-0.1	-0.8	-1.0	-1.7
Paterson Railway Bridge	BMT WBM (1997)	11.8	13.2	14.1	20.9
	WMA (2016)	11.3	12.1	12.7	18.7
	Difference	-0.5	-1.1	-1.4	-2.2
Paterson Road Bridge	BMT WBM (1997)	10.0	10.6	11.1	15.0
	WMA (2016)	10.1	10.6	11	14.8
	Difference	+0.1	-	-0.1	-0.2
Floodplain Mindaribba	BMT WBM (1997)	5.4	6.9	7.4	10.8
	WMA (2016)	4.8	6.3	6.9	9
	Difference	-0.6	-0.6	-0.5	-1.8
Floodplain Iona	BMT WBM (1997)	6.3	6.8	7.4	10.8
	WMA (2016)	4.2	6	6.6	8.9
	Difference	-2.1	-0.8	-0.8	-1.9

The present study used a more sophisticated 2D hydraulic modelling approach compared with the previous study (which used a 1D modelling approach). The DEM used in the TUFLOW model in the current study is based on LiDAR processed in 2012/2013 which is more accurate that the DEM used in the 1997 study. The 2D approach reflects changes to current industry best practice for catchment-wide flood studies since the previous study was undertaken. For the hydraulic analysis of complex overland flow paths, a 2D model provides several key advantages when compared to a traditional 1D model. For example, in comparison to a 1D approach, a 2D model can:

- provide localised detail of any topographic and /or structural features that may influence flood behaviour,
- better resolve the flow behaviour of overland flow paths and flood problem areas,
- inherently represent the available flood storage within the floodplain.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. It is likely that the modelling for the present study more accurately defines the amount of available flood storage in the overbank floodplain, and the interactions between the main channel flow and the overbank storage areas. It is relatively common for 1D models to underestimate the amount of available flood storage, and therefore over-estimate peak flood levels.

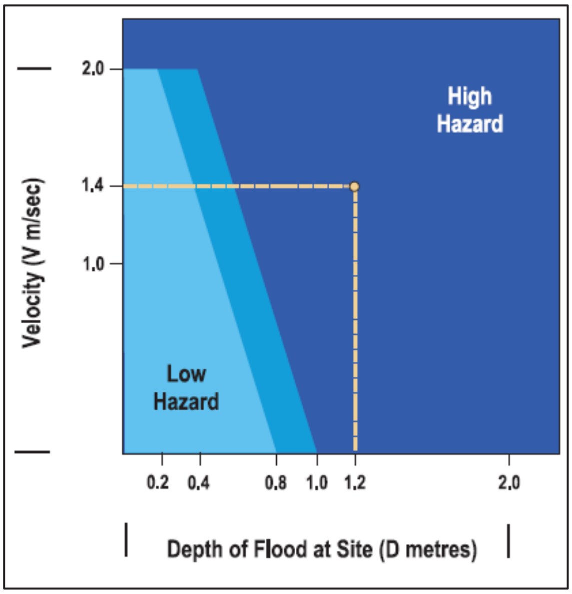
Similarly for velocity results, a 1D model can only provide an average velocity for a given flow cross-section across the floodplain. This average cross-section velocity will not identify localised areas of higher velocity around specific floodplain features, whereas a 2D model can resolve these localised changes in velocity. As identified by WBM in the 1997 flood study report, the 1D modelling "*does not show any localised (high) velocities which occur from obstructions, during overtopping of levees, etc. The velocities shown are indicative of average water velocity across the river or floodplain.*" In light of this constraint, the flood velocities estimated in this study are considered to be reasonably consistent with the previous study. Overbank floodplain velocities are generally estimated to be low (less than 0.5 m/s), with localised pockets of higher velocity.

It is recommended that the flood levels determined in the present study should supersede the previous study for ongoing planning purposes.

10.7.3. Provisional Flood Hazard Categorisation

Provisional hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual (Reference 1), the relevant section of which is shown in Diagram 2. For the purposes of this report, the transition zone presented in Diagram 2 (L2) was considered to be high hazard.

Diagram 2: Provisional "L2" Hydraulic Hazard Categories (Reference 1)



Classification of "true" flood hazard requires consideration of other contributing factors, such as evacuation routes, potential for isolation, and proximity of essential services. Such classification is typically undertaken at the subsequent FRMS&P stage. However the hazard maps (Figure C17 to Figure C19) have been updated to identify obvious areas of potential high hazard resulting from isolation, to inform interim planning decisions until an FRMS&P is completed. This is a preliminary assessment of true hazard and is not comprehensive.

10.7.4. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (Reference 1). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria, which is similar to the methodology proposed by Howells et. al, 2003 (Reference 14), but modified slightly to be more consistent with other similar studies undertaken in the Port Stephens and Maitland Council areas (e.g. the Williams River and Hunter River flood studies):

- Floodway is defined as areas where:
  - the peak value of velocity multiplied by depth (V x D) > 0.5 m^2/, **OR**
  - peak velocity > 1.0 m/s **AND** peak depth > 0.2 m

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 1.0 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 1.0 m.

The provisional hydraulic categories mapping is shown on Figure C20 to Figure C22.

Port Stephens Council advised that their development control policies also require consideration of a rainfall intensity increase of 20%, as well as sea level rise. It was established in Reference 5 that projected sea level rise benchmarks through to 2100 do not significantly affect design flood levels in the Hunter and Paterson River upstream of Green Rocks. Additional mapping of hydraulic categories was therefore created for the following scenario:

- 1% AEP Paterson River design storm with 20% increased rainfall intensity.

The provisional hydraulic categories mapping incorporating 20% increase in Paterson River rainfall intensity is shown on Figure D2 (Appendix D).

Note that this mapping does not include consideration of the Hunter River 1% AEP design flood event (Reference 5), which should also be considered for development control planning.

10.7.5. Road Inundation

An analysis of road inundation has been undertaken at key locations in the study. The key locations as well as the event in which the road is overtopped is shown in Figure 35. The depth of inundation of on each of the key roads for the full range of design events is shown in Table 39.

Table 39 – Depth of Inundation (m) on Road at Key Locations

Point	Location	Road Level (mAHD)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
2	Vacy Bridge	21.0	0	0	0	0	0	0.2	1.1	5
R2	Gresford Rd	19.5	0	0	0	0.4	0.8	1.3	2.2	6.2
3	Horns Crossing	10.0	6.8	8	9	9.7	10.3	11	11.9	15.9
5	Gostwyck Bridge	18.0	0	0	0	0	0	0	0.9	4.8
R5	Gresford Rd Paterson	10.6	0	0	0.8	1.6	2.2	2.8	3.5	8.3
R6	Tocal Rd & Queen St	7.8	1.3	2.2	2.9	3.5	3.9	4.4	4.9	8.2
R7	Tocal Rd Paterson	9.7	0	0	0.5	0.8	1.4	1.8	2.3	5.1
7	Paterson Rd Bridge	11.5	0	0	0	0	0	0	0.2	3.1
R9	Tocal Rd Webbers Creek	8.2	0.2	1	1.5	2	2.4	2.8	3.3	6.1
R10	Webbers Creek Bridge	9.5	0	0	0.2	0.7	1.1	1.5	2	4.8
R11	Paterson Rd Dunns Creek	6.1	0	0	2.8	3.5	4	4.4	4.9	7.3
R12	Paterson Rd Iona	4.9	0	0.7	1.1	1.8	2.2	2.5	3	5.2
R13	Iona Public School	2.6	0	0.8	1.6	3.4	4	4.5	4.9	6.3
R14	Clarence Town Road Woodville	3.7	0	0	0.4	2.3	2.8	3.3	3.7	5
13	Dunmore Bridge	8.3	0	0	0	0	0	0	0	0.2
R16	Phoenix Park Rd - Largs	3.4	0	0.2	0.6	2.7	3	3.3	3.8	4.8
R17	Wallalong Rd	2.6	0	0	0	0	0.2	0.5	0.9	2.1
R18	Butterwick Rd	5	0.1	0.1	0.1	1	1.6	2.1	2.5	3.9
R19	High Street (between Hinton and Wallalong)	2..1	0	0	0	0.6	1.4	2	2.5	4.1

Several of the roads in the study area are cut in relatively frequent events such as the 20% AEP. A summary of the frequency of inundation for major roads and bridges is given in Table 40.

Table 40 – Summary of Overtopping Frequency for Major Bridges and Roads

Location ID (Figure 35)	Bridge/Road	Waterway	Overtopping Event
2	Vacy Bridge	Paterson River	Between 1% and 0.5% AEP
R2	Gresford Rd	Floodplain	Between 5% and 2% AEP
3	Horns Crossing	Allyn River	< 20% AEP
5	Gostwyck Bridge	Paterson River	Between 0.5% and 0.2% AEP
R5	Gresford Rd Paterson	Floodplain	Between 10% and 5% AEP
R6	Tocal Rd & Queen St	Floodplain	< 20% AEP
R7	Tocal Rd Paterson	Floodplain	Between 10% and 5% AEP
7	Paterson Rd Bridge	Paterson River	Between 0.5% and 0.2% AEP
R9	Tocal Rd Webbers Creek	Webbers Creek	< 20% AEP
R10	Webbers Creek Bridge	Webbers Creek	Between 10% and 5% AEP
R11	Paterson Rd Dunns Creek	Dunns Creek	Between 10% and 5% AEP
R12	Paterson Rd Iona	Floodplain	Between 20% and 10% AEP
R13	Iona Public School	Floodplain	Between 20% and 10% AEP
R14	Clarence Town Road Woodville	Floodplain	Between 10% and 5% AEP
13	Dunmore Bridge	Paterson River	Between 0.2% AEP and PMF
R16	Phoenix Park Rd - Largs	Floodplain	Between 20% and 10% AEP
R17	Wallalong Rd	Floodplain	Between 2% and 1% AEP
R18	Butterwick Rd	Floodplain	< 20% AEP
R19	High Street (between Hinton and Wallalong)	Floodplain	Between 5% and 2% AEP

Table 41 relates the gauge height at Gostwyck Bridge to anticipated road and bridge overtopping locations. This summary is based on design flood event modelling, and real floods may vary, particularly the further the location of interest from the Gostwyck Bridge gauge. However, the information is intended to assist the SES for planning purposes based on flood warning information provided by the Bureau of Meteorology, since these warnings generally include a predicted flood level at the Gostwyck Bridge gauge.

Table 41 – Major Bridge and Road Overtopping (Gauge Heights at Gostwyck Bridge)

Event & Gauge Level Gostwyck Bridge	Location ID (Figure 35)	Bridge/Road Overtopped
20% AEP = 13.3 m	3	Horns Crossing
	R6	Tocal Rd & Queen St
	R9	Tocal Rd Webbers Creek
	R18	Butterwick Rd
10% AEP = 14.4 m	All of the above, plus:	
	R12	Paterson Rd Iona
	R12	Paterson Rd Iona
	R16	Phoenix Park Rd - Largs
5% AEP = 15.3 m	All of the above, plus:	
	R5	Gresford Rd Paterson
	R6	Tocal Rd & Queen St
	R10	Webbers Creek Bridge
	R11	Paterson Rd Dunns Creek
	R14	Clarence Town Road Woodville
2% AEP = 16.3 m	All of the above, plus:	
	R2	Gresford Rd
	R19	High Street (between Hinton and Wallalong)
1% AEP = 17.1 m	All of the above, plus:	
	R17	Wallalong Rd
0.5% AEP = 17.9 m	All of the above, plus:	
	2	Vacy Bridge
0.2% AEP = 19.1 m	All of the above, plus:	
	5	Gostwyck Bridge
	7	Paterson Rd Bridge
PMF = 23.2 m	All of the above, plus:	
	13	Dunmore Bridge

10.7.6. Spillway Overtopping Hinton

The three spillways at Hinton located on the eastern levee between Wallalong Road and Hinton Bridge allow water to overtop the levee into the Hinton floodplain in a controlled manner especially in the smaller event. Flood waters are contained inside the levee system up to the 5% AEP event.

The flows (m^3/s) over the spillways as well as the entire section of levee between Wallalong Road and Hinton Bridge are shown in Table 42.

Table 42 – Levee Spillway Flows (m^3/s) - Section from Wallalong Rd to Hinton Bridge

Spillway	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
1	0	0	0	80	340	550	850	2330
2	0	0	0	10	60	90	140	490
3	0	0	0	30	100	170	250	710
Entire Levee	0	0	0	140	740	1350	2180	5680

Sections of the Paterson River levee system are overtopped in events starting from the 20% AEP and onwards, with the entire levee system overtopping in the 2% AEP event. The event for which each section of levee is overtopped is displayed in Figure C25.

10.7.7. Preliminary Flood Planning Area

The preliminary Flood Planning Area (FPA) was determined by adding 0.5 m freeboard to the Paterson River 1% AEP flood level, and "stretching" this surface across the topography. This extent was merged with the FPA of the Hunter River taken from the 2015 FRMS&P (Reference 19) to create a combined FPA of the Paterson River and Hunter River for the 1% AEP event. The FPA identifies land that is below the 1% AEP plus freeboard level, and is finalised at the Floodplain Risk Management Study stage when appropriate freeboard levels are determined. The preliminary FPA for Paterson River and its tributary creeks is shown in Figure C23.

The dominant flood mechanism in the downstream reaches of the Paterson River is the Hunter River. That is, the flood level at Hinton from a 1% AEP Hunter River flood is significantly higher that the levels from a 1% AEP flood on the Paterson (assuming some coincident flooding in both scenarios). For areas downstream of Dunmore Bridge the 1% AEP flood levels from the Hunter River Flood Study (Reference 5) are to be used for developmental purposes. An example of the discrepancies in peak flood levels in shown in Table 43.

Table 43 – Paterson River vs Hunter River 1% AEP Flood Levels

Location ID (Figure 35)	Location	1% AEP Paterson River (mAHD)	1% AEP Hunter River (mAHD)	Difference (m)
14	Clarence Town Road Floodplain	6.4	6.9	0.5
15	Largs Floodplain	6.4	6.9	0.5
16	Hinton Floodplain	3.5	5.8	2.3
17	Hinton Bridge	6	6.5	0.5
18	Phoenix Park Floodplain	6.1	6.6	0.5

Port Stephens Council advised that their development control policies also require consideration of potential climate change impacts. Under Council policy, development in Port Stephens is required to be built to climate benchmarks for the year 2100, including consideration of sea level rise and increases to rainfall intensity. Port Stephens Council formally adopted the State Government's sea level rise benchmarks from 2009 which are 0.4m by 2050 and 0.9m by 2100. Port Stephens Council also advised that they typically incorporate an assumption of a 20% increase in rainfall intensity into the 2100 Flood Planning Level.

It was established in Reference 5 that the projected sea level rise benchmarks through to 2100 do not significantly affect design flood levels in the Hunter and Paterson River upstream of Green Rocks. However, increases to design rainfall intensity would result in increases to Flood Planning Levels throughout the Paterson Valley, and a broader extent of land subject to flood planning controls (the FPA). An additional FPA extent was therefore created by combining the following scenarios:

- 1% AEP Paterson River design storm with 20% increased rainfall intensity; and
- Hunter River 1% AEP design event (no rainfall increase).

The FPA extent incorporating 20% increase in Paterson River rainfall intensity is shown on Figure D1 (Appendix D), consistent with the planning requirements of Port Stephens Council.

10.7.8. Peak Flood Level Profiles

Longitudinal profiles of the peak flood level within the Paterson River for the 5% AEP, 1% AEP and PMF events are shown on Figure C24.

The gradient of the 5% AEP flood is relatively even through the study area, although slightly steeper in the upper reaches. This indicates there are no particular reaches of high energy loss for these moderate size events. The steepest parts of the profiles (i.e. where there is a notable afflux or drop in flow energy) are associated with sharp bends in the river, such as near Paterson (chainage 16 km). Similar behaviour is noted for the 1% AEP event, although there is a more pronounced drop around chainage 22.5 km, which is associated with the sharp river bend to the east of the Tocal Agricultural Centre. The afflux at the major bridge and road crossing is not pronounced for the 5% and 1% AEP events, since most of the bridges have high decks that do not influence the flow in these events.

For the PMF event, there is a more pronounced influence on the peak flood profile from some of the bridges (notably Gostwyck Bridge), however the sharp river bends are the locations of most significant energy dissipation, and steeper afflux. These bend losses can be significant for large flood events, due to differences in the direction of the channelized flow (which follows the meandering river) and the broader floodplain flow (which goes more directly downstream), creating significant sheer stresses and energy losses. The 2D modelling approach used or this study is better at resolving this energy dissipation behaviour at bends than the 1D modelling methods used previously, although there are significant vertical turbulence components that are not resolved by the 2D scheme. 1D modelling does not resolve the energy losses around the bends at all unless the modeller makes the decision to include an energy loss parameter for that particular reach.

11. SENSITIVITY ANALYSIS

11.1. Overview

A number of sensitivity analyses were undertaken for the modelling to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made. These sensitivity scenarios are shown in Table 44.

Table 44 – Overview of Sensitivity Analysis

Scenario	Description
Manning's "n"	The hydraulic roughness values were increased and decreased by 20%
Climate Change	Sensitivity to rainfall and runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under the current guidelines;

11.2. Climate Change

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Changes to surface and atmospheric temperatures may affect climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

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

- greenhouse gas concentrations continue to increase;
- global sea level has risen about 0.1 m to 0.25 m in the past century;
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

11.2.1. Rainfall Increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy for use as yet (Reference 14).

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the Paterson River catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government's (Reference 14) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

11.2.2. Sea Level Rise

Flood levels on the Paterson River are not significantly affected by the currently projected levels for sea level rise. This was examined in Reference 5.

11.3. Sensitivity Analysis Results

The sensitivity scenario results were compared for the 1% AEP rainfall event with the 10% AEP Hunter River flooding. A summary of peak flood level differences at various locations is provided in:

- Table 45 for variations in Mannings 'n' roughness; and
- Table 46 for variations in climate conditions

11.3.1. Roughness Variations

Overall peak flood levels were found to be sensitive to a variation in the roughness parameter which was already ascertained in the calibration process. The greatest variation in peak flood levels was at Gostwyck Bridge with a variation of +/- 0.5m. The flood level modelled at Gostwyck Bridge in the 1% AEP flood event is 17.1 mAHD.

Table 45 – Results of Roughness Variation Sensitivity Analysis – 1% AEP Levels (m AHD)

Point	Location	Peak Flood Level 1% AEP (10% AEP Hunter River)	Difference with 1% AEP (m)	
			Roughness Decreased by 20%	Roughness Increased by 20%
1	Paterson River Upstream of Vacy	21.8	-0.39	0.34
2	Vacy Bridge	20.7	-0.36	0.36
3	Horns Crossing	20.3	-0.39	0.41
4	Gostwyck PINEENA Gauge	19.3	-0.48	0.46
5	Gostwyck Bridge	17.1	-0.5	0.49
6	Paterson Rail Bridge	12.7	-0.23	0.24
7	Paterson Road Bridge	11	-0.17	0.16
8	Webbers Creek Bridge	10.6	-0.14	0.14
9	Dunns Creek Floodplain	10.2	-0.11	0.12
10	Mindaribba Floodplain	6.9	-0.05	0.03
11	Iona Floodplain	6.6	-0.15	0.15
12	Woodville Floodplain	6.9	-0.04	0.03
13	Dunmore Bridge	6.6	-0.08	0.07
14	Clarence Town Road Floodplain	6.4	-0.09	0.08
15	Largs Floodplain	6.4	-0.07	0.07
16	Hinton Floodplain	3.5	-0.19	0.17
17	Hinton Bridge	6	-0.07	0.05
18	Phoenix Park Floodplain	6.1	-0.09	0.07
19	Morpeth Bridge	6.6	-0.16	0.13

11.3.2. Climate Variation

The effect of increasing the design rainfalls by 10%, 20% and 30% was evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area. Generally speaking, each incremental 10% increase in rainfall results in an increase in peak flood levels at most of the locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day conditions. The largest variation in peak flood level occurred on Paterson River at Gostwyck Bridge.

Table 46 - Results of Climate Change Analysis – 1% AEP Levels (m)

Point	Location	Peak Flood Level 1% AEP (10% AEP Hunter River)	Difference with 1% AEP (m)		
			Rain +10%	Rain +20%	Rain +30%
1	Paterson River Upstream of Vacy	21.8	0.5	0.97	1.42
2	Vacy Bridge	20.7	0.58	1.14	1.66
3	Horns Crossing	20.3	0.59	1.16	1.74
4	Gostwyck PINEENA Gauge	19.3	0.72	1.39	2.04
5	Gostwyck Bridge	17.1	0.76	1.51	2.22
6	Paterson Rail Bridge	12.7	0.49	0.93	1.36
7	Paterson Road Bridge	11	0.35	0.66	0.97
8	Webbers Creek Bridge	10.6	0.34	0.65	0.95
9	Dunns Creek Floodplain	10.2	0.37	0.68	0.98
10	Mindaribba Floodplain	6.9	0.14	0.24	0.43
11	Iona Floodplain	6.6	0.3	0.54	0.7
12	Woodville Floodplain	6.9	0.12	0.2	0.34
13	Dunmore Bridge	6.6	0.13	0.26	0.42
14	Clarence Town Road Floodplain	6.4	0.18	0.32	0.48
15	Largs Floodplain	6.4	0.16	0.31	0.46
16	Hinton Floodplain	3.5	0.24	0.41	0.61
17	Hinton Bridge	6	0.12	0.21	0.32
18	Phoenix Park Floodplain	6.1	0.14	0.25	0.37
19	Morpeth Bridge	6.6	0.11	0.19	0.27

12. RECOMMENDATIONS

It is recommended that following the conclusion and adoption of the Paterson River Flood Study; combined flood level and DCP mapping be developed utilising results from the Paterson River Flood Study and the Hunter River Flood Study (Reference 5). The DCP mapping can be tailored to meet each Council's individual needs or developed after a consultation process with all stakeholders.

13. PUBLIC EXHIBITION

13.1. Public Submissions

The Draft Paterson River Flood Study was placed on Public Exhibition from 22nd September to 21st October at the following locations:

- Maitland Council – Website, Citizen Service Centre, Maitland Library, Thornton Library
- Port Stephens Council – Website, Council Administration Centre
- Dungog Council - Website, Council Administration Centre

From the month long public exhibition period, two public submissions were received, which are attached in Appendix E. The submissions related to levee modification works undertaken by OEH on the Wallalong levee in early 2016. The main points raised in the public submissions are as follows:

- Objection of the modification works;
- Questioning of the approval for the works and consultation process or lack thereof;
- Concerns that the modification works will adversely impact flooding on their properties;
- A request that the levee be put back to pre-modification conditions.

13.2. Response to Public Submissions

In response to the public submissions received WMAwater notes the following:

- The modelling completed for this study does not include the levee modification works carried out in early 2016. The levee topography utilised in the study is based on pre-modification levels from aerial survey collected in 2012 and 2013. The results and mapping outputs reflect pre-modification conditions.
- A separate modelling analysis undertaken for OEH quantified the changes to peak flood levels resulting from the levee modifications, for both Hunter River flooding and Paterson River flooding (attached in Appendix E).
- OEH is currently investigating further modifications to the levee with the intention of minimising the changes in flood behaviour compared to pre-modification conditions (as mapped for this study). WMAwater understands this process will involve community consultation.

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WMAwater, 2017

Figures

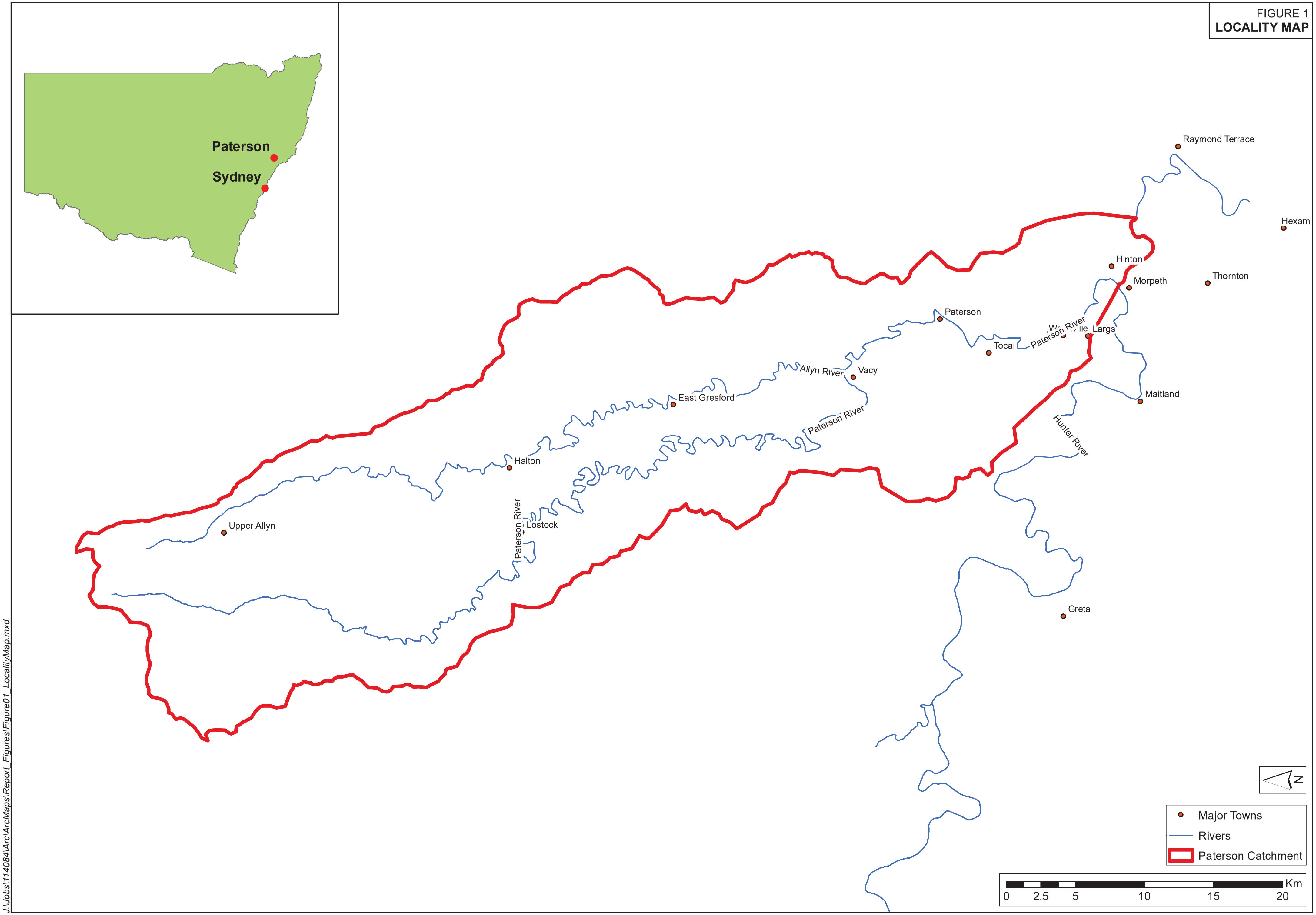

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FIGURE 2
STUDY AREA

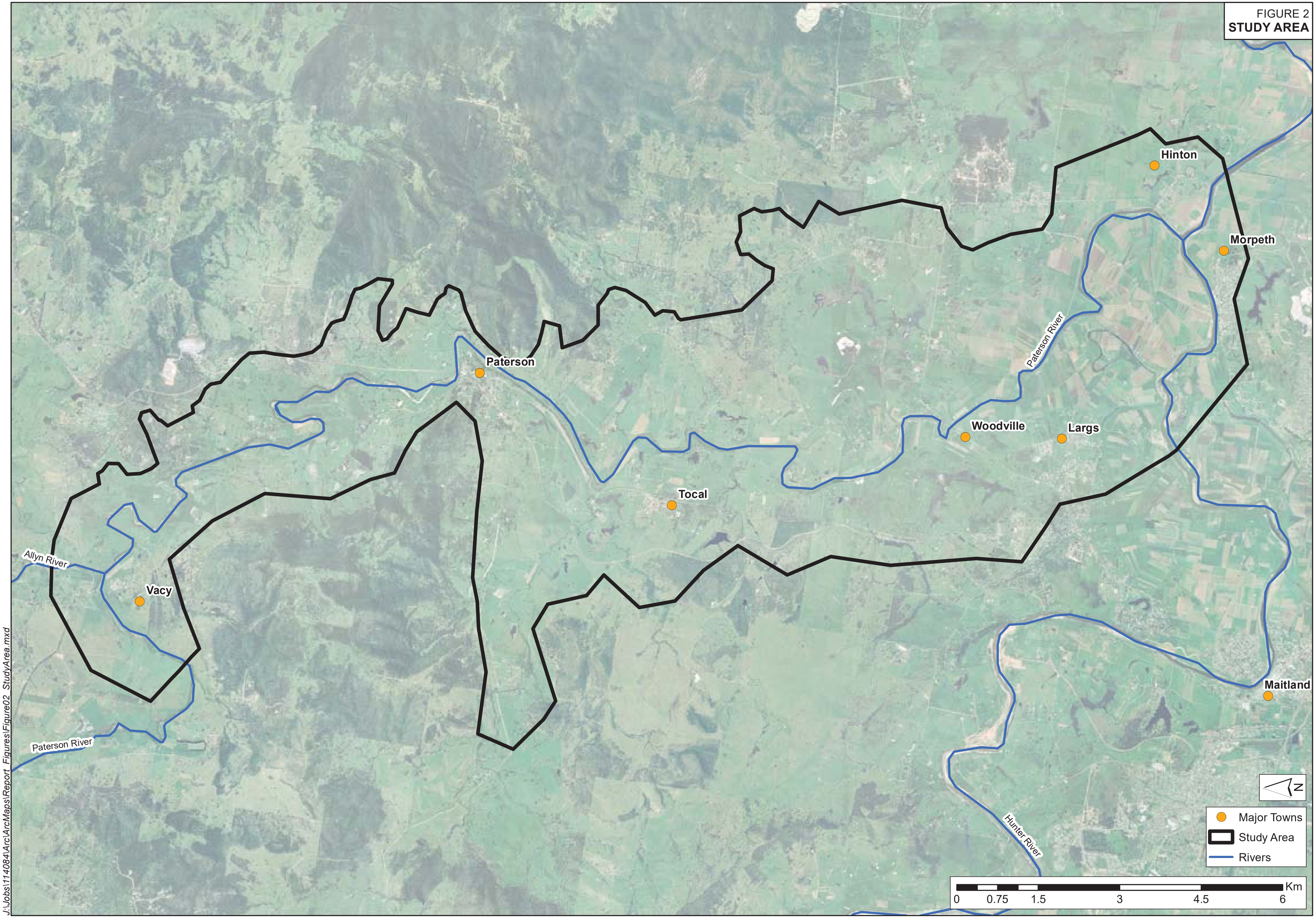

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FIGURE 3
AVAILABLE SURVEY DATA

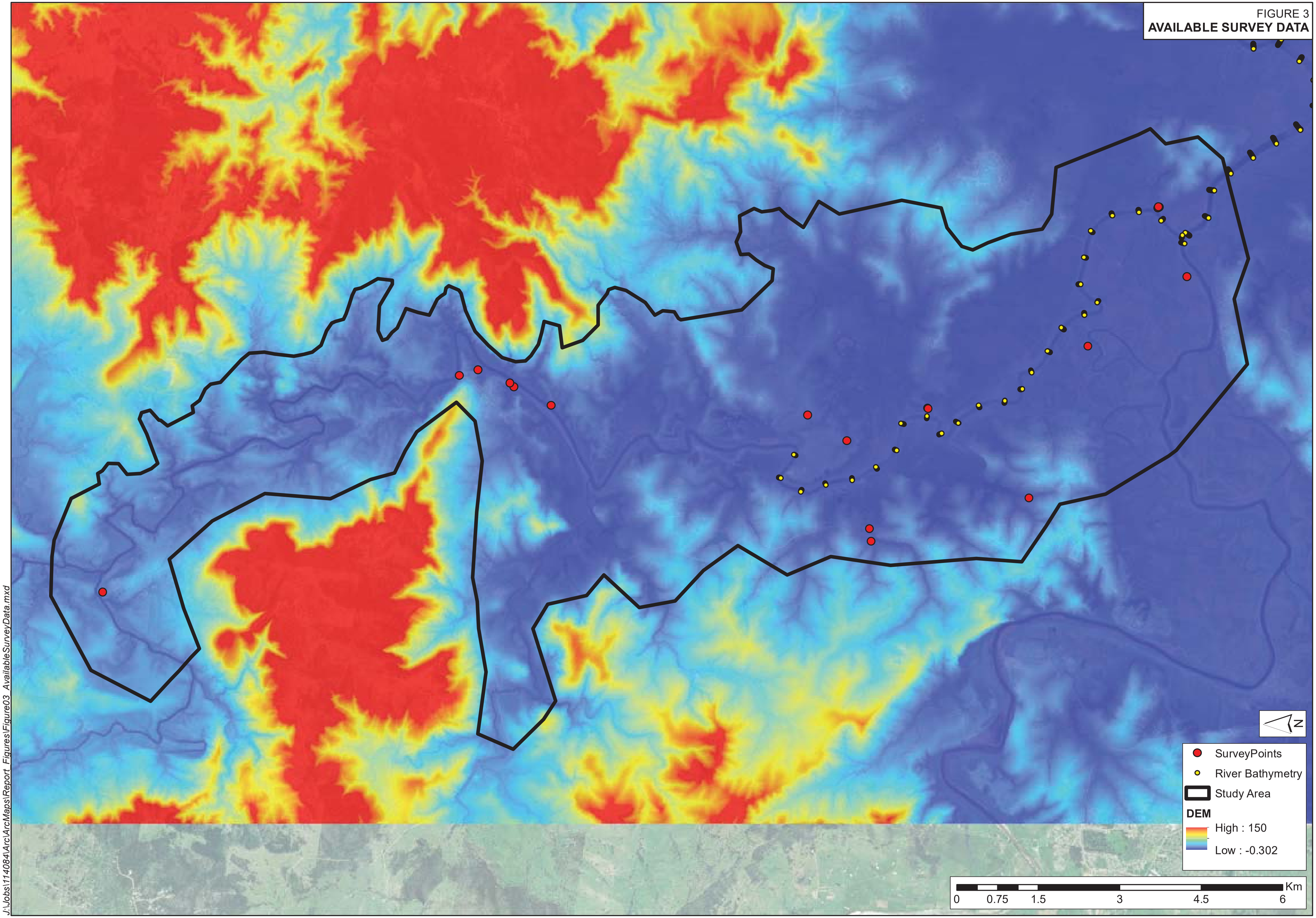

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FIGURE 4
RIVER GAUGES

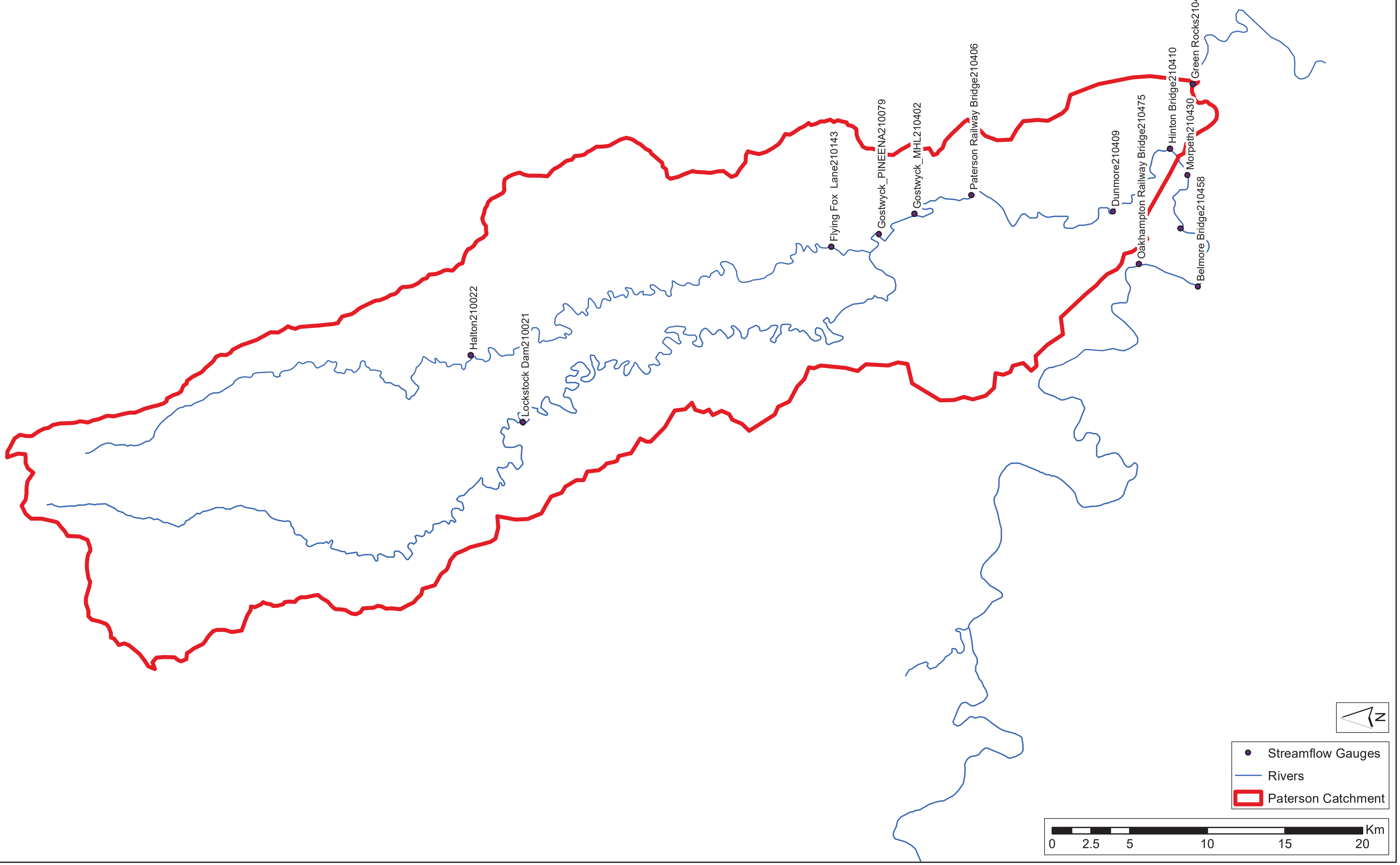

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FIGURE 5

ALLYN RIVER HALTON - 210022

RATING CURVE AND GAUGINGS

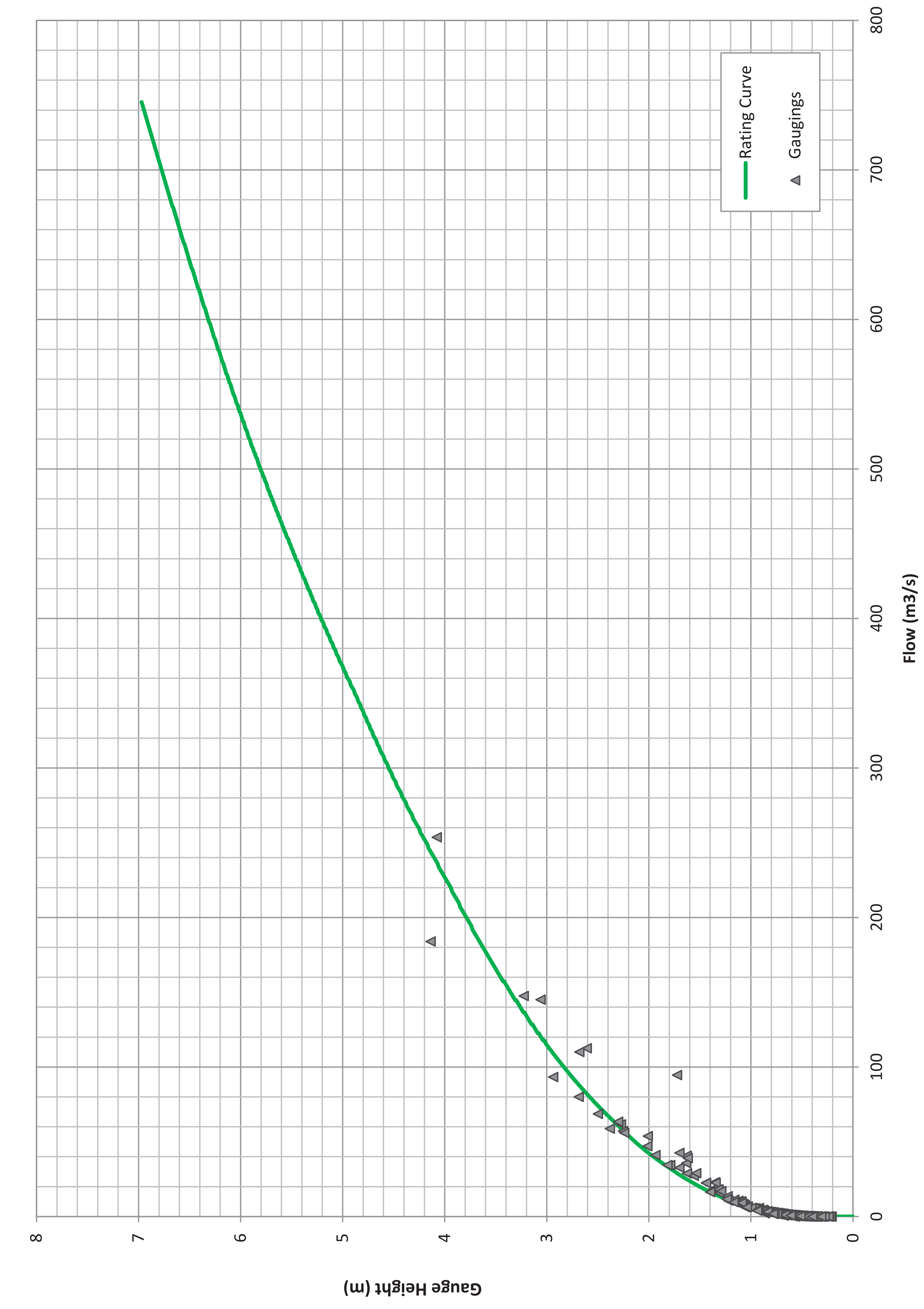

FIGURE 6

PATERSON RIVER AT LOSTOCK DAM- 210021
RATING CURVE AND GAUGINGS

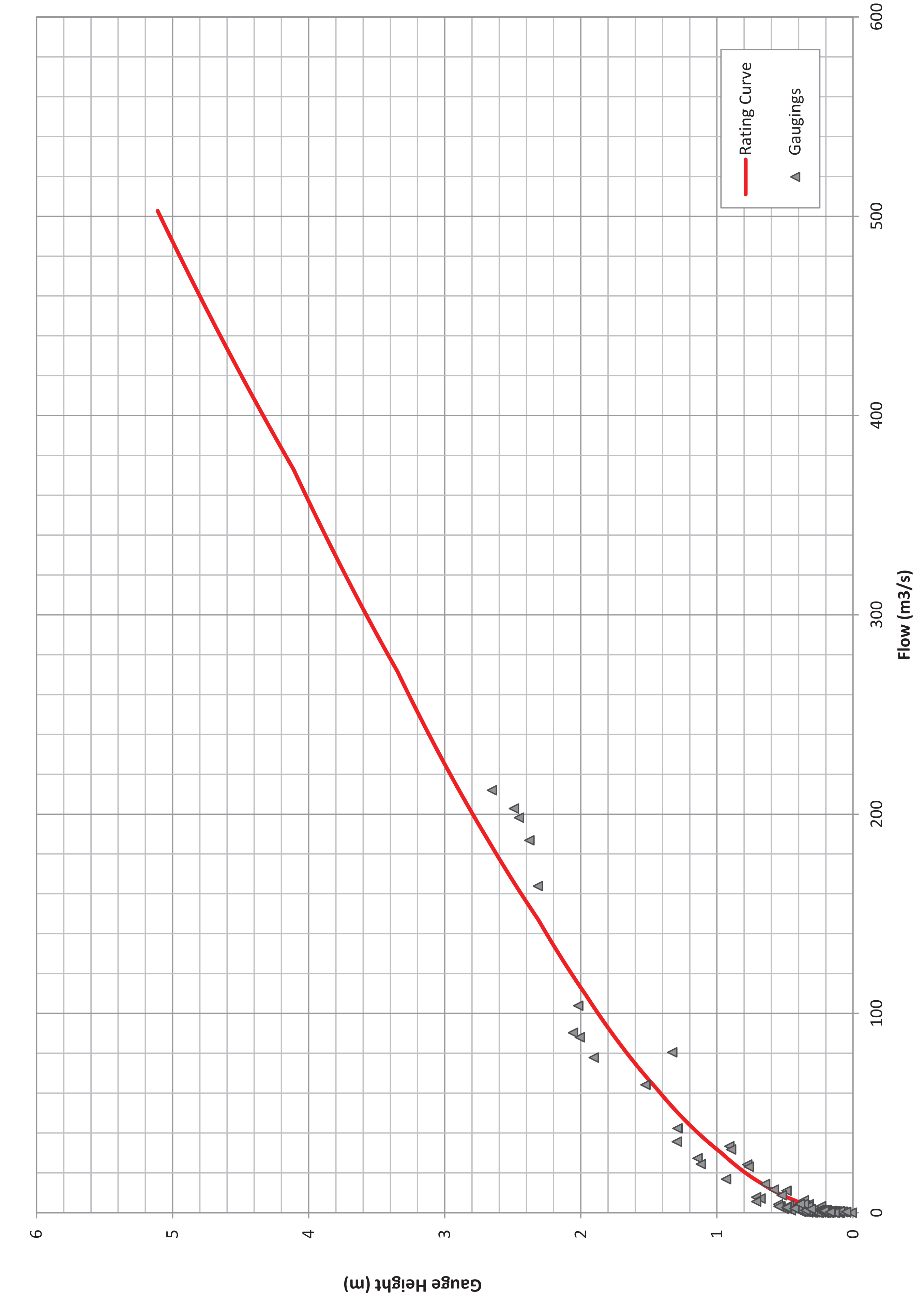

FIGURE 7
ALLYN RIVER FLYING FOX LANE - 210043
RATING CURVE AND GAUGINGS

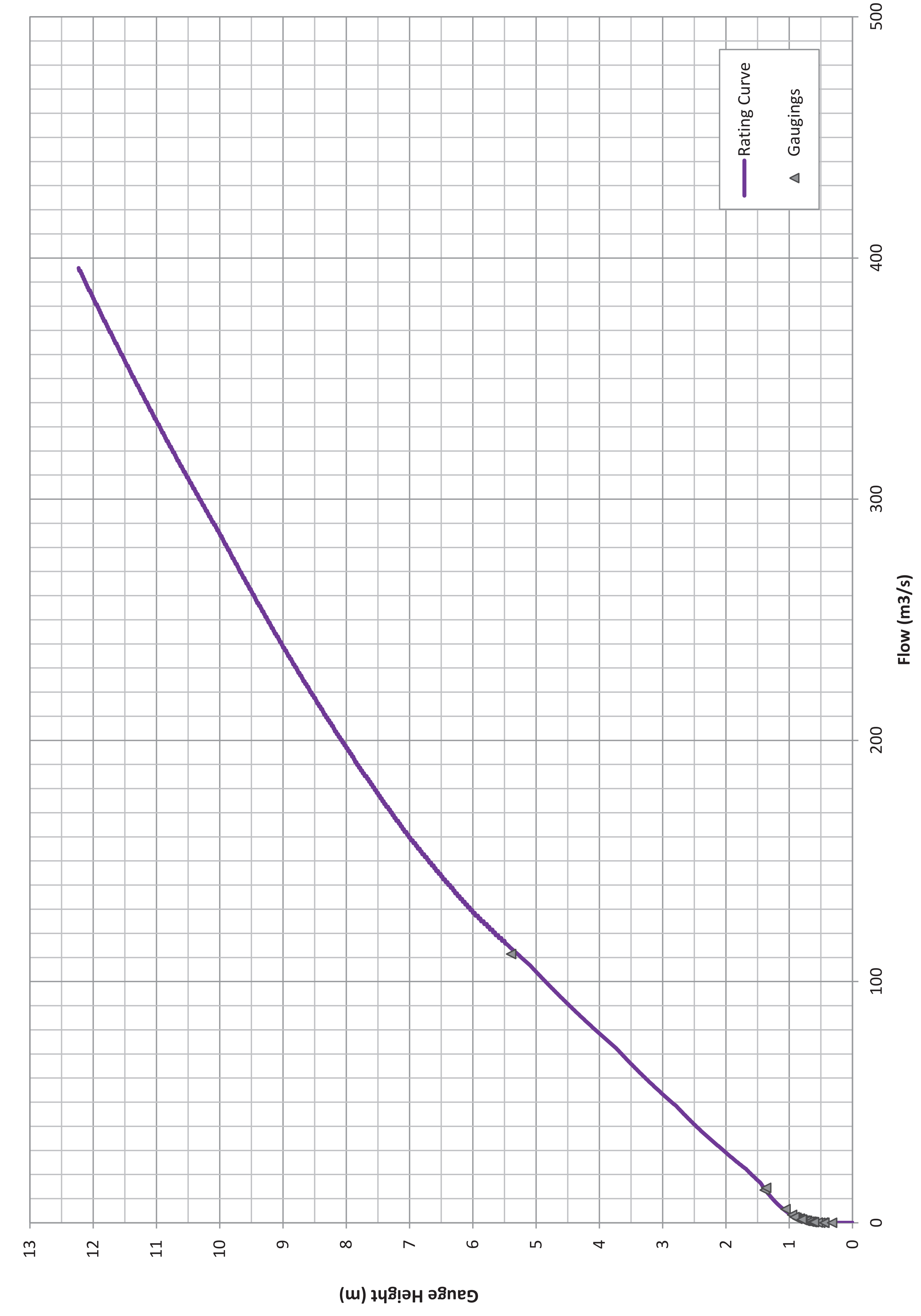

FIGURE 8
PATERSON RIVER GOSTWYCK PINEENA - 2100079
RATING CURVE AND GAUGINGS

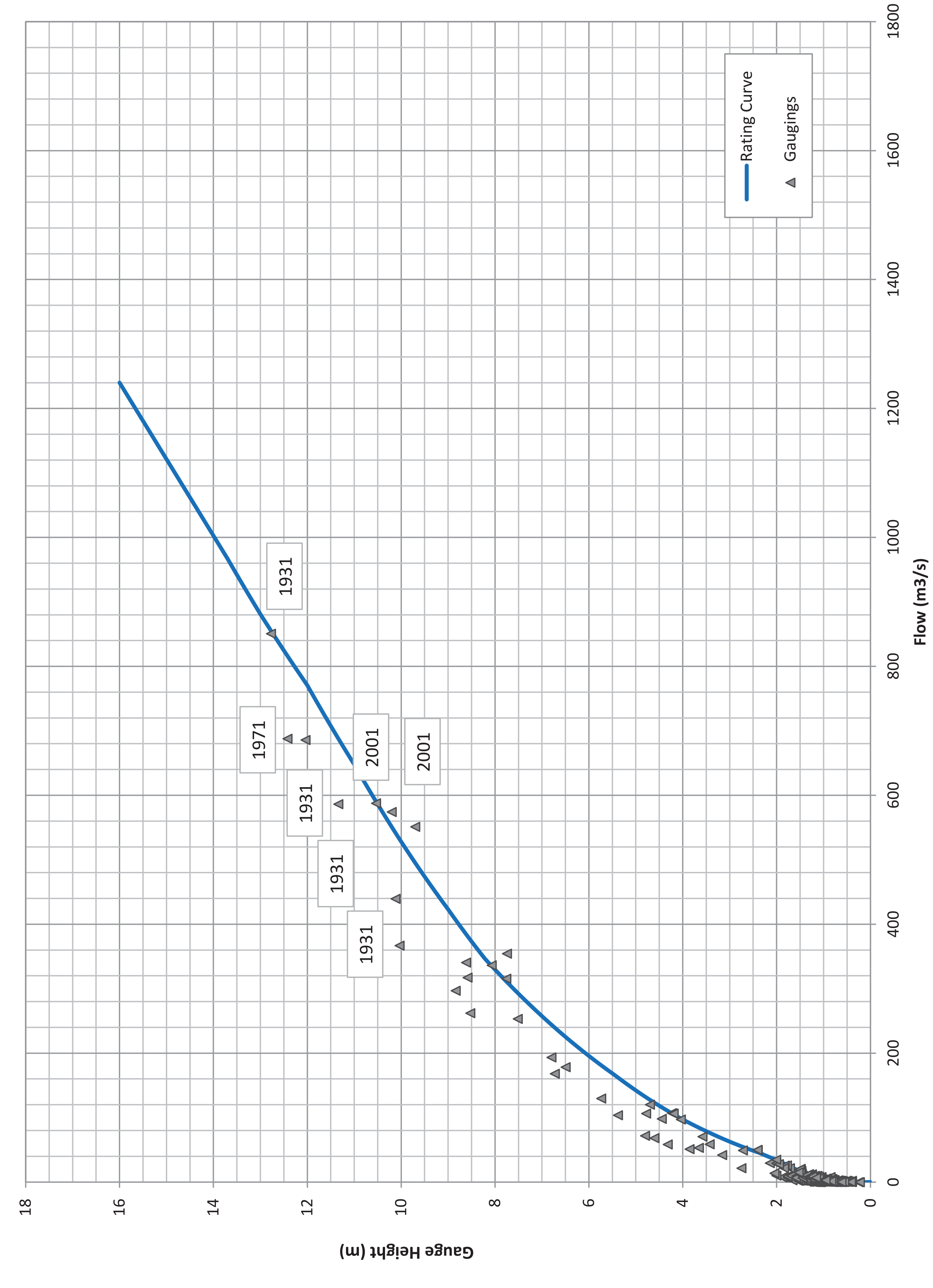

FIGURE 9
WATER LEVEL DATA
MARCH 1977 EVENT

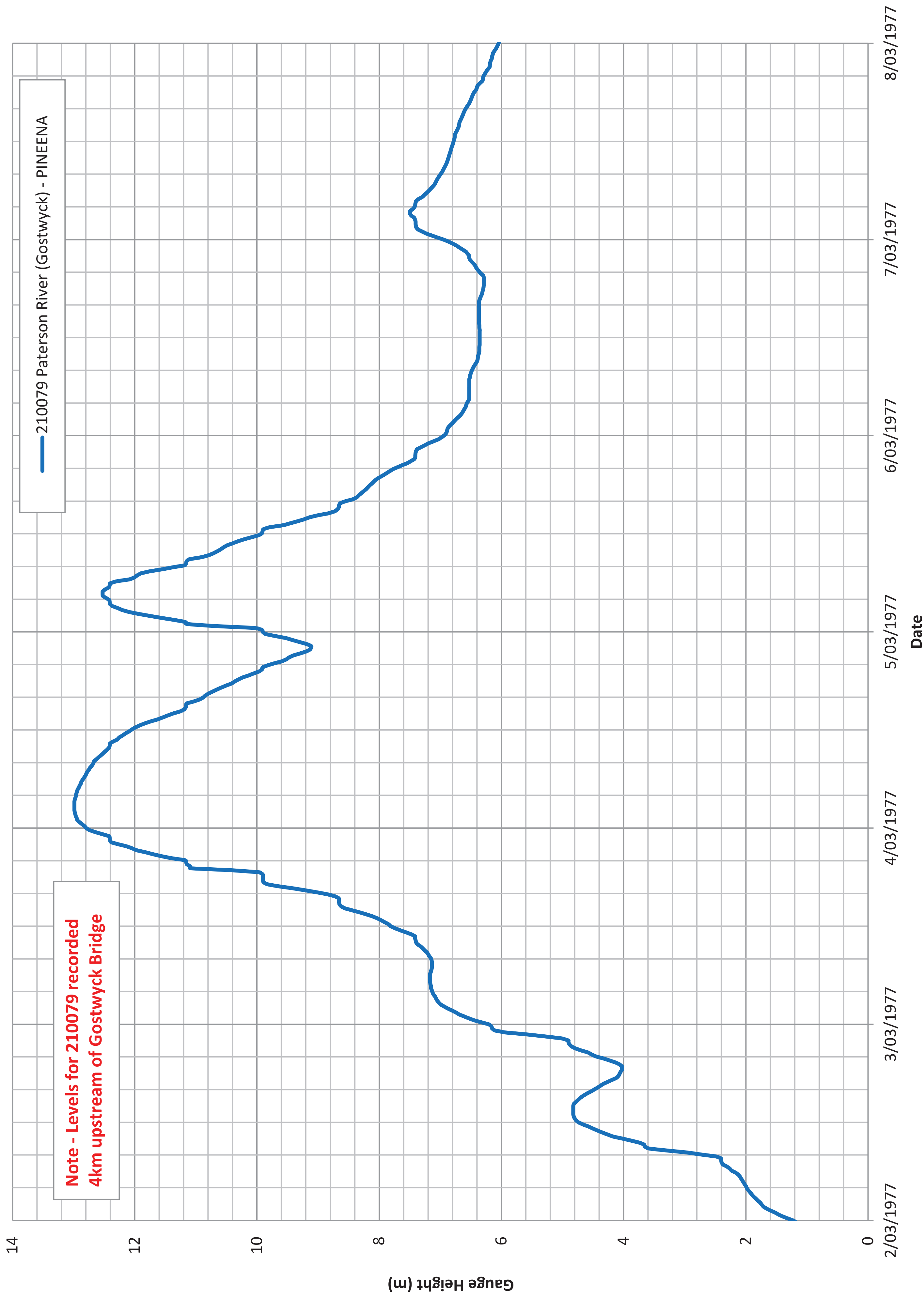

FIGURE 10
WATER LEVEL DATA
MARCH 1978 EVENT

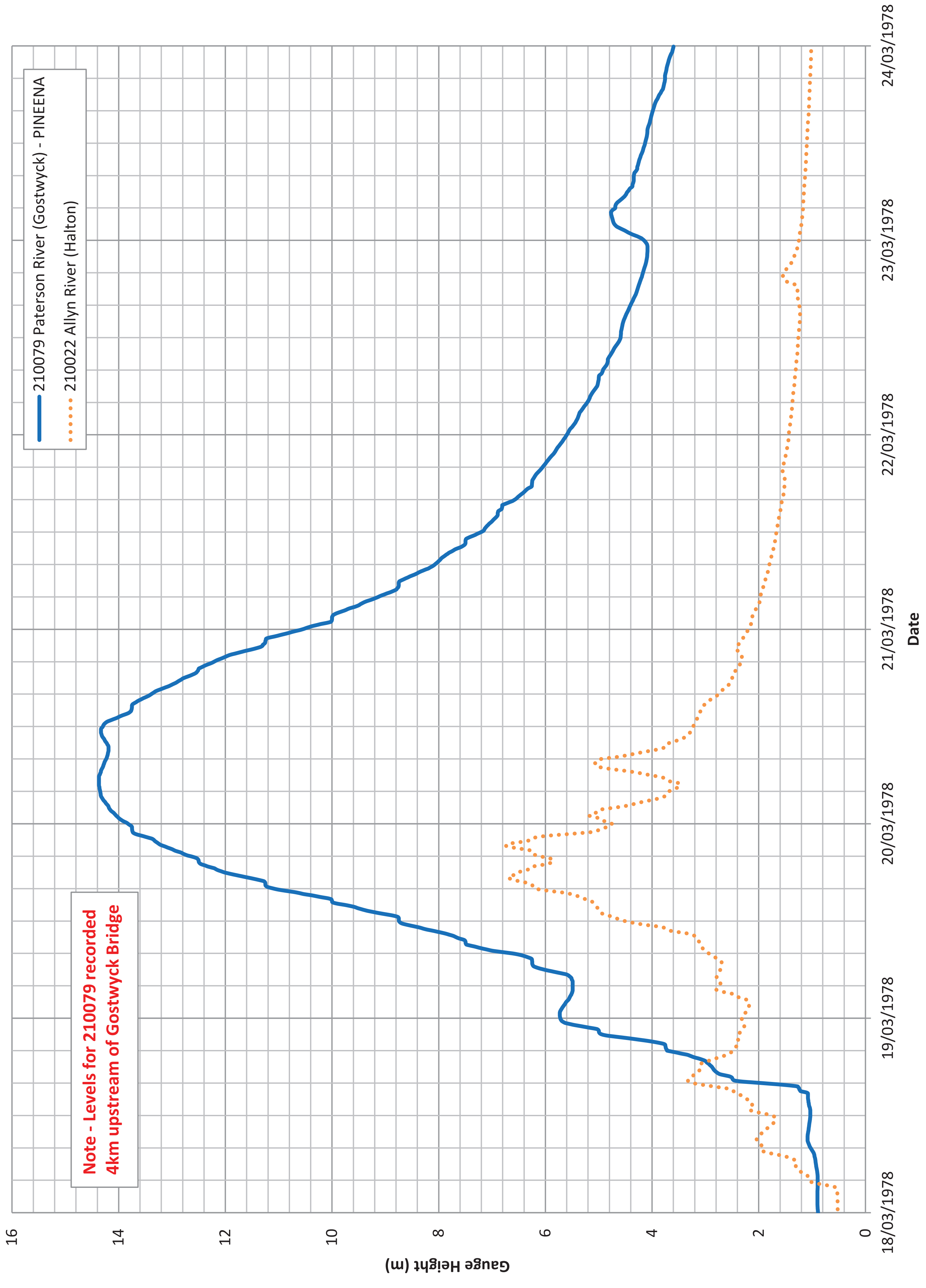

FIGURE 11
WATER LEVEL DATA
OCTOBER 1985 EVENT

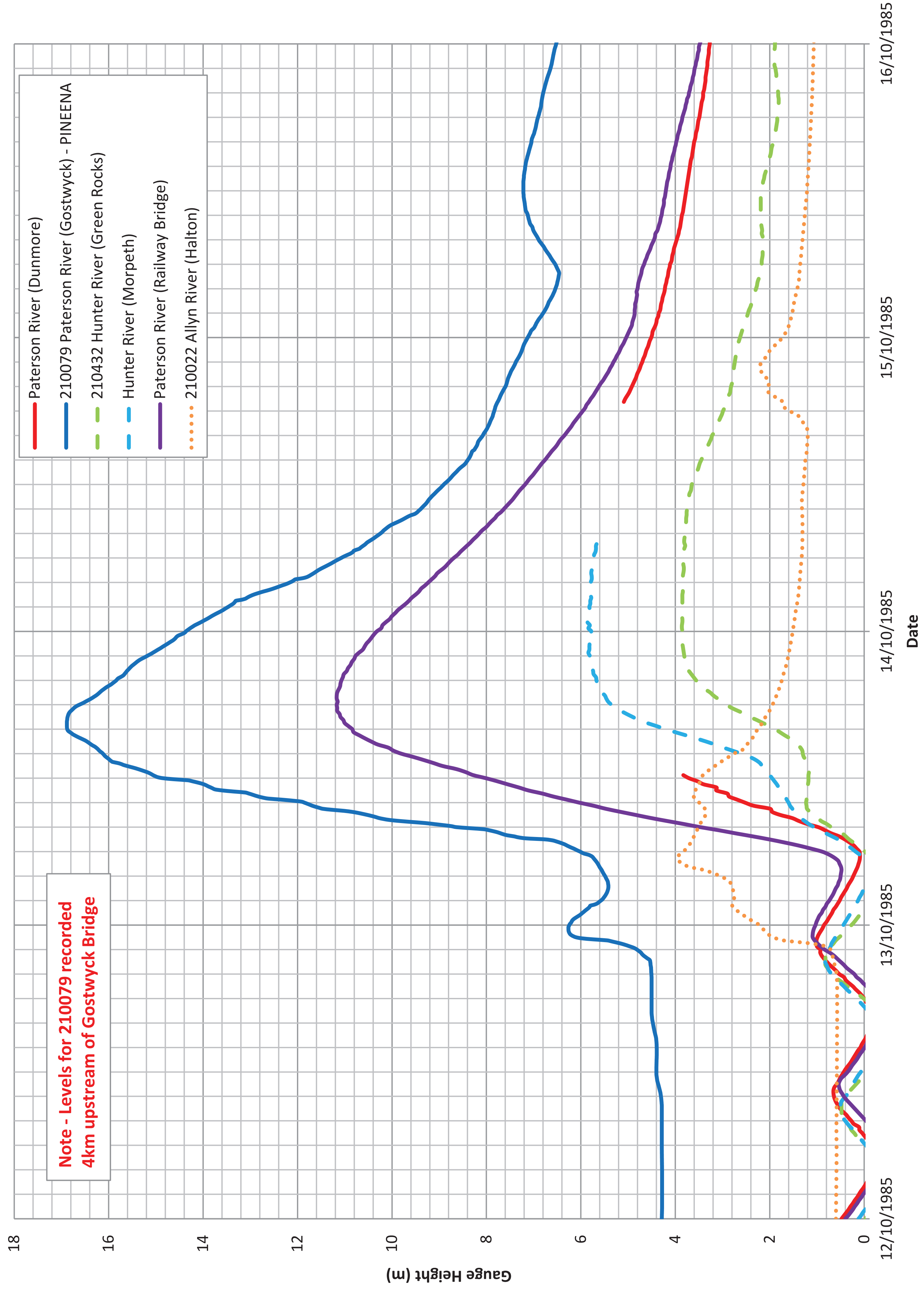

FIGURE 12
WATER LEVEL DATA
FEBRUARY 1990 EVENT

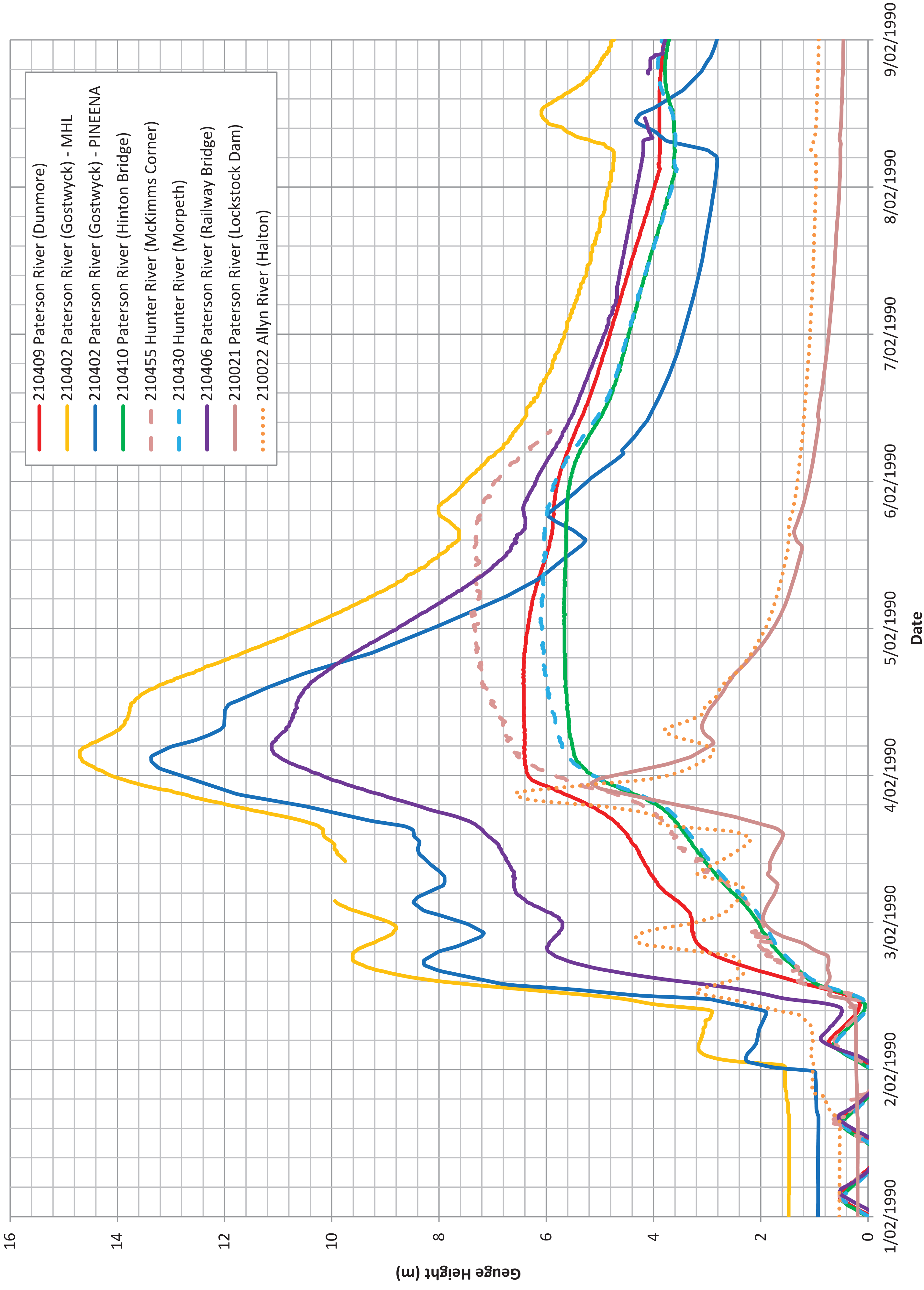

FIGURE 13
WATER LEVEL DATA
MARCH 1995 EVENT

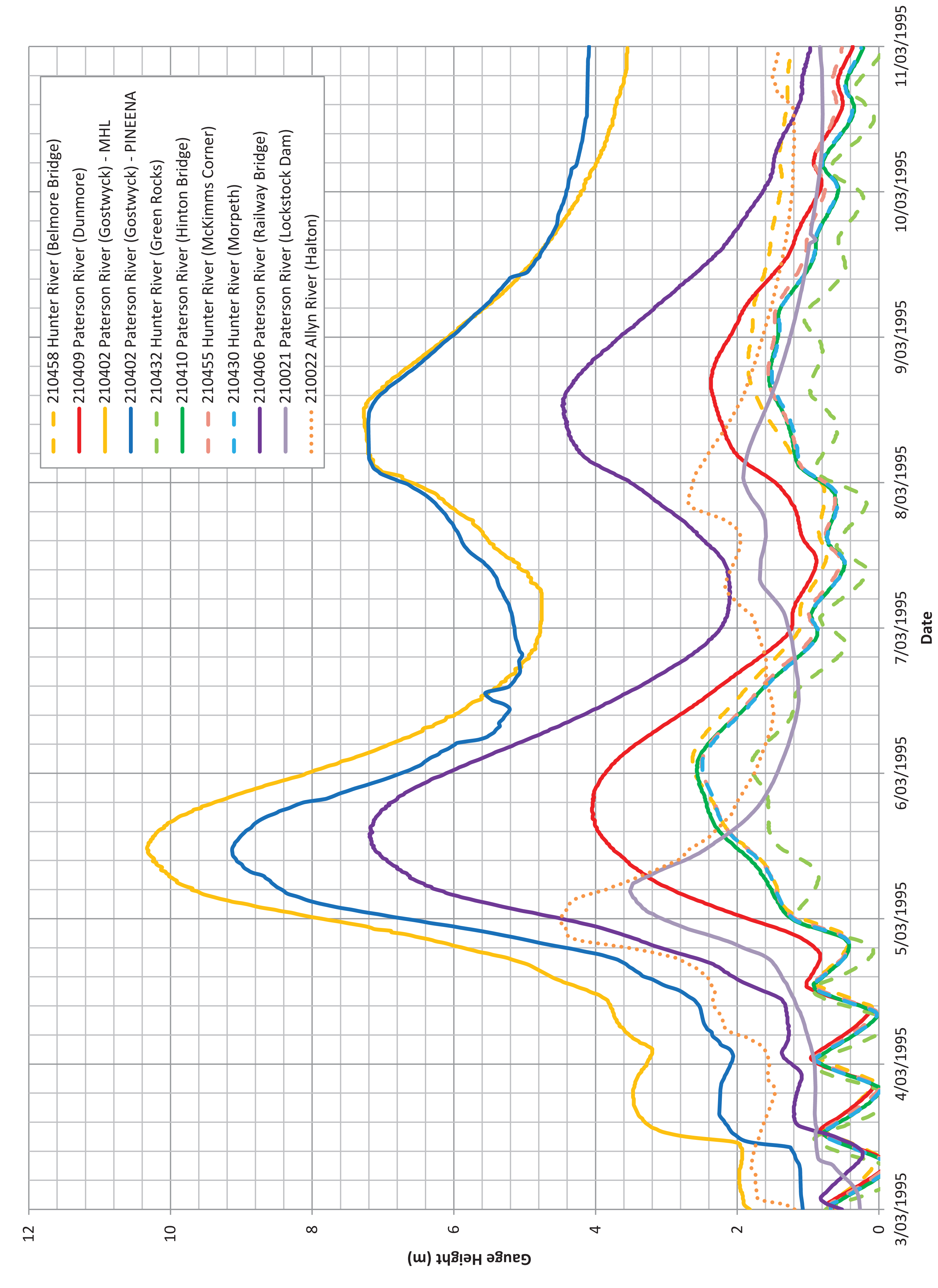

FIGURE 14
WATER LEVEL DATA
MARCH 2001 EVENT

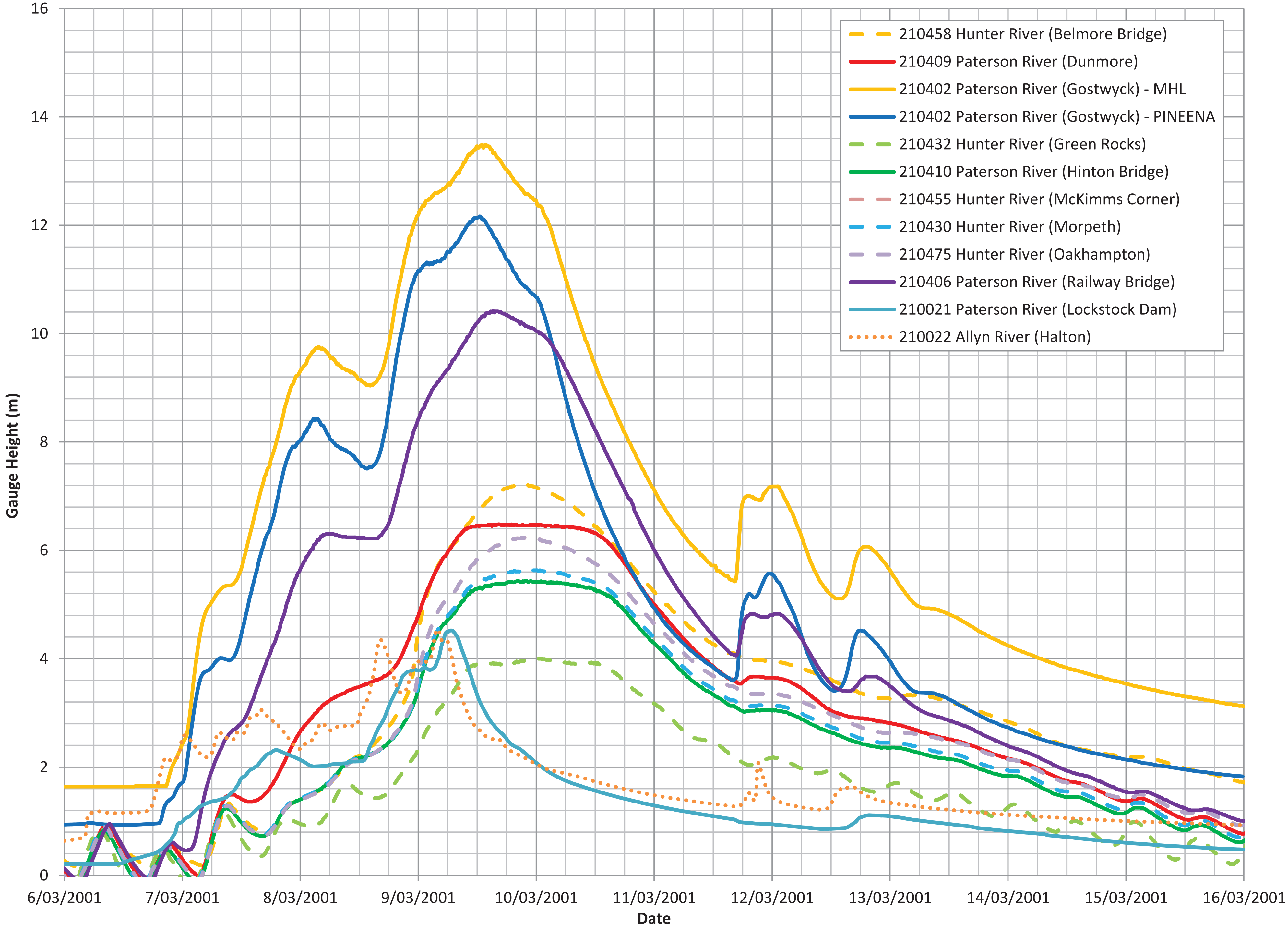

FIGURE 15
WATER LEVEL DATA
JUNE 2007 EVENT

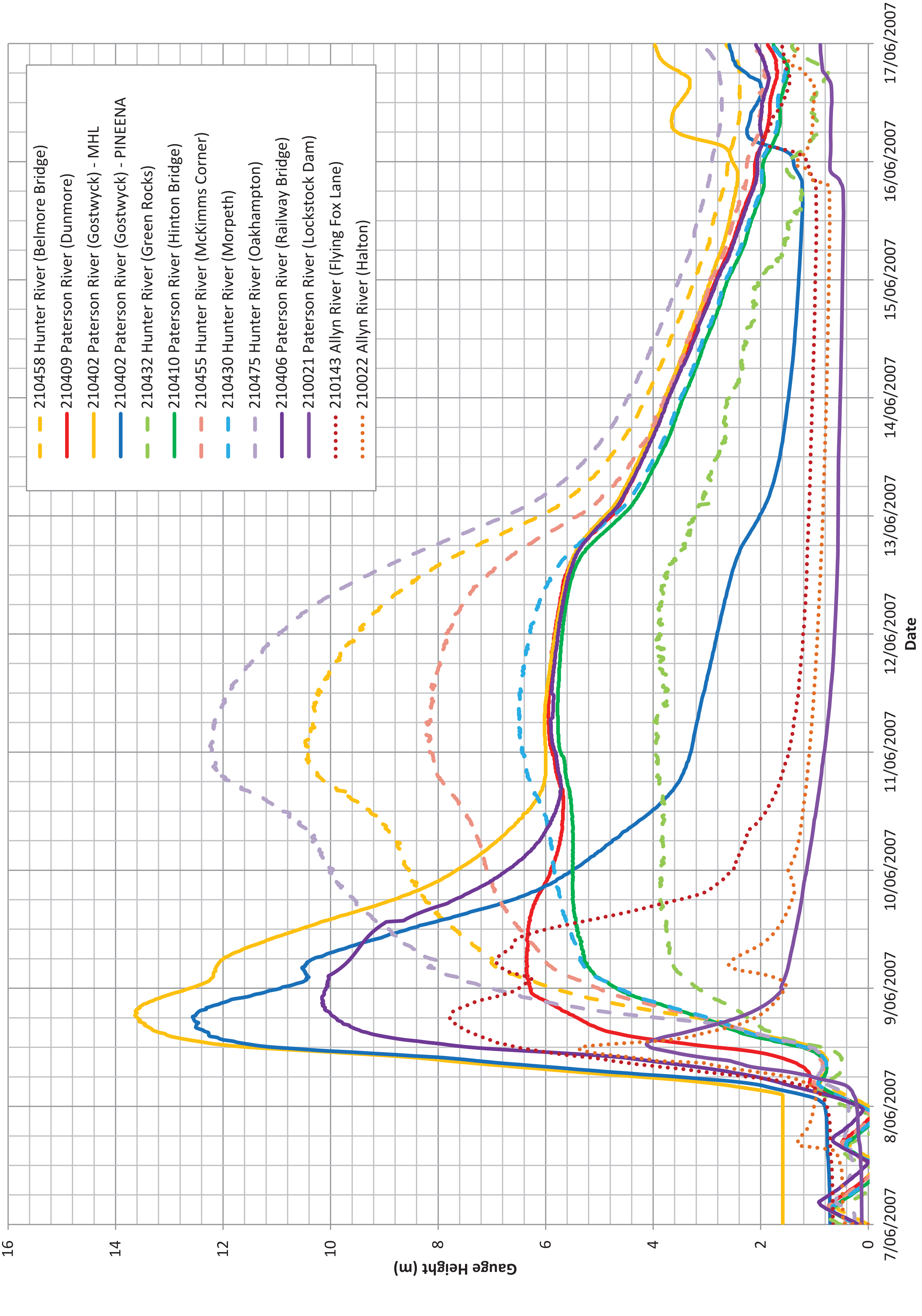

FIGURE 16

WATER LEVEL DATA

JUNE 2011 EVENT

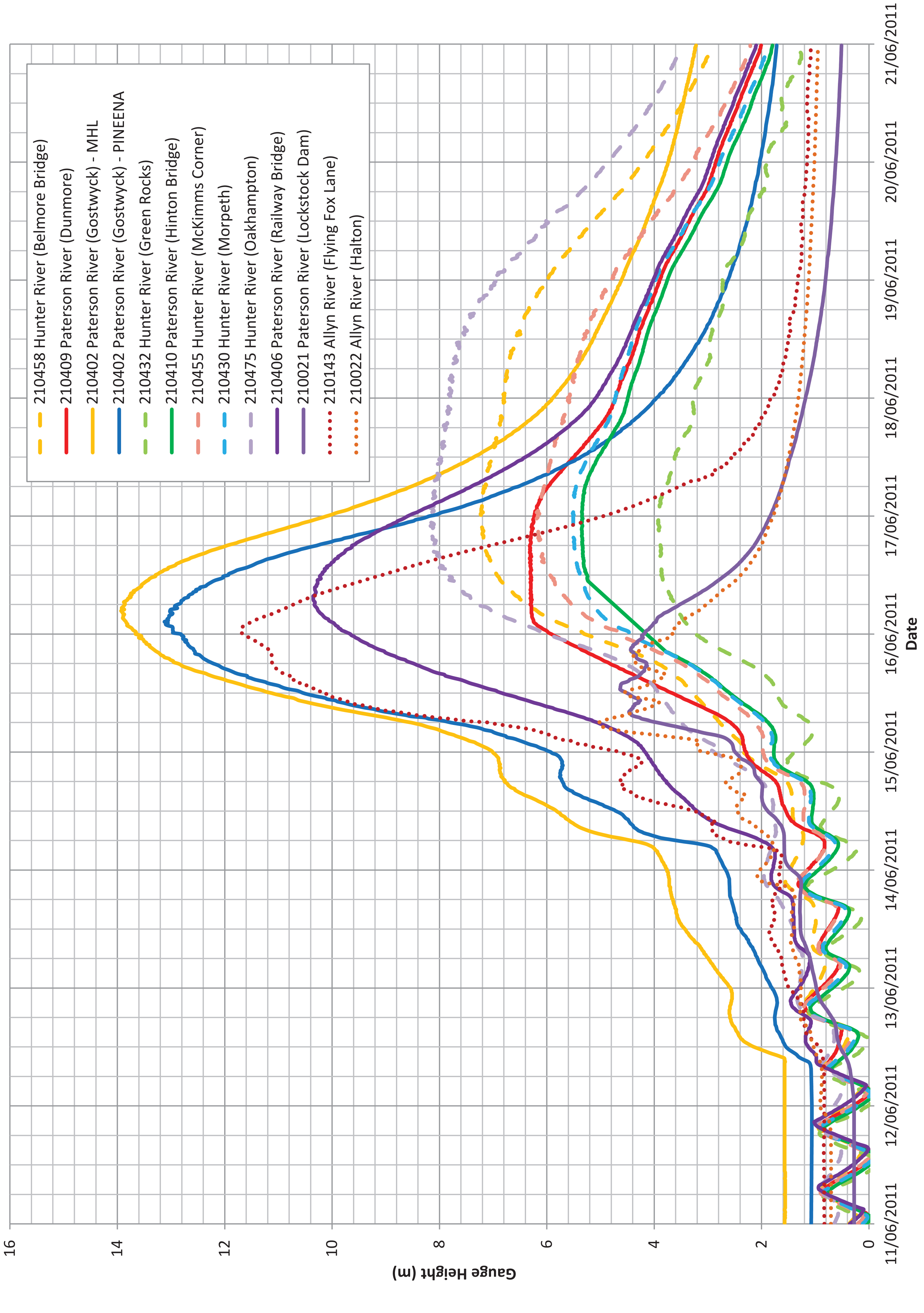

FIGURE 17
WATER LEVEL DATA
MARCH 2013 EVENT

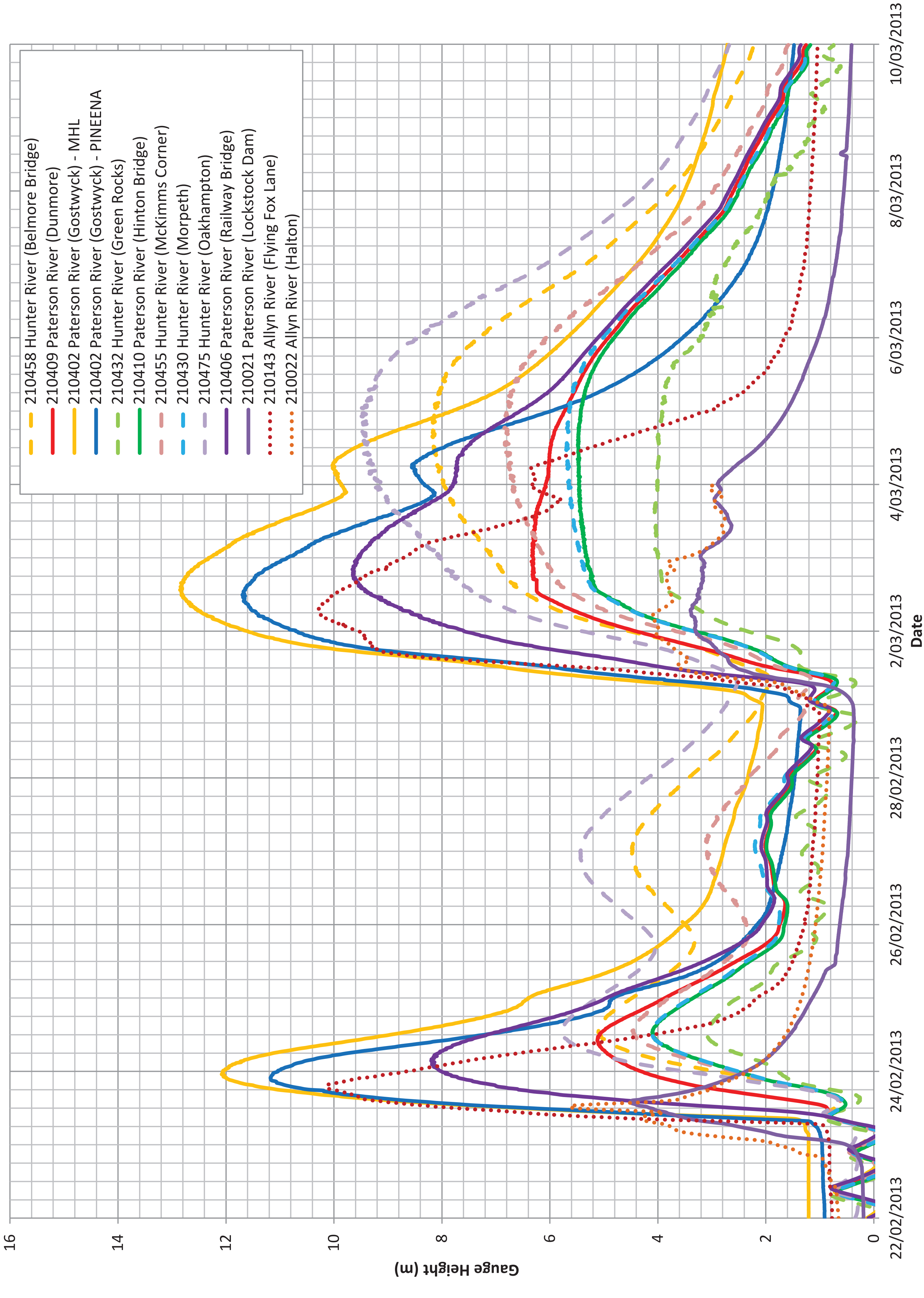

FIGURE 18
WATER LEVEL DATA
NOVEMBER 2013 EVENT

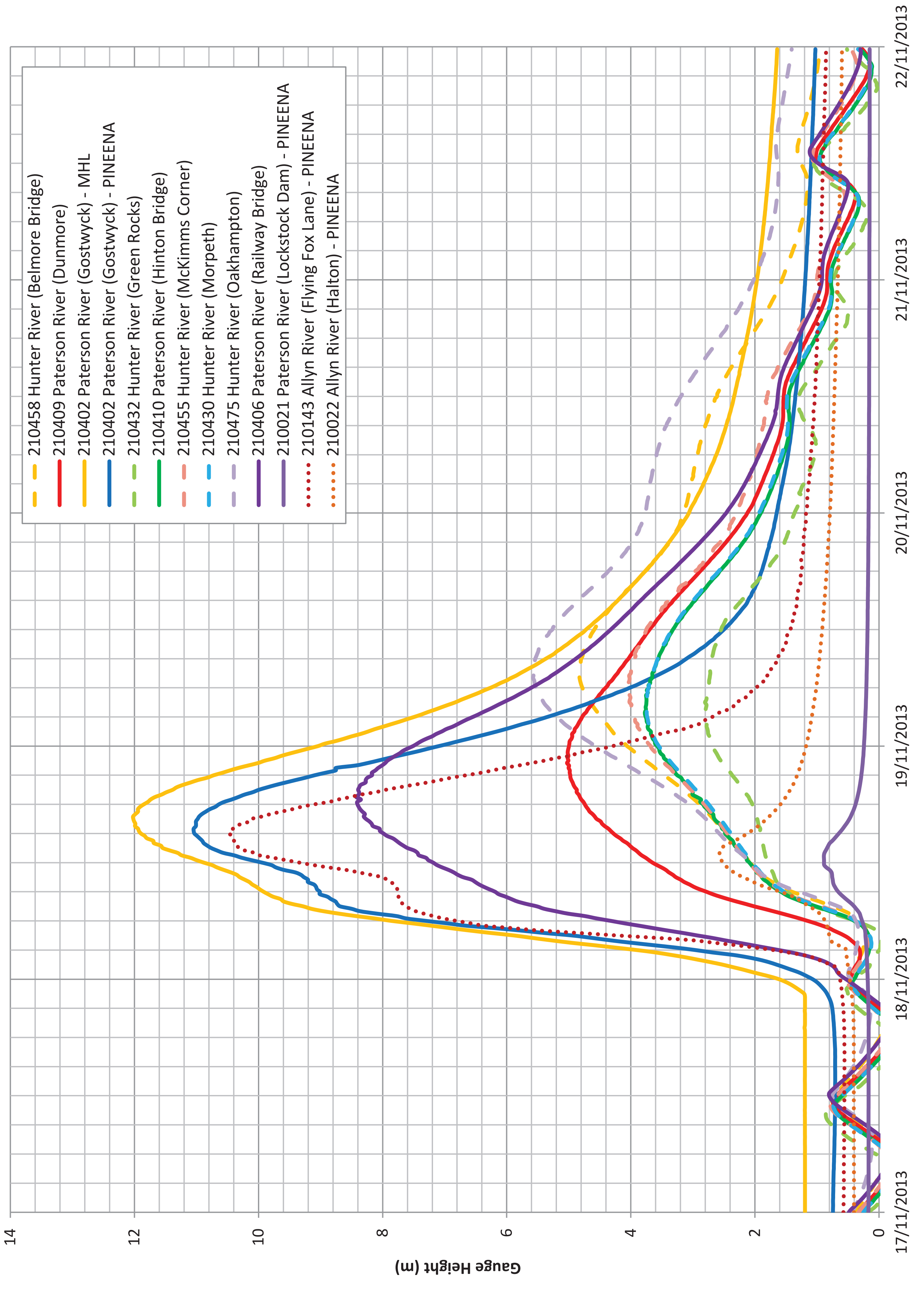

FIGURE 19
WATER LEVEL DATA
APRIL 2015 EVENT

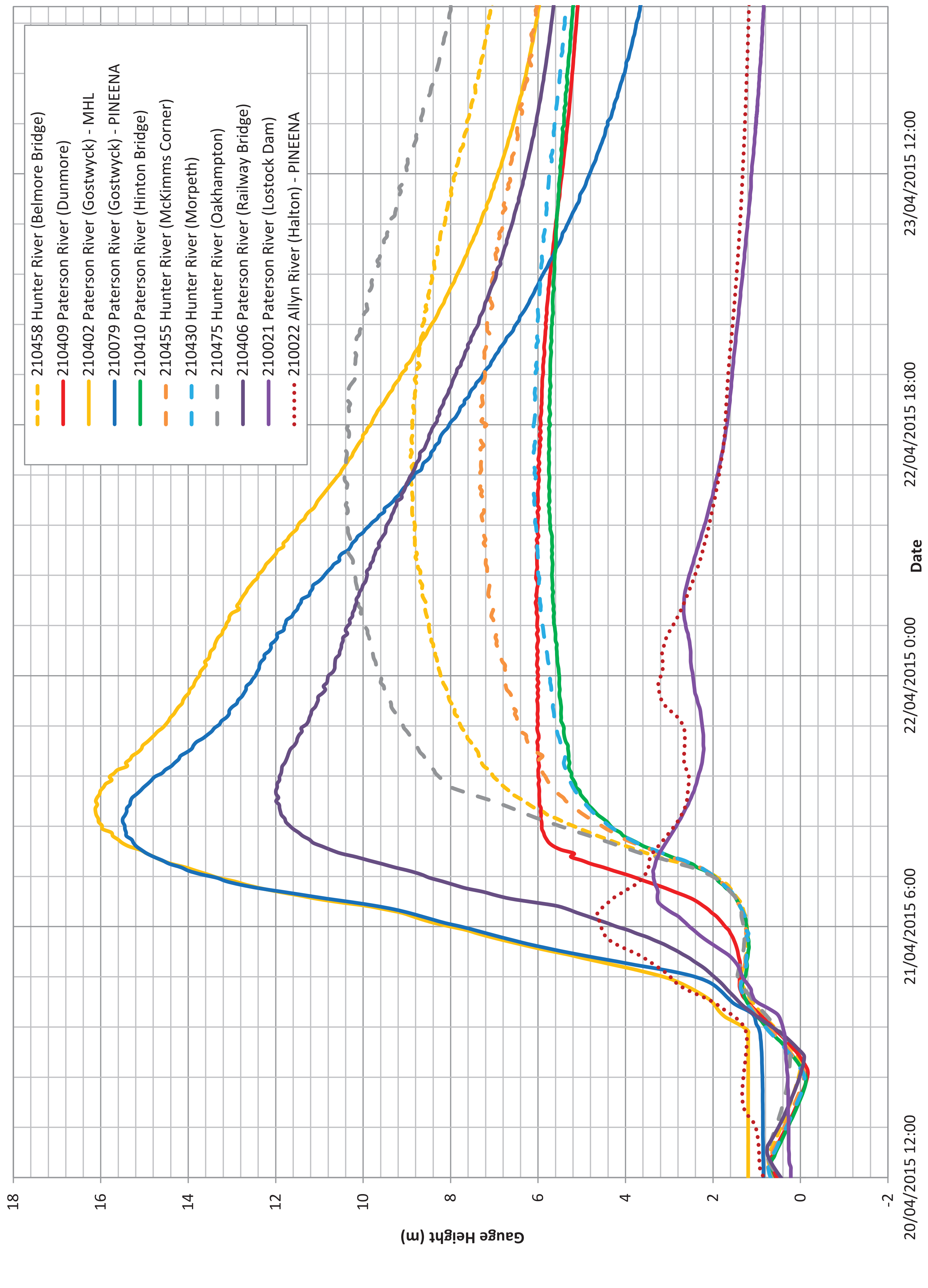

FIGURE 20
PLUVIOMETER RAIN GAUGES

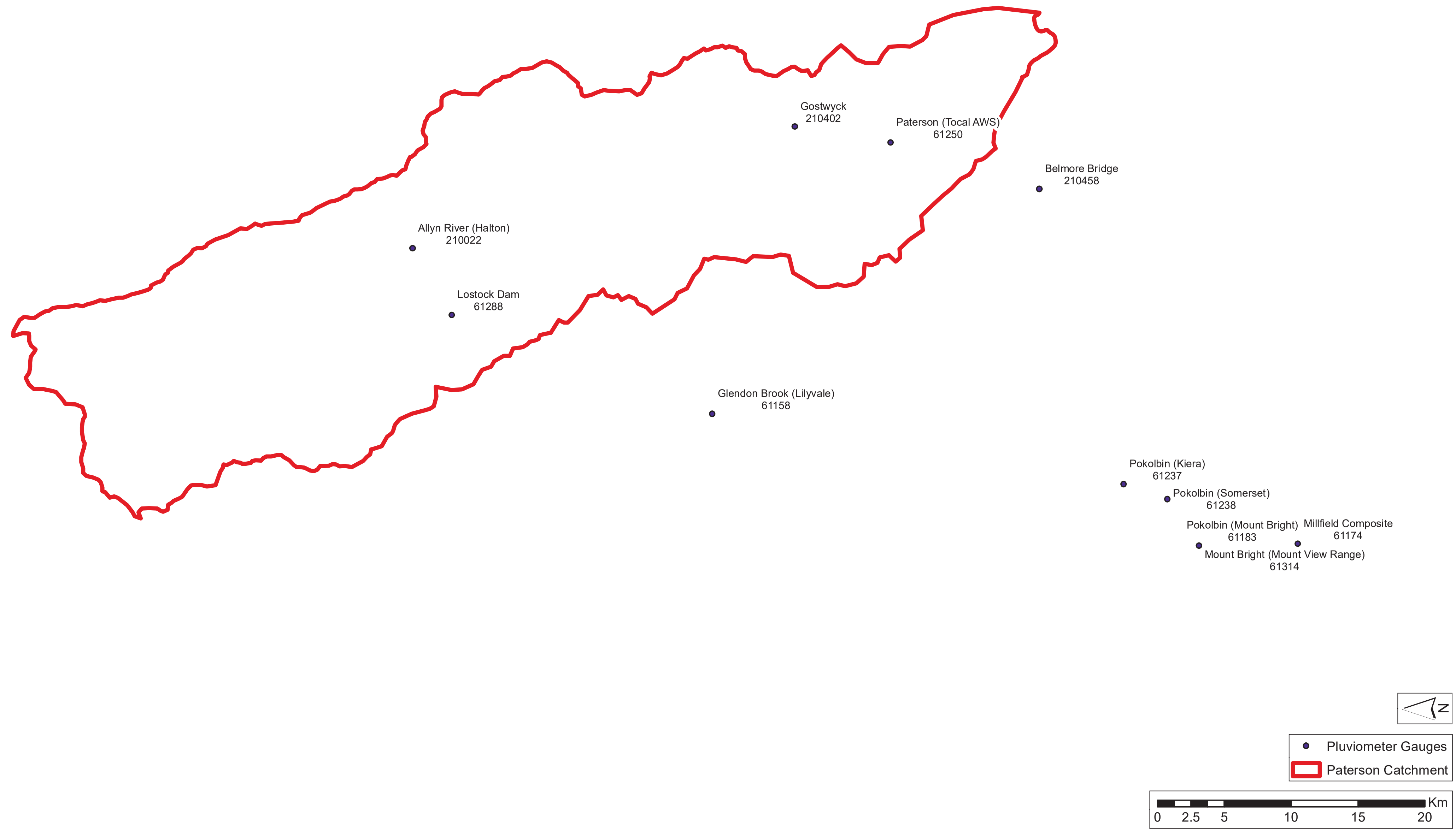

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FIGURE 21
DAILY RAINFALL GAUGES

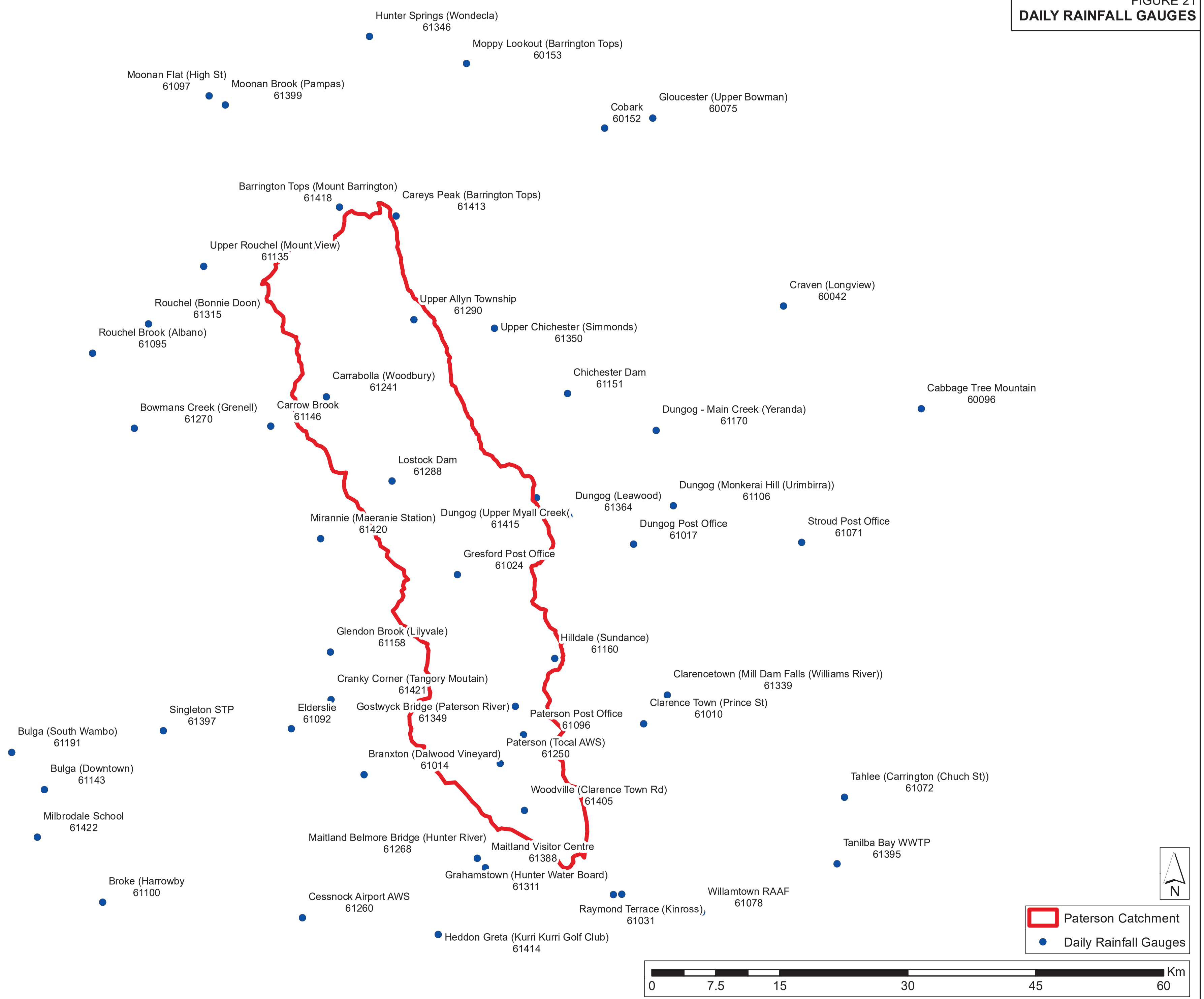

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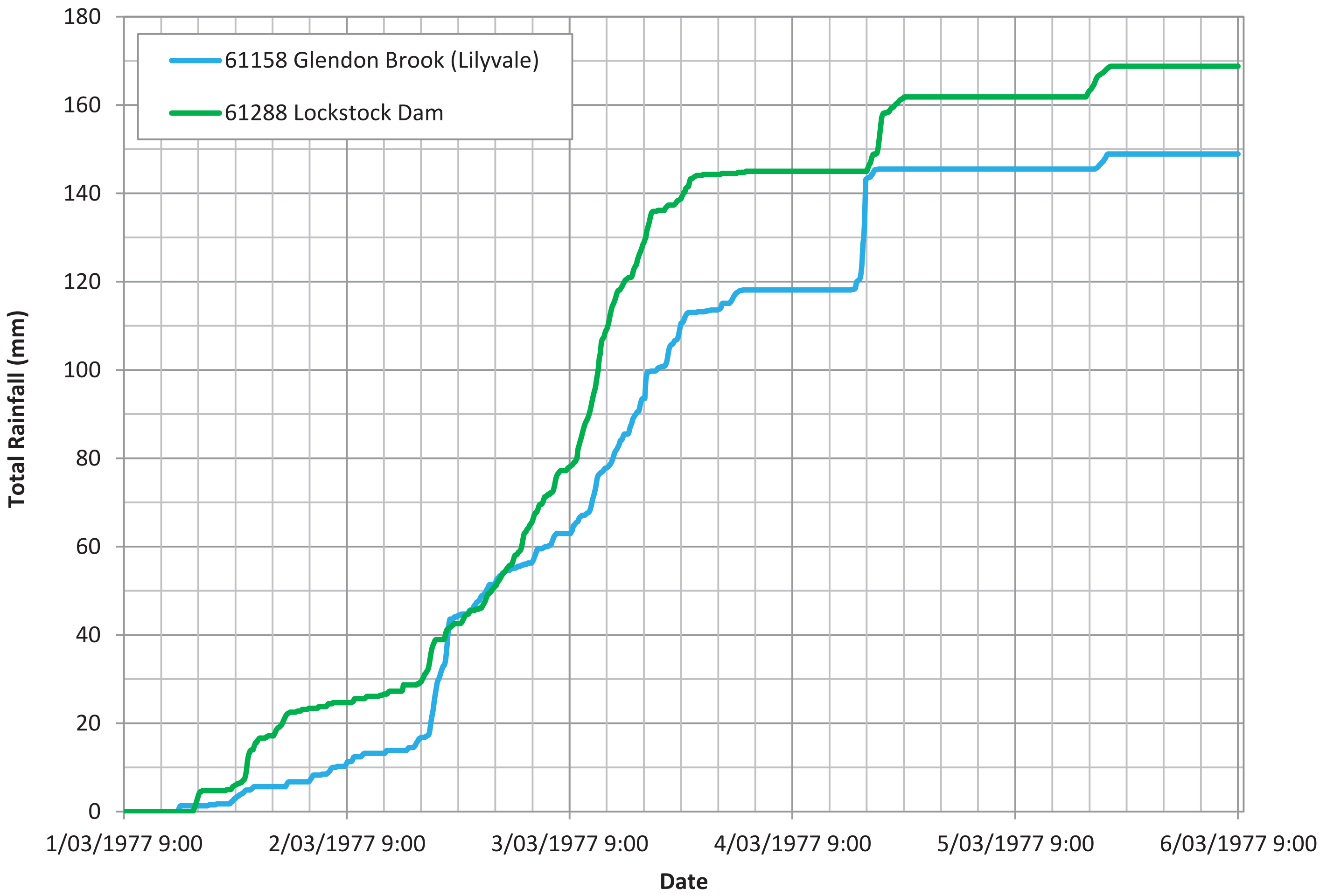
FIGURE 22
RAINFALL DATA
MARCH 1977 EVENT



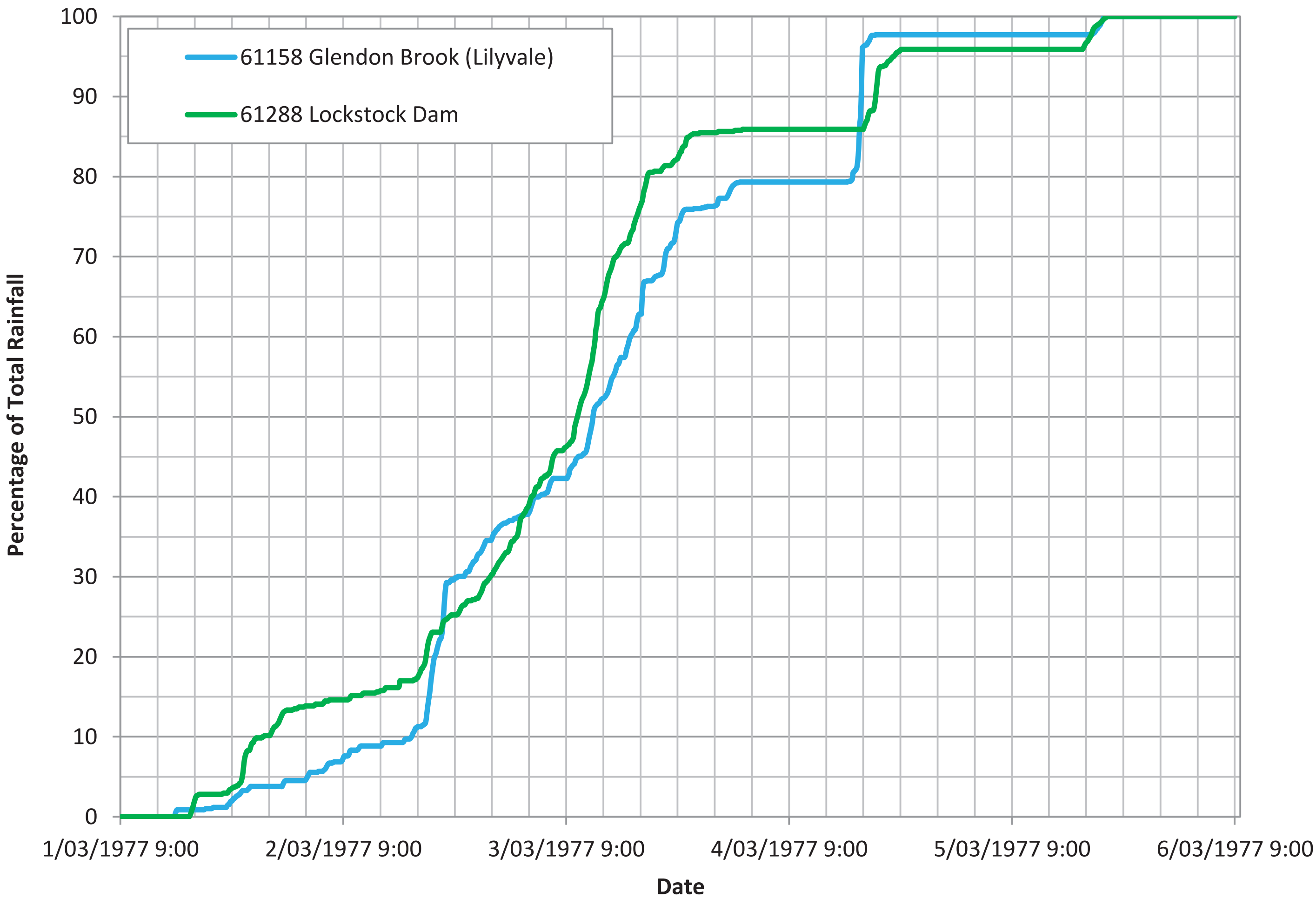
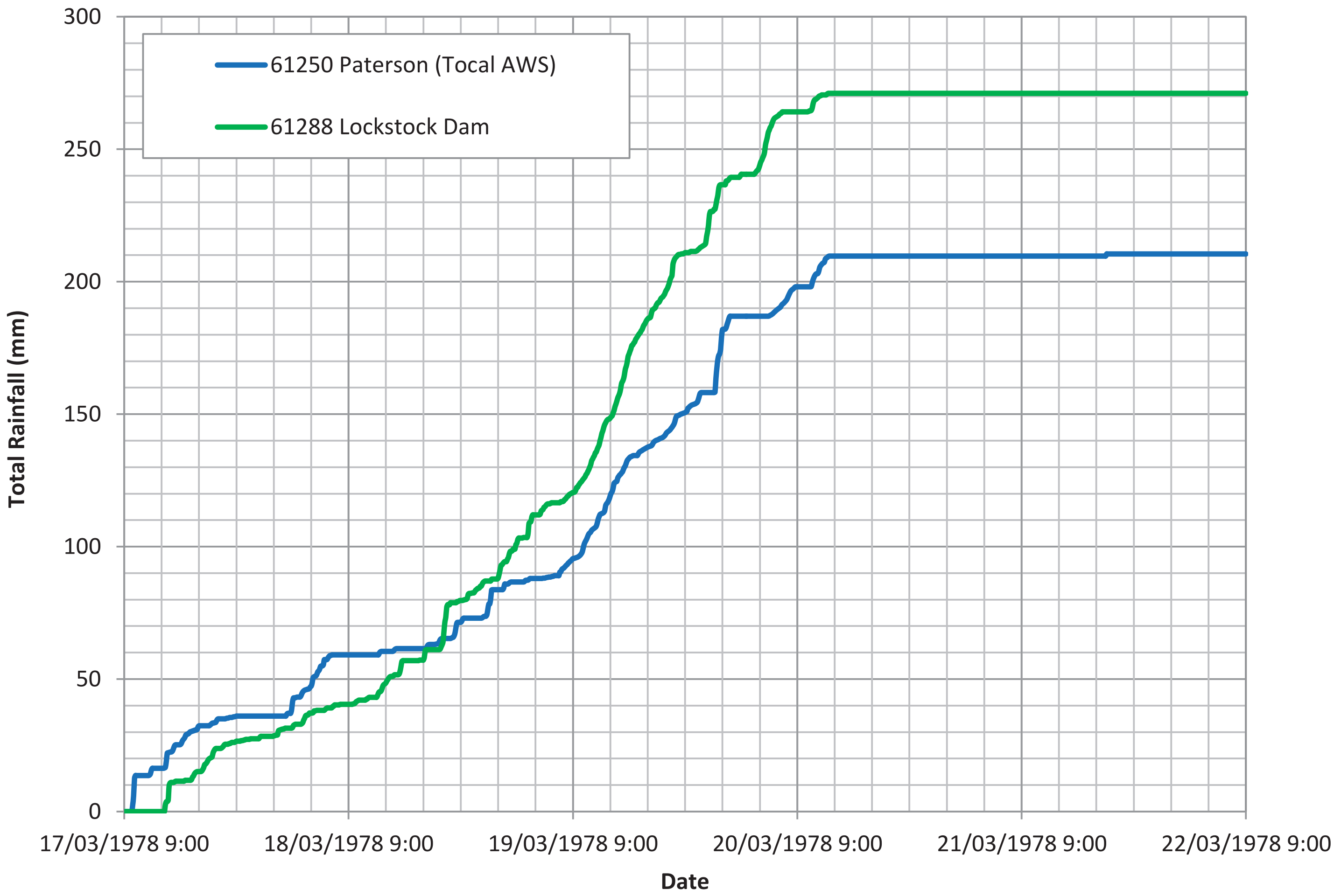


FIGURE 23
RAINFALL L DATA
MARCH 1978 EVENT



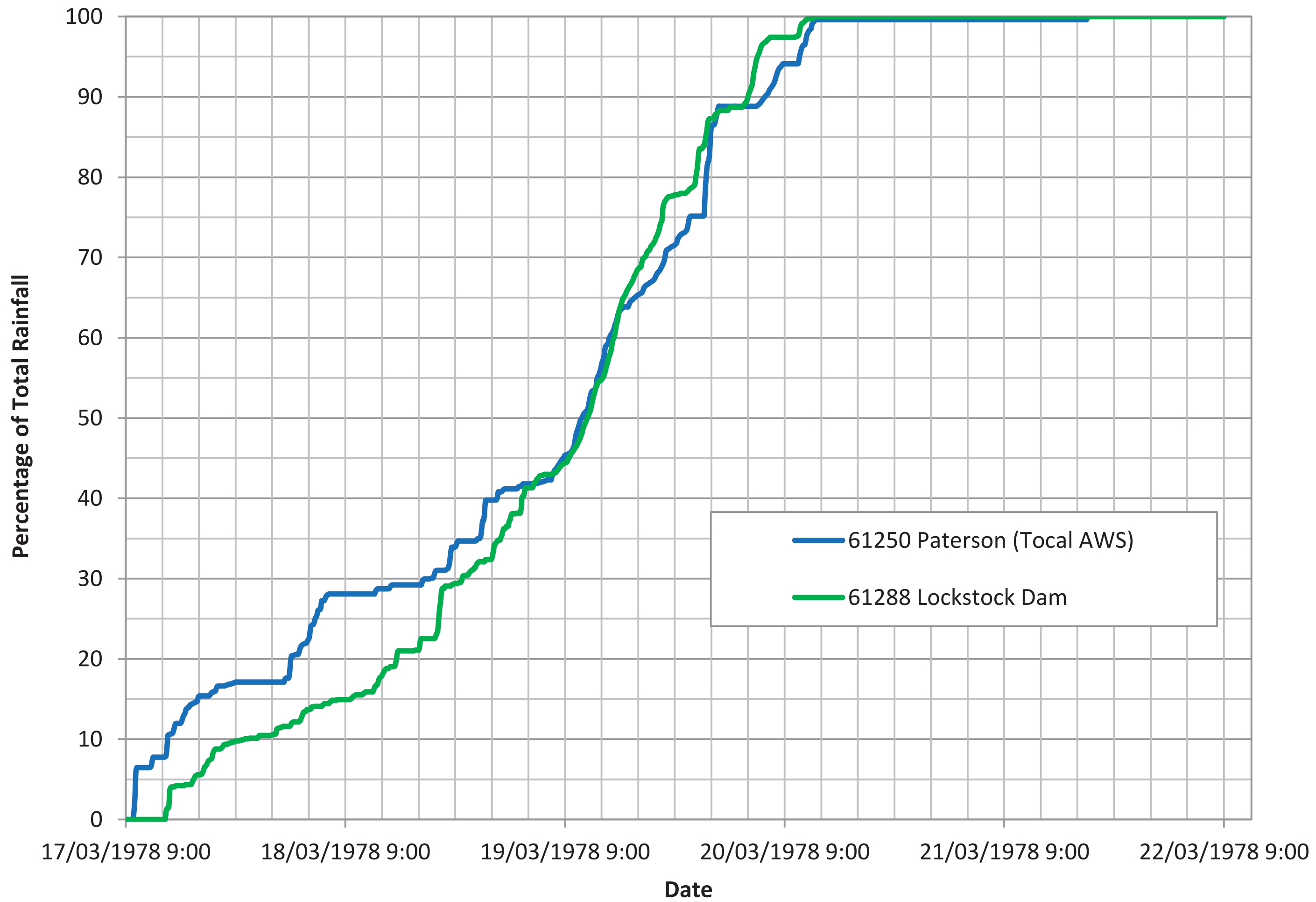


FIGURE 24
RAINFALL DATA
MARCH 2001 EVENT

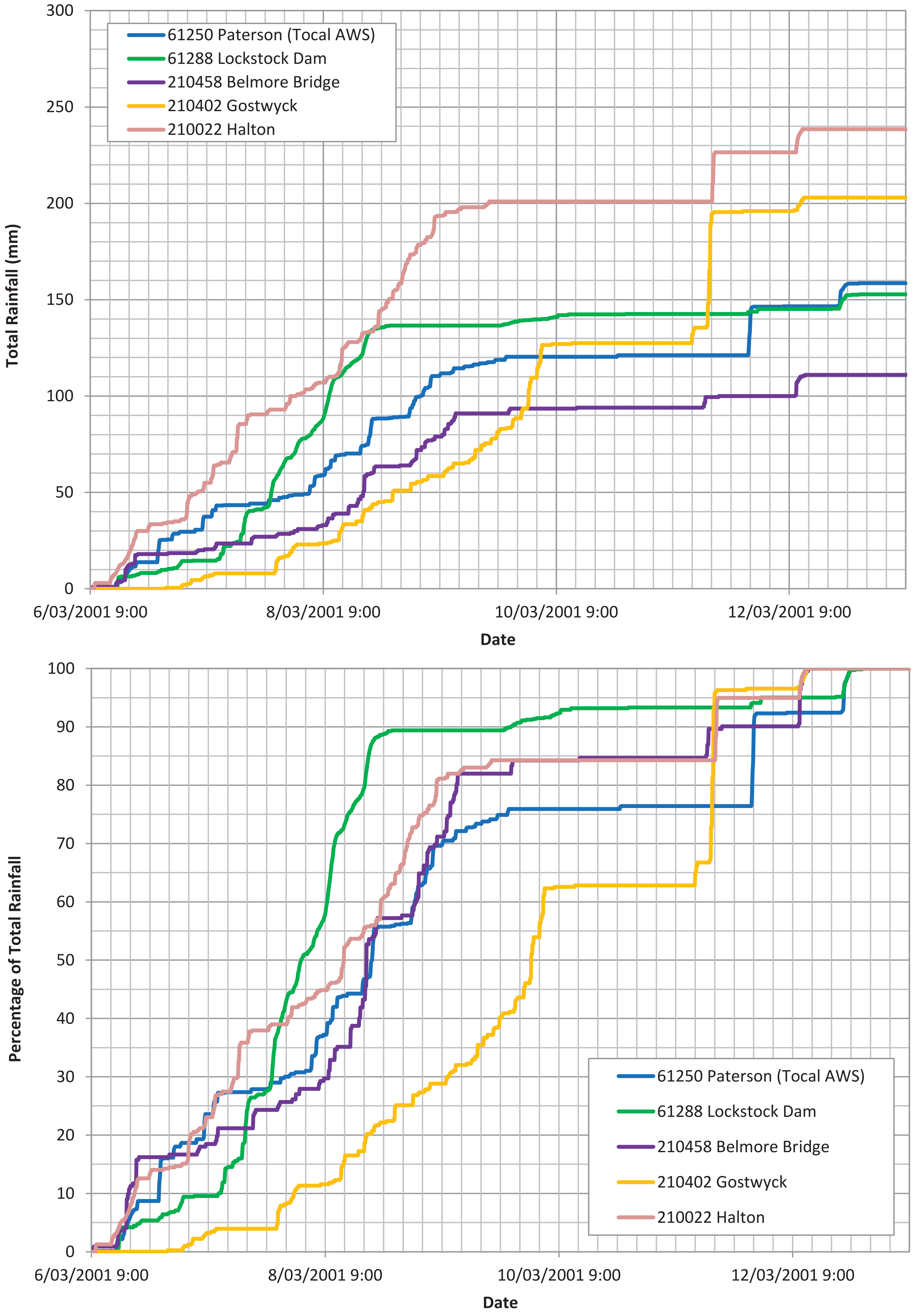
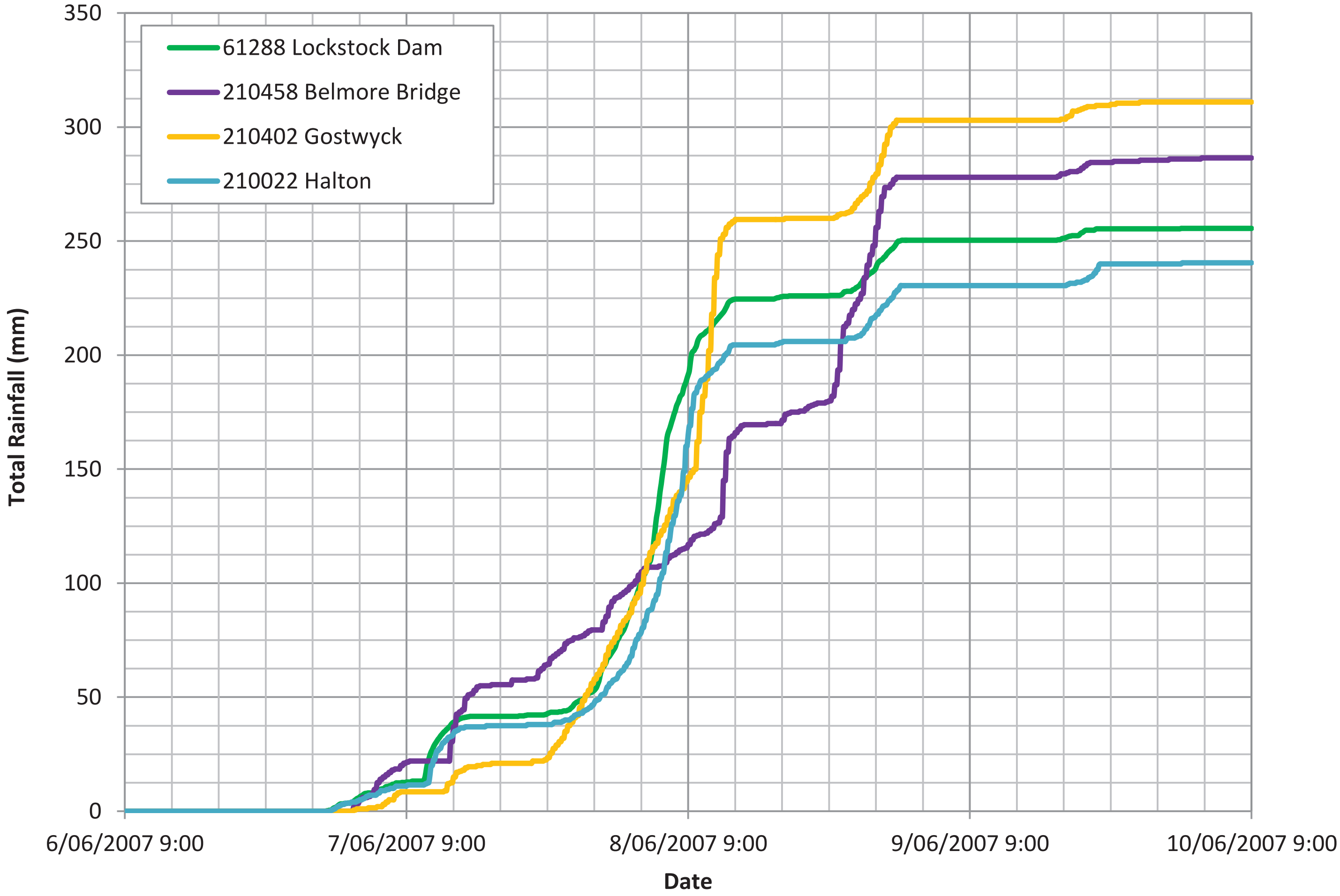


FIGURE 25
RAINFALL DATA
JUNE 2007 EVENT



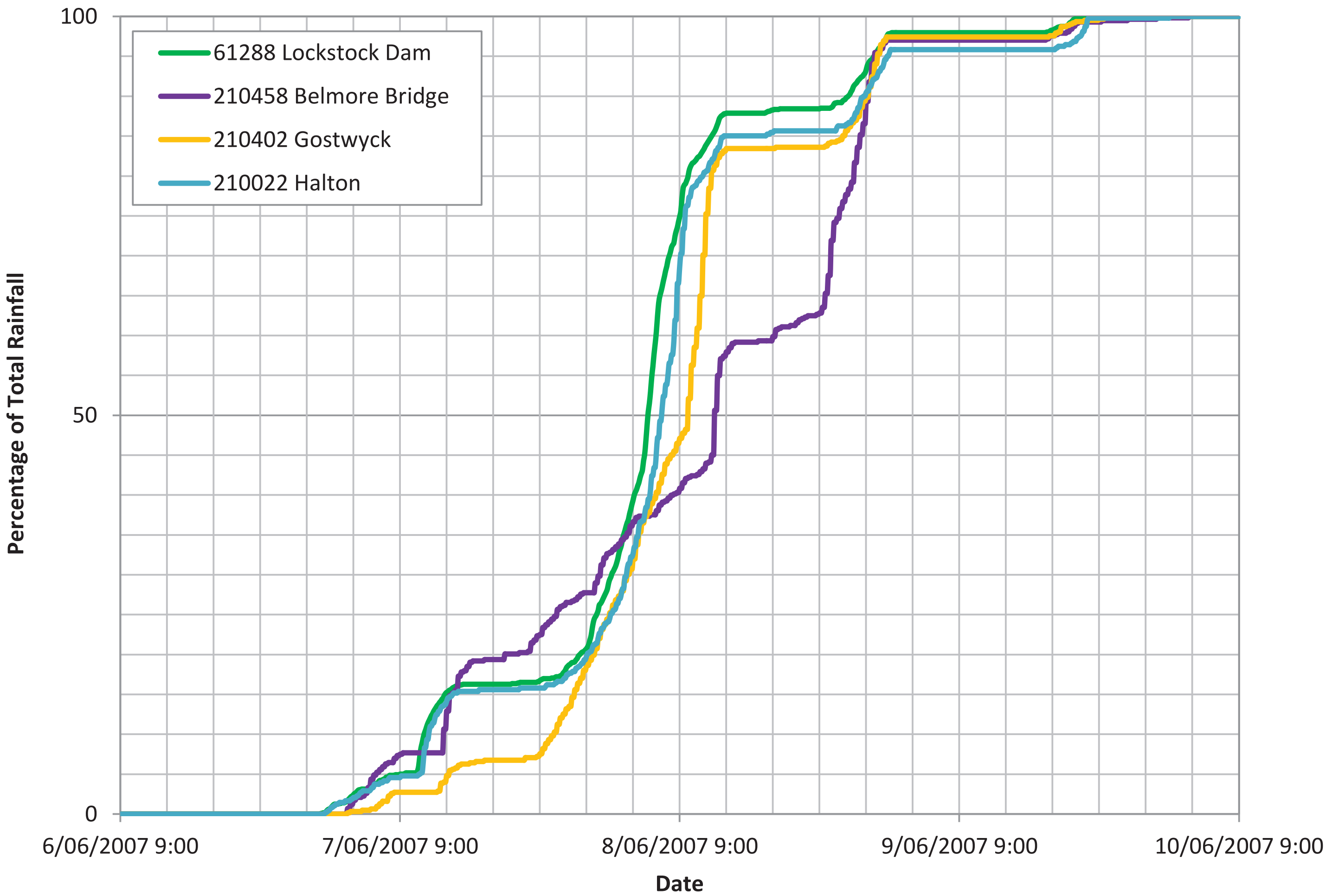
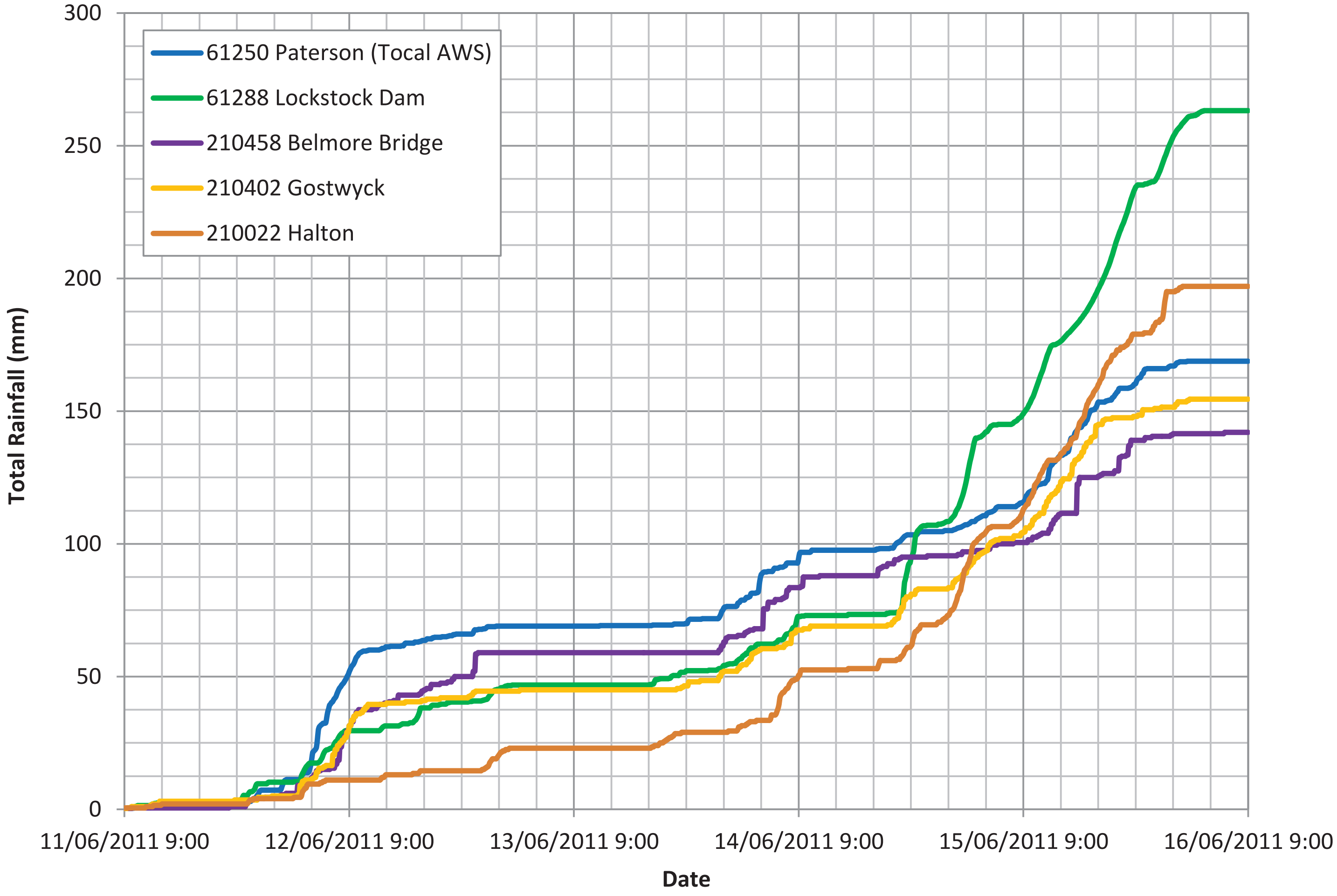


FIGURE 26
RAINFALL DATA
JUNE 2011 EVENT



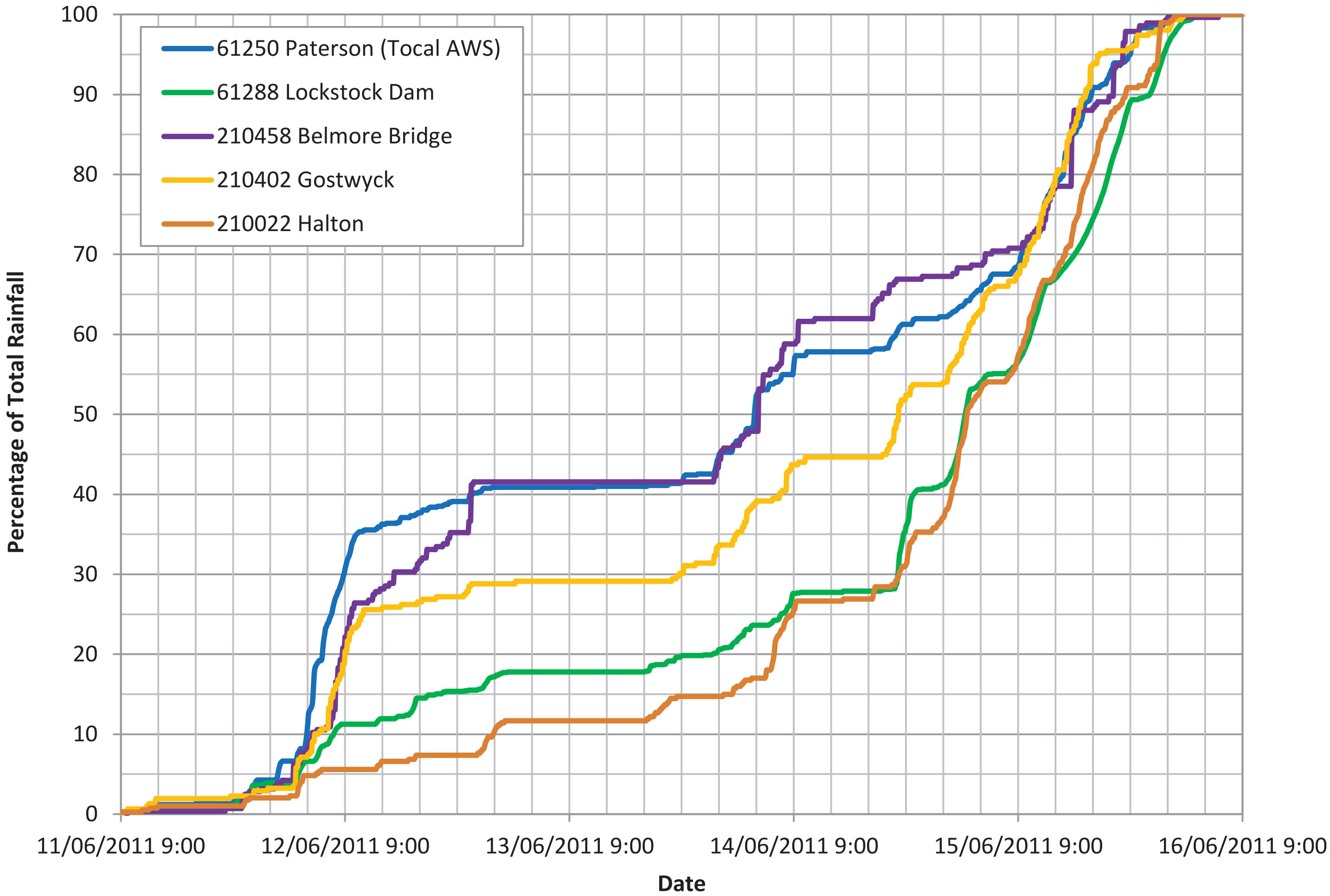
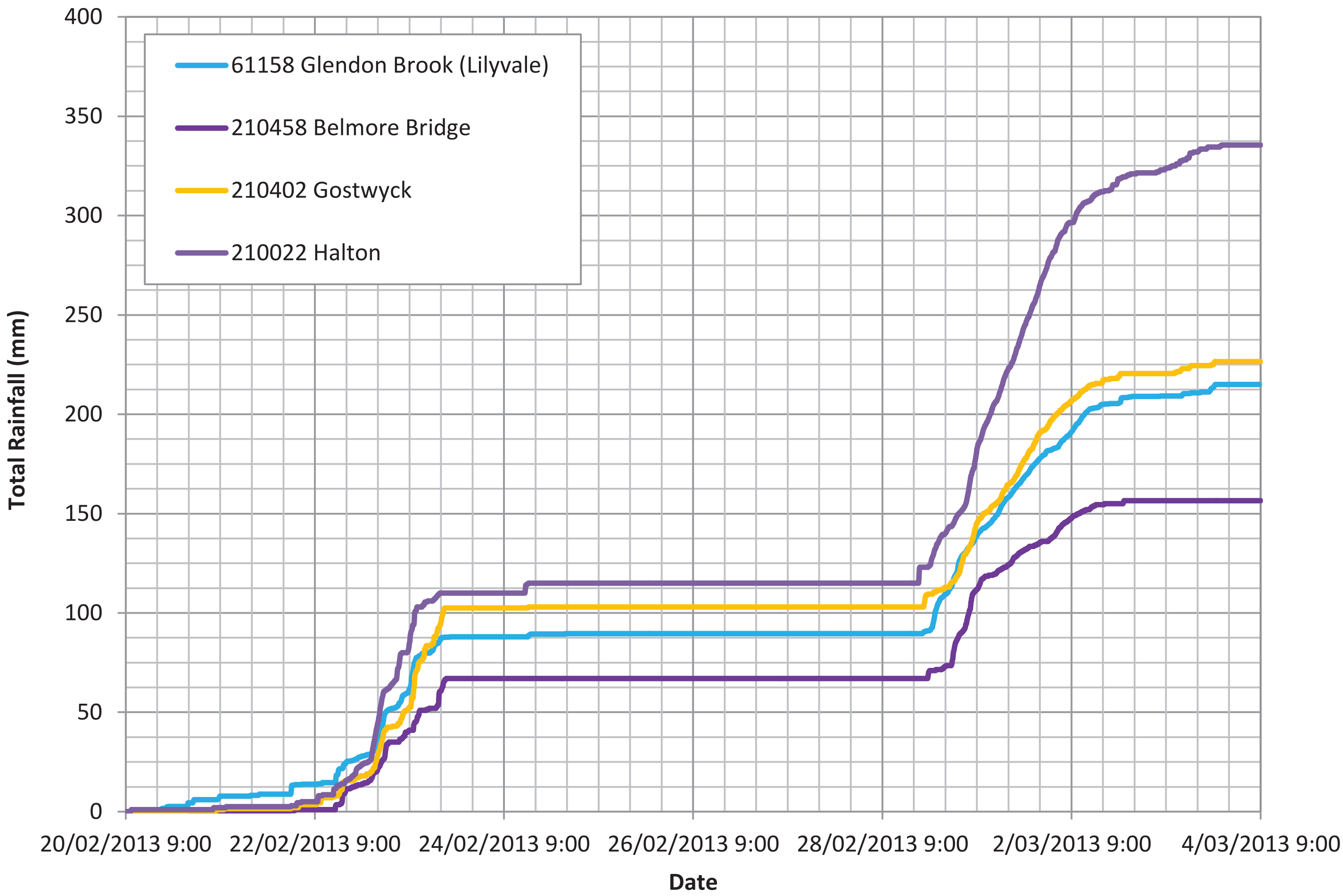


FIGURE 27
RAINFALL DATA
MARCH 2013 EVENT



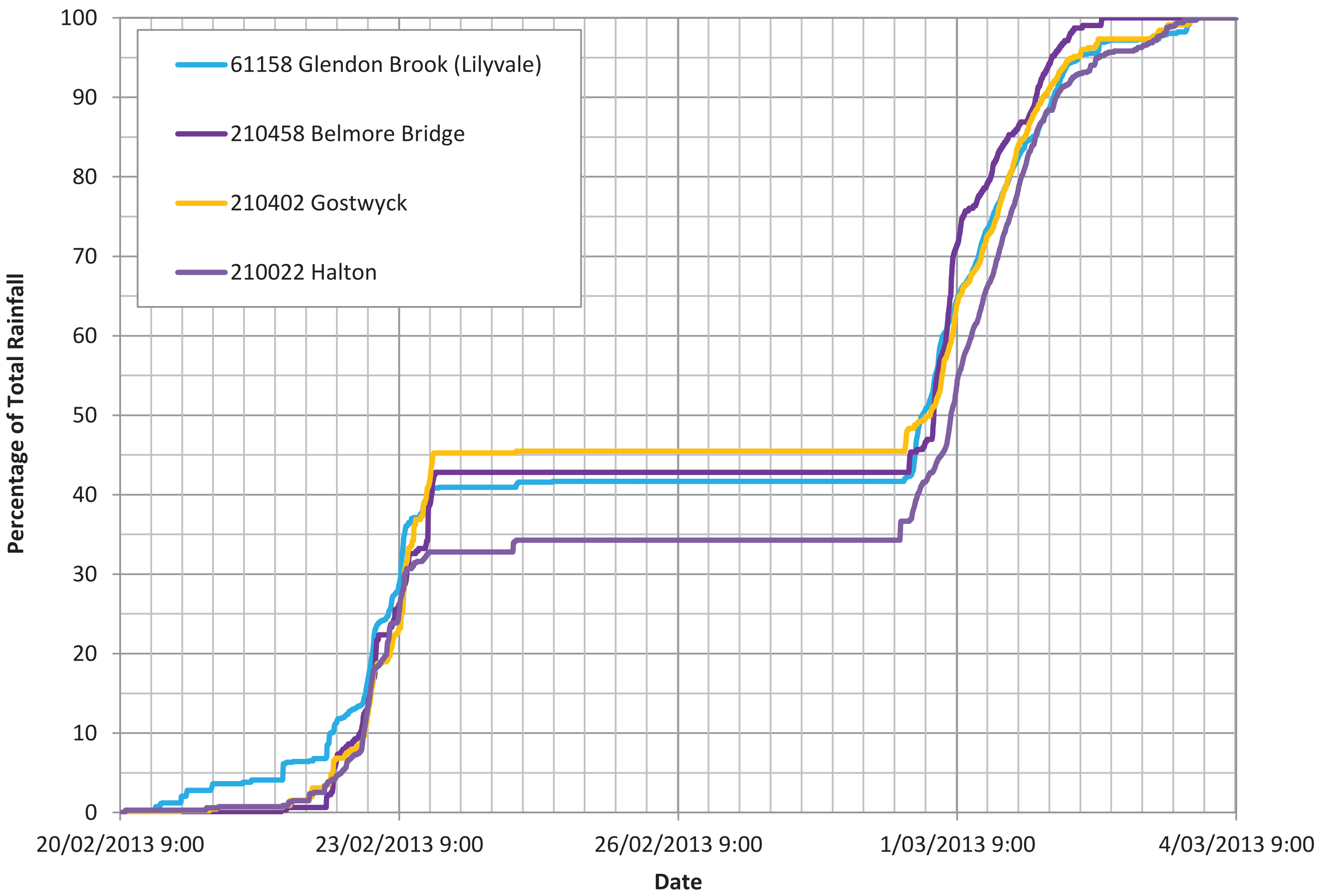
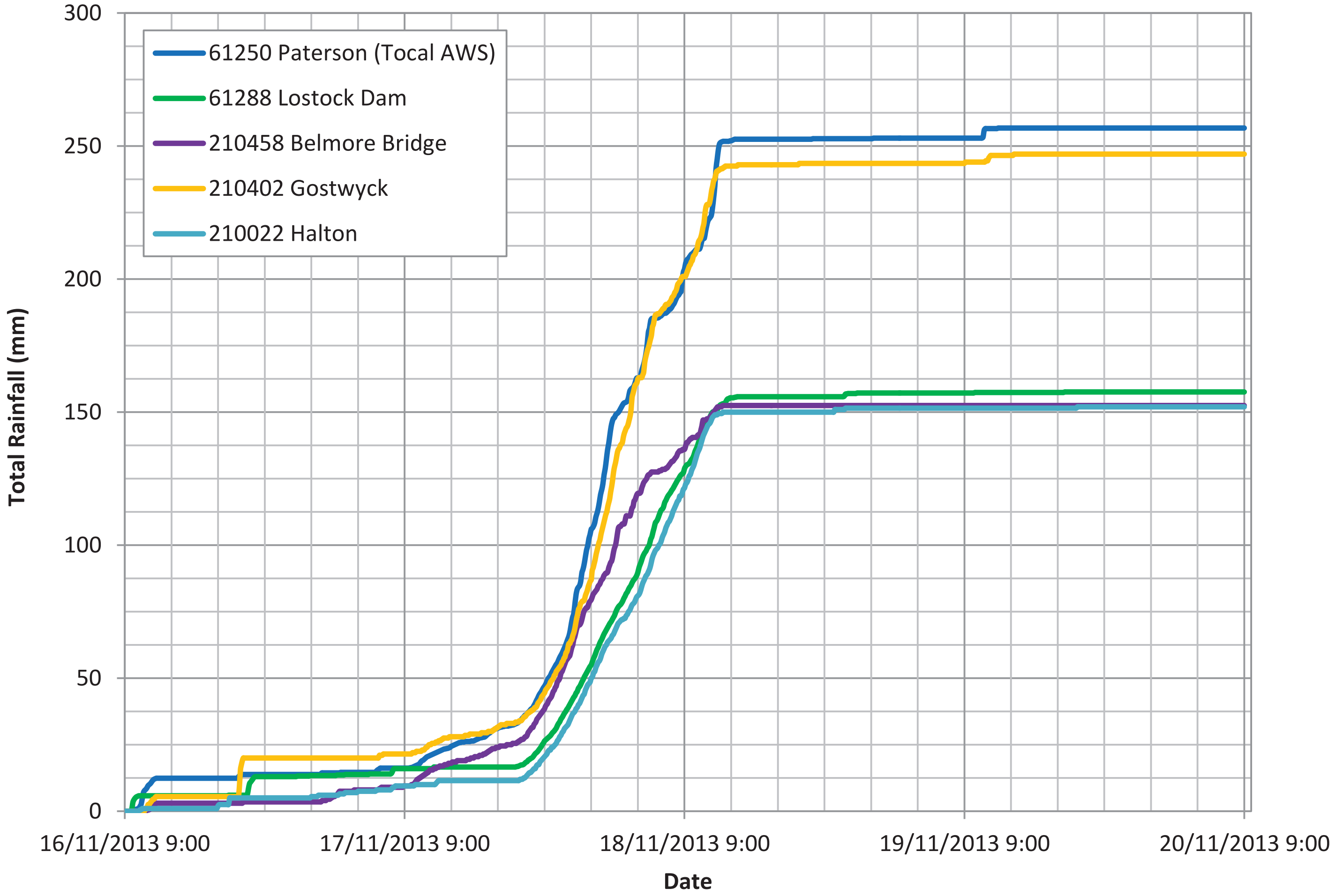


FIGURE 28
RAINFALL L DATA
NOVEMBER 2013 EVENT



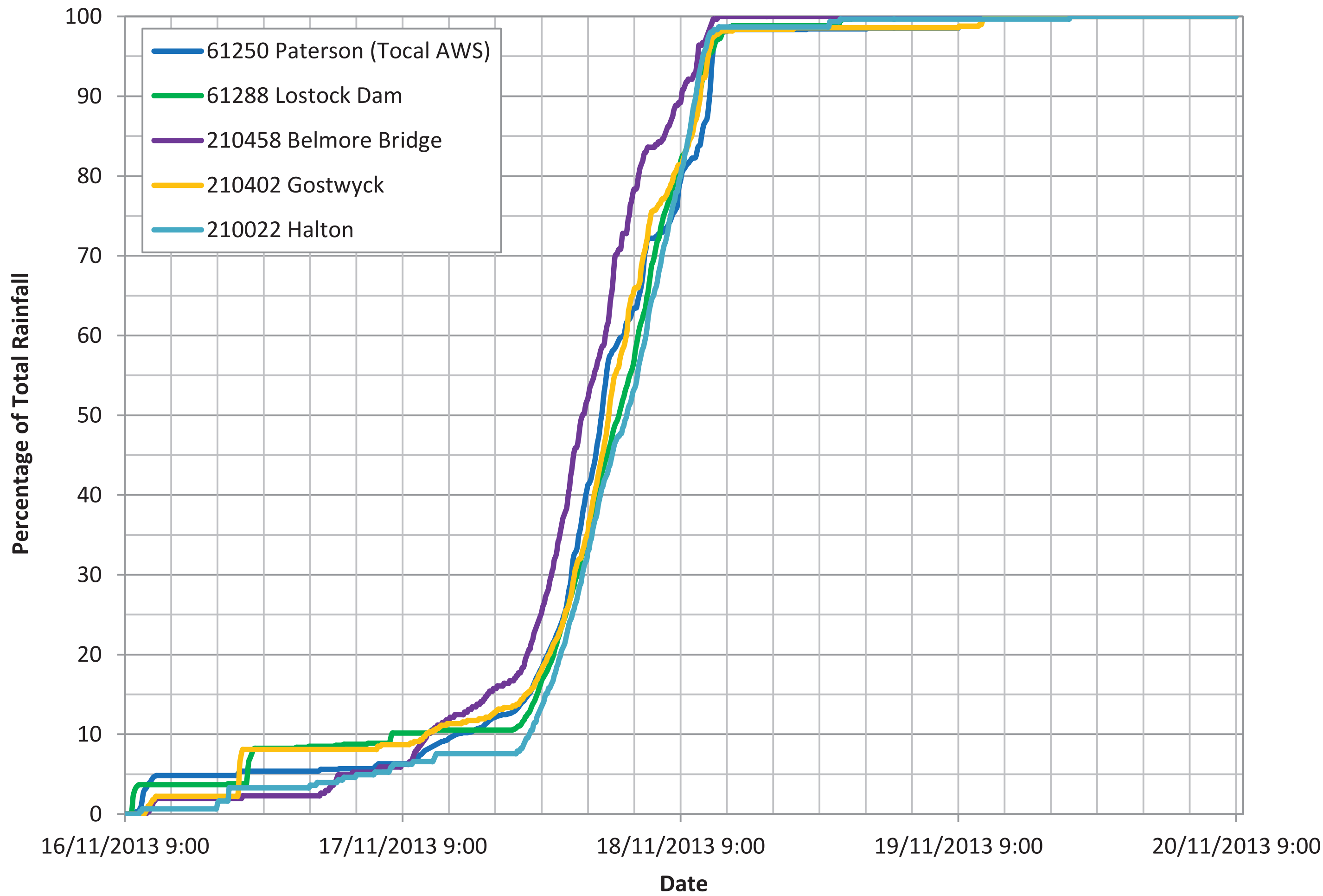
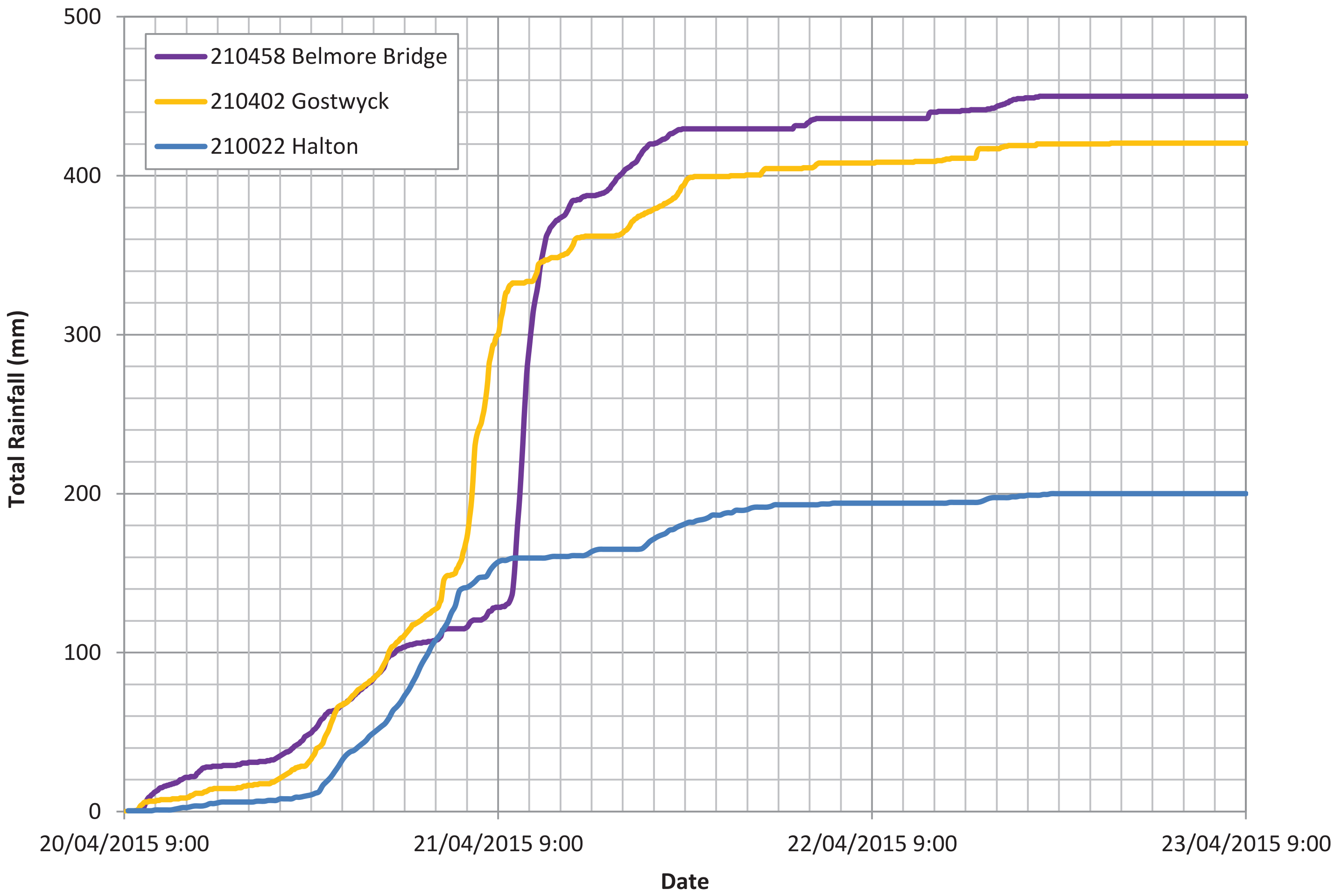


FIGURE 29
RAINFALL L DATA
APRIL 2015 EVENT



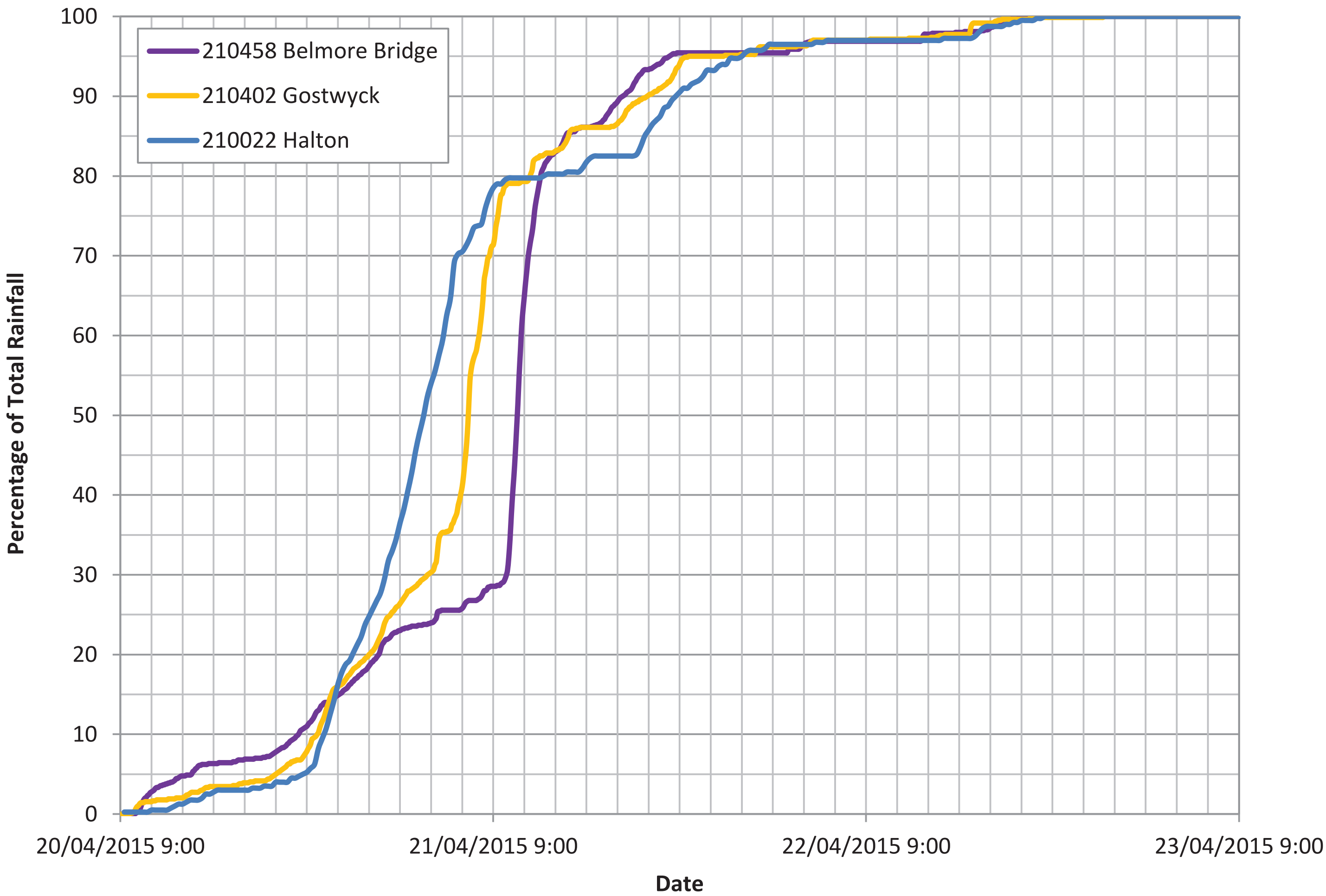
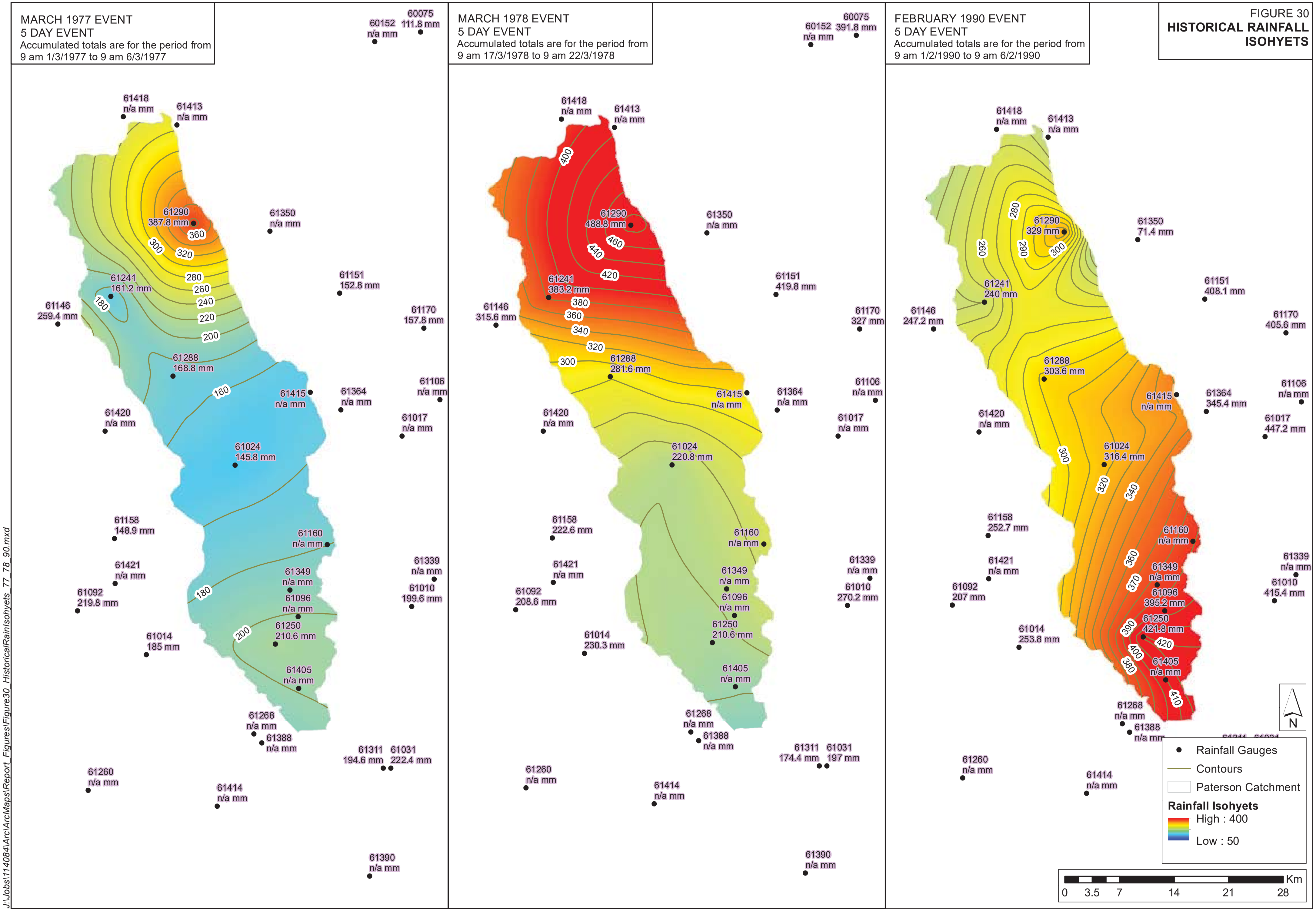


FIGURE 30
HISTORICAL RAINFALL ISOHYETS



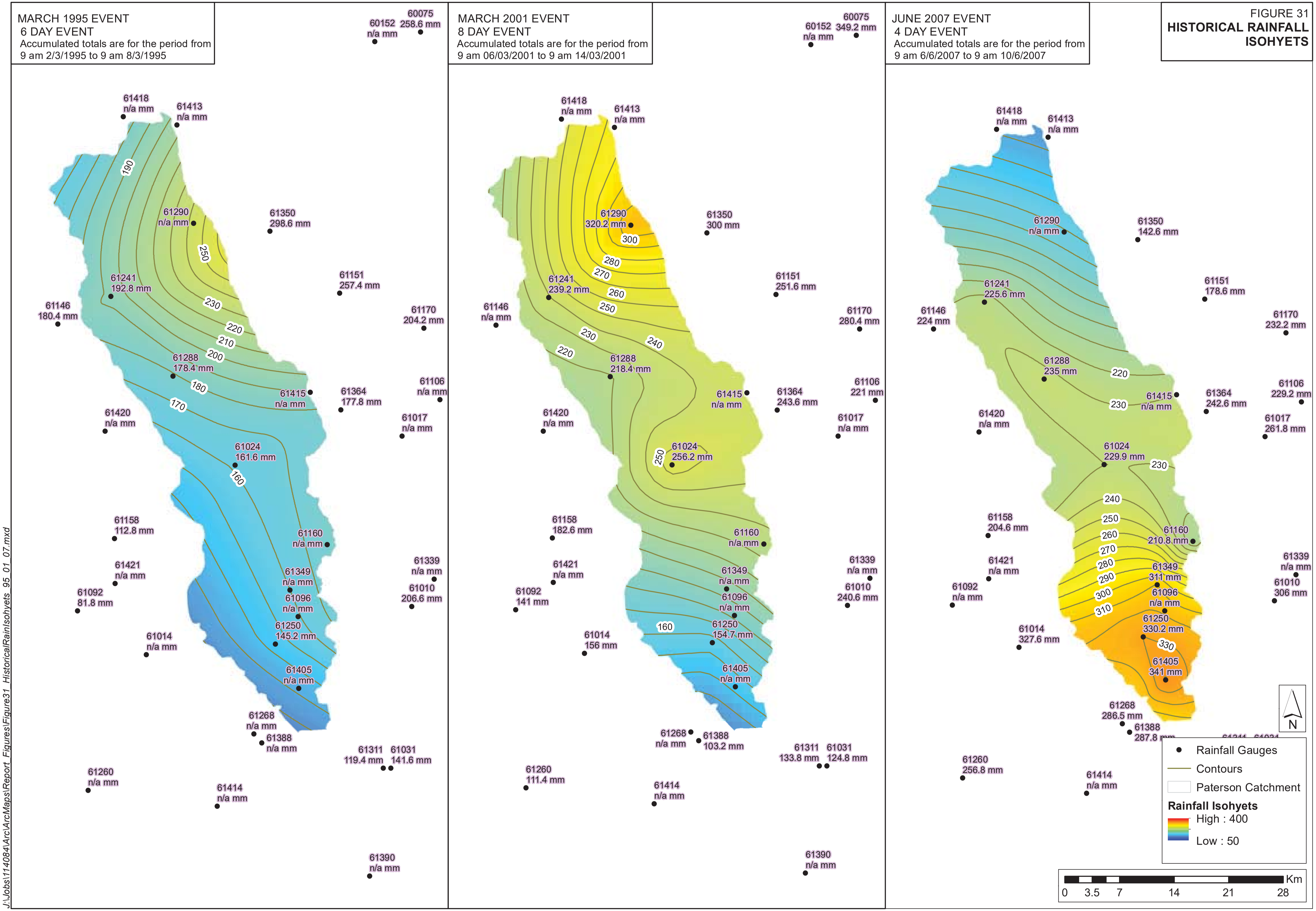


FIGURE 31
HISTORICAL RAINFALL ISOHYETS
MARCH 1995 EVENT
6 DAY EVENT
Accumulated totals are for the period from 9 am 2/3/1995 to 9 am 8/3/1995
60152 n/a mm
60075 258.6 mm
61418 n/a mm
61413 n/a mm
61290 n/a mm
61350 298.6 mm
61151 257.4 mm
61241 192.8 mm
61146 180.4 mm
61170 204.2 mm
61288 178.4 mm
61415 n/a mm
61364 177.8 mm
61106 n/a mm
61420 n/a mm
61017 n/a mm
61024 161.6 mm
61158 112.8 mm
61160 n/a mm
61339 n/a mm
61421 n/a mm
61349 n/a mm
61010 206.6 mm
61092 81.8 mm
61096 n/a mm
61250 145.2 mm
61014 n/a mm
61405 n/a mm
61268 n/a mm
61388 n/a mm
61311 119.4 mm
61031 141.6 mm
61260 n/a mm
61414 n/a mm
61390 n/a mm
MARCH 2001 EVENT
8 DAY EVENT
Accumulated totals are for the period from 9 am 06/03/2001 to 9 am 14/03/2001
60152 n/a mm
60075 349.2 mm
61418 n/a mm
61413 n/a mm
61290 320.2 mm
61350 300 mm
61151 251.6 mm
61241 239.2 mm
61146 n/a mm
61170 280.4 mm
61288 218.4 mm
61415 n/a mm
61364 243.6 mm
61106 221 mm
61420 n/a mm
61017 n/a mm
61024 256.2 mm
61158 182.6 mm
61160 n/a mm
61339 n/a mm
61421 n/a mm
61349 n/a mm
61010 240.6 mm
61092 141 mm
61096 n/a mm
61014 156 mm
61250 154.7 mm
61405 n/a mm
61268 n/a mm
61388 103.2 mm
61311 133.8 mm
61031 124.8 mm
61260 111.4 mm
61414 n/a mm
61390 n/a mm
JUNE 2007 EVENT
4 DAY EVENT
Accumulated totals are for the period from 9 am 6/6/2007 to 9 am 10/6/2007
61418 n/a mm
61413 n/a mm
61290 n/a mm
61350 142.6 mm
61151 178.6 mm
61241 225.6 mm
61146 224 mm
61170 232.2 mm
61288 235 mm
61415 n/a mm
61364 242.6 mm
61106 229.2 mm
61420 n/a mm
61017 261.8 mm
61024 229.9 mm
61158 204.6 mm
61160 210.8 mm
61339 n/a mm
61421 n/a mm
61349 311 mm
61010 306 mm
61092 n/a mm
61096 n/a mm
61014 327.6 mm
61250 330.2 mm
61405 341 mm
61268 286.5 mm
61388 287.8 mm
61260 256.8 mm
61414 n/a mm
N
Rainfall Gauges
Contours
Paterson Catchment
Rainfall Isohyets
High : 400
Low : 50
0 3.5 7 14 21 28 Km
J:\Jobs\114084\Arc\ArcMaps\Report_Figures\Figure31_HistoricalRainIsohyets_95_01_07.mxd

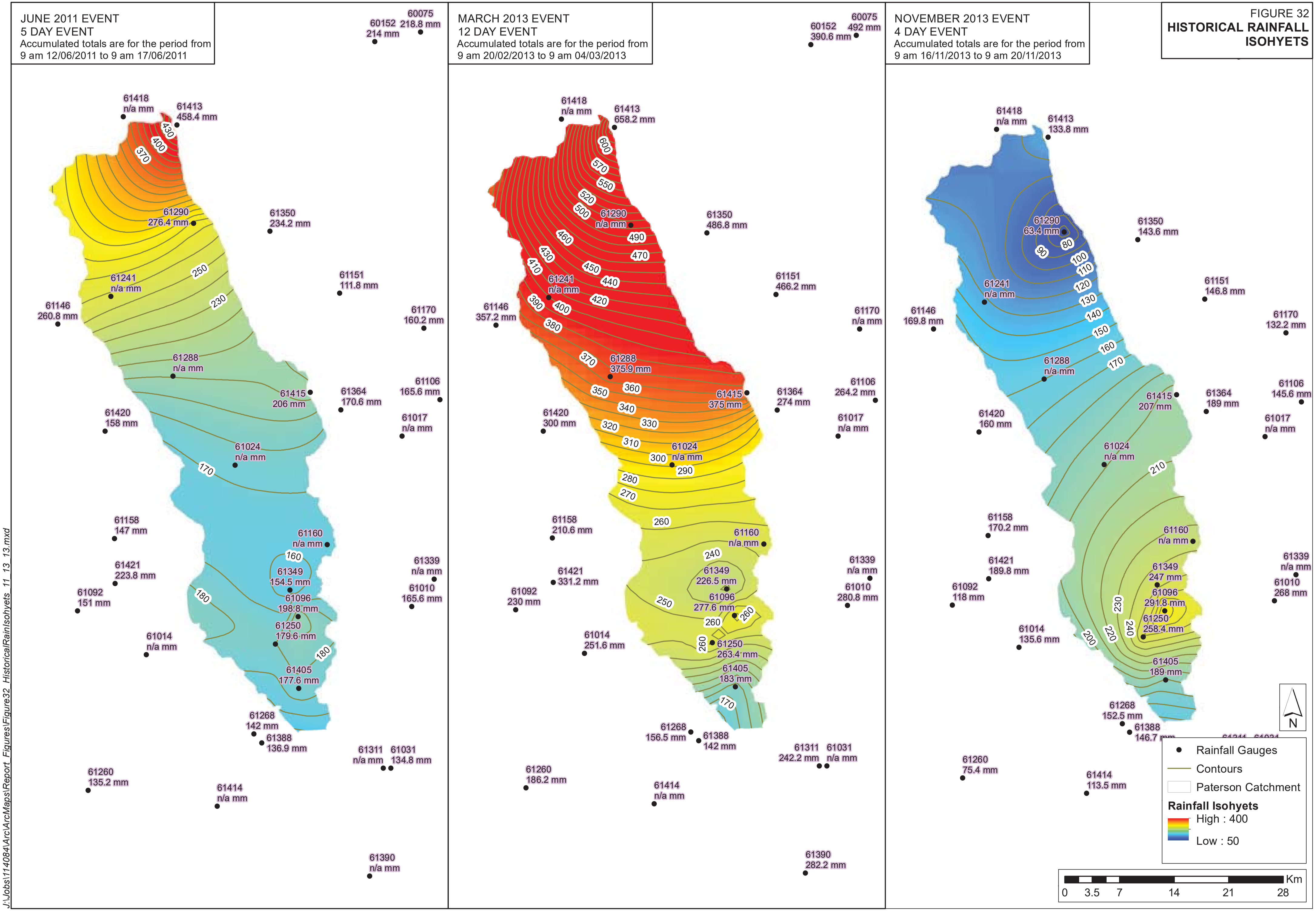
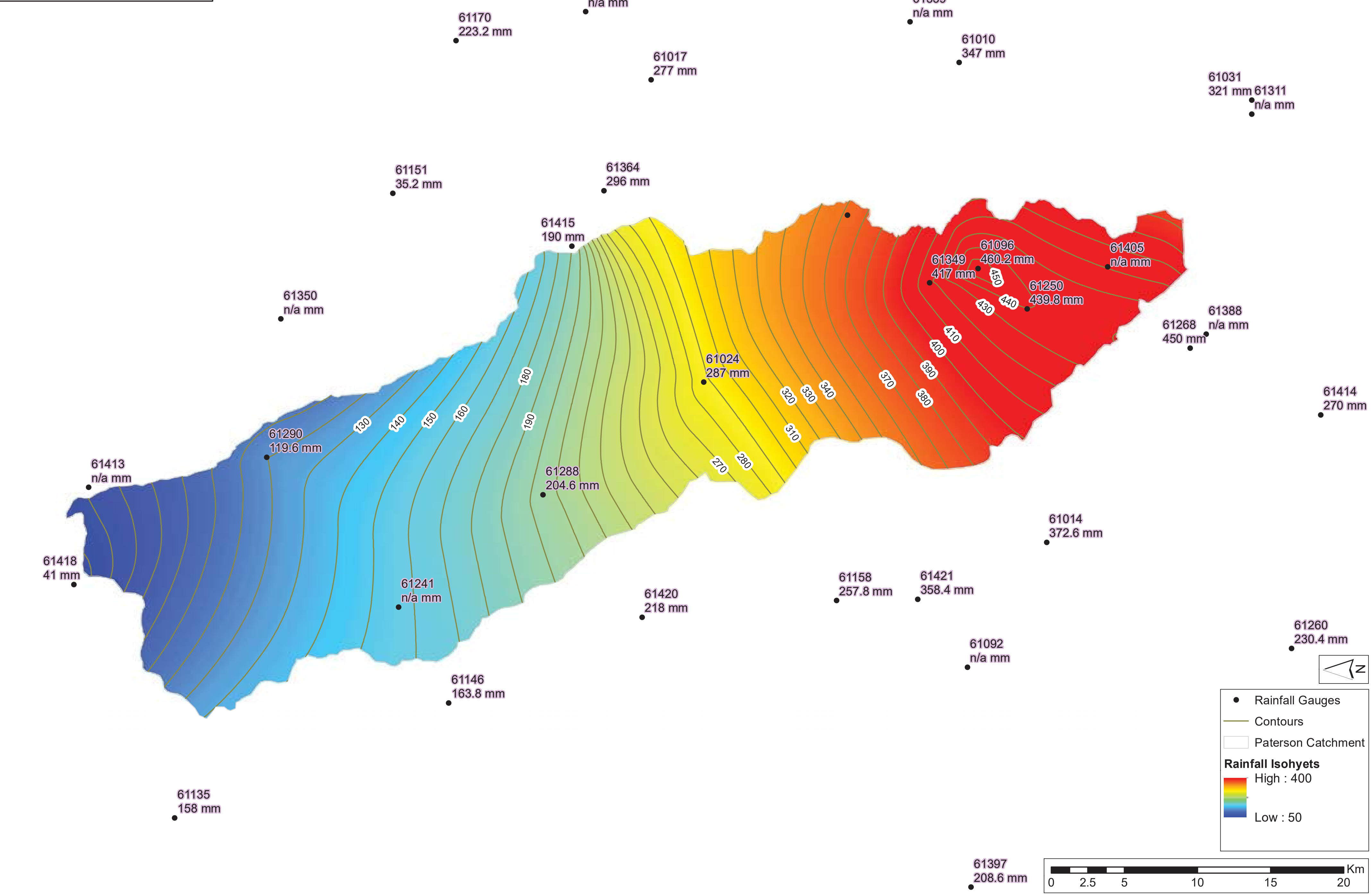


FIGURE 32
HISTORICAL RAINFALL ISOHYETS
JUNE 2011 EVENT
5 DAY EVENT
Accumulated totals are for the period from 9 am 12/06/2011 to 9 am 17/06/2011
MARCH 2013 EVENT
12 DAY EVENT
Accumulated totals are for the period from 9 am 20/02/2013 to 9 am 04/03/2013
NOVEMBER 2013 EVENT
4 DAY EVENT
Accumulated totals are for the period from 9 am 16/11/2013 to 9 am 20/11/2013
N
Rainfall Gauges
Contours
Paterson Catchment
Rainfall Isohyets
High : 400
Low : 50
0 3.5 7 14 21 28 Km
J:\Jobs\114084\Arc\ArcMaps\Report_Figures\Figure32_HistoricalRainIsohyets_11_13_13.mxd

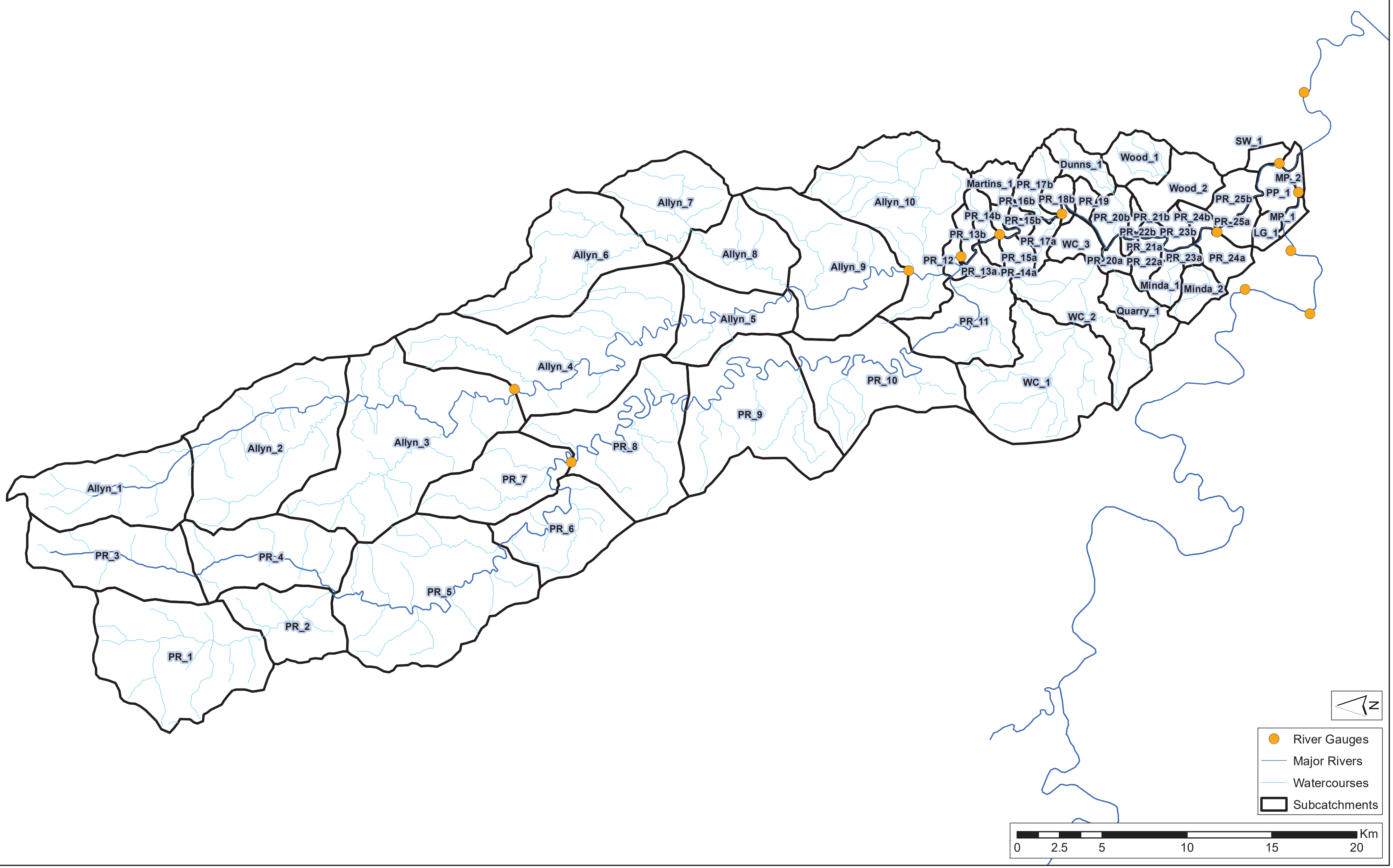
APRIL 2015 EVENT
3 DAY EVENT
Accumulated totals are for the period from 9 am 20/04/2015 to 9 am 23/04/2015

FIGURE 33
HISTORICAL RAINFALL ISOHYETS APRIL 2015



J:\Jobs\114084\Arc\ArcMaps\Report_Figures\Figure33_HistoricalRainIsohyets_15.mxd

FIGURE 34a
HYDROLOGICAL MODEL LAYOUT



J:\Jobs\114084\Arc\ArcMaps\Report_Figures\Figure34a_HydrologicModelLayout.mxd

FIGURE 34B
HYDROLOGICAL MODEL LAYOUT

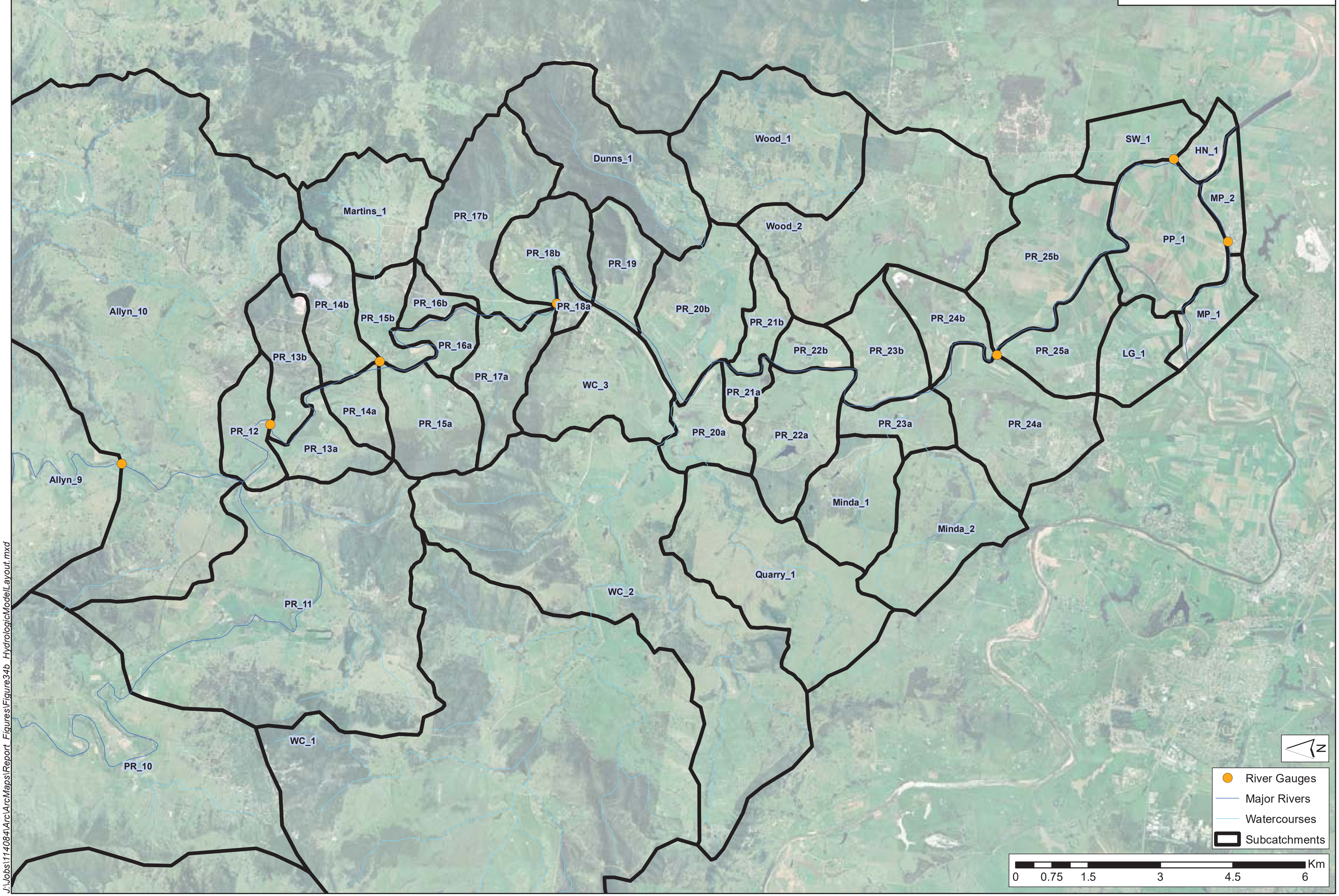
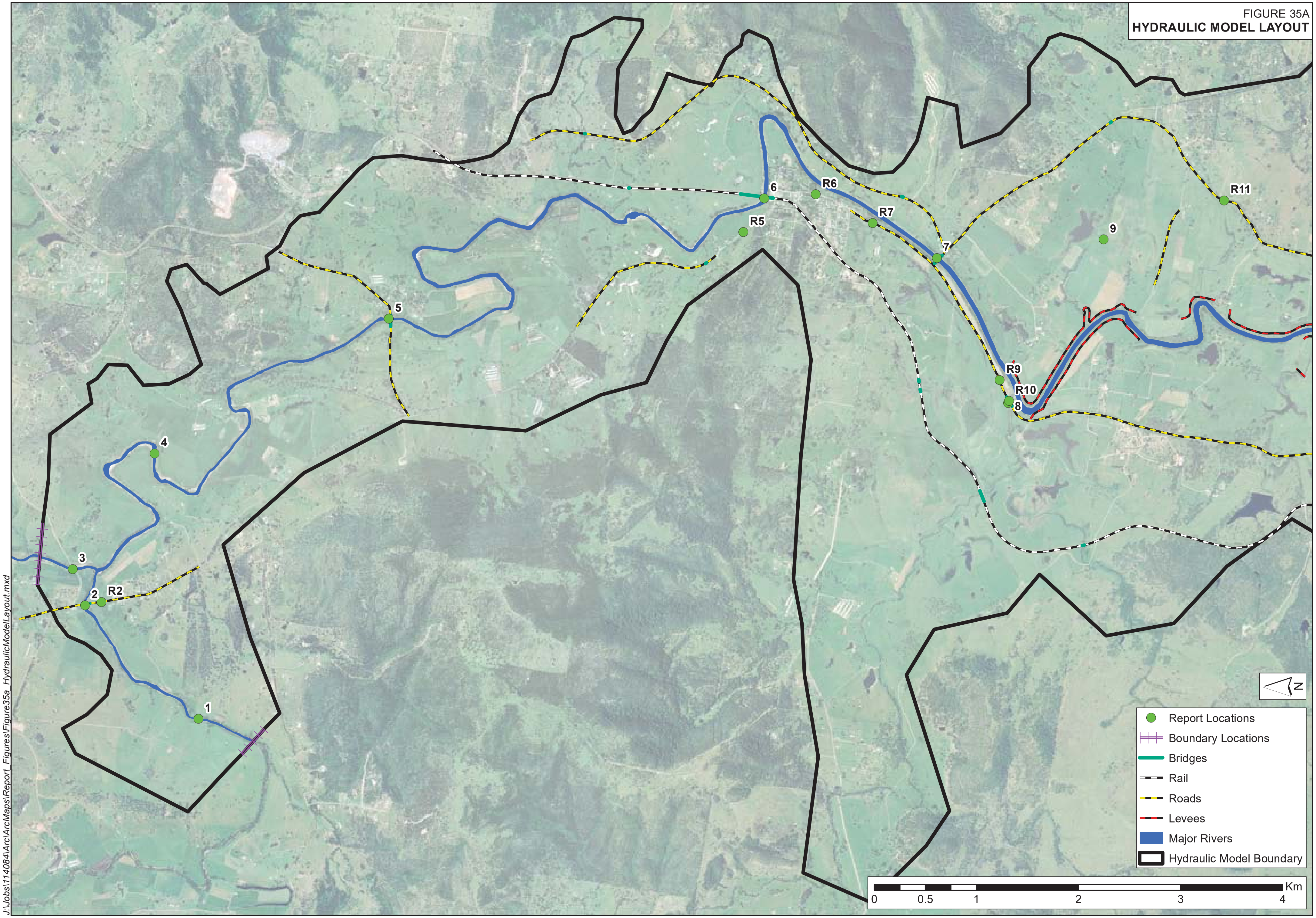
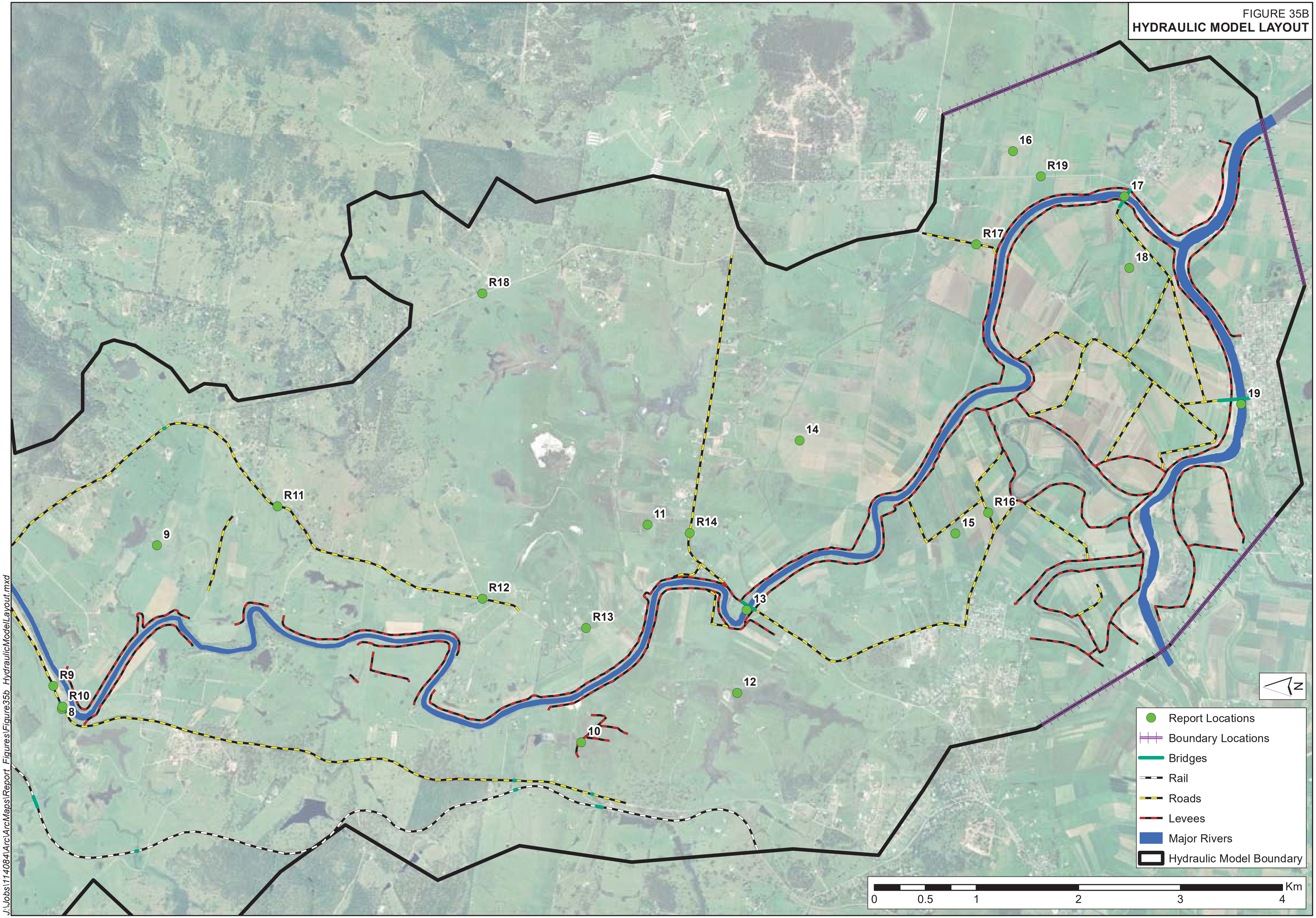


FIGURE 35A
HYDRAULIC MODEL LAYOUT



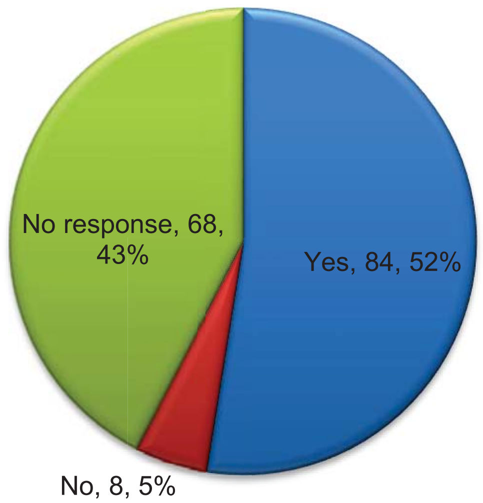
J:\Jobs\114084\Arc\ArcMaps\Report_Figures\Figure35a_HydraulicModelLayout.mxd

FIGURE 35B
HYDRAULIC MODEL LAYOUT

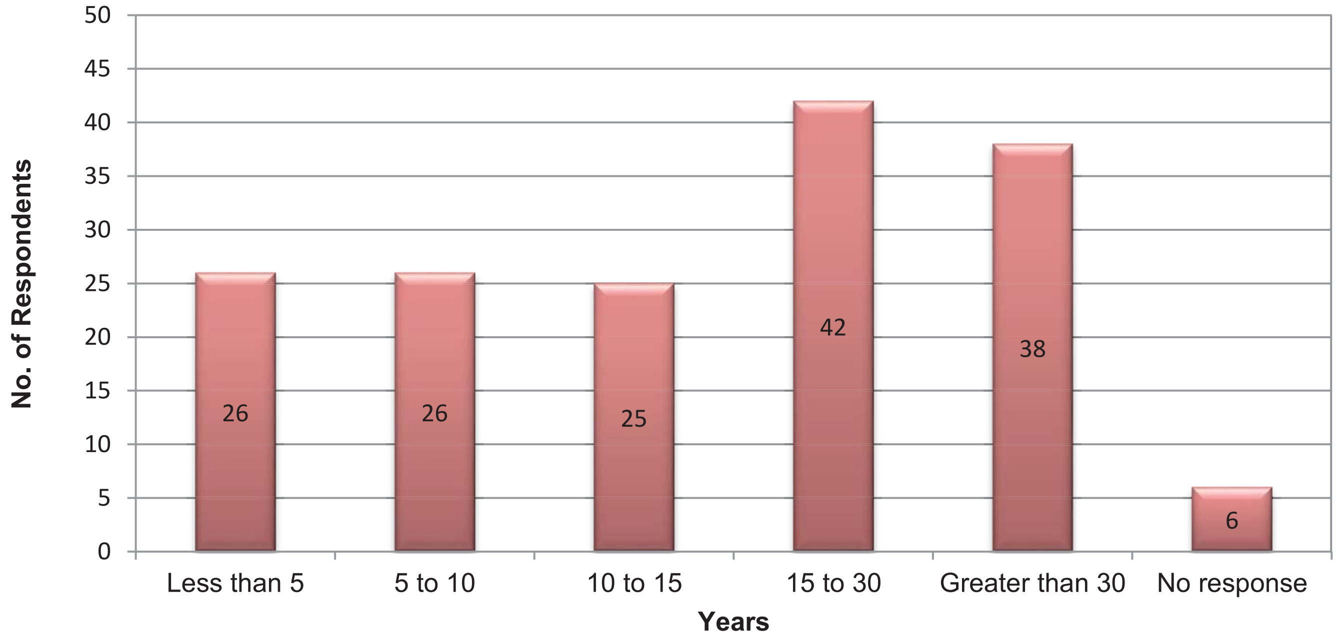


J:\Jobs\114084\ArcArcMaps\Report Figures\Figure35b HydraulicModelLayout.mxd

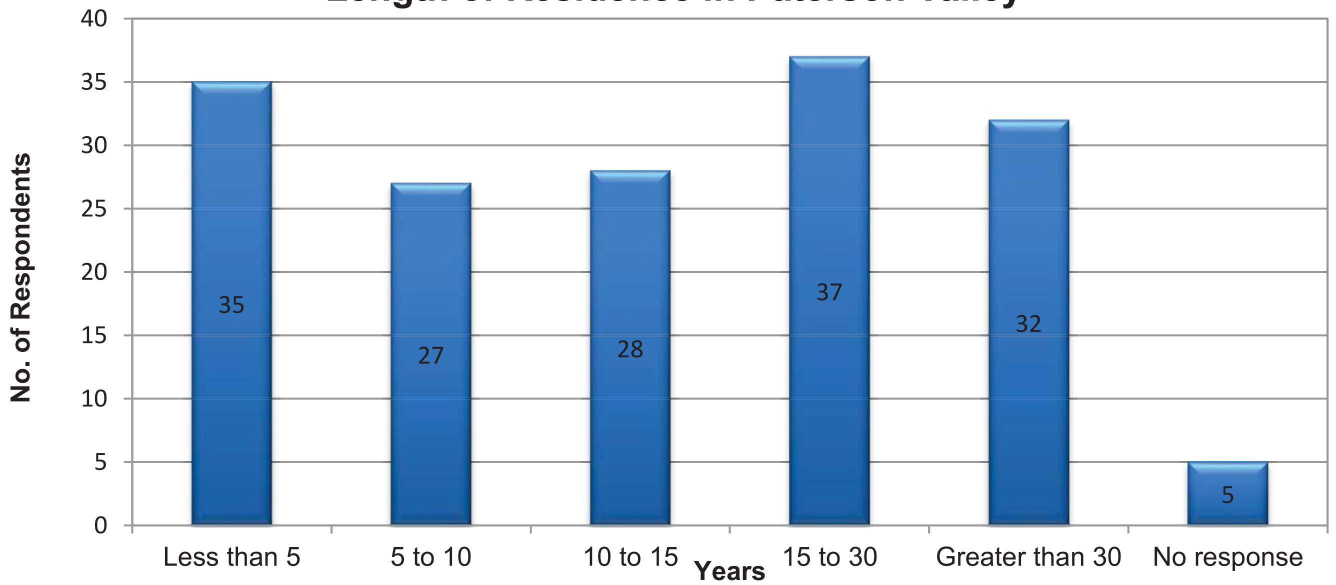
Residents Contactable

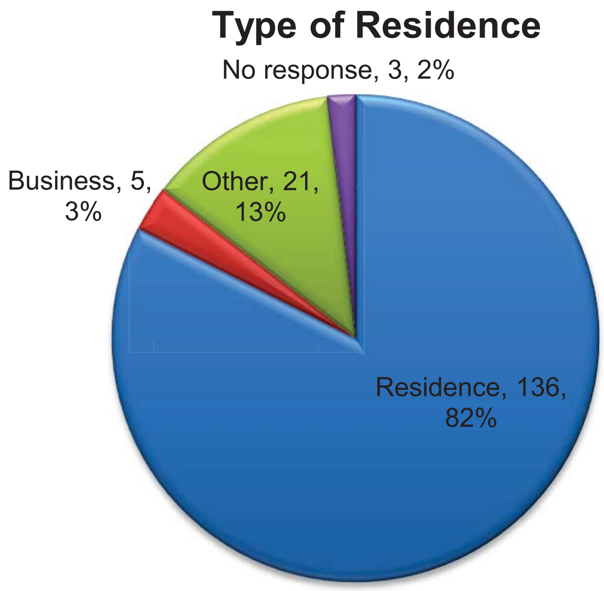


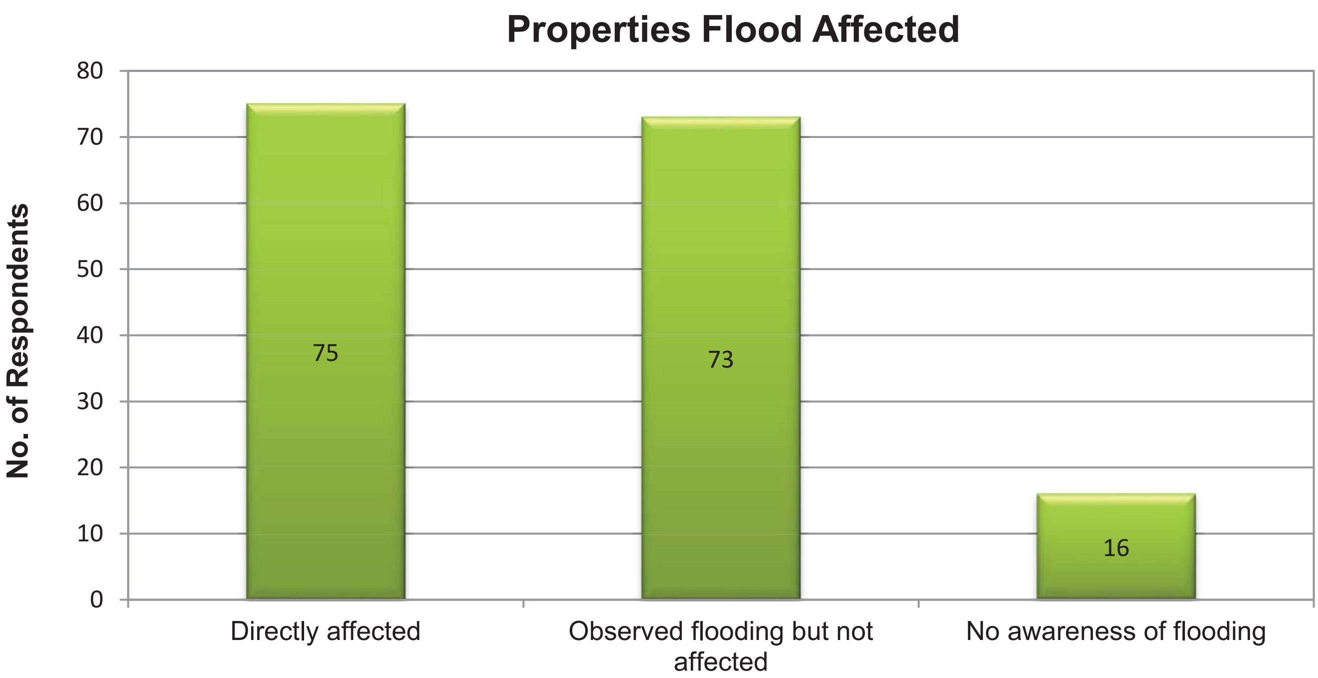
Period of Living/Owning/Working on Property



Length of Residence in Paterson Valley




Type of Residence
No response, 3, 2%
Business, 5, 3%
Other, 21, 13%
Residence, 136, 82%


Properties Flood Affected
No. of Respondents
80
70
60
50
40
30
20
10
0
75
73
16
Directly affected
Observed flooding but not affected
No awareness of flooding

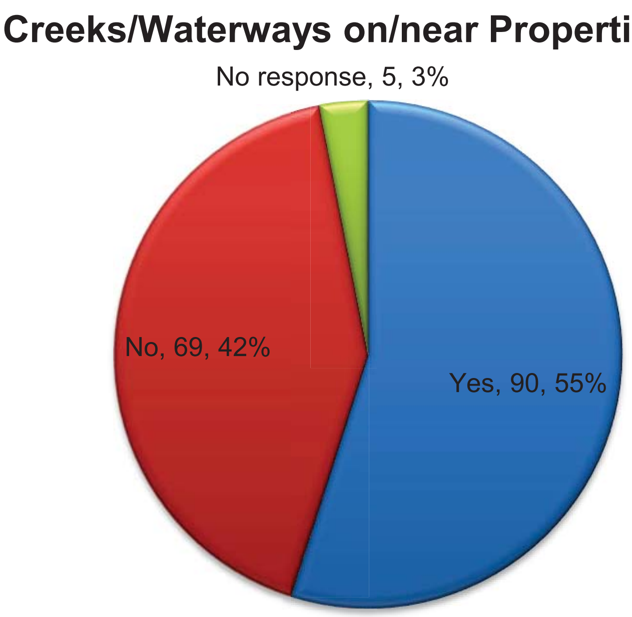
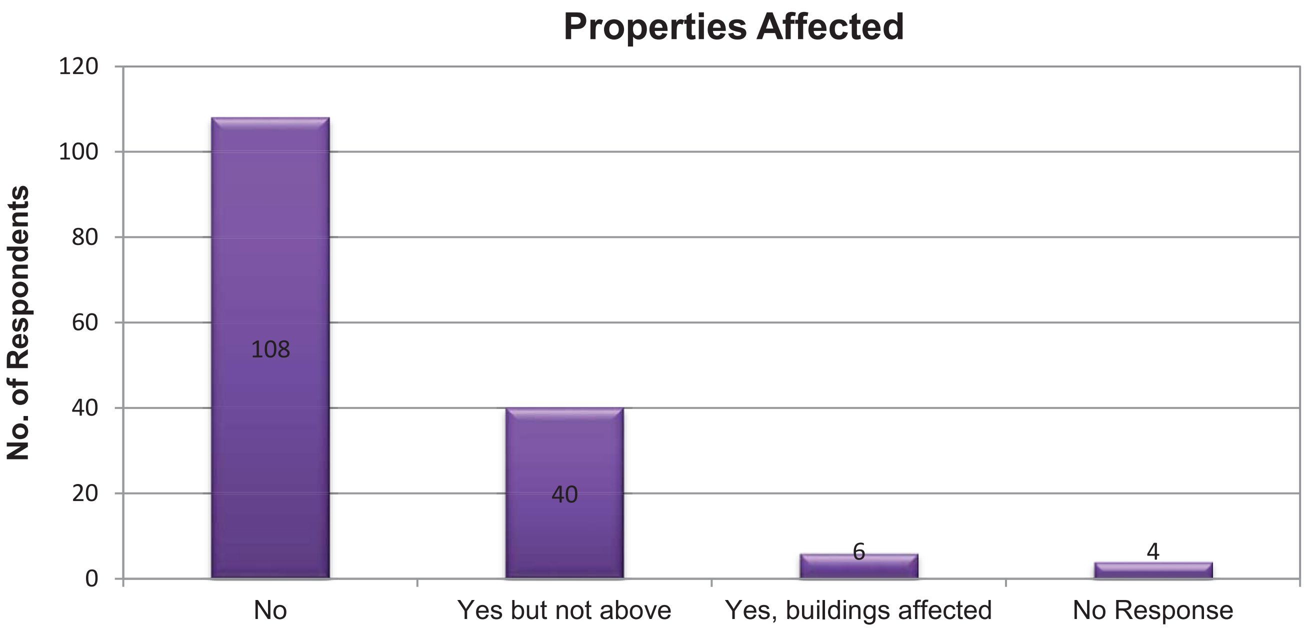
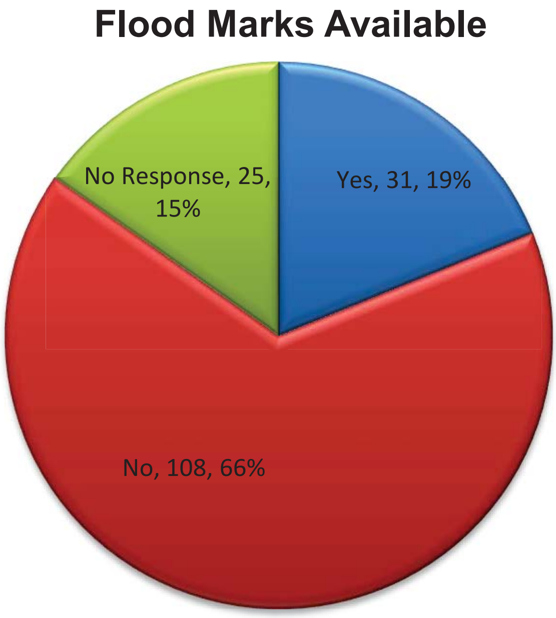

Creeks/Waterways on/near Properties
No response, 5, 3%
No, 69, 42%
Yes, 90, 55%

Figure 36C
COMMUNITY CONSULTATION RESPONSES





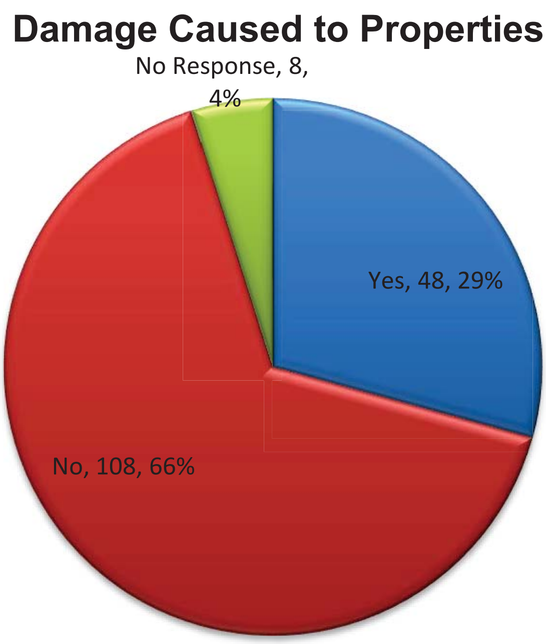
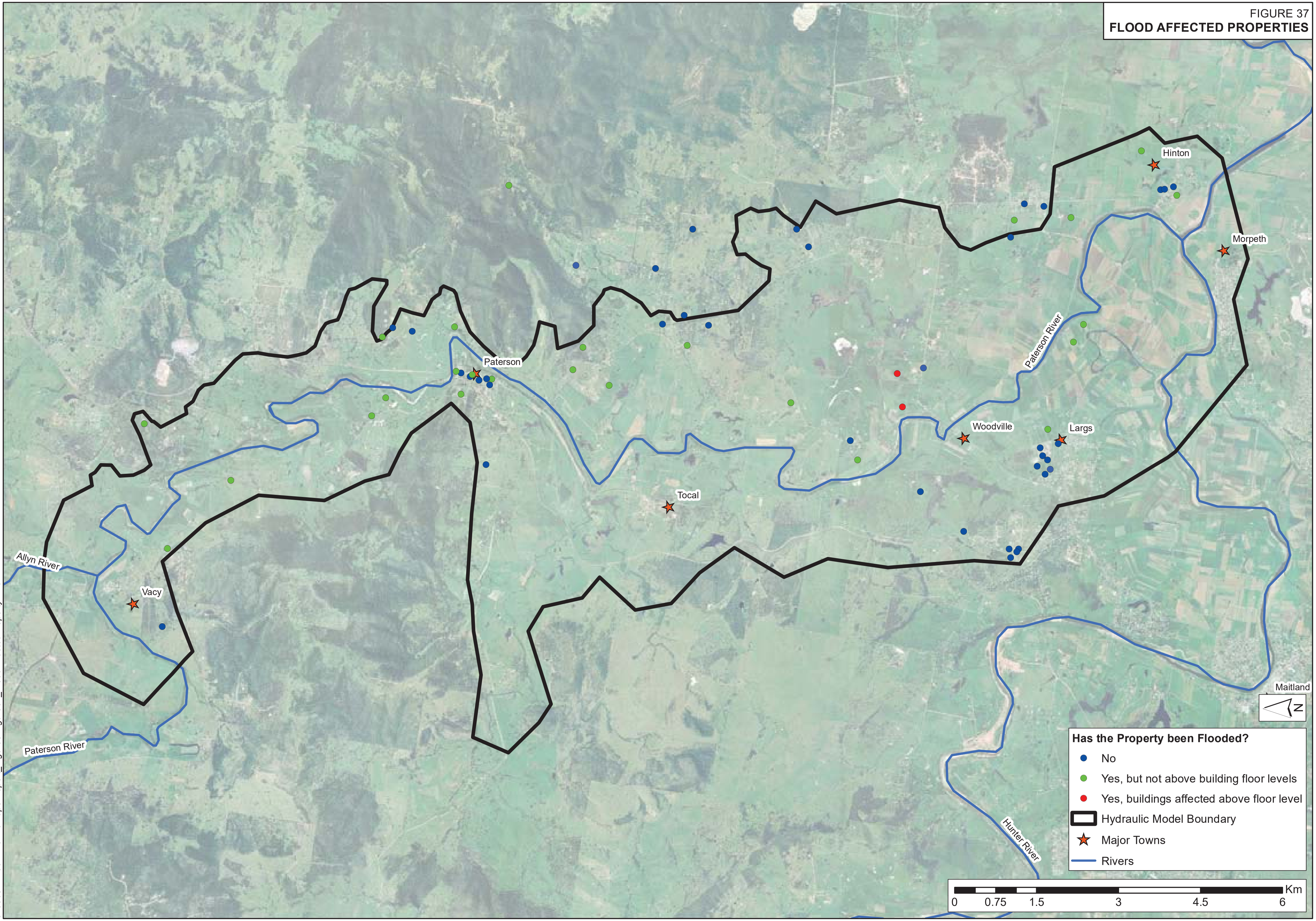


FIGURE 37
FLOOD AFFECTED PROPERTIES



J:\Jobs\114084\ArcMaps\Report_Figures\Figure37_FloodAffectedProperty.mxd

FIGURE 38

PATERSON RIVER GOSTWYCK PINEENA - 210079

REVISED RATING CURVE AND GAUGINGS

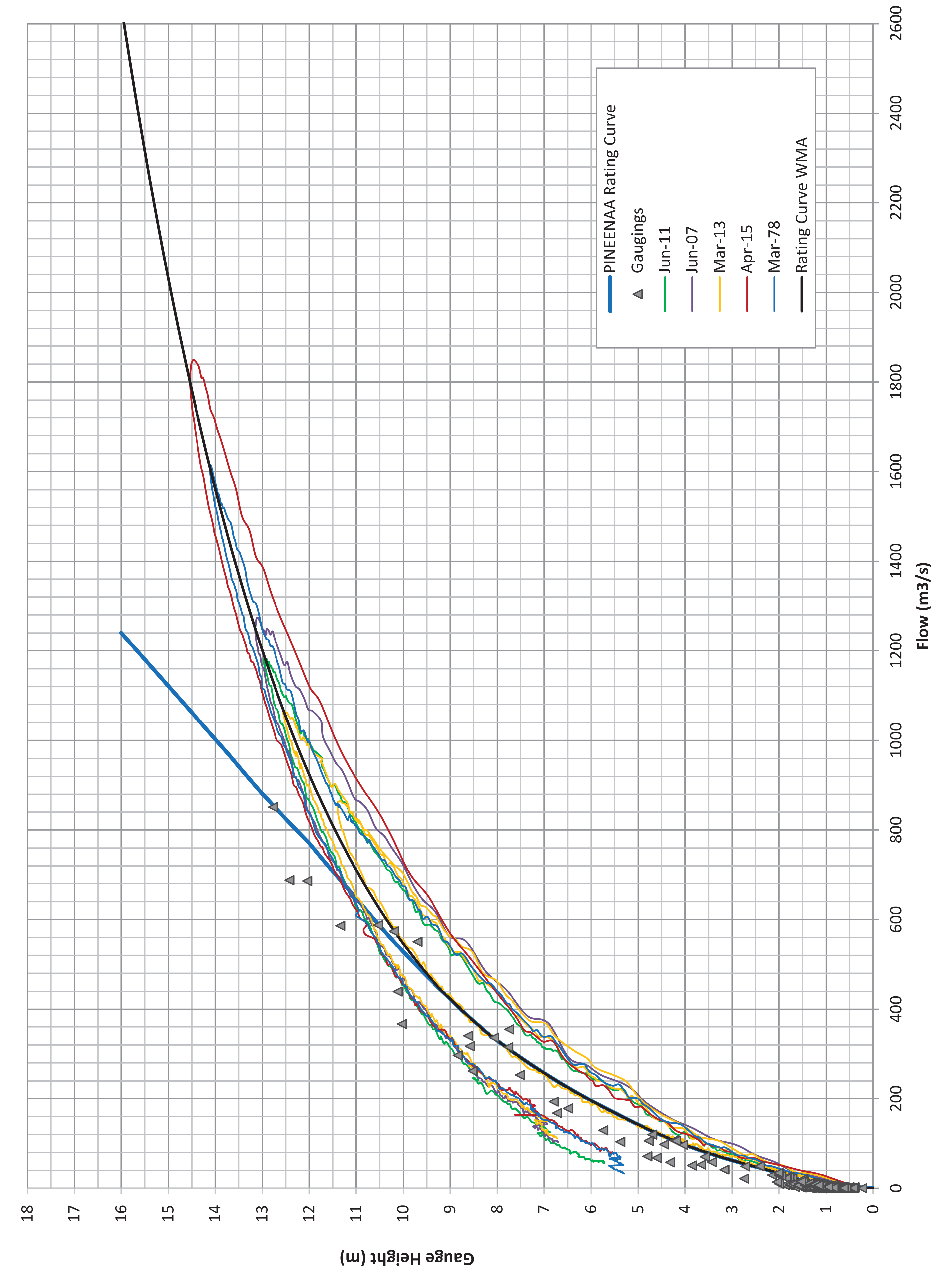


FIGURE 39
PATERSON RIVER GOSTWYCK - 210079
FFA - LP3 DISTRIBUTION

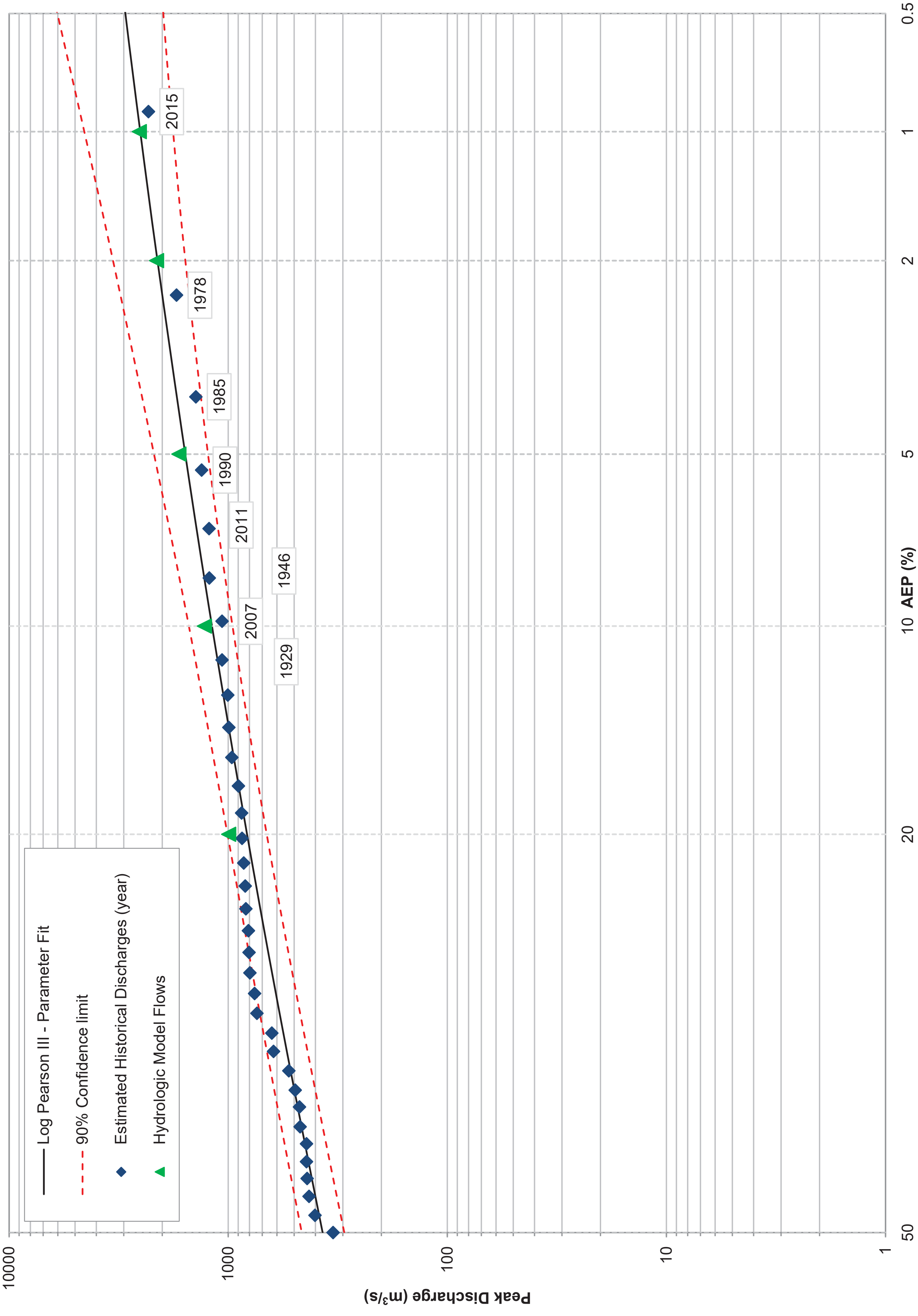
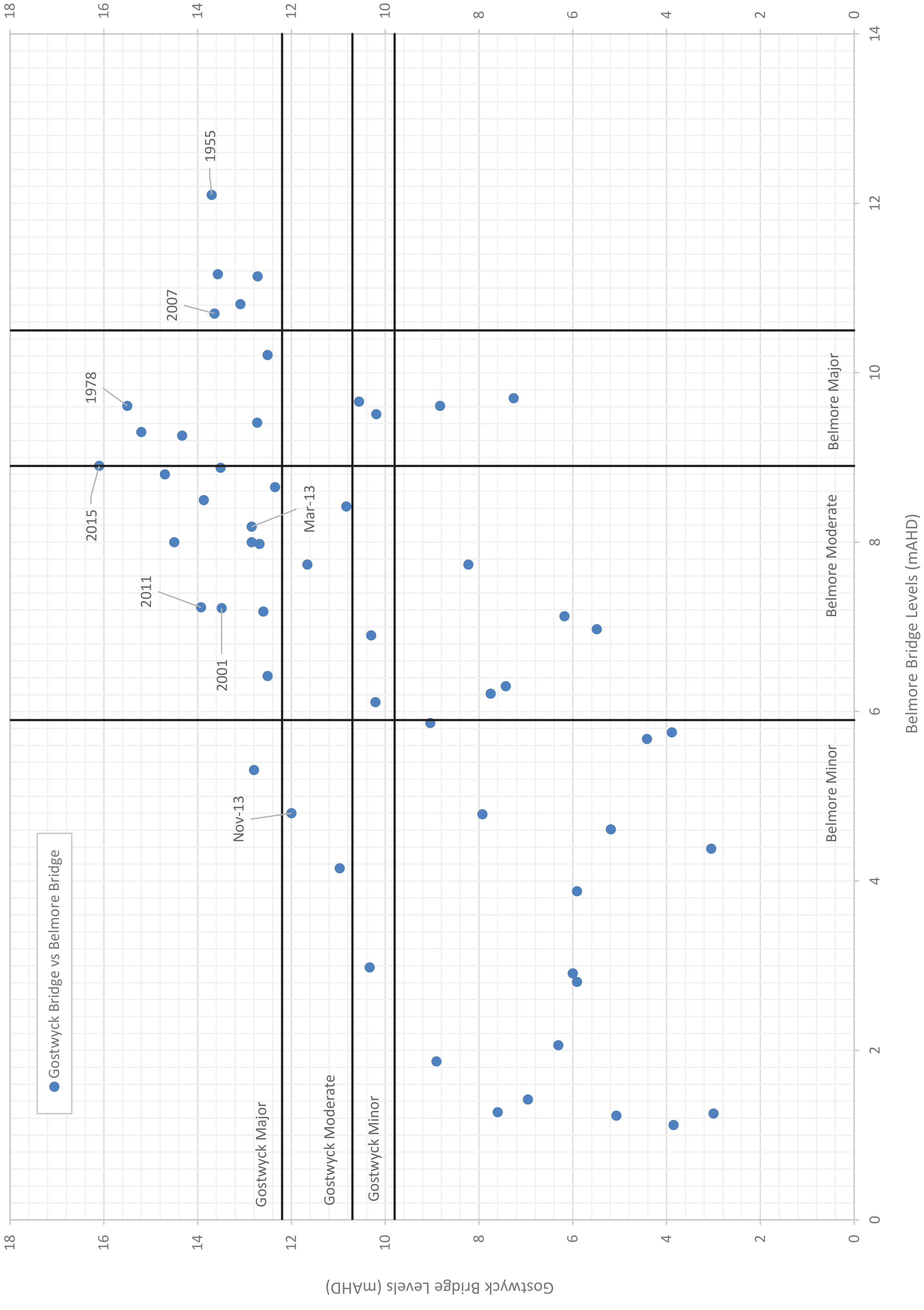


FIGURE 40

HISTORICAL COMPARISON

HUNTER RIVER v PATERSON RIVER



Appendix A

APPENDIX A: GLOSSARY of TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The

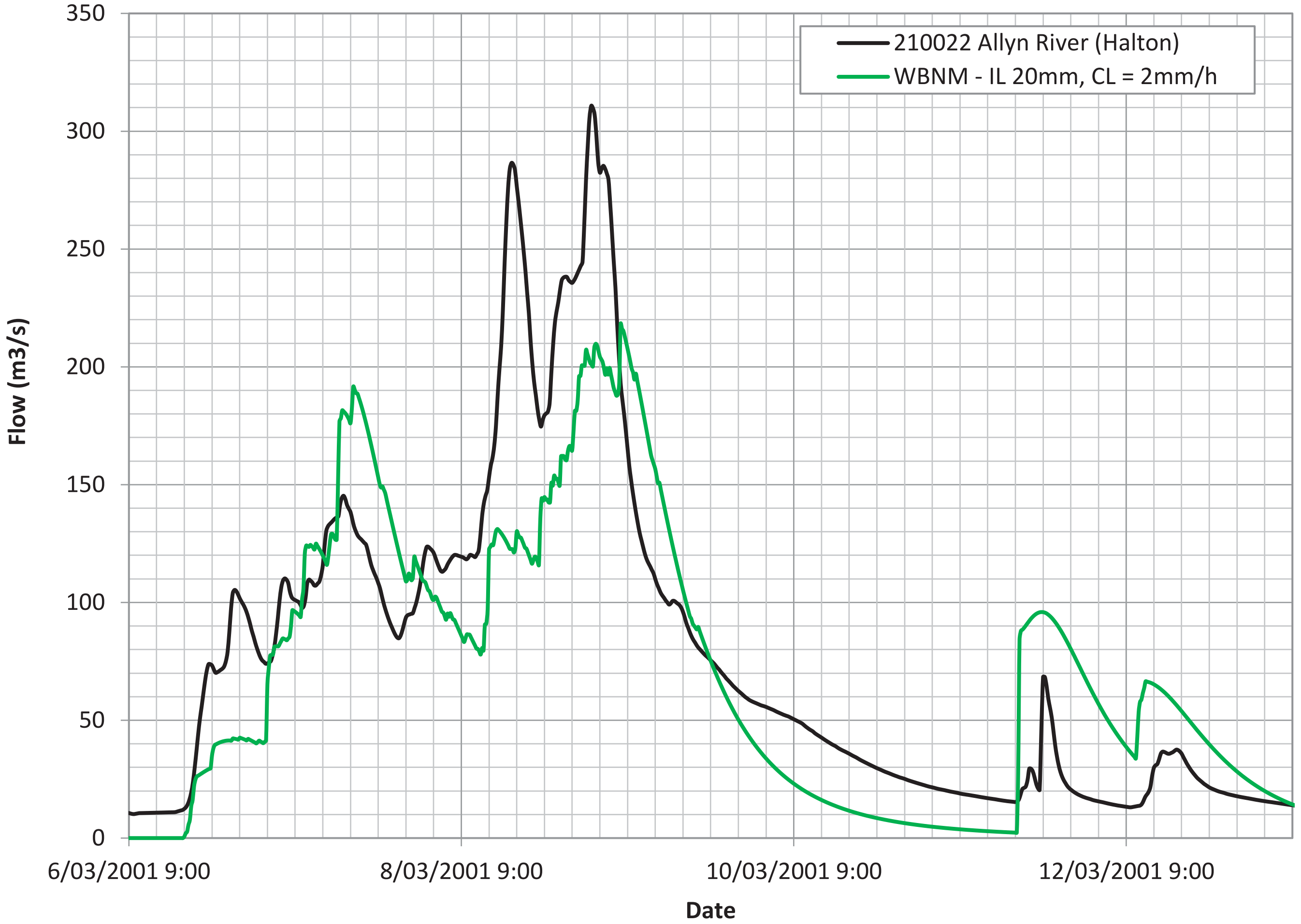
	effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL’s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.

flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

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

Appendix B

FIGURE B1
HYDROLOGIC MODEL CALIBRATION
MARCH 2001 EVENT



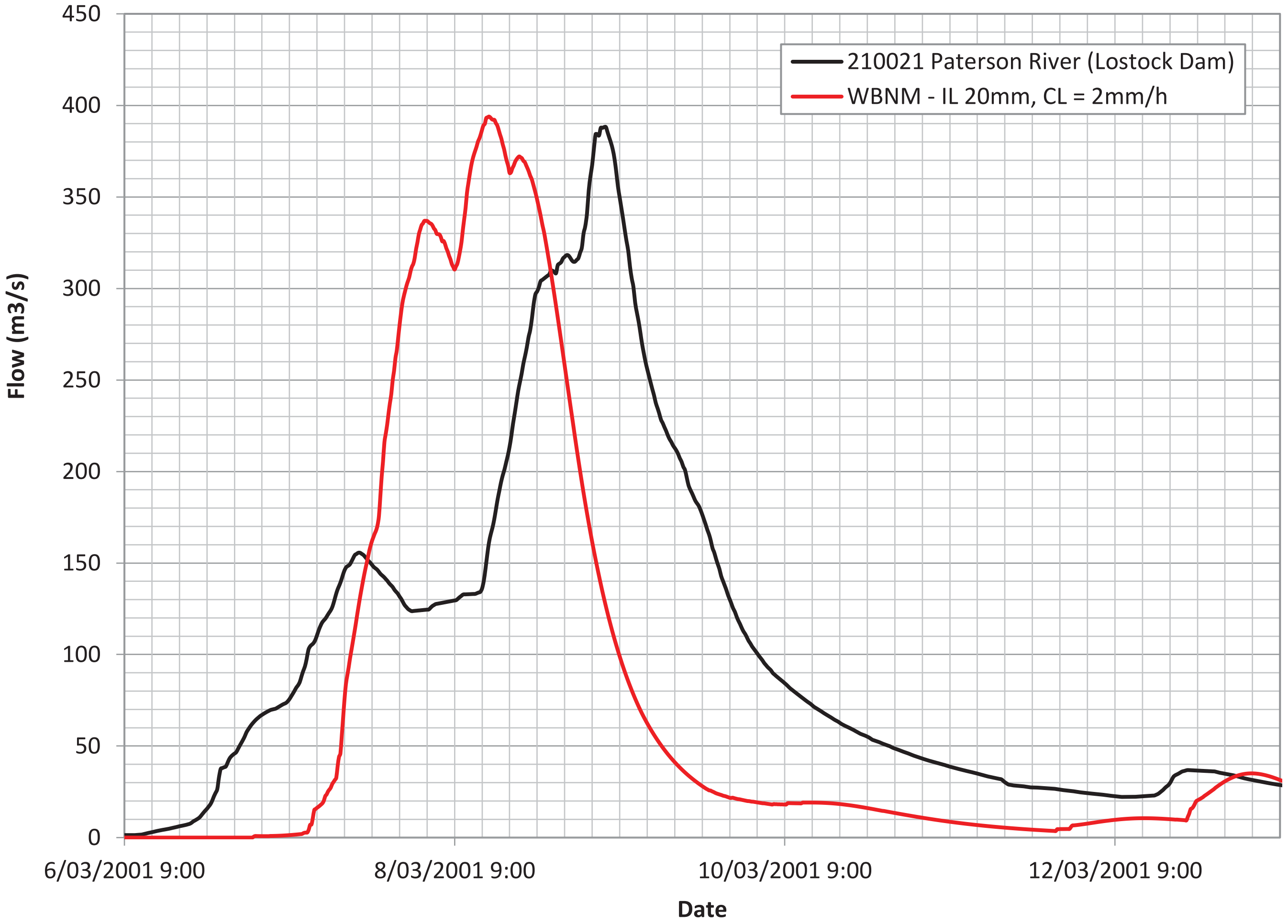
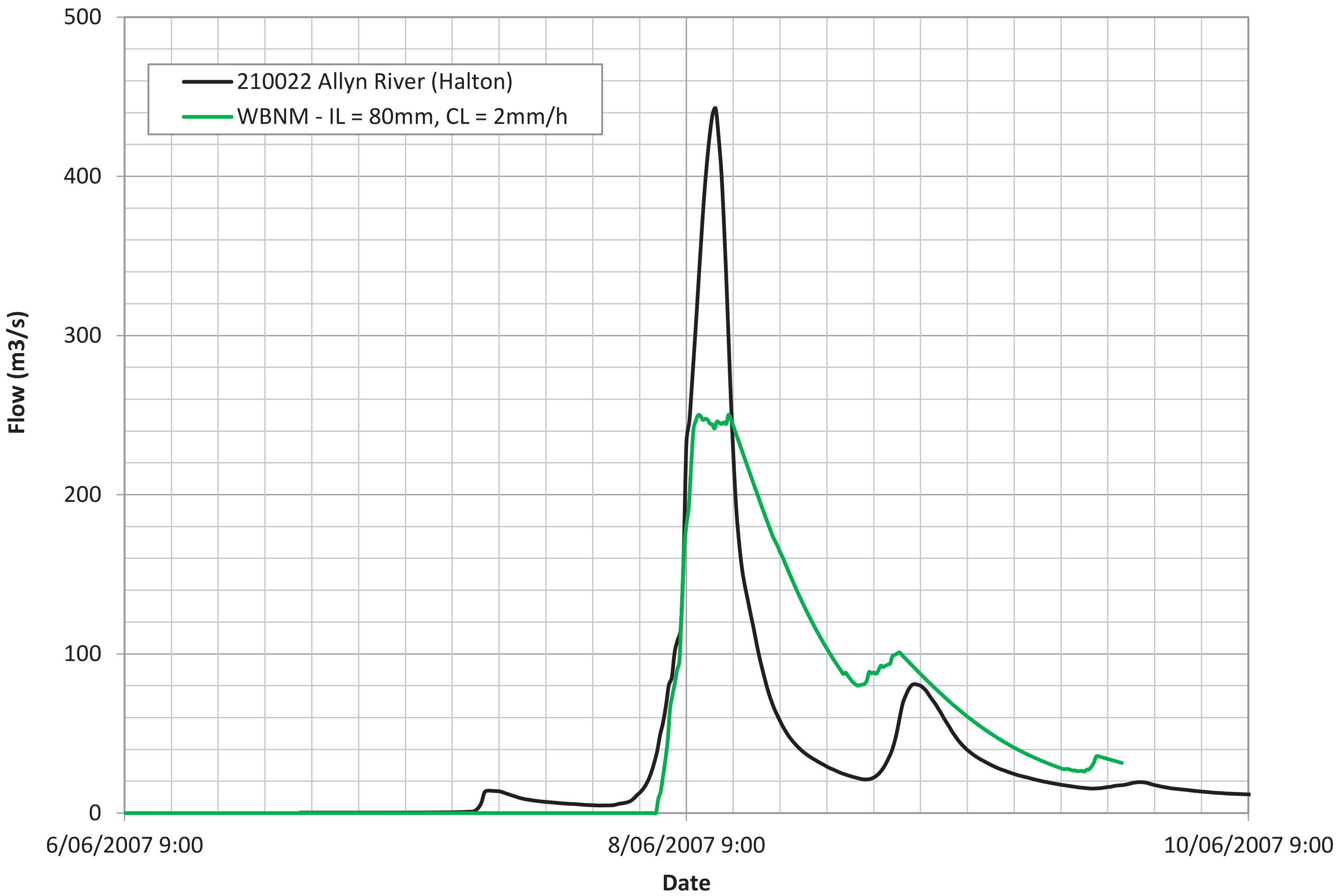


FIGURE B2
HYDROLOGIC MODEL CALIBRATION
JUNE 2007 EVENT



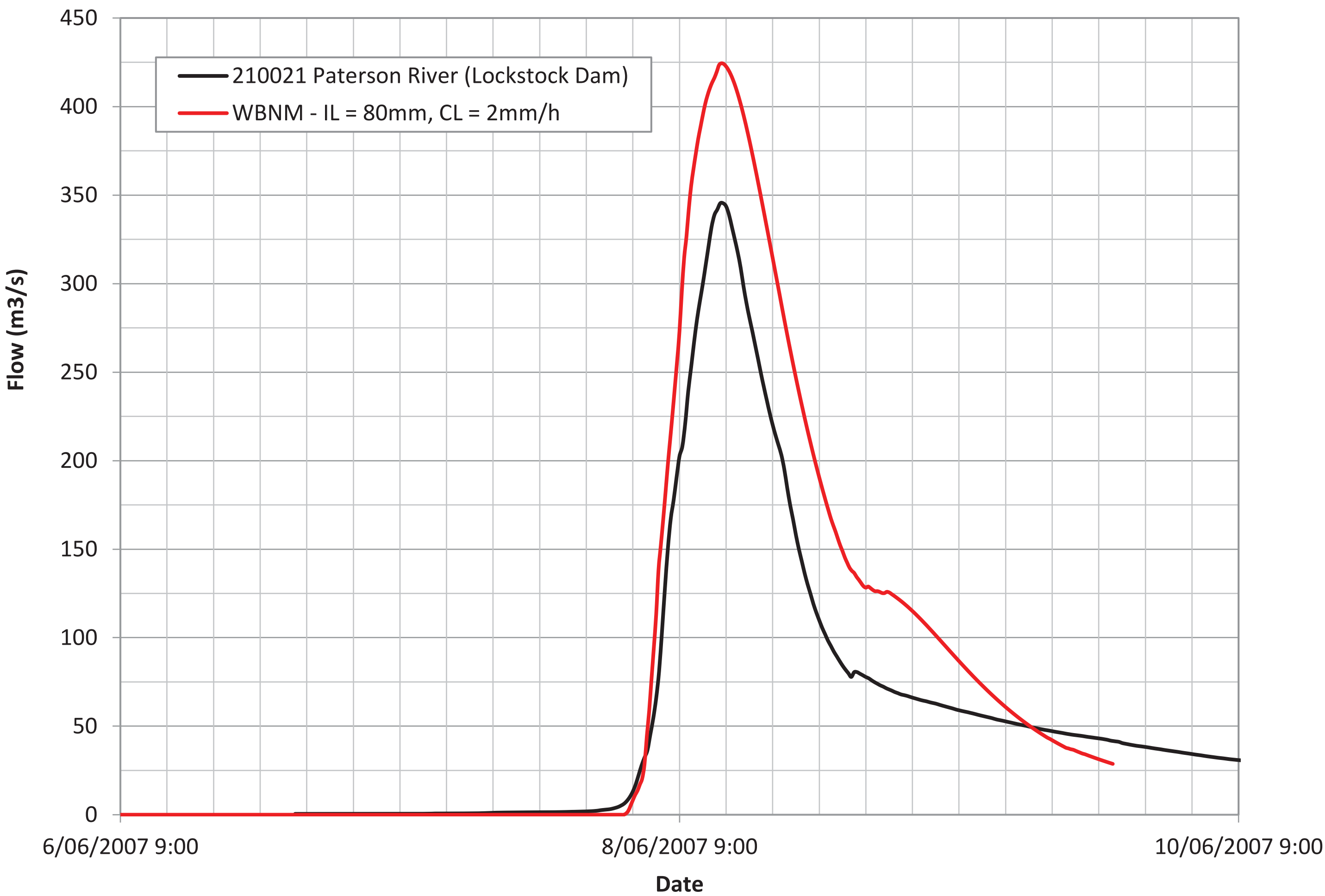
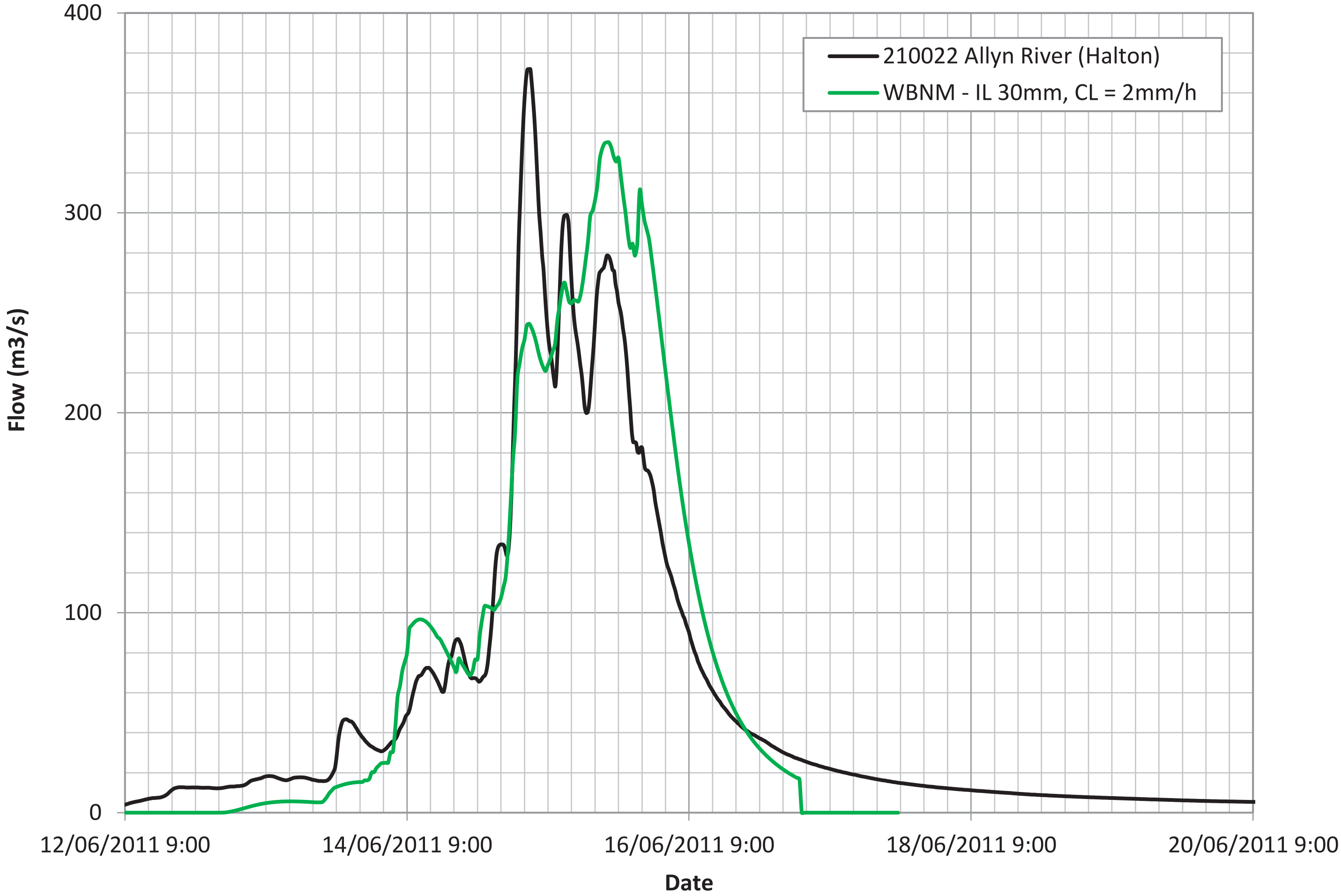


FIGURE B3
HYDROLOGIC MODEL CALIBRATION
JUNE 2011 EVENT



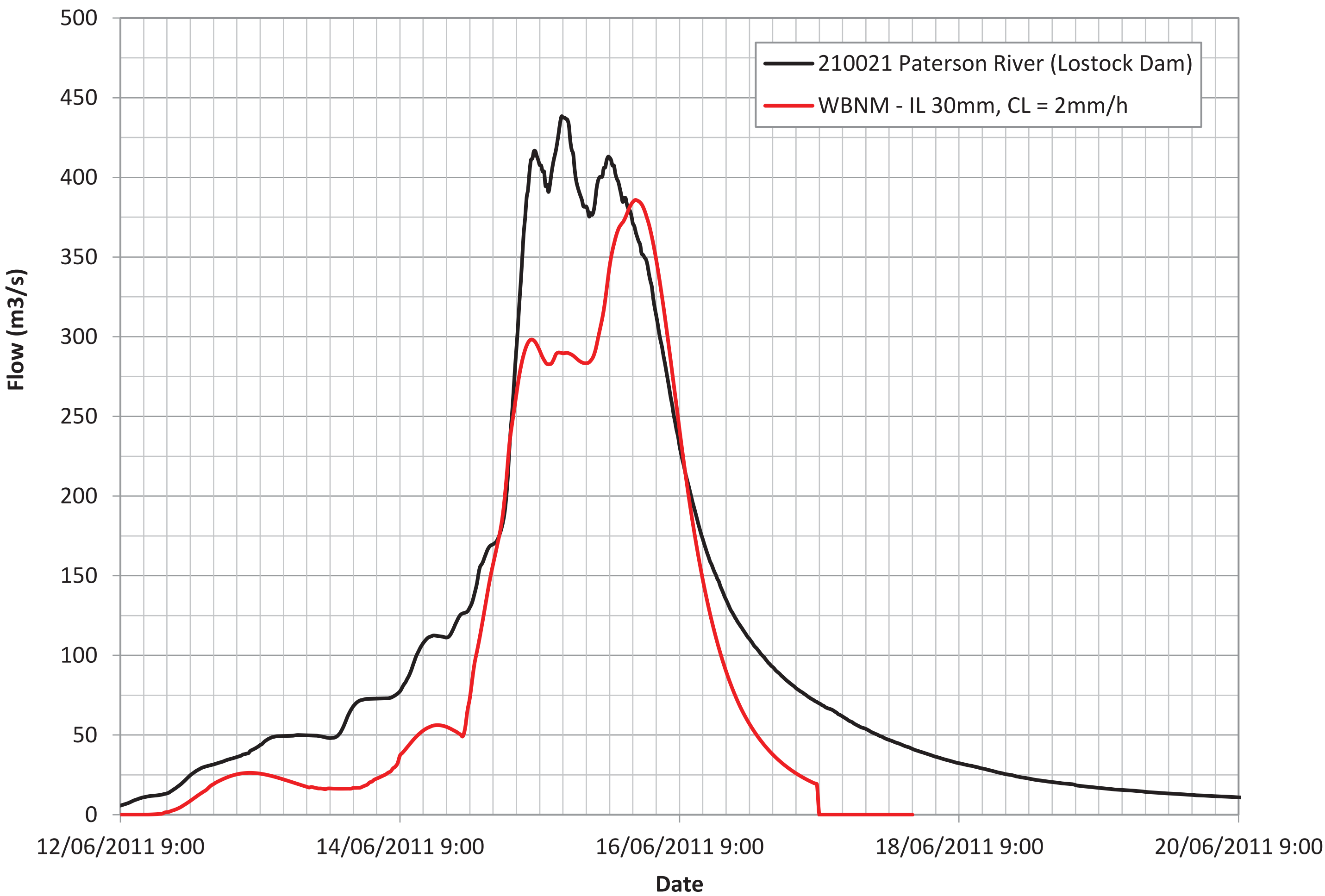
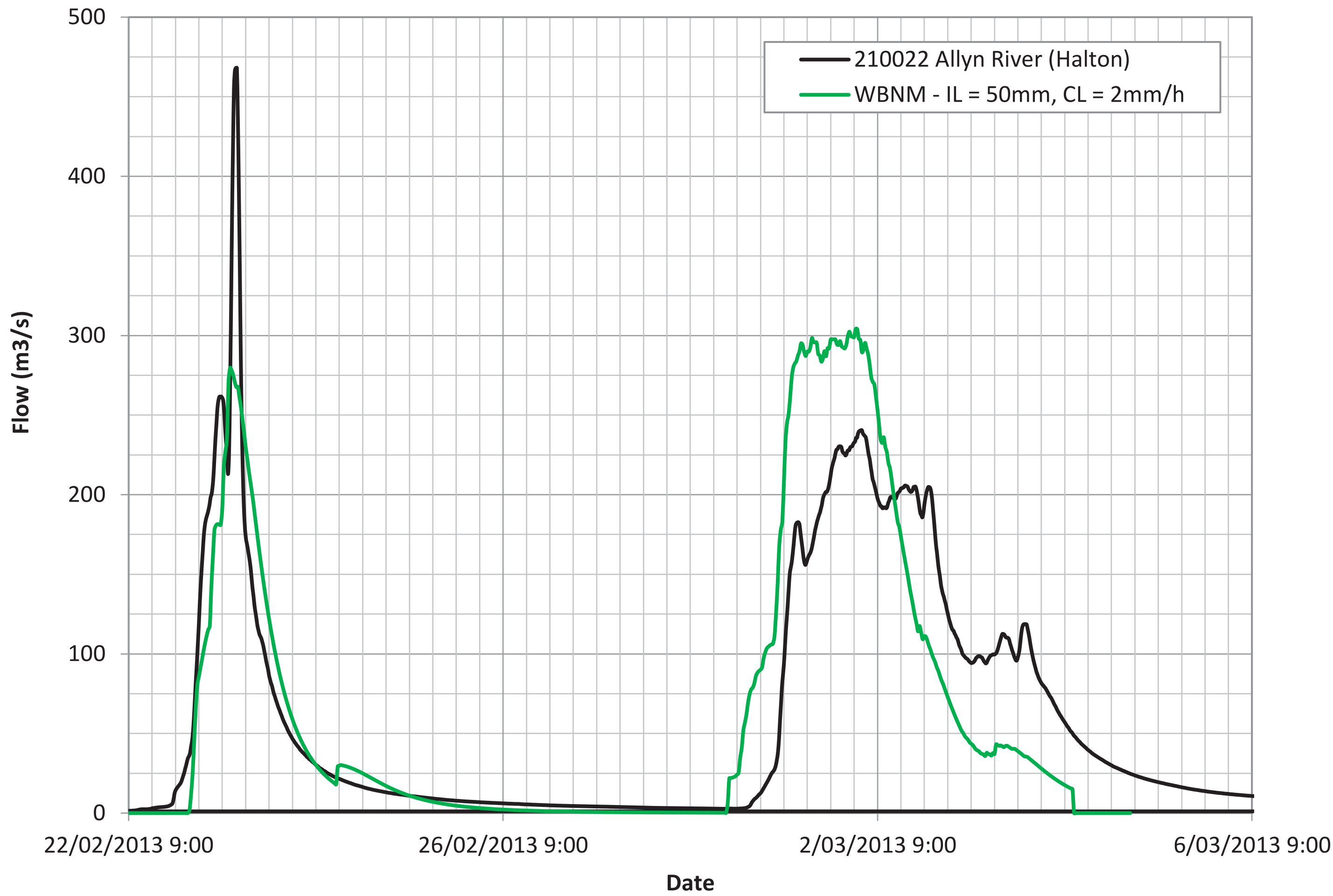
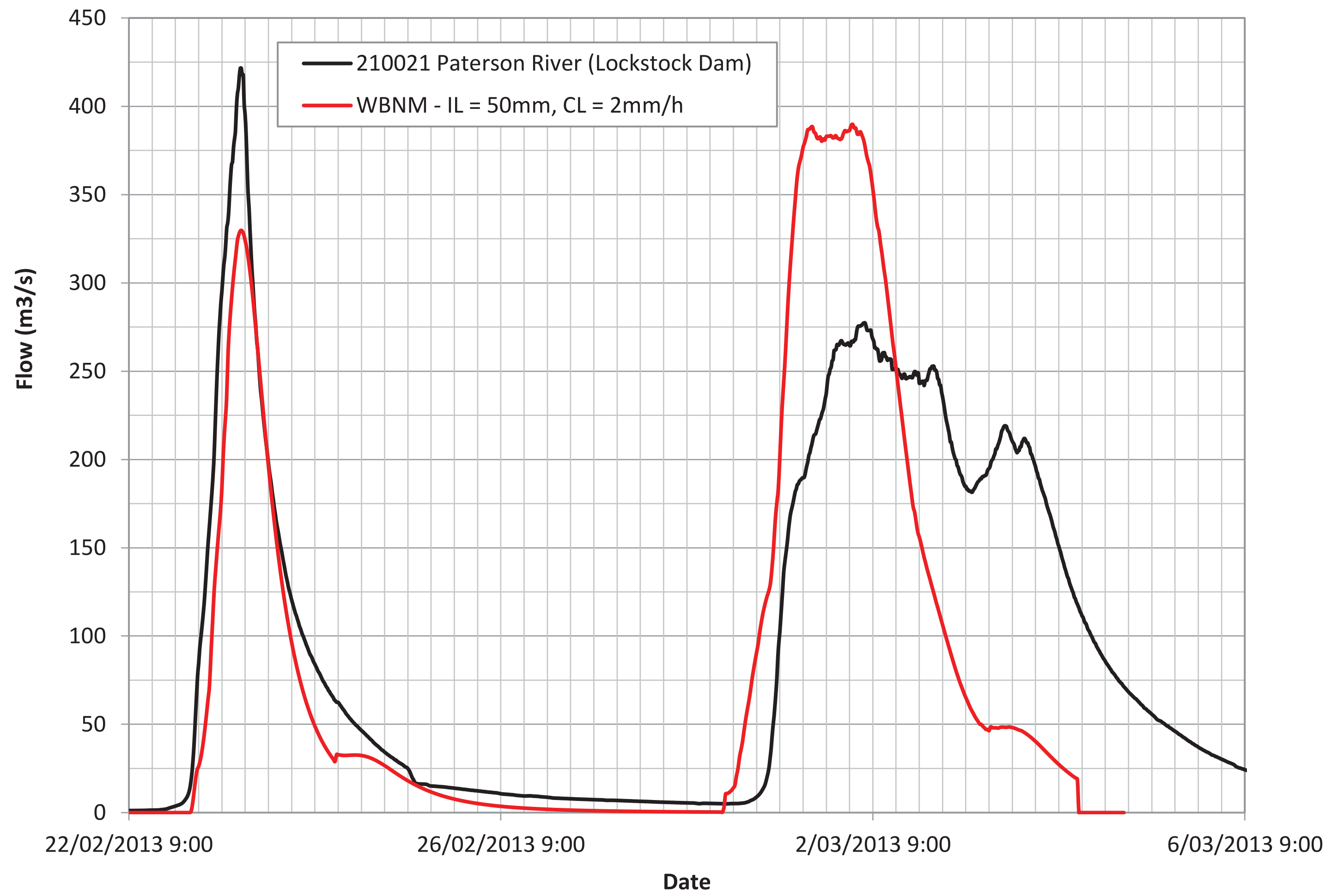
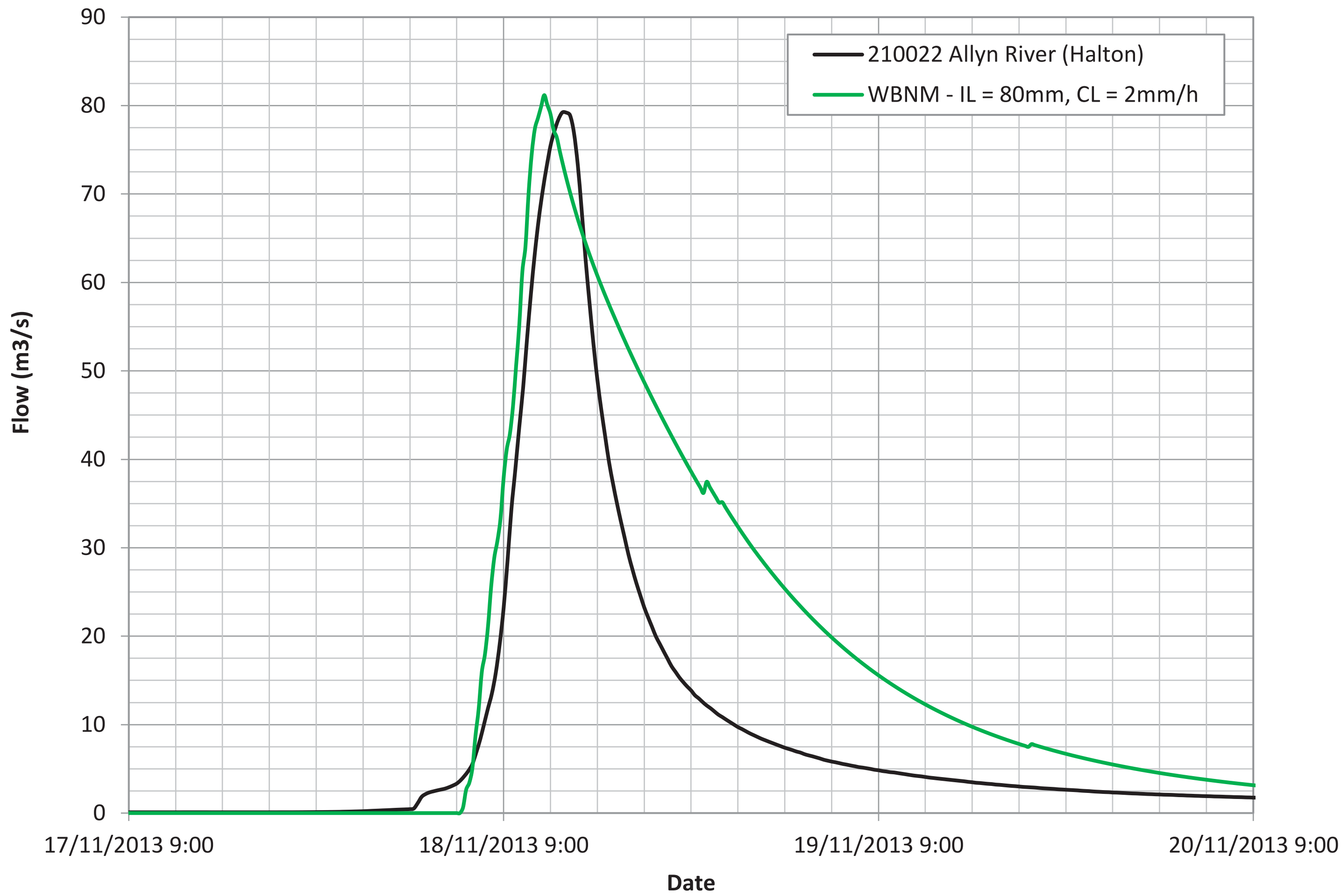


FIGURE B4
HYDROLOGIC MODEL CALIBRATION
MARCH 2013





HYDROLOGIC MODEL CALIBRATION
NOVEMBER 2013



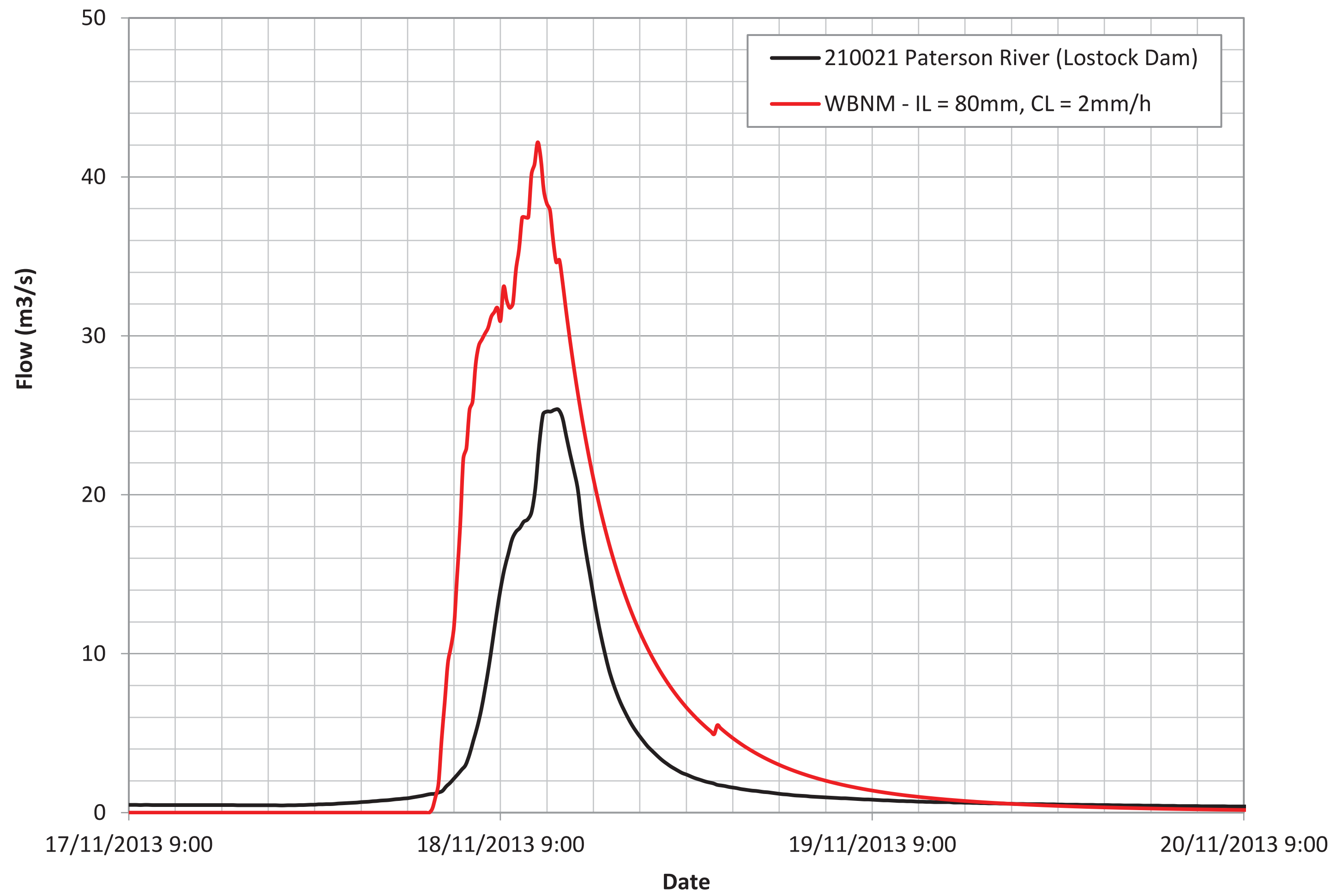
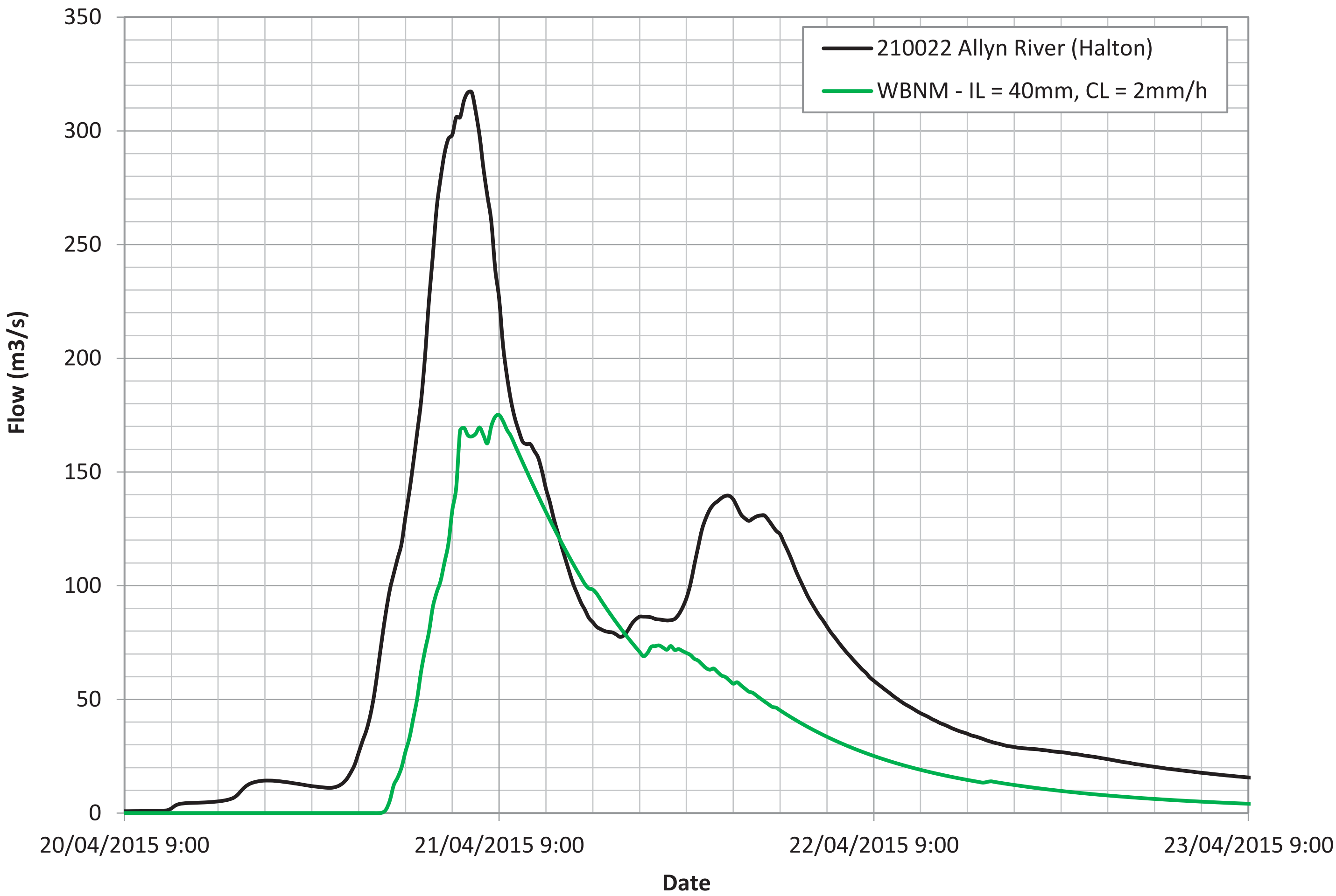


FIGURE B6
HYDROLOGIC MODEL CALIBRATION
APRIL 2015



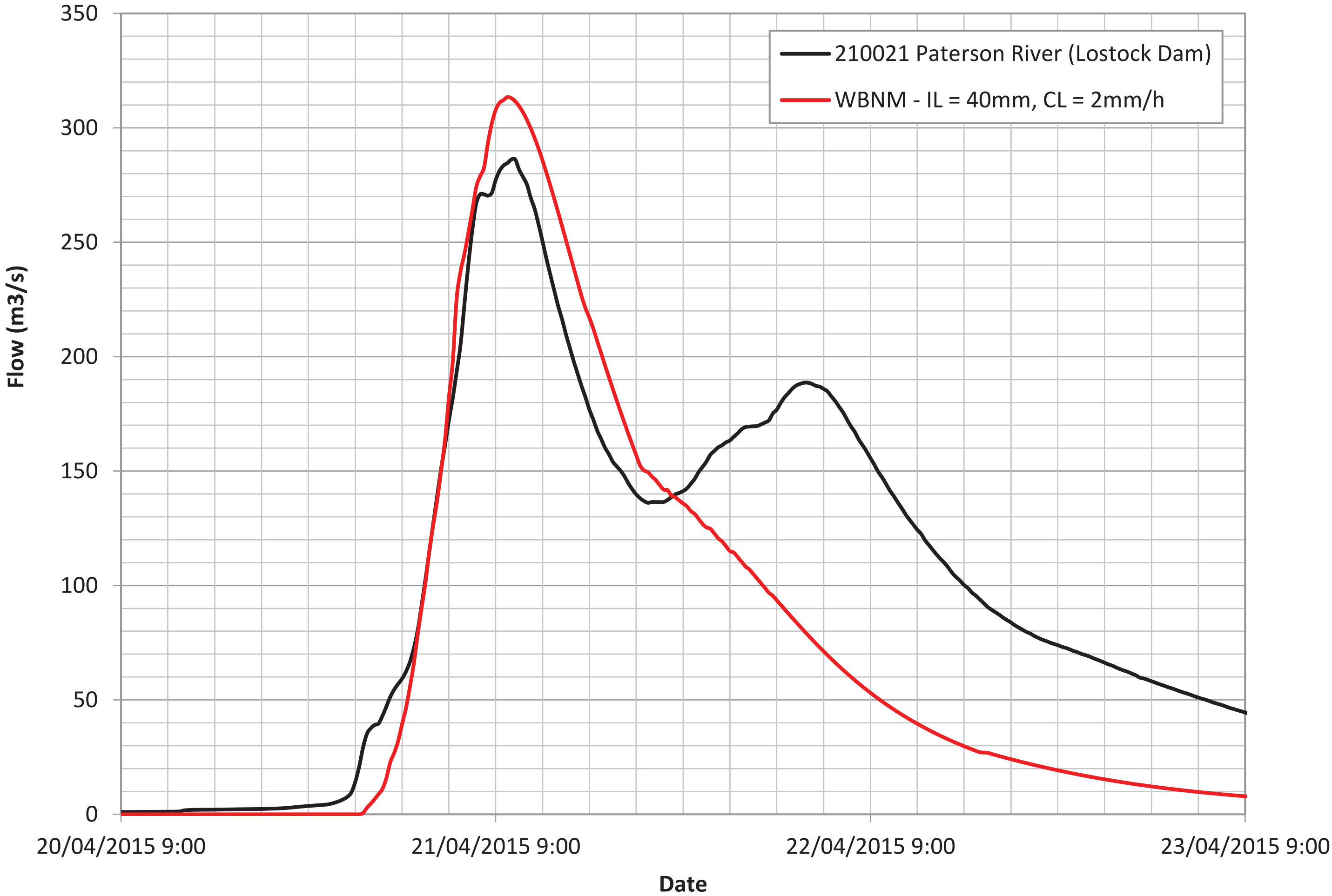
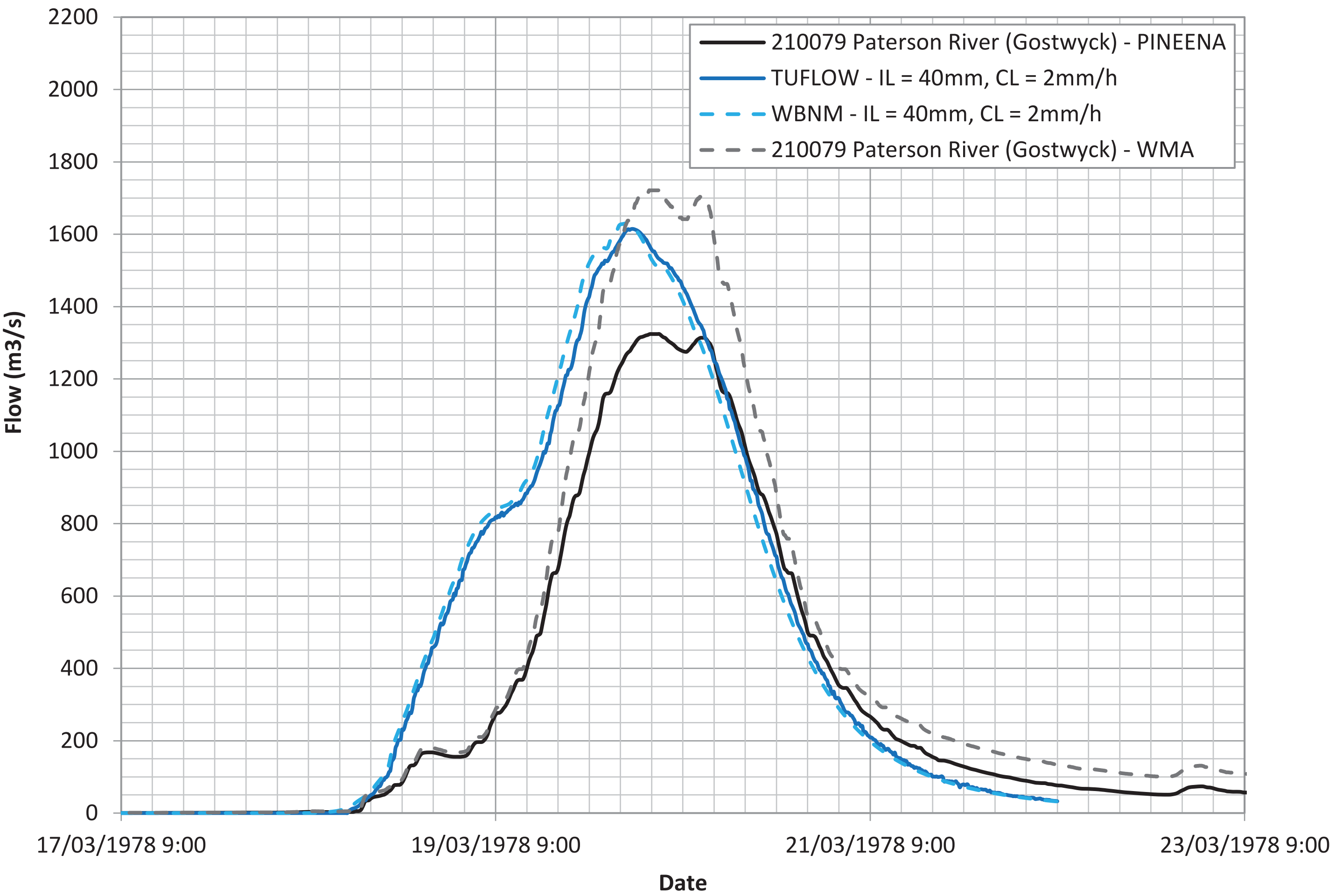


FIGURE B7
HYDRAULIC MODEL CALIBRATION
MARCH 1978 EVENT



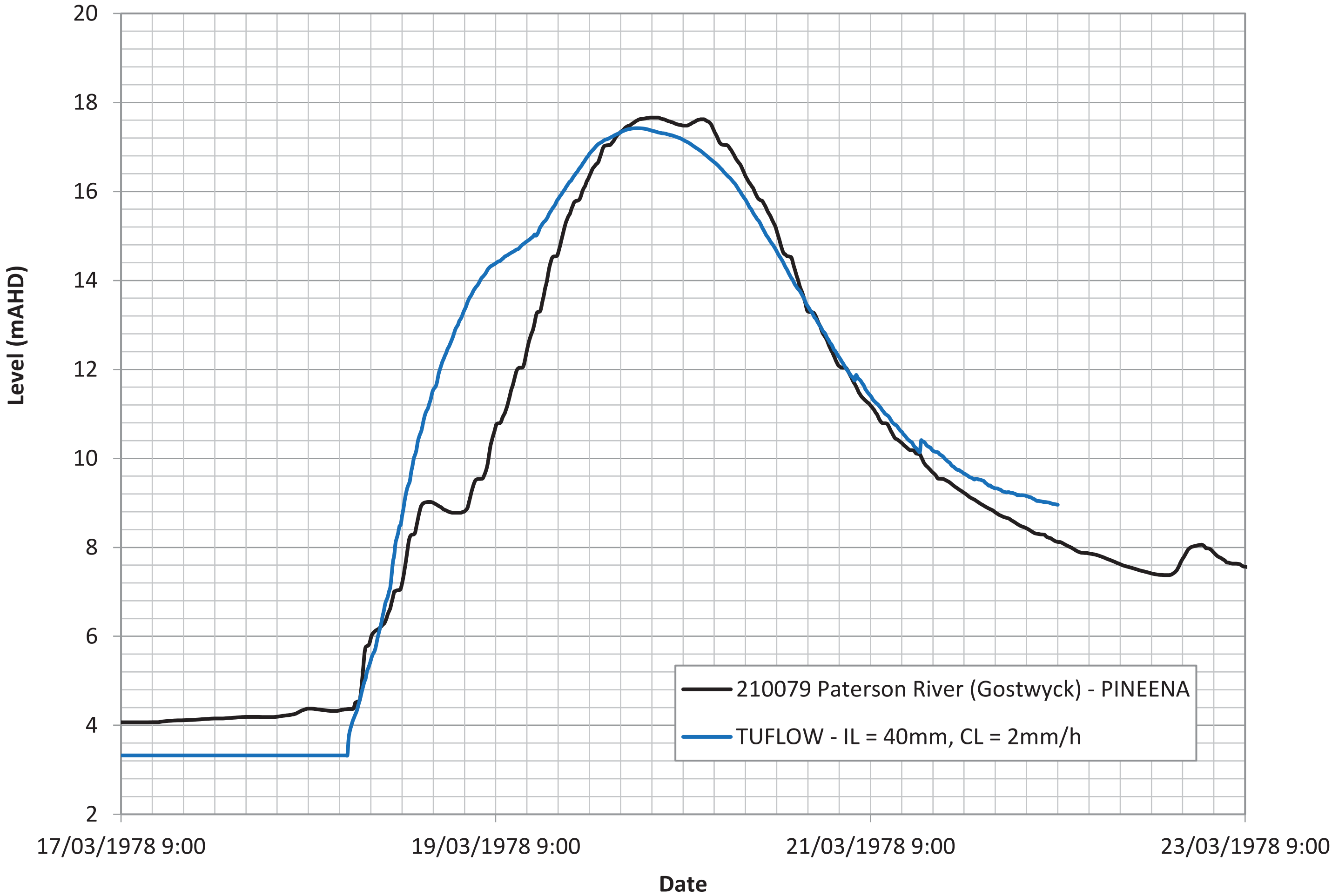
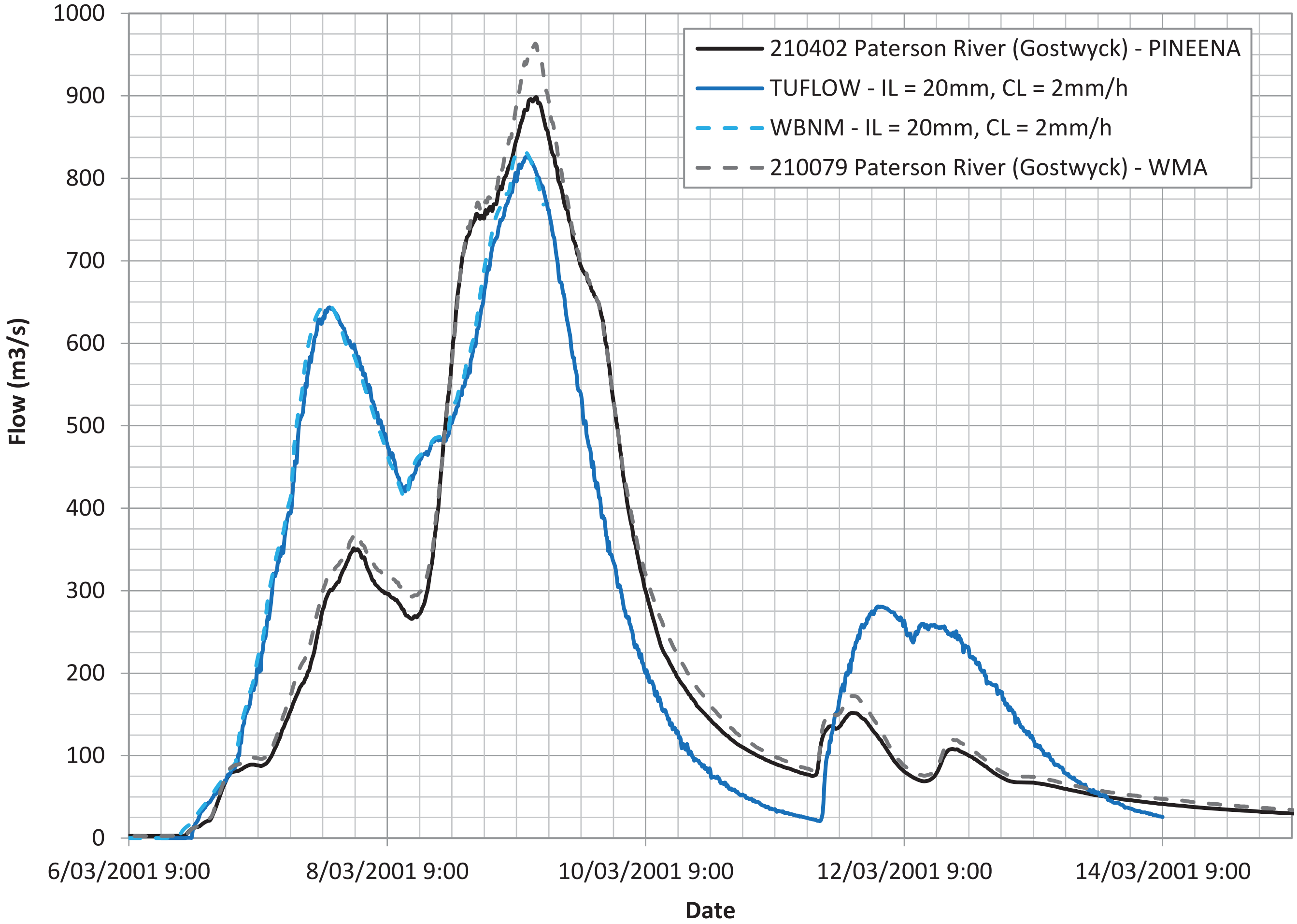
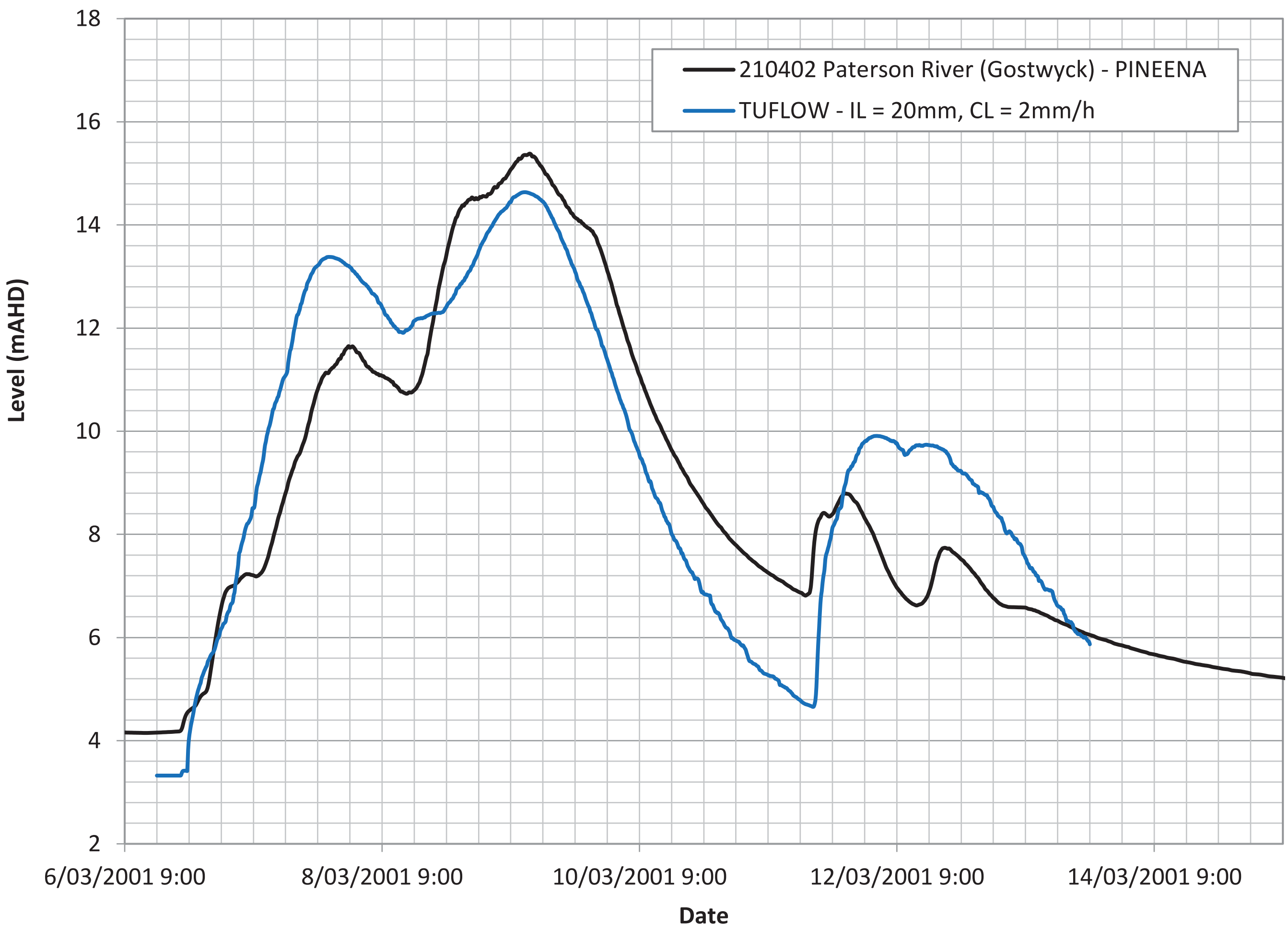
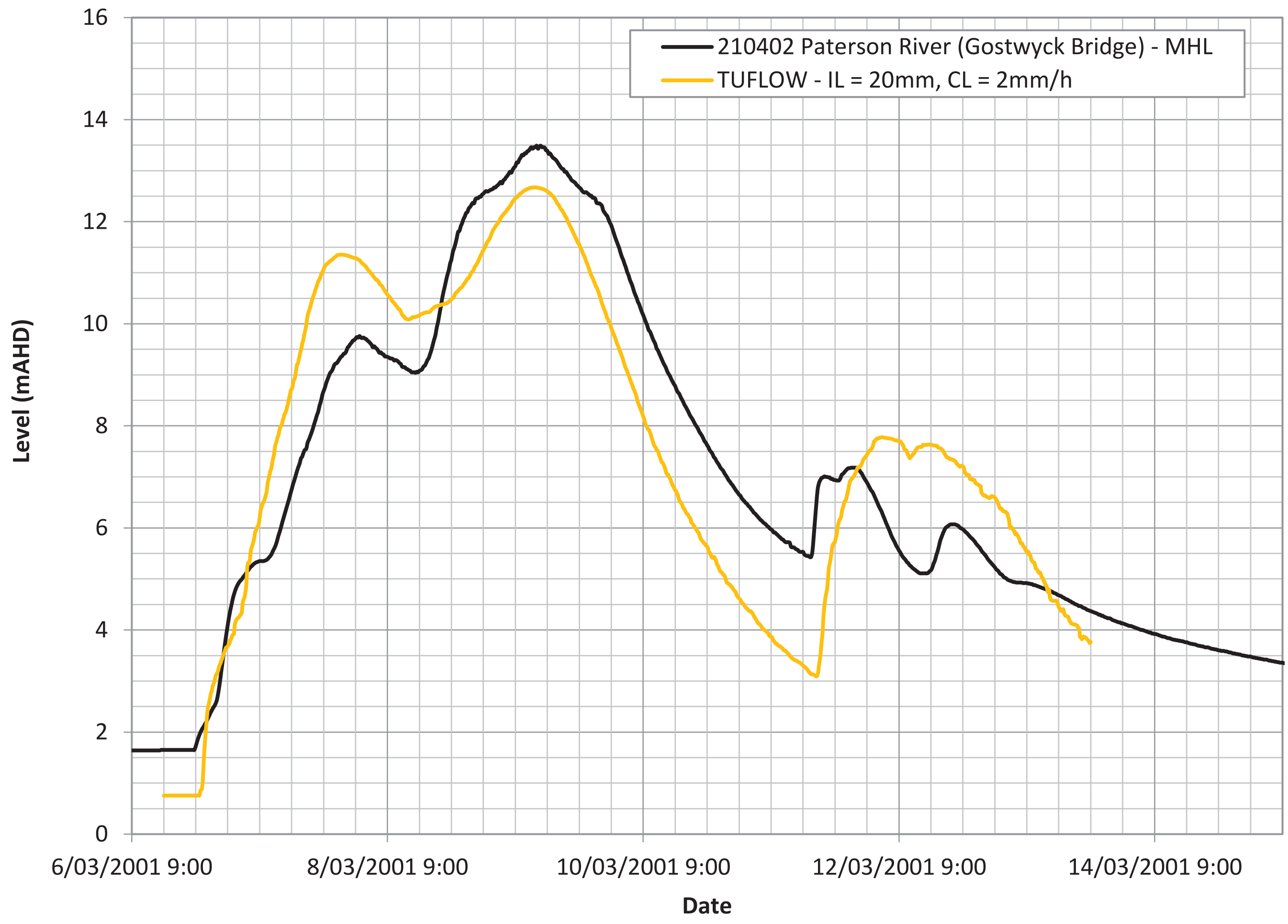


FIGURE B8
HYDRAULIC MODEL CALIBRATION
MARCH 2001 EVENT





HYDRAULIC MODEL CALIBRATION
MARCH 2001 EVENT



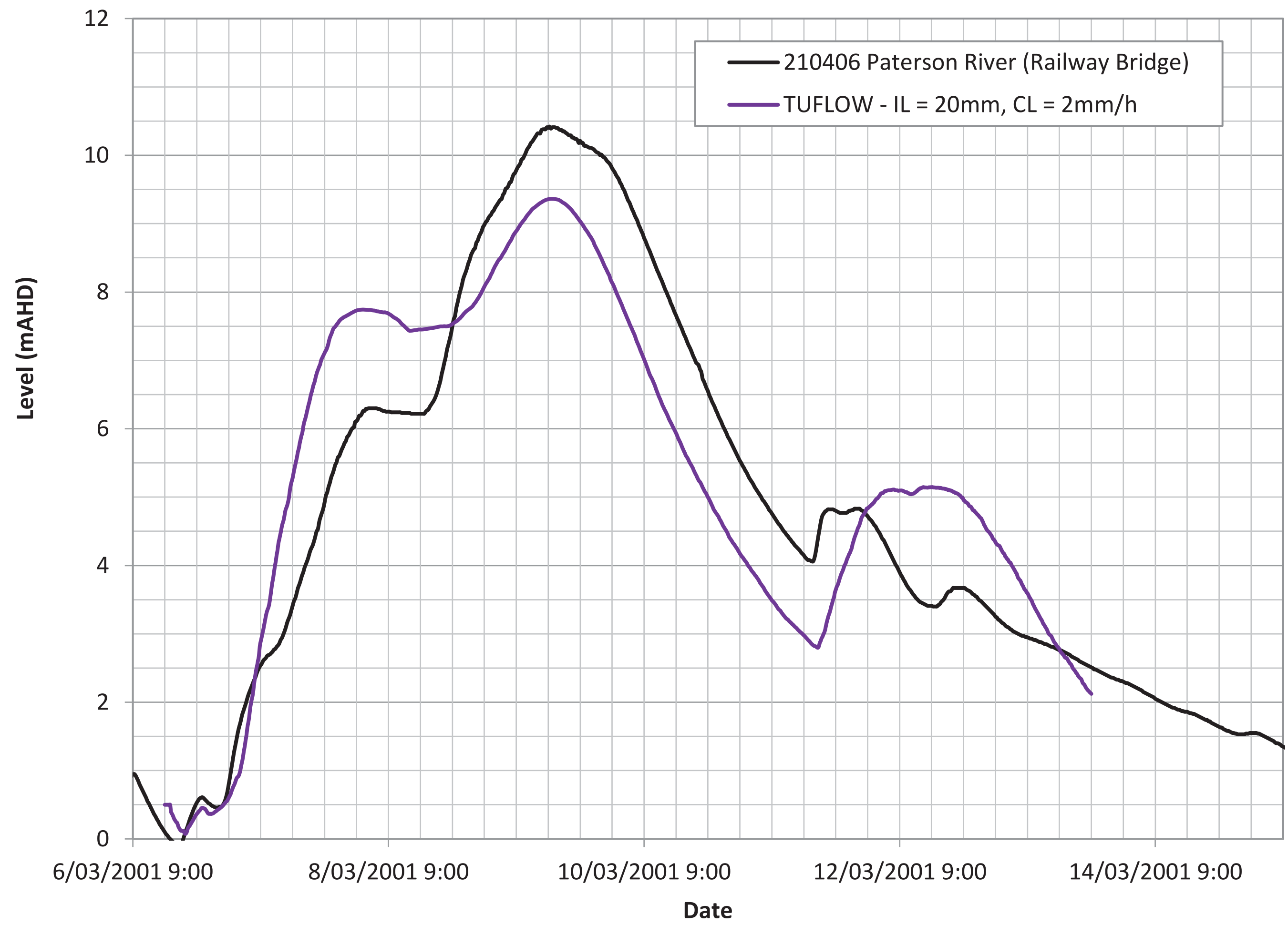
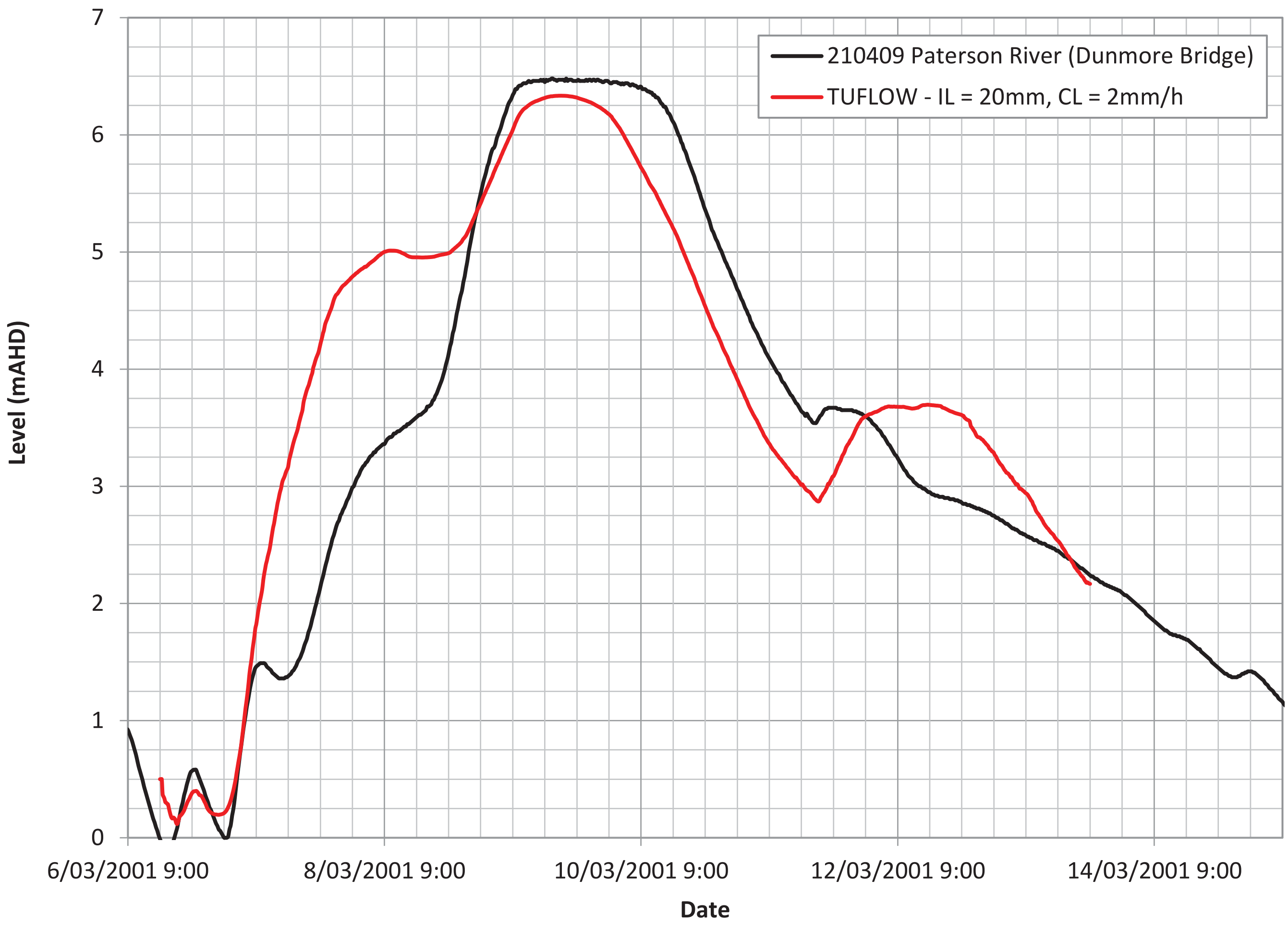


FIGURE B10
HYDRAULIC MODEL CALIBRATION
MARCH 2001 EVENT



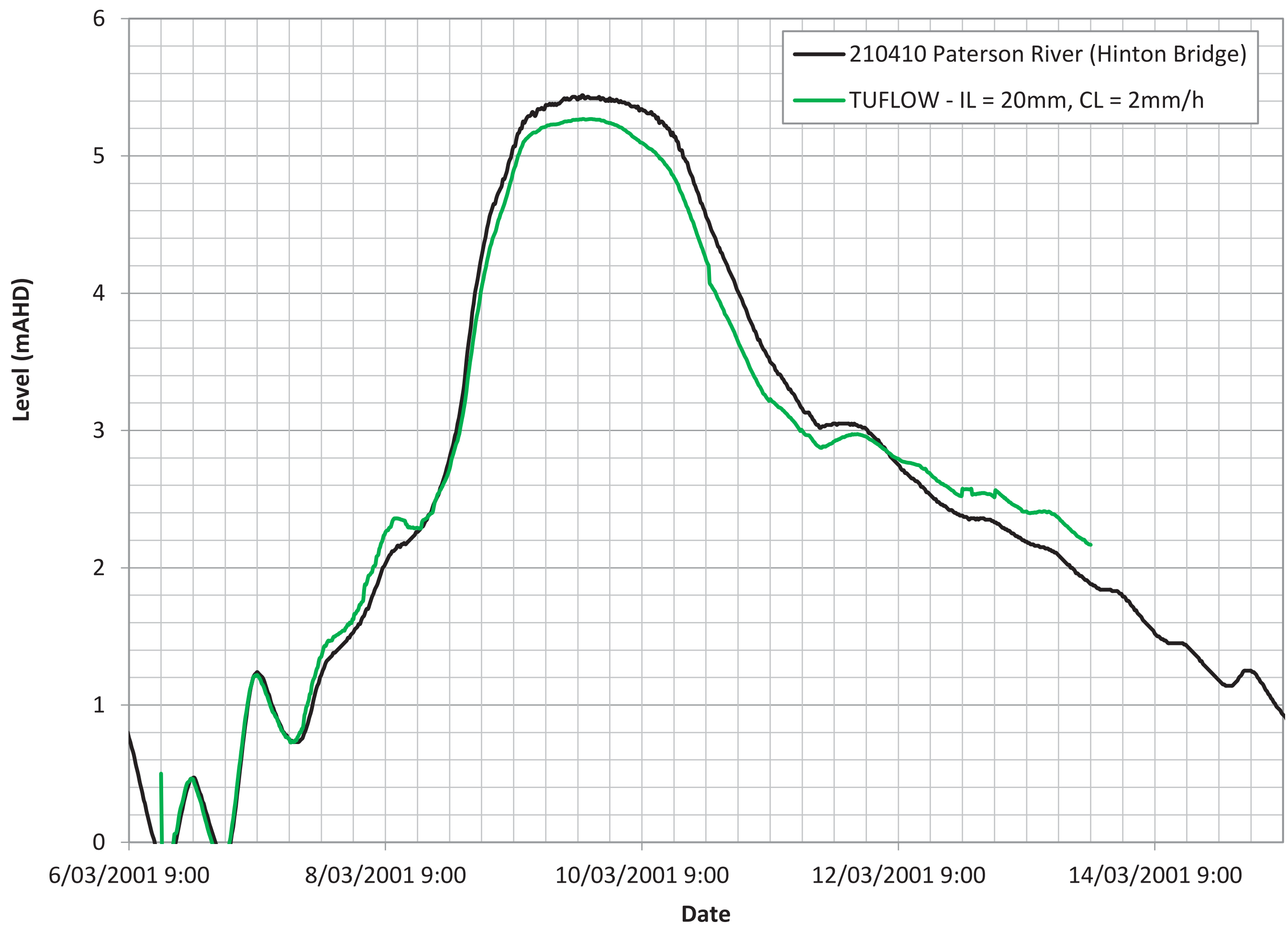


FIGURE B11
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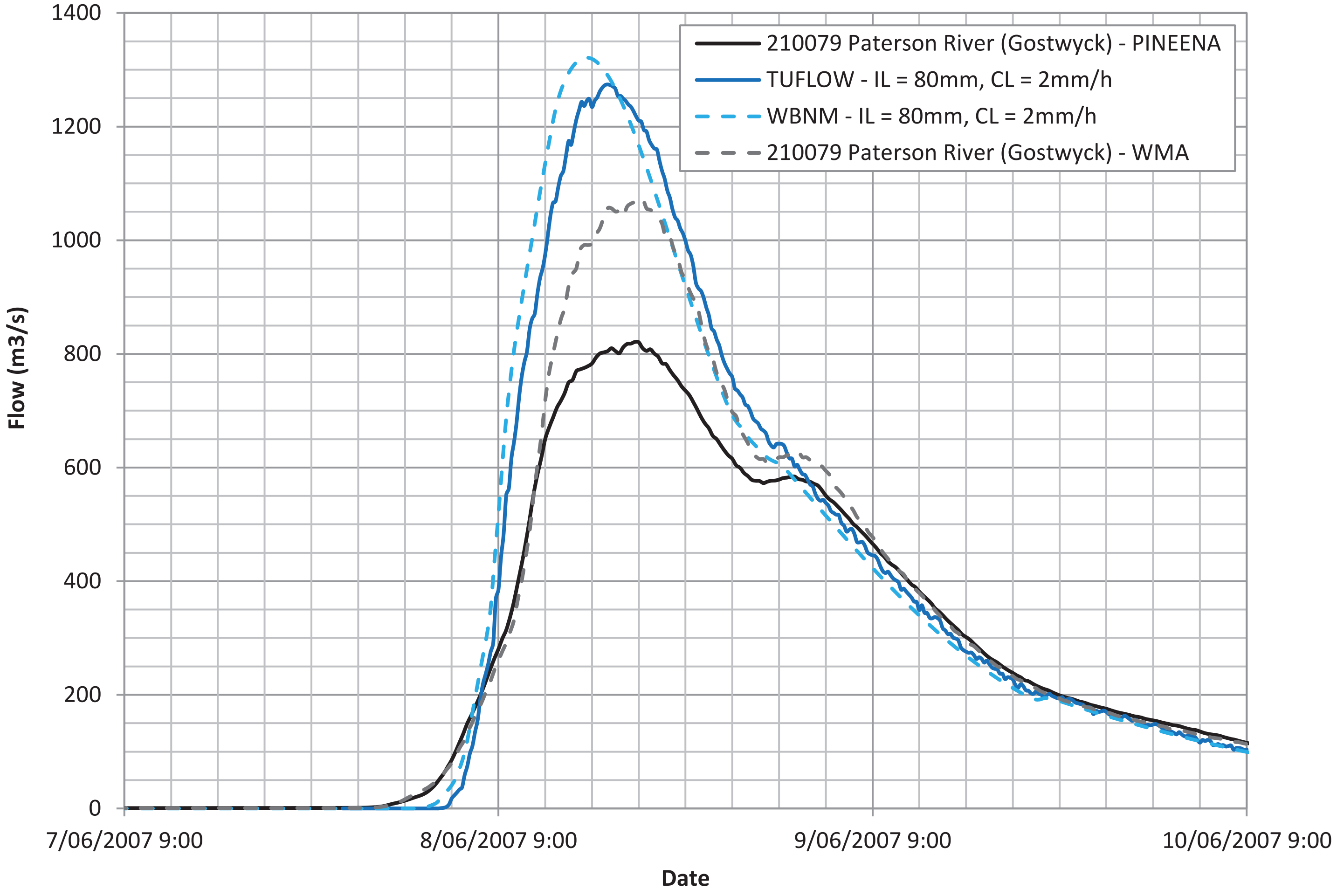
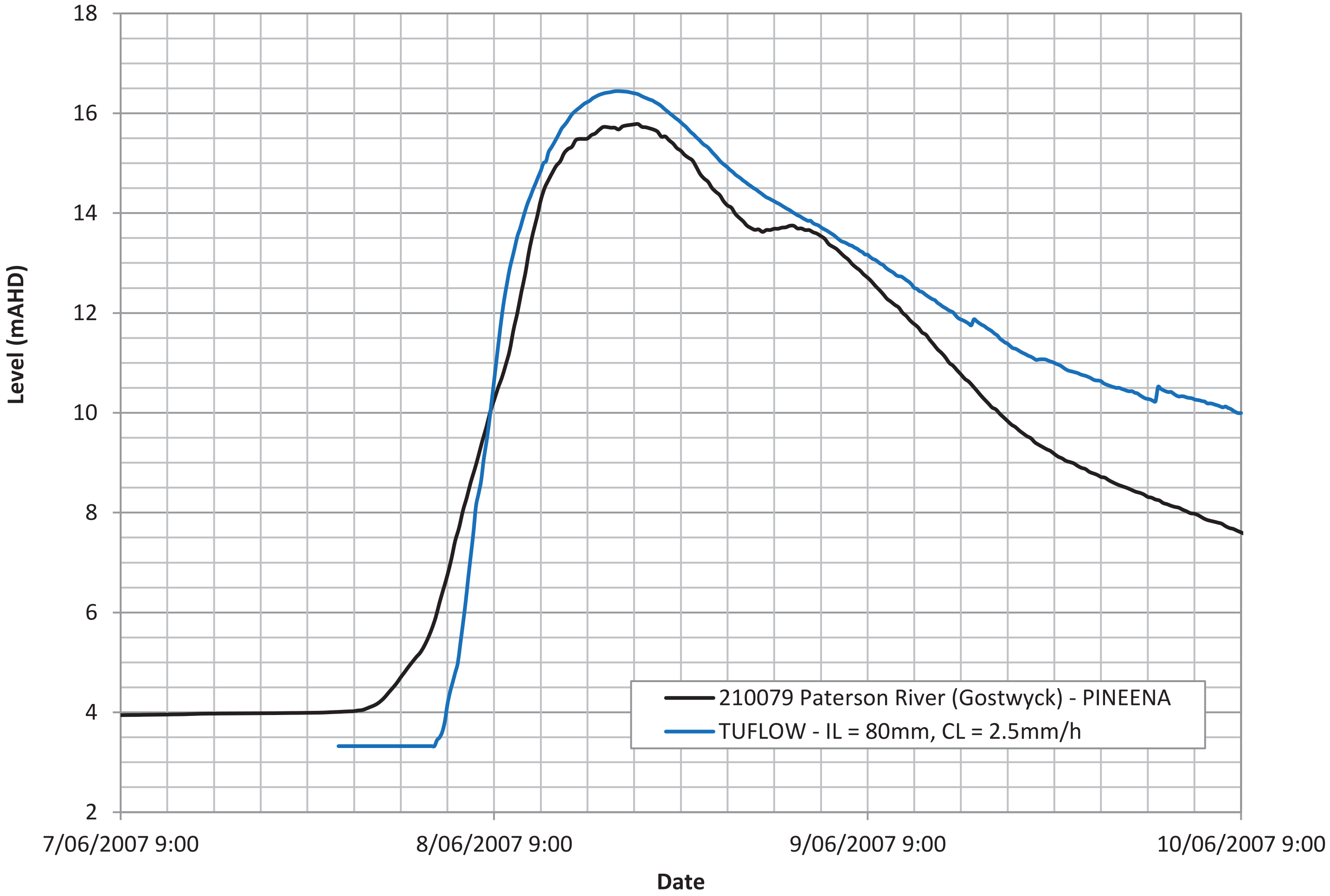
JUNE 2007 EVENT





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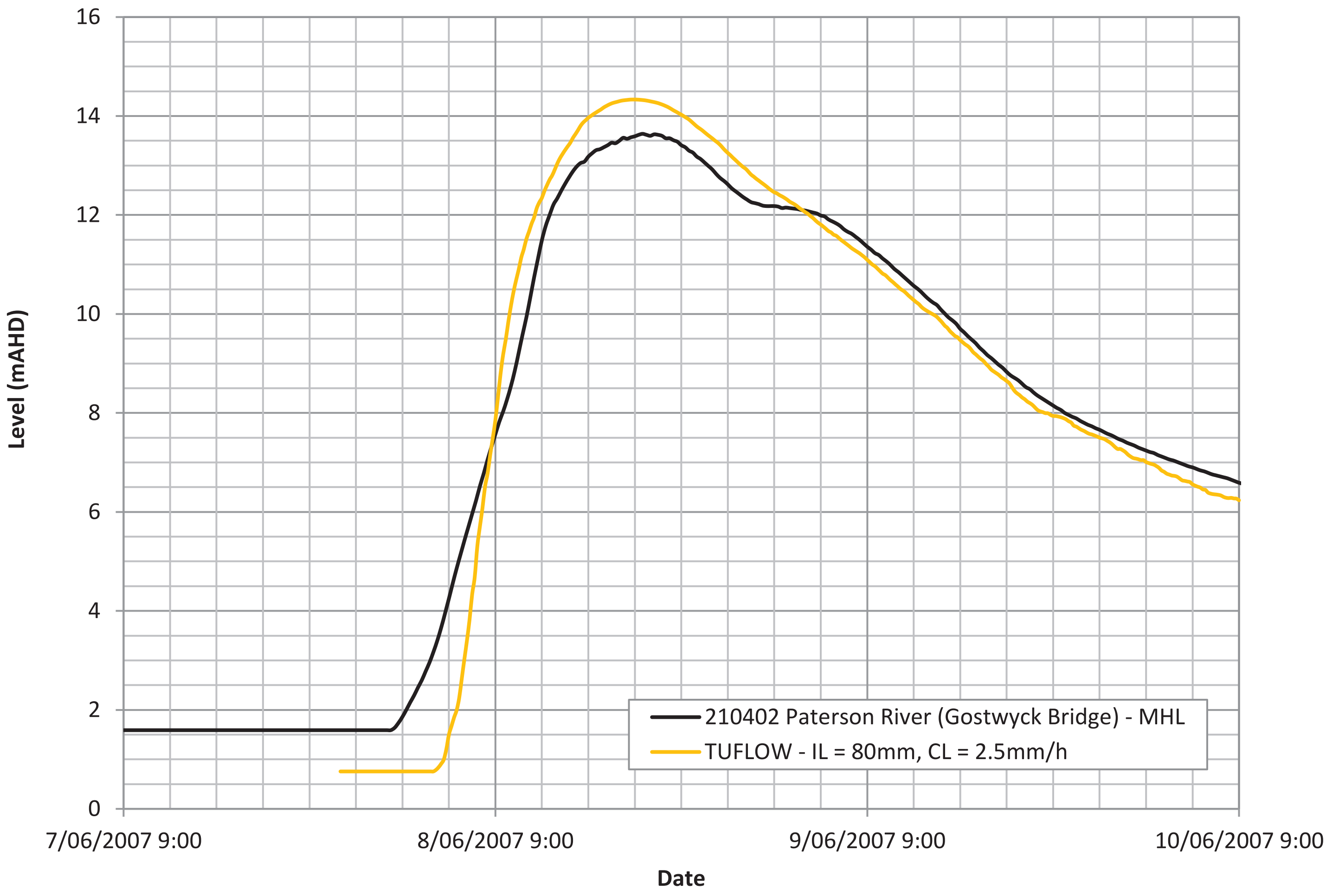


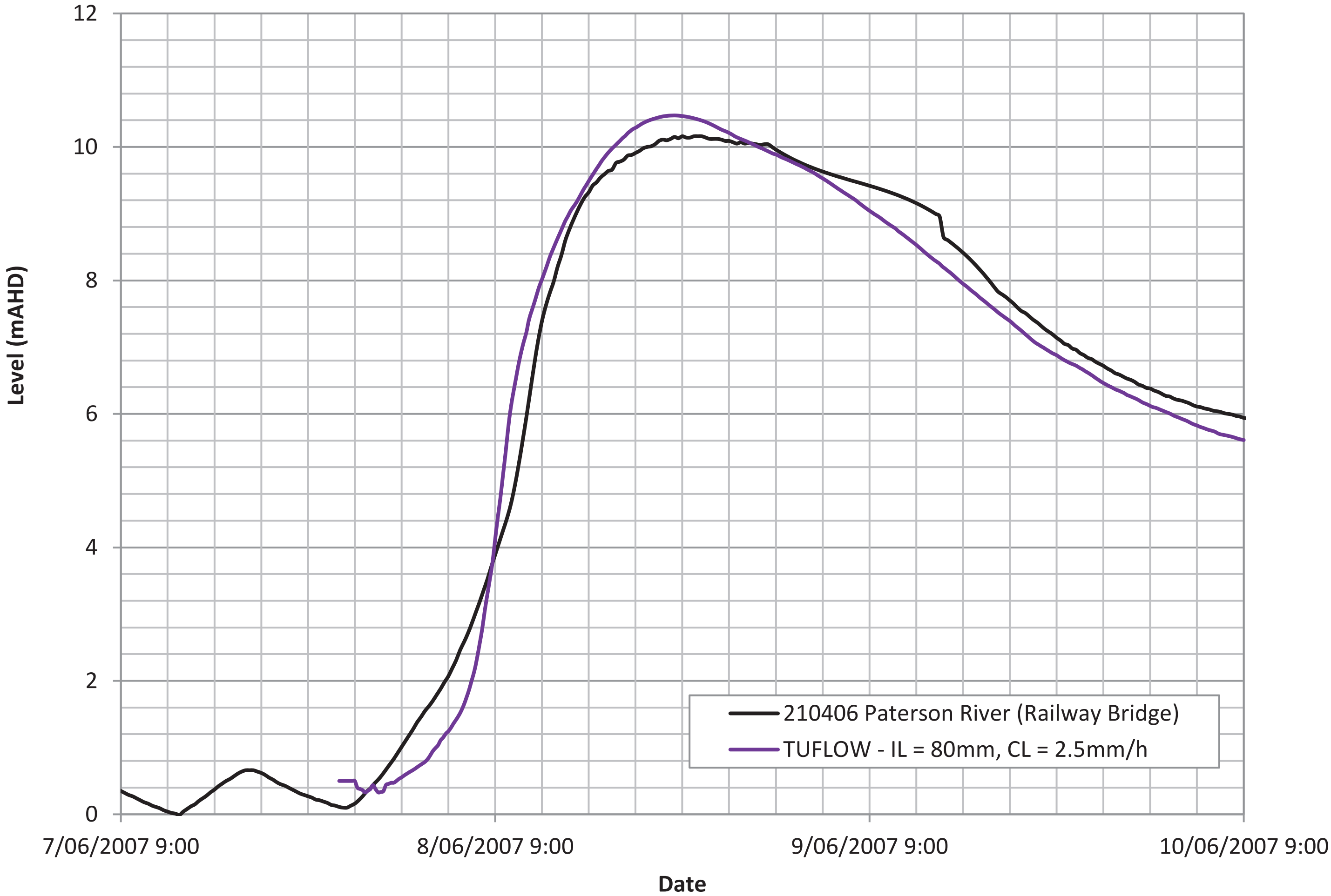
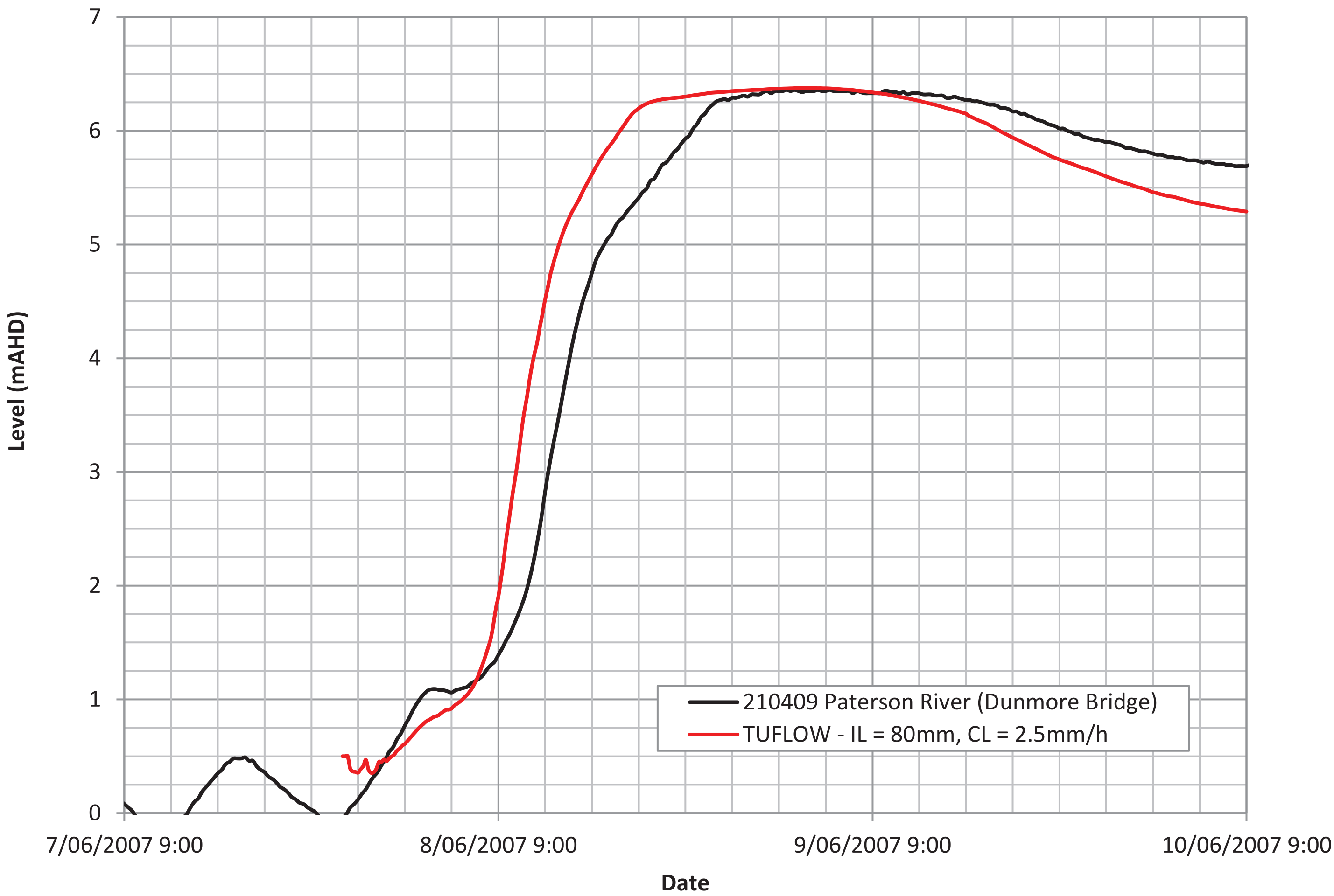


FIGURE B13
HYDRAULIC MODEL CALIBRATION
JUNE 2007 EVENT



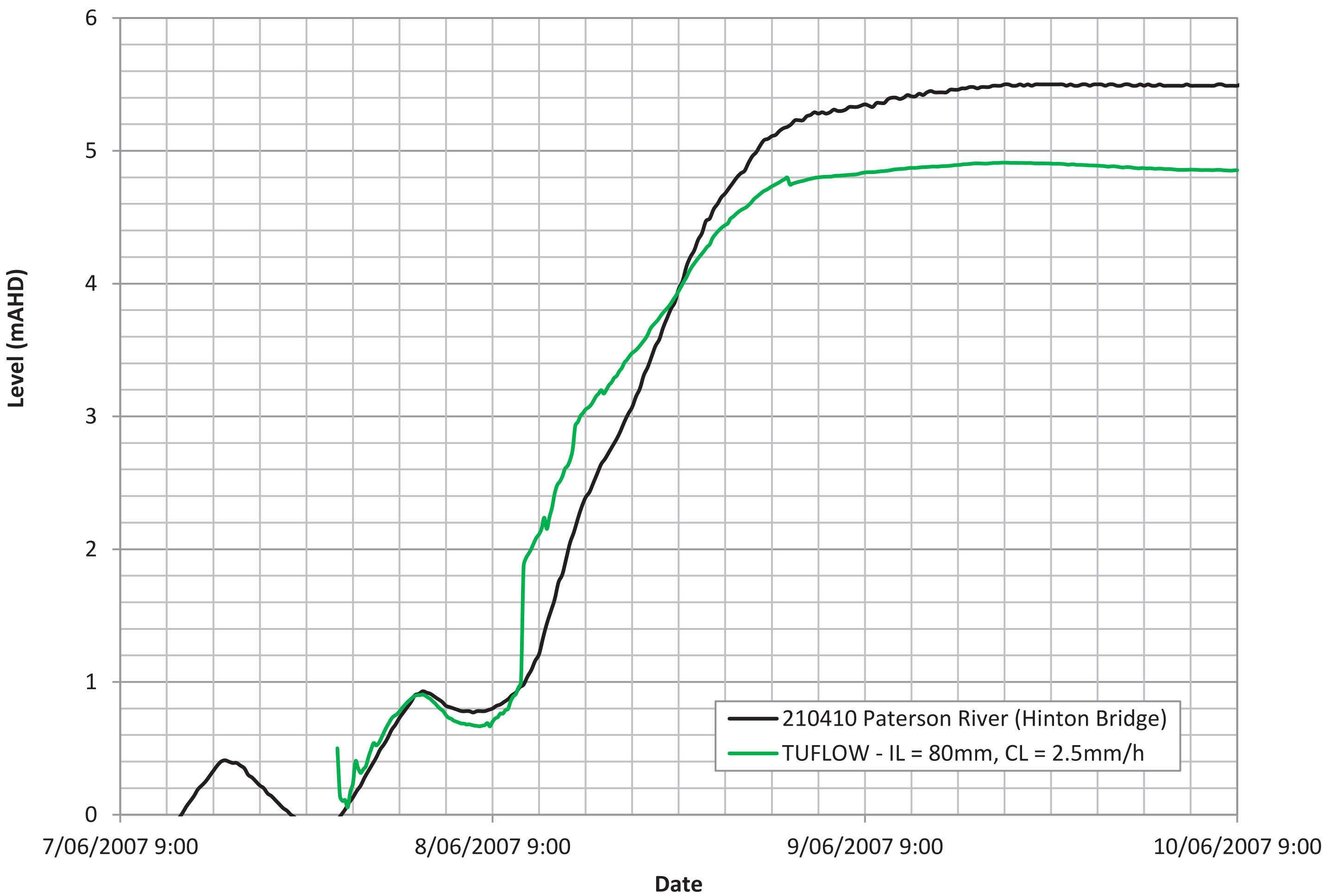
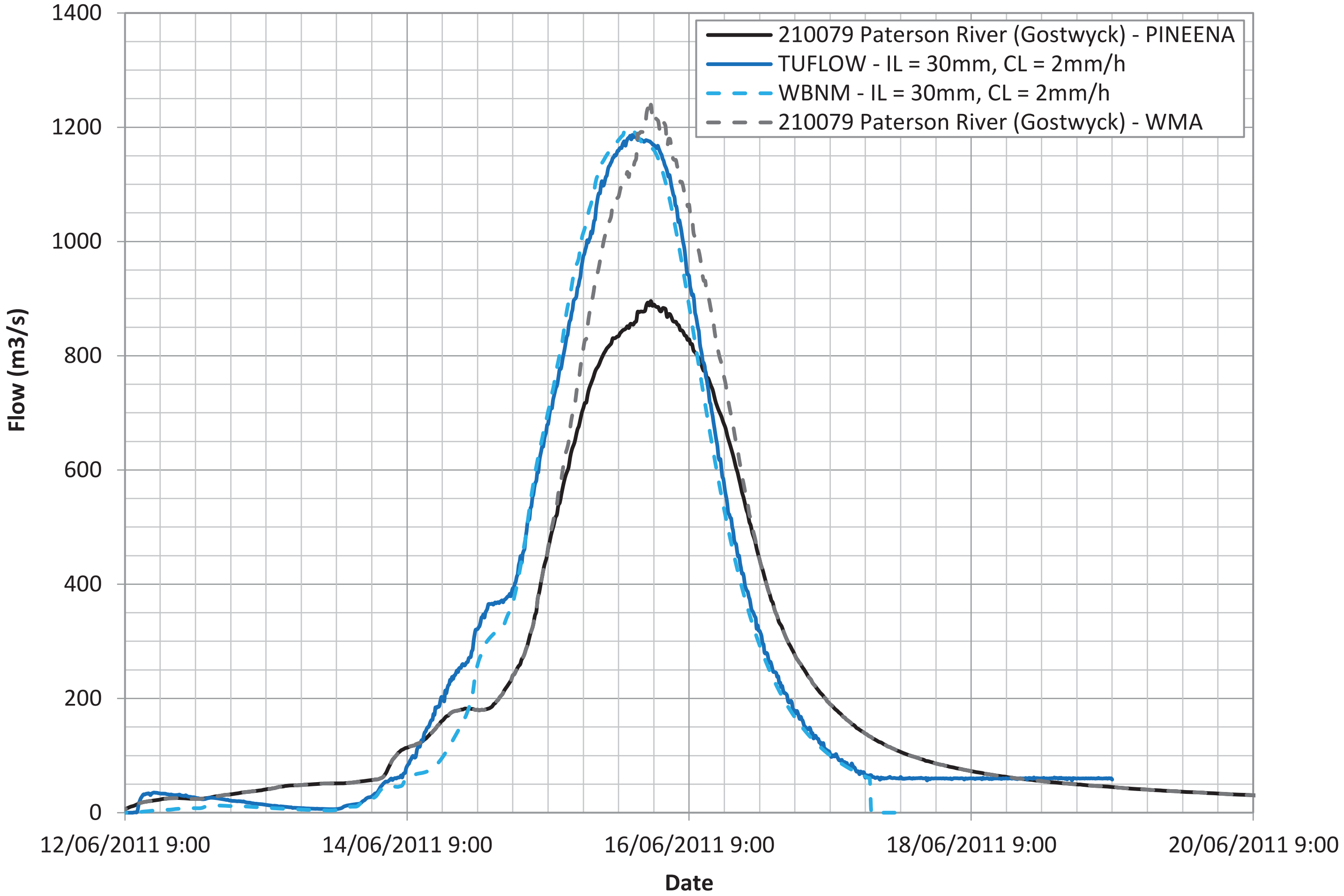


FIGURE B14
HYDRAULIC MODEL CALIBRATION
JUNE 2011 EVENT



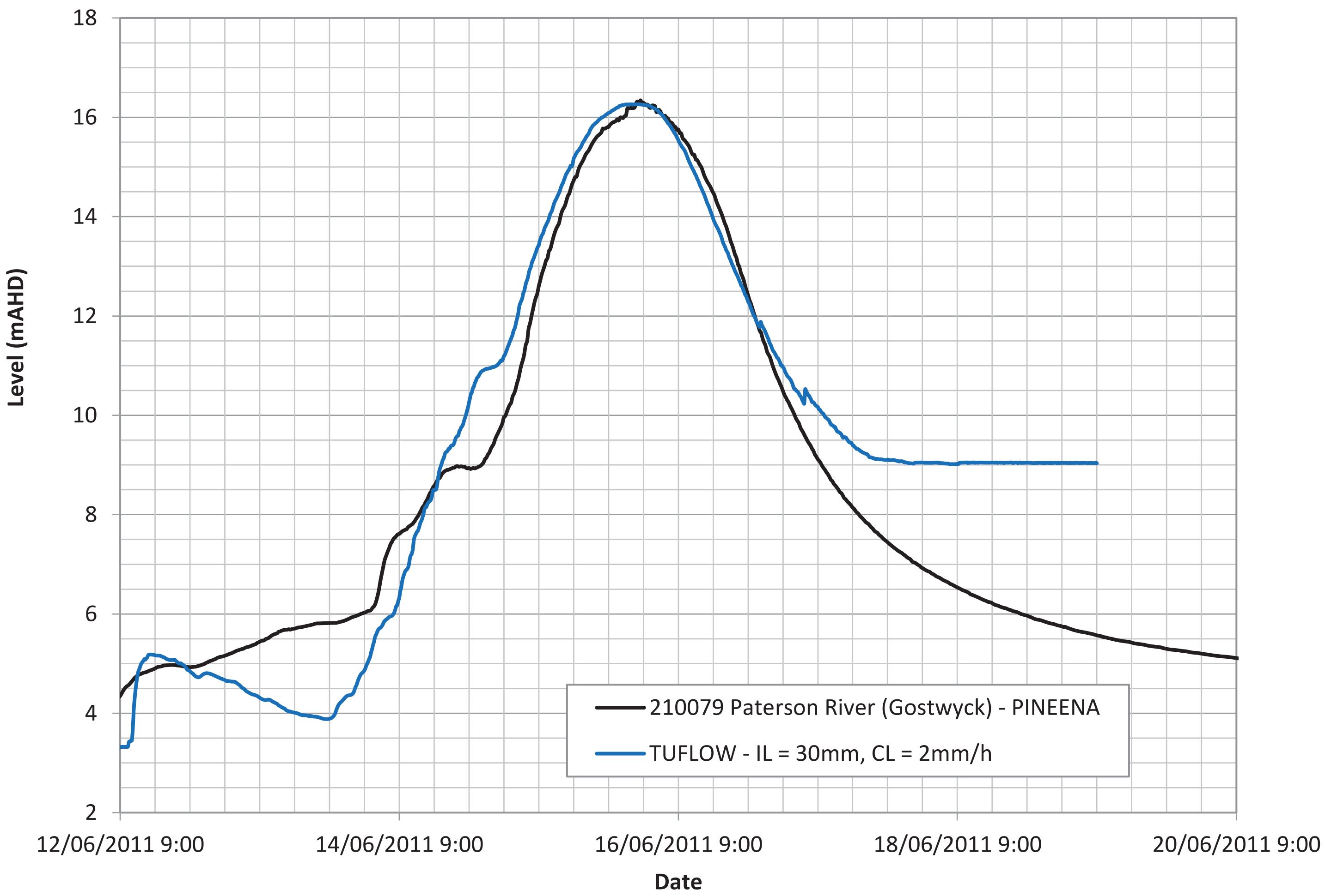


FIGURE B15
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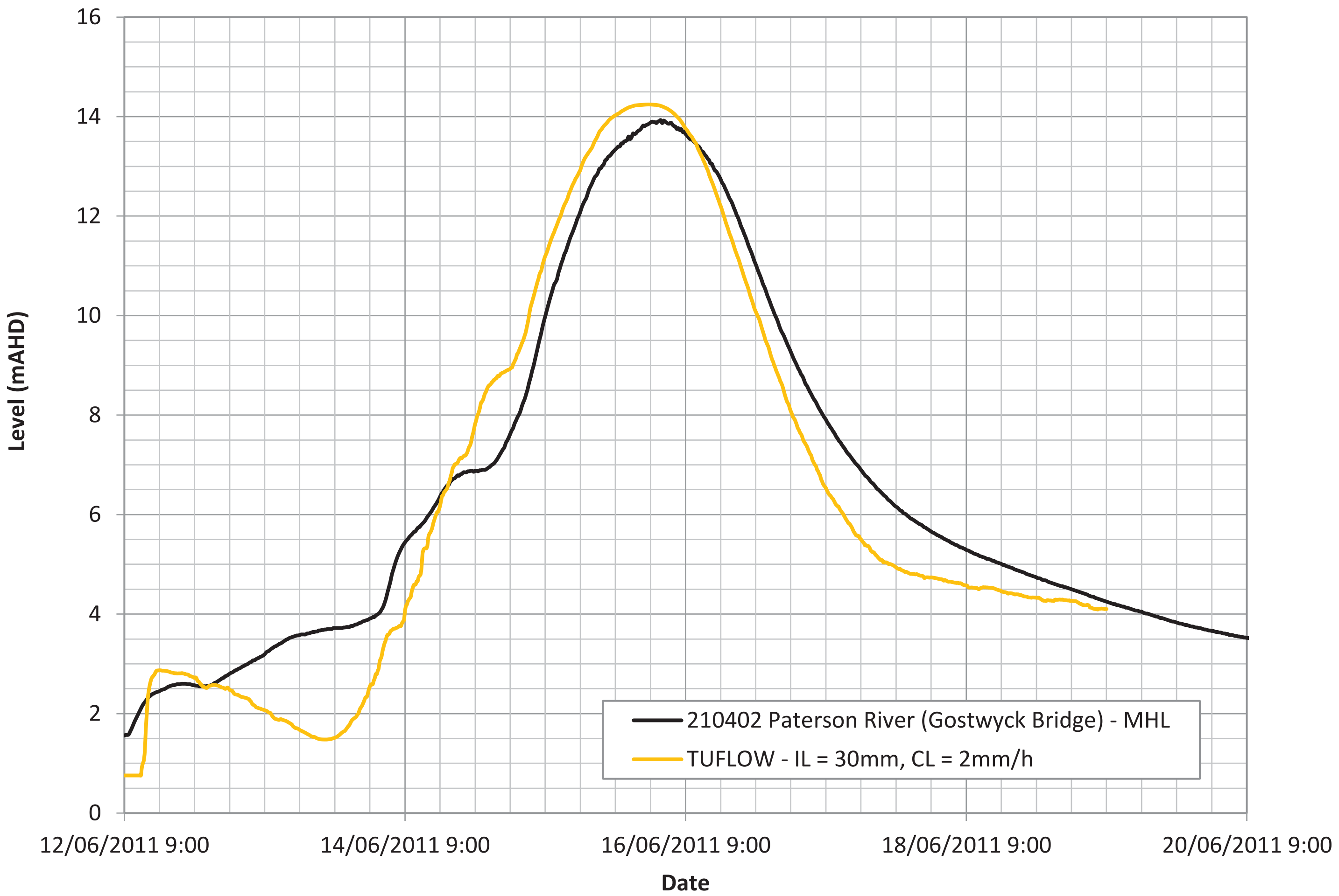

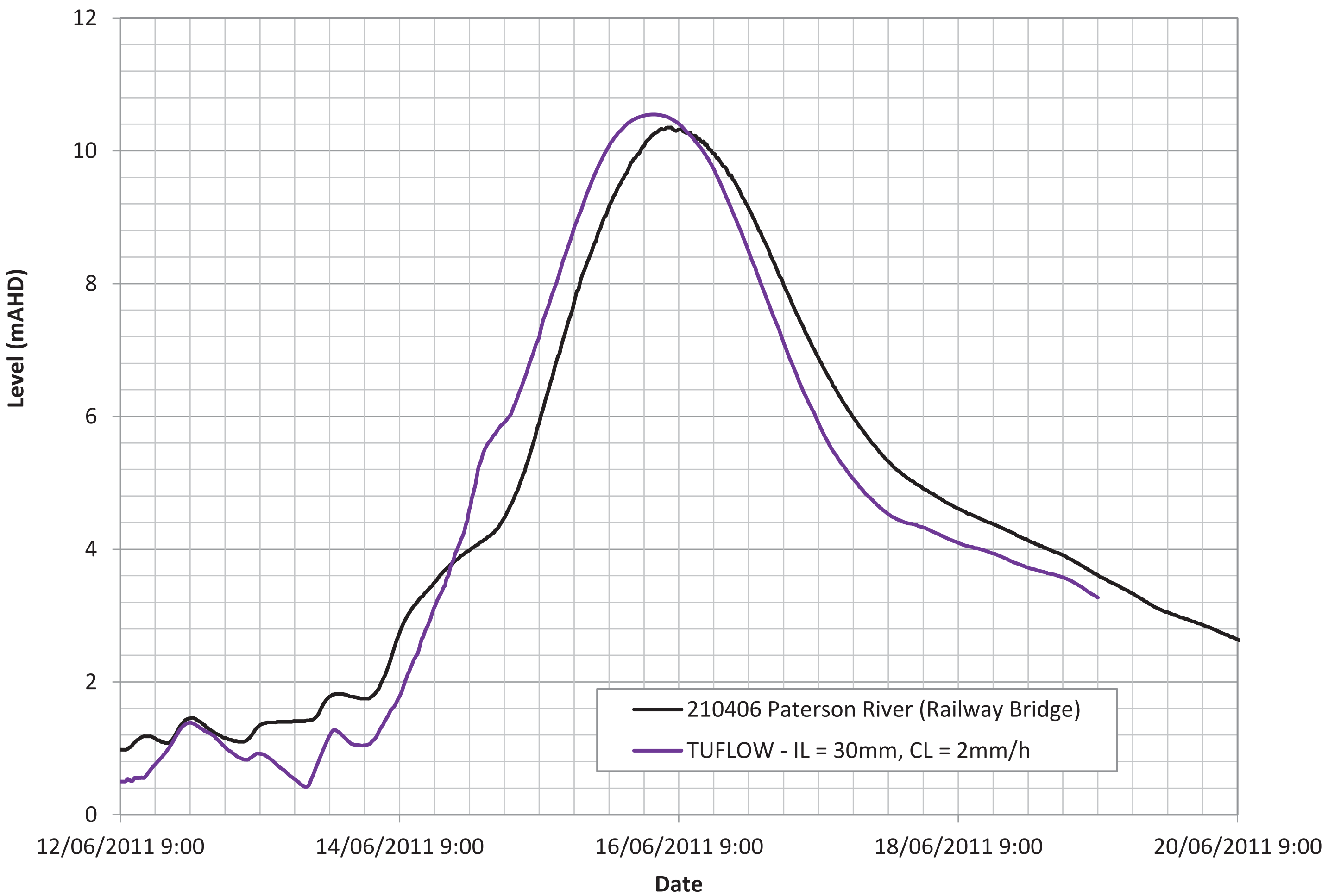

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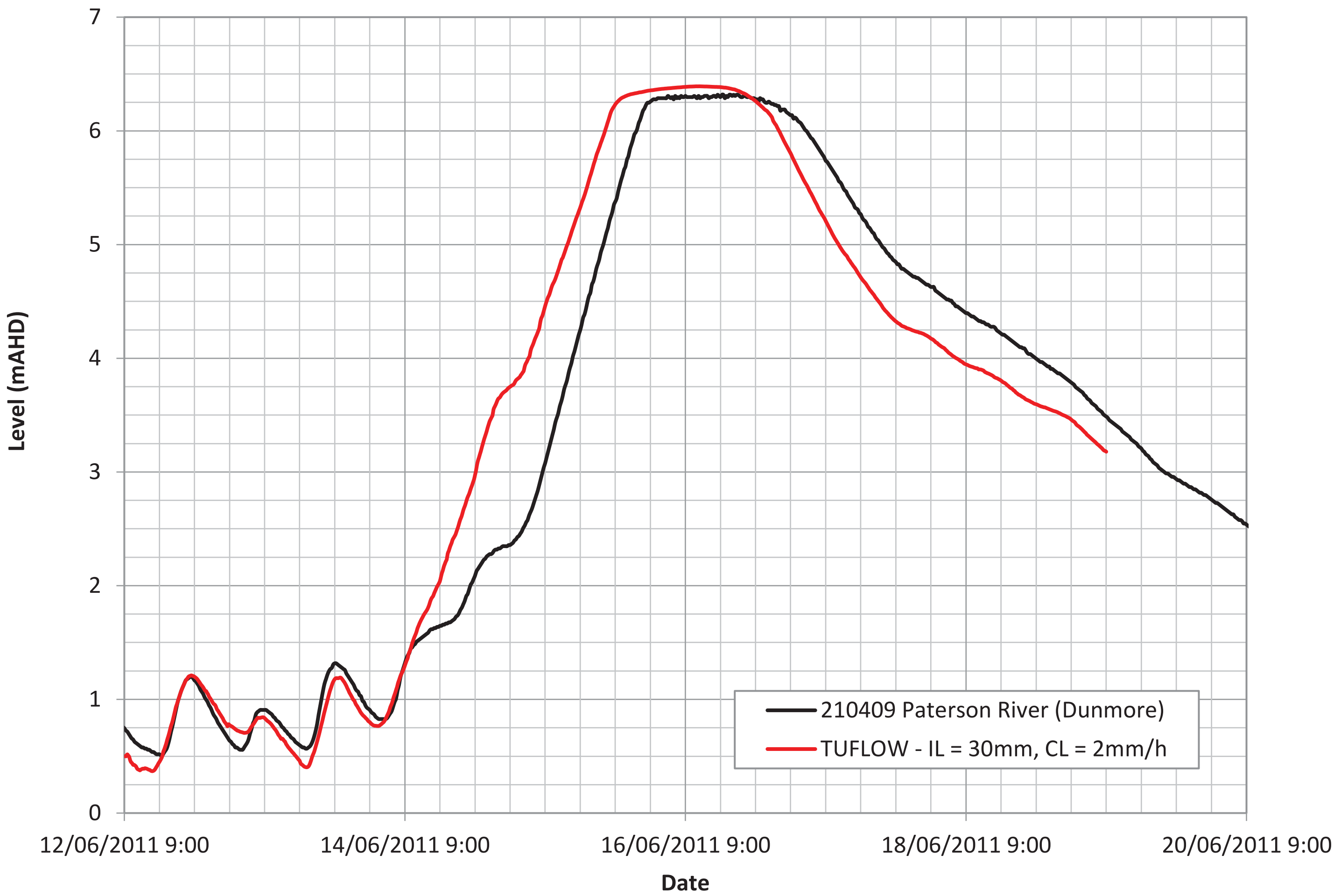


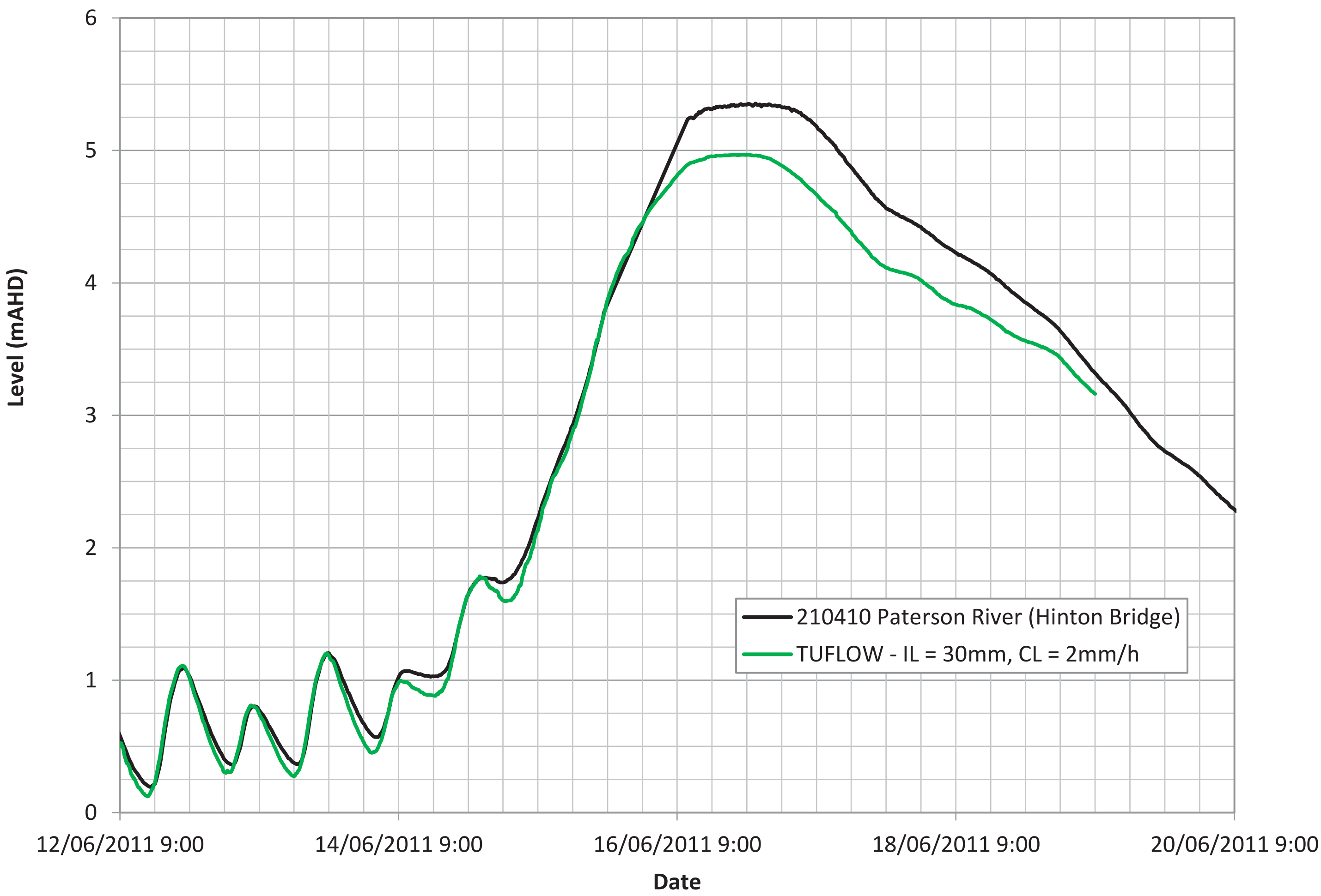
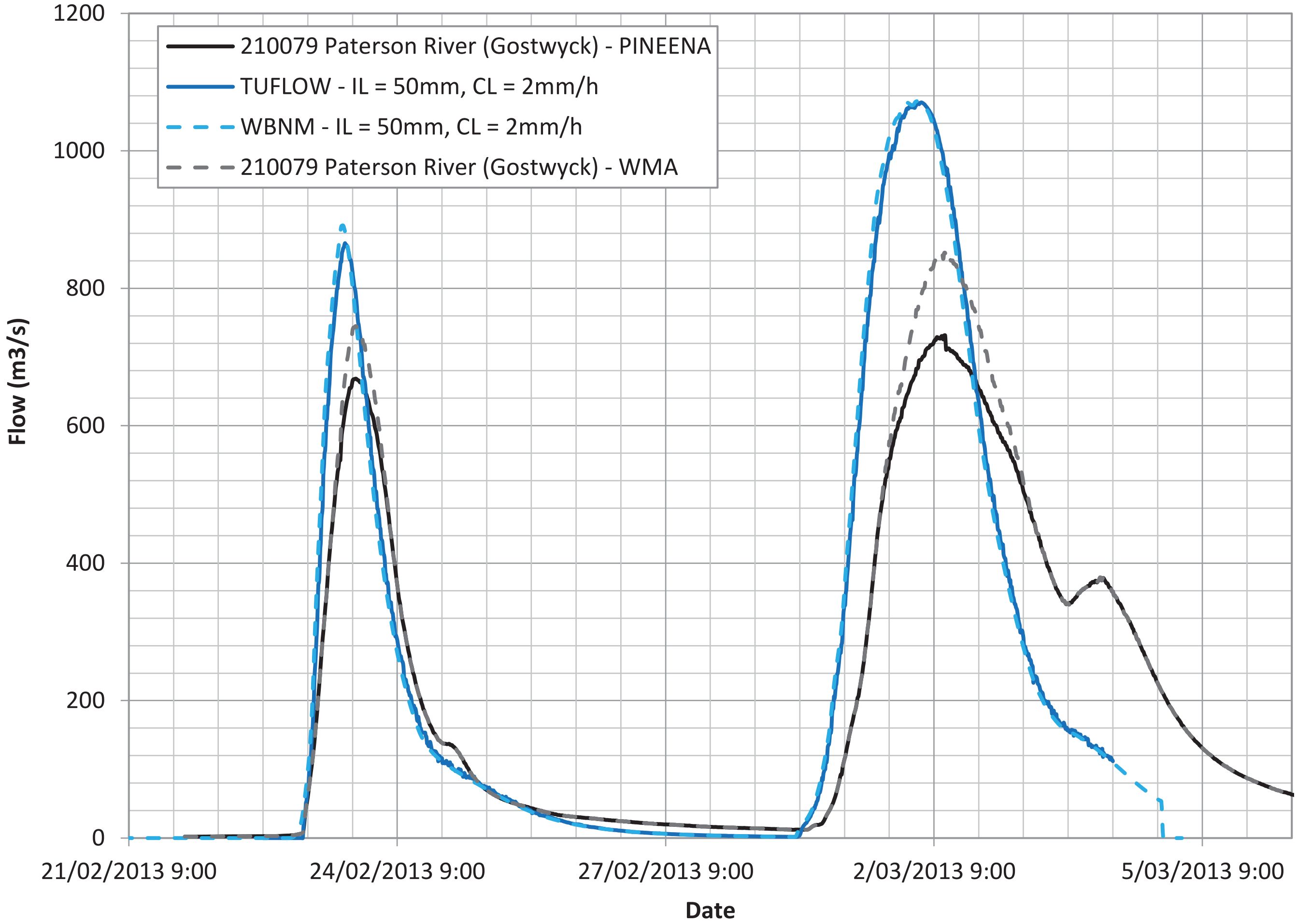
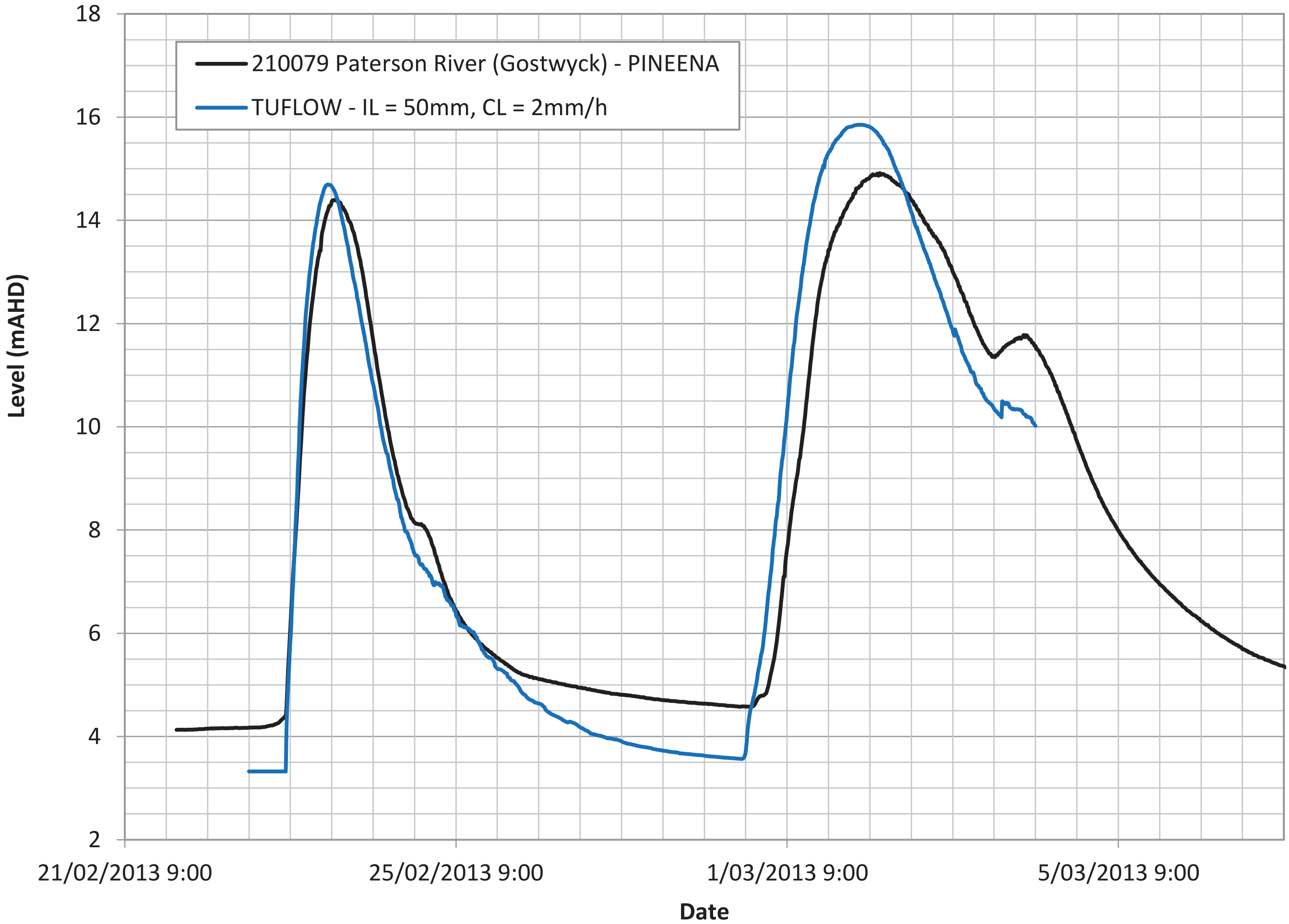


FIGURE B17
HYDRAULIC MODEL CALIBRATION
MARCH 2013 EVENT





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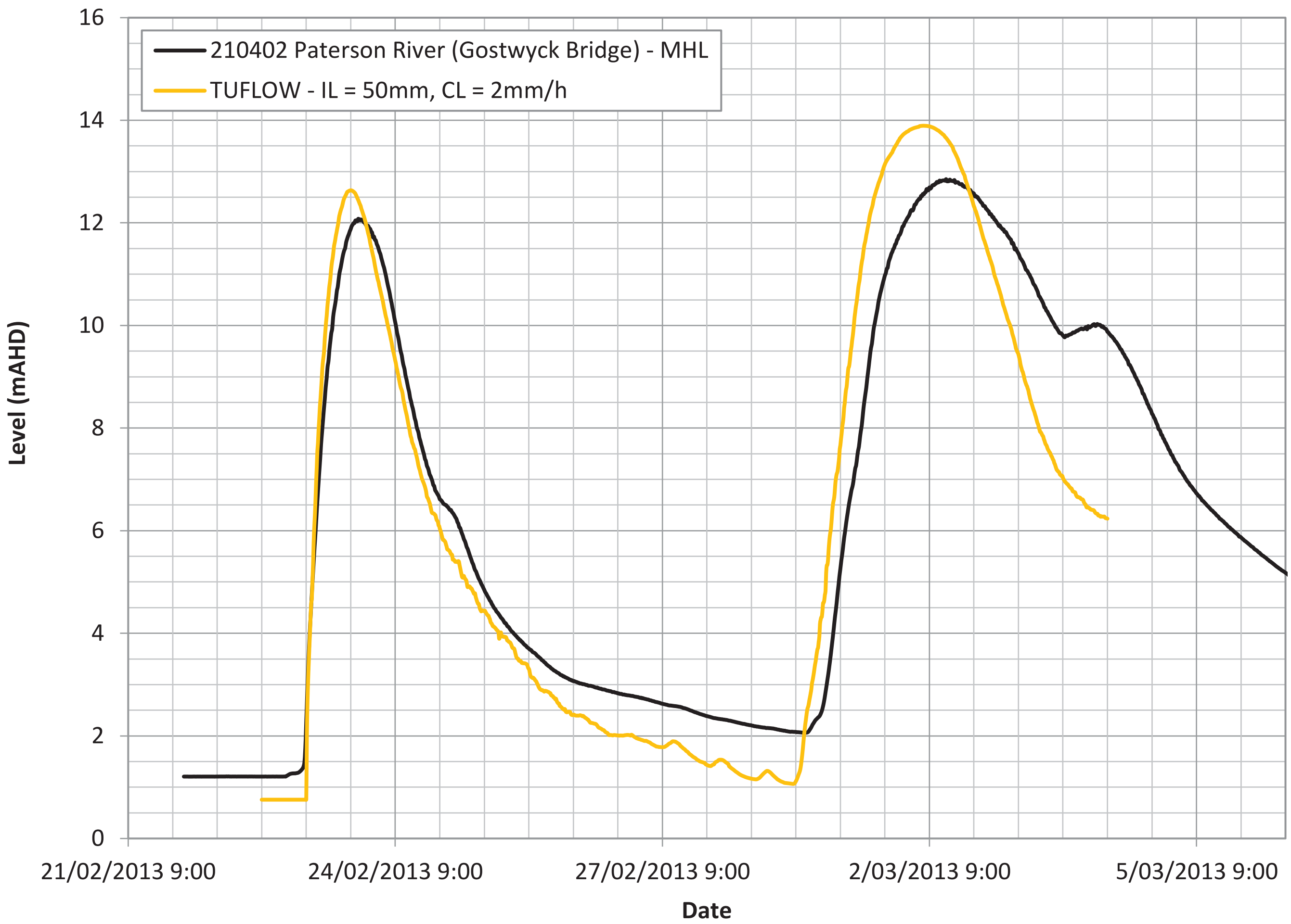
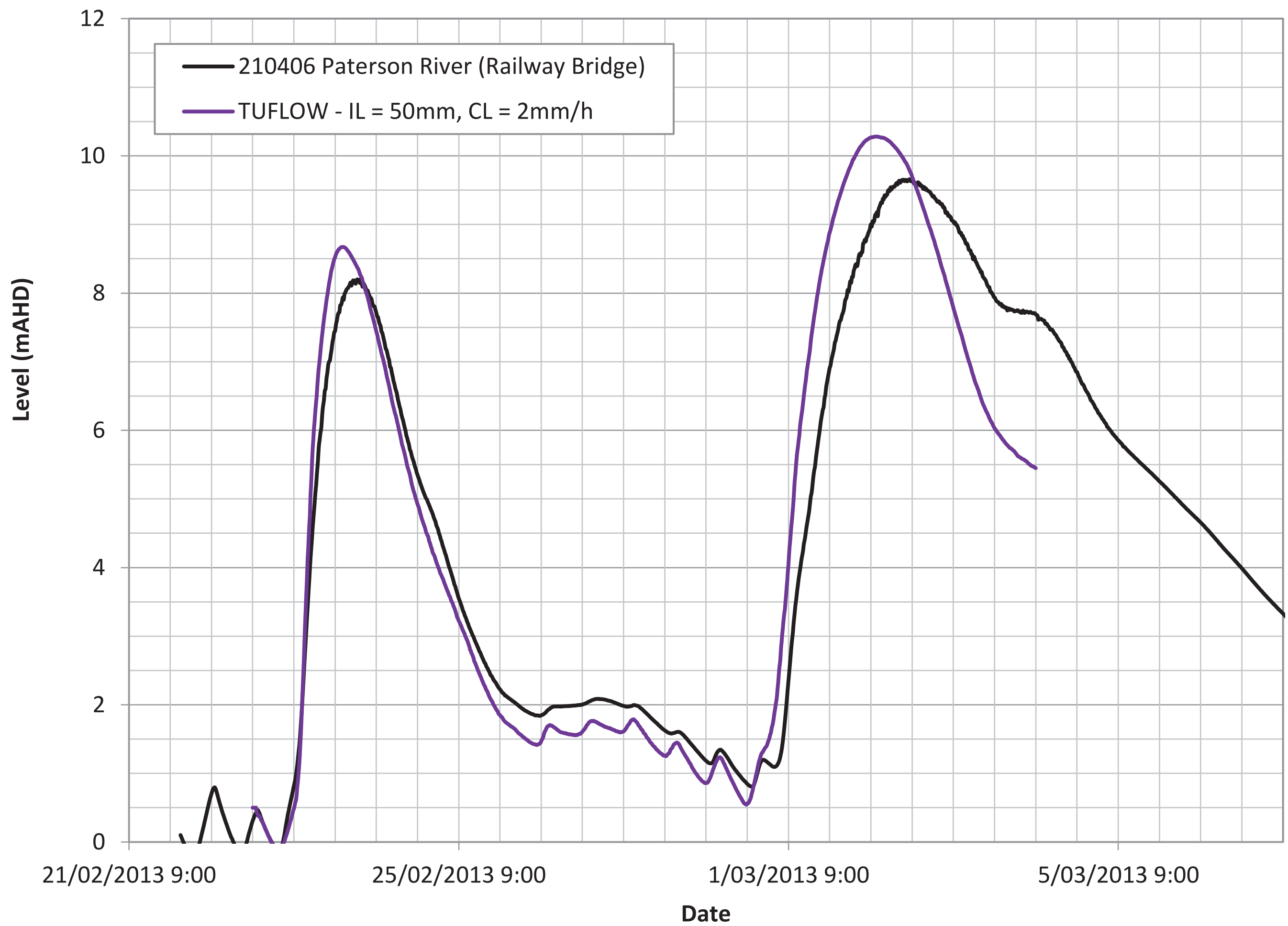
MARCH 2013 EVENT





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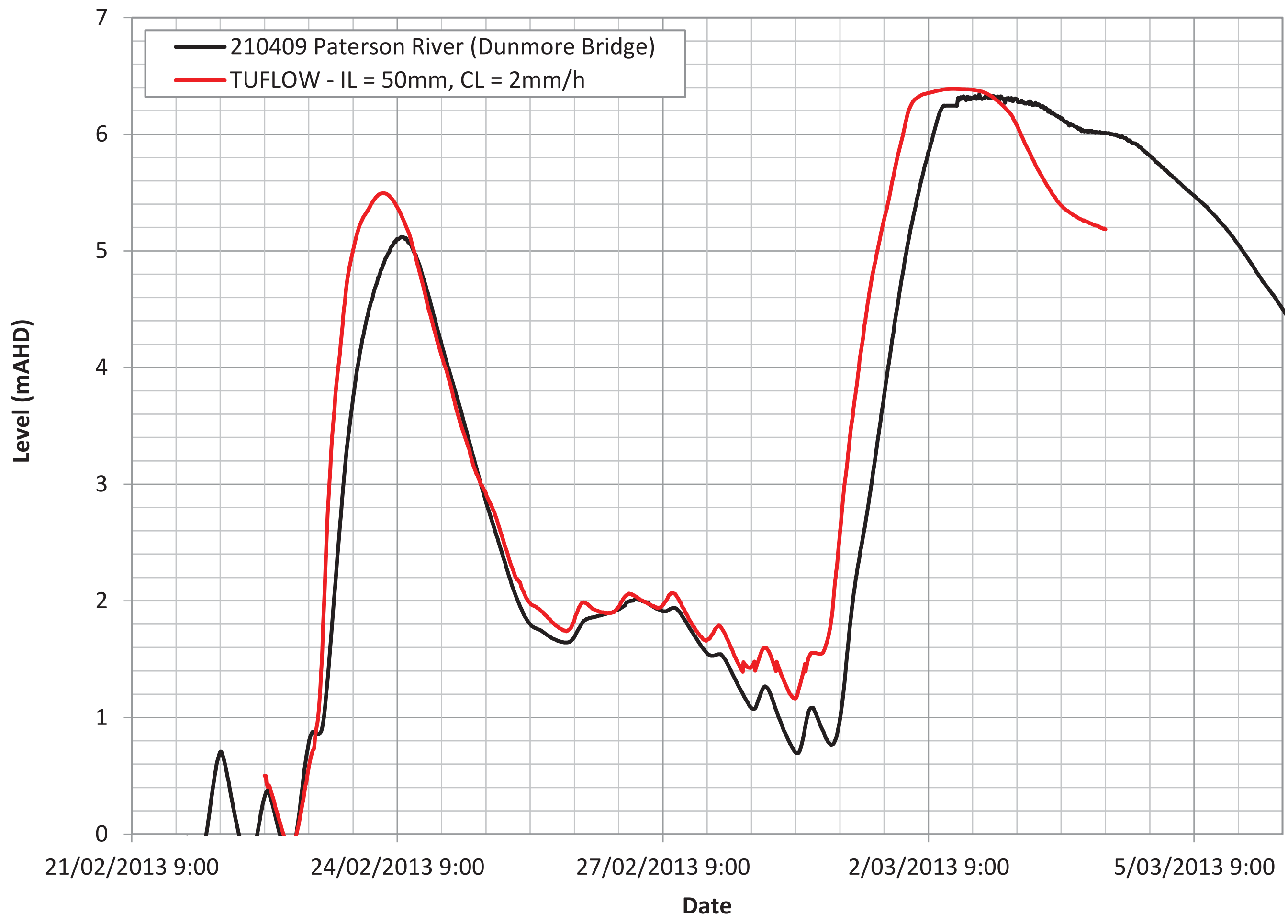

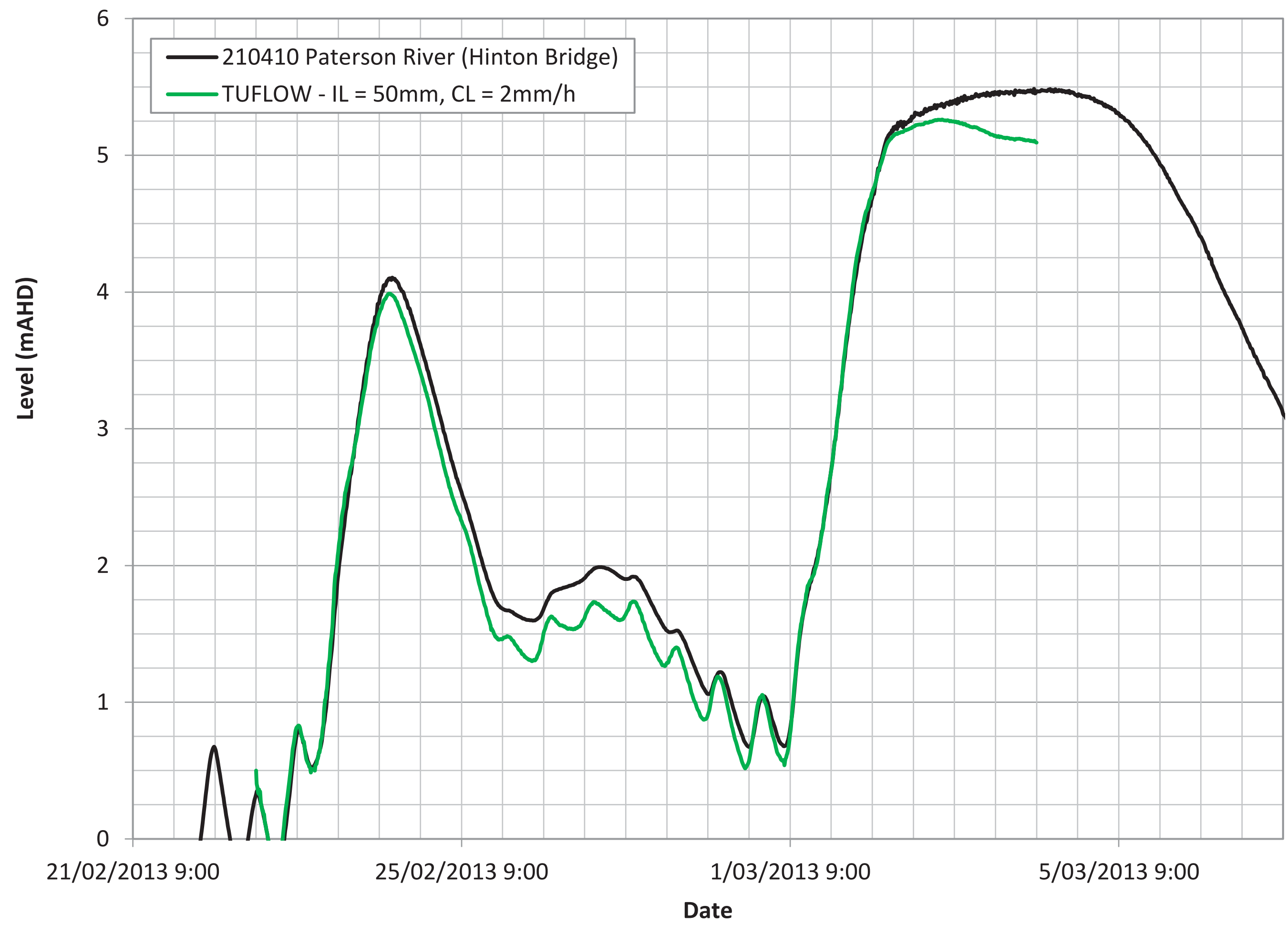

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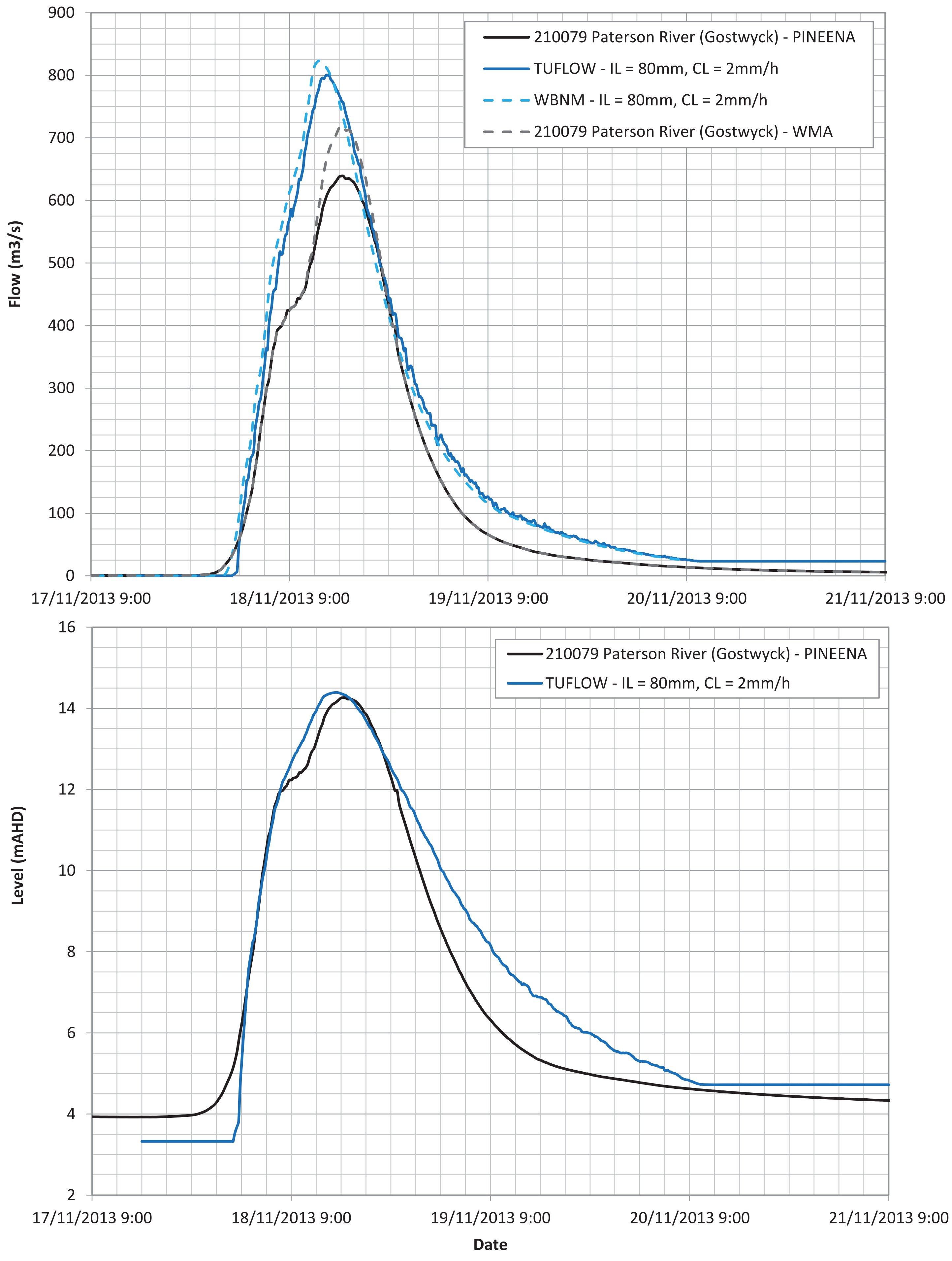
NOVEMBER 2013 EVENT



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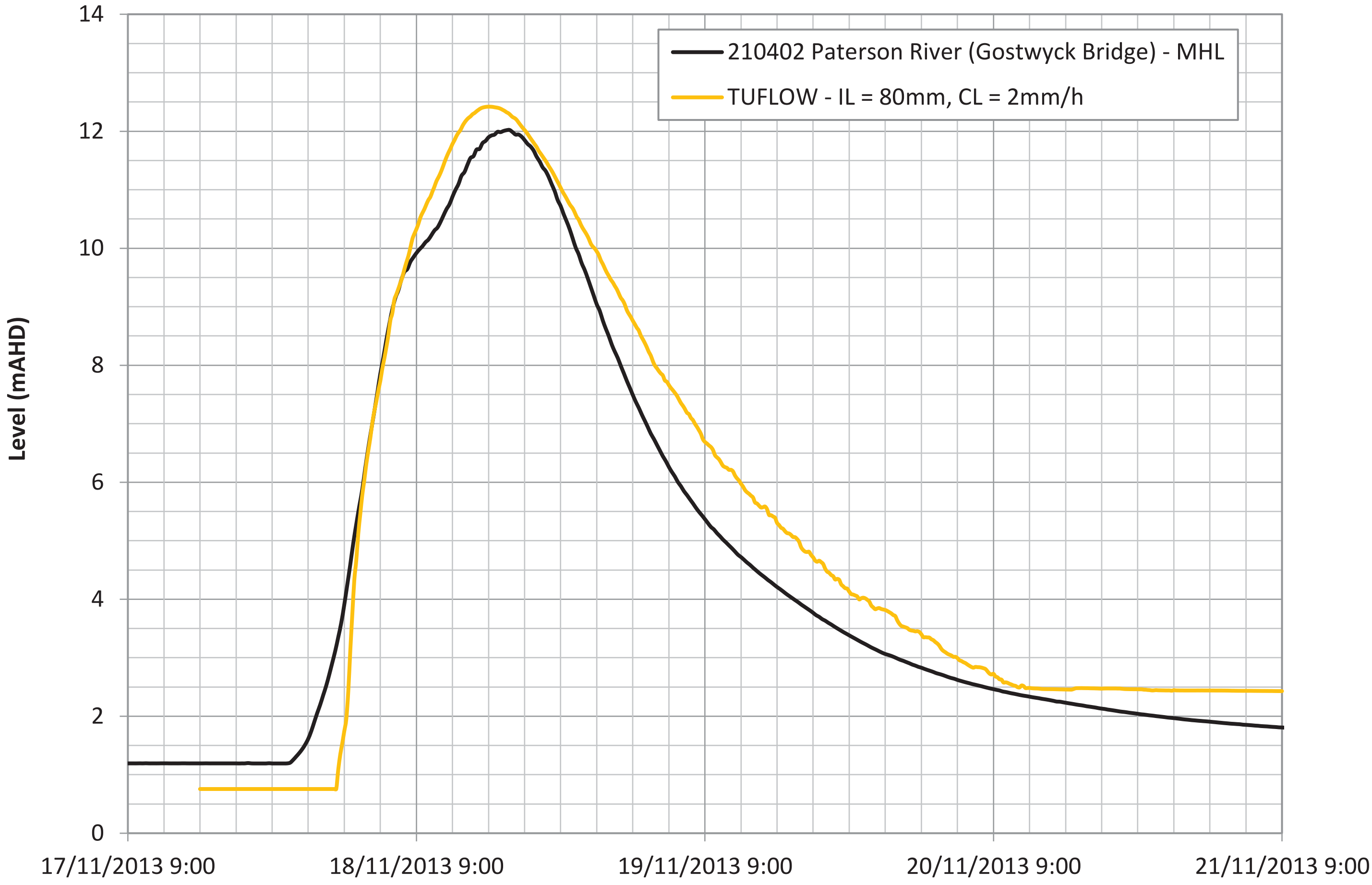

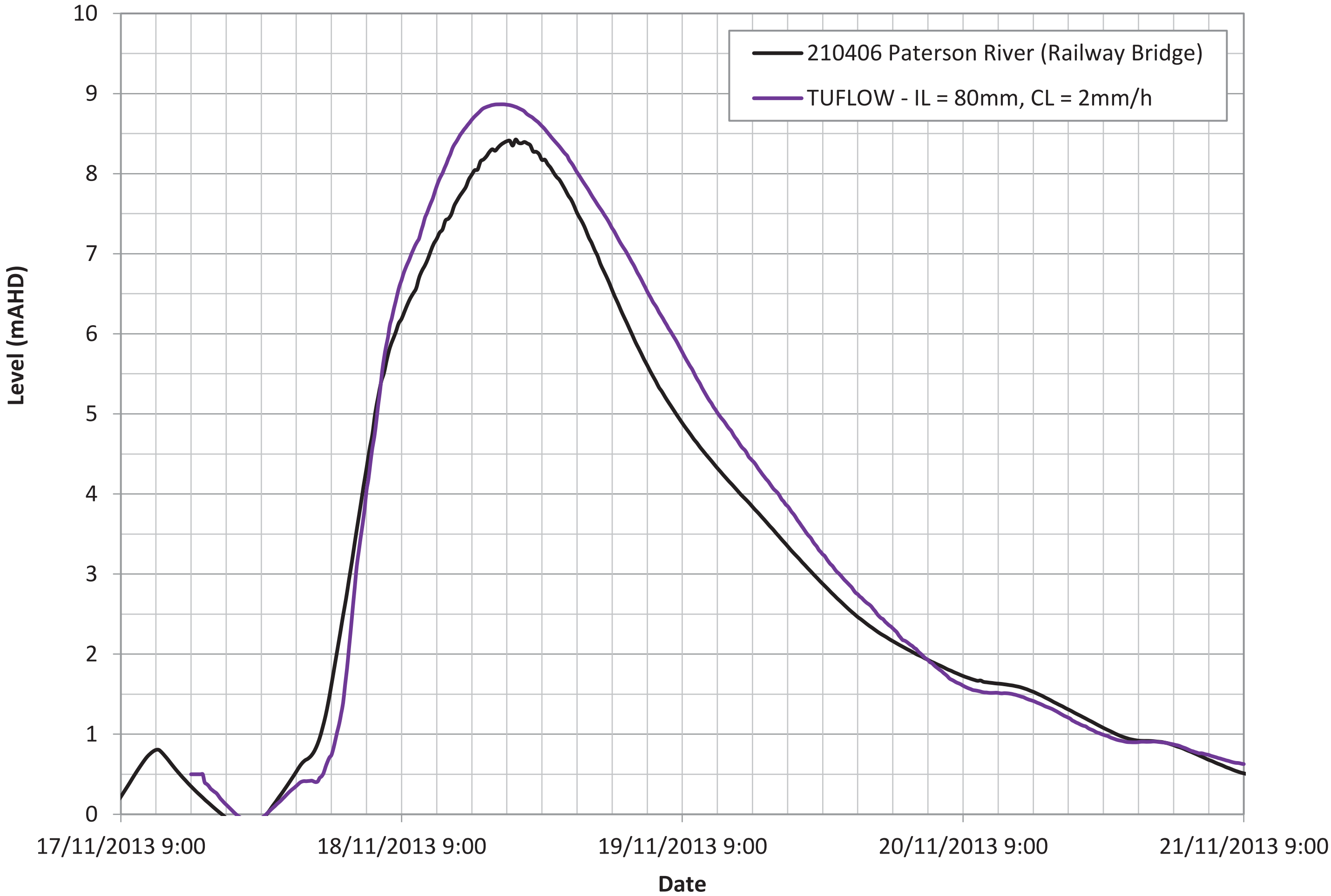

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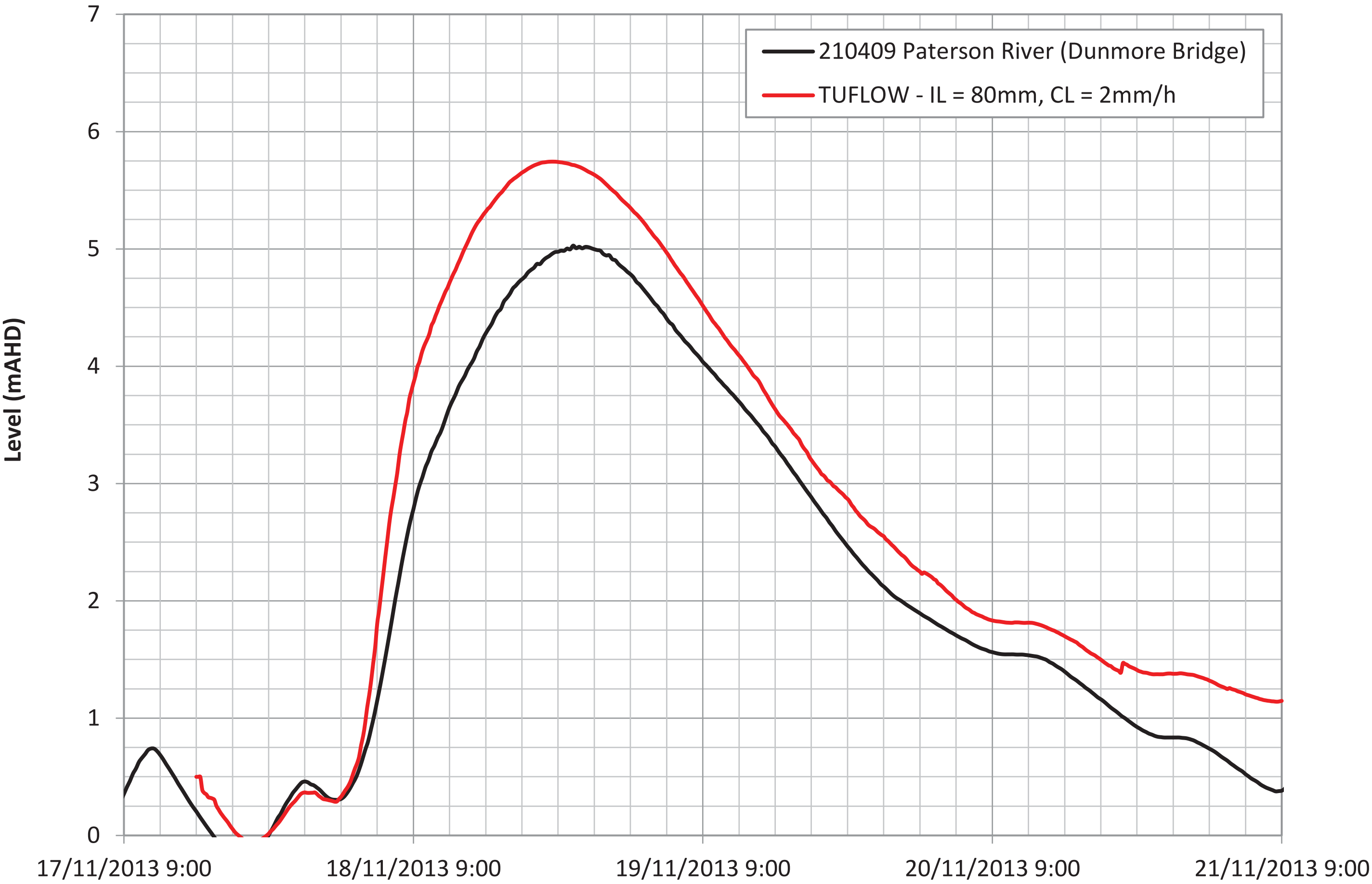


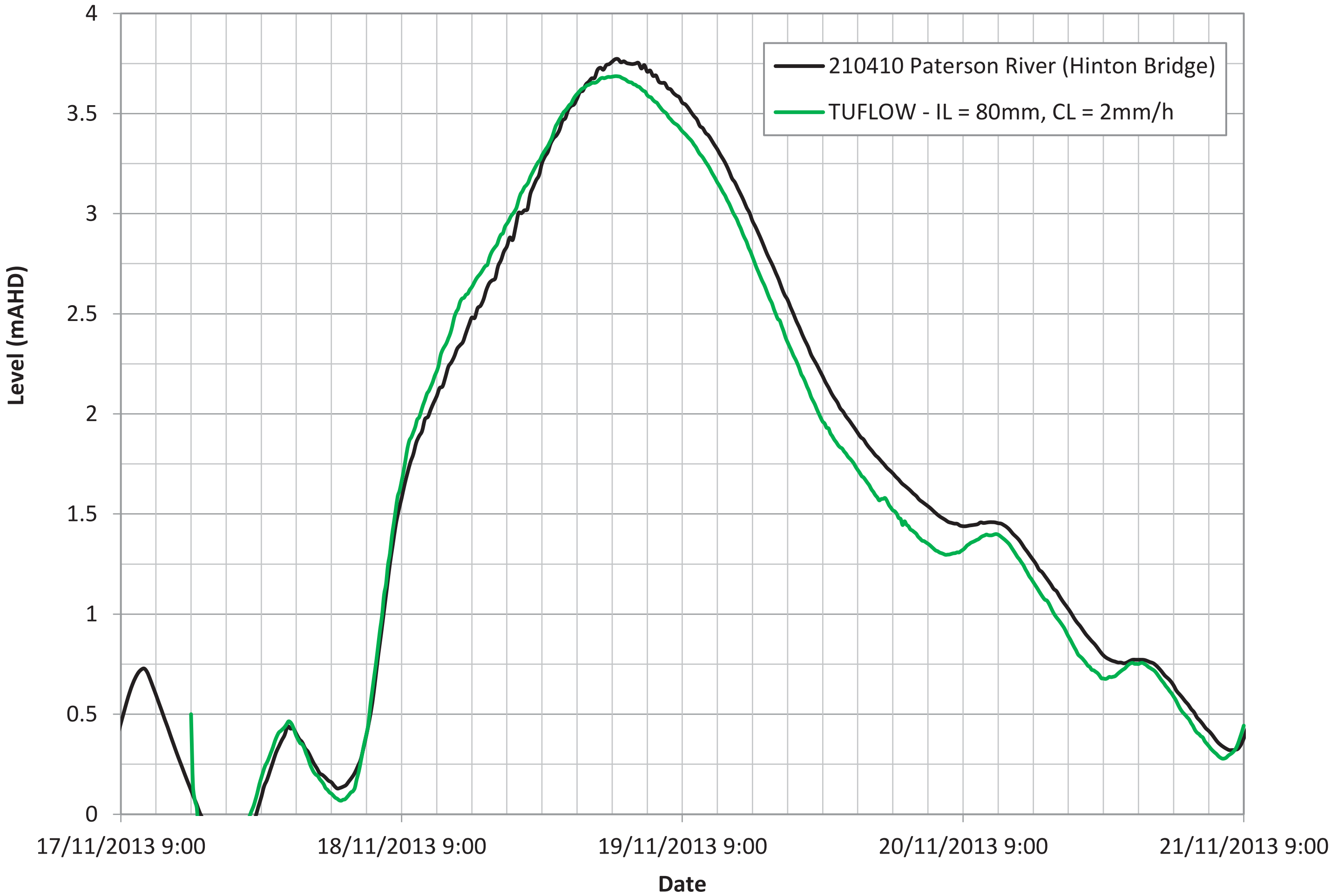
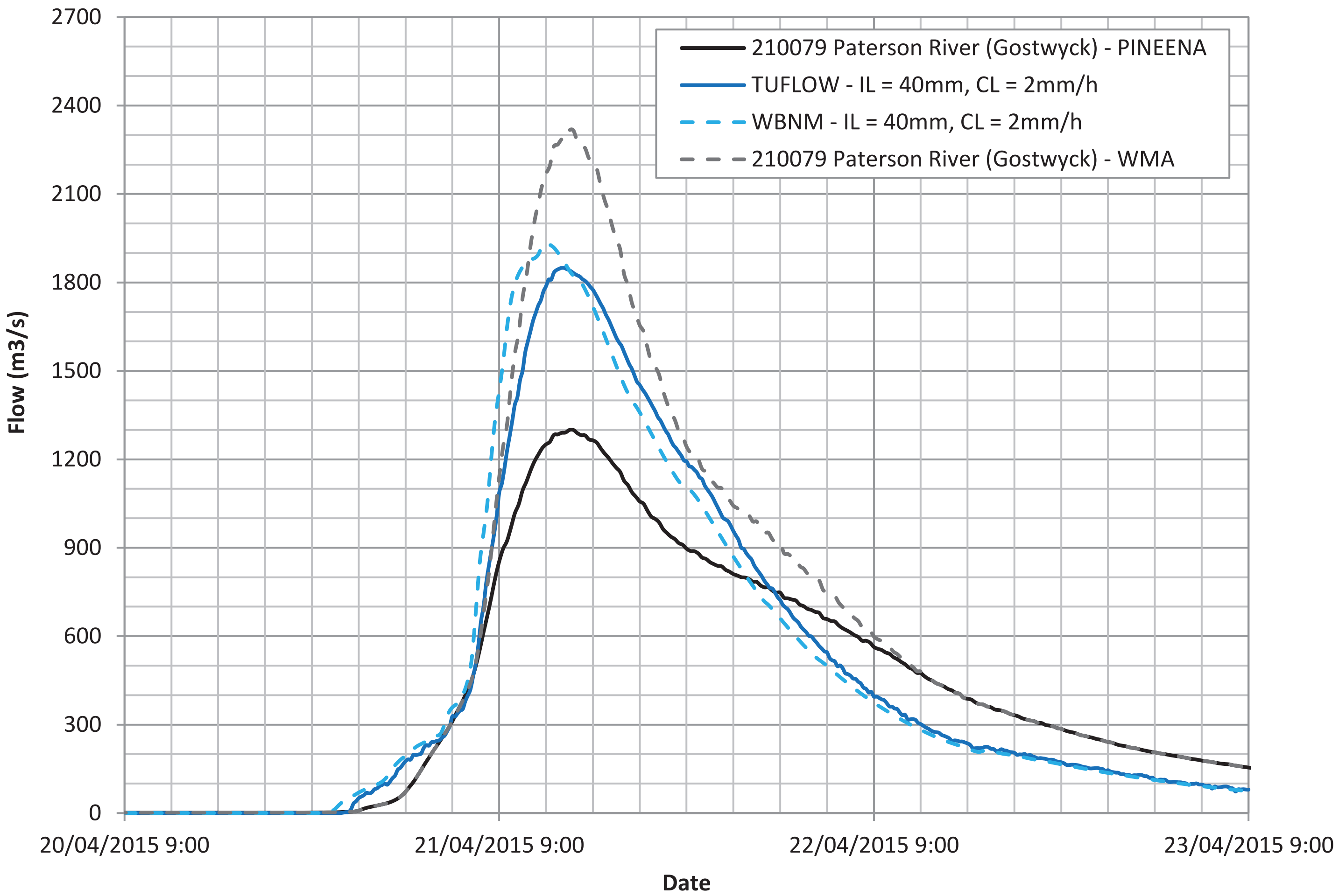


FIGURE B23
HYDRAULIC MODEL CALIBRATION
APRIL 2015 EVENT



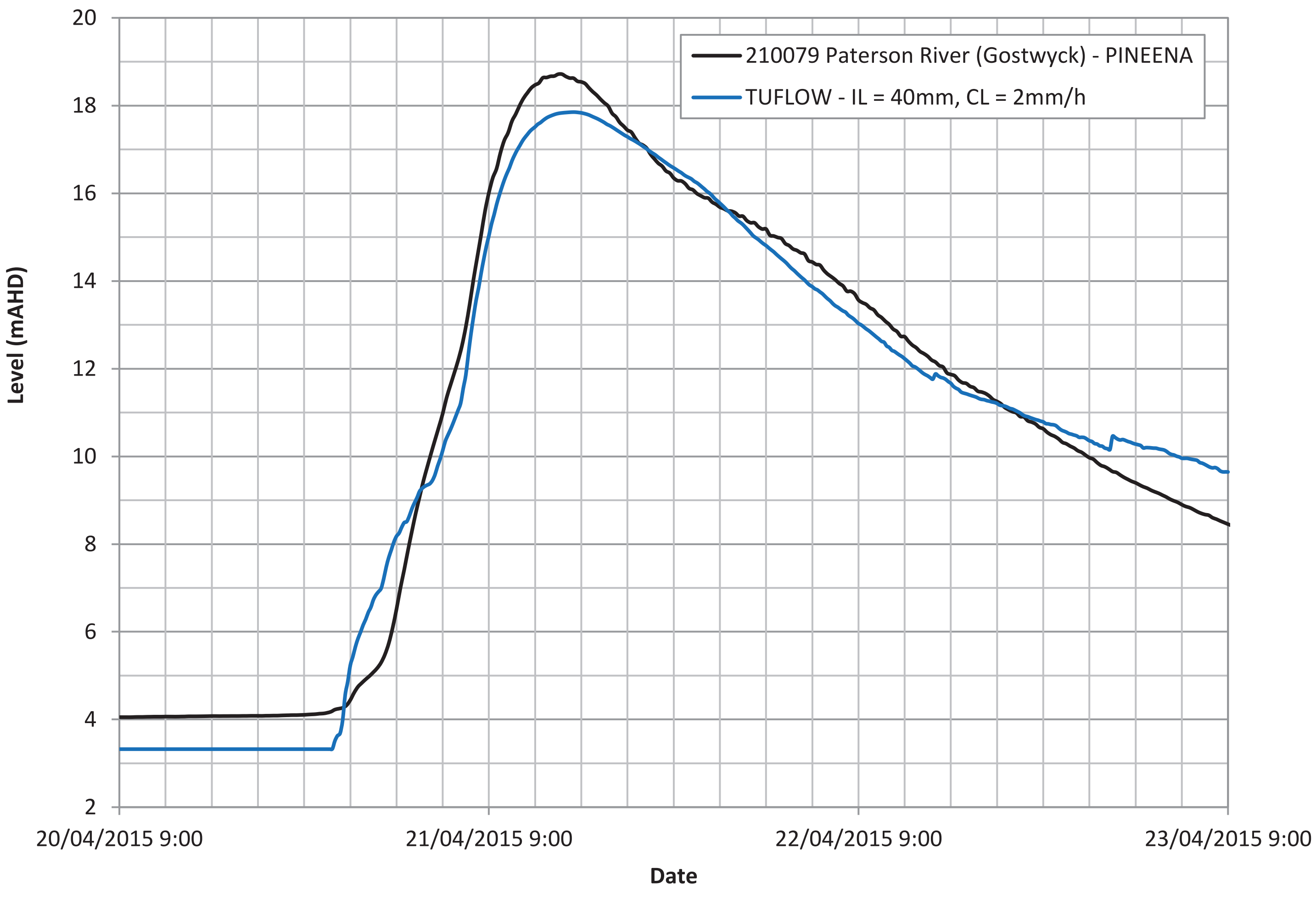
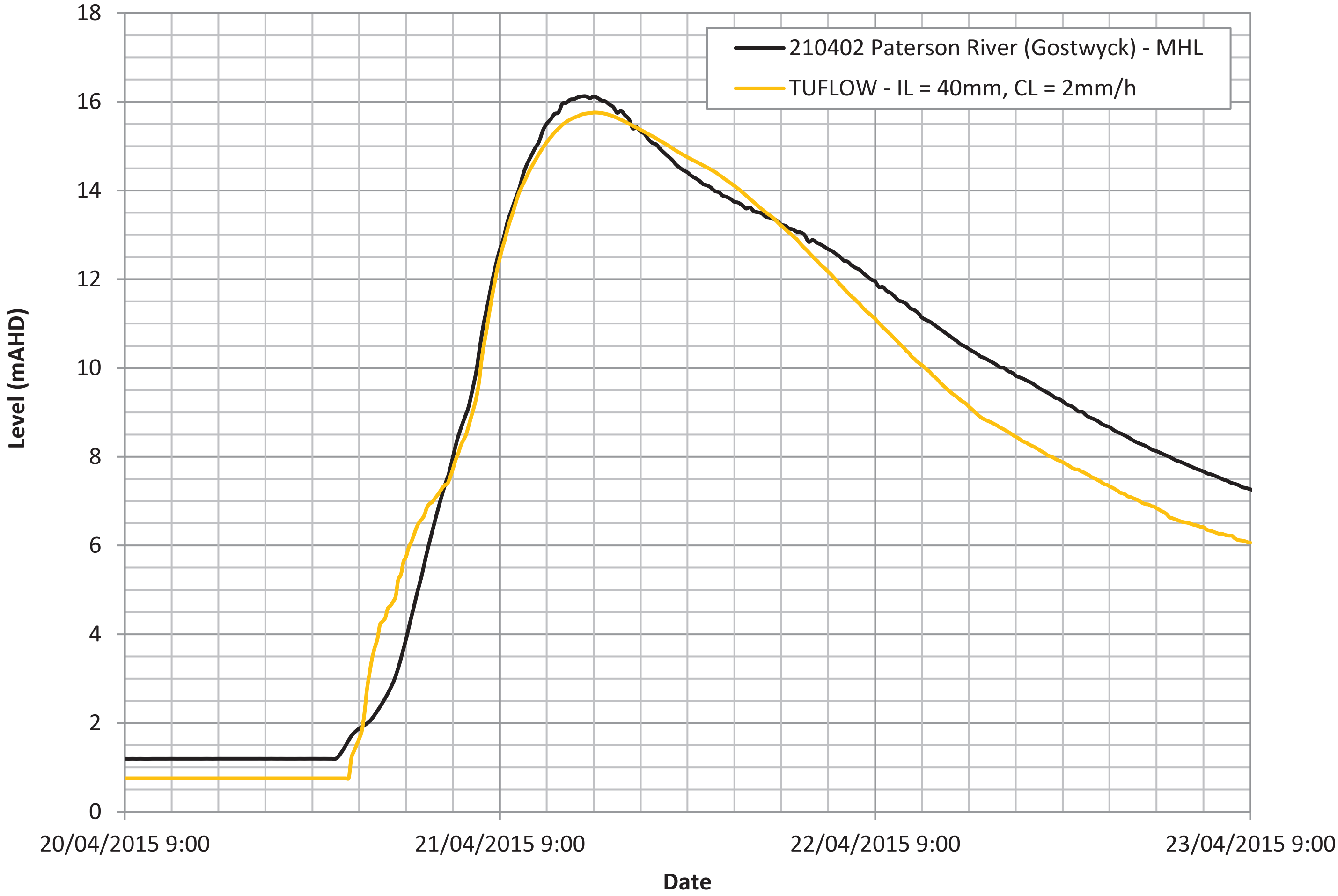


FIGURE B24

HYDRAULIC MODEL CALIBRATION
APRIL 2015 EVENT



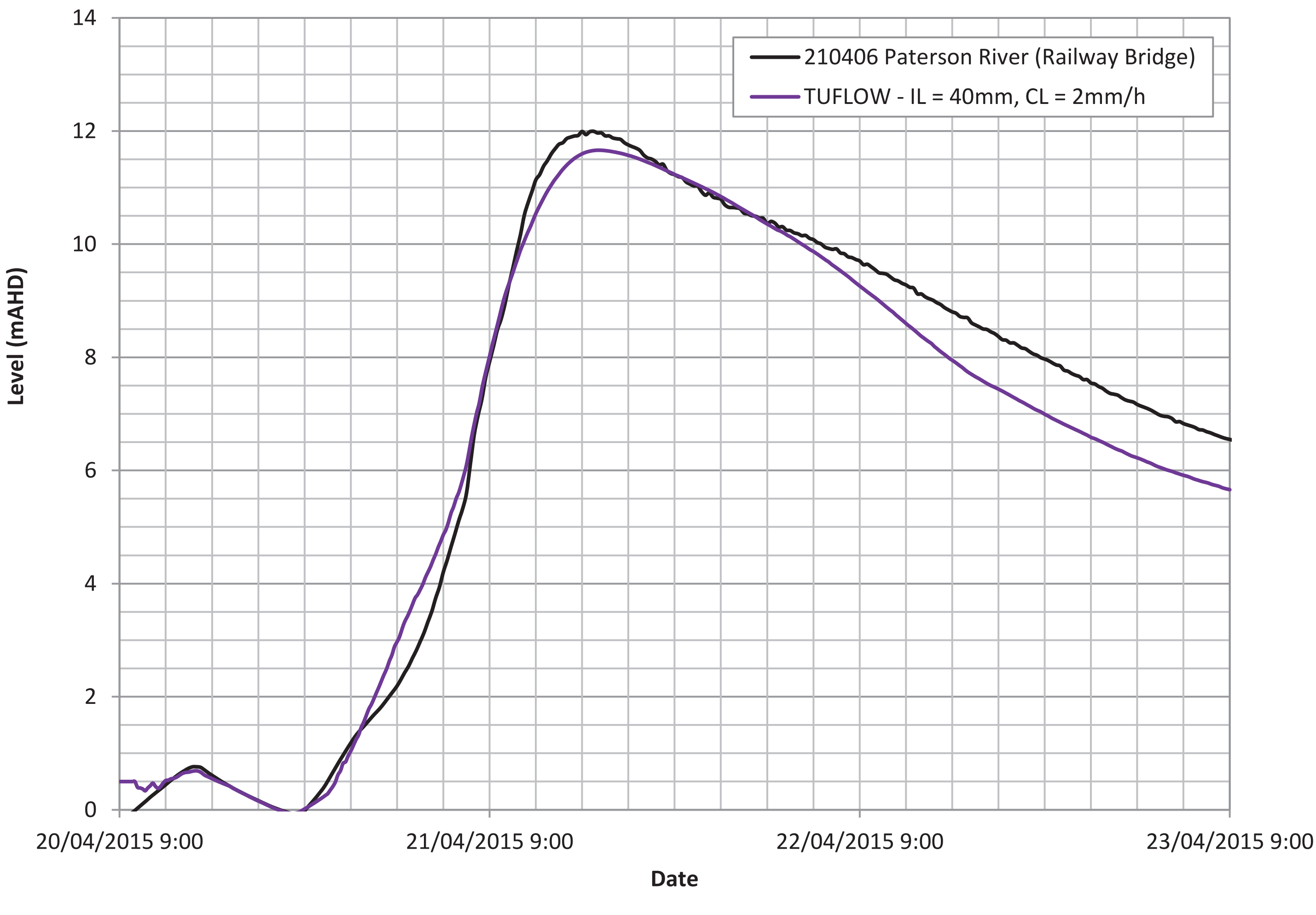
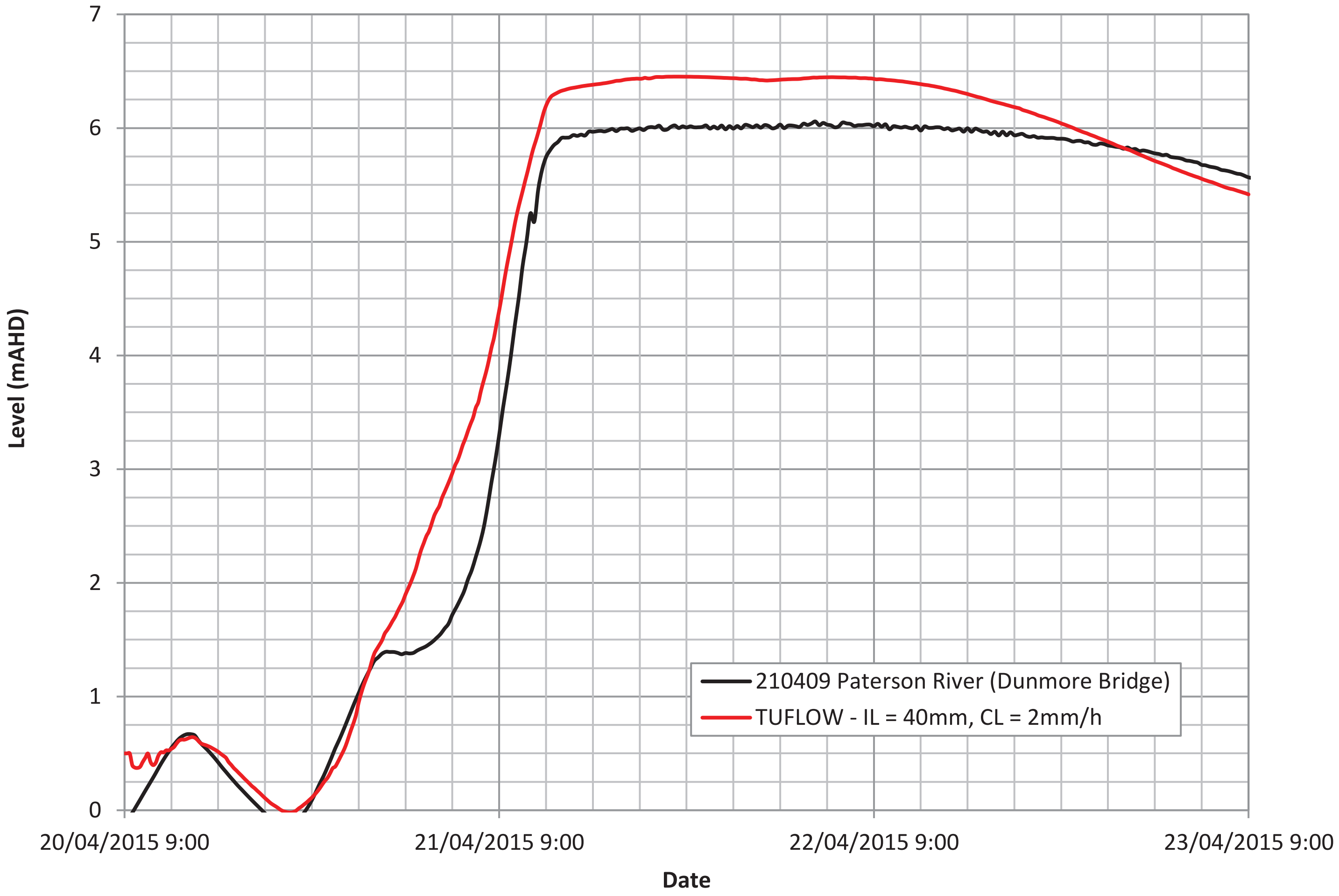


FIGURE B25
HYDRAULIC MODEL CALIBRATION
APRIL 2015 EVENT



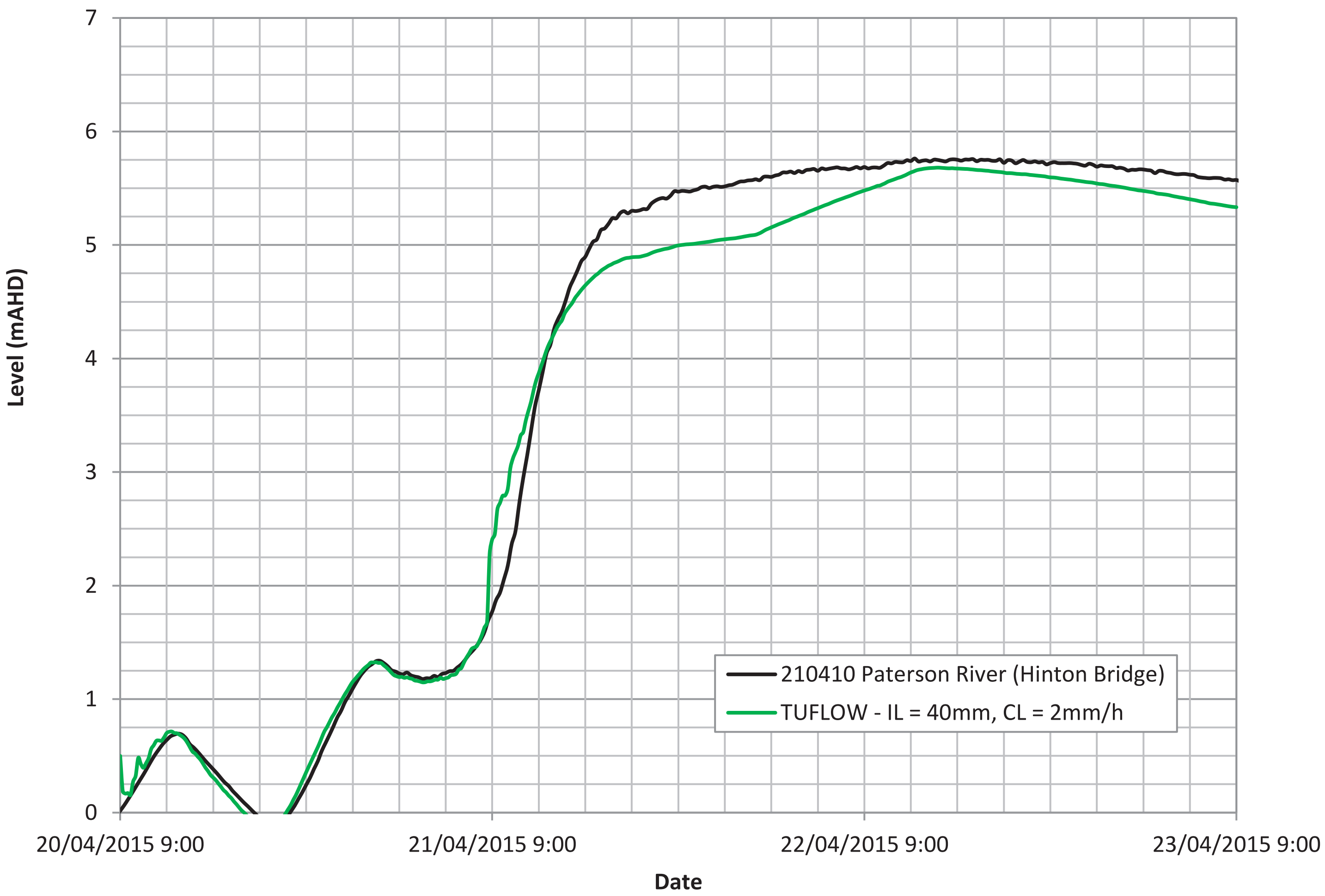
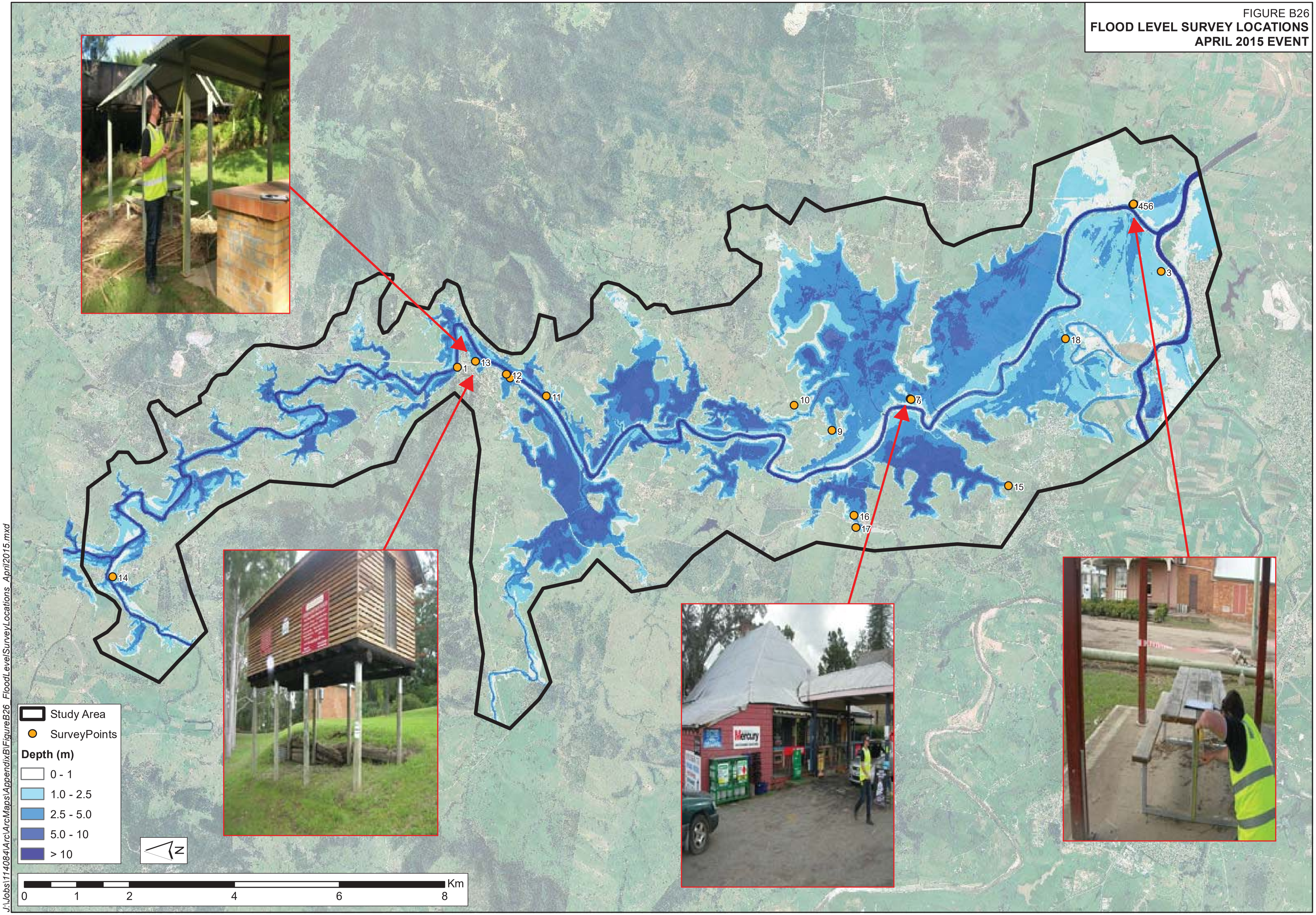


FIGURE B26
FLOOD LEVEL SURVEY LOCATIONS
APRIL 2015 EVENT



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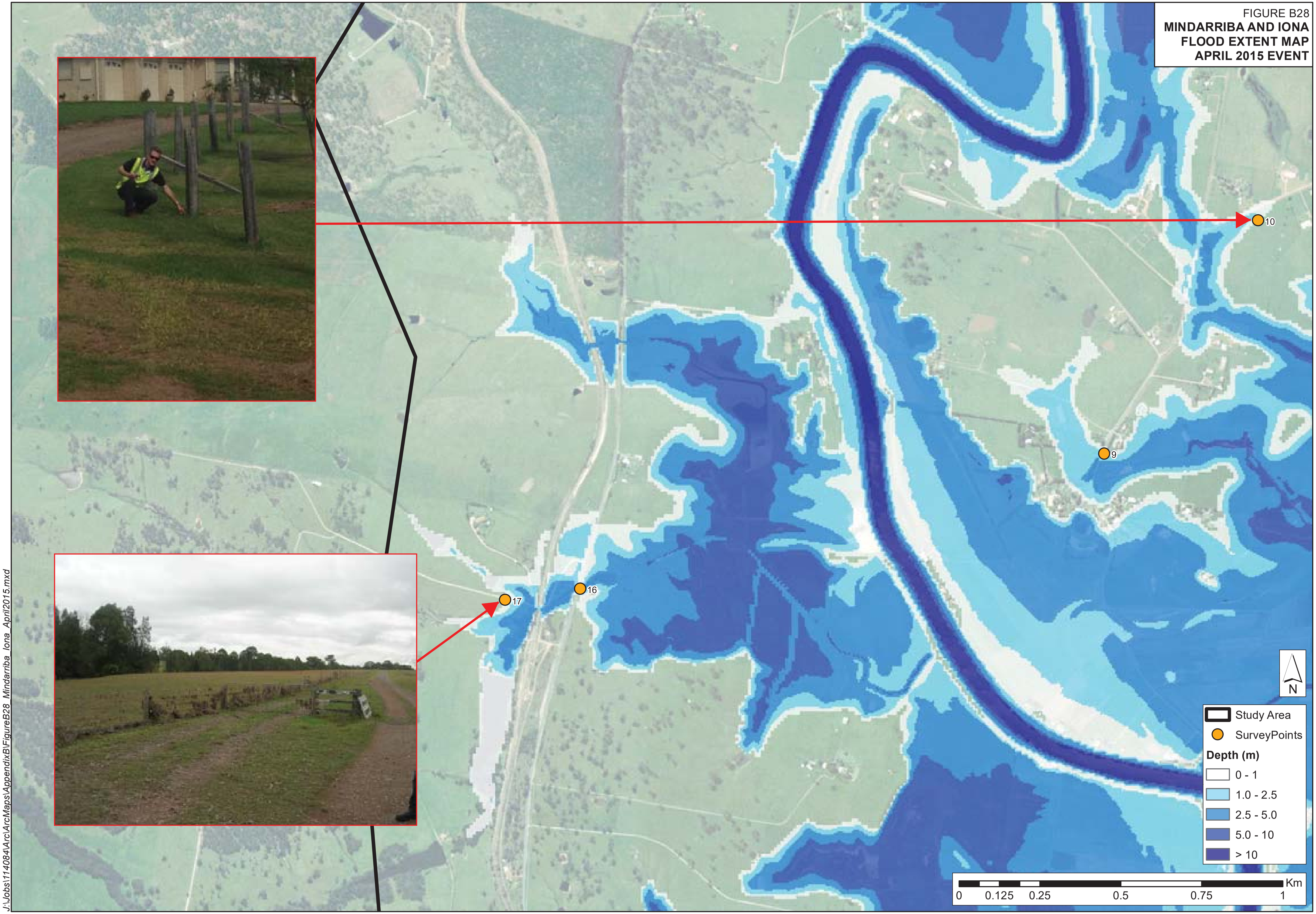
J:\Jobs\114084\Arc\ArcMaps\AppendixB\FigureB27_BolwarraHeights_PhoenixPark_April2015.mxd

FIGURE B28
MINDARRIBA AND IONA FLOOD EXTENT MAP APRIL 2015 EVENT



J:\Jobs\114084\Arc\ArcMaps\AppendixB\FigureB28_Mindarriba_Iona_April2015.mxd

Appendix E

20/10/16.

Paterson River Draft – River Study.
Vacy to Hinton
(closing 21/10/16 at 4pm)

The General Manager.
Maitland Council.

I hereby object to this draft, on the grounds that this will increase flooding to the areas of Phoenix Park, Dunmore Millers Forest and Berry Park ares.

My property is on the banks of the Paterson River.

The levee opposite me, on the Wallalong side has recently been raised – this will now have more flood waters coming to my farm.

I request the levee be put back to what it was.

– Diane Burton
212 Phoenix Park Rd
Phoenix Park (P.O Box 1 Morpeth 2321)
49301477 0429-616-318
email: diane.b212@bigpond.com

20th October, 2016

Exhibition of Draft Paterson River Flood Study Vacy to Hinton.

Draft Study: Reference No. 103/64/4

We refer to the above Draft and have a number of issues:

1. The landholders in Phoenix Park did not receive any survey with regard to this.

2. We would like to know what proposed works that are to be carried out on the levee's and spillways. Has any work been given approval to be commenced prior to any objections, or a draft study being carried out on the Hunter River?

3. We would like to draw your attention to the attached extracts from your draft, stating that both drafts would be required before any work commenced.

4. We therefore object to the work already carried out, which has removed spillways on the Woodville Wallalong side of the Paterson River in the last six months, without any feasibility study in regard to the impact of these works. There was no consultation in regard to this work and when requested to stop we were ignored by the Office of Environment and Heritage, Newcastle. These works in our mind are illegal under the Water Management Act 2000.

We lodge this objection on behalf of the Phoenix Park Landholders.

Raymond Burton
PH: 0418346867

Cyril Suters
Ph: 0249301682

Table 32 – Hunter River Inflows (m^3/s)

Event	Hunter In-bank (m^3/s)	Hunter Left Over-bank (m^3/s)	Hunter Right Over-bank (m^3/s)
50% AEP	713	0	0
20% AEP	1345	0	290
10% AEP	1700	0	631
5% AEP	1781	325	851
2% AEP	1830	1047	1049
1% AEP	1851	1558	1331
0.5% AEP	2060	2653	2845
0.2 % AEP	2100	6274	4533
PMF	2096	9287	7356

Dynamic design tailwater levels for the Hunter River were modelled, based on model results from (Reference 5). The max tailwater levels at the two Hunter River outflow locations are shown in Table 33.

Table 33 – Hunter River Tailwater (mAHD)

Event	Hunter In-bank (mAHD)	Hunter Left Over-bank (mAHD)
50% AEP	3.7	Ground Level
20% AEP	5.0	2.6
10% AEP	5.2	4.3
5% AEP	5.4	4.9
2% AEP	5.7	5.7
1% AEP	5.9	5.9
0.5% AEP	6.3	6.3
0.2 % AEP	7.2	7.3
PMF	8.1	8.2

Note that the results presented below are for Paterson River flooding, in combination with smaller Hunter River flood events as outlined in Table 33. In the lower Paterson River floodplain, the Hunter River design flood levels (from Reference 5) are often the critical level for flood planning and development control purposes. The results from both studies should be considered for floodplain management decision-making.

10.7. Design Flood Modelling Results

The results for the study are presented as:

- Peak flood depth and level contours in Figure C1 to Figure C8
- Peak flood velocities in Figure C9 to Figure C16

10.7.4. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (Reference 1). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria, which is similar to the methodology proposed by Howells et. al, 2003 (Reference 14), but modified slightly to be more consistent with other similar studies undertaken in the Port Stephens and Maitland Council areas (e.g. the Williams River and Hunter River flood studies):

- Floodway is defined as areas where:
  - the peak value of velocity multiplied by depth (V x D) > 0.5 m^2/, OR
  - peak velocity > 1.0 m/s AND peak depth > 0.2 m

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 1.0 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 1.0 m.

The provisional hydraulic categories mapping is shown on Figure C20 to Figure C22.

Port Stephens Council advised that their development control policies also require consideration of a rainfall intensity increase of 20%, as well as sea level rise. It was established in Reference 5 that projected sea level rise benchmarks through to 2100 do not significantly affect design flood levels in the Hunter and Paterson River upstream of Green Rocks. Additional mapping of hydraulic categories was therefore created for the following scenario:

- 1% AEP Paterson River design storm with 20% increased rainfall intensity.

The provisional hydraulic categories mapping incorporating 20% increase in Paterson River rainfall intensity is shown on Figure D2 (Appendix D).

Note that this mapping does not include consideration of the Hunter River 1% AEP design flood event (Reference 5), which should also be considered for development control planning.

12. RECOMMENDATIONS

It is recommended that following the conclusion and adoption of the Paterson River Flood Study, combined flood level and DCP mapping be developed utilising results from the Paterson River Flood Study and the Hunter River Flood Study (Reference 5). The DCP mapping can be tailored to meet each Council's individual needs or developed after a consultation process with all stakeholders.

For areas downstream of Dunmore Bridge the 1% AEP flood levels from the Hunter River Flood Study (Reference 5) are to be used for developmental purposes.

RECOMMENDATIONS

It is recommended that following the conclusion and adoption of the Paterson River Flood Study, combined flood level and DCP mapping be developed utilising results from the Paterson River Flood Study and the Hunter River Flood Study (Reference 5). The DCP mapping can be tailored to meet each Council's individual needs or developed after a consultation process with all stakeholders.

DESIGN FLOOD ESTIMATION

Two approaches were investigated to determine design flood magnitude. Flood Frequency Analysis and design rainfall modelling were both undertaken with similar results for peak flow at key gauges. The design rainfall approach was adopted as it provides a more holistic result for the entire study area, especially in regard to flood mapping of the Paterson River floodplains and tributaries.

The study included modelling of the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF design flood events, with mapping provided for peak flood depths and levels, peak velocities, hydraulic hazard and hydraulic categories.

KEY OUTCOMES

The study has quantified flood behaviour in the study area and the modelling tools that have been developed will assist Maitland City Council, Port Stephens Council and Dungog Council to undertake flood related planning decisions for future and existing development. A summary of key outcomes is as follows:

- The April 2015 flood event was equivalent to between a 2% and 1% AEP event in the study area;
- Vacy Bridge is above the 1% AEP flood level but overtopped in the 0.5% AEP event;
- Gostwyck Bridge is above the 0.5% AEP level but overtopped in the 0.2% AEP event;
- Paterson Road Bridge is above the 0.5% AEP level but overtopped in the 0.2% AEP event;
- Webbers Creek Bridge is above the 10% AEP level but overtopped in the 5% AEP event;
- Dunmore Bridge is above the 0.2% AEP level;
- The Horns Crossing causeway on the Allyn River is impassable in all events modelled.
- Major roads throughout the catchment are cut in events beginning at the 20% AEP event. This has implications for emergency response planning as well as planning future development in the catchment;
- The primary damages resulting from flooding in the study area are likely to be infrastructure damage to roads, bridges and railway lines, damages to agricultural equipment (farm machinery, structures, fences, etc.), and loss of crops and livestock;
- Existing residential and commercial buildings are generally at a low risk from flooding.
- This flood study will provide planning tools for Council to mitigate flood risk to future development in the catchment.

The outcomes relating to road closures are expected to be mainly of interest to the SES in formulating flood response procedures.

Note that the results presented in this study are for Paterson River flooding, in combination with smaller coincident Hunter River flood events. In the lower Paterson River floodplain, the Hunter River design flood levels (from Reference 5) are often the critical level for flood planning and development control purposes. The results from both studies should be considered for floodplain management decision-making.

Several of the roads in the study area are cut in relatively frequent events such as the 20% AEP. A summary of the frequency of inundation for major roads and bridges is given in Table 40.

Table 40 – Summary of Overtopping Frequency for Major Bridges and Roads

Location ID (Figure 35)	Bridge/Road	Waterway	Overtopping Event
2	Vacy Bridge	Paterson River	Between 1% and 0.5% AEP
R2	Gresford Rd	Floodplain	Between 5% and 2% AEP
3	Horns Crossing	Allyn River	< 20% AEP
5	Gostwyck Bridge	Paterson River	Between 0.5% and 0.2% AEP
R5	Gresford Rd Paterson	Floodplain	Between 10% and 5% AEP
R6	Tocal Rd & Queen St	Floodplain	< 20% AEP
R7	Tocal Rd Paterson	Floodplain	Between 10% and 5% AEP
7	Paterson Rd Bridge	Paterson River	Between 0.5% and 0.2% AEP
R9	Tocal Rd Webbers Creek	Webbers Creek	< 20% AEP
R10	Webbers Creek Bridge	Webbers Creek	Between 10% and 5% AEP
R11	Paterson Rd Dunns Creek	Dunns Creek	Between 10% and 5% AEP
R12	Paterson Rd Iona	Floodplain	Between 20% and 10% AEP
R13	Iona Public School	Floodplain	Between 20% and 10% AEP
R14	Clarence Town Road Woodville	Floodplain	Between 10% and 5% AEP
13	Dunmore Bridge	Paterson River	Between 0.2% AEP and PMF
R16	Phoenix Park Rd - Largs	Floodplain	Between 20% and 10% AEP
R17	Wallalong Rd	Floodplain	Between 2% and 1% AEP
R18	Butterwick Rd	Floodplain	< 20% AEP
R19	High Street (between Hinton and Wallalong)	Floodplain	Between 5% and 2% AEP

10. DESIGN EVENT MODELLING

10.1. Overview

Design flood levels in the study area are a combination of inflows from the Paterson and Allyn Rivers upstream of Vacy, rainfall over the catchment downstream of Vacy and Hunter River inflows upstream of McKimms Corner (Reference 5). The design flows determined from the design rainfall approach were very similar to the flows determined from the FFA. Therefore the design rainfall approach has been used as it provides a more holistic result for the entire study area, especially in regard to flood mapping of the Paterson River floodplains and tributaries. A comparison of the flows at the Gostwyck PINEENA gauge (210079) for the design rainfall and FFA approach are shown in Table 28.

Table 28 – Comparison of Flows (m^3/s) – Design Rainfall vs FFA

Event	Design Rainfall (m^3/s)	FFA (m^3/s)
20% AEP	1000	820
10% AEP	1280	1190
5% AEP	1680	1570
2% AEP	2130	2100
1% AEP	2530	2520
0.5% AEP	2990	2950

10.2. Upstream Inflows

Design peak inflows from the Paterson River and Allyn River are shown in Table 29.

Table 29 – Paterson River and Allyn River Design Peak Inflows

Event	Paterson River (m^3/s)	Allyn River (m^3/s)
20% AEP	566	487
10% AEP	726	610
5% AEP	936	795
2% AEP	1172	1015
1% AEP	1403	1222
0.5% AEP	1647	1439
0.2 % AEP	1979	1736
PMF	4568	3855

A reasonable match is made to all the flood marks except for flood mark 16 which was considered to be of low accuracy due to poor visibility of the actual mark inside the culvert. A good match was made to the flood extent marks shown in Figure B27 at Bolwarra Heights and the levee on Phoenix Park Road. The flood mark recorded on the levee shows the levee did not overtop which was replicated in the model. The break out at Iona is shown Figure B28 with a good match to the flood extent recorded.

Table 23 – Peak Flood Levels April 2015

Gauge	Recorded (mAHD)	Modelled (mAHD)	Difference	Percentage	Calibration
Gostwyck - 210079	18.72	17.85	-0.87	-4.6%	Good
Gostwyck Bridge - 210402	16.12	15.75	-0.37	-2.3%	Good
Paterson RB -210406	11.99	11.66	-0.33	-2.8%	Good
Dunmore - 210409	6.06	6.45	0.39	6.4%	Fair
Hinton Bridge - 210410	5.76	5.68	-0.08	-1.4%	Good

OFFICE OF ENVIRONMENT AND HERITAGE

HUNTER RIVER HYDRAULIC ASSESSMENT – PATERSON RIVER LEVEE MODIFICATION

APRIL 2017

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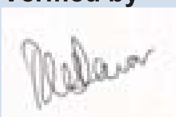
HUNTER RIVER HYDRAULIC ASSESSMENT – PATERSON RIVER LEVEE MODIFICATION

FINAL REPORT

APRIL 2017

Project **Hunter River Hydraulic Assessment – Paterson River Levee Modification**	**Project Number** **116035**
Client Office of Environment and Heritage	**Client's Representative** Richard Murphy
Authors Dan Morgan Rhys Hardwick-Jones	**Prepared by** 
Date **3 April 2017**	**Verified by**  Richard Dewar

Revision	Description	Distribution	Date
1	Draft report for client review	OEH	December 2016
2	Final Draft Report	OEH	March 2017
3	Final Report	OEH	April 2017

HUNTER RIVER HYDRAULIC ASSESSMENT – PATERSON RIVER LEVEE MODIFICATION

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
ARR	Australian Rainfall and Runoff
EOT	Early Overtop
FFA	Flood Frequency Analysis
HRFRMS	*Hunter River Floodplain Rick Management Study and Plan*
HRFS	*Hunter River Branxton to Green Rocks Flood Study*
LOT	Late Overtop
mAHD	meters above Australian Height Datum
NSD	Newcastle Sewerage Datum
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PRFS	*Paterson River Flood Study*
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WAE	Work-As-Executed
WBNM	Watershed Bounded Network Model (hydrologic model)

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

1. Flood Study

- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management

- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan

- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan

- Construction of flood mitigation works, and use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

1. INTRODUCTION

The Office of Environment and Heritage (OEH) has modified part of the levee system on the Paterson River, including raising of existing levees and early overtops (EOT). The works were completed between February and March 2016. The extent of the modification works is along a stretch of approximately 4 km that begins approximately 1 km downstream of Dunmore Bridge and ends approximately 250 m downstream of Wallalong Road, on the eastern bank of the Paterson River. The extent of the works is shown in Image 1 and Figure 1.

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WMAwater was engaged by the Office of Environment and Heritage (OEH) to undertake a hydraulic assessment of the completed works to identify the effect on flood behaviour using available TUFLOW hydraulic models of the Lower Hunter River and Paterson River. These models were previously developed as part of catchment-wide flood studies (see Section 2.2 for details). WMAwater were engaged to undertake the assessment for Paterson River flooding in May 2016, and for joint Hunter River / Paterson River flooding in October 2016.

Image 1 - Extent of Levee Modification Works

WMAwater previously completed the *Hunter River Branxton to Green Rocks Flood Study* (HRFS, Reference 1) for Maitland Council and Cessnock Council and the *Hunter River*

Floodplain Risk Management Study and Plan (HRFRMS, Reference 2) for Maitland Council. The results supplied herein were prepared by utilising the hydraulic models developed for both studies.

WMAwater is currently undertaking the *Paterson River Flood Study* (PRFS, Reference 3), with the study at the public exhibition phase. The majority of the PRFS (including flood modelling) was completed before the levee modification works were undertaken. WMAwater became aware of the modification works in May 2016, at approximately the same time that a draft report was submitted to Council.

The modelling for the PRFS is based on conditions prior to the levee modification conditions and that study is not related to the modification works. The purpose of the PRFS is to understand existing flood risk on the Paterson River, and prepare modelling tools that can be used to assist in floodplain management decision making. The PRFS is currently on hold until an understanding of the levee modification works, community consultation, and any subsequent remediation works is resolved. It is likely that the design flood modelling and mapping for the draft PRFS will be revised at a later date to reflect the modification works and ay additional works that may occur.

Prior to modelling of the Hunter River flood mechanisms as part of this assessment, WMAwater completed an assessment of the effect of the levee works on flooding solely from the Paterson River, entitled *Hydraulic Assessment – Paterson River Levee Upgrade* (Reference 4).

2. BACKGROUND

2.1. Study Area

The Hunter River has a catchment of some 16,500 km^2 to Singleton and 17,600 km^2 to Maitland which is approximately 50 km straight line or 85 km river distance downstream. The Hunter River has experienced many floods in the past with the largest since European settlement recorded in February 1955. Subsequently large floods have occurred in February 1971, March 1977 and June 2007 (these events were large floods at both Singleton and Maitland)

For this assessment the study area that is of interest is located on the Hunter River between Oakhampton and Green Rocks and on the Paterson River between Dunmore Bridge and the confluence with the Hunter. The area of interest also includes the floodplains and flood affected areas in the suburbs of Bolwarra, Lorn, Pitnacree, Raworth, Phoenix Park, Woodville, Wallalong, Hinton, Duckenfield and Morpeth.

2.2. Previous Studies

2.2.1. Hunter River Branxton to Green Rocks Flood Study – Final 2010 (HRFS)

This HRFS (Reference 1), undertaken by WMAwater, determined Hunter River design flood levels for the entire Maitland City LGA, and superseded the 1998 Flood Study. Reasons for initiating the study and updating the design flood levels included:

- The use of a two-dimensional (2D) model to simulate flood behaviour, an advancement over one-dimensional (1D) techniques used in the previous study;
- The availability of detailed topographic data from Airborne Laser Scanning (ALS) has enabled the use of 2D models, an accurate definition of topographic features in the floodplain and the ability to provide accurate flood extent and depth mapping;
- The need to obtain design flood level estimates upstream of Oakhampton (not previously available);
- Advancements in flood frequency estimation, used to determine design flow rates on the Hunter River;
- The June 2007 flood was the third largest flood since February 1955 and over 30 peak levels were recorded by residents as well as at thirteen automatic water levels recorders within the study area. This event therefore provided suitable data for model calibration;
- The June 2007 event equalled the January 1971 event at Singleton, exceeded the 1971 peak at Greta (by 0.7 m) but was 0.4 m lower than 1971 at Maitland (Belmore Bridge). This apparent "anomaly" together with the relatively "slow" travel time of the flood peak from Singleton in 2007 was not well re-produced by existing models and required some further investigation; and
- There was a general need to review the results of the October 1998 Flood Study and establish a computer model for use in the evaluation of climate change scenarios as well as to investigate potential development options.

The following tasks were undertaken in the Flood Study:

- collection of historical flood data;
- flood frequency analysis for Oakhampton/Belmore Bridge;
- development of hydrologic (WBNM) and hydraulic (TUFLOW) models, calibrated against historical flood behaviour (June 2007, February 1971 and February 1955);
- design flood estimation (including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP, and 0.5% AEP events as well as the PMF);
- assessment of provisional flood hazard (for the PMF and 1% AEP events).

The hydraulic model developed for HRFS study was the one primarily relied upon for this assessment.

2.2.2. Hunter River Floodplain Risk Management Study and Plan – Final 2015 (Reference 2)

The objectives of the study were to identify and compare various management options, including an assessment of their social, economic and environmental impacts. The primary aim of the Plan is to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk. The management options that were investigated were:

- Flood Mitigation Measures:
  - Sharkies Lane Levee;
  - Private Trzecinski Bridge Levee;
  - Maitland Ring levee Upgrade;
  - Modify Spillway Levels;
  - Reinforce Oakhampton Road Control.
- Property Modification Levels:
  - House Raising / Flood Proofing / Amphibious Housing;
  - Voluntary Purchase;
  - Rezoning;
  - Development Control Planning and Flood Planning Levels.
- Response Modification Measures:
  - Upgrade Evacuation Route (existing Long Bridge);
  - Upgrade Evacuation Route (realigned Long Bridge);
  - Flood Warning and Evacuation Planning;
  - Public Information and Raising Flood Awareness.

2.2.3. Paterson River Flood Study (Draft) – 2016 (PRFS)

The PRFS (Reference 3) is currently being undertaken by WMAwater on behalf of Maitland Council, Port Stephens Council and Dungog Council, and is at the draft pubic exhibition phase. The Paterson River has a total catchment area of approximately 1200 km^2. The area of interest for this study is the floodplain from Vacy (near of the confluence of the Paterson and Allyn Rivers) to the confluence with the Hunter River at Hinton. This portion of the catchment has an area of approximately 105 km^2.

It should be noted that the PRFS was essentially completed without WMAwater having knowledge of the levee modification works. The levee survey and LiDAR data obtained and incorporated into the PRFS does not include the levee modification works, and therefore the results from the study are based on conditions prior to the works' completion.

The study is currently on hold. The PRFS is currently on hold until an understanding of the levee modification works and any subsequent remediation works is resolved. It is likely that the design flood modelling and mapping for the draft PRFS will be revised at a later date to reflect the modification works and ay additional works that may occur.

The components of the study are to:

- collate available historical flood related data;
- analyse historical rainfall and flooding data;
- undertake a community consultation program;
- develop robust computational hydrologic and hydraulic models and calibrate them against multiple historical events;
- undertake a flood frequency analysis based on the historical record
- determine the flood behaviour including design flood levels, velocities and flood extents within the catchments;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increase in rainfall intensities
- to assess the floodplain categories in accordance with Council policy and undertake provisional hazard mapping; and
- to determine and map the flood planning area in accordance with the floodplain development manual

The study comprised two distinct modelling components:

- WBNM (Hydrologic) – The model was used to calculate the flow hydrographs for input into the TUFLOW model.
- TUFLOW (Hydraulic) – The 2D hydraulic model was used to assess the complex flow regimes of Paterson River and its tributaries and how these flows interact with the floodplain and levee system.

Two approaches were investigated to determine design flood magnitude. Flood Frequency Analysis and design rainfall modelling were both undertaken with similar results for peak flow at key gauges. The design rainfall approach was adopted as it provides a more holistic result for the entire study area, especially in regard to flood mapping of the Paterson River floodplains and tributaries.

The study included modelling of the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF design flood events, with mapping provided for peak flood depths and levels, peak velocities, hydraulic hazard and hydraulic categories.

2.2.4. Hydraulic Assessment – Paterson River Levee Upgrade – 2016

An initial assessment of the Paterson River levee modification works on the eastern bank was undertaken by WMAwater at the request of OEH (Reference 3). The extent of the modification works is along a stretch of approximately 4 km that begins approximately 1 km downstream of Dunmore Bridge and ends approximately 250 m downstream of Wallalong Road, on the eastern bank of the Paterson River.

The assessment was undertaken using the modelling package developed as part of the PRFS (Reference 3). The assessment primarily focused on the Paterson River design flood events that were modelled in PRFS. The design events investigated for the assessment were the 20% AEP, 10% AEP, 5% AEP, 1% AEP design events and the April 2015 historical event.

The April 2015 event was modelled as a calibration event for the PRFS. This event was modelled over a 72 hour period, with the rainfall and temporal patterns were determined from daily and pluviometer rainfall gauges in the catchment. This event was assessed for the levee modification assessment as it was the largest flood recorded on the Paterson with a peak flood level of 16.1 mAHD recorded at Gostwyck Bridge. This flood event is strong in the memory of local residents, and therefore useful in conveying the outcomes of the assessment as part of any ongoing consultation activity.

In order to undertake a reliable impact assessment of the levee modification works, the section of levee that was modified was isolated in the model so that only that section of the levee varies in the base case (before levee works) and post-modification (after levee works) scenarios. The only differences between the “base case” and “post modification” scenarios are the levee crest profiles along the extent of the works. Other areas in the model were left constant, even where there were slight discrepancies in the available survey data, to ensure that the impact assessment only identified the flood impacts of the modification works.

The levee works (including raising) that were undertaken on the eastern levee bank were found not to have a significant impact on flood behaviour or peak flood levels for events up to and including the 5% AEP event (for flooding of the Paterson River without significant Hunter River flooding). This is because the smaller Paterson floods would not overtop the affected sections of levee, with or without the modification works. This finding is only for smaller Paterson River floods without significant Hunter River flooding occurring in conjunction.

For larger floods, which would have overtopped the modified section of levee, it was found the levee modifications will alter flood levels in the river and on the surrounding floodplains. The magnitude of the increases and decreases in peak flood levels on the floodplains varies spatially but is in the order of ±0.1 m (for flooding of the Paterson River without significant Hunter River flooding). Flood levels will typically be increased upstream of the works, and decreased downstream of the works, for these larger flood events.

The assessment described above did not include consideration of the levee modifications on flooding from the Hunter River. The present report addresses the impacts of the works on Hunter River flood behaviour.

2.3. Hunter River Flood Behaviour

There is a constriction of the Hunter River at the Oakhampton railway bridge crossing. Downstream of this point, for large flood events, there are three main flow paths of the Hunter River:

- The Hunter River main channel, which contains all flow up to events of around the 10% AEP magnitude.
- The Oakhampton Floodway, which passes between Maitland and the high ground of Rutherford and Telarah in the west and discharges into a large flood storage area south of Maitland (the Wallis Creek and Swamp/Fishery Creek floodplains). This area drains back into the Hunter River at Wallis Creek, and at Porters Hollow via the East Maitland floodway.
- Bolwarra Floodway – Traverses the Bolwarra Flats and then discharges back into the Hunter River in the King Island and Phoenix Park areas or overtops the Paterson River and enters the Wallalong floodplain.

The HRFS indicated that flow is primarily in-bank for the Hunter River 50% AEP event with some shallow overbank flooding of low-lying areas on the Lower Paterson River and downstream of Morpeth. The 50% AEP event is large enough for the formation of an anabranch flow-path from Porters Hollow (just downstream of Harry Boyle Bridge), through Howes Lagoon, and re-joining the Hunter River immediately upstream of Morpeth.

In the 20% AEP event the Narrow Gut flowpath begins to operate with floodwaters from the Hunter River entering Narrow Gut and then flowing across the western Paterson River spillway and into the Paterson River. From there, floodwaters either overtop the spillway on the eastern Paterson levee bank and enter the Wallalong floodplain, or continue further down the Paterson River.

In the 10% AEP event the Oakhampton and Bolwarra Spillways are just overtopped (with only inconsequential impacts). In the 10% AEP event, the majority of rural floodplain areas downstream of Harry Boyle bridge are inundated, including Raworth, Largs/Kings Island, Phoenix Park, Woodville, Wallalong, Duckenfield, Millers Forest, and McClymonts Swamp.

In larger flood events between 5% AEP and 2% AEP magnitude, significant overtopping of the Oakhampton and Bolwarra Spillways will occur, with high hazard flow occurring in each of the respective floodways, resulting in widespread inundation throughout Louth Park and the Bolwarra Flats. The deck level of Long Bridge is overtopped between a 5% and 2% AEP flood. Wyburns Levee, which extends eastwards from the Wallis Creek floodgates to Morpeth Road near Reid Street, is overtopped in floods greater than the 5% AEP, resulting in flooding of the Pitnacree area.

In the 1% AEP event, most of South and Central Maitland is inundated, with depths exceeding 2.5 m in large areas of Horseshoe Bend, and along the railway corridor including Maitland railway station. The extent of inundation is up to 4 km wide at some points. While Lorn is protected from inundation by levees along the Hunter River, the flood level in the river is up to 3 m higher than average ground levels in the area. Low-lying areas at the east of Lorn are inundated by backwater flooding from the Bolwarra Flats.

3. DATA

3.1. Topography

3.1.1. LiDAR - HRFS

The LiDAR utilised for the HRFS was obtained for the Maitland LGA and part of Cessnock LGA from Photomapping Services, Melbourne. This data was verified against approximately 380 surveyed data points obtained across the Maitland LGA and the accuracy confirmed as:

- The standard deviation of the error between the aerial survey and ground survey is less than 0.15 m
- The mean of the error is less than +/- 0.1 m.

3.1.1. LiDAR - PRFS

Light Detection and Ranging (LiDAR) survey of the PRFS study area and its immediate surroundings was provided by Land and Property Information (LPI). The data for the Maitland area was collected in 2012 and the Raymond Terrace area in 2013. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The accuracy is typically ± 0.15 m for clear terrain.

3.1.2. Levee Survey 2011 (OEH)

OEH provided detailed survey of the Paterson River levee system. The levee survey begins at Tocal and continues through to the confluence with the Hunter River. This survey was used as the basis for refinement of the pre-modification scenario modelled by WMAwater.

3.1.3. Levee Survey 2016 (OEH)

OEH provided detailed survey of the levee system after completion of the modification works. The survey begins at Dunmore Bridge and continues through to approximately 500m past Wallalong Road. The location of the survey is shown in Figure 2, Figure 3 and Figure 4. This survey was used as the basis for refinement of the post-modification scenario modelled by WMAwater.

3.1.4. Hunter River Flood Mitigation Plans 1967 (Department of Public Works)

The original plans by Department of Public Works for the Hunter Valley Flood Mitigation – Woodville – Wallalong – Greenwattle – Levees were provided by OEH. The plans are attached in Appendix B.

3.2. Development of Hydrologic and Hydraulic Models

3.2.1. Hydrological Model

The hydrological approach was to utilise Flood Frequency Analysis (FFA) for the Hunter River and a WBNM hydrological model for the tributaries. The FFA determined the peak flows for design events on the Hunter River, with the hydrograph shape being based on the February 1955 historical flood event.

3.2.2. Hydraulic Model

The hydraulic model was developed using the TUFLOW 1D/2D modelling software (WMAwater, 2015). The catchment topography was based on LIDAR survey, bathymetric survey of the tidal zone, and detail survey of levee bank crests. A digital elevation model with a 10 m grid resolution was developed from these survey datasets. WMAwater calibrated the models to multiple events with a good match to recorded data being achieved across the full range of events. The calibration events were:

- February 1955
- February 1971
- March 1977
- June 2007

4. PATERSON RIVER LEVEE

A major levee system was constructed in the 1960s and 1970s by the Department of Public Works. The levee system is built on the major floodplains, beginning at the township of Tocal and continuing to the confluence of the Hunter River where it meets the Hunter River levee system. The levee system has a considerable influence on flood behaviour, especially in smaller events, where a large proportion of flow is contained within the river by the levee system.

The section of levee that is being investigated as part of this assessment is the eastern levee beginning approximately 1 km south of Dunmore Bridge and ending just south of Wallalong Road.

4.1. Levee Survey Data

There are two detail surveys of the levee that were used in this assessment with their profiles shown in Figure 5. The levee surveys form the basis of the assessment as they represent the levee topography before and after the modification works.

Levee Survey (2011)

The survey undertaken by OEH samples the levee topography at approximately 100 m intervals. The survey identifies the EOTs, but they would be more defined if the survey was undertaken at smaller intervals along the levee profile. The levee height differs from the 1967 design although the location of the EOTs are very similar. There could be multiple explanations for the discrepancy in levels:

- Subsidence of levee through natural soil and gravitational forces, vehicles traversing the levee and livestock grazing
- Erosion from flooding
- The levee not constructed exactly to the design plans.

Levee Survey (2016)

The survey undertaken by OEH samples the levee topography at irregular intervals ranging from 10 m to 160 m. The majority of the EOT sections have been filled by up to 0.5 m along the entire levee profile.

4.2. Historical Design Data

Woodville – Wallalong – Greenwattle – Levees (Design Plans 1967)

The design plans were developed in 1967 by the NSW Department of Public Works. The design plans detail the proposed eastern levee design beginning at Wallalong Road and finishing in the area south of Dunn's Creek. The plans consists of a detailed longitudinal section and plan of the proposed levee design. The plans were converted from imperial to metric and from the Newcastle Sewerage Datum (NSD) to the Australian Height Datum (mAHD). The conversion from NSD to mAHD was taken as -1.02 m (from Reference 5). The design displays multiple EOT sections along the stretch of the levee profile.

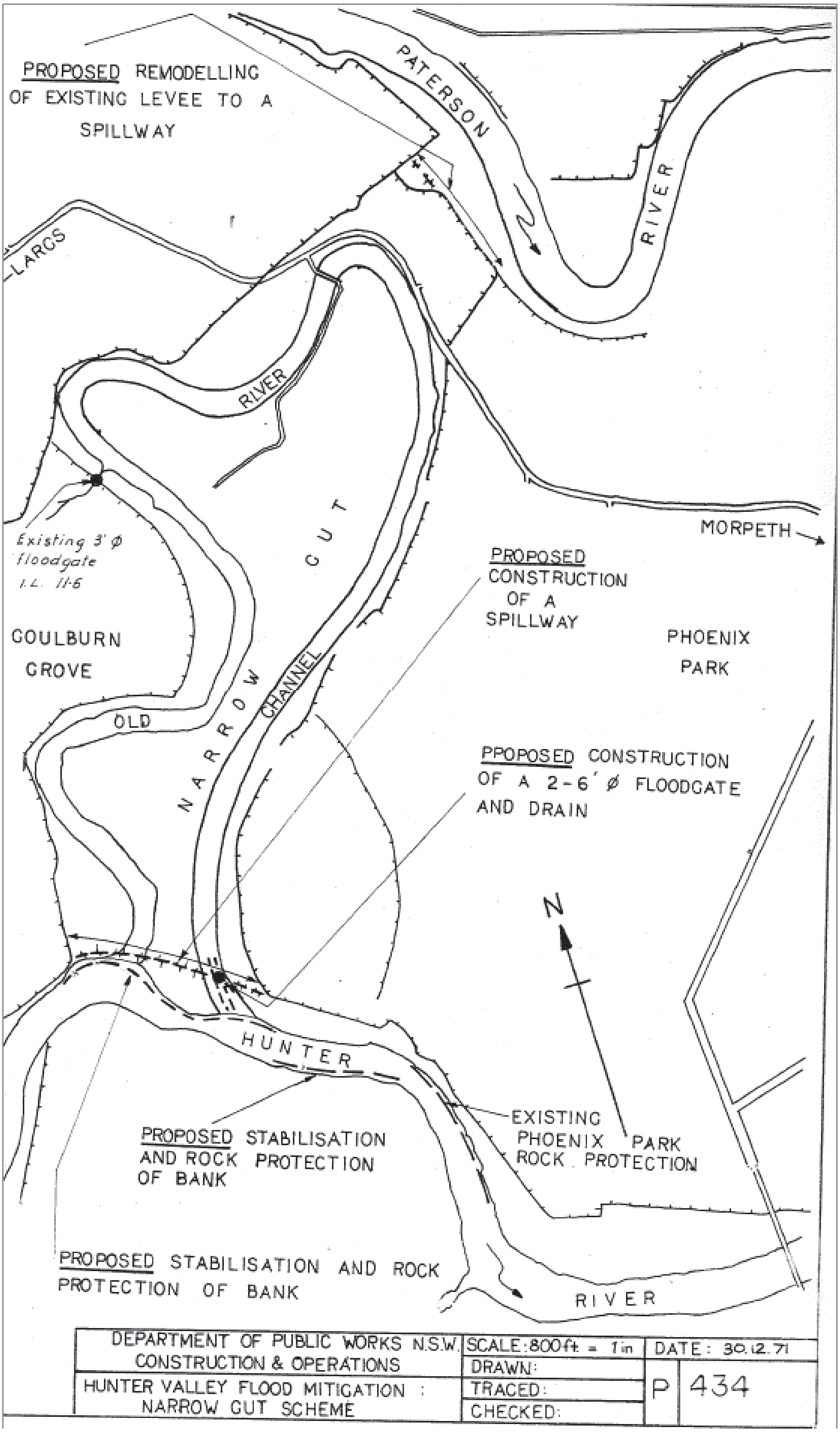
The historical design plans obtained from OEH detail how the proposed levee was intended to operate. There are approximately 15 early EOT sections in the design between Wallalong Road and Dunmore Bridge. The location of the EOT sections are also identified in the levee survey (2011) with a comparison profile shown in Figure 5. It is not known if the levee was built to the design as Work-As-Executed (WAE) drawings are not available, nor detailed survey of the levee post construction. The difference in levee topography may be due to many factors over the last 50 years, including natural subsidence, compaction due to vehicles traversing the levee, livestock grazing and erosion due to wind, rain or overtopping.

It is worth noting that the levee scheme was designed in the 1960's and 1970's without the benefit of computer models, with the design developed utilising hand calculations. The conclusions from the design process regarding flood behaviour and the protection each levee provides with regard to magnitude of flood event would differ from an analysis undertaken at the current time.

4.3. Narrow Gut Scheme

Initial plans developed in 1971 for the Narrow Gut Scheme (Reference 6) are shown in Image 2 and Appendix B. WAE drawings were not available, but the levee survey (2011) and the presence of the floodgate at Narrow Gut shown in Image 3 suggests the proposed works were undertaken in a similar fashion to the proposed design. The plans suggest the reasoning behind the Narrow Gut Scheme is to allow floodwaters from the Hunter River to spill into Narrow Gut, then be conveyed either, into the Paterson River and downstream towards Hinton, or over the Paterson River and spilling into the Wallalong floodplain through the EOT sections on the eastern levee. Figure 5 shows the location of the flowpath on the western levee and the EOT section on the eastern levee. It would normally be expected that the second flow mechanism mentioned above would be impeded by raising the spillway levels on the eastern levee, as is the case for the modification works that were undertaken.

Image 2 – Plans for Narrow Gut Spillway and Flowpath



The Narrow Gut flow path has the potential to be affected by the levee modification works that have been undertaken, particularly in flood events where this flood runner is active but broader parts of the floodplain are not inundated. For example, in Hunter River flood events between 20% AEP magnitude and 10% AEP magnitude, the Narrow Gut flow path is the primary breakout on the northern side of the lower Hunter River floodplain, since the Bolwarra Spillway would not overtop in these events.

Image 3 – Narrow Gut Flood Gate

The interactions between the various flow paths in and adjacent to Narrow Gut and the major flow paths of the Hunter River and Paterson River are extremely complex and would vary considerably between each flood, due to the unique nature of coincident flooding between the two river systems.

The assessment tools available at the time of design were simple in nature compared to the tools available today and not sufficient to understand all of these interactions. The 2D modelling now available (as used for this assessment) provides a better understanding of how the scheme behaves as it was built and has operated for the last 50 years. To some degree the original design objectives are moot with regards to ongoing works on the scheme, unless there is a clear benefit from re-optimising the scheme, and the affected community is amenable to changes. Typically, changes would involve some members of the community becoming disadvantaged, which limits the scope and feasibility changes being carried out, even if they are in line with the original design objectives.

5. ASSESSMENT METHODOLOGY

5.1. Levee Topography

The original model topography developed for Reference 1 and Reference 2 was based on LiDAR aerial survey, without additional detail survey of levee crests. For this study, additional detail was included for the levees east of Morpeth Bridge based on the PRFS levee topography. This data included a combination of the detail survey from 2011/2012 (provided by OEH) and additional LiDAR survey undertaken by the NSW Department of Land & Property Information (LPI) in 2013/2014. The reasoning for this approach was to assess the same levee topography that was assessed in Reference 4 so that the results would be comparable.

For the levee assessment additional detail was required for the section of levee under consideration (that is, the reach between Dunmore Bridge and Hinton). The “base case” scenario was developed using the 2011/2012 detail survey to define the levee bank crests. The “post-modification” scenario was developed using additional detail survey collected by OEH in June 2016, which captured the levee crest profile after the modification works were completed. The survey covers a 5.8 km section of the levee system starting at Dunmore Bridge and concluding downstream of Wallalong Road. The extent of this survey is shown in Figure 2.

In order to undertake a reliable impact assessment of the levee modification works, all aspects of the modelling were consistent except for changes to the modified section of levee. The only differences between the “base case” and “post modification” scenarios are the levee crest profiles along the extent of the works. This methodology ensures that the impact assessment only identified the flood impacts of the modification works. The data sources for each scenario are illustrated on Figure 3 and Figure 4.

The difference of the levee topography between the base case (before levee works) and post-modification case (after levee works) is displayed in Figure 5.

5.2. Joint Flooding of the Hunter and Paterson Rivers

A comprehensive statistical analysis of coincident flooding on the Hunter River and Paterson River is not within the scope of this study. However there are several historical examples of significant Hunter and Paterson River floods occurring in conjunction, since the flood-producing rainfalls on these catchments are often generated by similar meteorological systems.

As no two floods are the same and to try and understand the effects of the levee works across a range of possible flooding combinations, 25 different hypothetical floods were modelled for this assessment. Each hypothetical flood was a combination of varying magnitudes of Hunter River flooding and Paterson River and tributary flooding. Additionally, the June 2007 historical flood was modelled since this involved significant flooding in both the Hunter River and Paterson River. The modelled flood events are summarised in Table 1.

Table 1 - Modelled Hunter River Floods

		Paterson River & Tributaries				
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Hunter River	20% AEP	✓	✓	✓	✓	✓
	10% AEP	✓	✓	✓	✓	✓
	5% AEP	✓	✓	✓	✓	✓
	2% AEP	✓	✓	✓	✓	✓
	1% AEP	✓	✓	✓	✓	✓

6. RESULTS

6.1. Impacts on Peak Flood Levels

The impact assessment of the levee modification works was undertaken for all 26 flood events modelled. The results are displayed on "impact maps," which show the difference in peak flood levels produced by the levee modification works, compared to the pre-modification scenario. The corresponding map number for each combination of Hunter River and Paterson River floods is shown in Table 2.

Table 2 – Impact Figures

		Paterson River & Tributaries				
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Hunter River	20% AEP	Figure 6	Figure 7	Figure 8	Figure 9	Figure 10
	10% AEP	Figure 11	Figure 12	Figure 13	Figure 14	Figure 15
	5% AEP	Figure 16	Figure 17	Figure 18	Figure 19	Figure 20
	2% AEP	Figure 21	Figure 22	Figure 23	Figure 24	Figure 25
	1% AEP	Figure 26	Figure 27	Figure 28	Figure 29	Figure 30

The figures show areas where peak flood levels would be increased or reduced. Areas where the difference is ±0.01 m are reported "no impact." This is consistent with the guidance from Engineers Australia (Reference 7), which indicates that typically "impacts less than 0.01 m are not reported, as they are considered to be within the precision of numerical model and data."

The maximum increases and minimum decrease in flood levels are shown in Table 3.

There are significant increases in peak flood levels across all events modelled with more pronounced increases in the smaller Hunter River events, especially in the Bolwarra floodway and the floodplain adjacent to Lorn. This is because in smaller Hunter River events the Bolwarra Spillway is not overtopped, and the Narrow Gut flood runner is the primary breakout location on the northern side of the Hunter downstream of Maitland. Raising of the Narrow Gut spillway on the eastern Paterson levee bank therefore obstructs flow through this area, resulting in a backwater effect through King Island and across the Bolwarra flats.

Discussion of the impacts for various combinations of Hunter River and Paterson River design event is discussed further below.

Table 3 – Increases and Decreases in Peak Flood Level

Hunter River Flood Event	Paterson River Flood Event	Max Increase in Flood Level (m)	Location	Min Decrease in Flood Level (m)	Location
20% AEP	20% AEP	+ 1.73 m	Largs	-3.20 m	Wallalong
	10% AEP	+ 0.92 m	Largs	-2.15 m	Wallalong
	5% AEP	+ 0.28 m	Largs	-0.87 m	Wallalong
	2% AEP	+ 0.11 m	Largs	-0.37 m	Four Mile Creek
	1% AEP	+ 1.21 m	Bolwarra	-0.13 m	Four Mile Creek
10% AEP	20% AEP	+ 0.24 m	Largs	-0.97 m	Wallalong
	10% AEP	+ 0.74 m	King Island	-0.17 m	Four Mile Creek
	5% AEP	+ 0.80 m	King Island	-0.18 m	Four Mile Creek
	2% AEP	+ 1.48 m	Bolwarra	-0.05 m	Four Mile Creek
	1% AEP	+ 0.78 m	Bolwarra	-0.27 m	McClymonts Swamp
5% AEP	20% AEP	+ 0.07 m	Largs	-0.03 m	Four Mile Creek
	10% AEP	+ 0.10 m	Largs	-0.02 m	Four Mile Creek
	5% AEP	+ 0.10 m	Largs	-0.02 m	McClymonts Swamp
	2% AEP	+ 0.15 m	Lorn	-	-
	1% AEP	+ 0.20 m	Lorn	-	-
2% AEP	20% AEP	+ 0.05 m	Largs	-0.03 m	Narrow Gut
	10% AEP	+ 0.05 m	Woodville	-0.03 m	Woodville
	5% AEP	+ 0.06 m	Largs	-0.03 m	Hinton
	2% AEP	+ 0.15 m	Lorn	-0.02 m	Hinton
	1% AEP	+ 0.19 m	Lorn	-0.02 m	Hinton
1% AEP	20% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	10% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	5% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	2% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	1% AEP	+ 0.06 m	Woodville	-	-

6.2. Description of Changes to Flood Behaviour

Hunter River 20% AEP Event

For the Hunter River 20% AEP event, the most significant impacts occur in combination with the Paterson River 20% AEP event. There are increases in peak flood levels of up to 0.1 m on the Phoenix Park floodplain, 0.28 m in Four Mile Creek and 0.45 m in McClymonts Swamp. Modelling indicates the largest increase in peak flood levels would be on the Largs floodplain with impacts of up to 1.73 m. There is also a significant area between Narrow Gut and King Island that is newly flooded as a result of the levee modification.

There are decreases in peak flood level of up to -3.2 m in on the Wallalong floodplain.

Hunter River 10% AEP Event

For the Hunter River 10% AEP event, the most significant impacts occur in combination with the Paterson River 2% AEP event. There are increases in peak flood levels of up to 0.25 m on King Island, 0.08 m on the Largs floodplain and 0.04 m on the Wallalong floodplain. Modelling indicates the largest increase in peak flood levels would be on the Bolwarra floodplain with impacts of up to 1.5 m. There is also a significant area of the Bolwarra floodplain that is newly flooded as a result of the levee modification.

There are decreases in peak flood level of up to -0.01 m in Narrow Gut, -0.02 m in Hinton and 0.05 m in Four Mile Creek.

Hunter River 5% AEP Event

For the Hunter River 5% AEP event, the most significant impacts occur in combination with the Paterson River 5% AEP event. There are increases in peak flood levels of up 0.07 m on the Wallalong floodplain, 0.06 m on the Bolwarra floodplain, 0.01 m on the Phoenix Park floodplain, 0.1 m on the Largs floodplain and 0.26 m near Lorn. There is also a small area near Lorn floodplain that is newly flooded as a result of the levee modification.

There are decreases in peak flood level of -0.02 m at Hinton.

Hunter River 2% AEP Event

For the Hunter River 2% AEP event, the most significant impacts occur in combination with the Paterson River 2% AEP event. There are increases in peak flood levels of up 0.15 m on the Lorn Floodplain, 0.06 m on the Wallalong floodplain, 0.06 m on the Largs floodplain, 0.01 m on the Phoenix Park floodplain and 0.02 m on the Bolwarra floodplain.

There are decreases in peak flood level of -0.02 m at Hinton.

Hunter River 1% AEP Event

For the Hunter River 1% AEP event, the most significant impacts occur in combination with the Paterson River 1% AEP event. There are increases in peak flood levels of 0.06 m on the Wallalong floodplain, 0.06 m on the Largs floodplain, 0.02 m on the Bolwarra floodplain and 0.02 m on the Phoenix Park floodplain.

There are no decreases in peak flood level.

6.3. Summary of Impacts from the Levee Modification Works

The interaction of the Hunter River and the Paterson River with their subsequent levee systems is extremely complex and even more so when considering the variety of coincidence flooding between the two rivers that has occurred throughout history. Throughout historical records no two floods are exactly the same, therefore the river and levee systems do not behave in exactly the same manner from flood to flood. There is no single flow path, spillway, road or section of levee that can be isolated when describing the flood mechanisms that are affected due to the levee modifications. There are multiple flood mechanisms that are affected by the levee modification works. It is the shift in these flood mechanism that result in the increase in peak flood levels and peak flood extents. The food mechanisms that have been identified as being affected are as follows:

- The raised section of eastern levee prevents floodwater spilling into the Wallalong floodplain until the flood level is higher than was previously (0.5m in some sections of levee). This results in floodwaters overtopping the western levee at an earlier time than previously and with greater volume. This results in increased peak flood level in the Largs floodplain. The effect of the obstruction is most pronounced in the modelled Hunter River 20% and 10% AEP events when the Bolwarra spillway and floodway are not operational. Excess floodwater in the Largs floodplain is conveyed in a westerly direction into the Bolwarra floodway. In events larger than a 10% AEP event the impacts are less pronounced as the Bolwarra floodway is operational with floodwater already having overtopped the Bolwarra spillway.
- The increased levee topography obstructs the Narrow Gut flow path. Flow from the Hunter River is conveyed through Narrow Gut, with a portion of that flow conveyed over the Paterson River which then fills the Wallalong Floodplain. The effect of the obstruction is most pronounced in the modelled Hunter River 20% and 10% AEP events when the Bolwarra spillway and floodway are not operational. Floodwaters that would normally be conveyed through Narrow Gut over the Paterson River and into the Wallalong Floodplain are prevented from doing so or do so in a less efficient manner. This behaviour has two consequences for flood behaviour:
  - Additional floodwater is conveyed down the Paterson River overtopping the Hinton spillways and increasing the flood levels in Hinton and McClymonts Swamp
  - Floodwaters inundate the Largs floodplain and are conveyed in a westerly direction down the Bolwarra floodway. In events larger than the modelled 10% AEP event the impacts are less pronounced as the Bolwarra floodway is operational with floodwater already having overtopped the Bolwarra spillway.
- The Wallalong Road is a control point for the Wallalong floodplain at approximately 6 mAHD. As the Wallalong floodplain fills up flood waters could equalise their levels with the Largs floodplain up to a level of 6 m until they overtopped Wallalong Road and entered McClymonts Swamp. A large section of the modified eastern levee is now at or above 6 mAHD, this impedes floodwaters in the Wallalong floodplain equalising levels with the floodwaters in the Largs floodplain. This results in increased levels in Wallalong floodplain.

6.4. Flood Profiles

Peak flood level and levee profiles for the Paterson River from Dunmore Bridge to the end of the modification works are shown in Figure 31 to Figure 38. The water level profiles were obtained from the PRFS (Reference 3) and the HRFS (Reference 1). The profiles demonstrate the different flood behaviour that is possible due to the very complex flood mechanism at work, resulting from the interaction of the Hunter and Paterson Rivers and their corresponding levee systems and floodplains. The profiles will provide valuable information in any levee design process. The figures are as follows:

- Figure 31 & Figure 32 – Peak level profiles for the design events from PRFS;
- Figure 33 & Figure 34 – Peak flood levels for the modelled historical events from PRFS;
- Figure 35 & Figure 36 – Peak level profiles for the design events from HRFS;
- Figure 37 & Figure 38 – Peak flood levels for the modelled historical events from HRFS.

7. CONCLUSIONS

7.1. Summary of Impact Assessment

The modelling undertaken indicates that the levee modification works significantly affect peak flood levels across a wide range of flood events, and cause a significant increase in flood extent Hunter River events of around 20% AEP to 10% AEP magnitude. The levee modification works cause the most pronounced impact to peak flood levels and extents in the modelled 20% AEP and 10% AEP Hunter River events when the Bolwarra floodway is not overtopped. The mechanisms at play are the raised section of the eastern levee preventing floodwaters spilling into the Wallalong floodplain until the flood level is higher than previously (0.5 m in some sections of levee) and the Narrow Gut floodway not operating as effectively and efficiently as previously.

The modification works will significantly change flood behaviour and peak flood levels in Woodville, Wallalong, Largs, Bolwarra, Lorn, King Island, Narrow Gut, Phoenix Park, McClymonts Swamp, Hinton and Four Mile Creek. In some instances the increases in peak flood level are relatively minor in comparison to the flood depths that would have occurred before the works. However, this does not necessarily mean the increases are insignificant. Any increase in flood levels has the potential to damage property, buildings, machinery and crops that may previously not have been damaged previously, or damaged less severely. Increases in inundation can also increase the duration of flooding, which can also increase tangible and intangible damages from flooding.

Significant works on the floodplain such as the alteration of levee schemes are typically undertaken under the NSW Flood Risk Management Program (e.g. as part of a Floodplain Risk Management Study and Plan). Modification of levee crest heights has the potential to significantly redistribute flood flows and flood levels. Consequently, planning for levee works requires these impacts to be assessed and communicated to all stakeholders. Such planning should generally include:

- Pre-construction surveys;
- hydraulic assessment of flood impacts (including strategic assessment of the impact of cumulative changes, not just modifications to individual sections – this may include consideration of original design heights);
- engagement with stakeholders to communicate impacts and provide opportunity for comment;
- development of detailed construction drawings;
- cost-benefit analysis of proposed works; and
- surveillance of contractor activities.

7.2. Recommendations

WMAwater considers that remediation works are required to redress or mitigate the adverse impacts caused by the levee modification works.

Returning the 4 km section of levee back to the pre-modification levels would be one way to restore flood behaviour to previous circumstances, but such a comprehensive remediation would potentially be unnecessarily costly. It may be possible to produce very similar behaviour by making more localised adjustments, with an emphasis on EOT sections and other parts of the levee system where the majority of overtopping flow occurs.

Such options would require further 2D hydraulic modelling investigation. The investigation is critical to ensure the mitigation works return flood behaviour and peak flood levels to as close to pre-modification conditions as possible. Community engagement and consultation are recommended to ensure transparency of the process, and to facilitate widespread stakeholder acceptance of the remediation works.

To summarise, WMAwater make the following recommendations.

- The 4 km stretch of levee that has been modified should preferably be returned to pre-modification levels (January 2016), however such comprehensive remediation works are likely to be cost-prohibitive and similar outcomes could potentially be achieved with more carefully targeted remediation works.
- Community consultation should be undertaken to understand the concerns of landholders and other stakeholders in the area.
- The interaction of Hunter River and Paterson River with their subsequent levee and flood mitigation systems is extremely complex, and 2D hydraulic modelling is required to adequately understand the potential impacts of the changes on flood behaviour. It is highly recommended that any future proposed modifications to the Lower Hunter Valley Flood Mitigation Scheme should be first assessed by detailed hydraulic assessment utilising calibrated 2D hydraulic modelling.
- A comprehensive overview assessment of the entire Lower Hunter Valley Flood Mitigation Scheme should be undertaken in order to define the existing system of levees, spillways and gates, and review which elements of the scheme have the most significant influence on flood behaviour. The scheme is a valuable asset to the community both economically and socially, and it is important to ensure it continues to function effectively. It has been over 50 years since many elements of the scheme were designed or constructed, and the design intentions are in some cases not well understood. Furthermore, modern computational flood assessment tools provide a significant increase in our ability to analyse and predict the complex flood interactions between different parts of the scheme.

  As part of such an assessment, the levee system could be analysed using existing aerial survey to create a database of crest levels, which could be used as the basis for future restorative maintenance works. There is ongoing maintenance cost for the levee system so it would be prudent to identify whether there are redundant sections of the system that provide no significant benefit. Reducing maintenance costs for these sections of the system could be redirected to the critical sections that provide the most significant benefit in reducing flood risk, or to future mitigation options that have been assessed to provide benefit to the community.

WMAwater recommends that the original drawings for the scheme to be used to set an upper bound for the design of any future levee profile. Additional lowing, from the original design profile, may be required if flood impacts are not in line with community expectations. This recommendation is based on the following considerations:

- The 1967 design EOT profile is close to the pre-modifications levels form chainage 1200m to 2400m. Between chainage 2500m and 4500m there are six locations where the profile is higher, with the range in height between 100mm and 250mm. This may be due to many factors over the last 50 years, including natural subsidence, compaction due to vehicles traversing the levee, livestock grazing and erosion due to flooding.
- However these considerations apply to all other parts of the levee system as well. If the eastern levee is returned to 1967 design conditions then an argument could be raised to return the western levee to 1967 design conditions which has the possibility to exacerbate the issues even further, and similar demands could reasonably be made about each element of the entire scheme.
- Any major changes to the levee system have the potential to produce significant changes to the flood behaviour that has been assessed as part of recent flood studies undertaken as part of the NSW Floodplain Risk Management Program. These studies are relied upon by Council to undertake their floodplain management and planning responsibilities, and the information from these studies is what is currently used to assess the suitability of development proposals in the floodplain. Changes to the established flood behaviour could potentially undermine these planning decisions.
- There is no way of determining if the levee was constructed as per the design drawings. Work-as-Executed plans or survey of the completed levee are not available to undertake a topographic comparison.
- This approach is in line with the recommendations from the ‘Hunter Valley Flood Mitigation Lower Hunter River Datum Conversion report, March 2017 (Reference 5), which recommends “*A conservative approach to design for future levee upgrades knowing that there is a level of uncertainty in the original datum adopted*”.

8. REFERENCES

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   WMAwater, September 2010.

2. Maitland Council
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   WMAwater, November 2015.

3. Maitland Council and Port Stephens Council
   Paterson River Flood Study (Draft)
   WMAwater, July 2016.

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   WMAwater, August 2016.

5. Hunter Valley Flood Mitigation – Lower Hunter River Datum Conversion
   Department of Public Works NSW, March 2017.

6. Flood Mitigation in the Lower Hunter Valley - Volume 1 - Flood Mitigation Works
   Department of Public Works NSW, 1974.

7. Department of Climate Change and Energy Efficiency
   Australian Rainfall and Runoff Revision Project 15: Two Dimensional Modelling Urban and Rural Floodplains
   Engineers Australia, 2012.

Figures

FIGURE 1
PATERSON RIVER
LEVEE SYSTEM MODIFICATION

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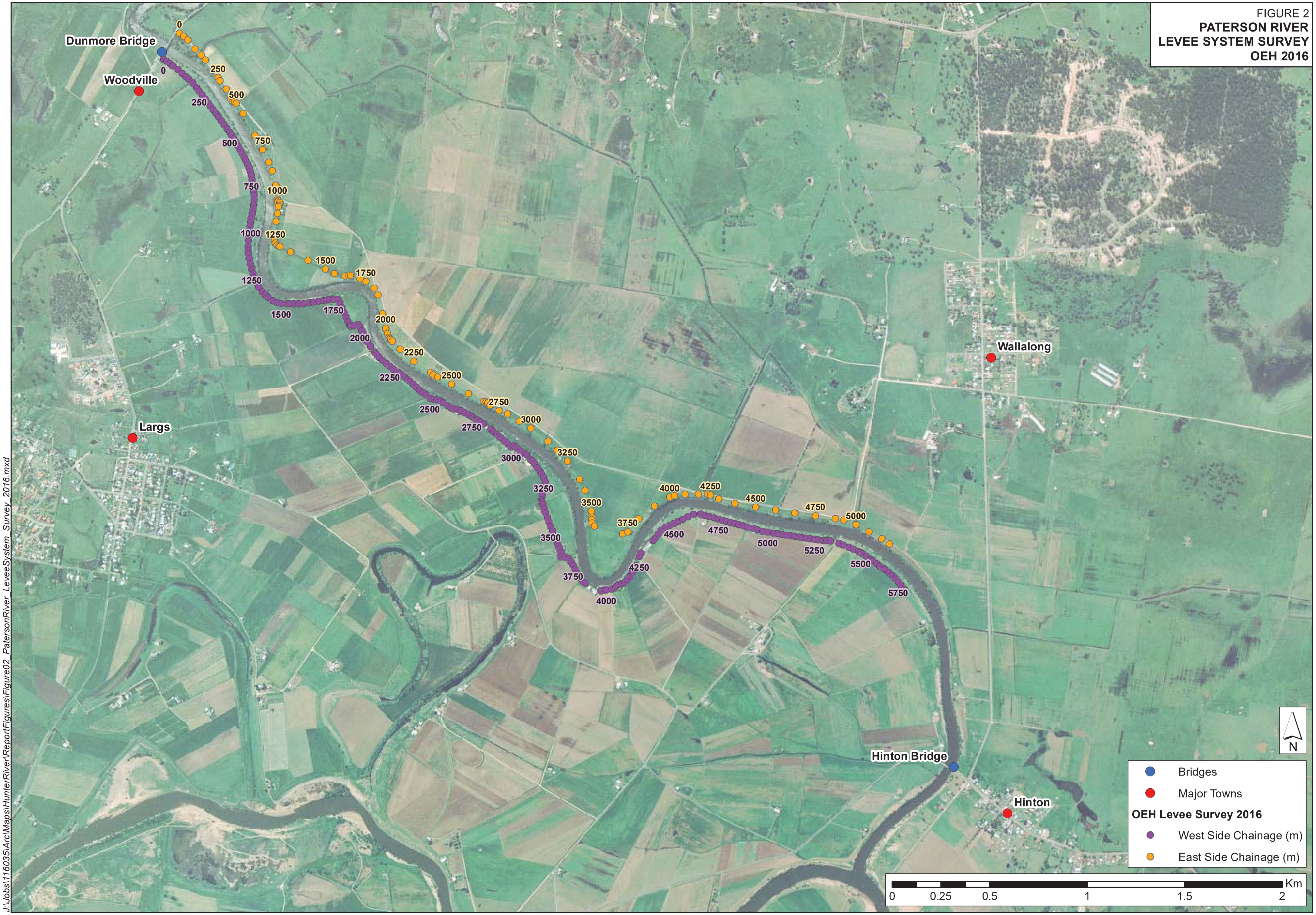
FIGURE 2
PATERSON RIVER LEVEE SYSTEM SURVEY OEH 2016



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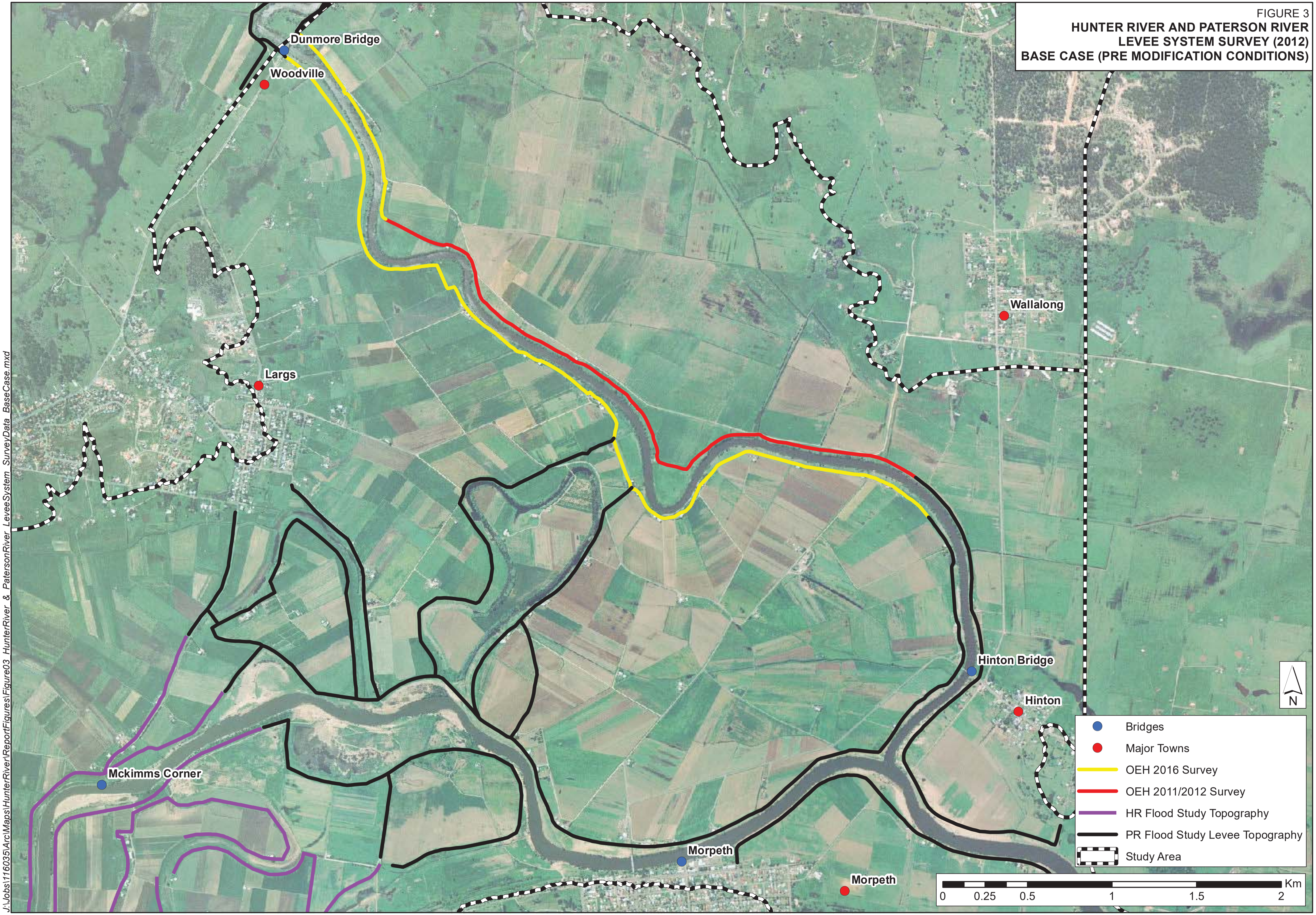
FIGURE 3
HUNTER RIVER AND PATERSON RIVER
LEVEE SYSTEM SURVEY (2012)
BASE CASE (PRE MODIFICATION CONDITIONS)
Dunmore Bridge
Woodville
Largs
Wallalong
Hinton Bridge
Hinton
Mckimms Corner
Morpeth
Morpeth
N
Bridges
Major Towns
OEH 2016 Survey
OEH 2011/2012 Survey
HR Flood Study Topography
PR Flood Study Levee Topography
Study Area
Km
0
0.25
0.5
1
1.5
2
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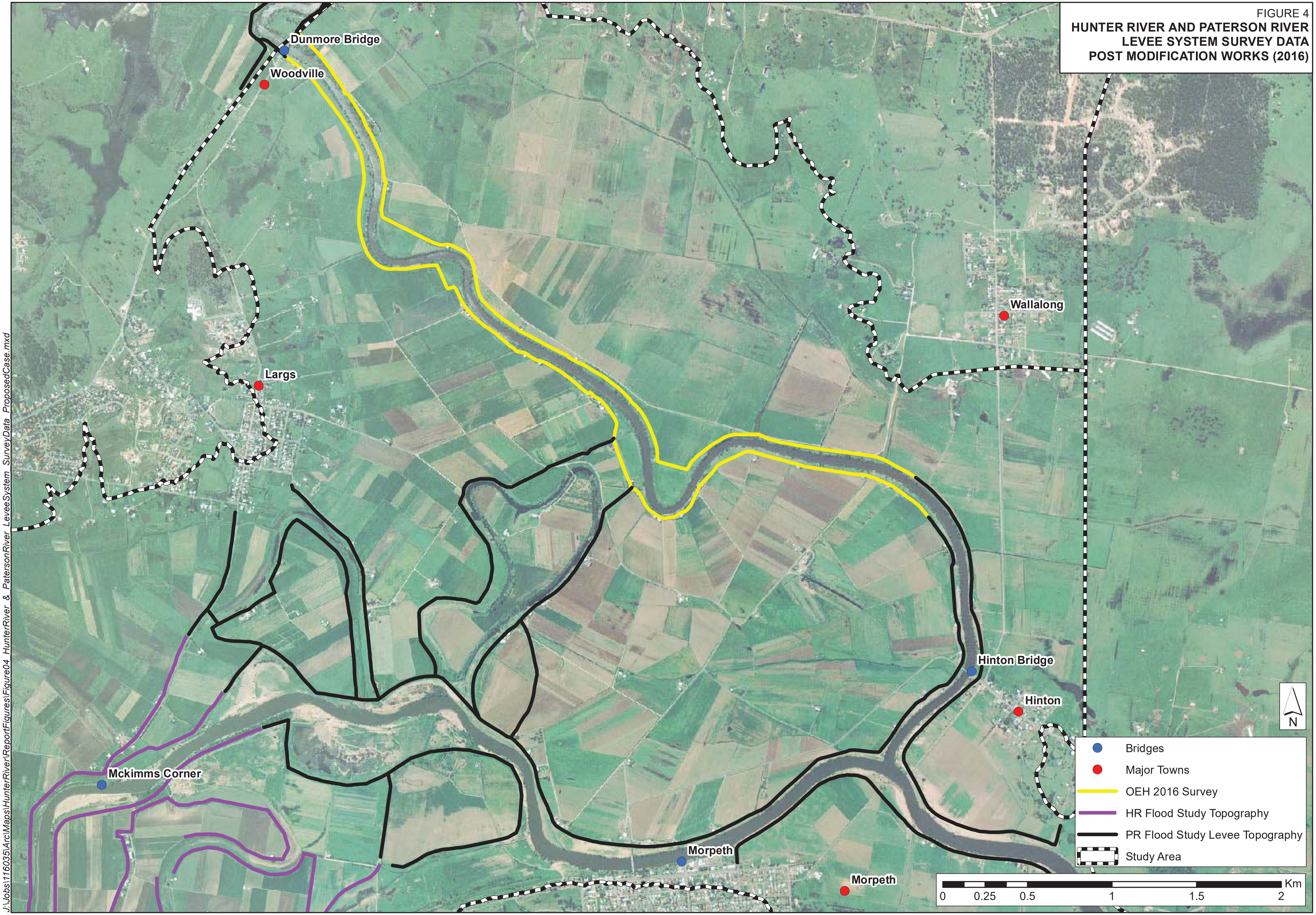

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FIGURE 5
PATERSON RIVER LEVEE PROFILE
BASE CASE vs POST MODIFICATION WORKS
vs 1967 DESIGN

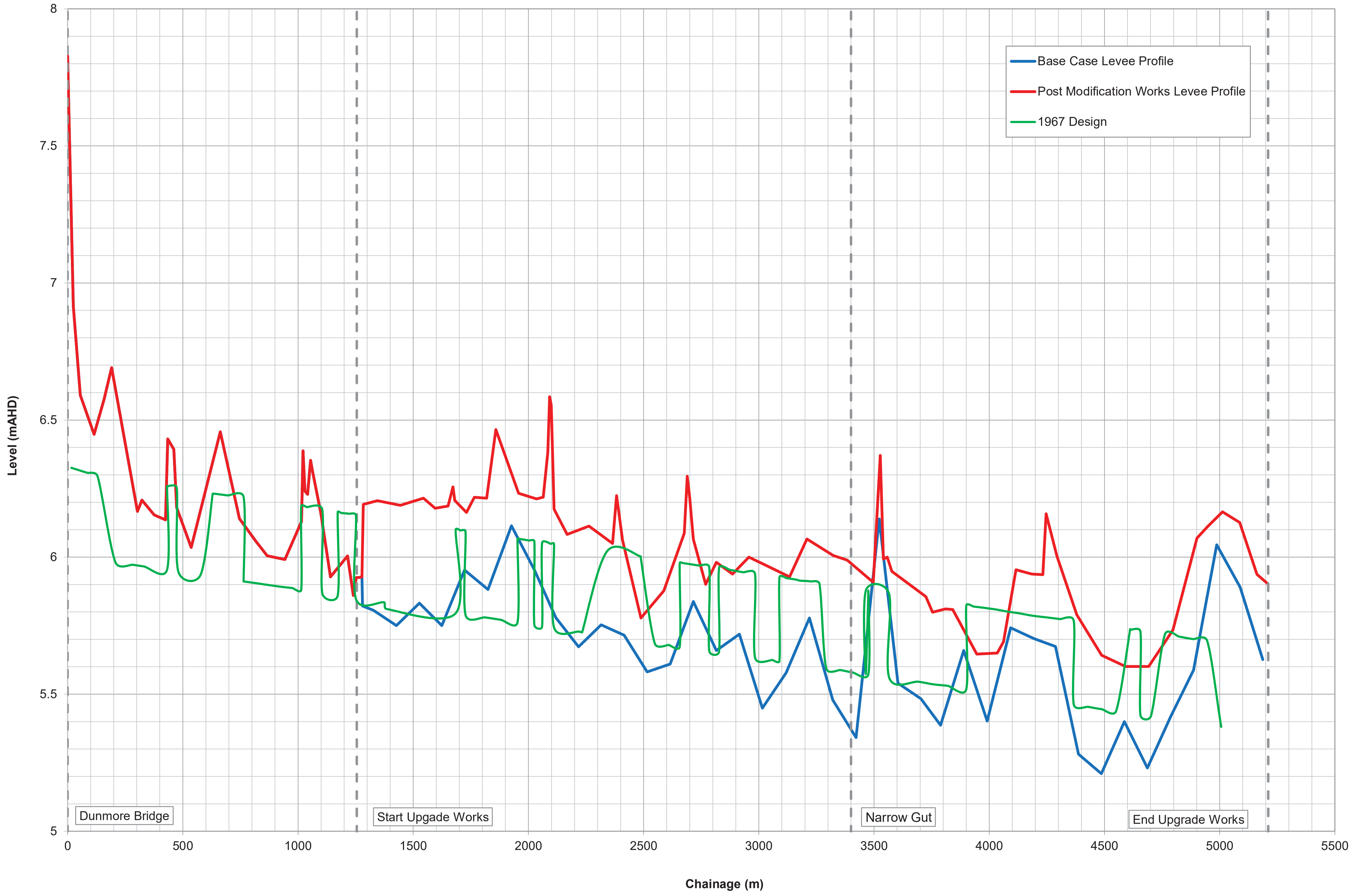

FIGURE 6
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 20% AEP EVENT
PRFS INFLOW

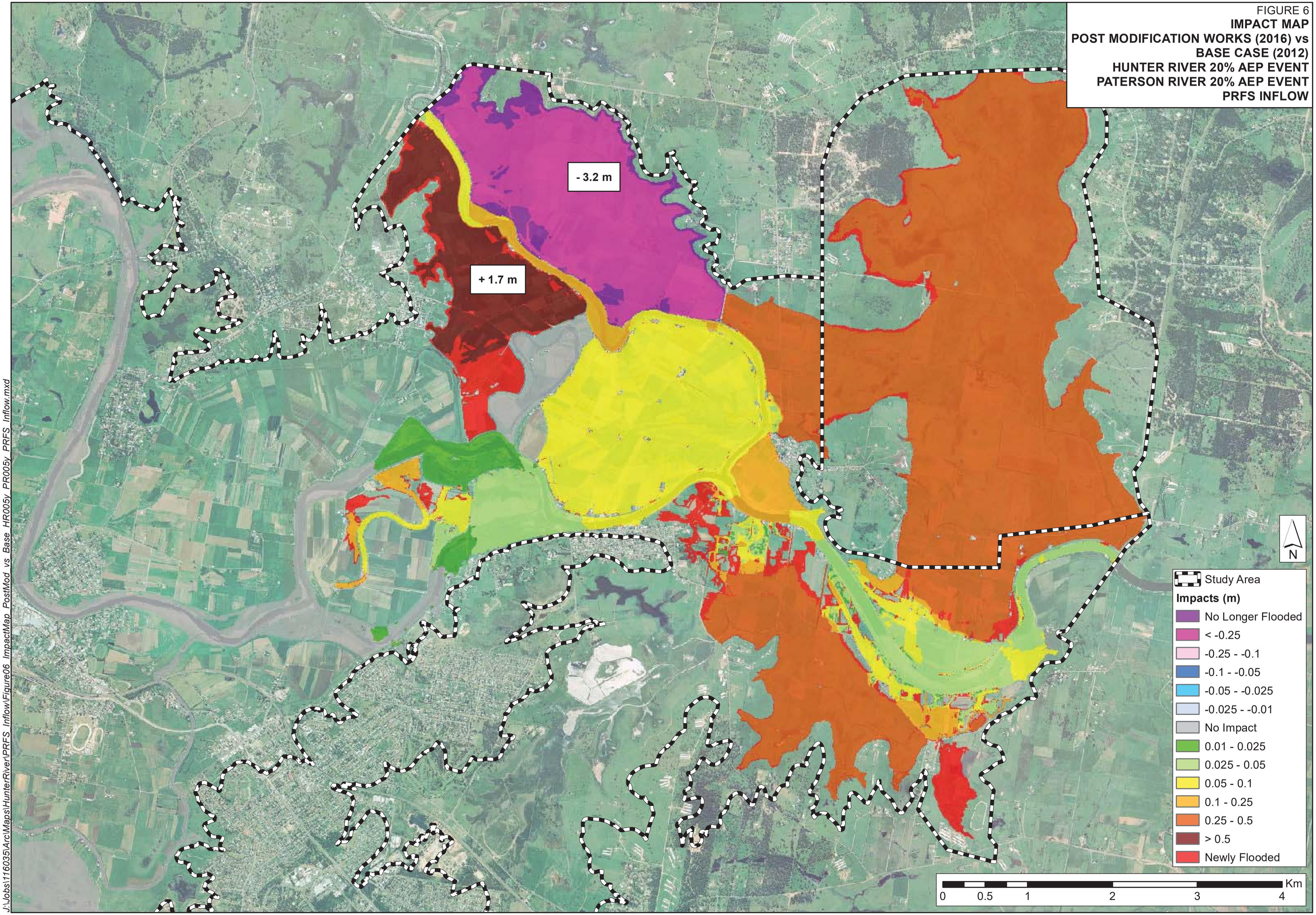

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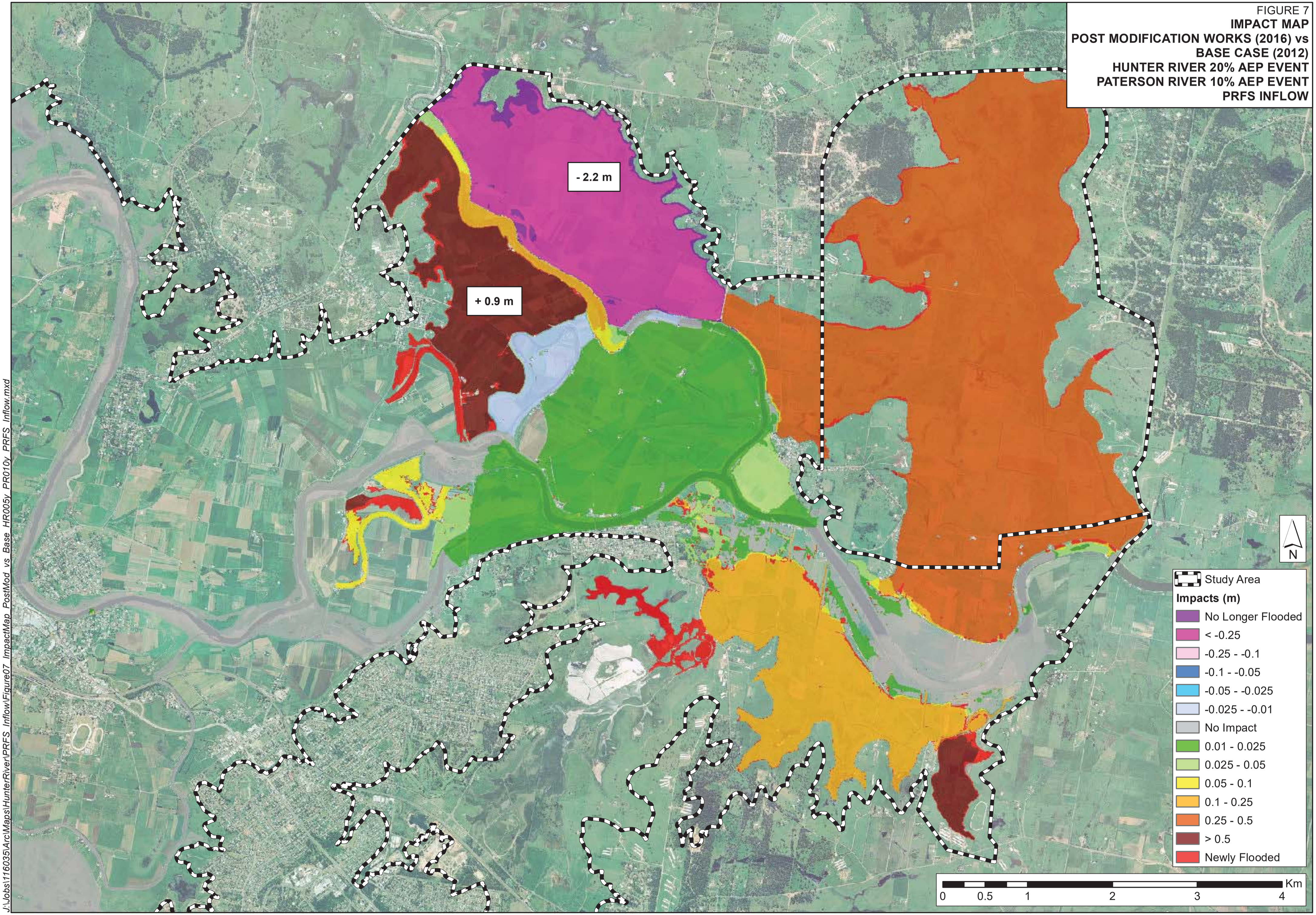
FIGURE 7
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW



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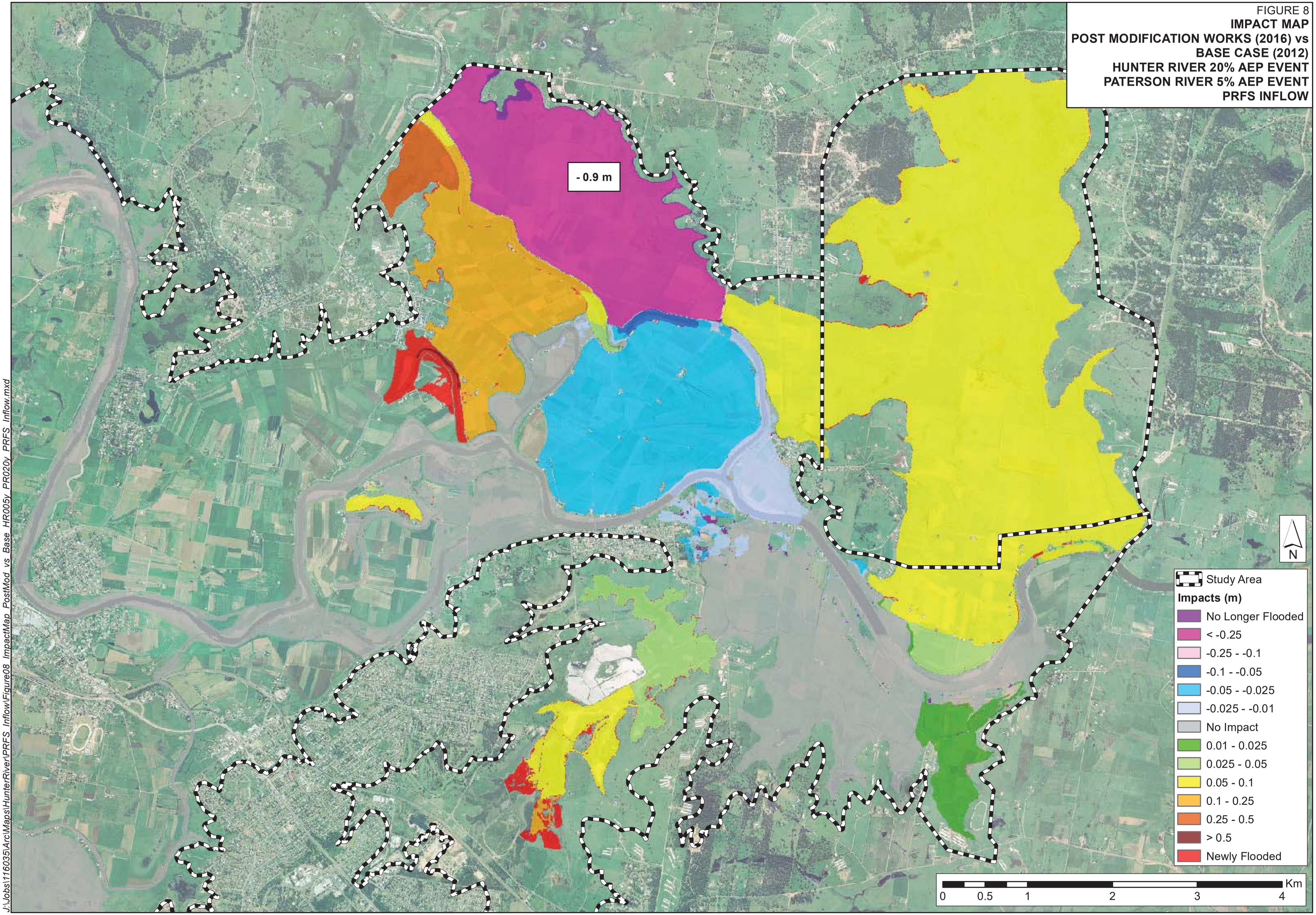
FIGURE 8
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 5% AEP EVENT
PRFS INFLOW
- 0.9 m
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0
0.5
1
2
3
4
Km
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure08 ImpactMap PostMod vs Base HR005y PR020y PRFS Inflow.mxd

FIGURE 9
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 2% AEP EVENT
PRFS INFLOW

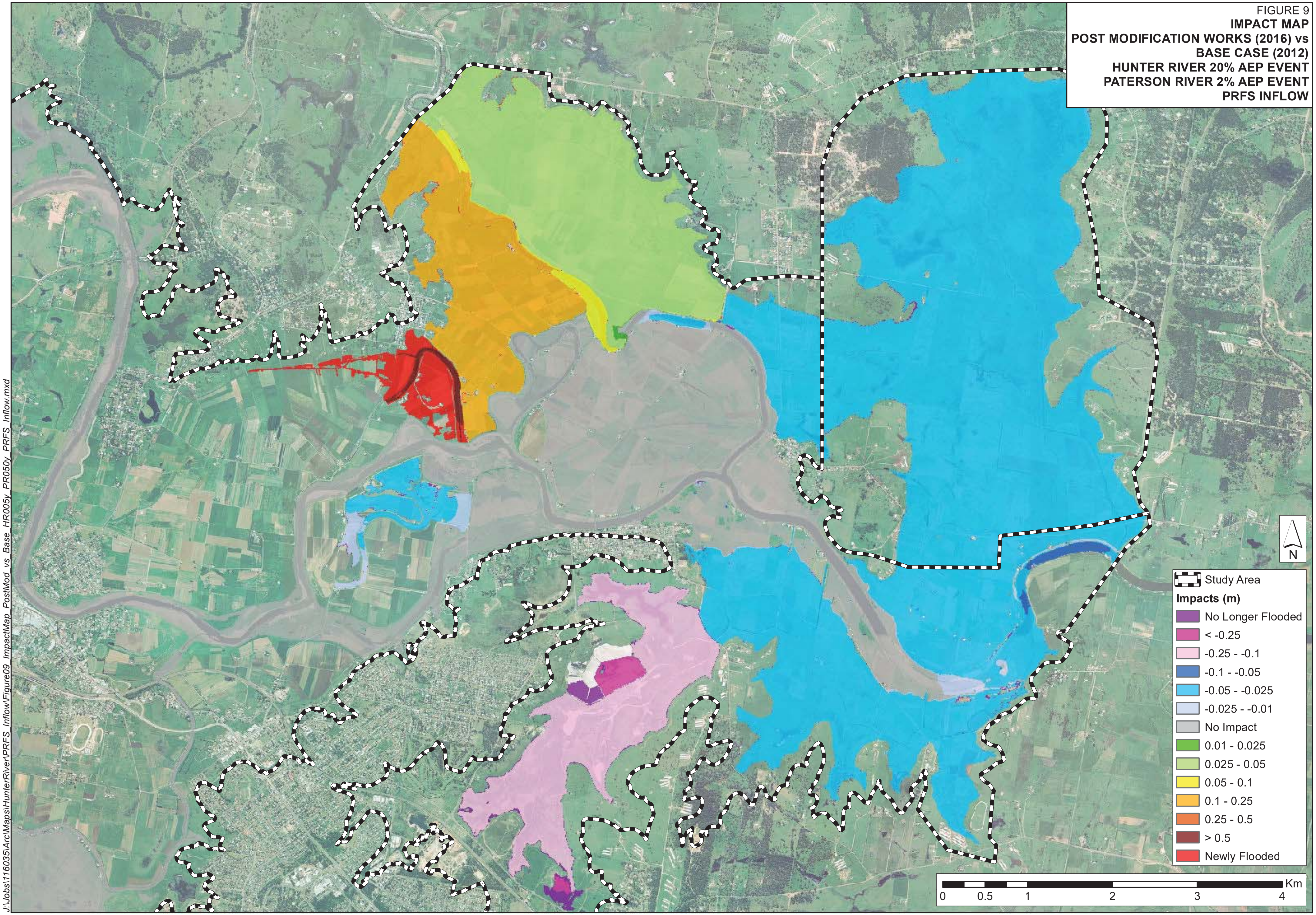

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FIGURE 10
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 1% AEP EVENT
PRFS INFLOW

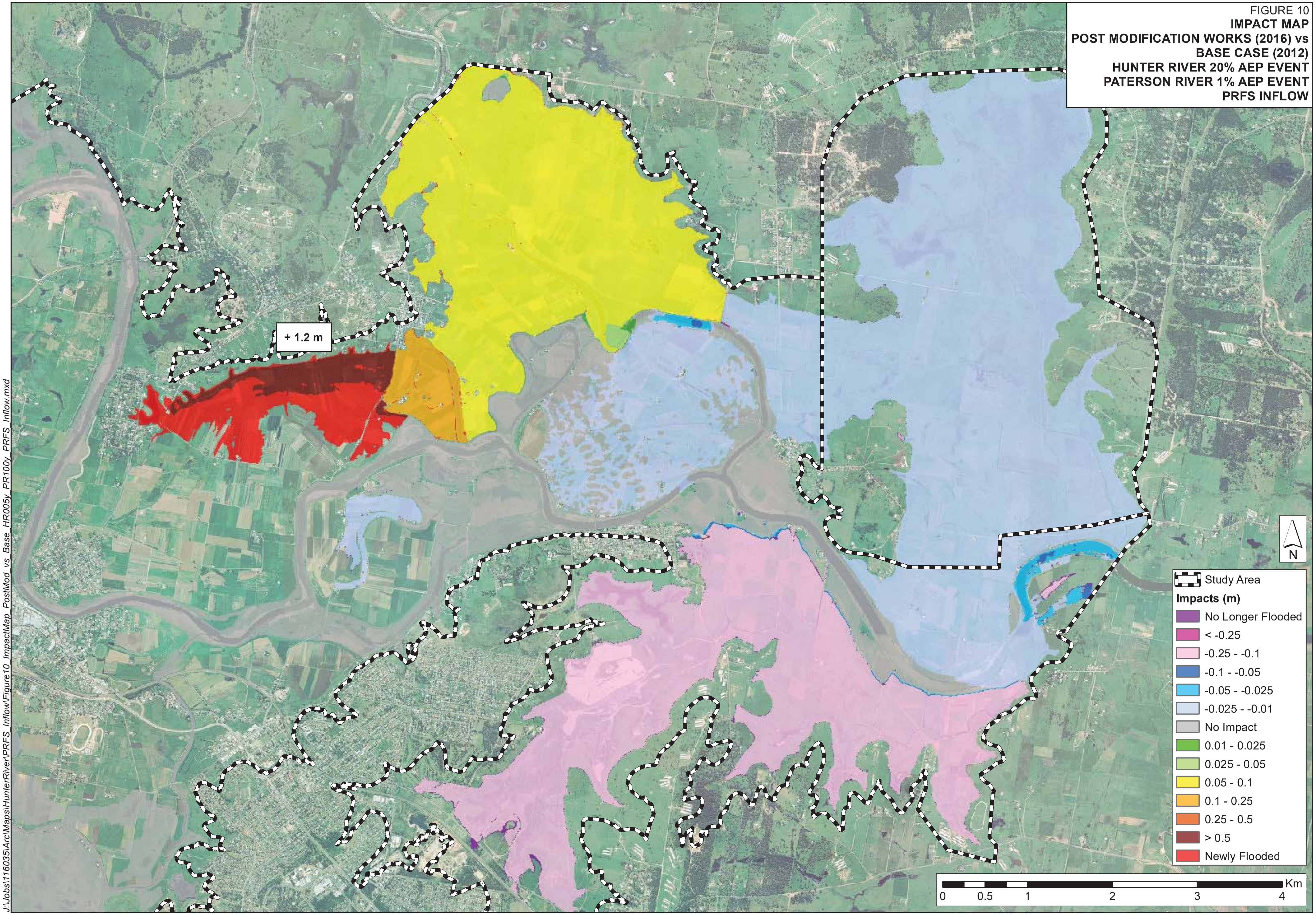

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FIGURE 11
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 10% AEP EVENT
PATERSON RIVER 20% AEP EVENT
PRFS INFLOW

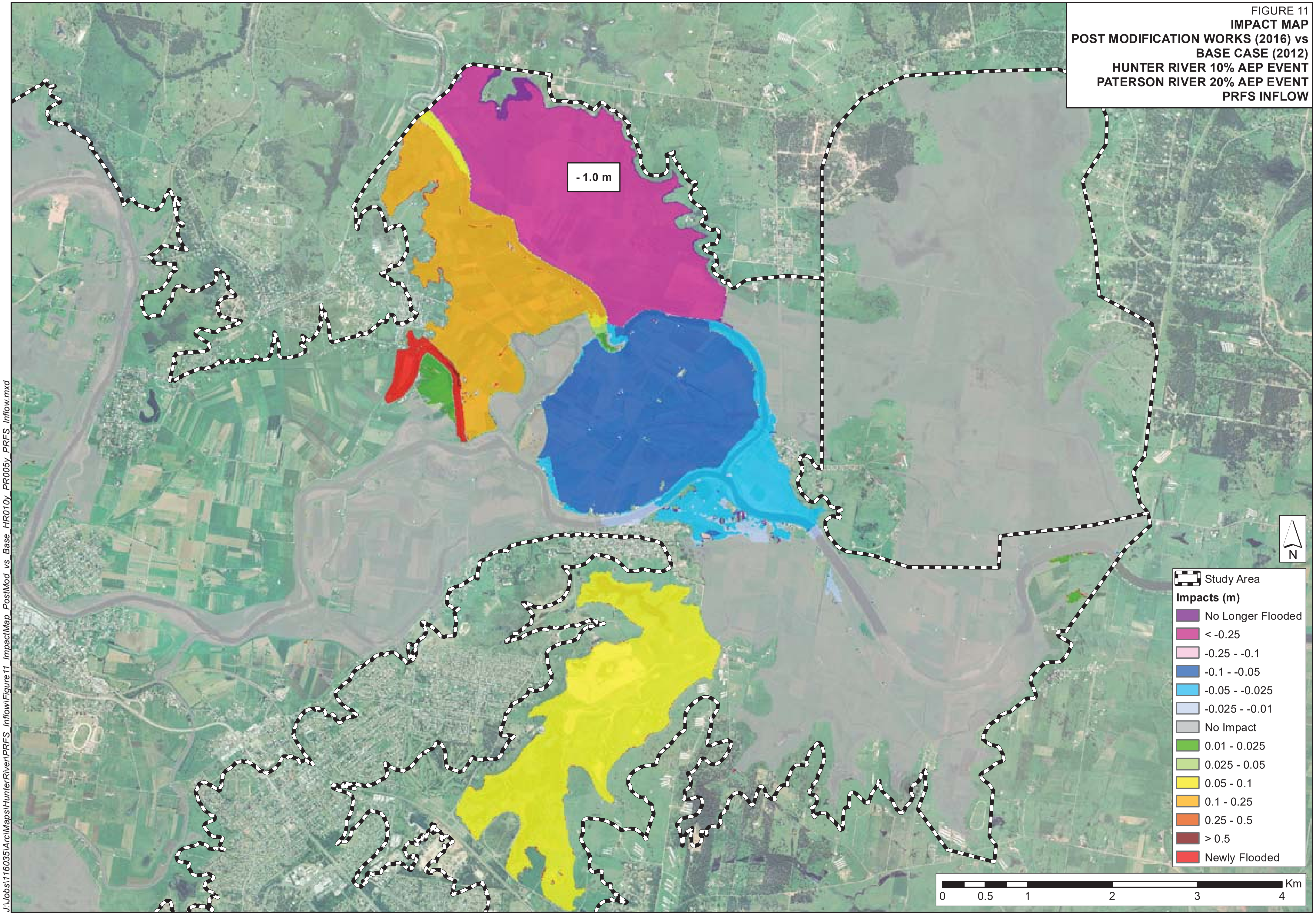

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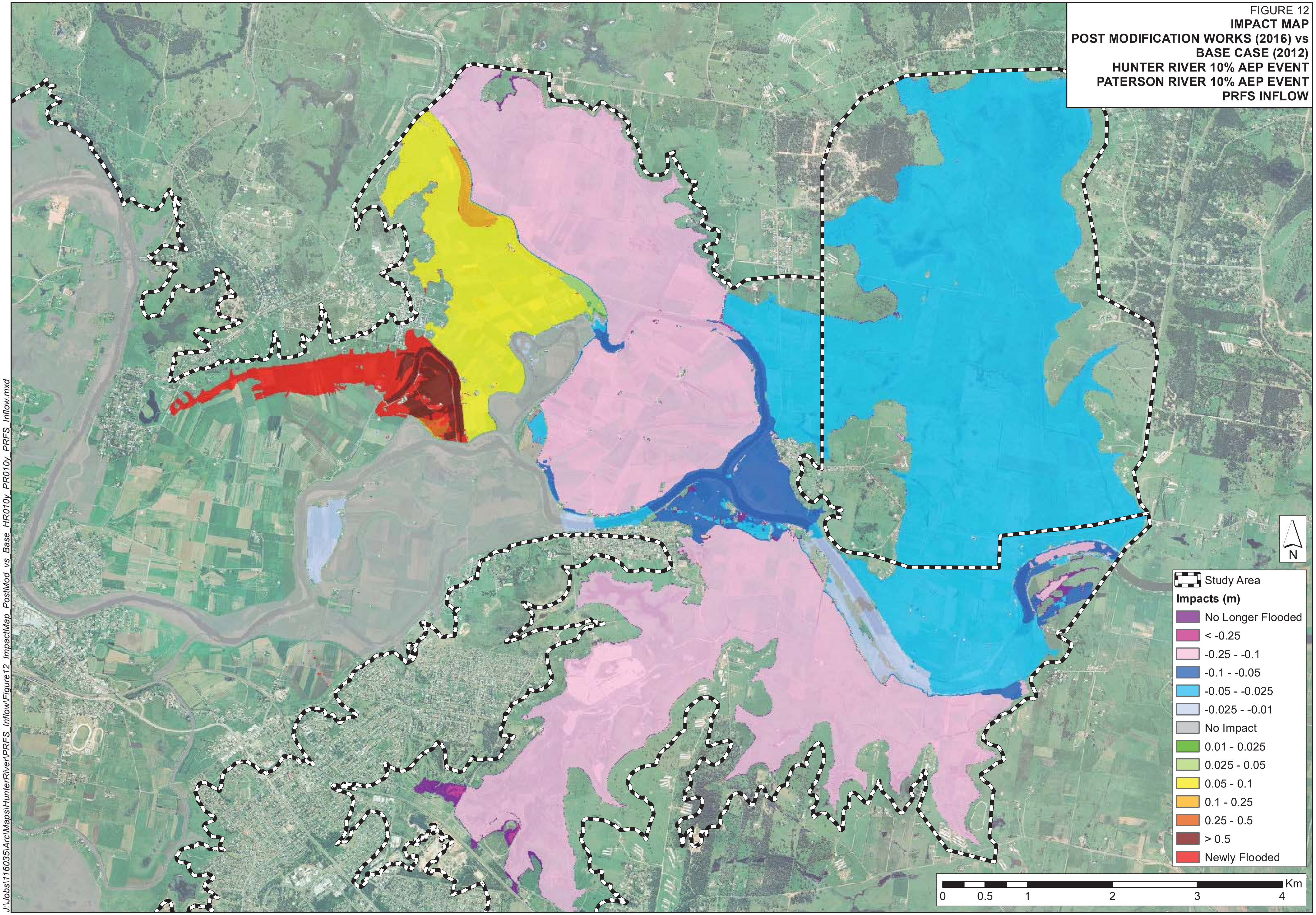
FIGURE 12
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 10% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW



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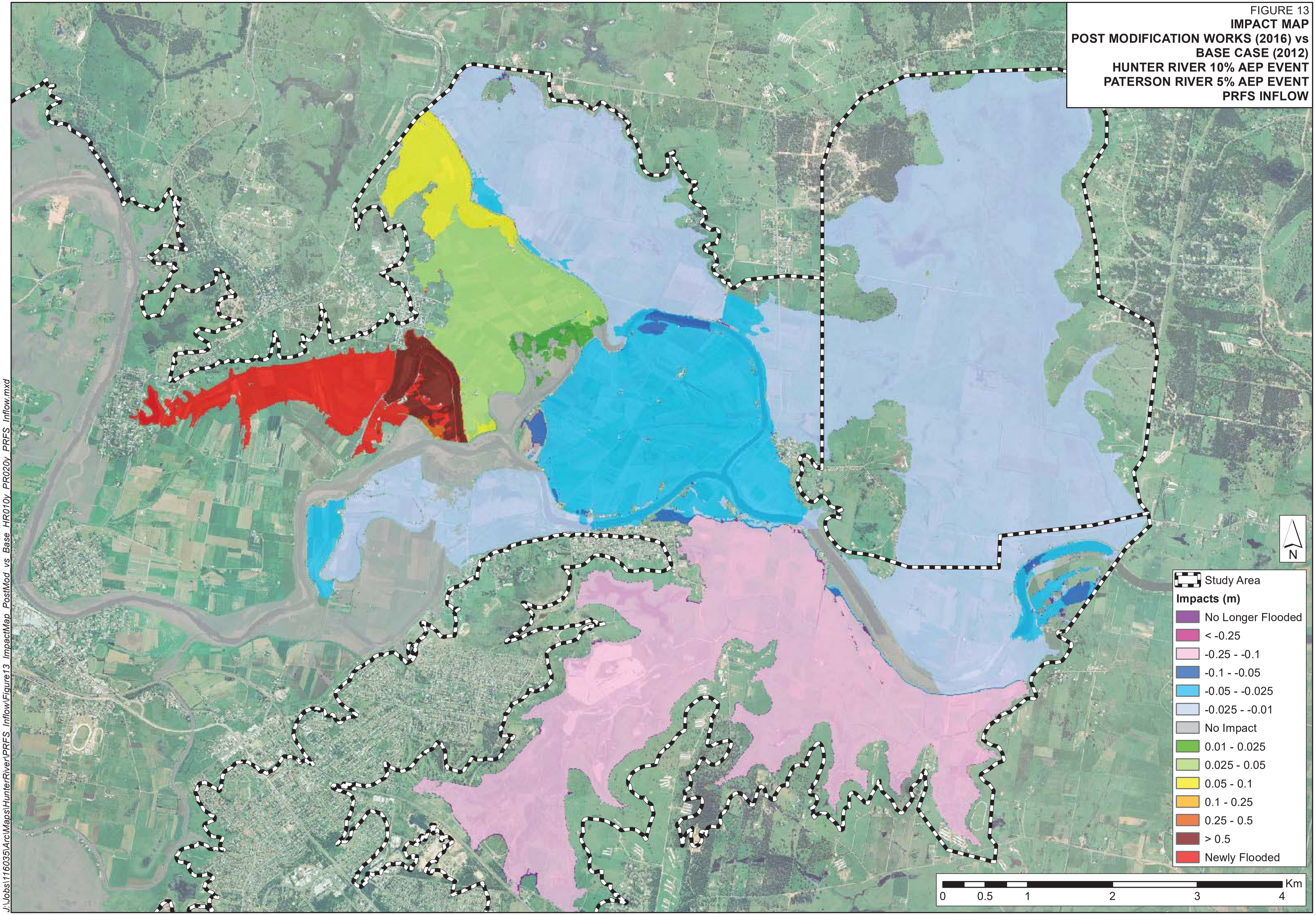
FIGURE 13
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 10% AEP EVENT
PATERSON RIVER 5% AEP EVENT
PRFS INFLOW
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0 0.5 1 2 3 4 Km
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure13 ImpactMap PostMod vs Base HR010y PR020y PRFS Inflow.mxd

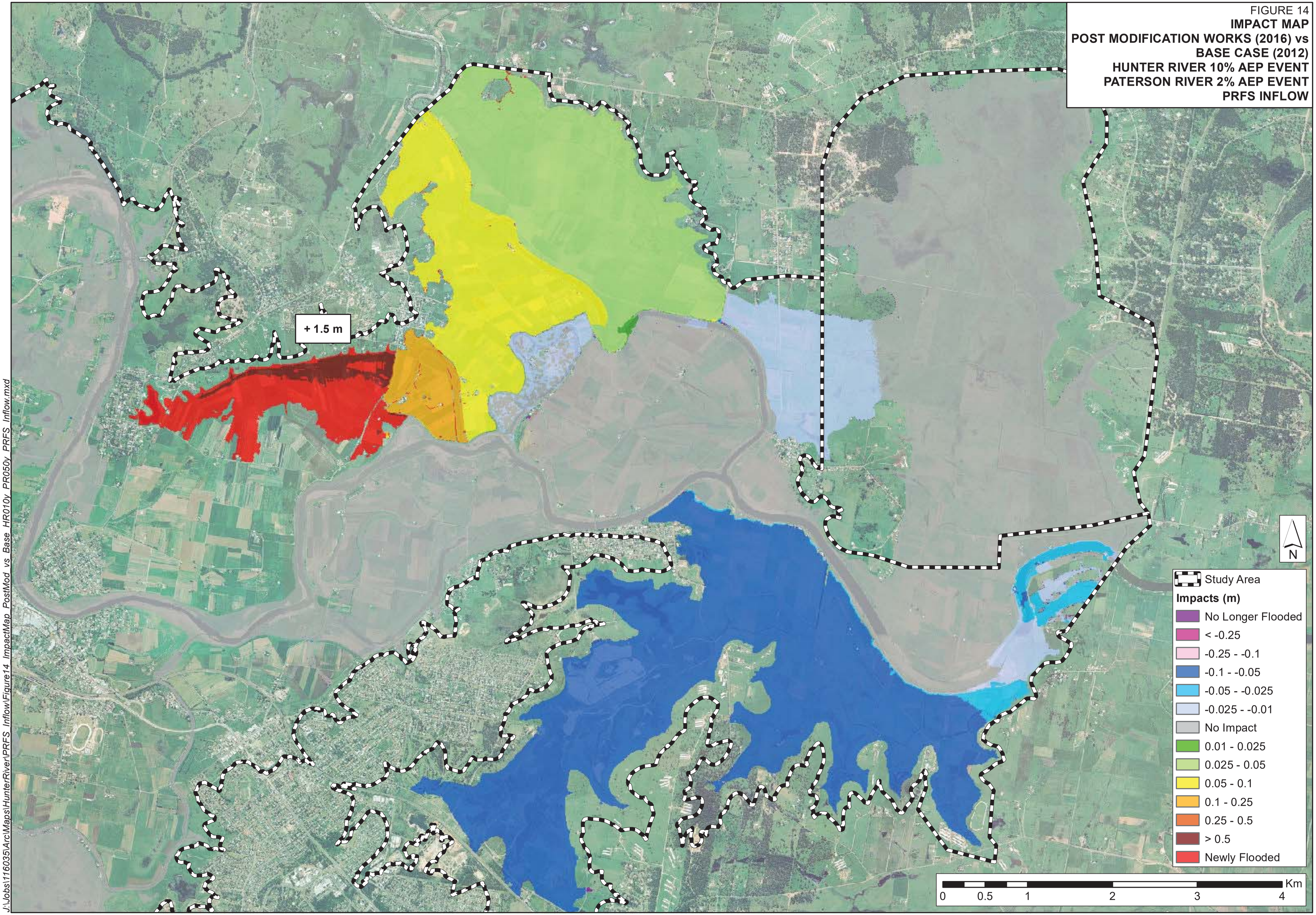
FIGURE 14
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 10% AEP EVENT
PATERSON RIVER 2% AEP EVENT
PRFS INFLOW
+ 1.5 m
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0
0.5
1
2
3
4
Km
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure14 ImpactMap PostMod vs Base HR010y PR050y PRFS Inflow.mxd

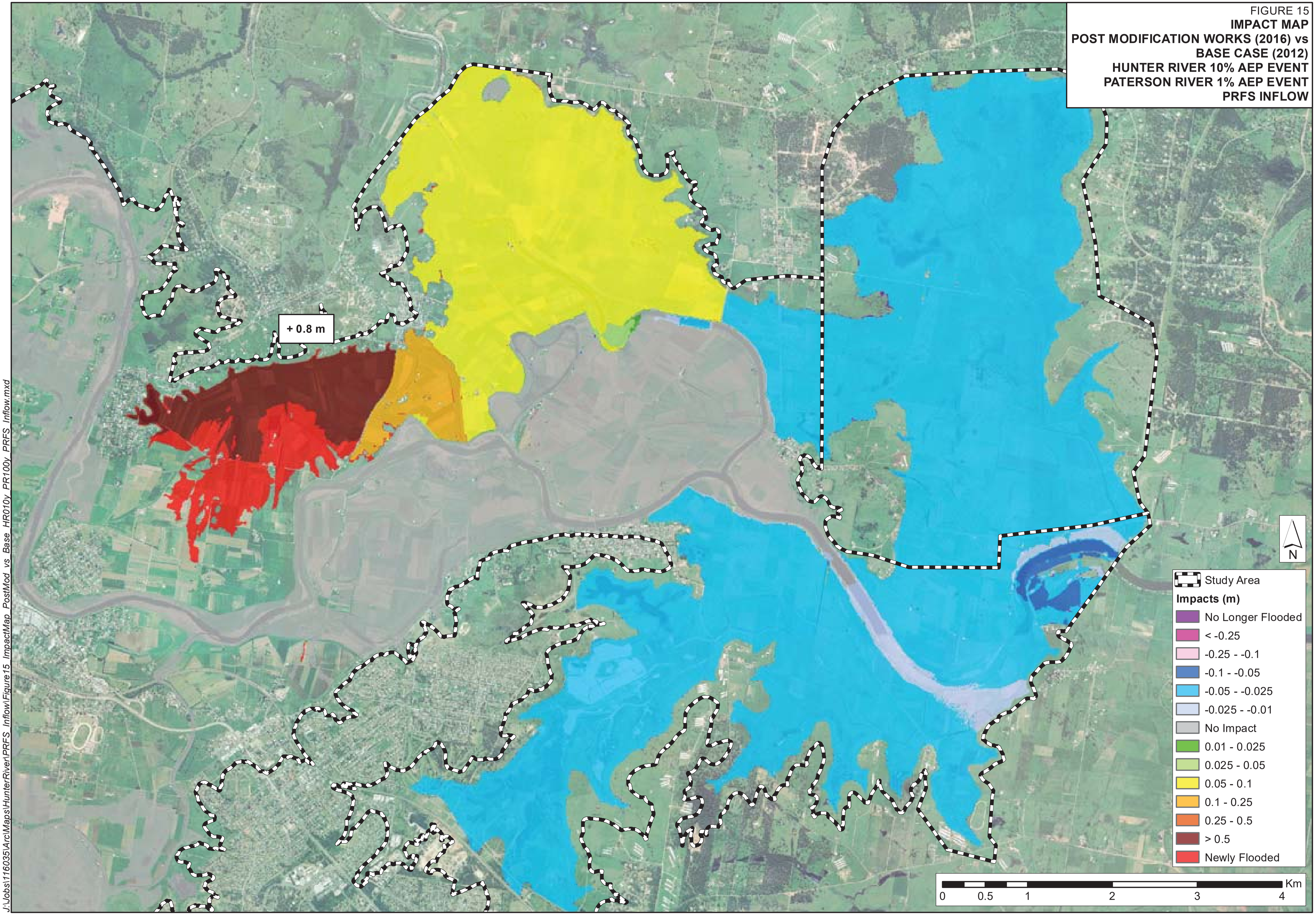

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FIGURE 16
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 5% AEP EVENT
PATERSON RIVER 20% AEP EVENT
PRFS INFLOW

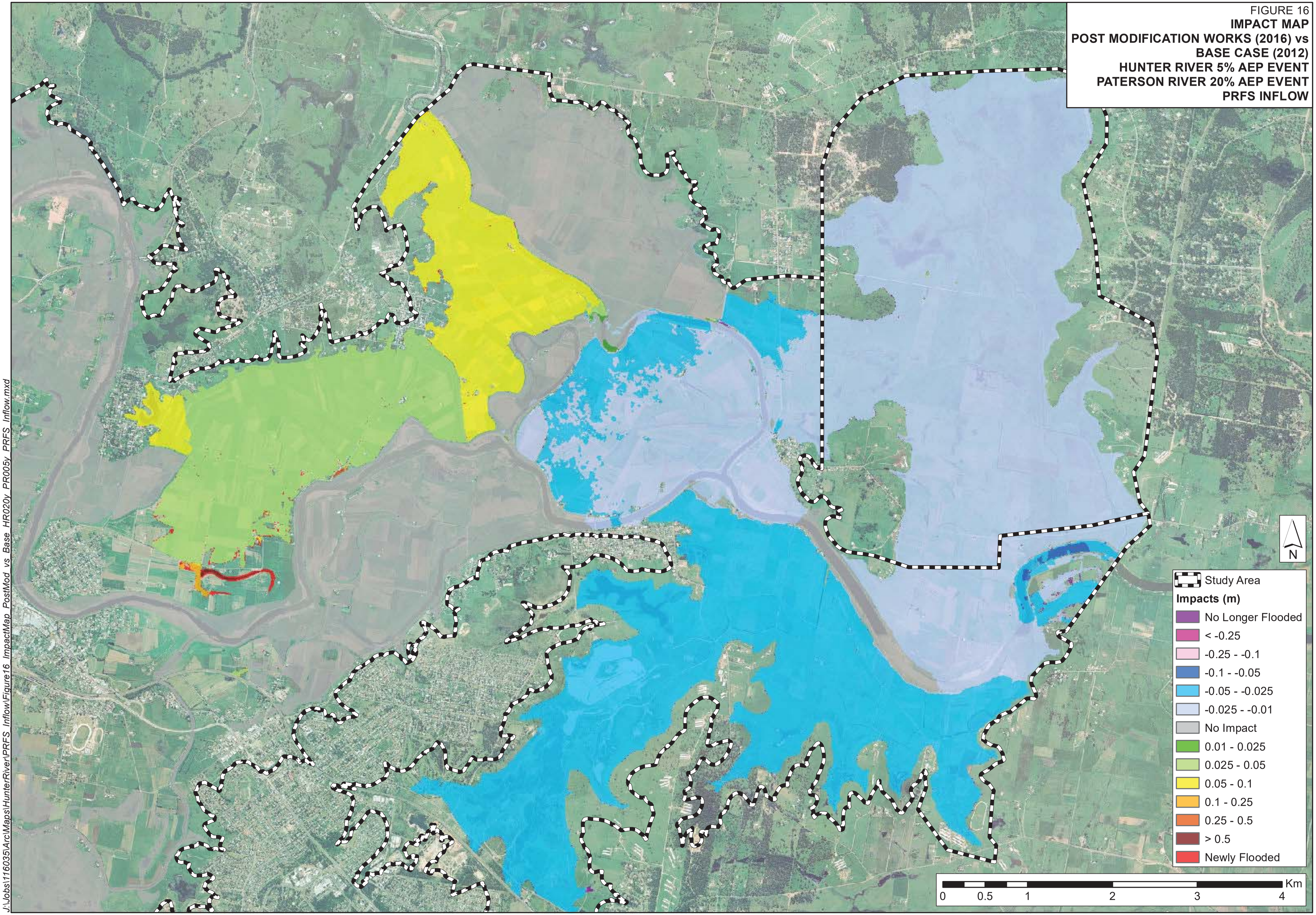

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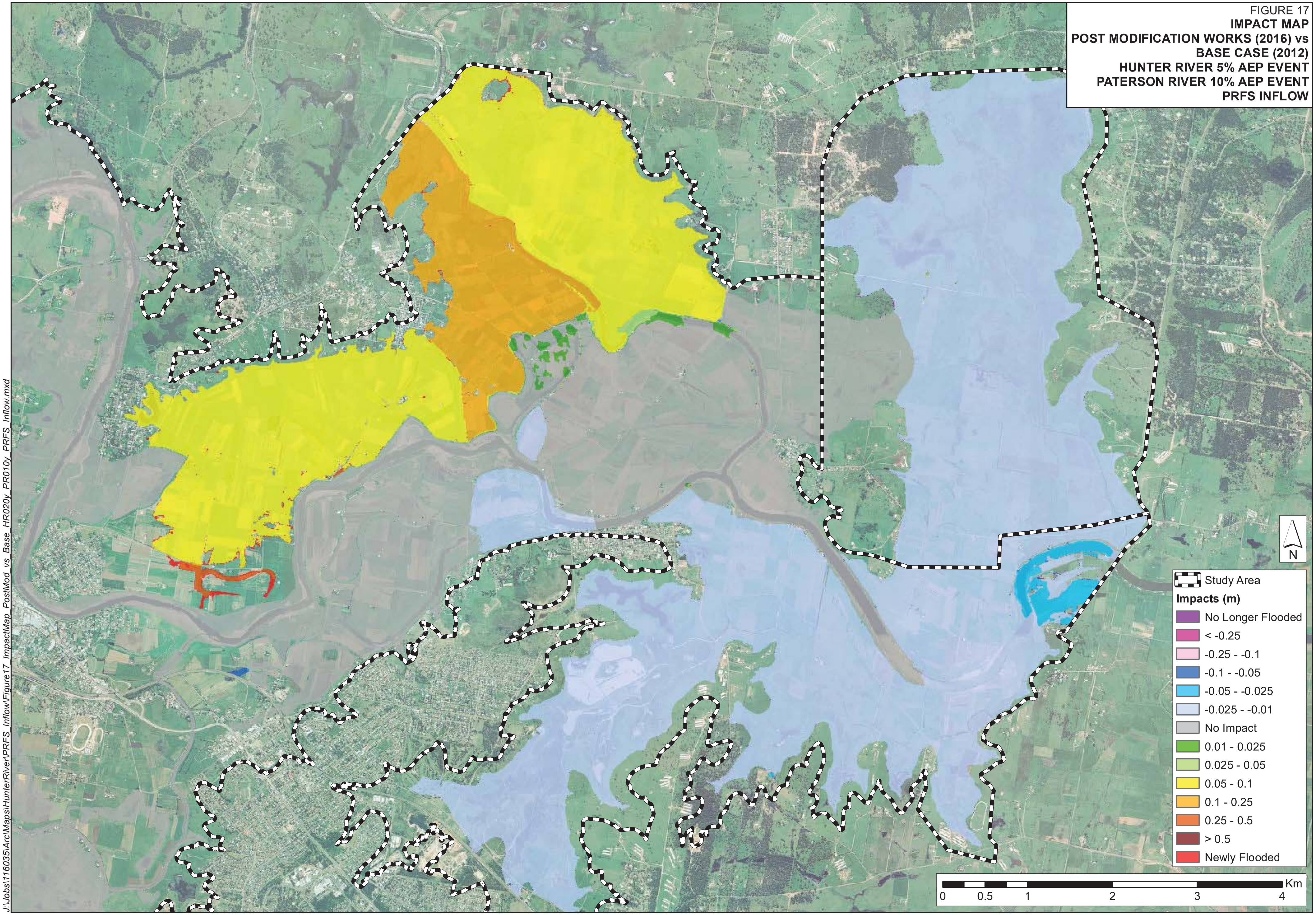
FIGURE 17
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 5% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW



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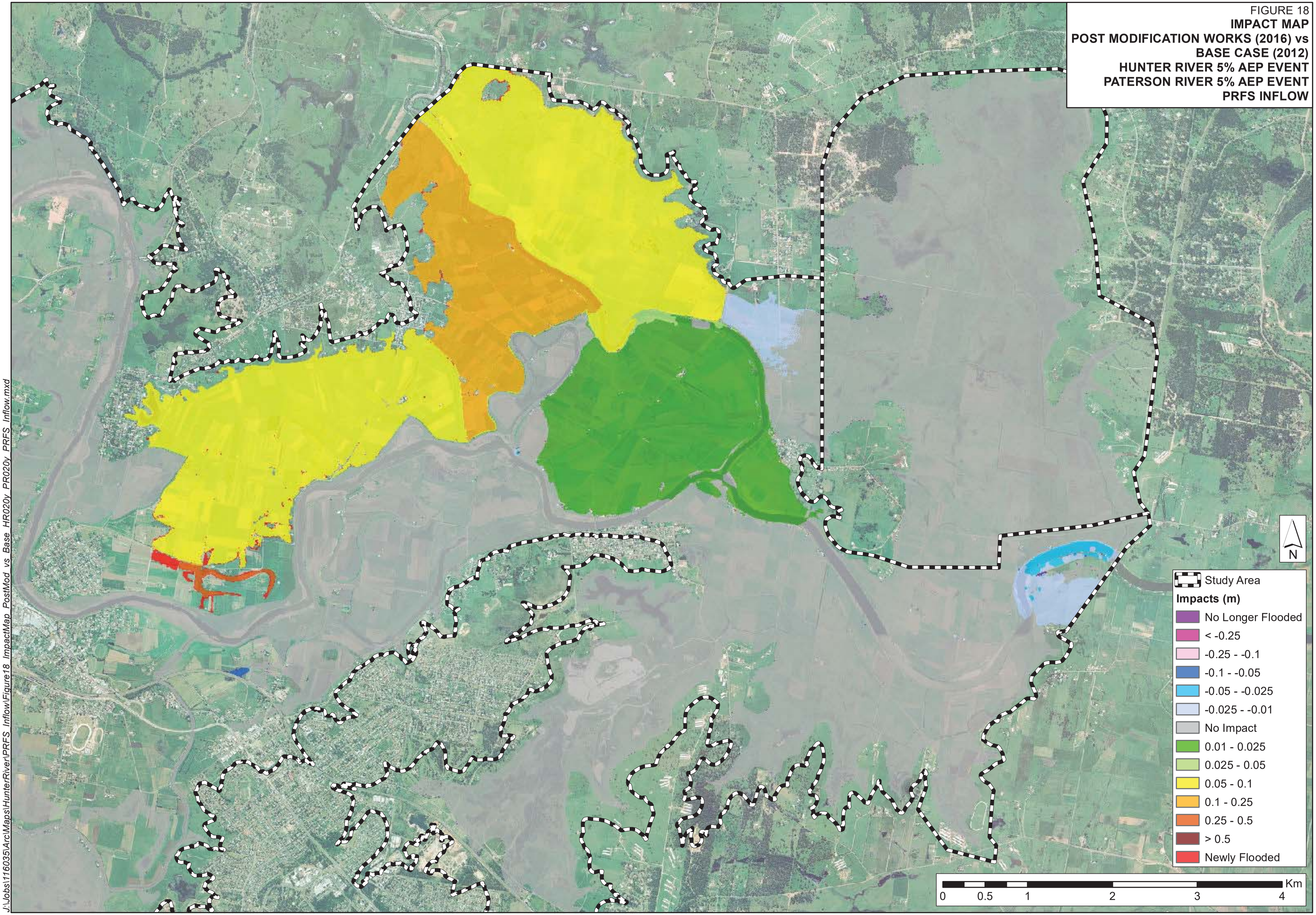


FIGURE 18
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 5% AEP EVENT
PATERSON RIVER 5% AEP EVENT
PRFS INFLOW
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0
0.5
1
2
3
4
Km
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure18 ImpactMap PostMod vs Base HR020y PR020y PRFS Inflow.mxd

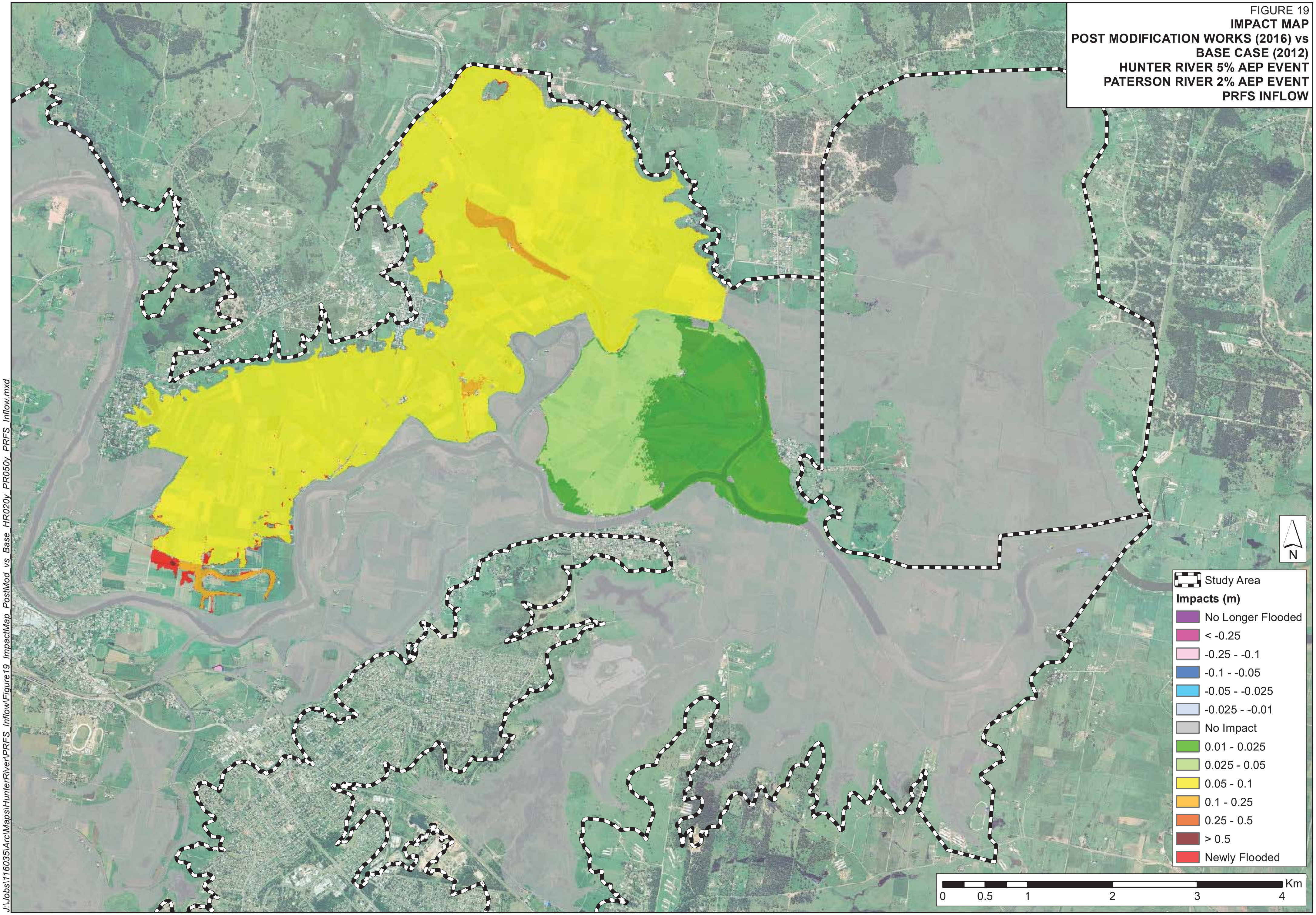
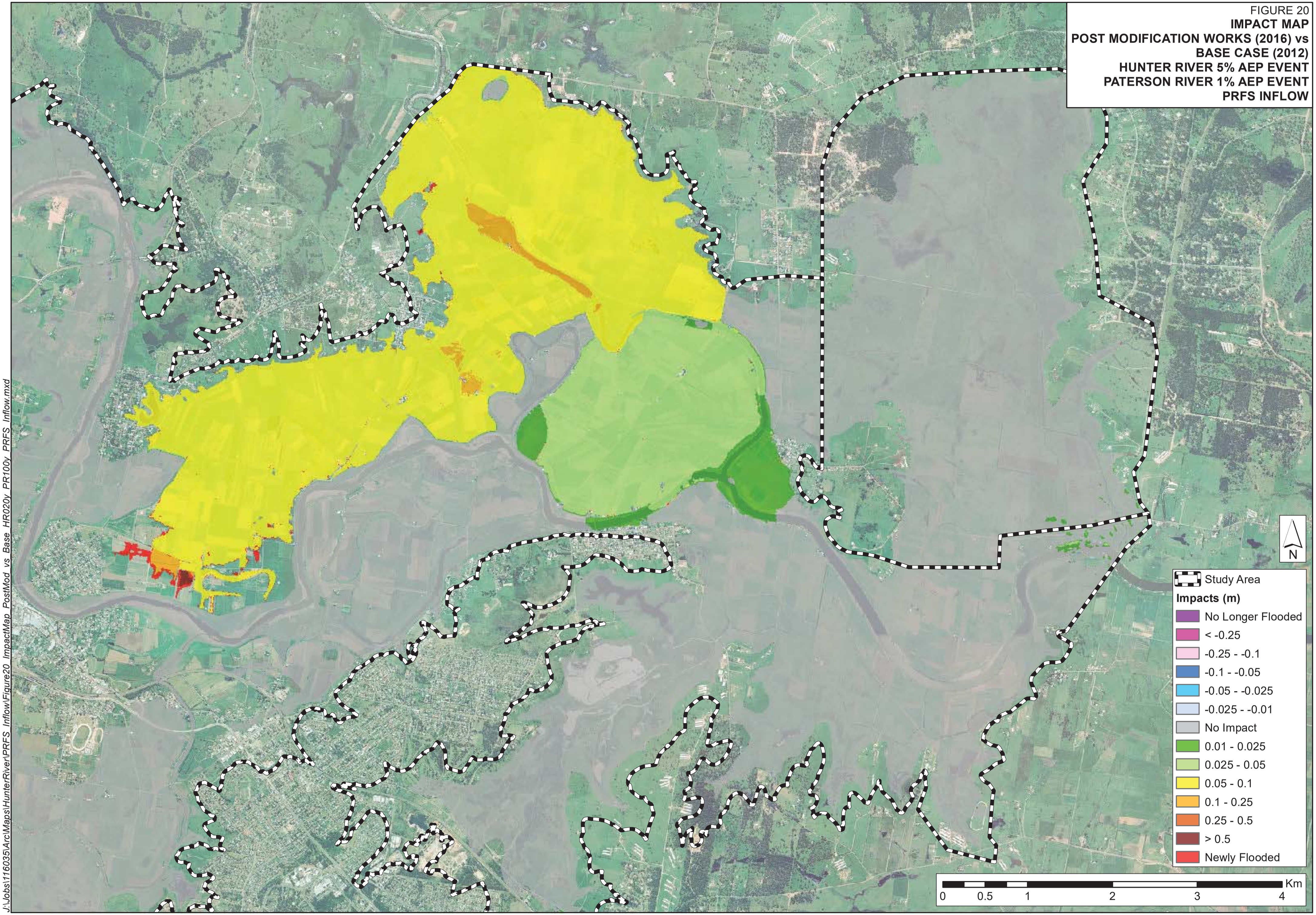


FIGURE 19
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 5% AEP EVENT
PATERSON RIVER 2% AEP EVENT
PRFS INFLOW
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0 0.5 1 2 3 4 Km
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS_Inflow\Figure19_ImpactMap_PostMod_vs_Base_HR020y_PR050y_PRFS_Inflow.mxd

FIGURE 20
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 5% AEP EVENT
PATERSON RIVER 1% AEP EVENT
PRFS INFLOW



J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure20_ImpactMap_PostMod_vs_Base_HR020y_PR100y_PRFS_Inflow.mxd

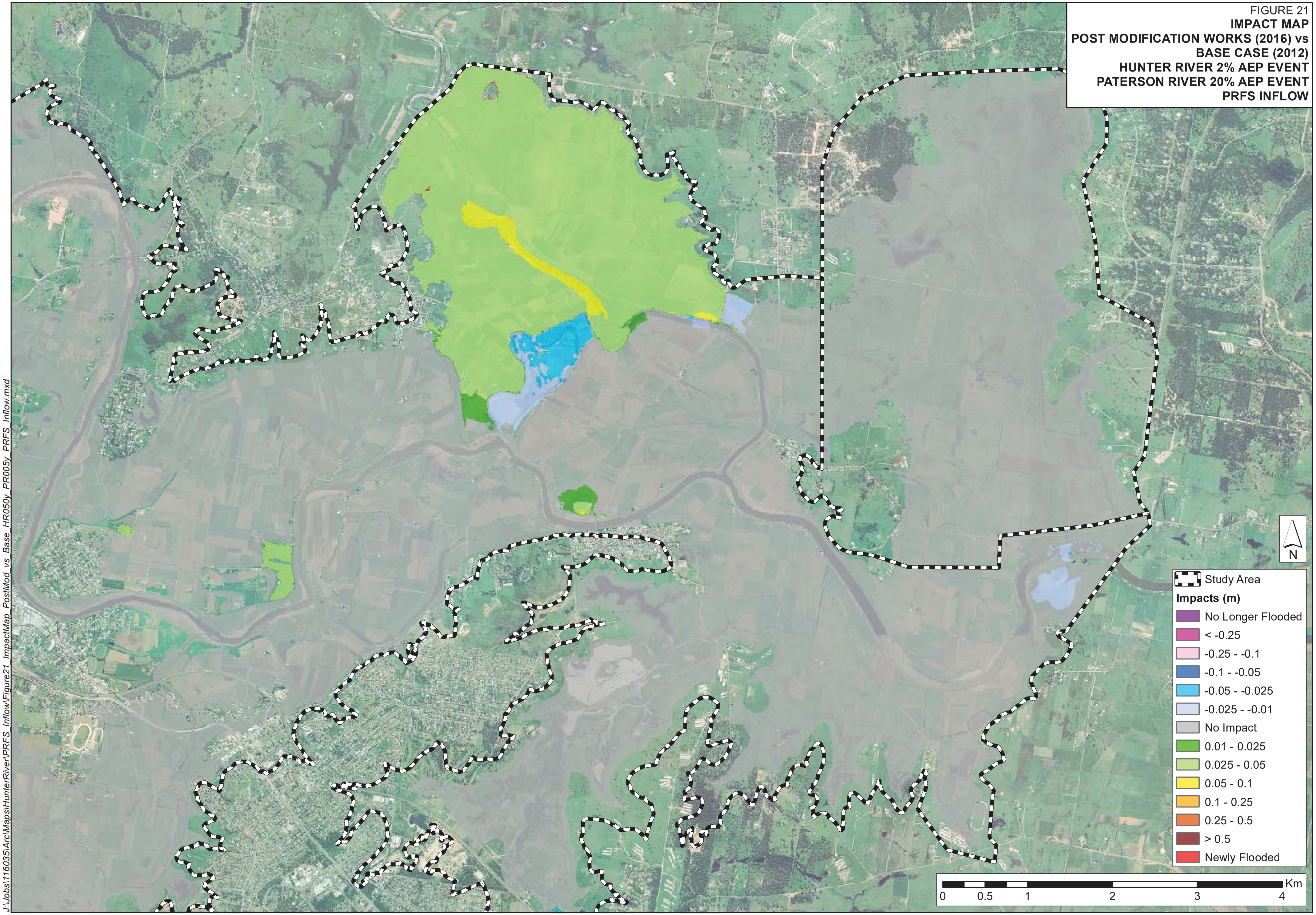
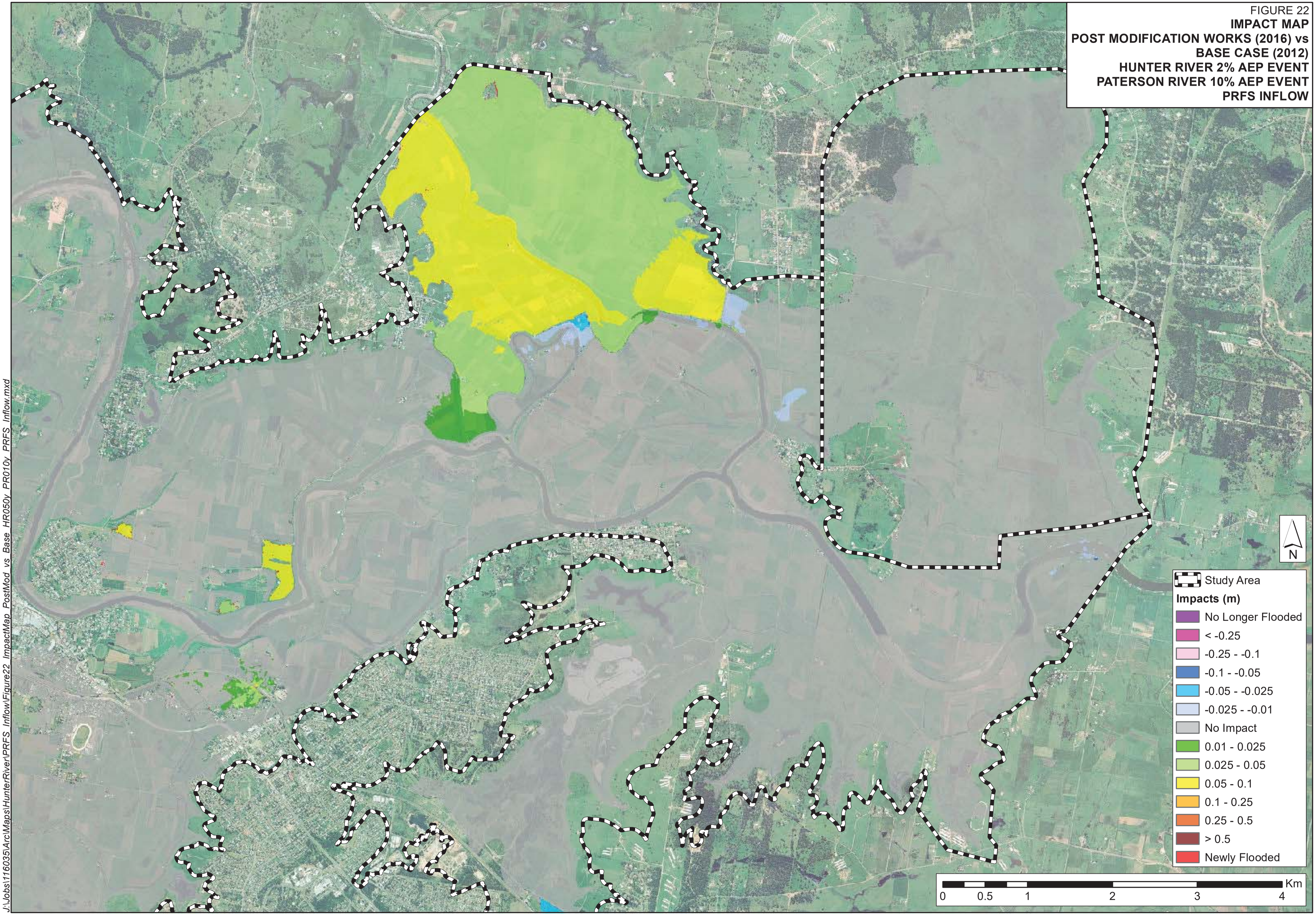


FIGURE 21
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 2% AEP EVENT
PATERSON RIVER 20% AEP EVENT
PRFS INFLOW

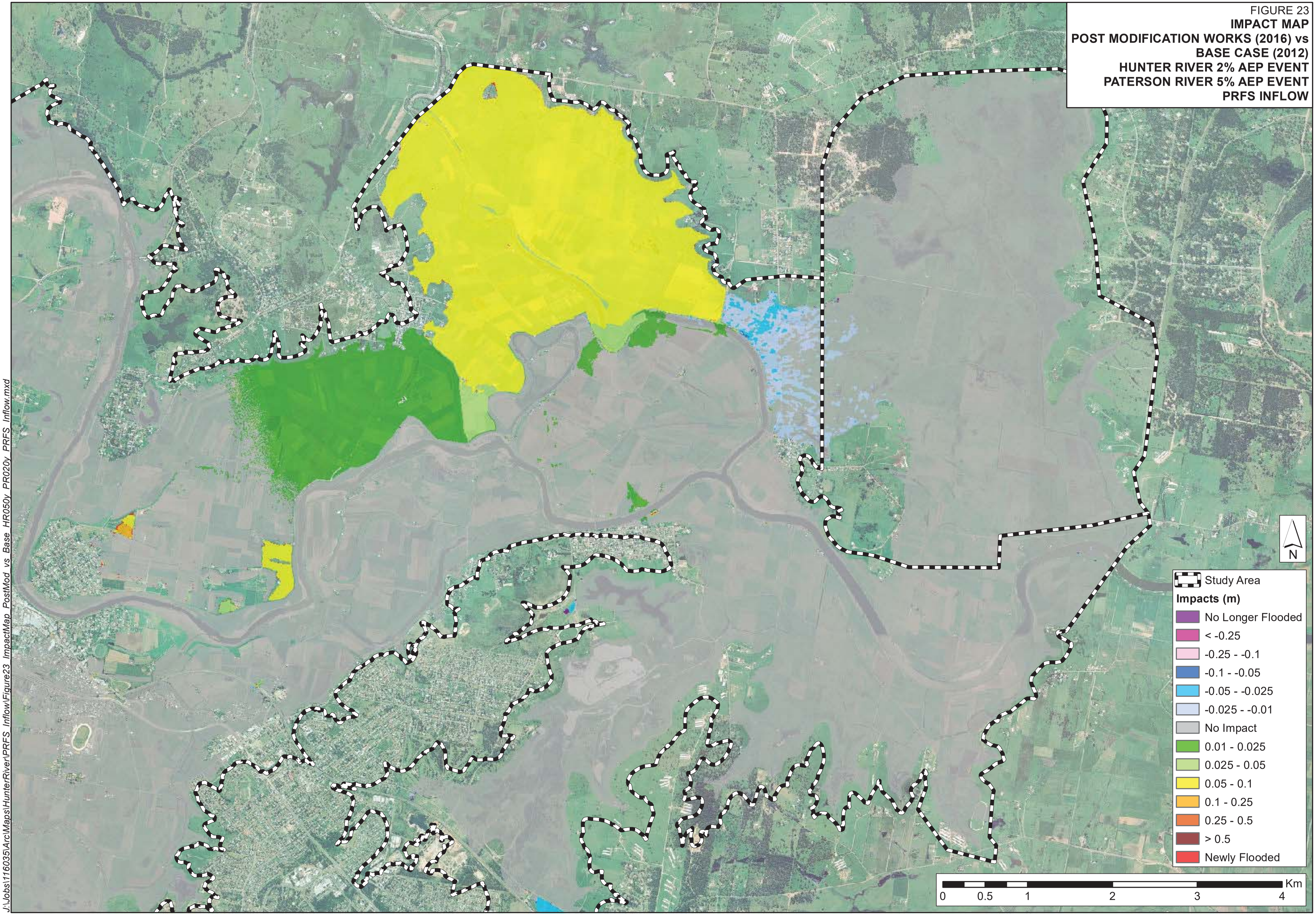
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure21_ImpactMap_PostMod_vs_Base_HR050y_PR005y_PRFS_Inflow.mxd

FIGURE 22
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 2% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW



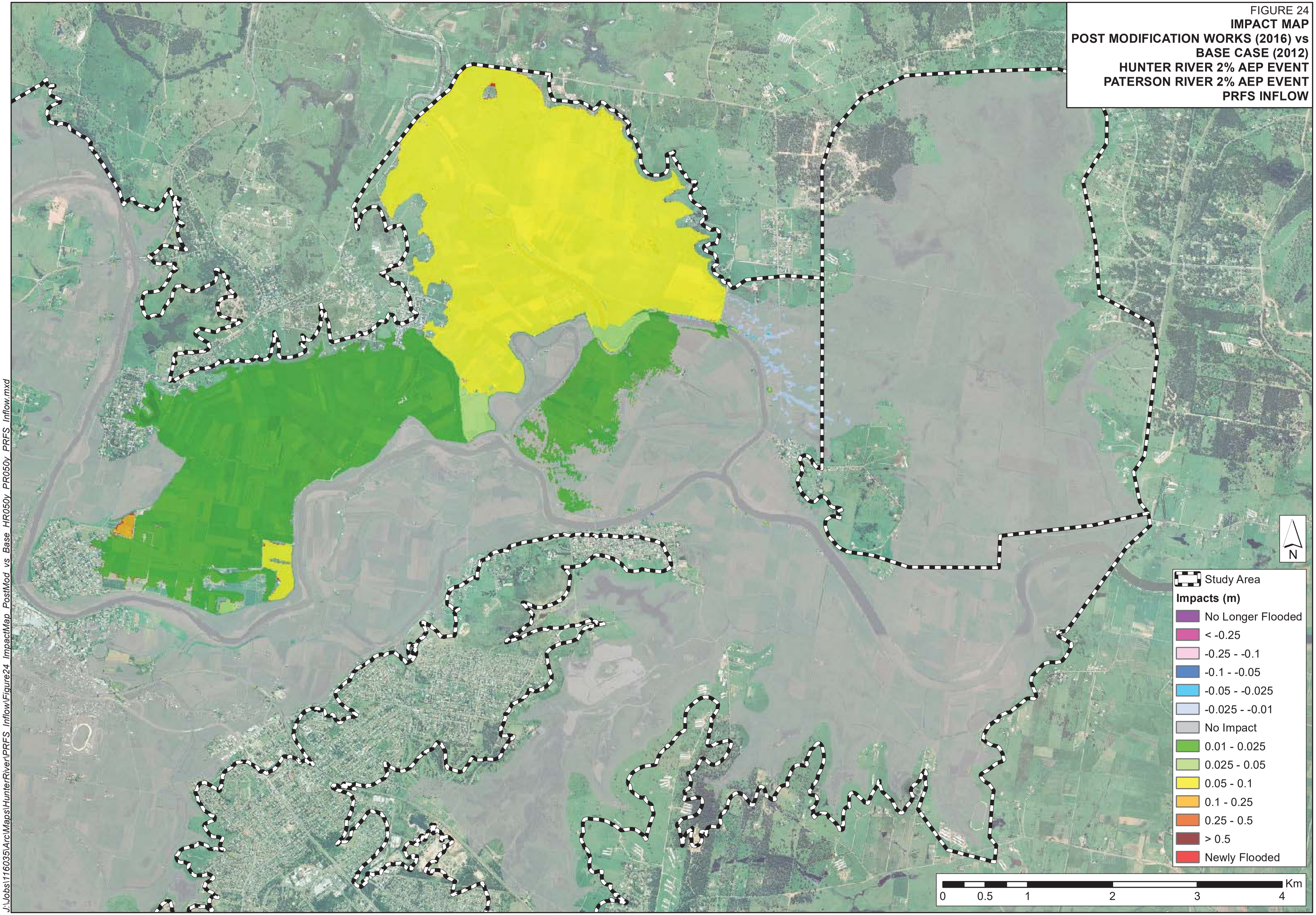
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure22 ImpactMap PostMod vs Base HR050y PR010y PRFS Inflow.mxd

FIGURE 23
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 2% AEP EVENT
PATERSON RIVER 5% AEP EVENT
PRFS INFLOW



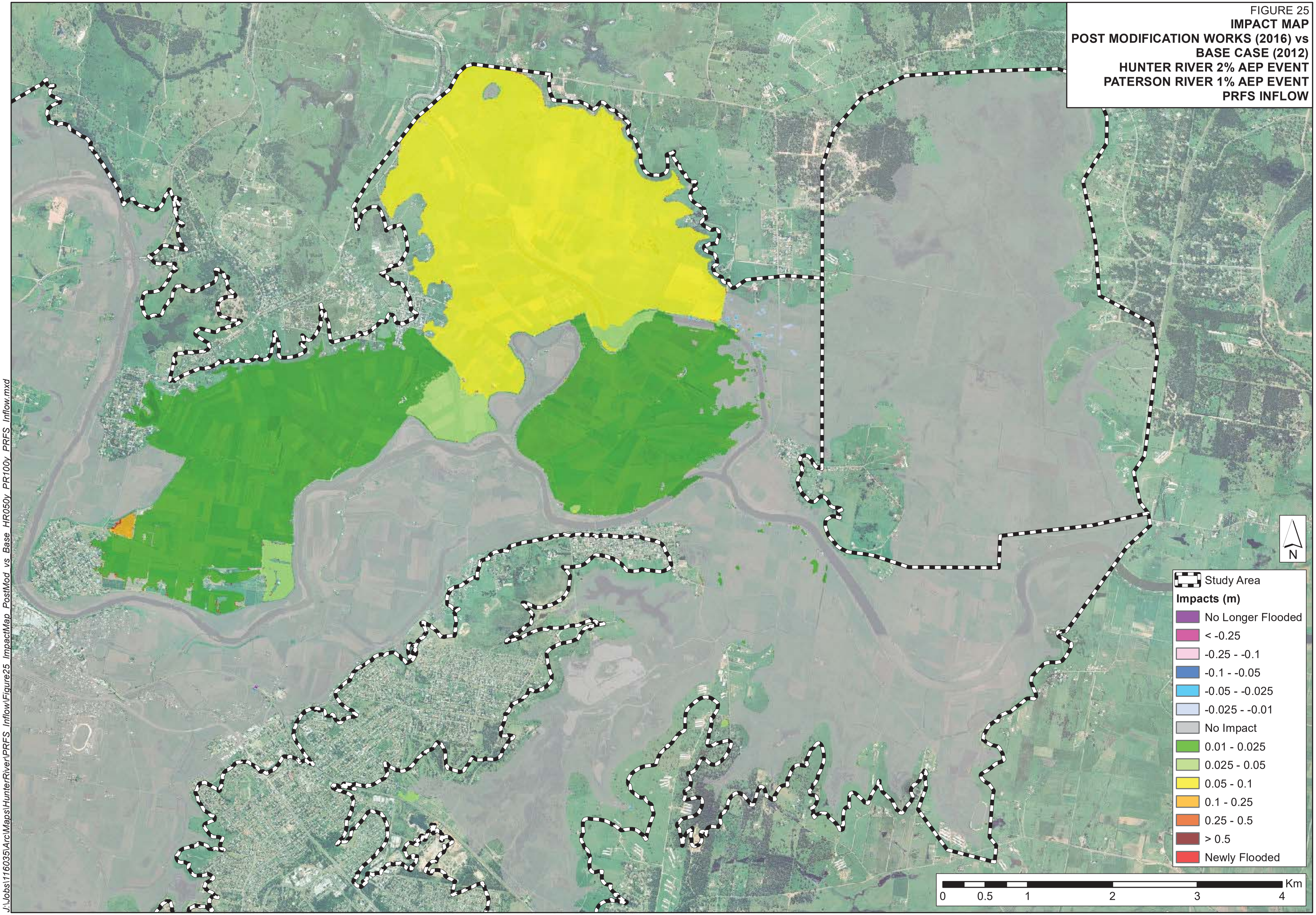
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure23_ImpactMap_PostMod_vs_Base_HR050y_PR020y_PRFS_Inflow.mxd

FIGURE 24
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 2% AEP EVENT
PATERSON RIVER 2% AEP EVENT
PRFS INFLOW



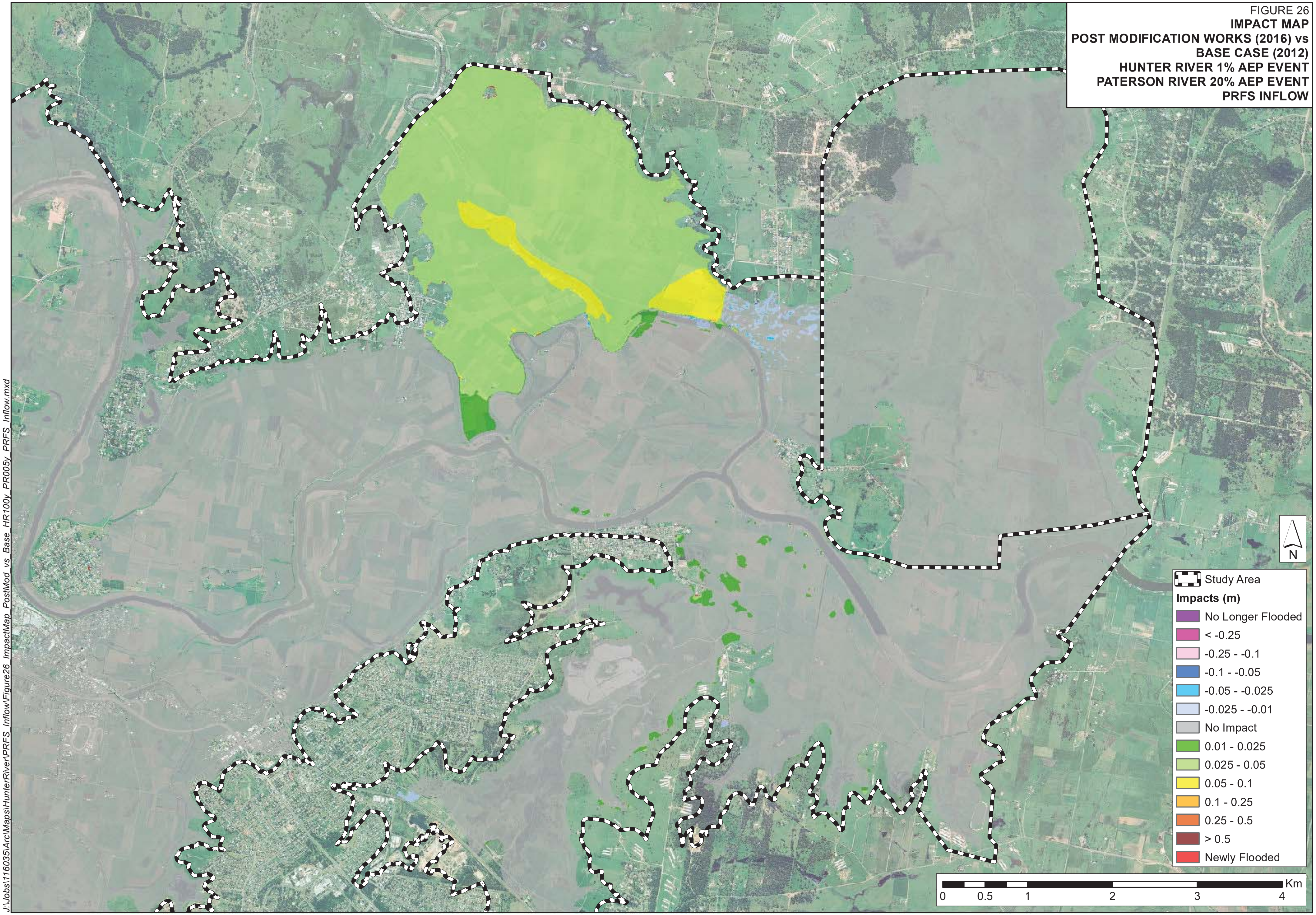
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure24_ImpactMap_PostMod_vs_Base_HR050y_PR050y_PRFS_Inflow.mxd

FIGURE 25
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 2% AEP EVENT
PATERSON RIVER 1% AEP EVENT
PRFS INFLOW



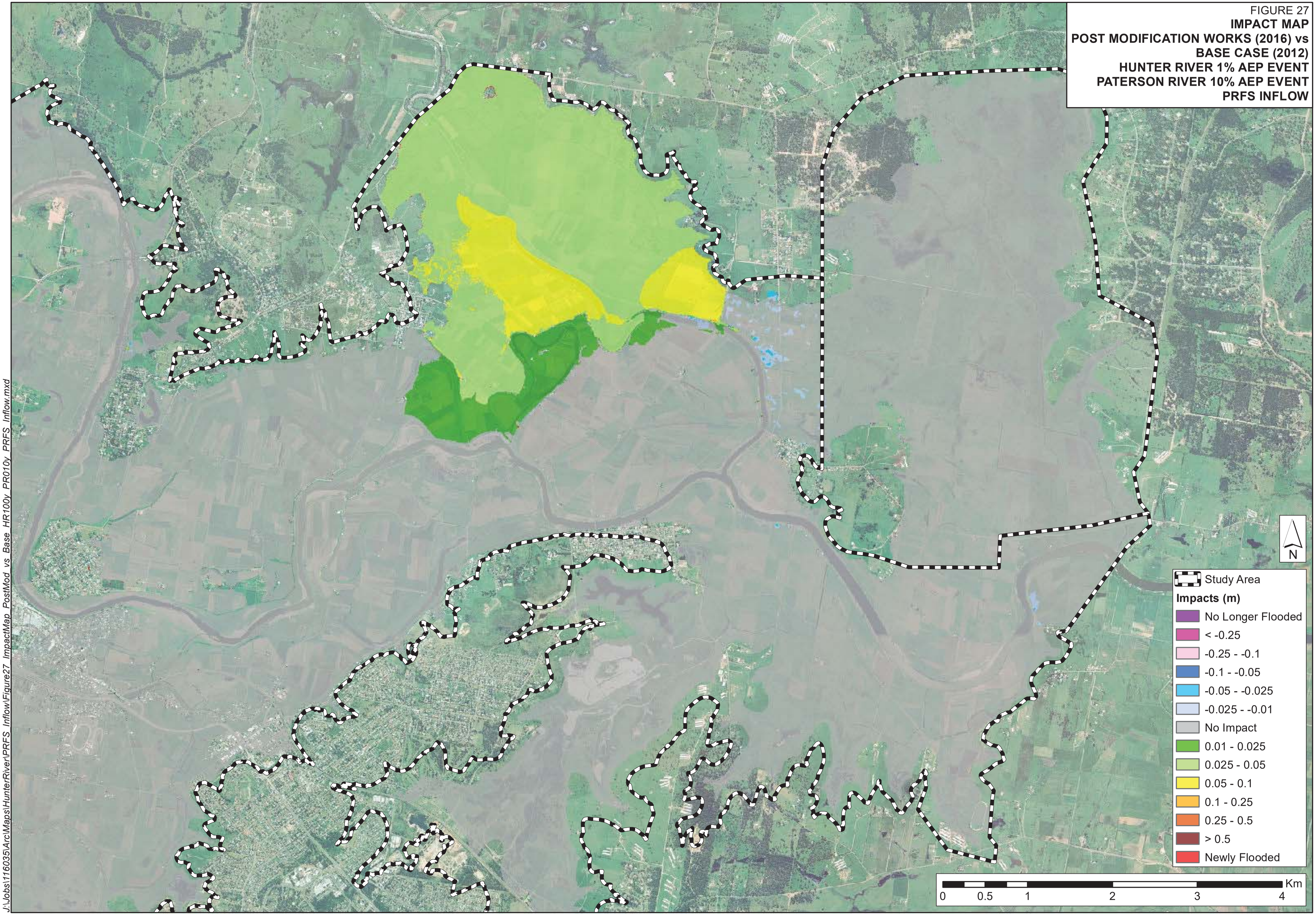
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS_Inflow\Figure25_ImpactMap_PostMod_vs_Base_HR050y_PR100y_PRFS_Inflow.mxd

FIGURE 26
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 1% AEP EVENT
PATERSON RIVER 20% AEP EVENT
PRFS INFLOW



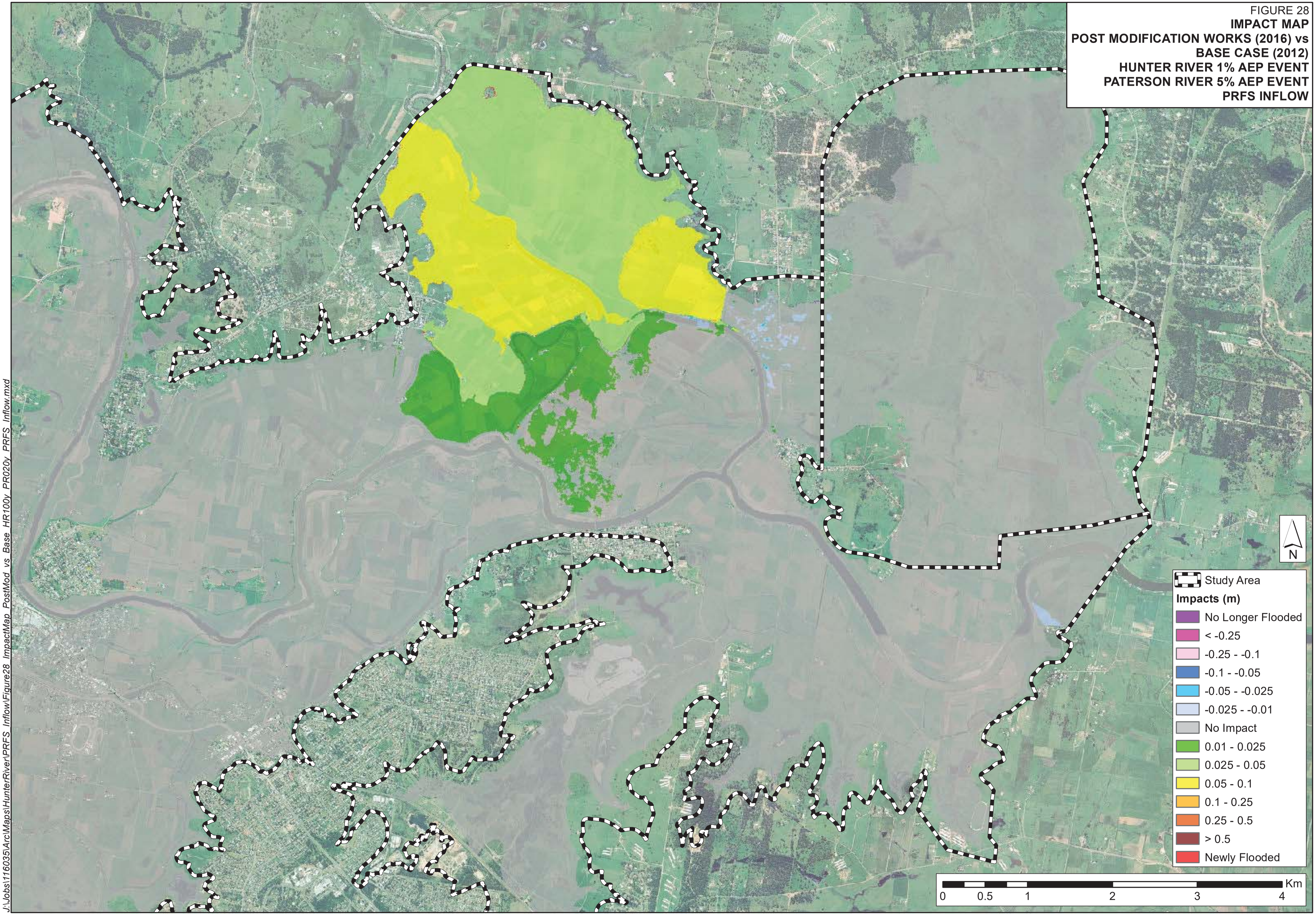
J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure26 ImpactMap PostMod vs Base HR100y PR005y PRFS Inflow.mxd

FIGURE 27
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 1% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW

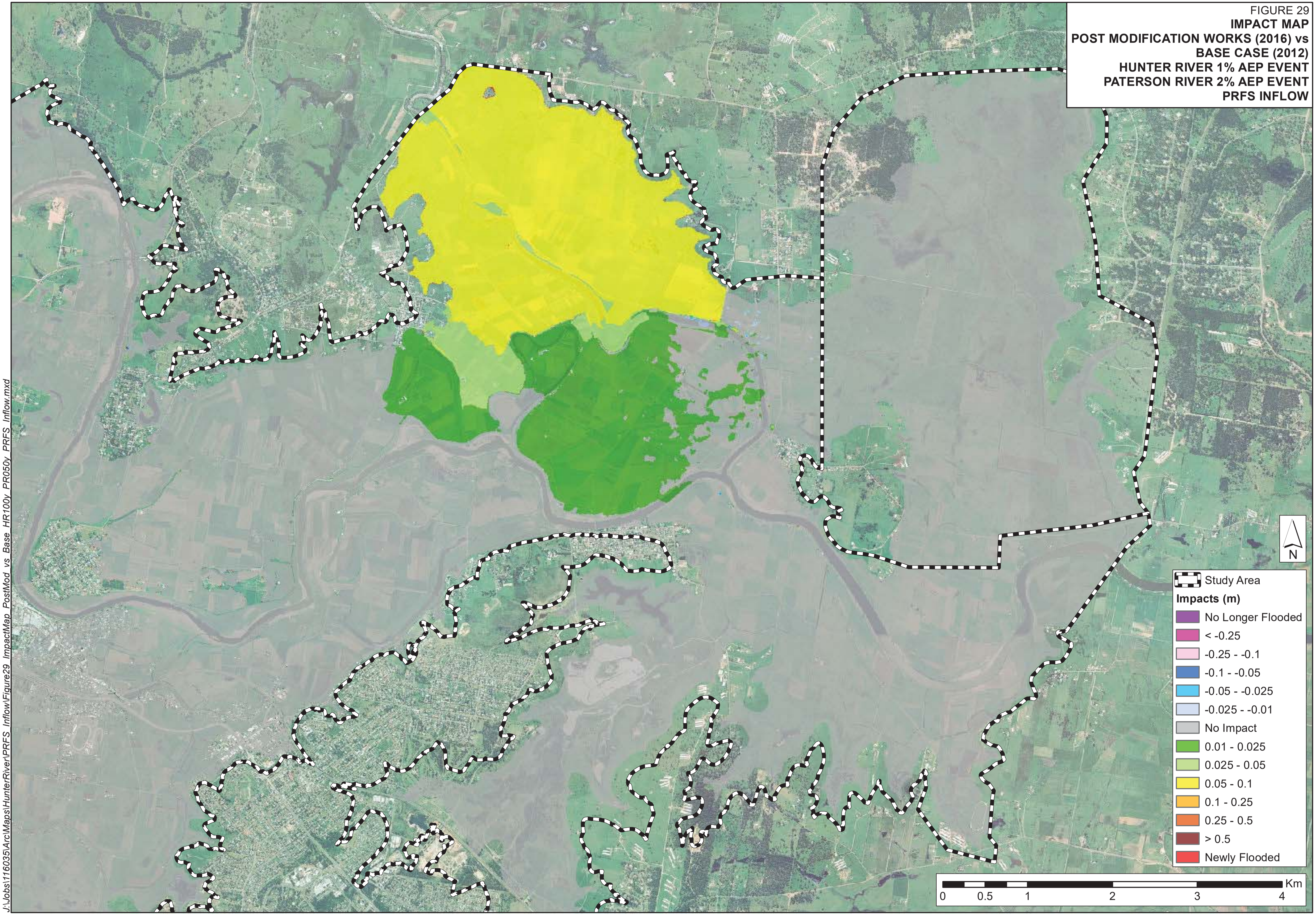


J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure27_ImpactMap_PostMod_vs_Base_HR100y_PR010y_PRFS_Inflow.mxd

FIGURE 28
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 1% AEP EVENT
PATERSON RIVER 5% AEP EVENT
PRFS INFLOW

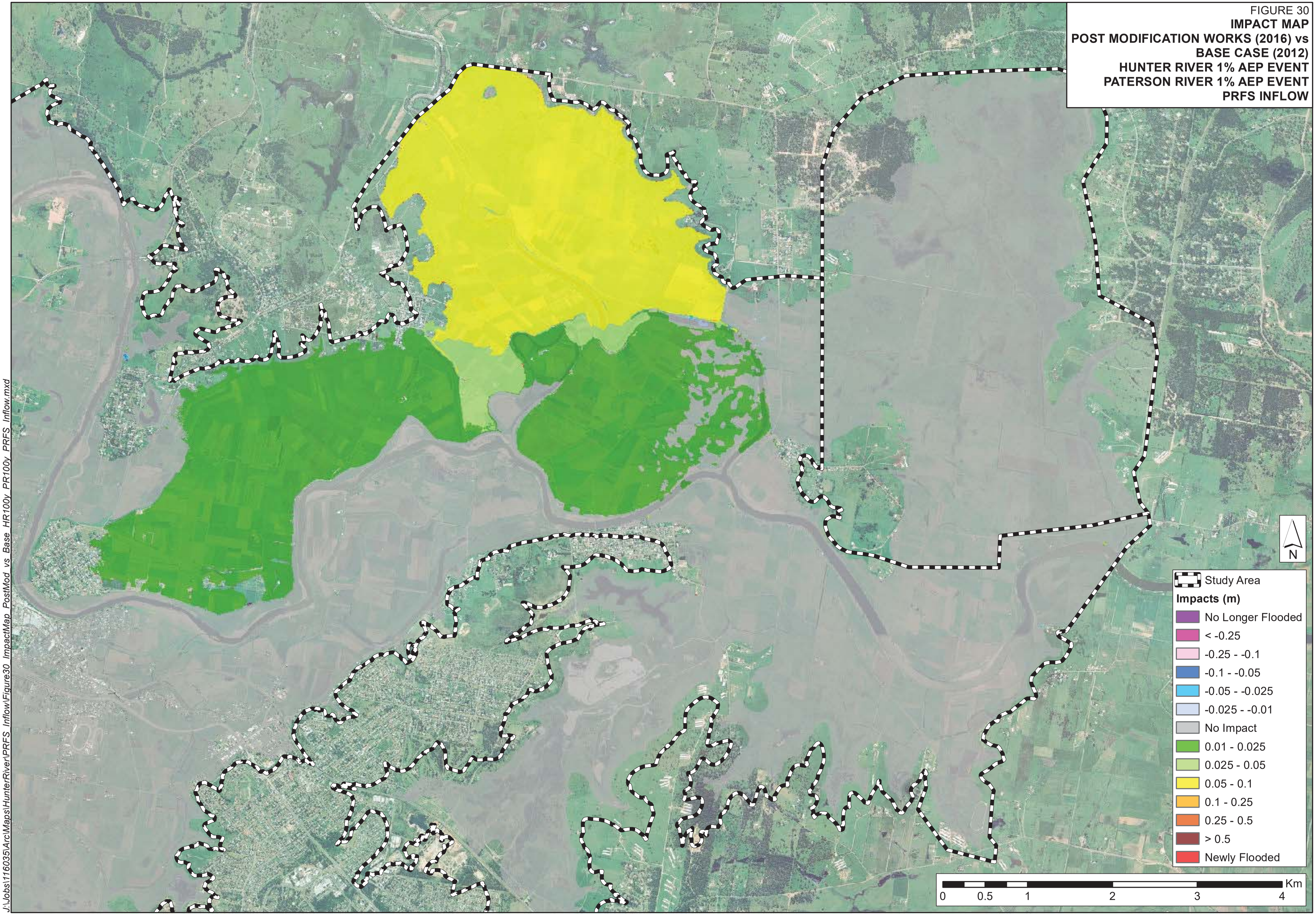


J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure28_ImpactMap_PostMod_vs_Base_HR100y_PR020y_PRFS_Inflow.mxd



J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure29 ImpactMap PostMod vs Base HR100y PR050y PRFS Inflow.mxd

FIGURE 30
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 1% AEP EVENT
PATERSON RIVER 1% AEP EVENT
PRFS INFLOW



J:\Jobs\116035\ArcMaps\HunterRiver\PRFS Inflow\Figure30 ImpactMap PostMod vs Base HR100y PR100y PRFS Inflow.mxd

FIGURE 31

PATERSON RIVER LEVEE PROFILE
EASTERN LEVEE
PATERSON RIVER FLOOD STUDY DESIGN EVENTS

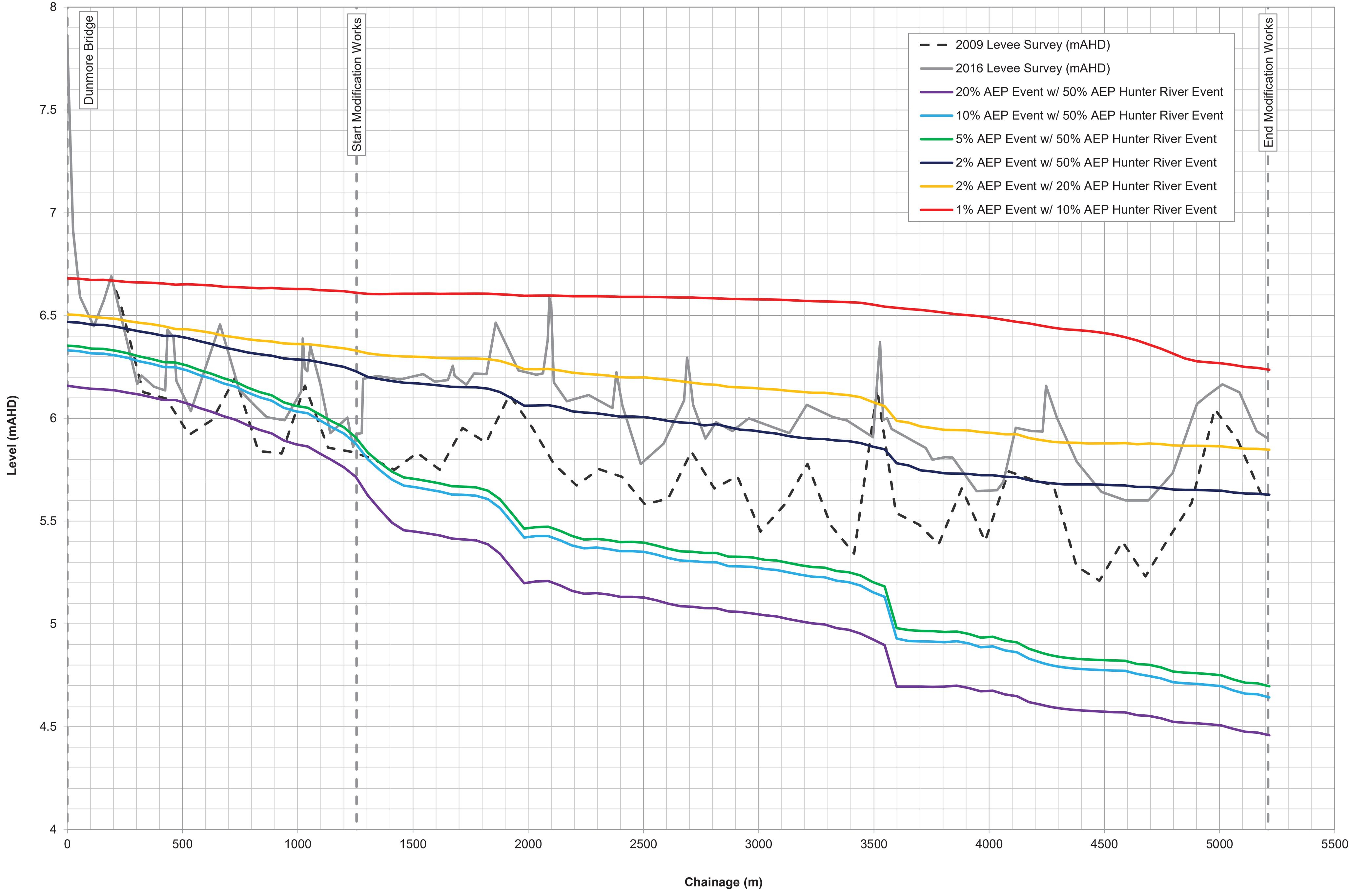


FIGURE 32

PATERSON RIVER LEVEE PROFILE

WESTERN LEVEE

PATERSON RIVER FLOOD STUDY DESIGN EVENTS

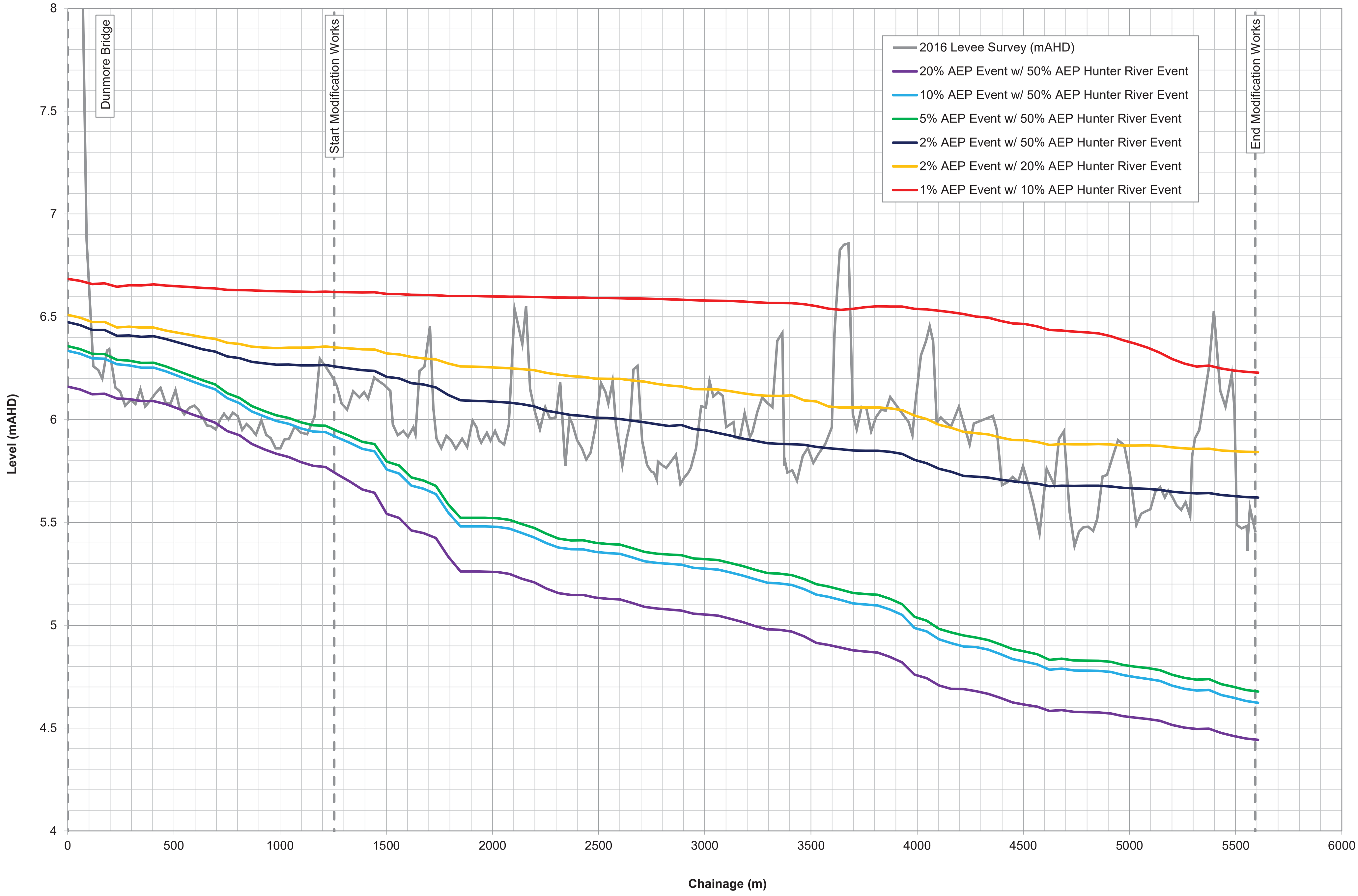


FIGURE 33
PATERSON RIVER LEVEE PROFILE
EASTERN LEVEE
PATERSON RIVER FLOOD STUDY MODELLED HISTORICAL EVENTS

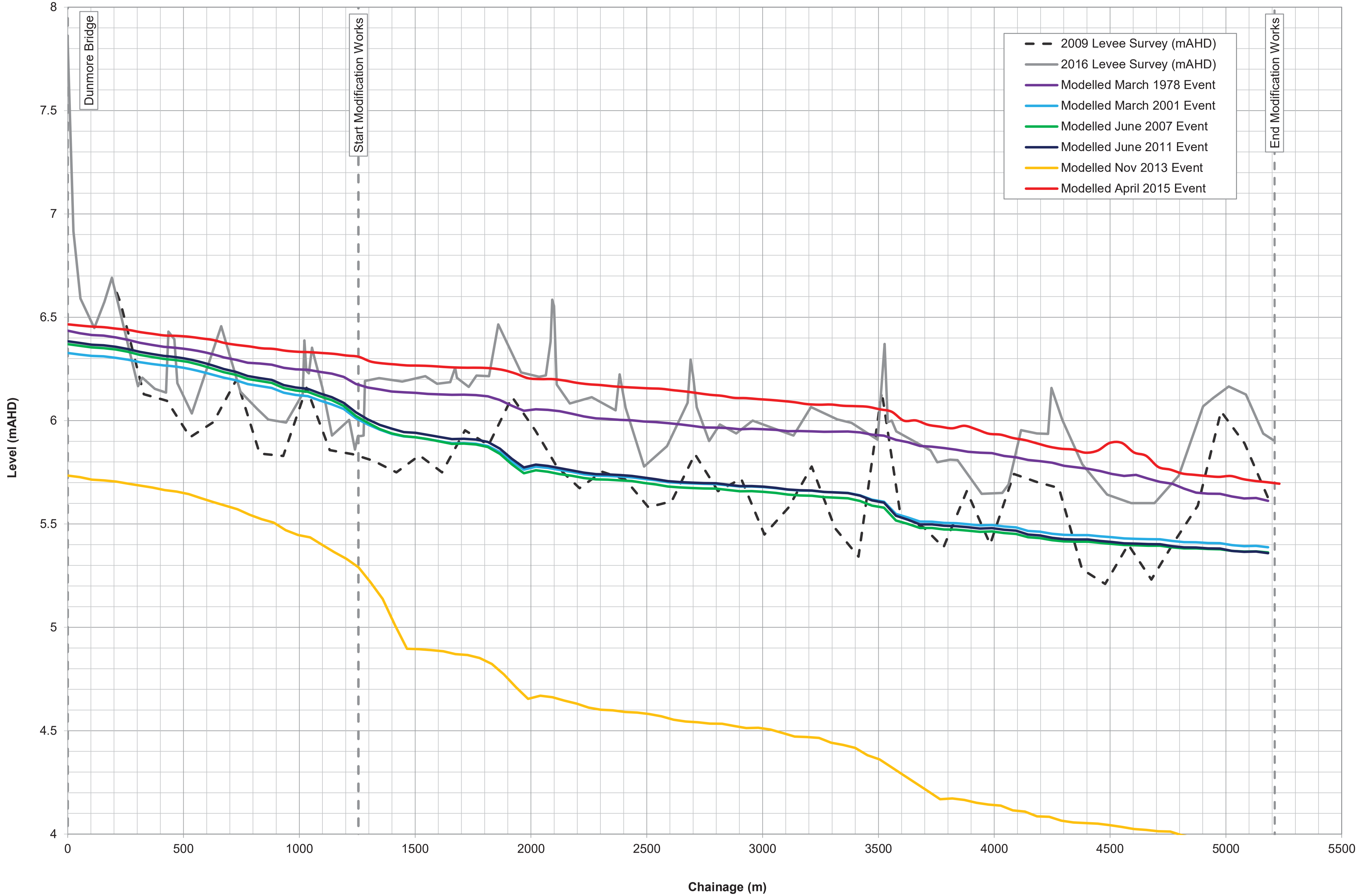


FIGURE 34

PATERSON RIVER LEVEE PROFILE
WESTERN LEVEE
PATERSON RIVER FLOOD STUDY MODELLED HISTORICAL EVENTS

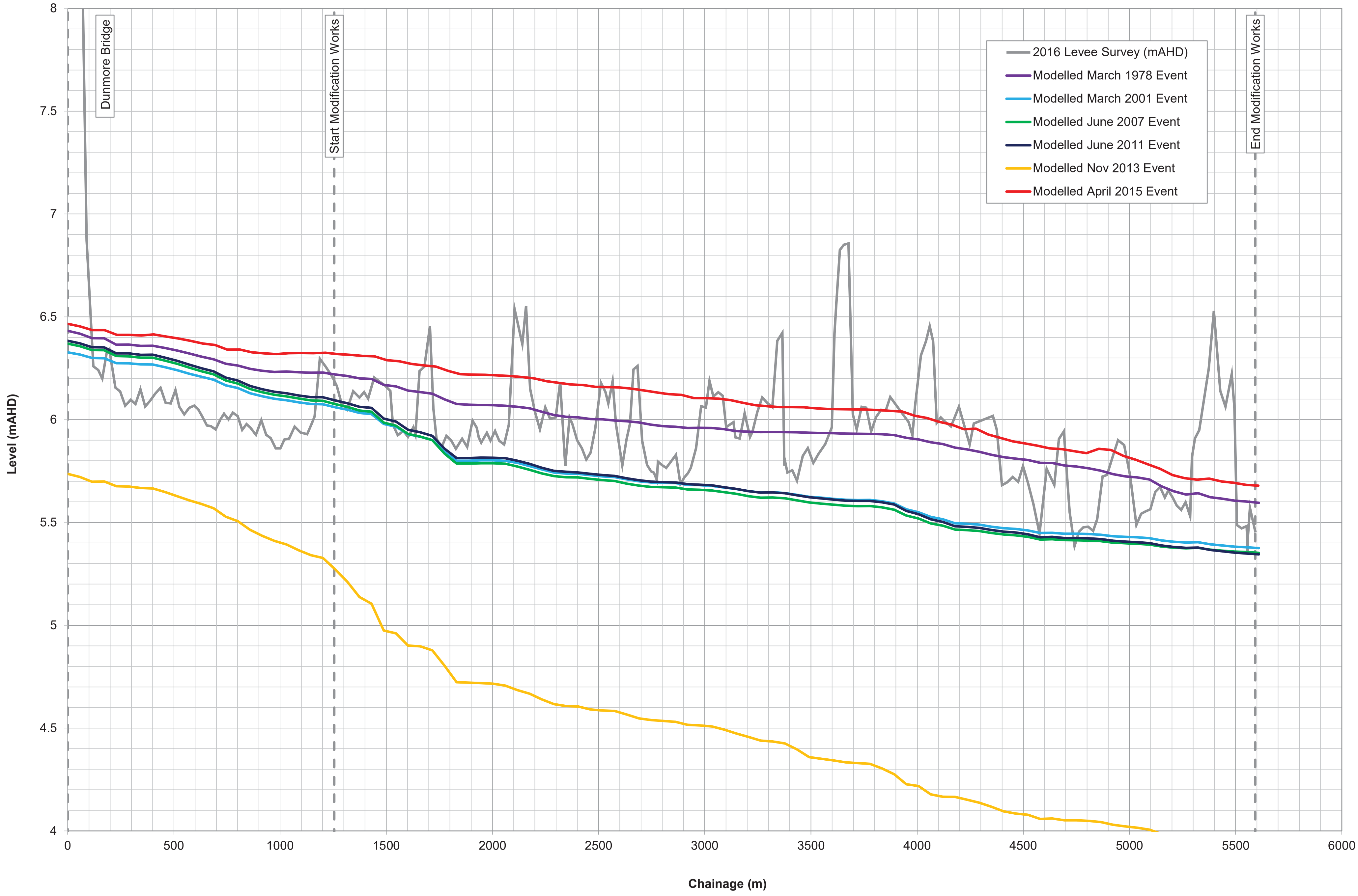


FIGURE 35

PATERSON RIVER LEVEE PROFILE

EASTERN LEVEE

HUNTER RIVER FLOOD STUDY DESIGN EVENTS

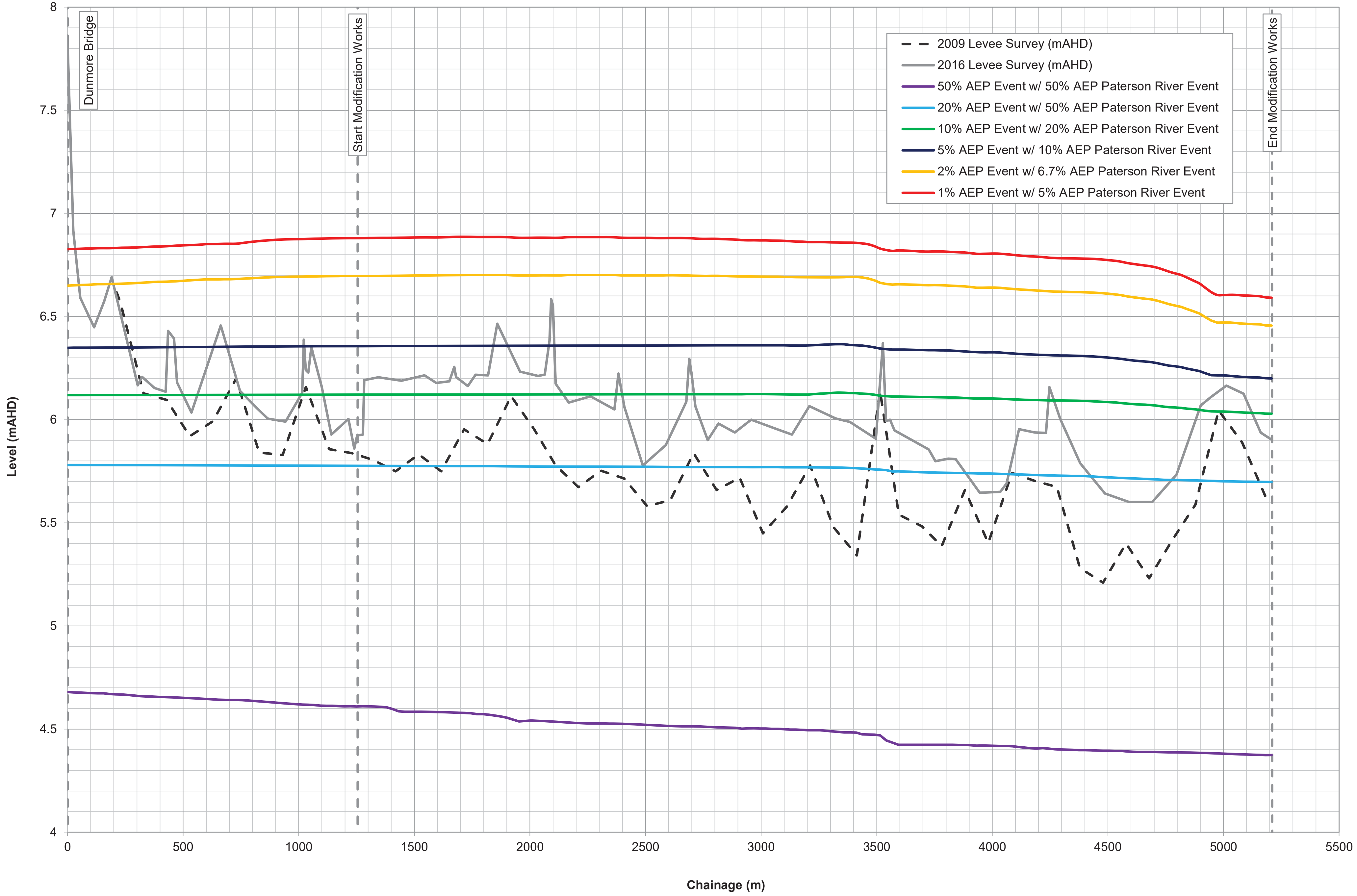


FIGURE 36
PATERSON RIVER LEVEE PROFILE
WESTERN LEVEE
HUNTER RIVER FLOOD STUDY DESIGN EVENTS

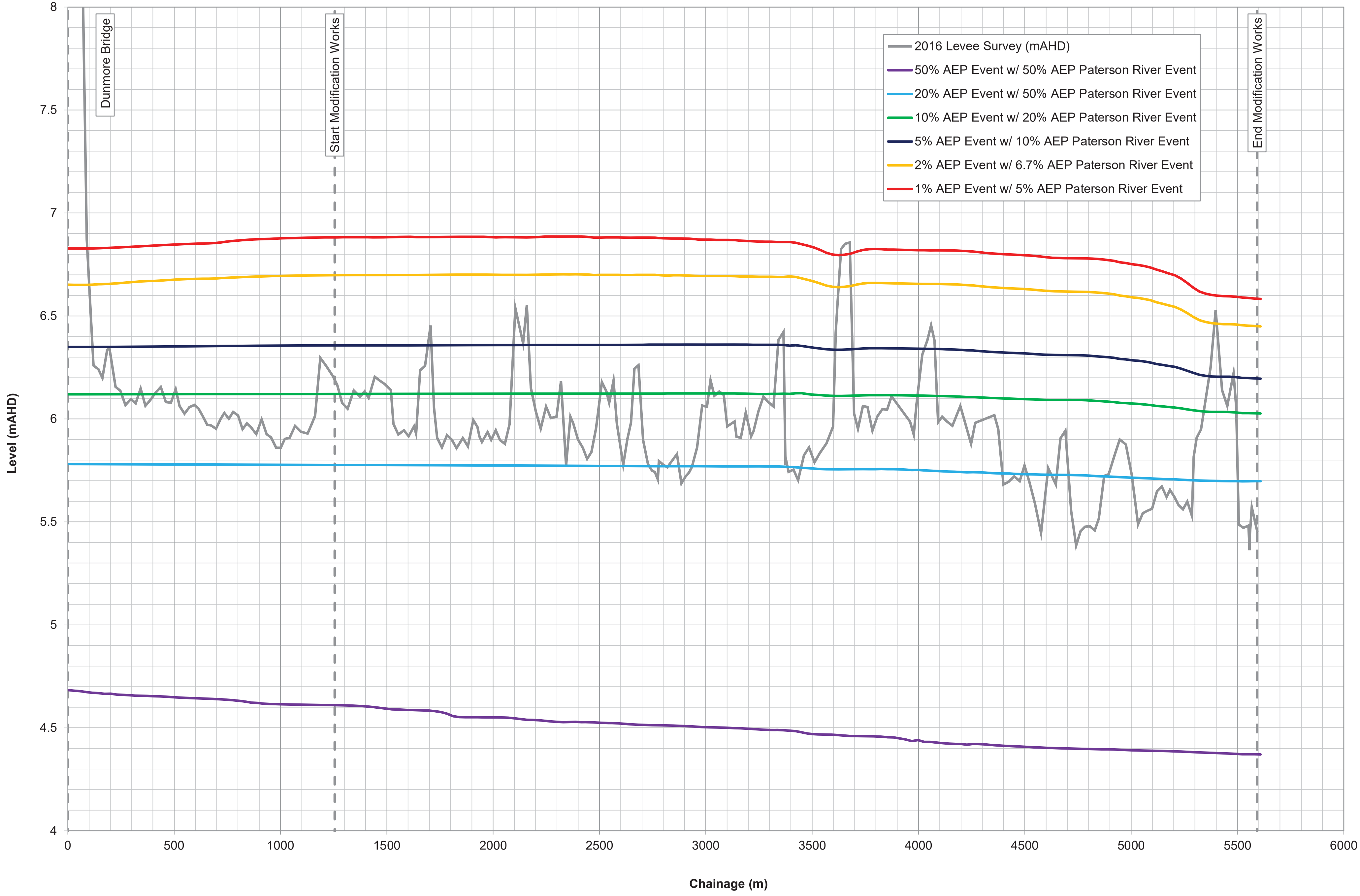


FIGURE 37

PATERSON RIVER LEVEE PROFILE
EASTERN LEVEE
HUNTER RIVER FLOOD STUDY MODELLED HISTORICAL EVENTS

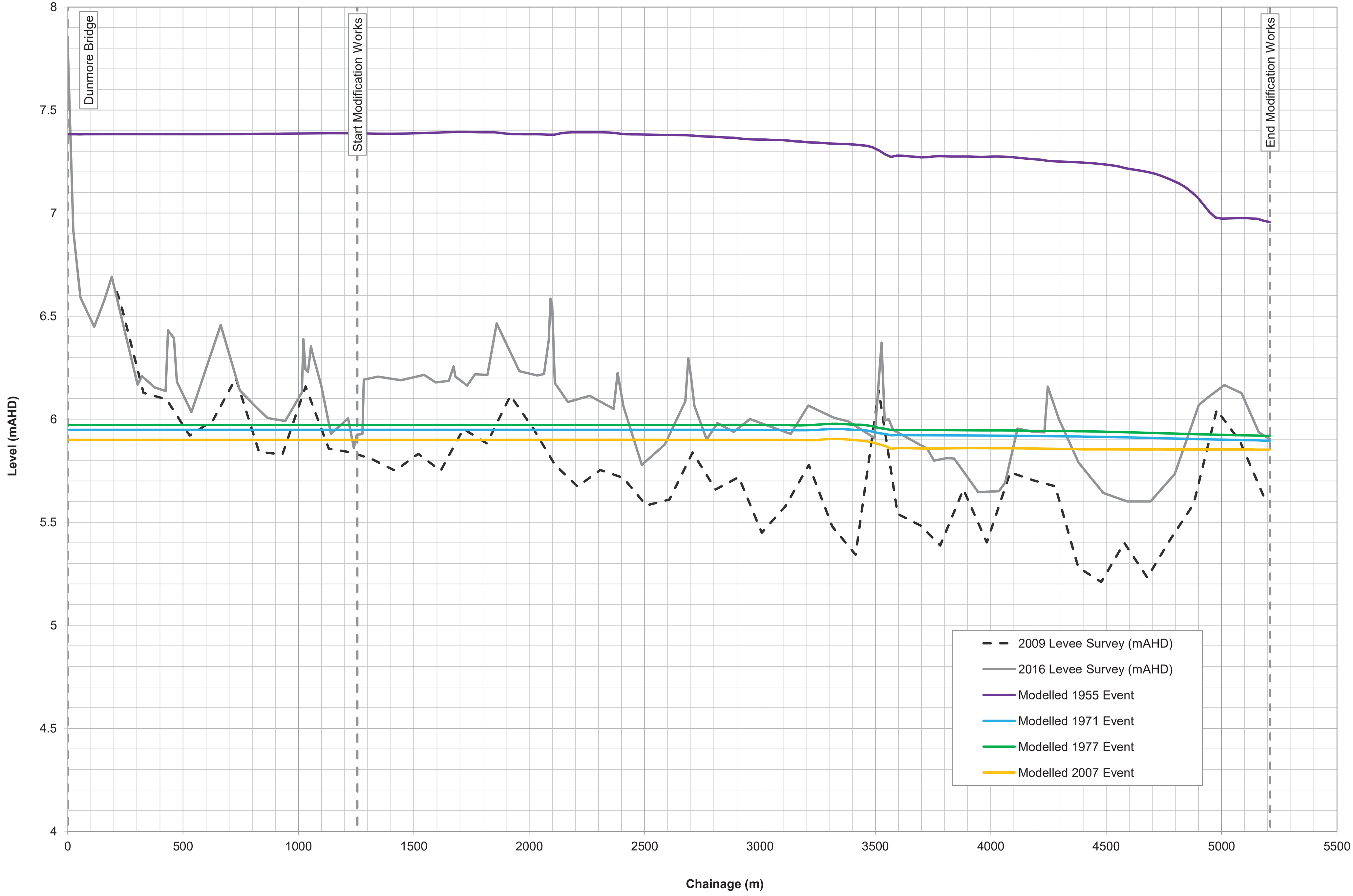
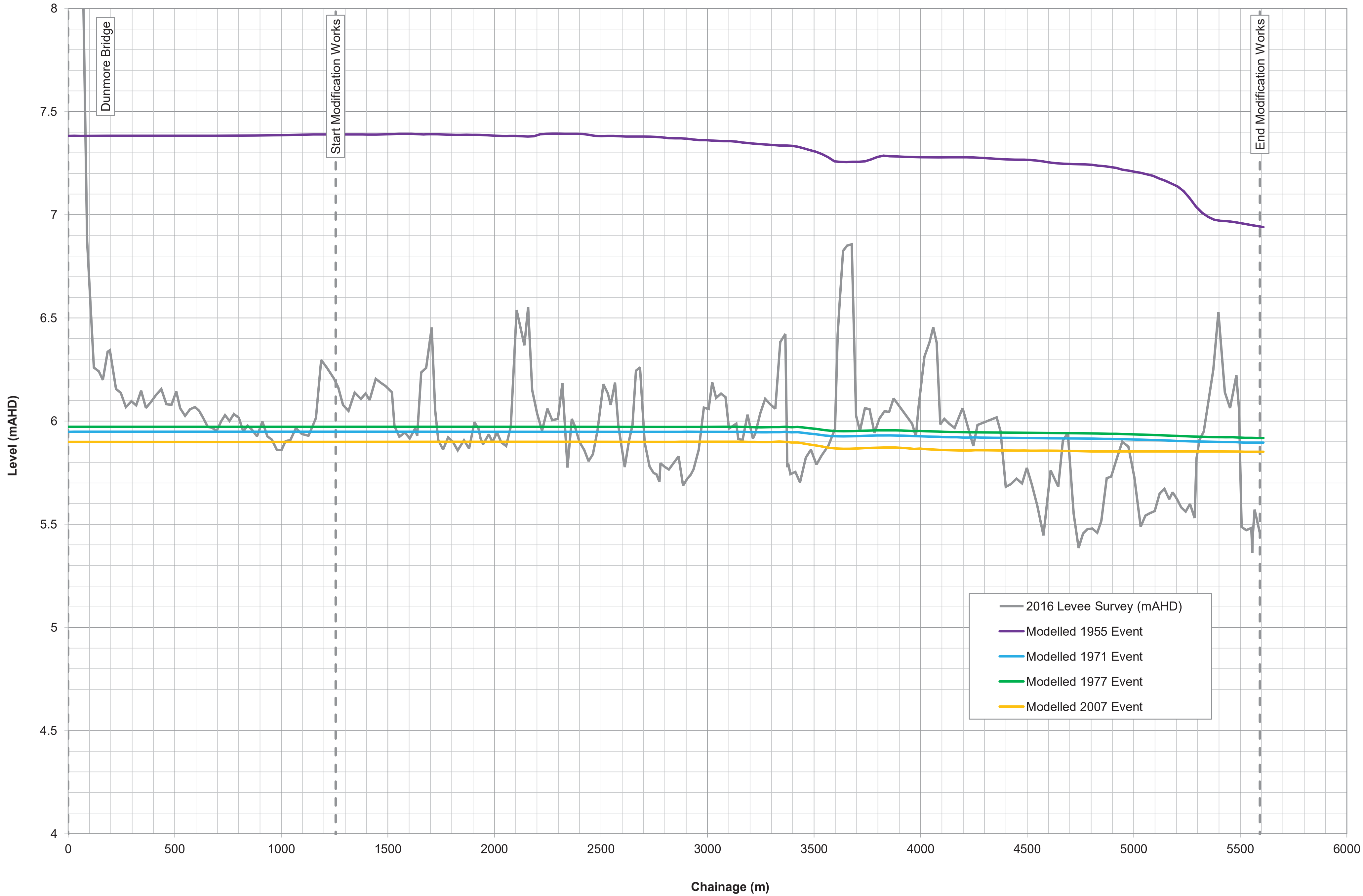


FIGURE 38

PATERSON RIVER LEVEE PROFILE
WESTERN LEVEE
HUNTER RIVER FLOOD TUDY MODELLED HISTORICAL EVENTS



Appendix A

APPENDIX A. GLOSSARY

FLOOD RISK TERMINOLOGY

Australian Rainfall and Runoff (ARR, editors Ball et al, 2016) recommends terminology that is not misleading to the public and stakeholders. Therefore the use of terms such as "recurrence interval" and "return period" are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			↓	
			PMP/ PMPDF	

ARR 2016 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table above describes how they are subtly different.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore an AEP is not assigned to the PMF>

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

Terms taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.

development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
early overtops	These are sections of levees that are intended to take initial overtopping flows. Consequently at the time of overtopping there is little to no tail water. To protect against scour, EOT have moderate land-side batters are typically in the order of 1 in 5 to 1 in 10, depending on the height of the levee.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range

	of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
late overtops	These are sections of levees that are typically 300mm higher than EOT. They are intended to provide additional protection to infrastructure such as floodgates and farm sheds. LOT were designed so that there was significant depth of tail water at overtopping, resulting in a lower risk of scour. LOT have steep land-side batters are typically in the order of 1 in 2.5.

local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

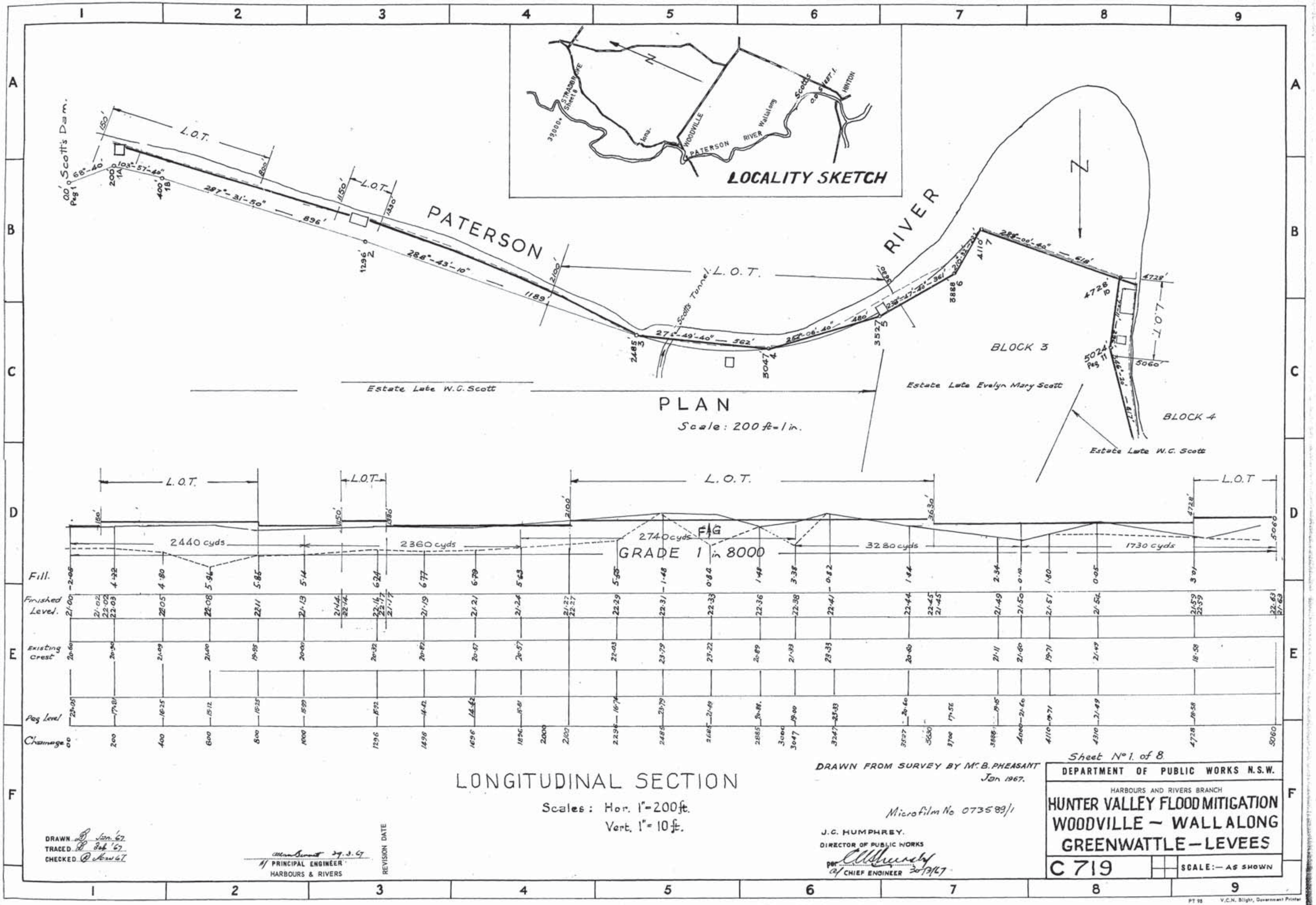
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:
	$ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
	
	$ water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
	
	$ major overland flow paths through developed areas outside of defined drainage reserves; and/or
	
	$ the potential to affect a number of buildings along the major flow path.

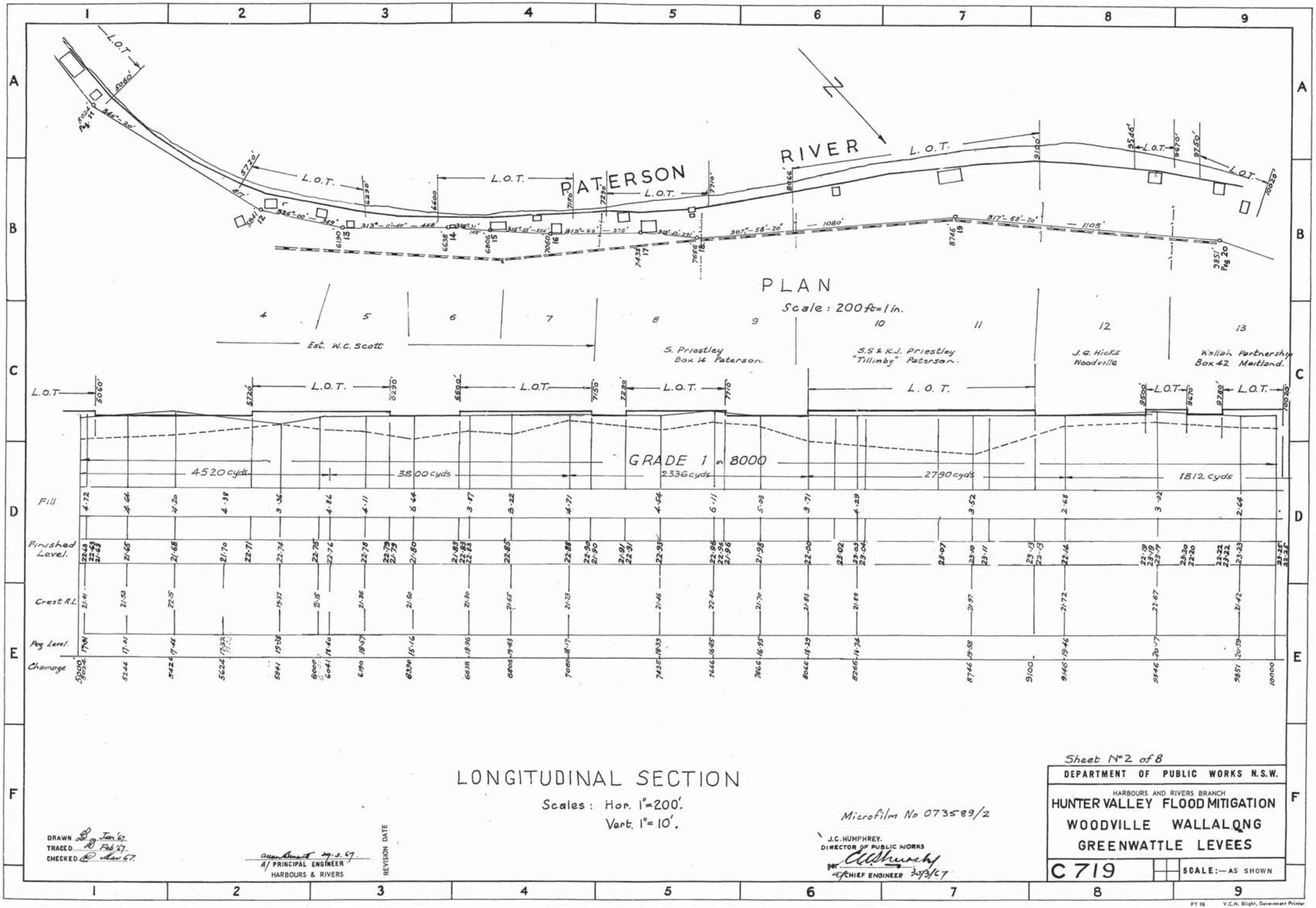
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the States rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas

	are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
spillways	Spillways are sections of levee designed to carry large flows of water for long periods. They typically have very flat back slopes (generally in the order of 1 in 50) which are protected by either grass or rock held in place by wire mesh and steel cable.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

APPENDIX B. HUNTER VALLEY FLOOD MITIGATION SCHEME


LOCALITY SKETCH
WOODVILLE
PATERSON RIVER
Wallalong
HINTON
PATERSON RIVER
L.O.T.
Scott's Dam.
Scotts Tunnel
BLOCK 3
BLOCK 4
Estate Late W.C. Scott
Estate Late Evelyn Mary Scott
PLAN
Scale: 200 ft = 1 in.
GRADE 1 in 8000
2440 cyds
2360 cyds
2740 cyds
3280 cyds
1730 cyds
Fill.
Finished Level.
Existing Crest
Peg Level
Chainage
LONGITUDINAL SECTION
Scales: Hor. 1" = 200 ft.
Vert. 1" = 10 ft.
DRAWN FROM SURVEY BY Mr. B. PHEASANT
Jan 1967.
Microfilm No 073589/1
J.C. HUMPHREY.
DIRECTOR OF PUBLIC WORKS
per
a/ CHIEF ENGINEER 30/3/67
a/ PRINCIPAL ENGINEER
HARBOURS & RIVERS
29.3.67
REVISION DATE
DRAWN Jan '67
TRACED Feb '67
CHECKED Mar '67
Sheet No 1. of 8.
DEPARTMENT OF PUBLIC WORKS N.S.W.
HARBOURS AND RIVERS BRANCH
HUNTER VALLEY FLOOD MITIGATION
WOODVILLE – WALLALONG
GREENWATTLE – LEVEES
C 719
SCALE:– AS SHOWN
PT 98
V.C.N. Blight, Government Printer


PATERSON RIVER
L.O.T.
PLAN
Scale: 200 ft = 1 in.
Est. W.C. Scott
S. Priestley Box 14 Paterson.
S.S & K.J. Priestley "Tillimby" Paterson.
J.G. Hicks Woodville
Kallah Partnership Box 42 Maitland.
GRADE 1 in 8000
4520 cyds
3800 cyds
2336 cyds
2790 cyds
1812 cyds
Fill
Finished Level.
Crest R.L.
Peg Level.
Chainage
LONGITUDINAL SECTION
Scales: Hor. 1" = 200'. Vert. 1" = 10'.
Microfilm No 073589/2
Sheet No 2 of 8
DEPARTMENT OF PUBLIC WORKS N.S.W.
HARBOURS AND RIVERS BRANCH
HUNTER VALLEY FLOOD MITIGATION
WOODVILLE WALLALONG
GREENWATTLE LEVEES
C 719
SCALE:— AS SHOWN
J.C. HUMPHREY. DIRECTOR OF PUBLIC WORKS
per [signature] A/CHIEF ENGINEER 30/3/67
A/ PRINCIPAL ENGINEER HARBOURS & RIVERS 29.3.67
DRAWN Jan '67
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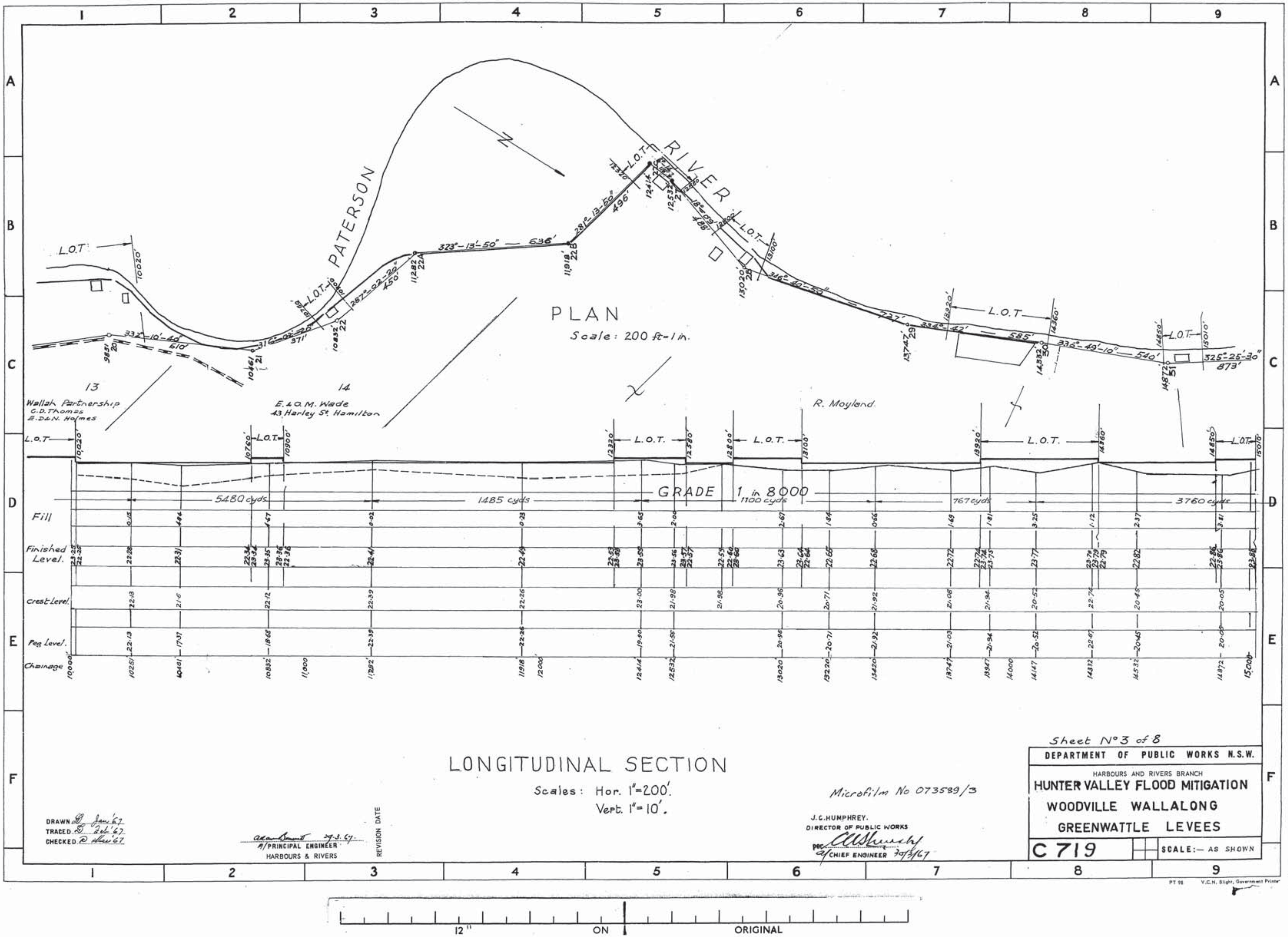
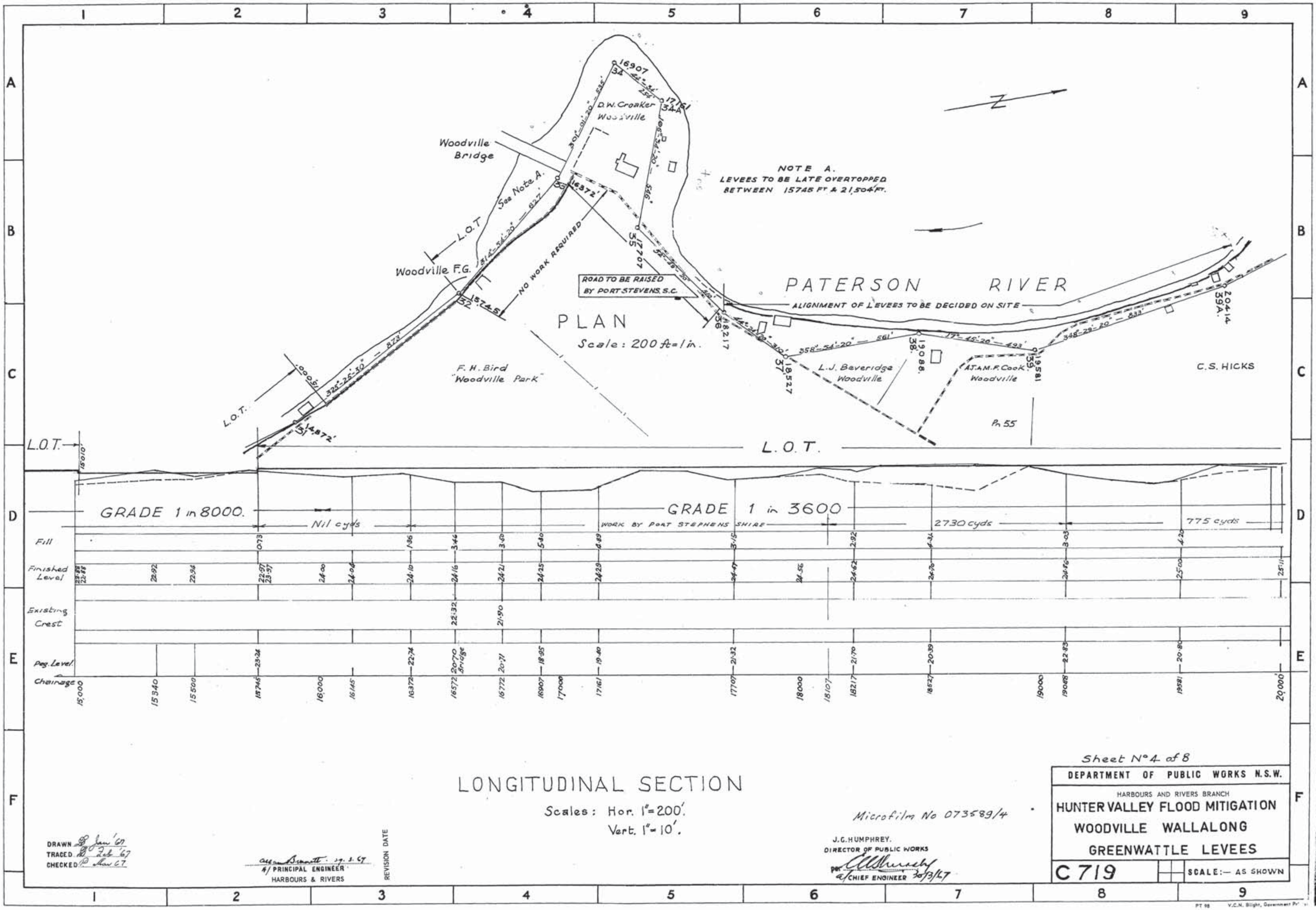
CHECKED Mar 67.
REVISION DATE
PT 98 V.C.N. Blight, Government Printer


PLAN
Scale: 200 ft-1 in.
PATERSON RIVER
L.O.T.
13
Wallah Partnership
C.D. Thomas
E.D.&N. Holmes
14
E.&O.M. Wade
43 Harley St. Hamilton
R. Moyland.
323°-13'-50" — 646'
GRADE 1 in 8000
5480 cyds
1485 cyds
1100 cyds
767 cyds
3760 cyds
Fill
Finished Level.
Crest Level.
Peg Level.
Chainage
LONGITUDINAL SECTION
Scales: Hor. 1"=200'.
Vert. 1"=10'.
Microfilm No 073589/3
Sheet N°3 of 8
DEPARTMENT OF PUBLIC WORKS N.S.W.
HARBOURS AND RIVERS BRANCH
HUNTER VALLEY FLOOD MITIGATION
WOODVILLE WALLALONG
GREENWATTLE LEVEES
C 719
SCALE:— AS SHOWN
DRAWN Jan '67
TRACED Feb '67
CHECKED Mar '67
PRINCIPAL ENGINEER
HARBOURS & RIVERS
REVISION DATE
J.C. HUMPHREY.
DIRECTOR OF PUBLIC WORKS
CHIEF ENGINEER 30/3/67
12" ON ORIGINAL



Sheet Nº 4 of 8

DEPARTMENT OF PUBLIC WORKS N.S.W.

HARBOURS AND RIVERS BRANCH

HUNTER VALLEY FLOOD MITIGATION

WOODVILLE WALLALONG

GREENWATTLE LEVEES

C 719 SCALE:— AS SHOWN

DRAWN Jan '67
TRACED Feb '67
CHECKED Mar '67

29. 3. 67
A/ PRINCIPAL ENGINEER
HARBOURS & RIVERS

REVISION DATE

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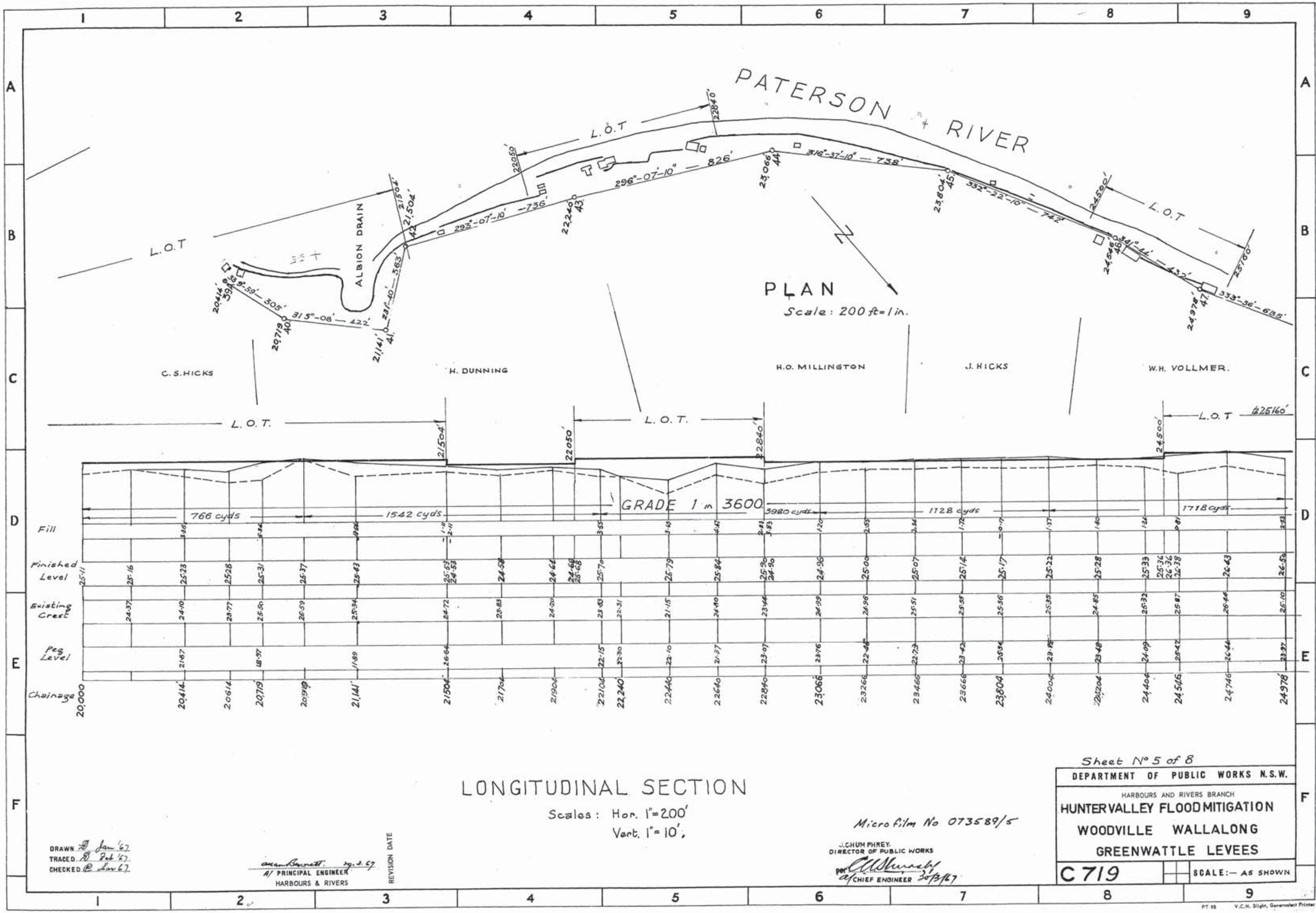
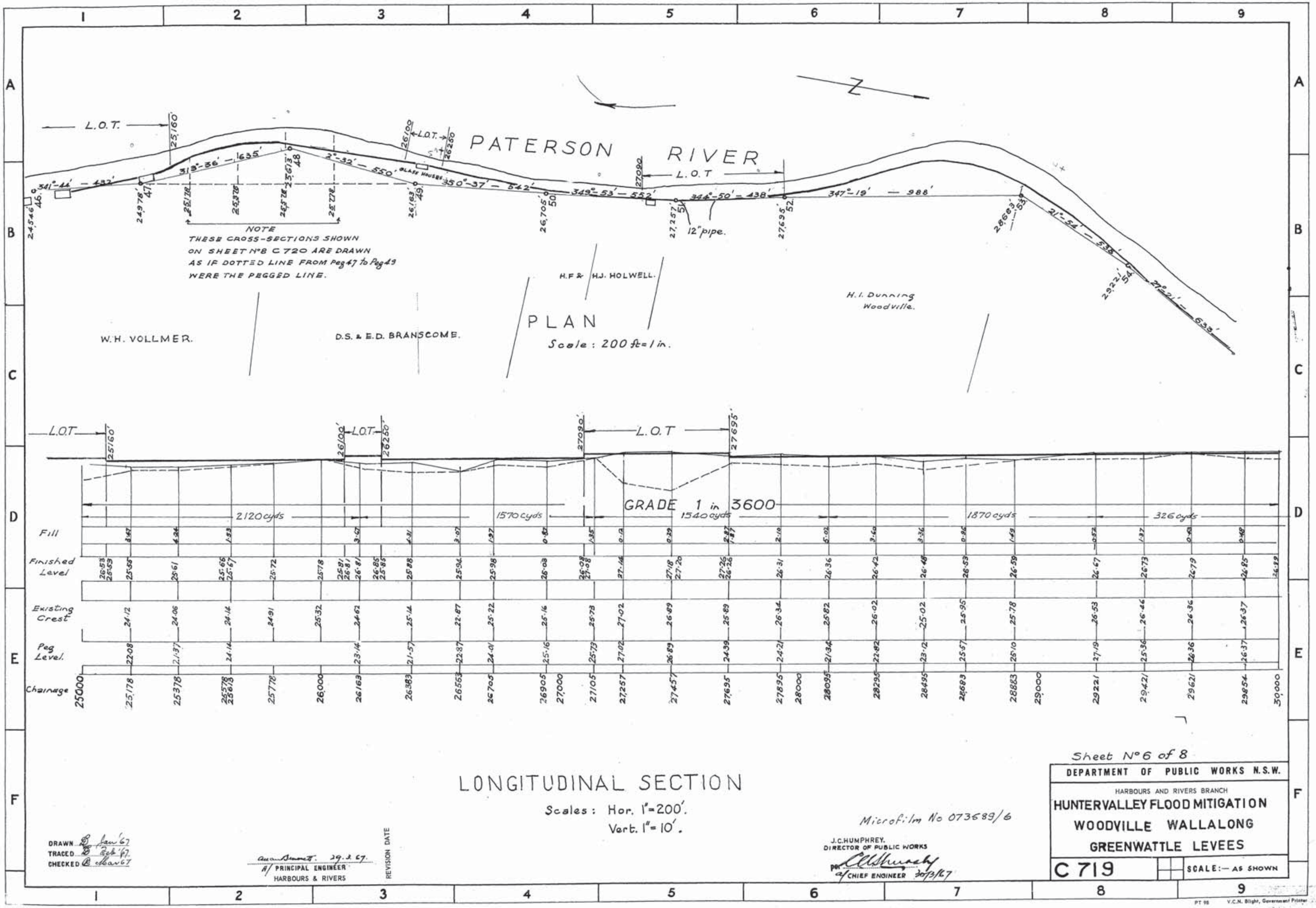
per
a/CHIEF ENGINEER 30/3/67

12" ON ORIGINAL



PATERSON RIVER
PLAN
Scale: 200 ft = 1 in.
ALBION DRAIN
L.O.T
C. S. HICKS
H. DUNNING
H.O. MILLINGTON
J. HICKS
W.H. VOLLMER.
GRADE 1 in 3600
766 cyds
1542 cyds
3980 cyds
1128 cyds
1718 cyds
Fill
Finished Level
Existing Crest
Peg Level
Chainage
LONGITUDINAL SECTION
Scales: Hor. 1" = 200'
Vert. 1" = 10'.
Micro film No 073589/5
J. CHUMPHREY.
DIRECTOR OF PUBLIC WORKS
per
a/CHIEF ENGINEER 30/3/67
A/ PRINCIPAL ENGINEER
HARBOURS & RIVERS
REVISION DATE
DRAWN Jan '67
TRACED Feb '67
CHECKED Jan 67
Sheet No 5 of 8
DEPARTMENT OF PUBLIC WORKS N.S.W.
HARBOURS AND RIVERS BRANCH
HUNTER VALLEY FLOOD MITIGATION
WOODVILLE WALLALONG
GREENWATTLE LEVEES
C 719
SCALE:— AS SHOWN
V.C.N. Blight, Government Printer


PATERSON RIVER
L.O.T.
NOTE
THESE CROSS-SECTIONS SHOWN ON SHEET Nº8 C.720 ARE DRAWN AS IF DOTTED LINE FROM Peg 47 to Peg 49 WERE THE PEGGED LINE.
12" pipe.
GLASS HOUSES
W.H. VOLLMER.
D.S. & E.D. BRANSCOME.
H.F & H.J. HOLWELL.
H.I. Dunning Woodville.
PLAN
Scale : 200 ft = 1 in.
GRADE 1 in 3600
2120 cyds
1570 cyds
1540 cyds
1870 cyds
326 cyds
Fill
Finished Level
Existing Crest
Peg Level.
Chainage
LONGITUDINAL SECTION
Scales : Hor. 1" = 200'.
Vert. 1" = 10'.
Microfilm No 073689/6
Sheet Nº 6 of 8
DEPARTMENT OF PUBLIC WORKS N.S.W.
HARBOURS AND RIVERS BRANCH
HUNTER VALLEY FLOOD MITIGATION
WOODVILLE WALLALONG
GREENWATTLE LEVEES
C 719
SCALE:— AS SHOWN
J.C. HUMPHREY.
DIRECTOR OF PUBLIC WORKS
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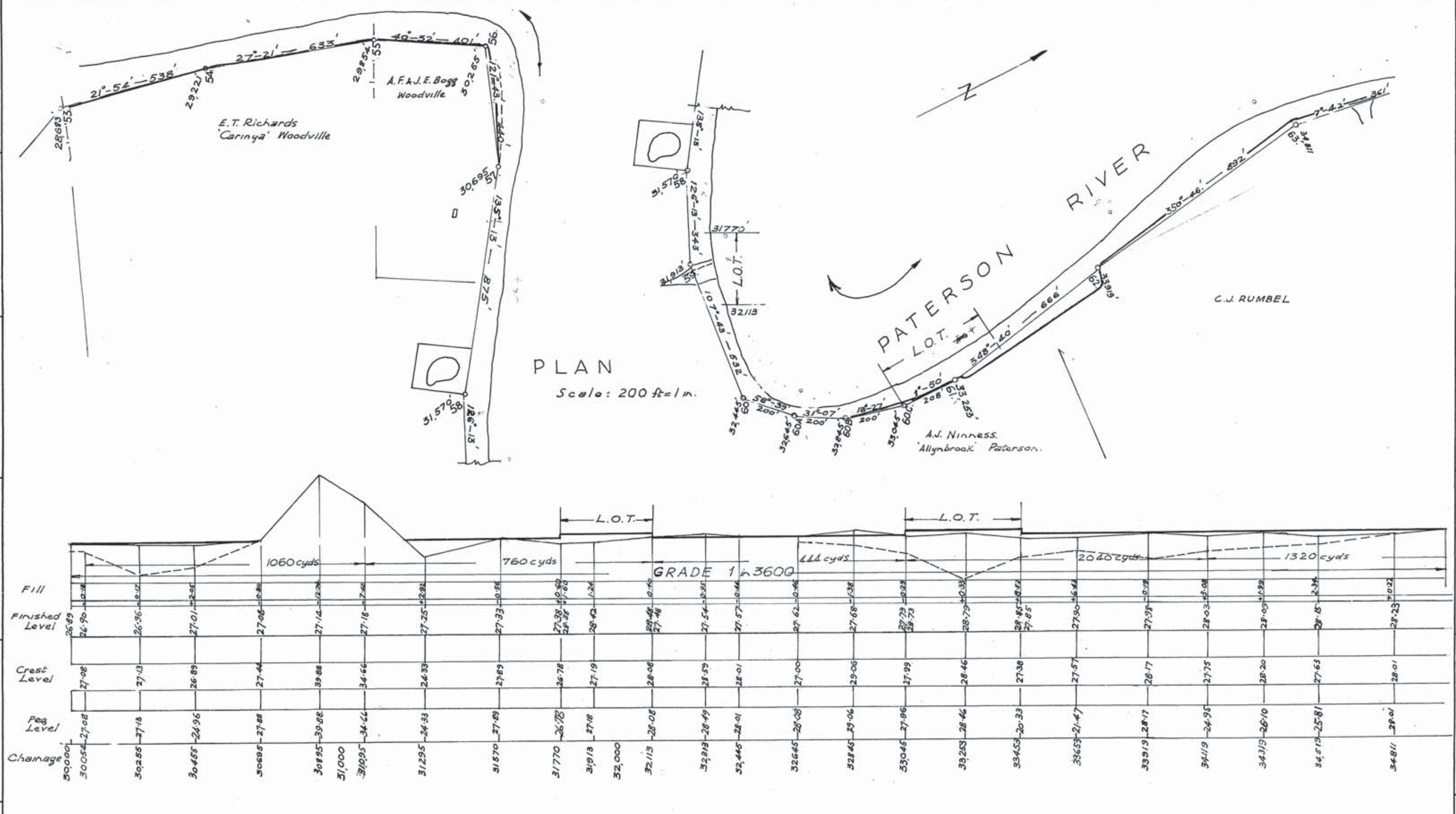
A/ PRINCIPAL ENGINEER
HARBOURS & RIVERS
29.3.67.
REVISION DATE
DRAWN Jan '67
TRACED Feb '67
CHECKED Mar '67
V.C.N. Blight, Government Printer



LONGITUDINAL SECTION

Scales: Hor. 1"=200'.
Vert. 1"=10'.

Microfilm No 073589/7

DRAWN Jan '67
TRACED Feb '67
CHECKED Mar '67

29.3.67
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HARBOURS & RIVERS

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Sheet N° 7 of 8

DEPARTMENT OF PUBLIC WORKS N.S.W.

HARBOURS AND RIVERS BRANCH

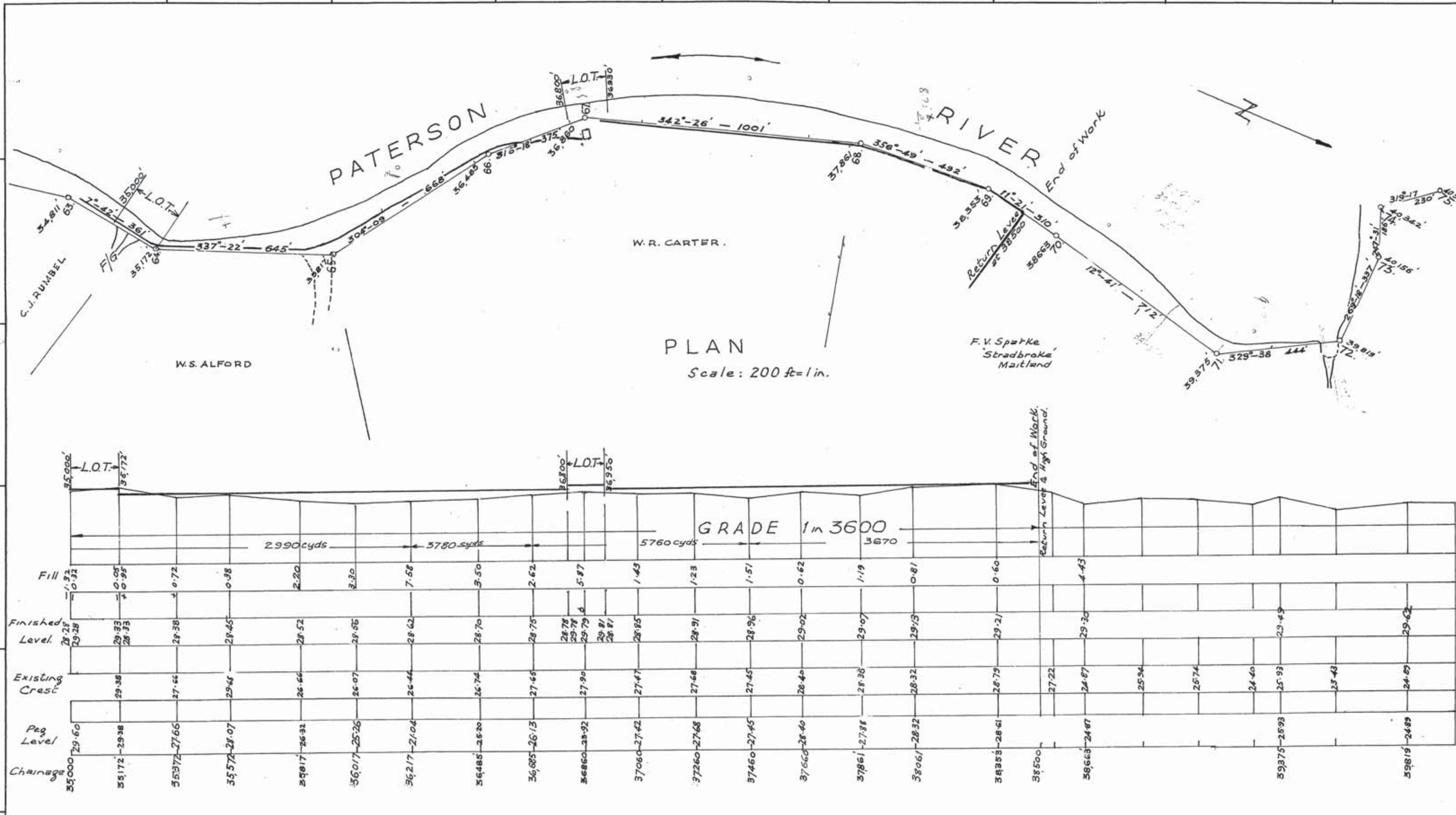
HUNTER VALLEY FLOOD MITIGATION

WOODVILLE WALLALONG
GREENWATTLE LEVEES

C 719

SCALE:— AS SHOWN

PT 98 V.C.N. Blight, Government Printer



LONGITUDINAL SECTION

Scales: Hor. 1"=200'.
Vert. 1"=10'.

Microfilm No 073589/8

Sheet No 8. of 8

DEPARTMENT OF PUBLIC WORKS N.S.W.

HARBOURS AND RIVERS BRANCH

HUNTER VALLEY FLOOD MITIGATION

WOODVILLE WALLALONG

GREENWATTLE LEVEES

C719

SCALE:— AS SHOWN

DRAWN D. Jan 67
TRACED L. Feb 67
CHECKED C. March 67

[signature] 29.3.67
A/PRINCIPAL ENGINEER
HARBOURS & RIVERS

REVISION DATE

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DIRECTOR OF PUBLIC WORKS
per [signature] 30/3/67
a/CHIEF ENGINEER

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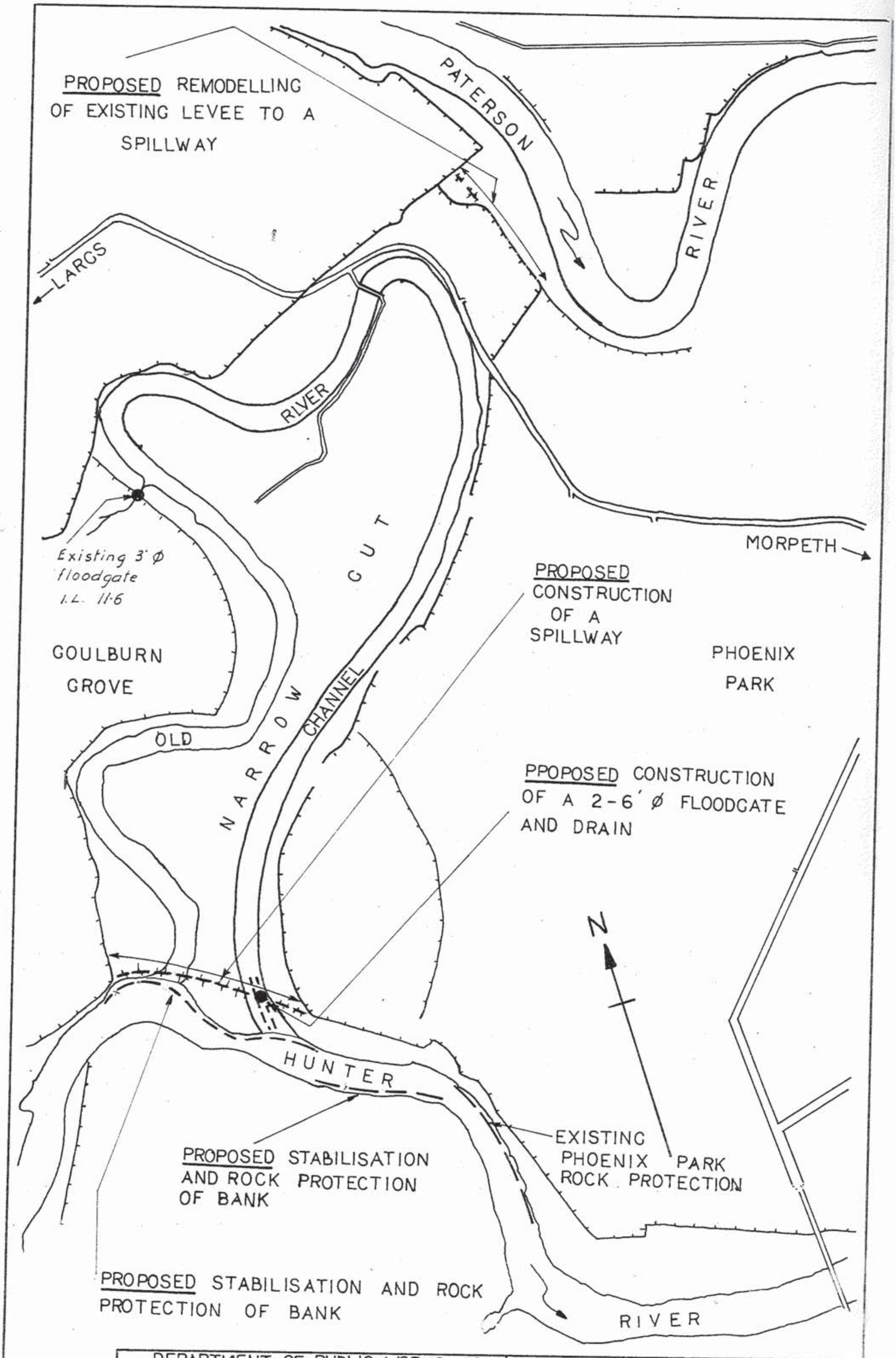
12" ON ORIGINAL



DEPARTMENT OF PUBLIC WORKS N.S.W. CONSTRUCTION & OPERATIONS	SCALE: 800 ft. = 1 in	DATE: 30.12.71
	DRAWN:	P 434
HUNTER VALLEY FLOOD MITIGATION : NARROW GUT SCHEME	TRACED:	
	CHECKED:	

maitland city council

PORT STEPHENS COUNCIL

DUNGOG SHIRE COUNCIL 1958

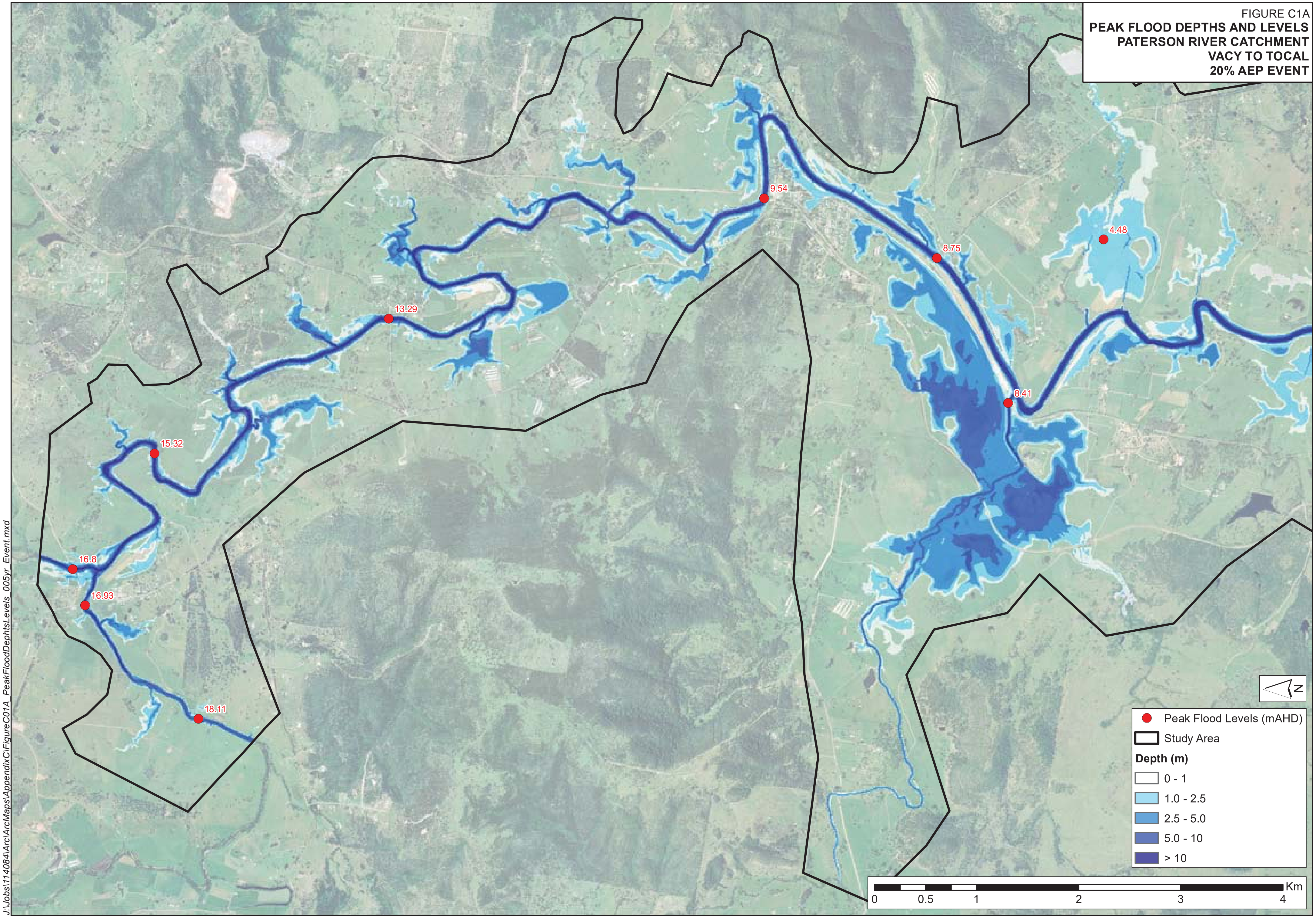
PATERSON RIVER FLOOD STUDY
VACY TO HINTON
VOLUME 2 – APPENDIX C & D

wma water

JUNE 2017

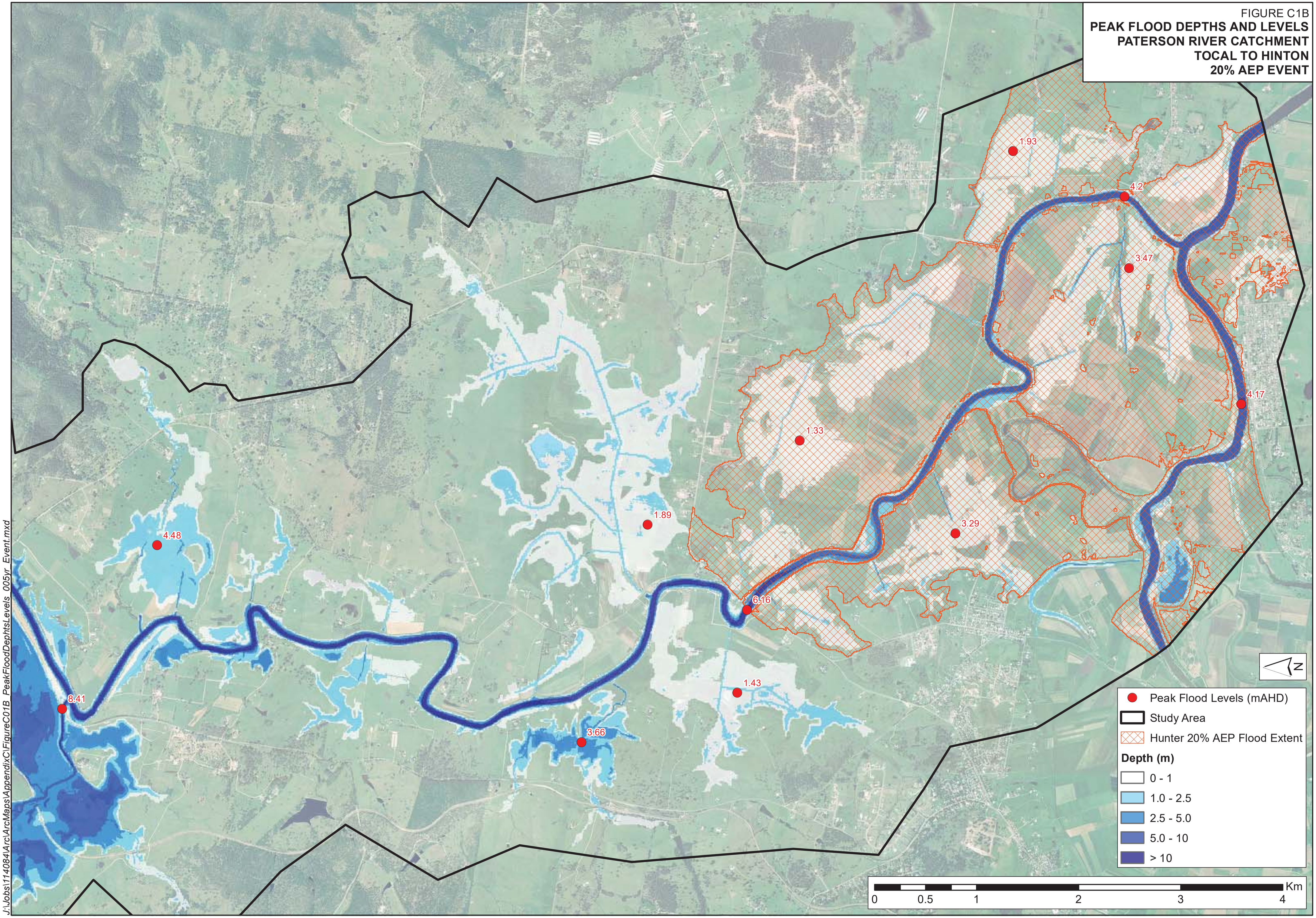
Appendix C

FIGURE C1A
PEAK FLOOD DEPTHS AND LEVELS
PATERSON RIVER CATCHMENT
VACY TO TOCAL
20% AEP EVENT



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC01A_PeakFloodDepthsLevels_005yr_Event.mxd

FIGURE C1B
PEAK FLOOD DEPTHS AND LEVELS
PATERSON RIVER CATCHMENT
TOCAL TO HINTON
20% AEP EVENT



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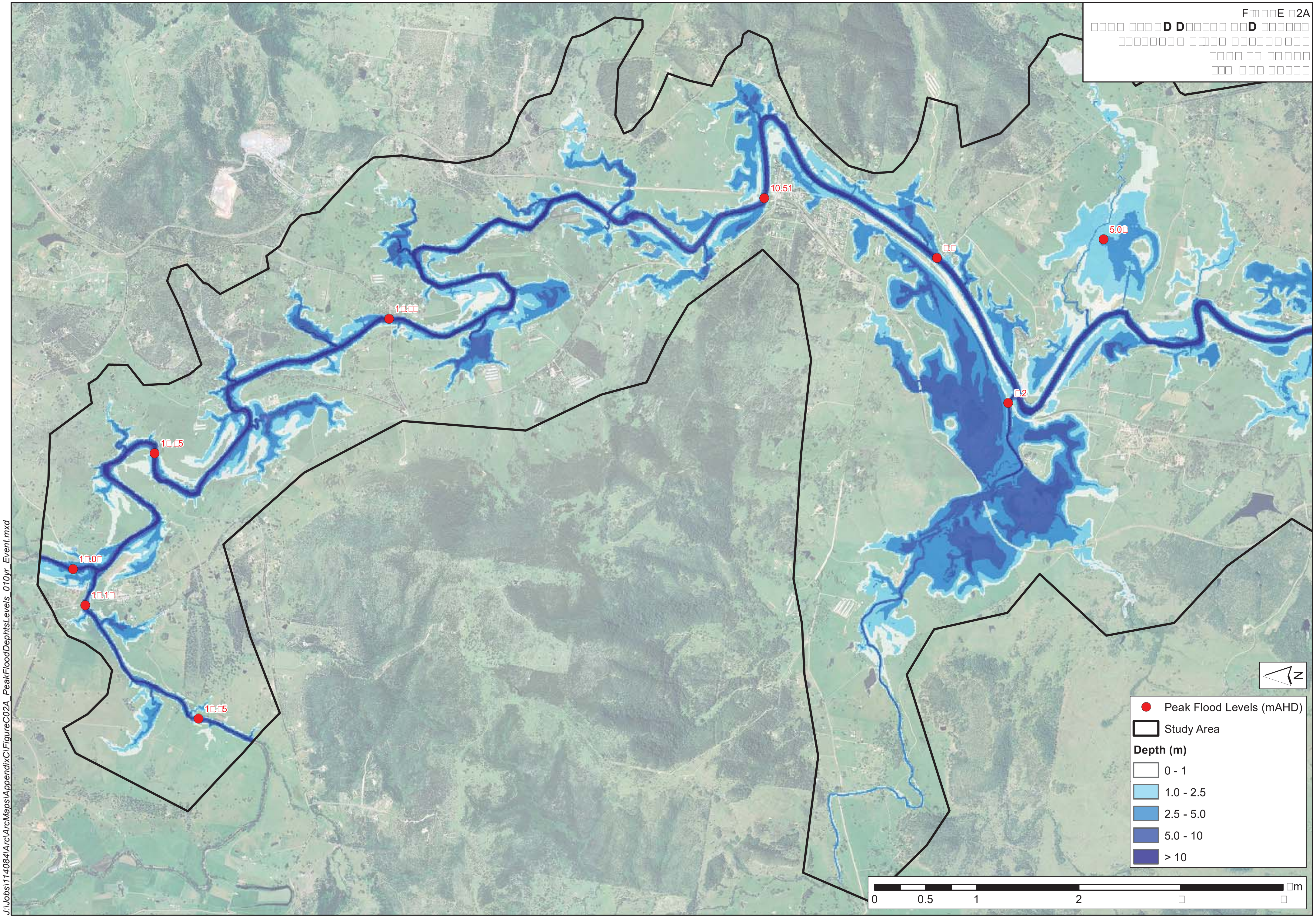


J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC02A_PeakFloodDephtsLevels_010yr_Event.mxd

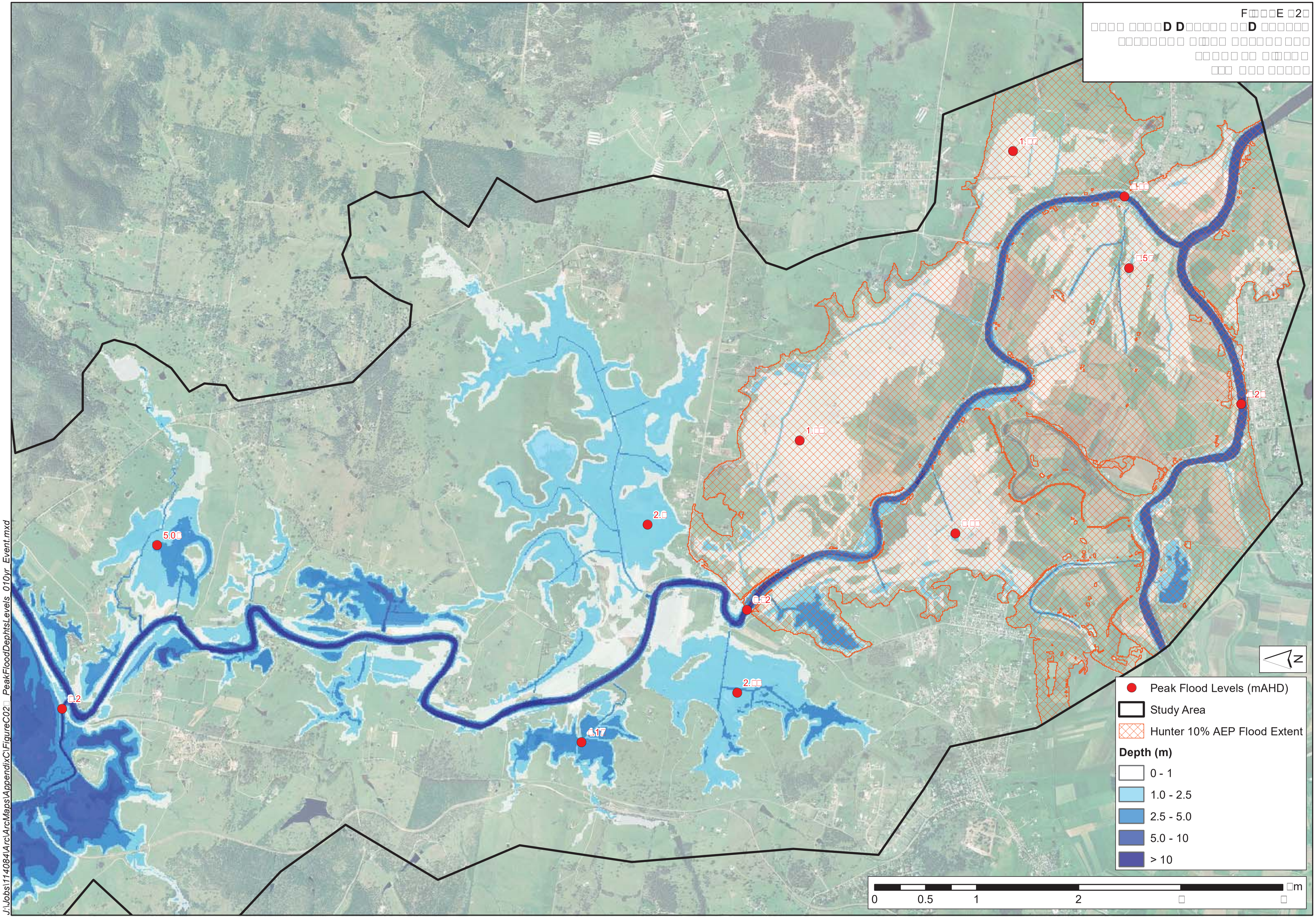
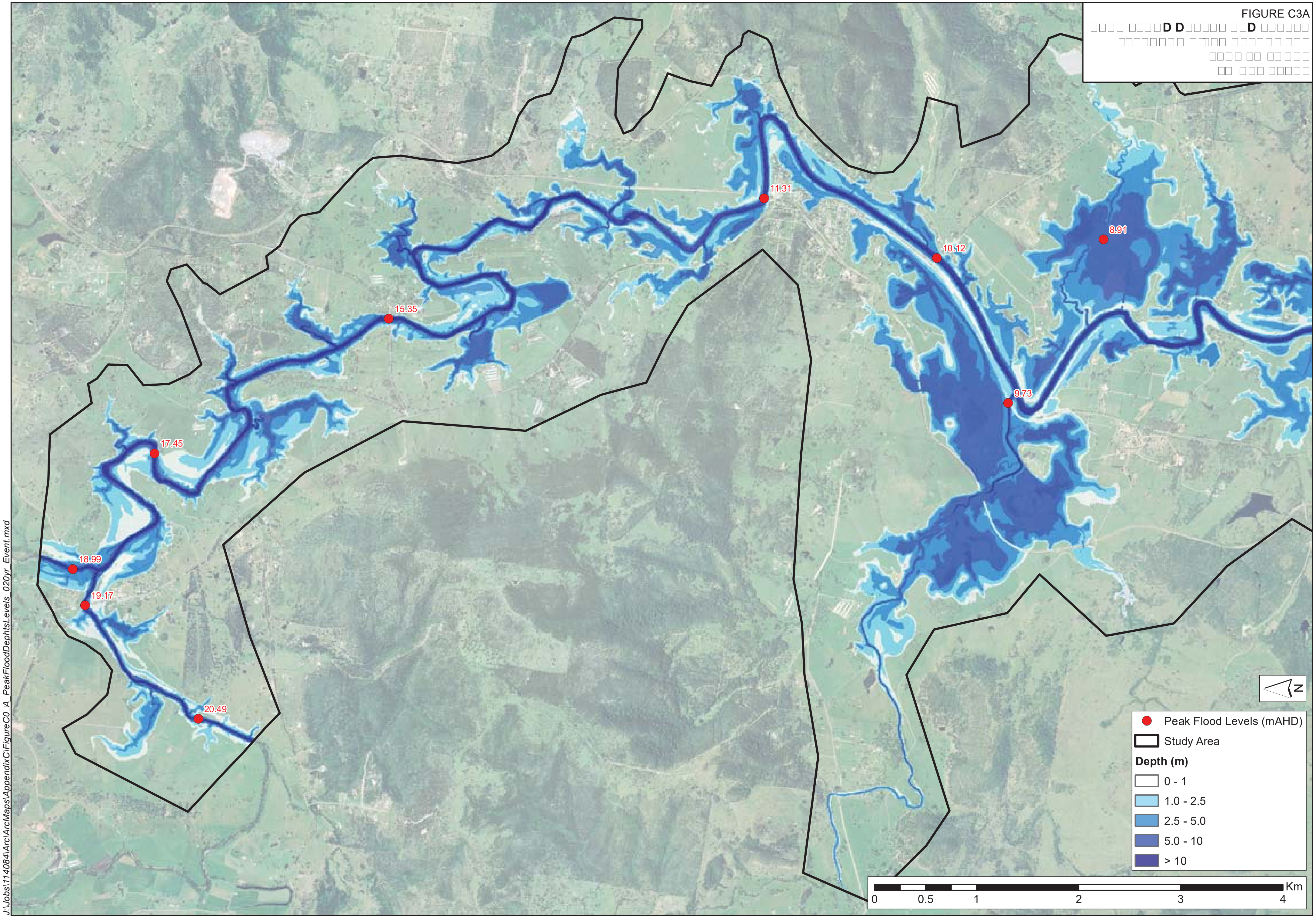
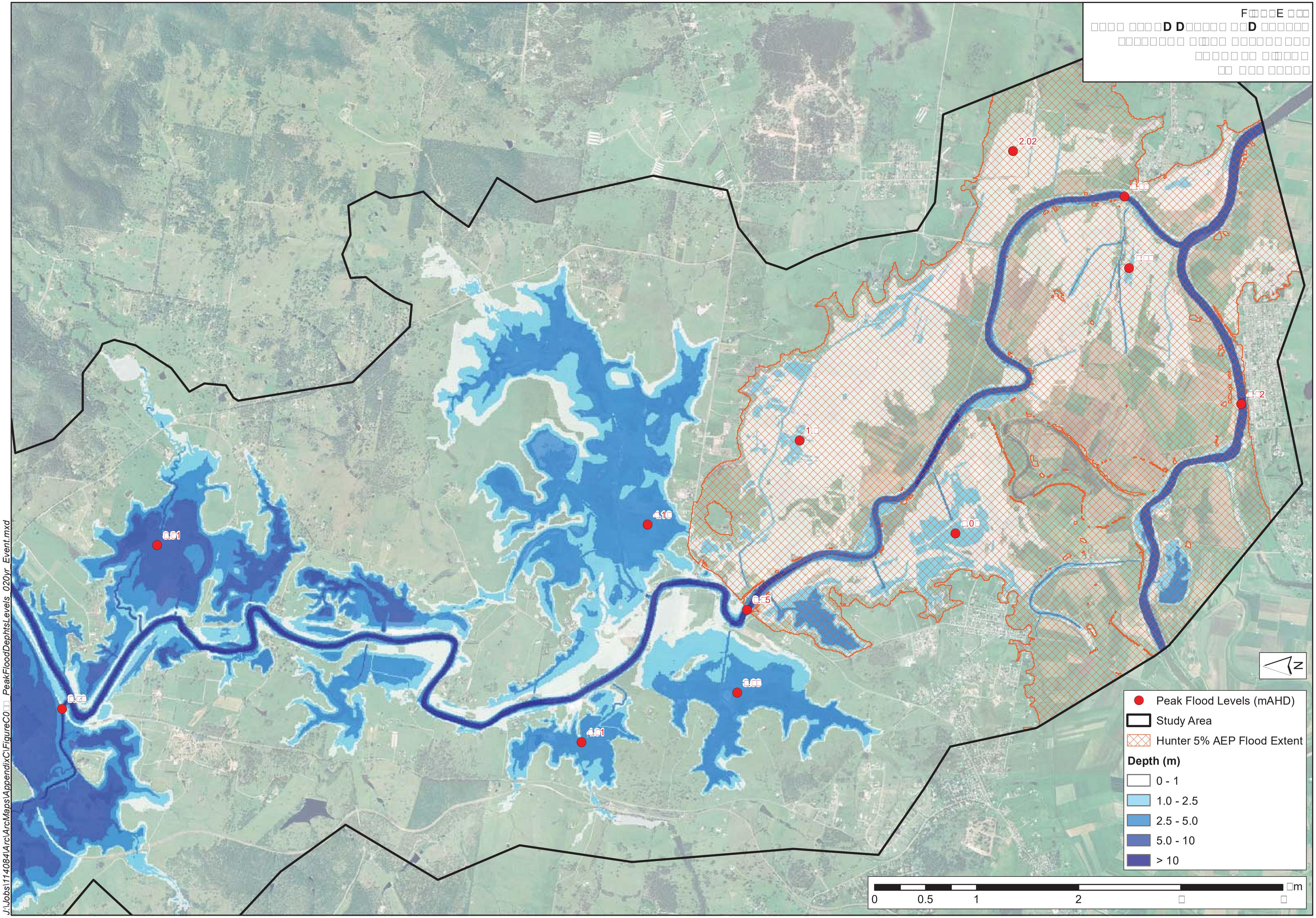

Peak Flood Levels (mAHD)
Study Area
Hunter 10% AEP Flood Extent
Depth (m)
0 - 1
1.0 - 2.5
2.5 - 5.0
5.0 - 10
> 10
0
0.5
1
2
4.17
N
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC02 PeakFloodDepthsLevels_010yr_Event.mxd

FIGURE C3A

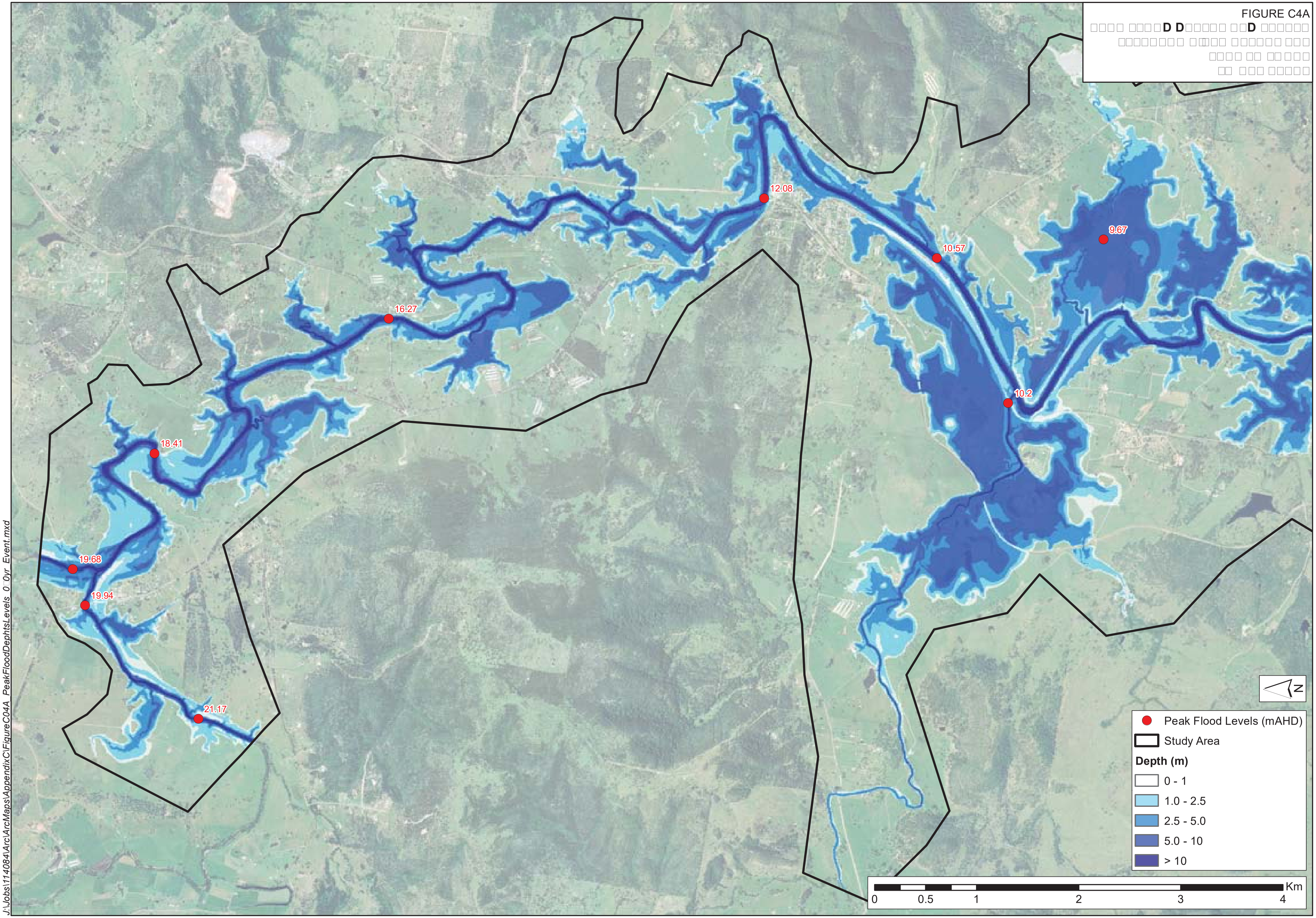


J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC0_A_PeakFloodDephtsLevels_020yr_Event.mxd

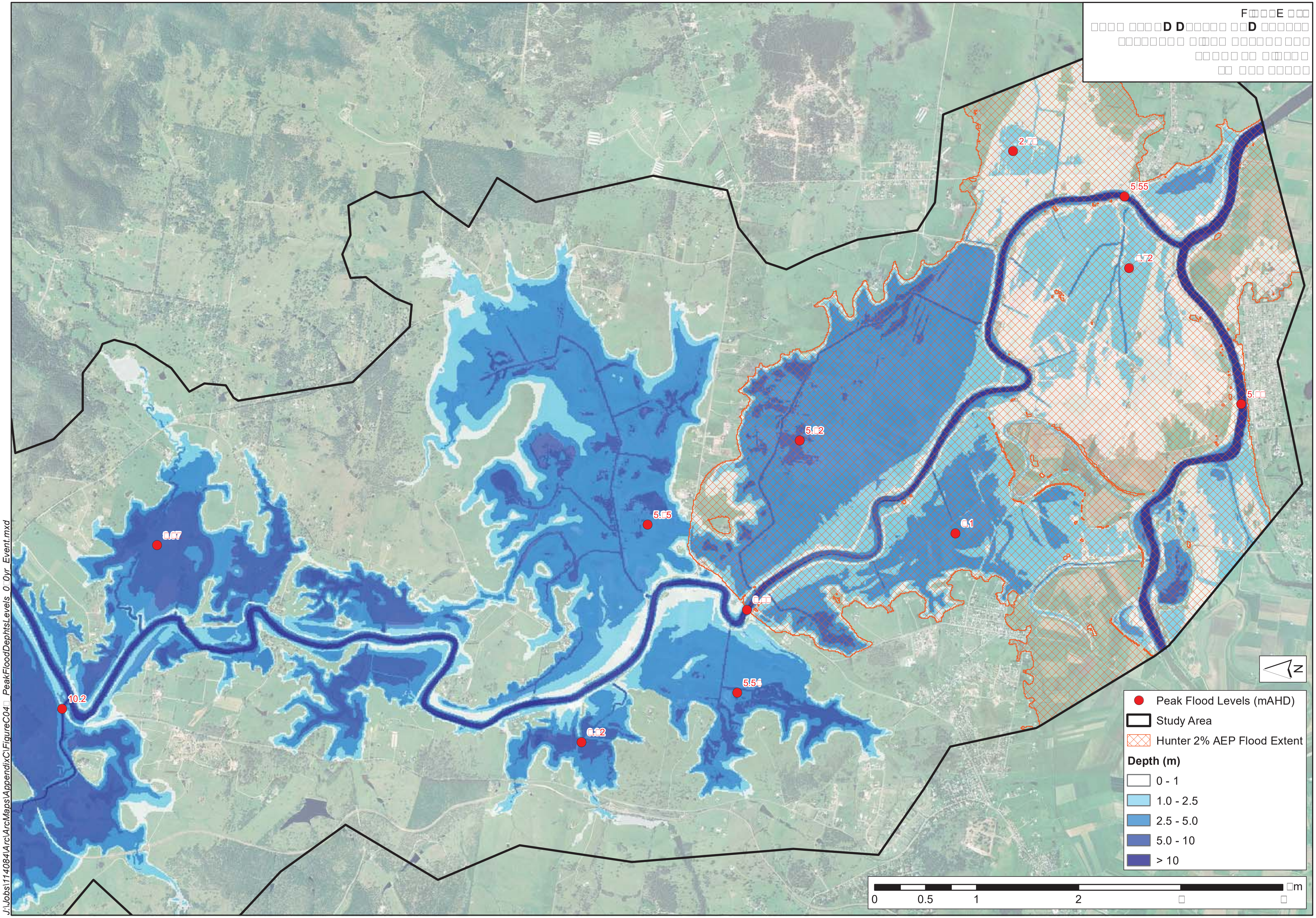


J:\Jobs\114084\Arc\ArcMaps\Appendix\C\FigureC0 PeakFloodDepthsLevels 020yr Event.mxd

FIGURE C4A

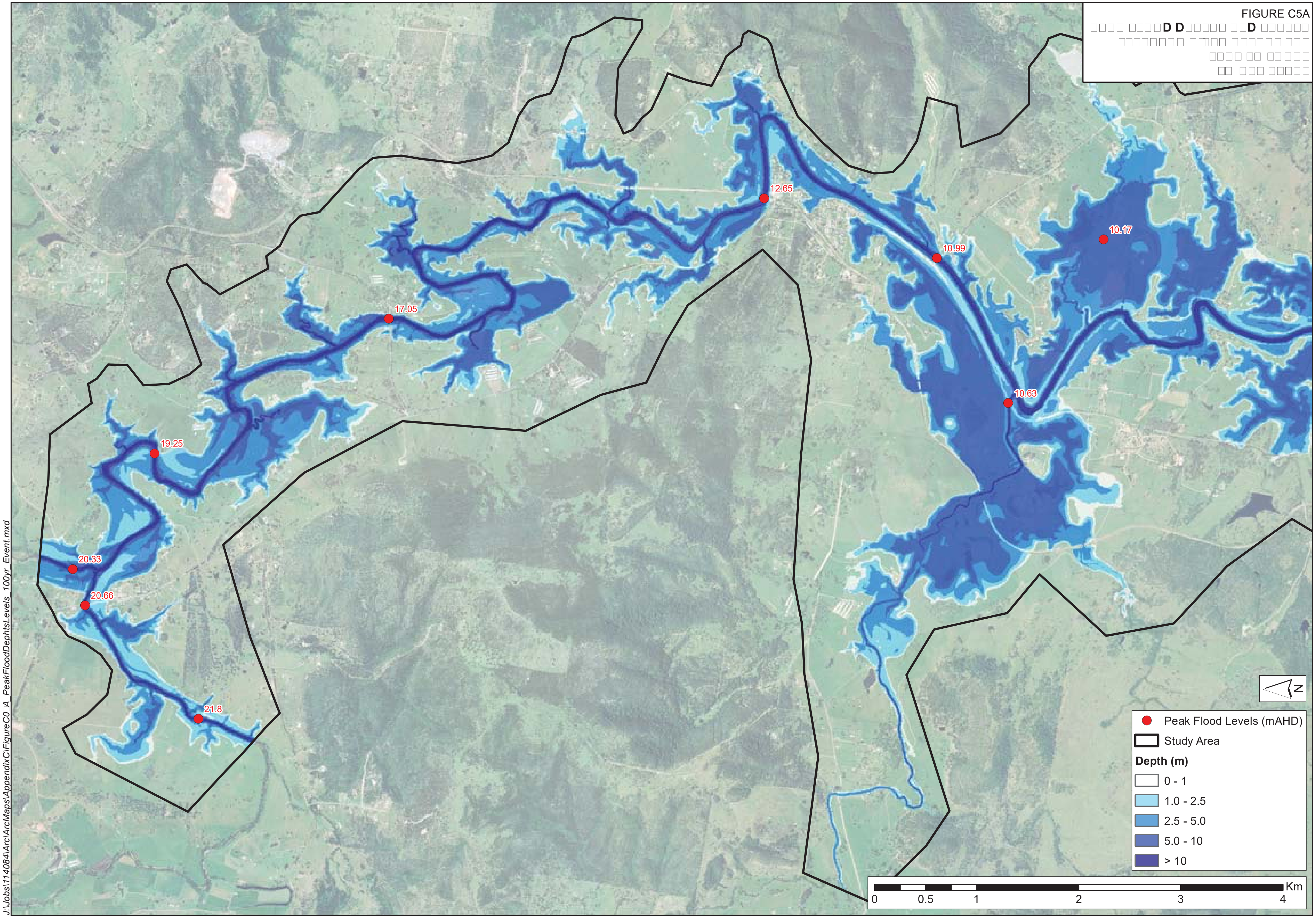


J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC04A_PeakFloodDepthsLevels_0_0yr_Event.mxd

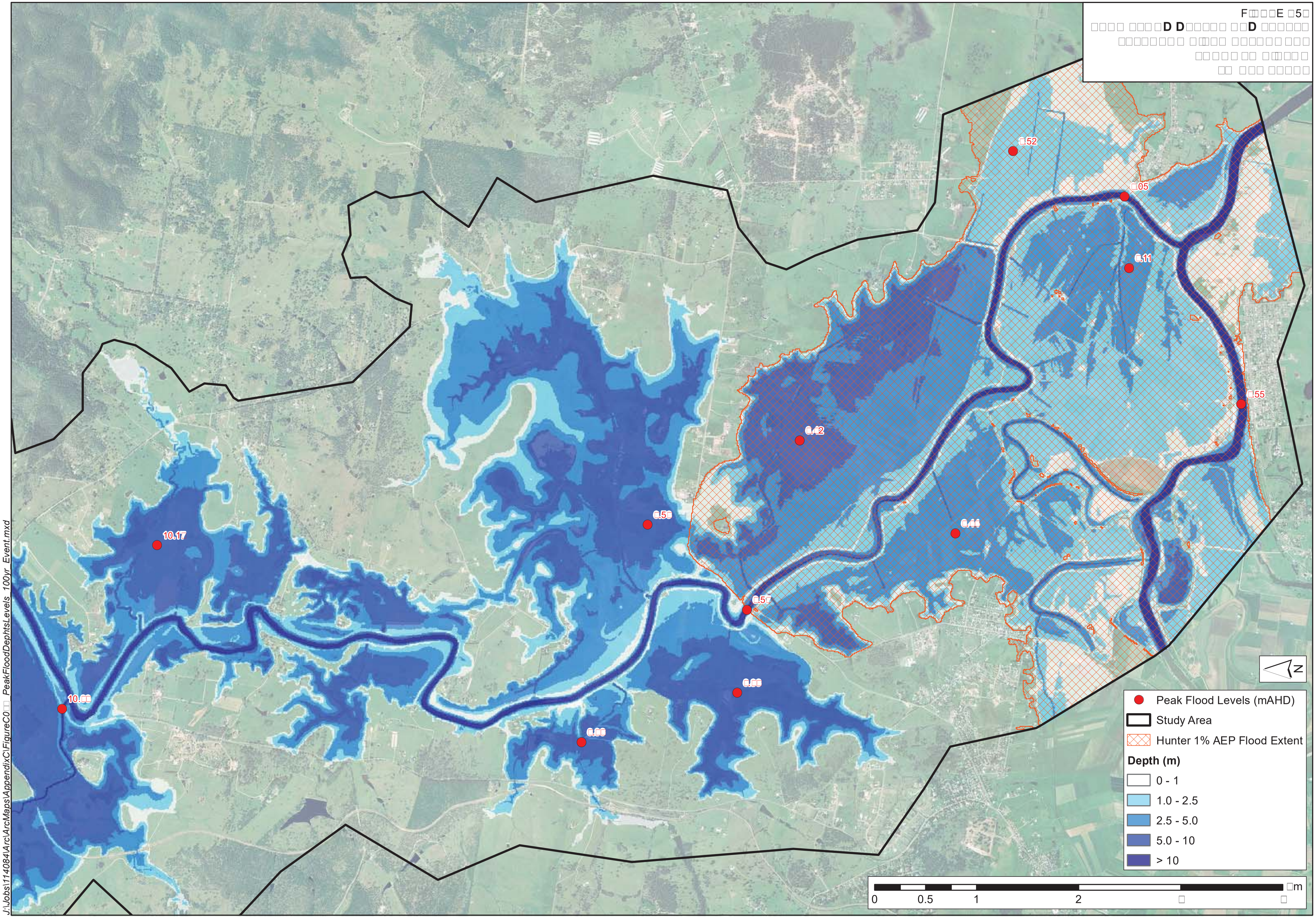


J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC04_ PeakFloodDepthsLevels_0_0yr_Event.mxd

FIGURE C5A



J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC0_A_PeakFloodDepthsLevels_100yr_Event.mxd



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC0 PeakFloodDepthsLevels 100yr Event.mxd

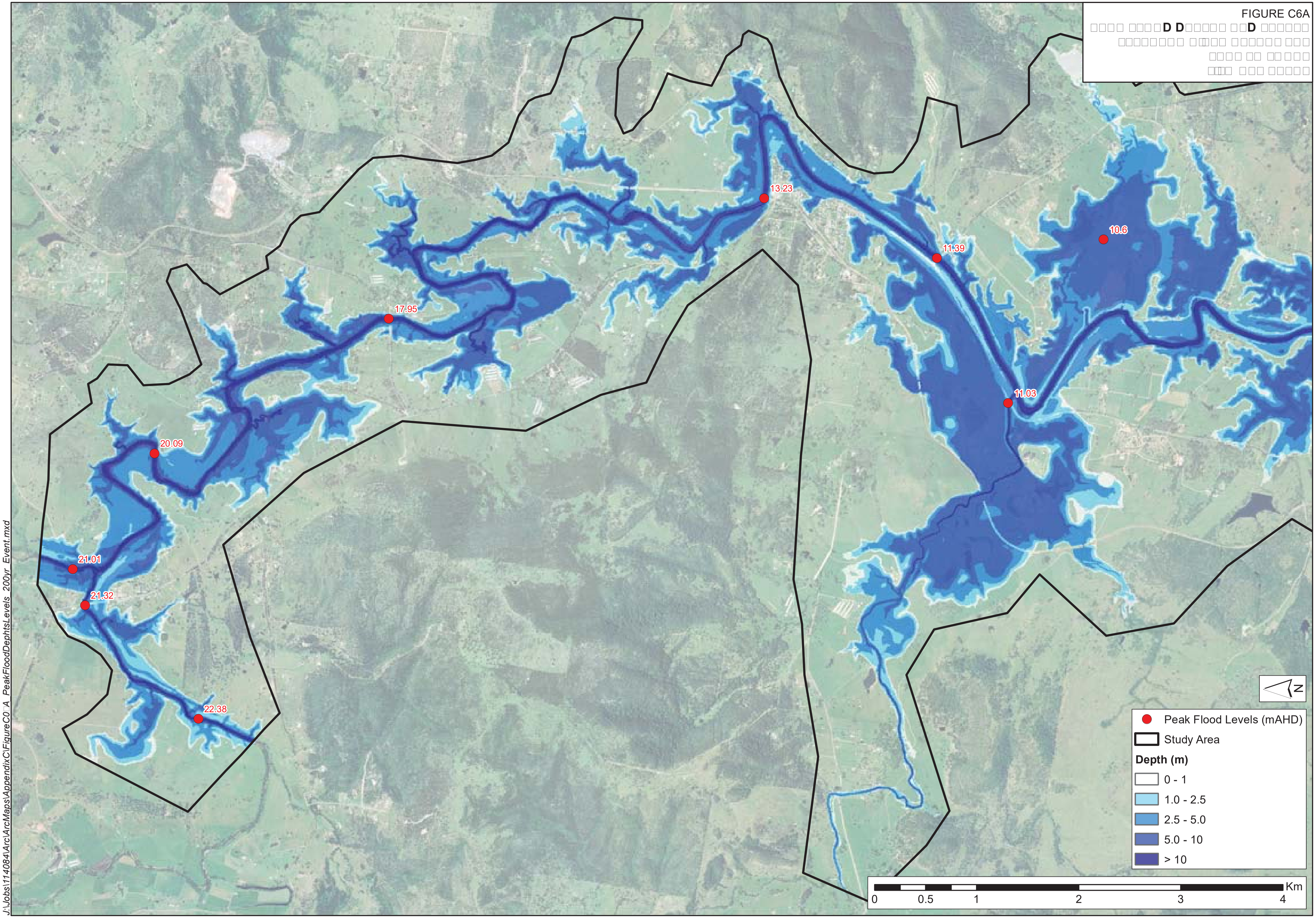


FIGURE C6A

J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC0_A_PeakFloodDephtsLevels_200yr_Event.mxd

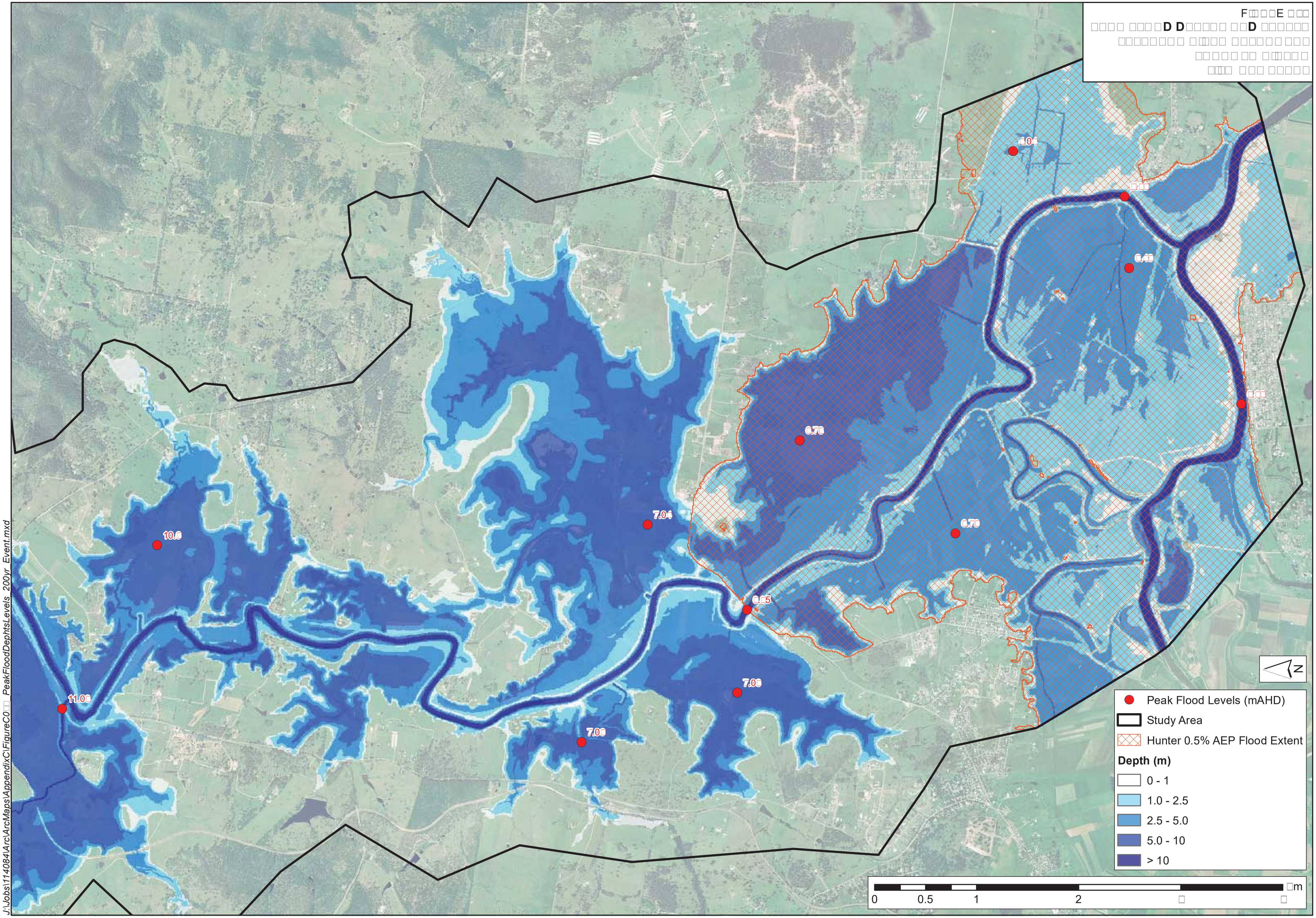
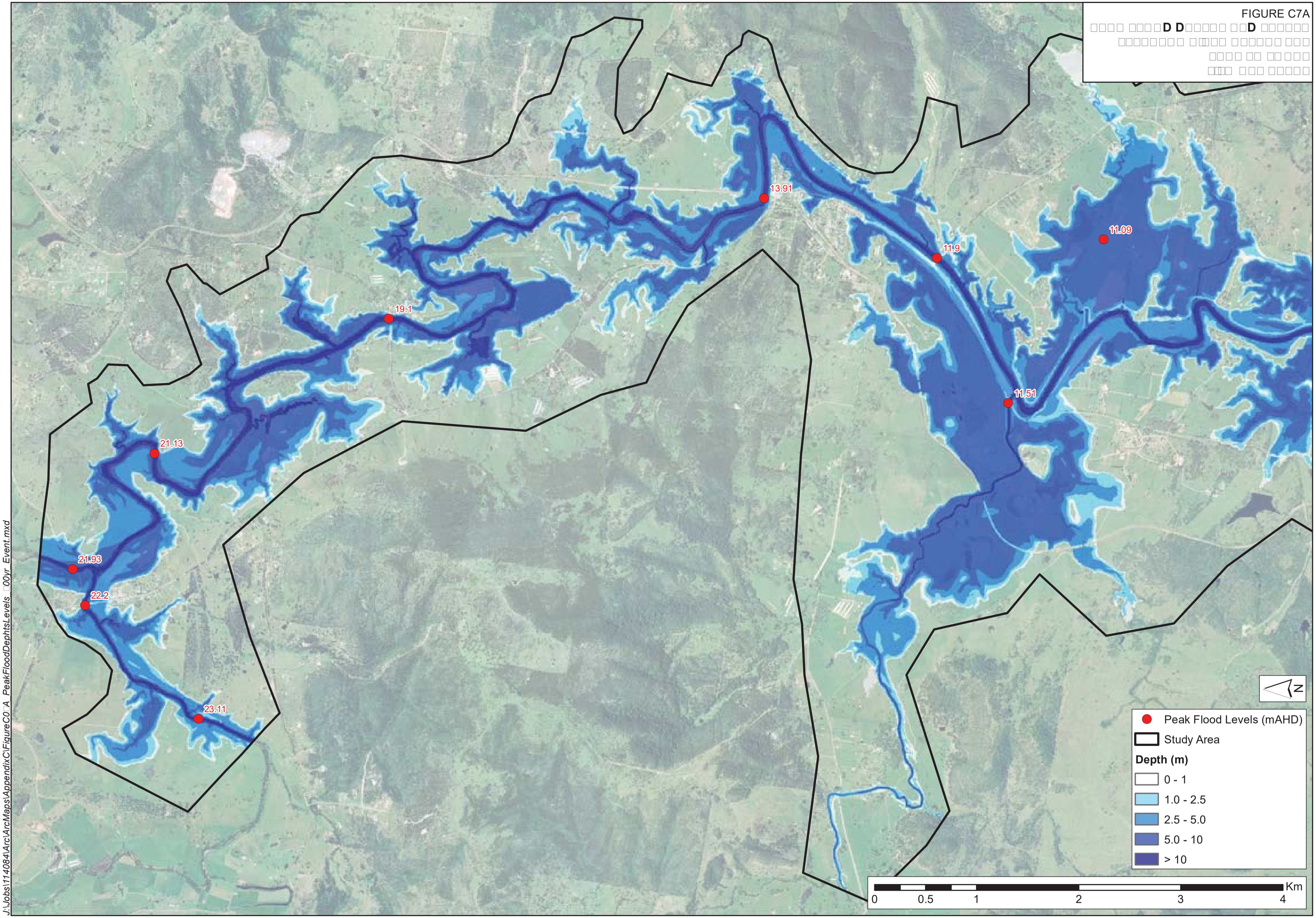
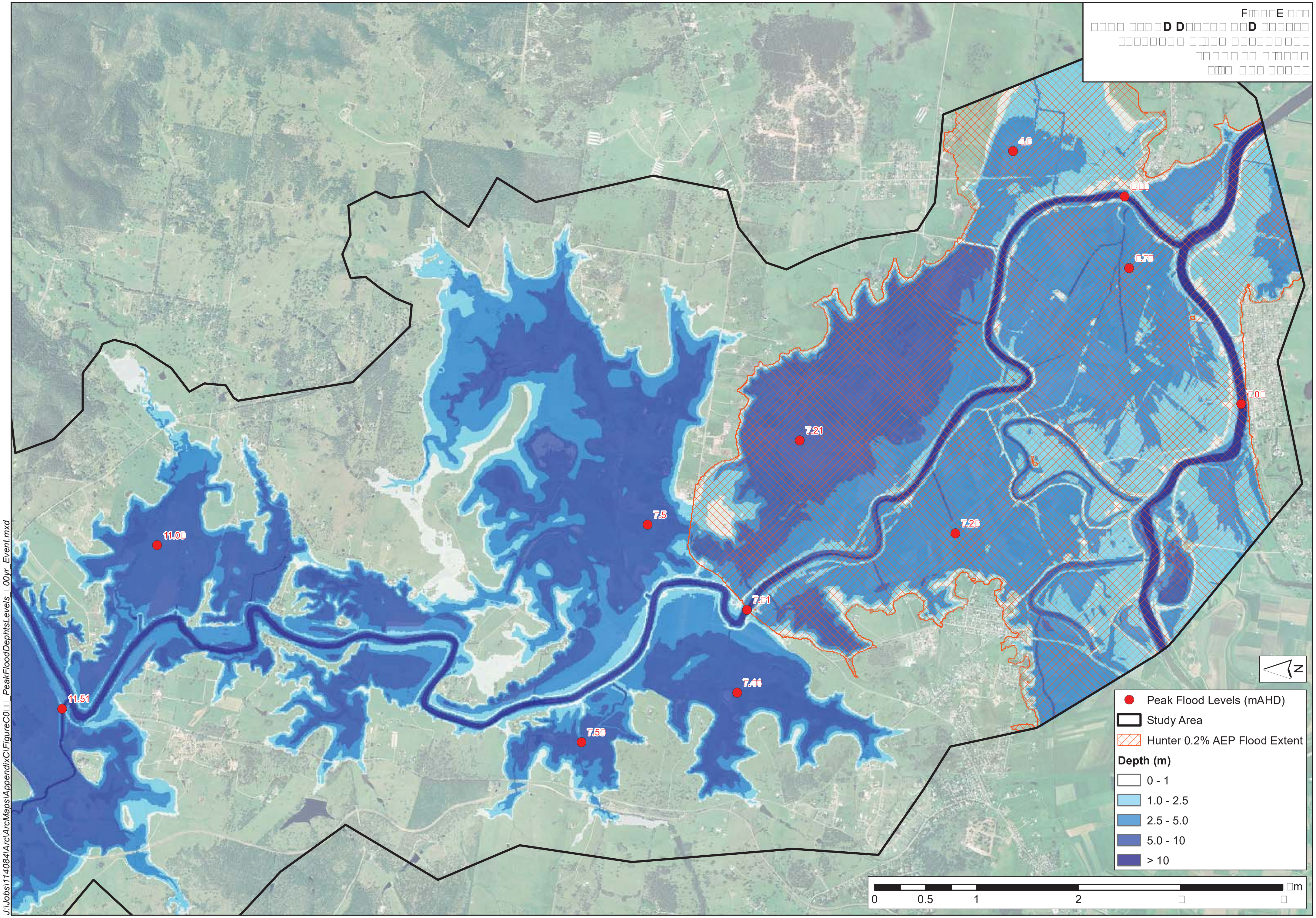

10.6
11.06
7.04
7.06
7.08
6.76
6.78
6.5
1.01
N
Peak Flood Levels (mAHD)
Study Area
Hunter 0.5% AEP Flood Extent
Depth (m)
0 - 1
1.0 - 2.5
2.5 - 5.0
5.0 - 10
> 10
0
0.5
1
2

FIGURE C7A

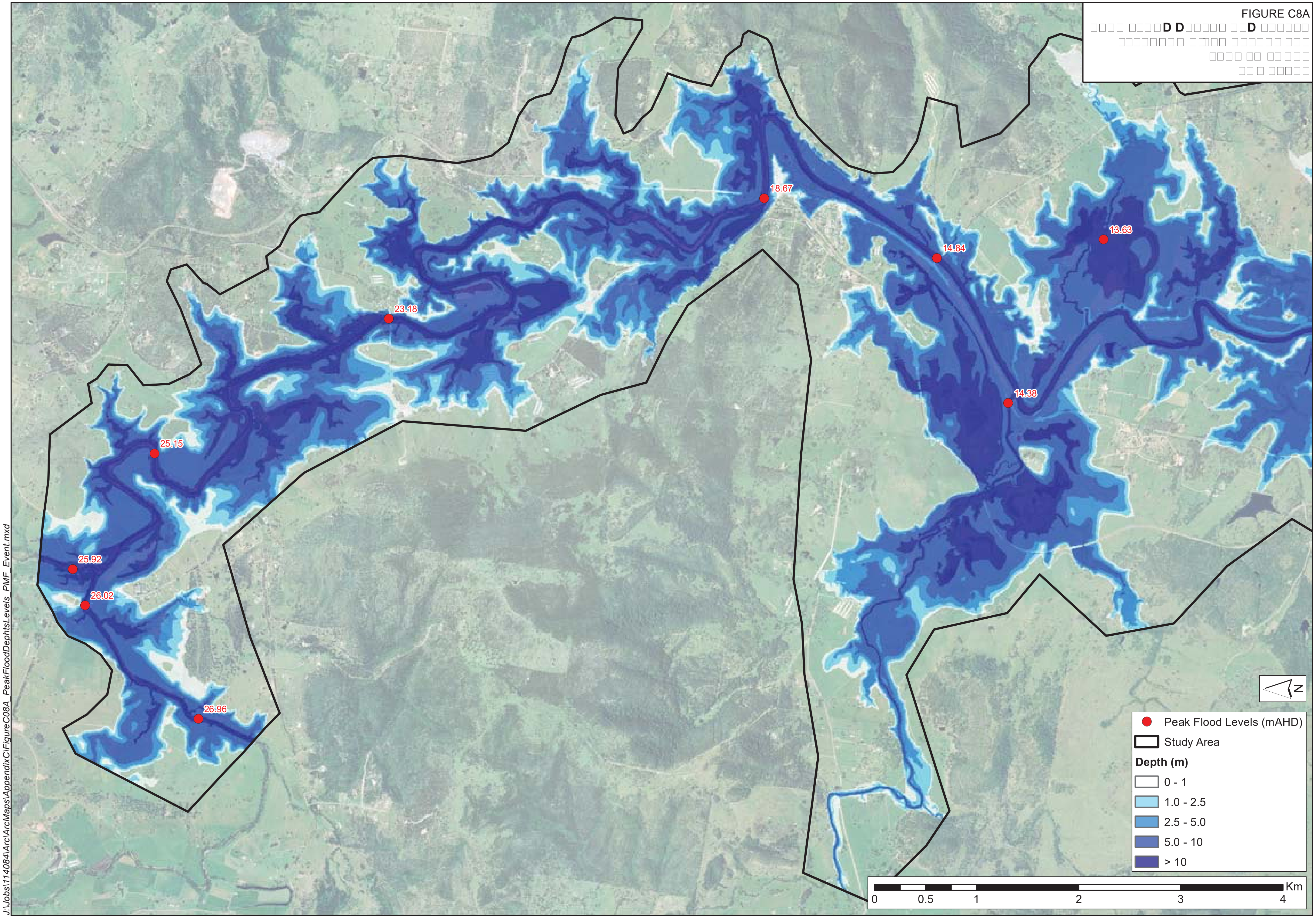


J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC0_A_PeakFloodDepthsLevels_00yr_Event.mxd

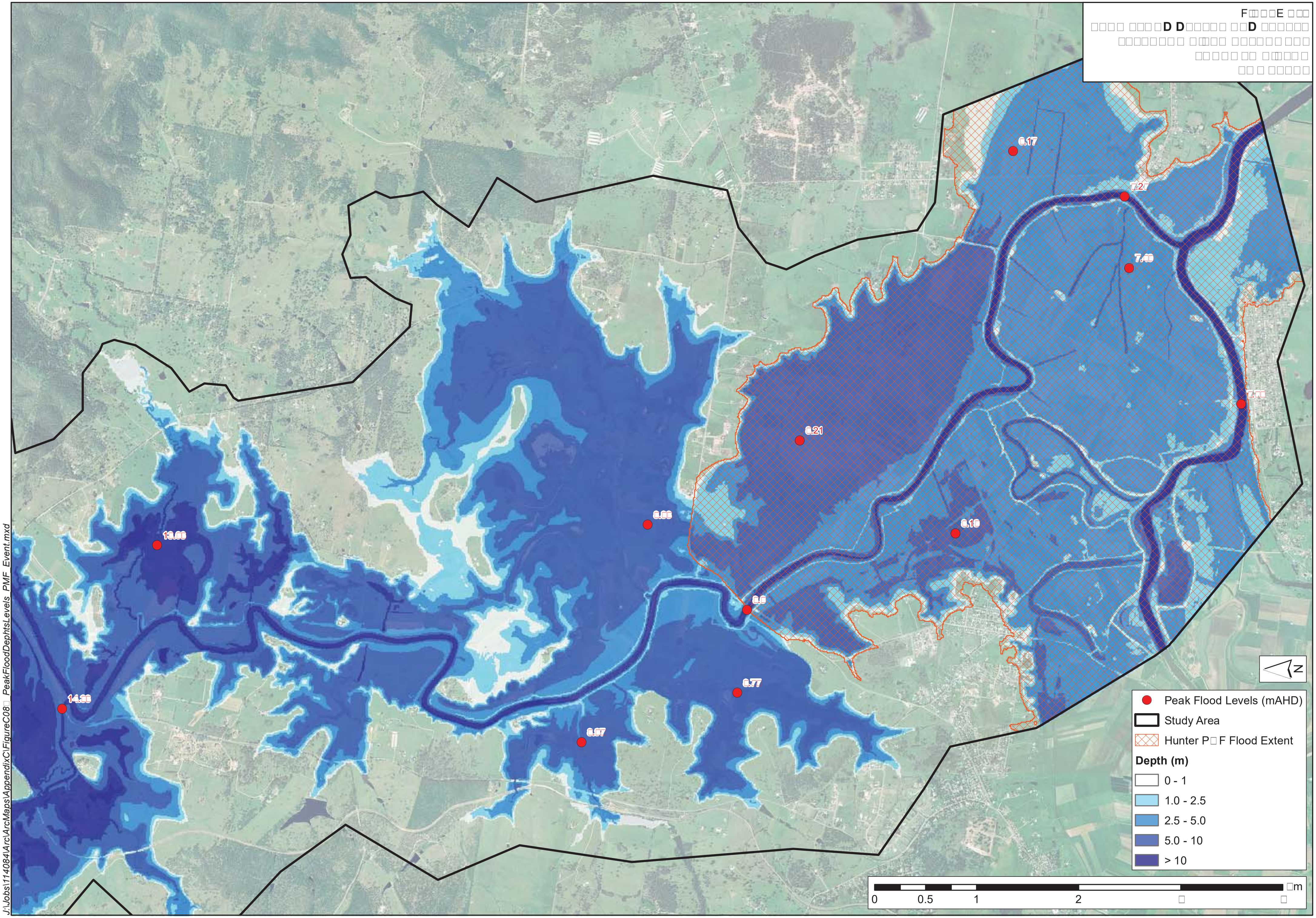


J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC0 PeakFloodDepthsLevels 00yr Event.mxd

FIGURE C8A



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC08A_PeakFloodDephtsLevels_PMF_Event.mxd



Peak Flood Levels (mAHD)
Study Area
Hunter PF Flood Extent
Depth (m)
0 - 1
1.0 - 2.5
2.5 - 5.0
5.0 - 10
> 10
0
0.5
1
2
m
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC08_PeakFloodDepthsLevels_PMF_Event.mxd

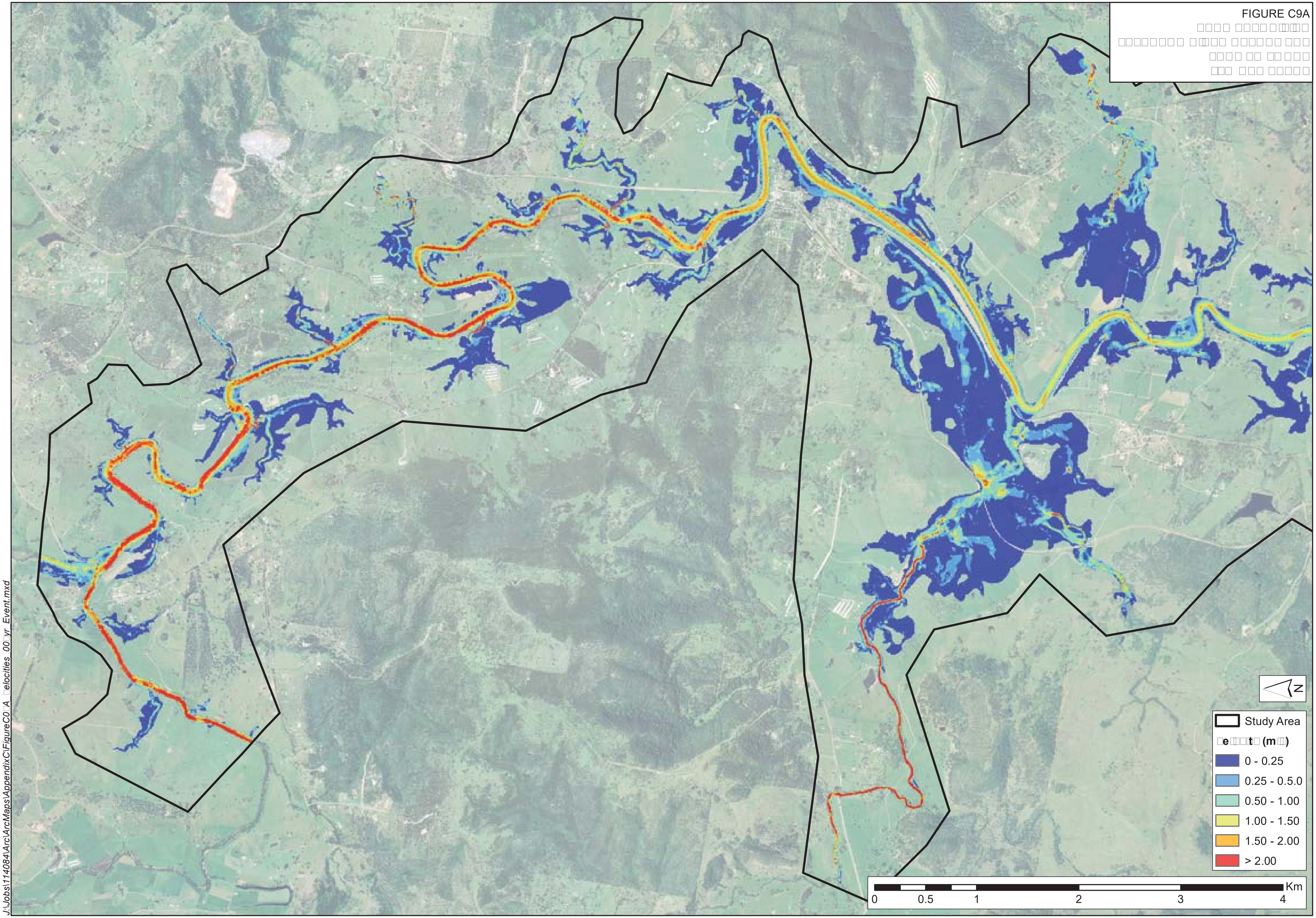
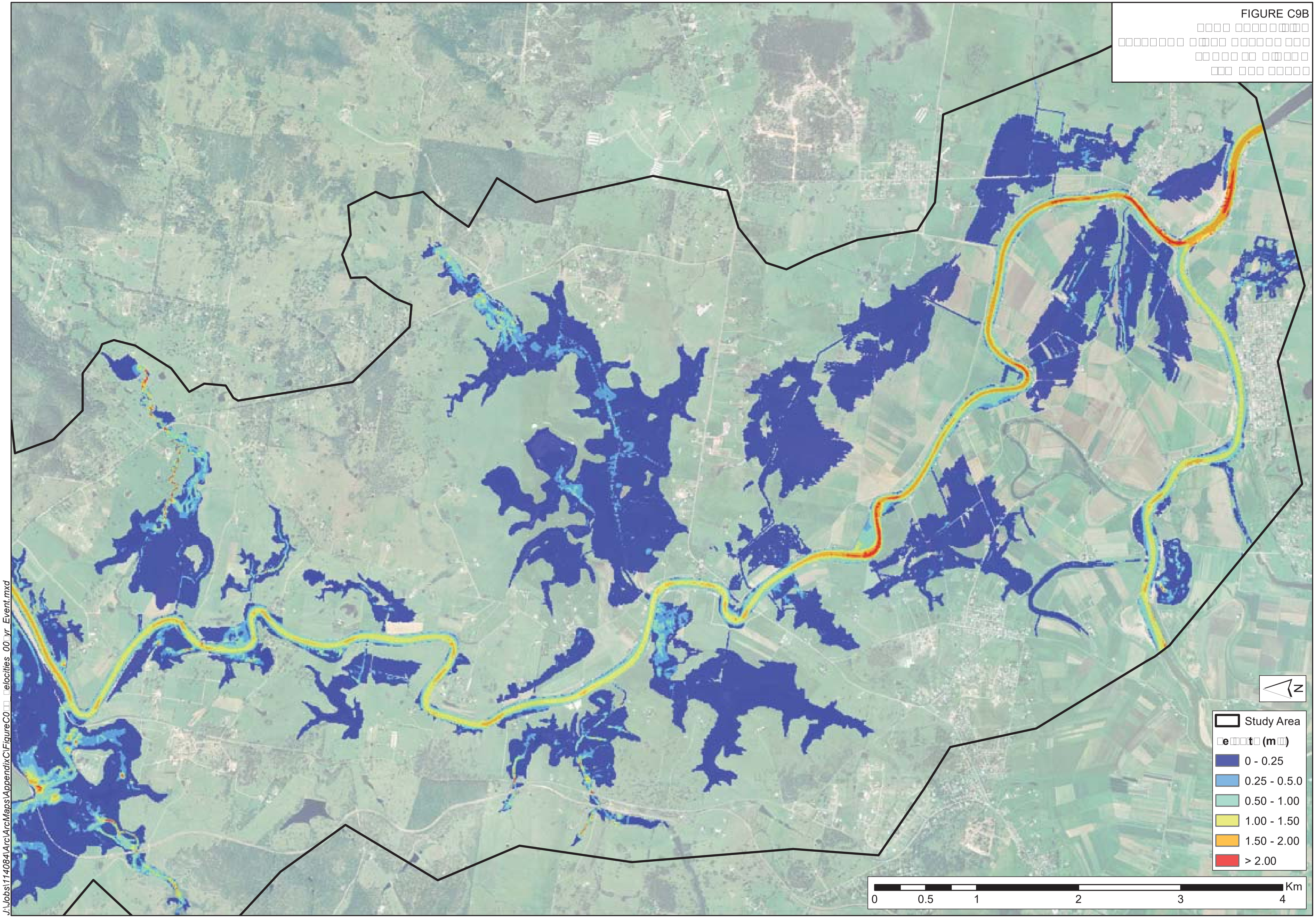


FIGURE C9A

J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC0 A elocities 00 yr Event.mxd



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC0 elocities 00 yr Event.mxd

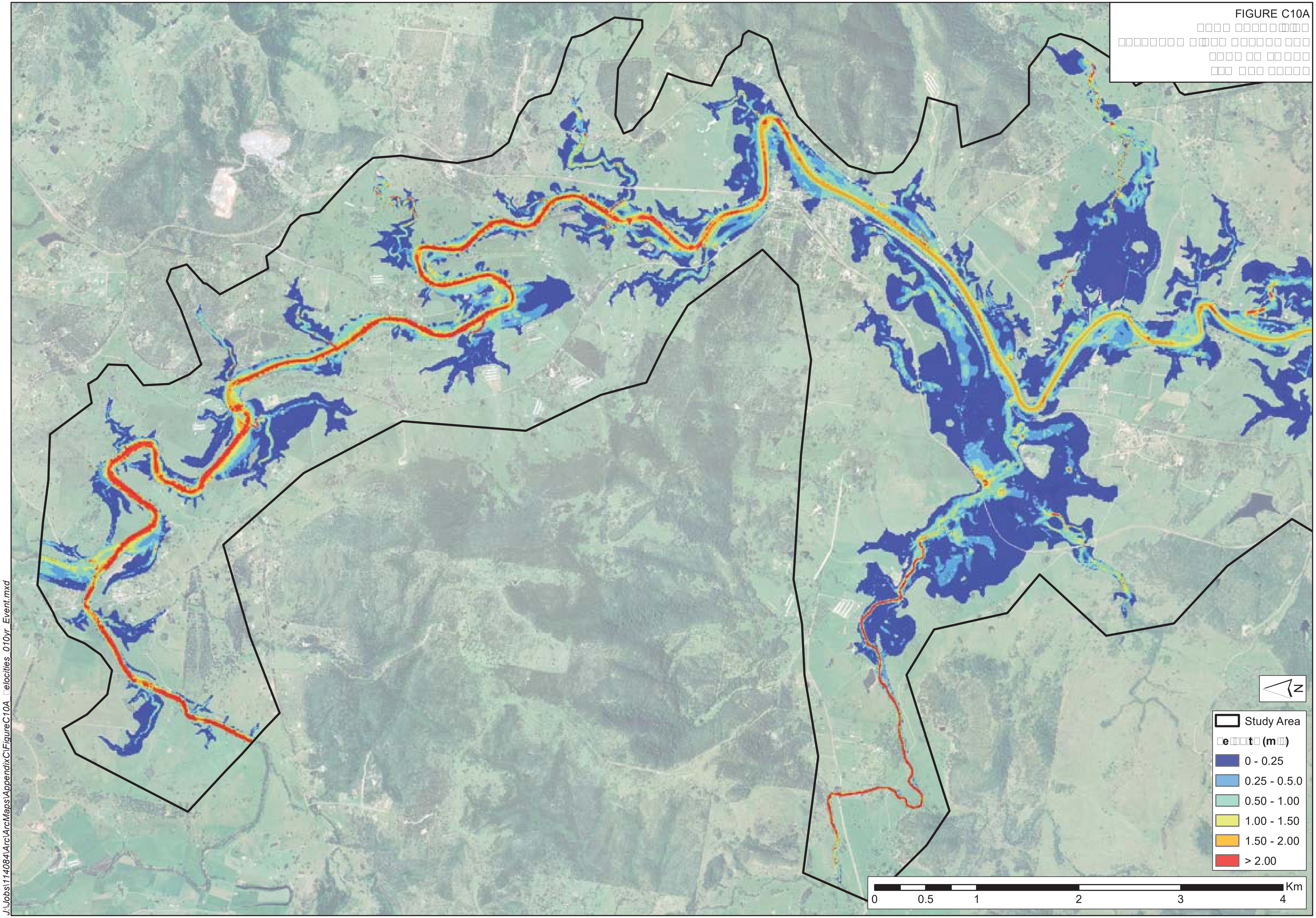
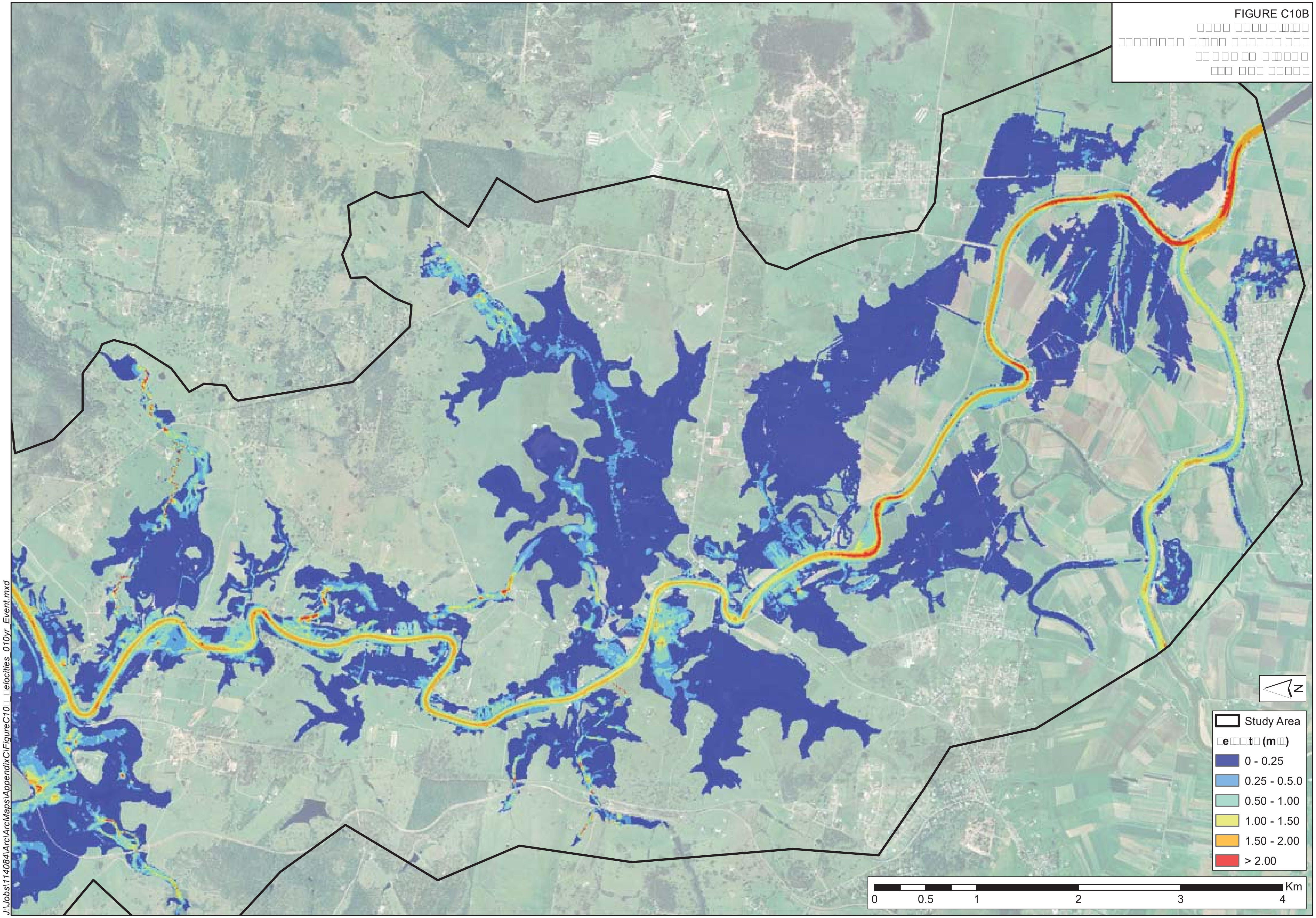


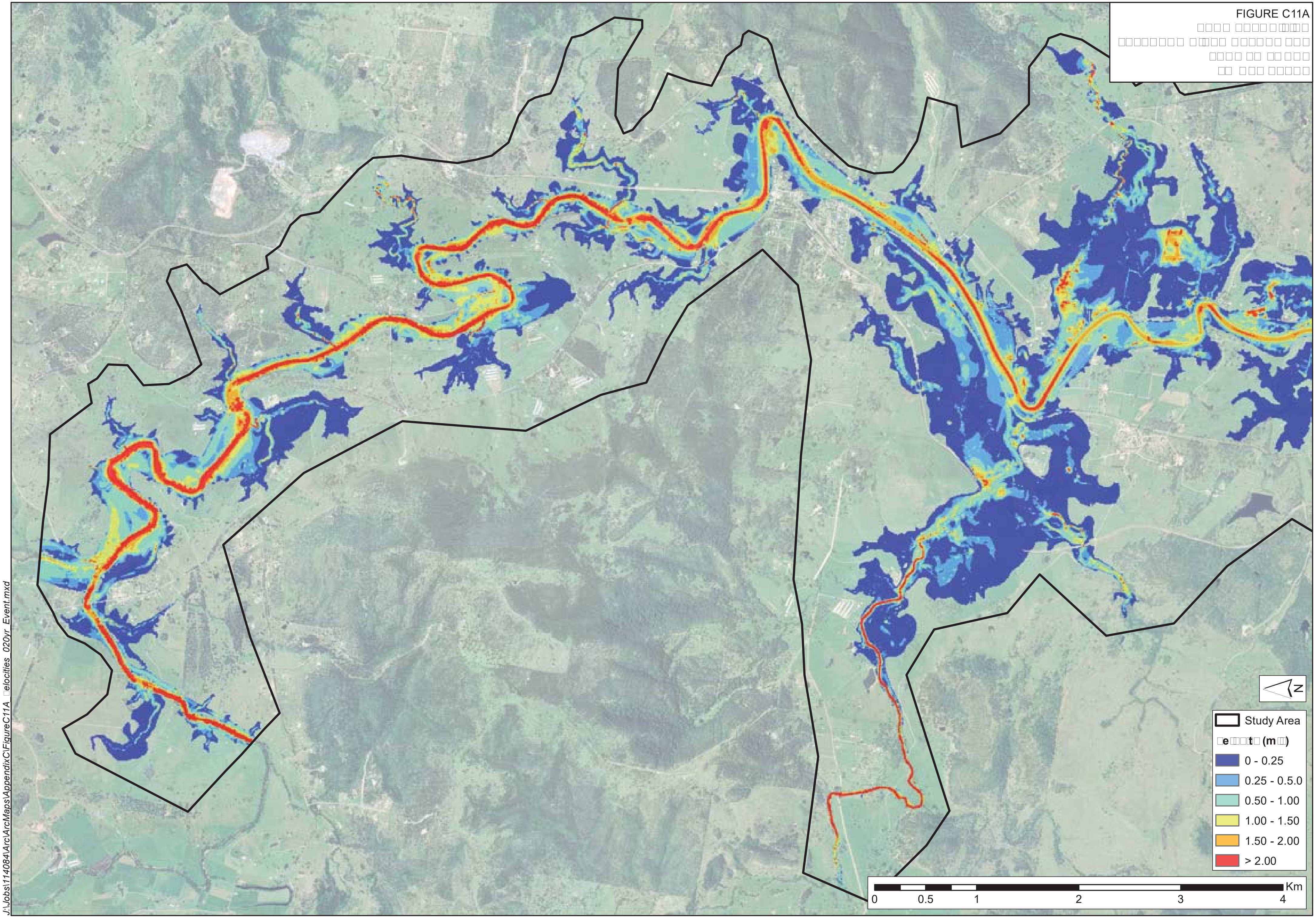
FIGURE C10A
Study Area
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
N
0
0.5
1
2
3
4
Km
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC10A elocities 010yr Event.mxd

FIGURE C10B



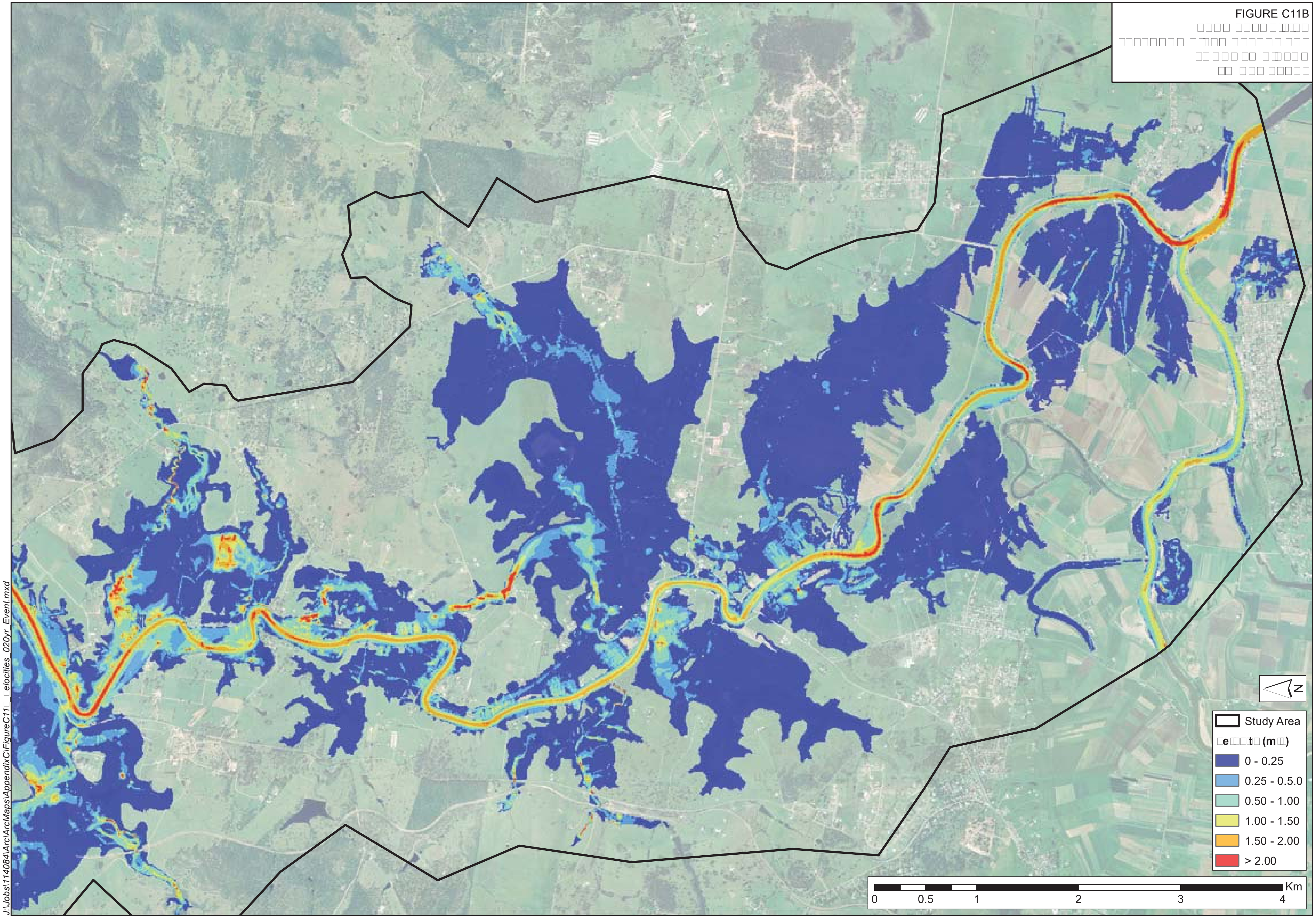
Study Area
(m)
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
Km
0
0.5
1
2
3
4
N
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC10 elocities 010yr Event.mxd

FIGURE C11A



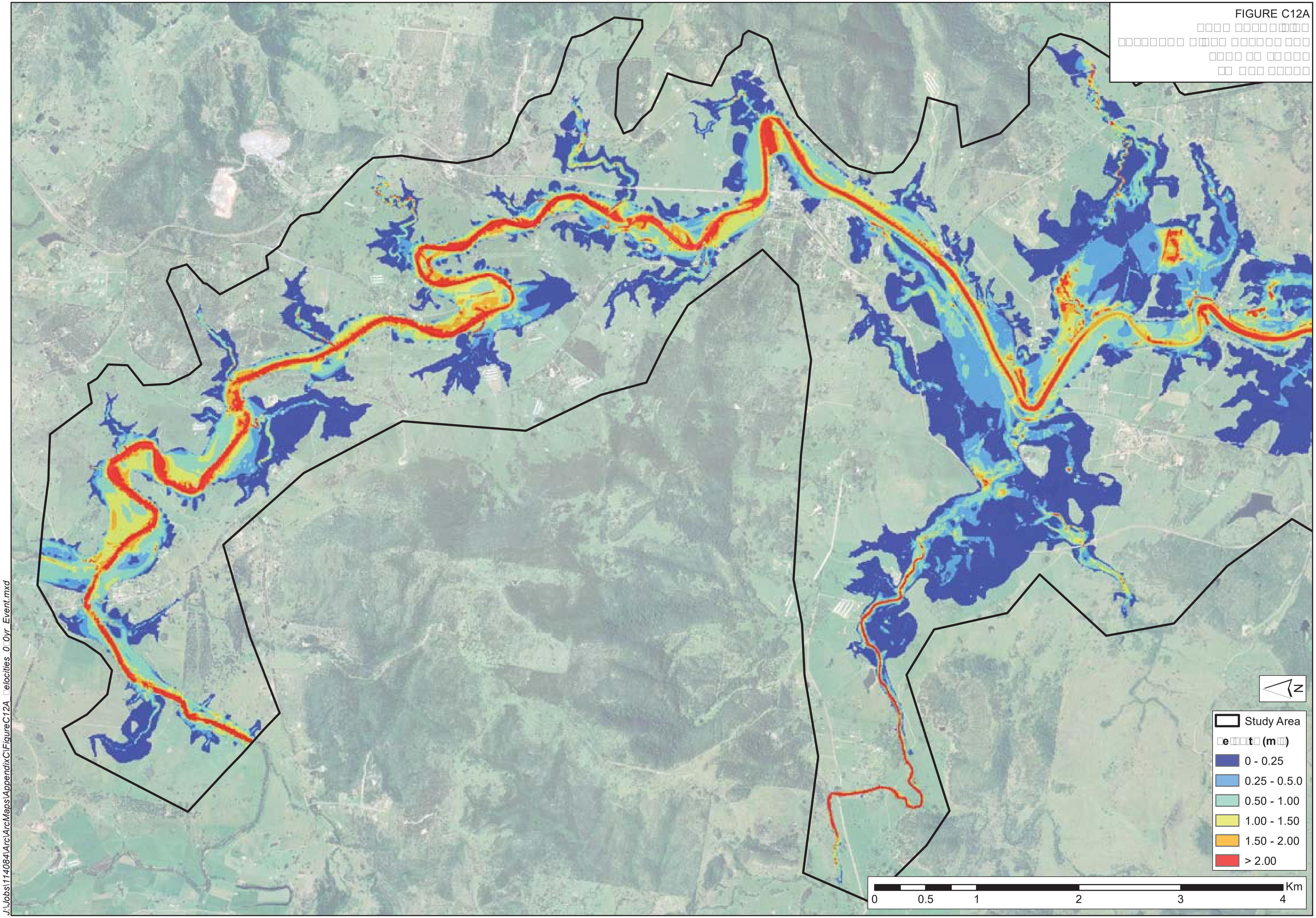
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC11A elocities 020yr Event.mxd

FIGURE C11B



J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC11 elocities 020yr Event.mxd

FIGURE C12A



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC12A

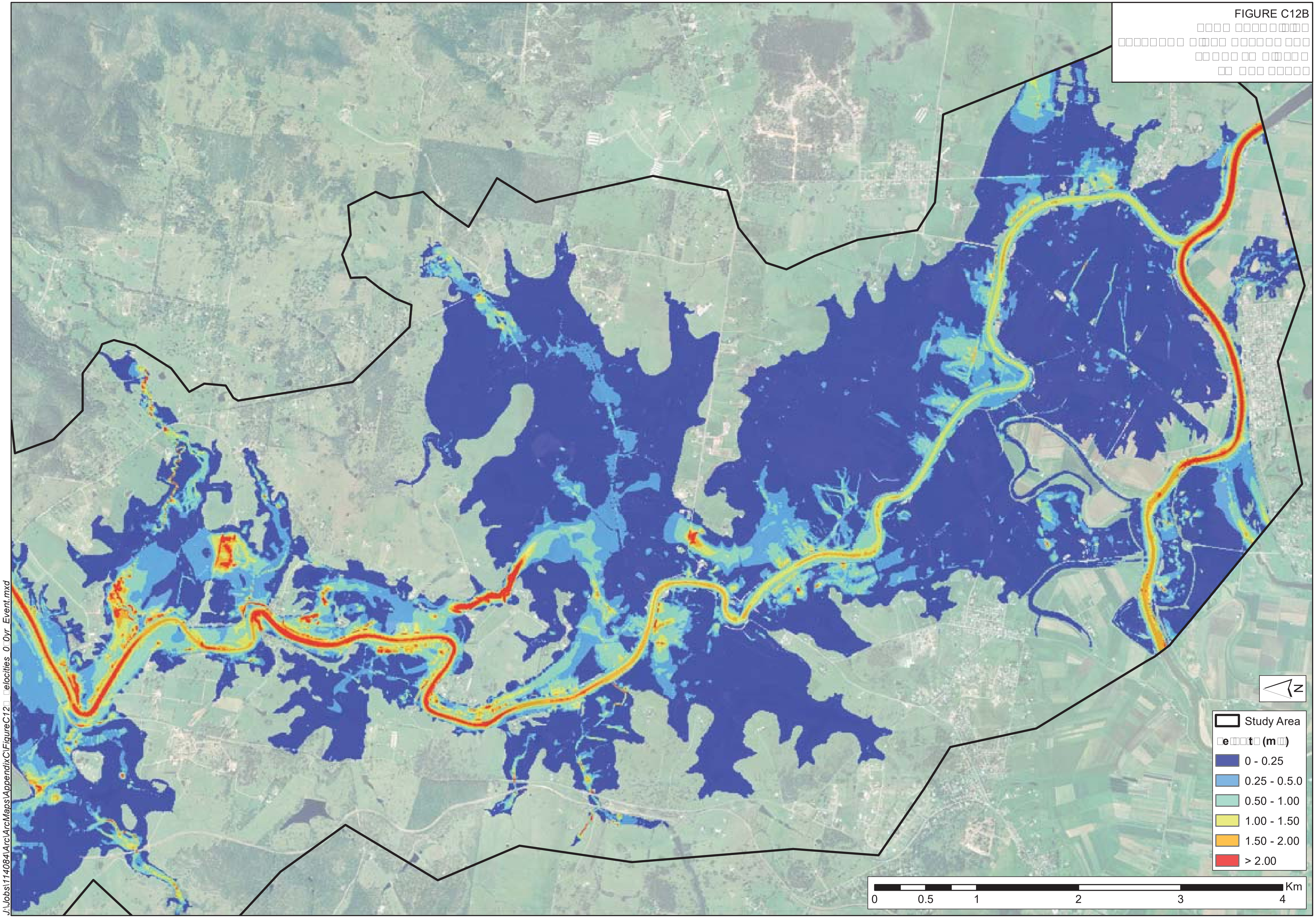
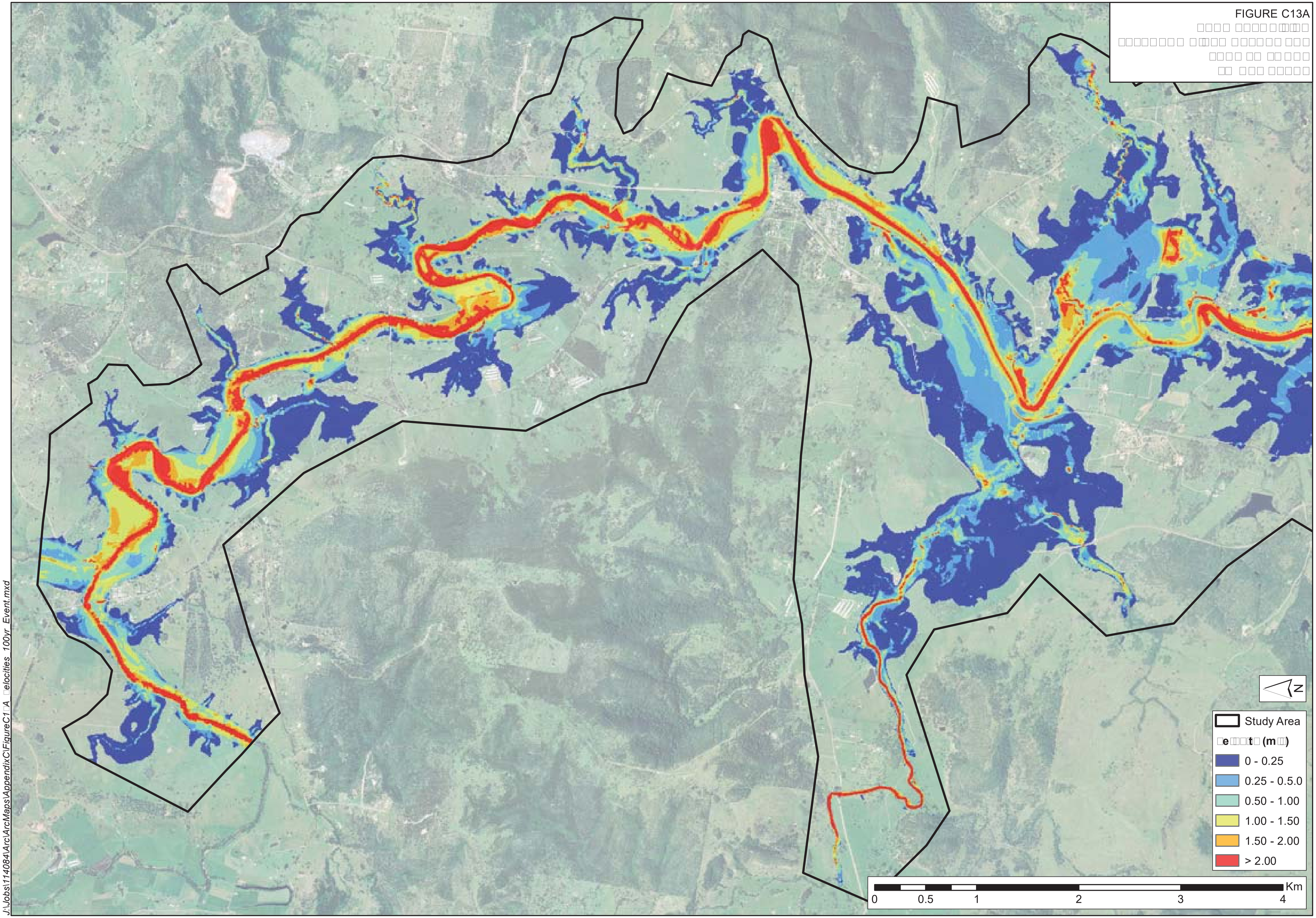

Study Area
e t (m)
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
N
0
0.5
1
2
3
4
Km
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC12 elocities 0 0yr Event.mxd

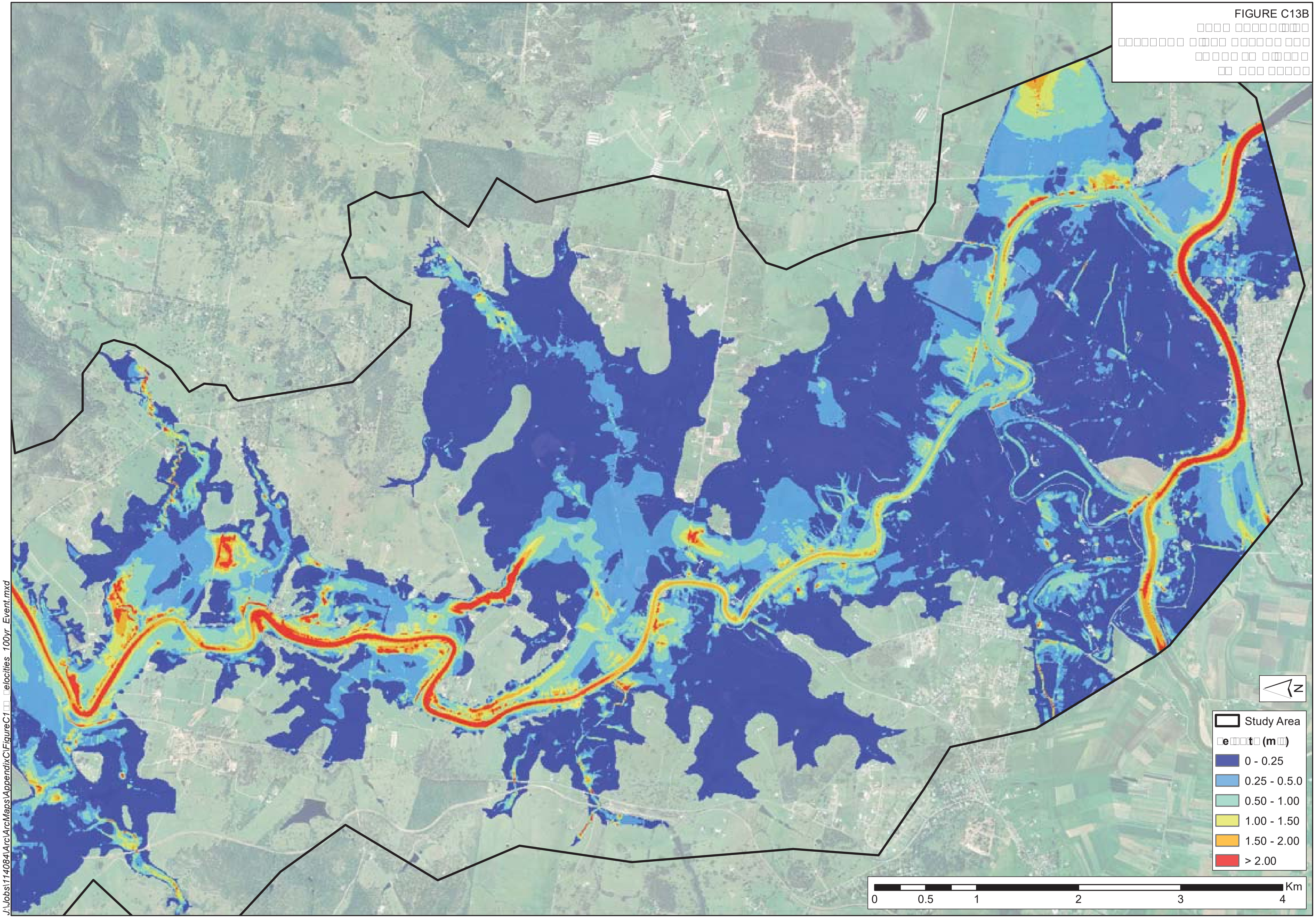
FIGURE C12B

FIGURE C13A



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC1 A elocities 100yr Event.mxd

FIGURE C13B



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC1 elocities 100yr Event.mxd

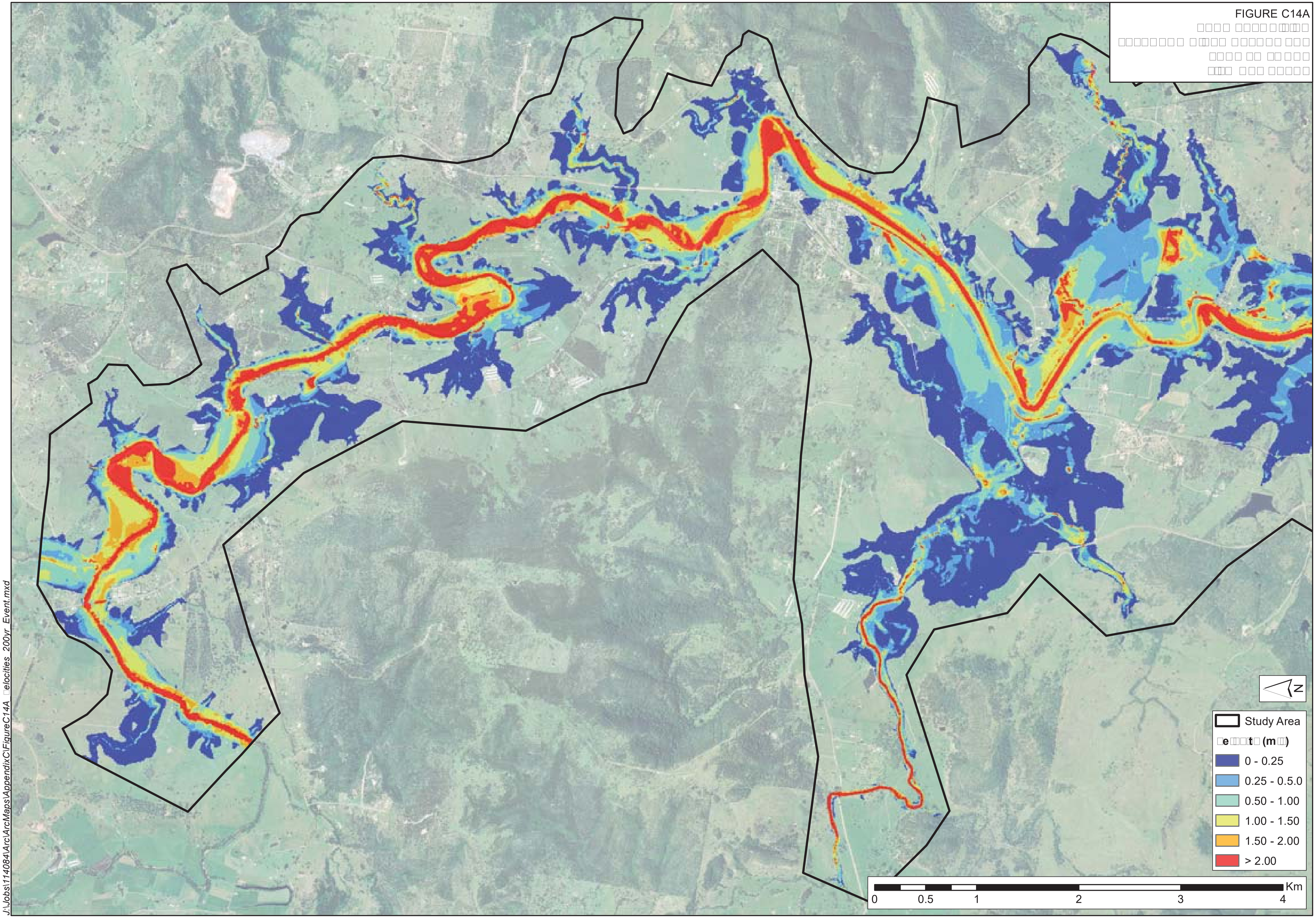


FIGURE C14A
Study Area
(m)
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
N
Km
0
0.5
1
2
3
4
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC14A elocities 200yr Event.mxd

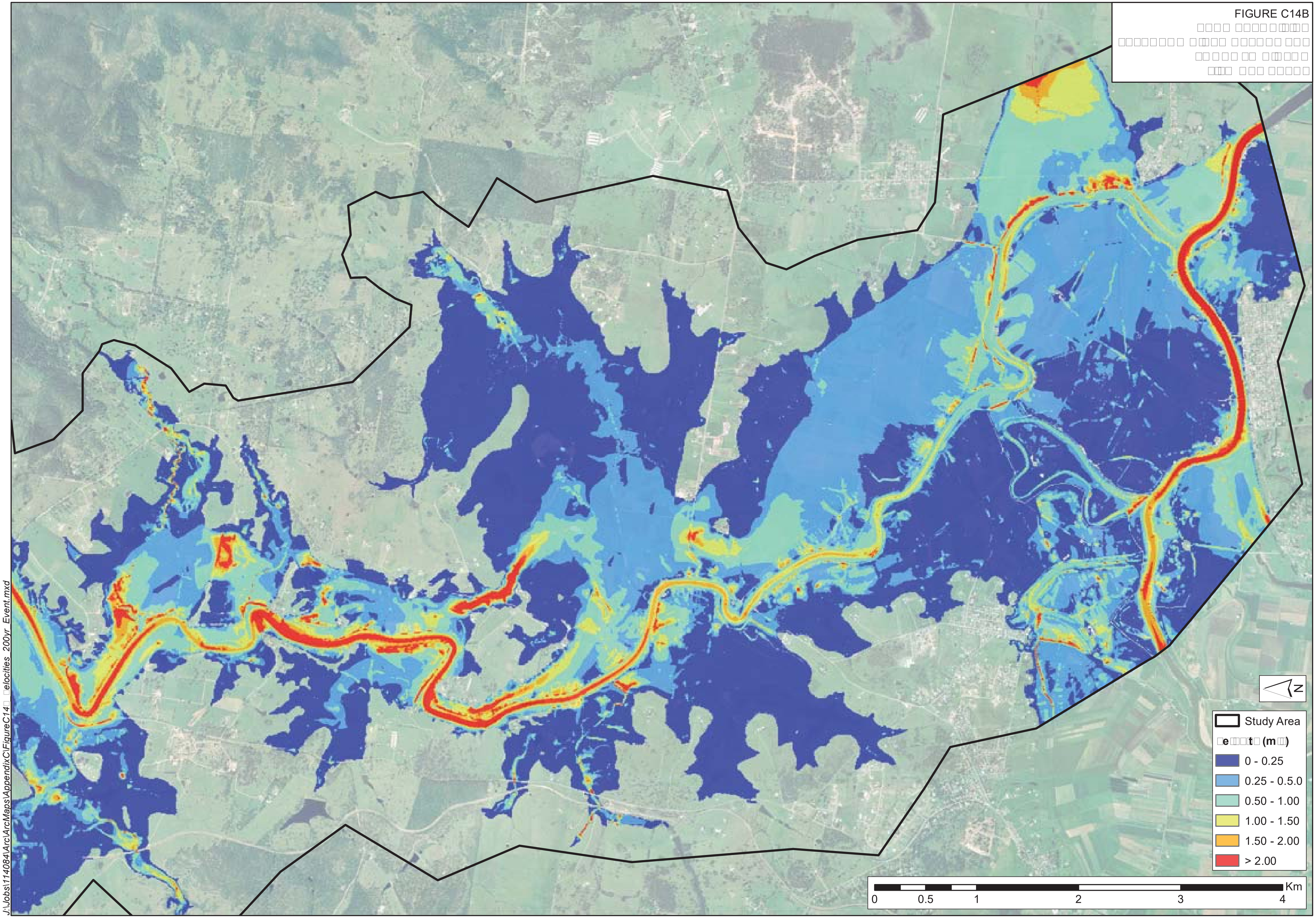


FIGURE C14B

J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC14 elocities 200yr Event.mxd

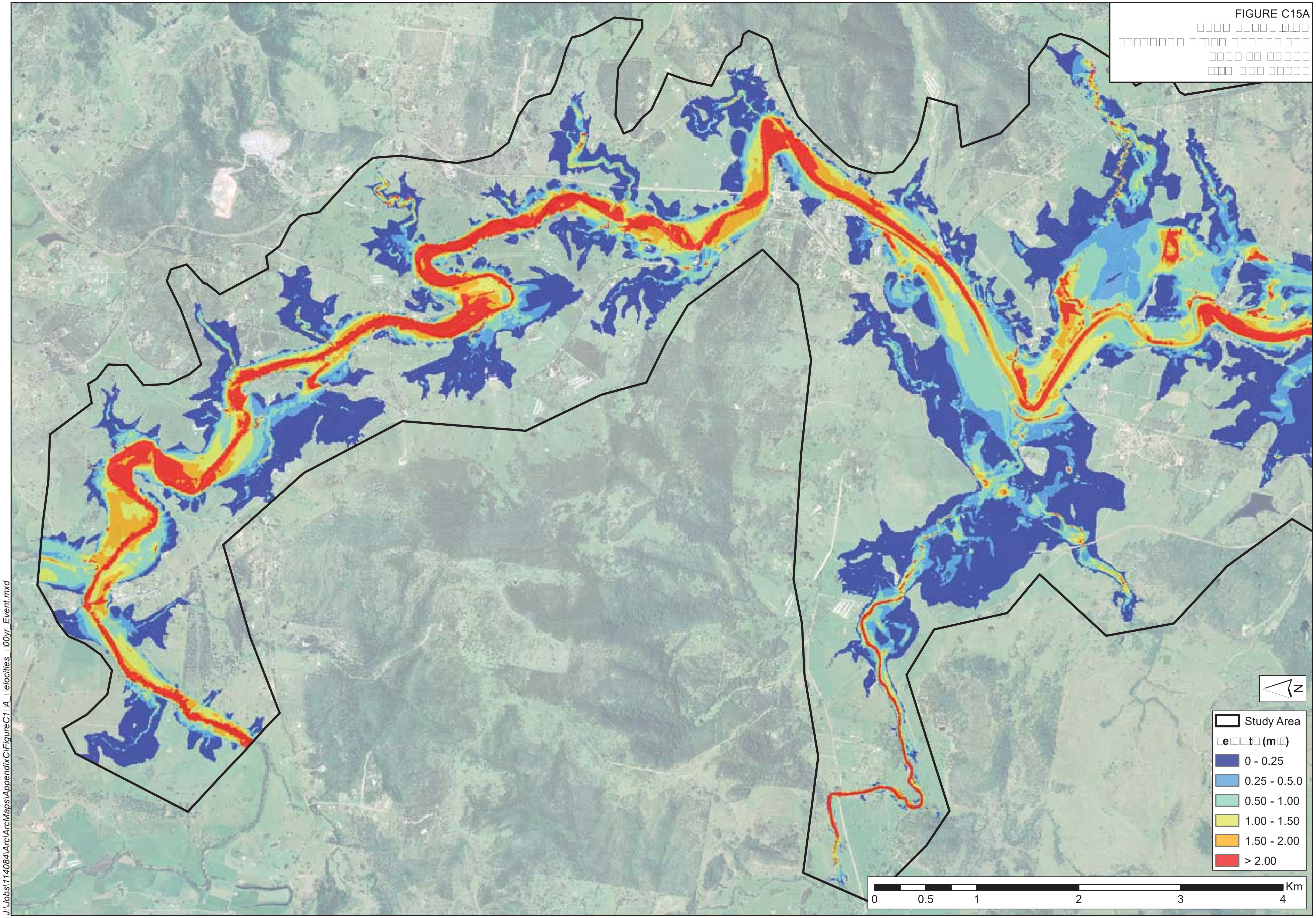
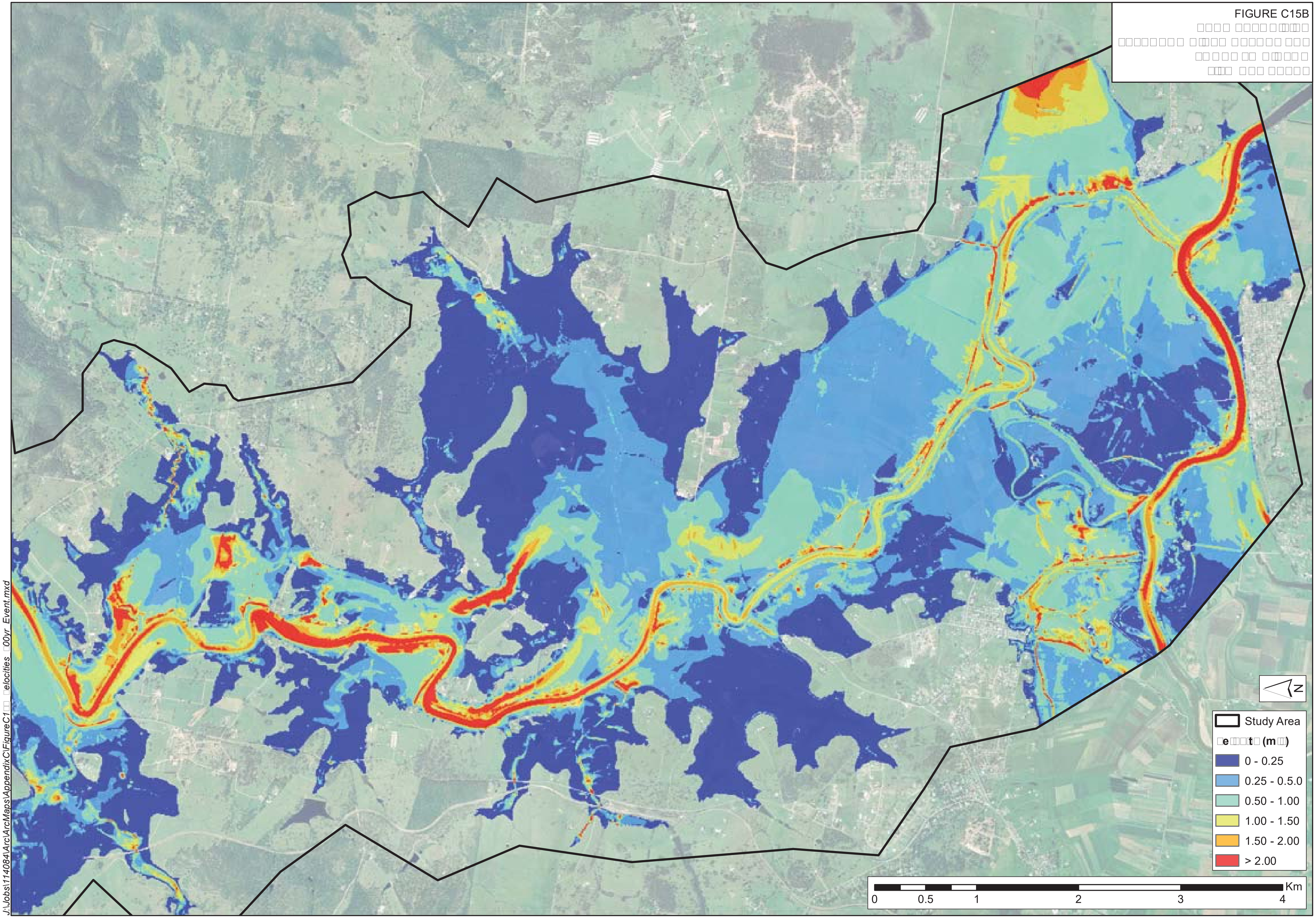


FIGURE C15A
N
Study Area
(m)
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
0.5
1
2
3
4
Km
J:\Jobs\114084\ArcArcMaps\Appendix C\FigureC1 A elocities 00yr Event.mxd

FIGURE C15B



Study Area
e t (m)
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
N
0
0.5
1
2
3
4
Km
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC1 elocities 00yr Event.mxd

FIGURE C16A

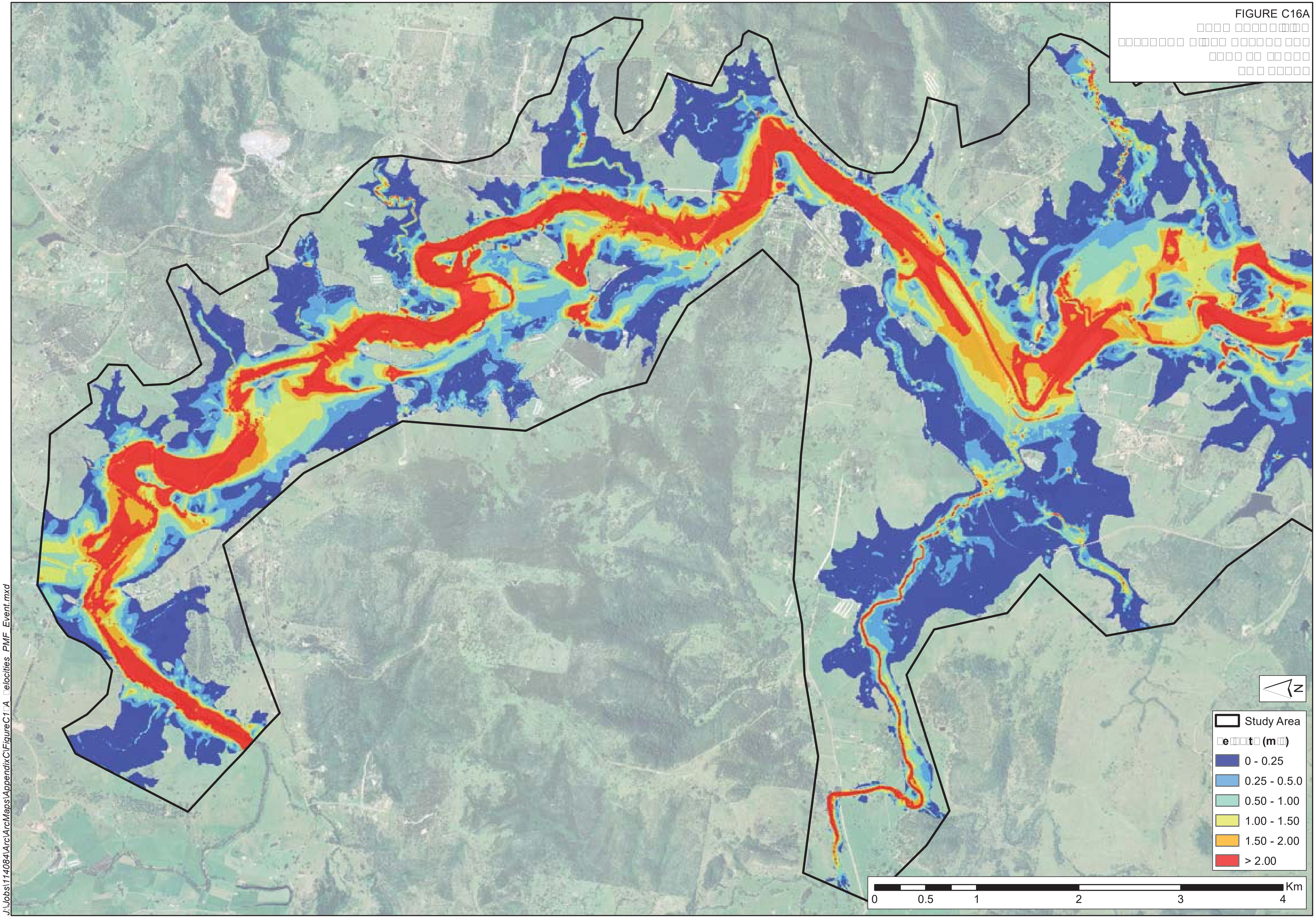
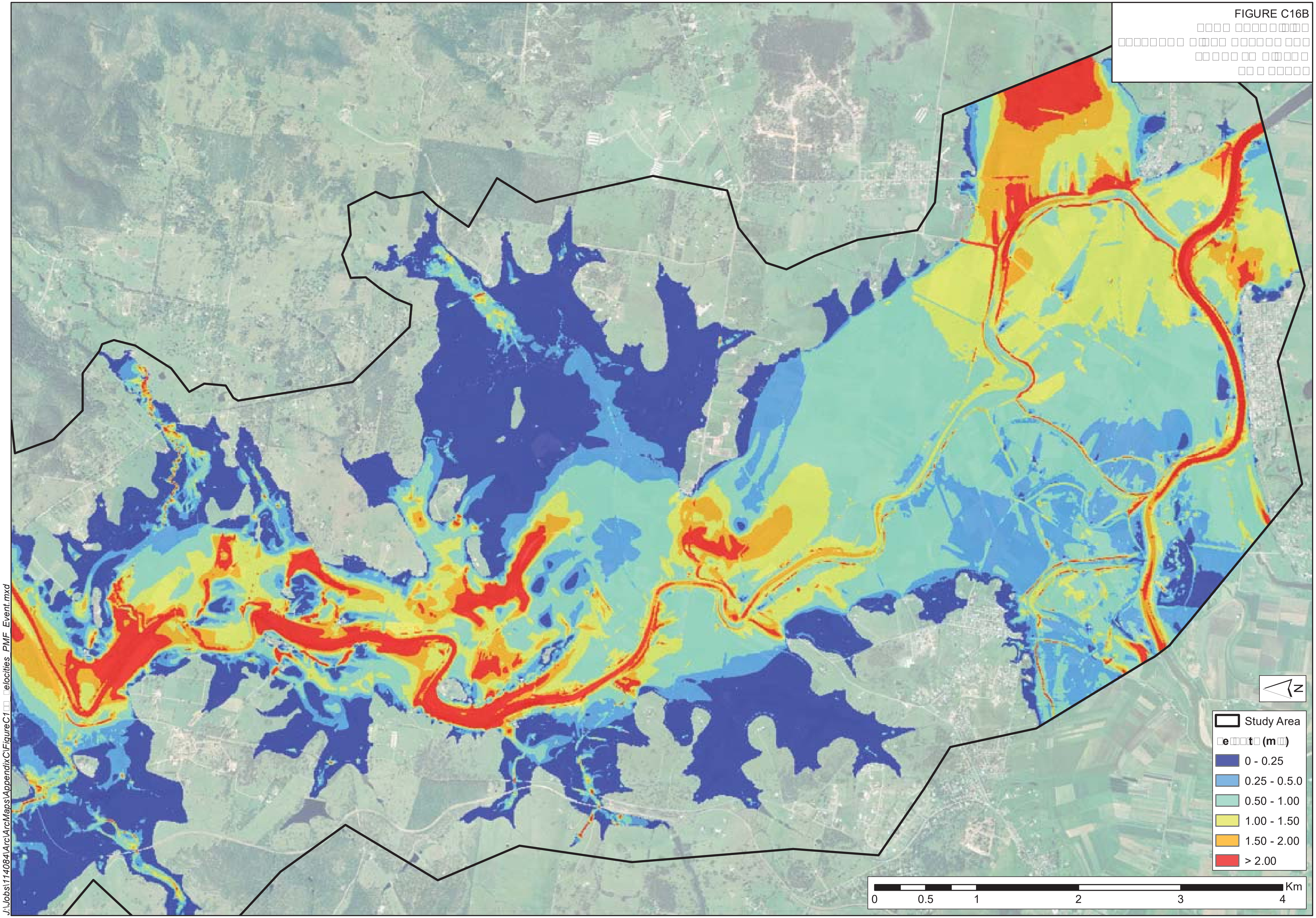
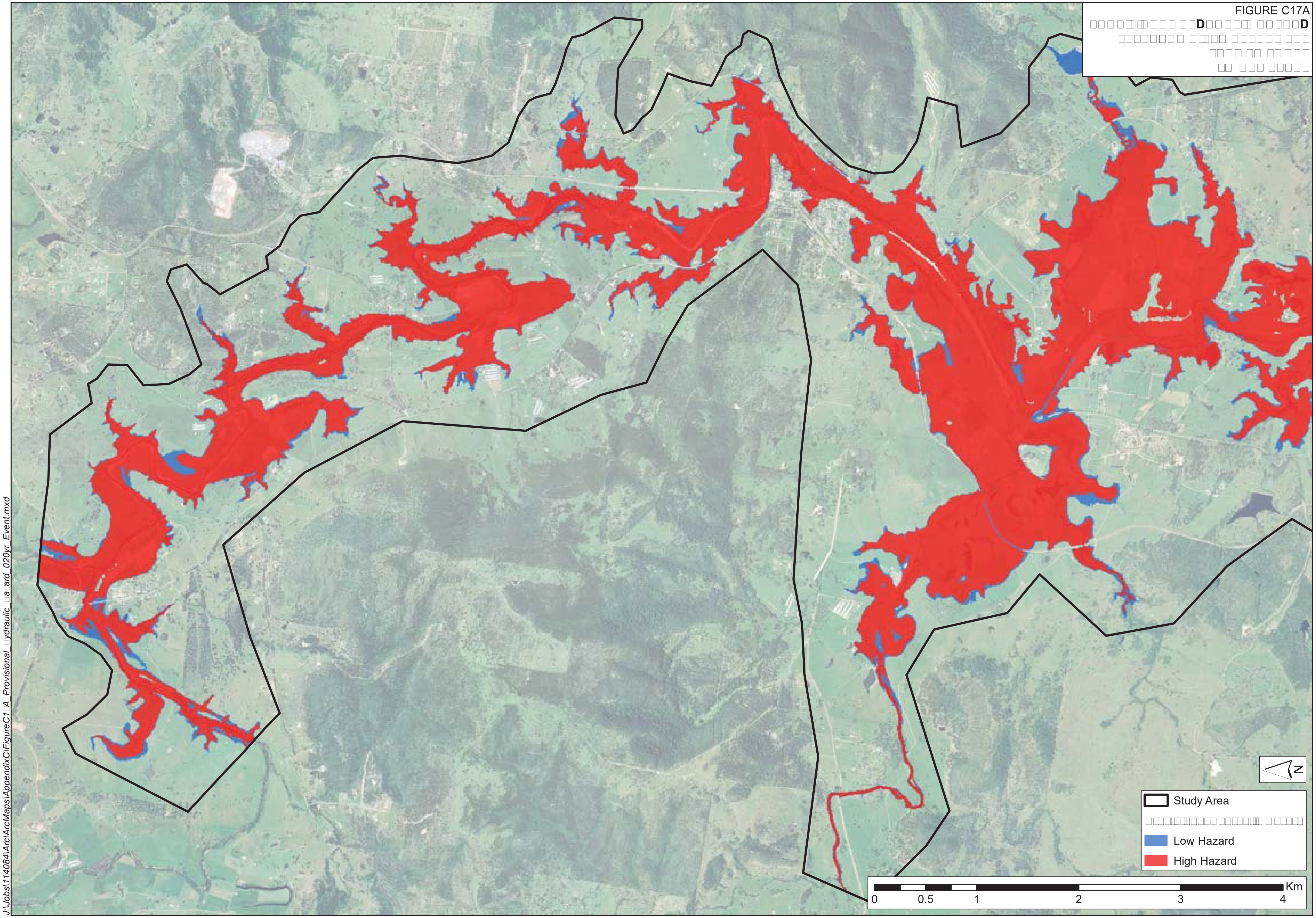

Study Area
0 - 0.25
0.25 - 0.5.0
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
N
Km
0
0.5
1
2
3
4
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC1 A elocities PMF Event.mxd

FIGURE C16B



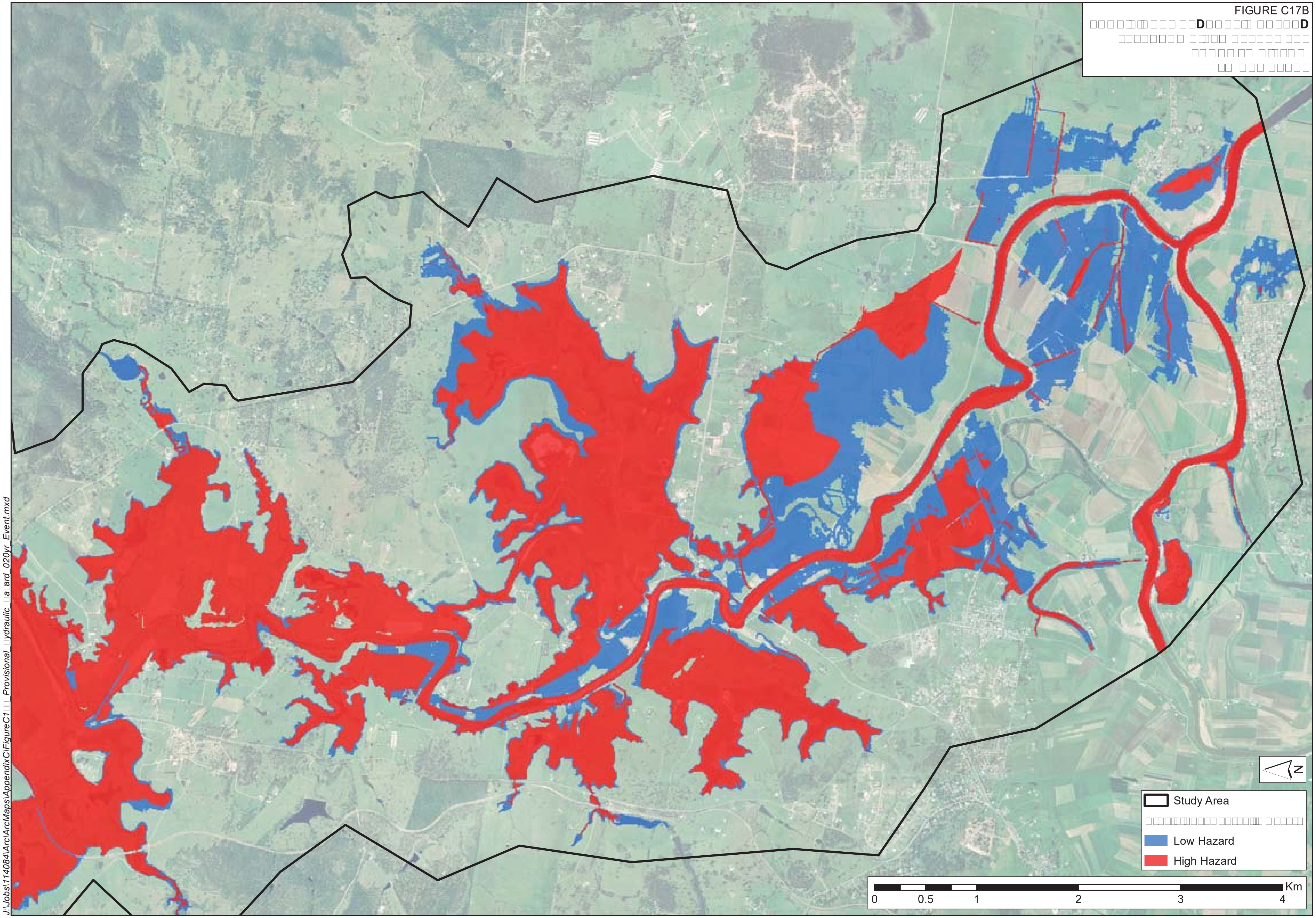
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC1 elocities PMF Event.mxd

FIGURE C17A



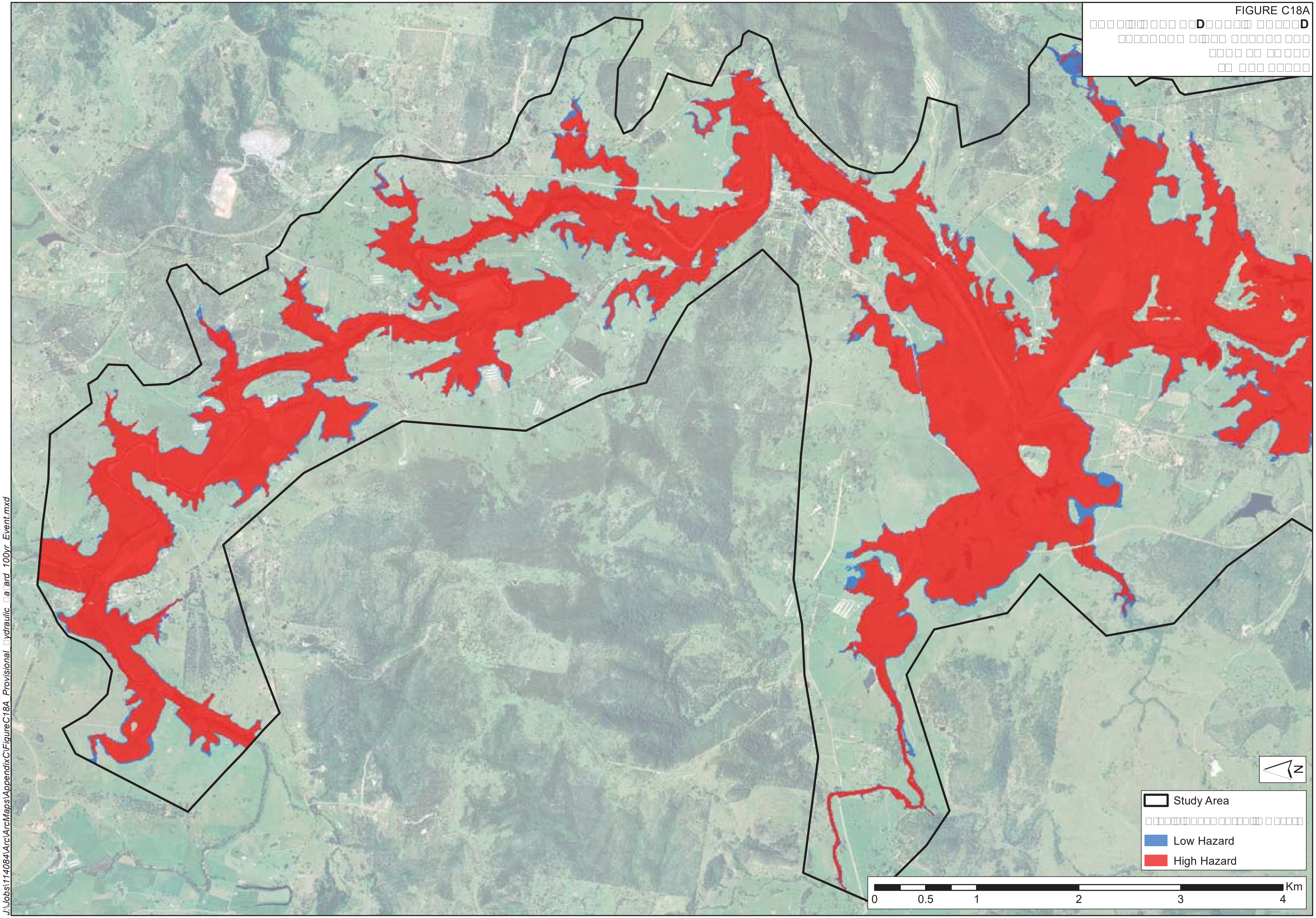
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC1 A Provisional ydraulic a ard 020yr Event.mxd

FIGURE C17B



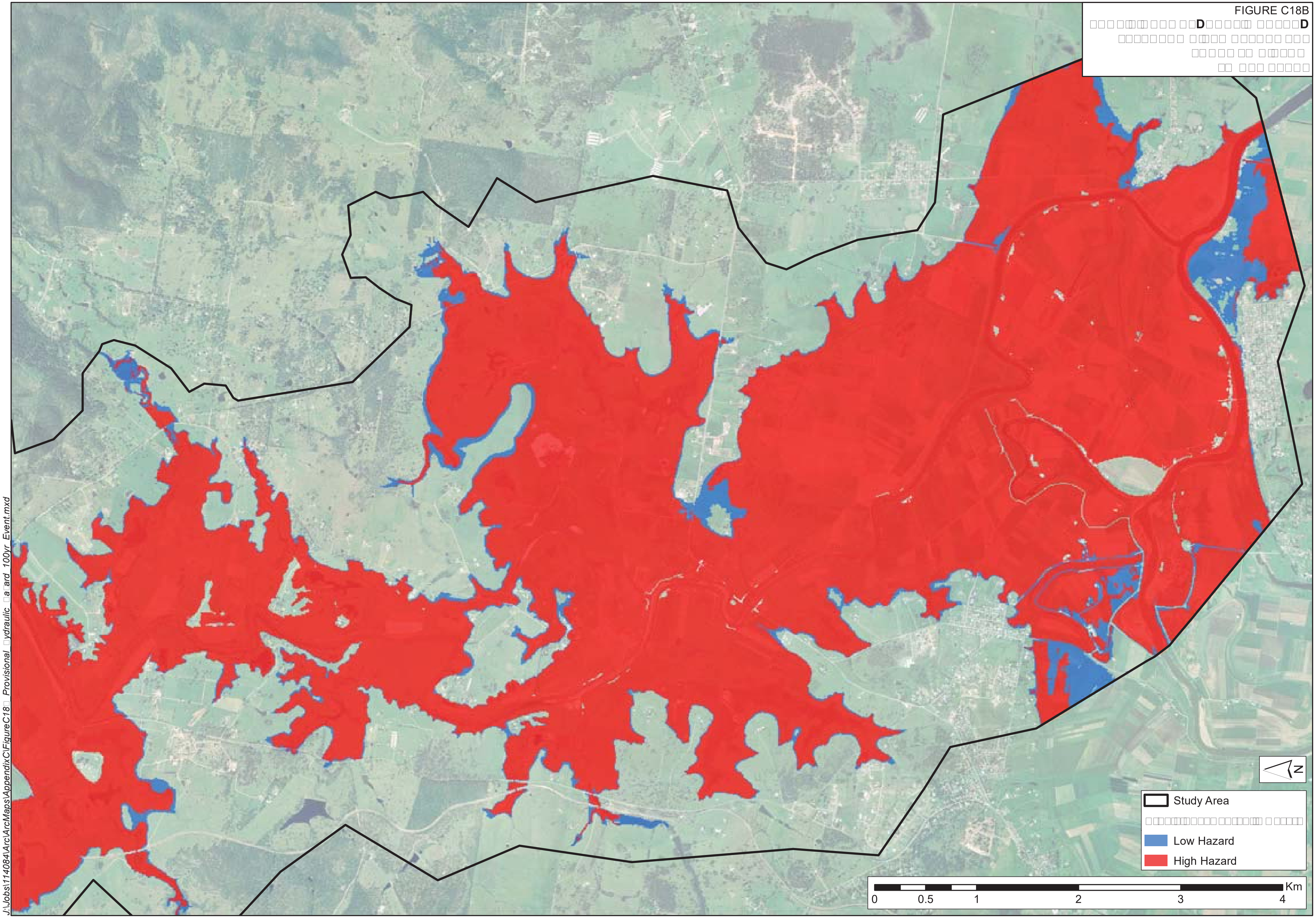
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC1 Provisional ydraulic ard 020yr Event.mxd

FIGURE C18A



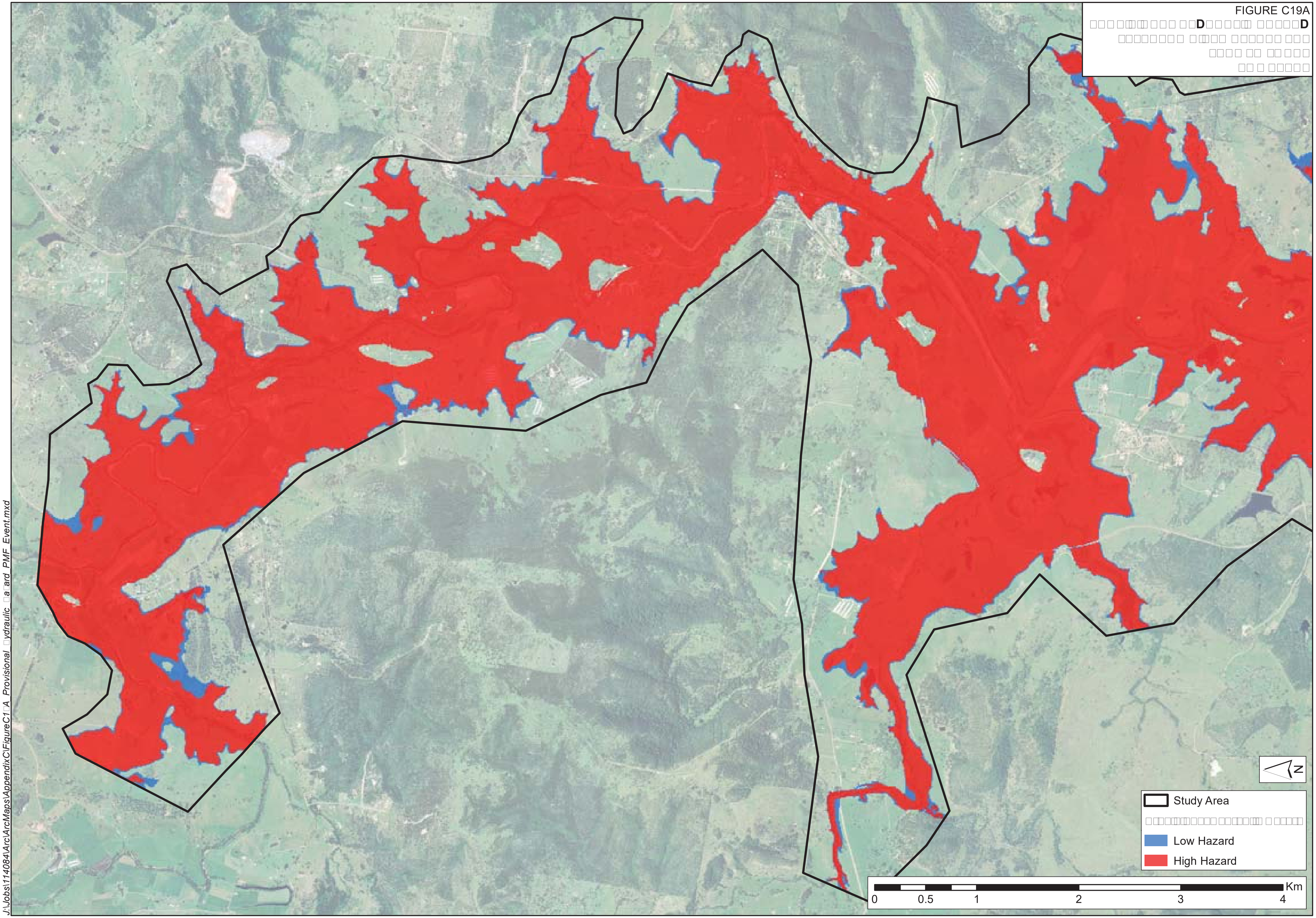
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC18A Provisional ydraulic a ard 100yr Event.mxd

FIGURE C18B



J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC18 Provisional ydraulic a ard 100yr Event.mxd

FIGURE C19A



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC1 A Provisional ydraulic a ard PMF Event.mxd

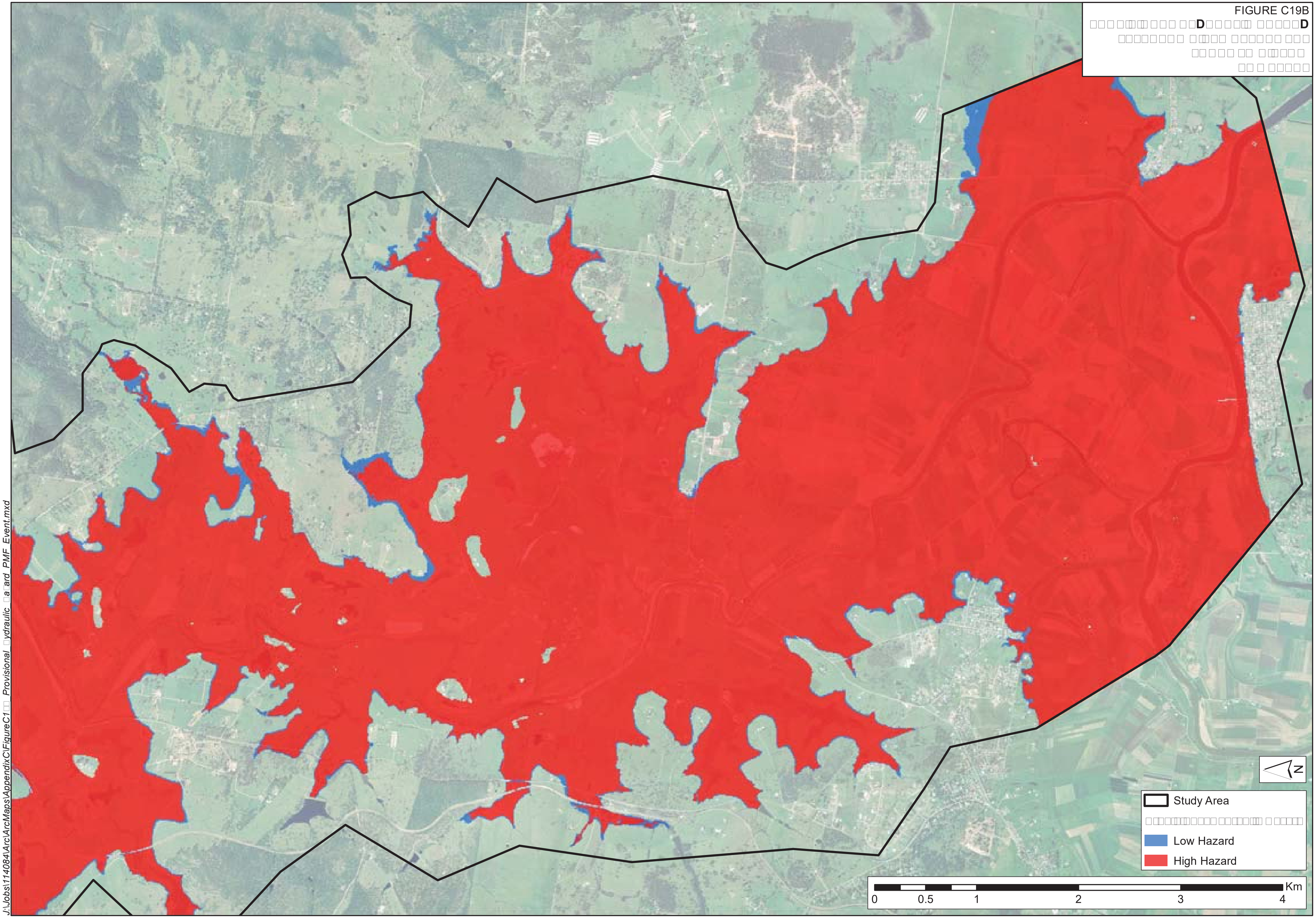


FIGURE C19B
Study Area
Low Hazard
High Hazard
0 0.5 1 2 3 4 Km
N
J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC1 Provisional ydraulic a ard PMF Event.mxd

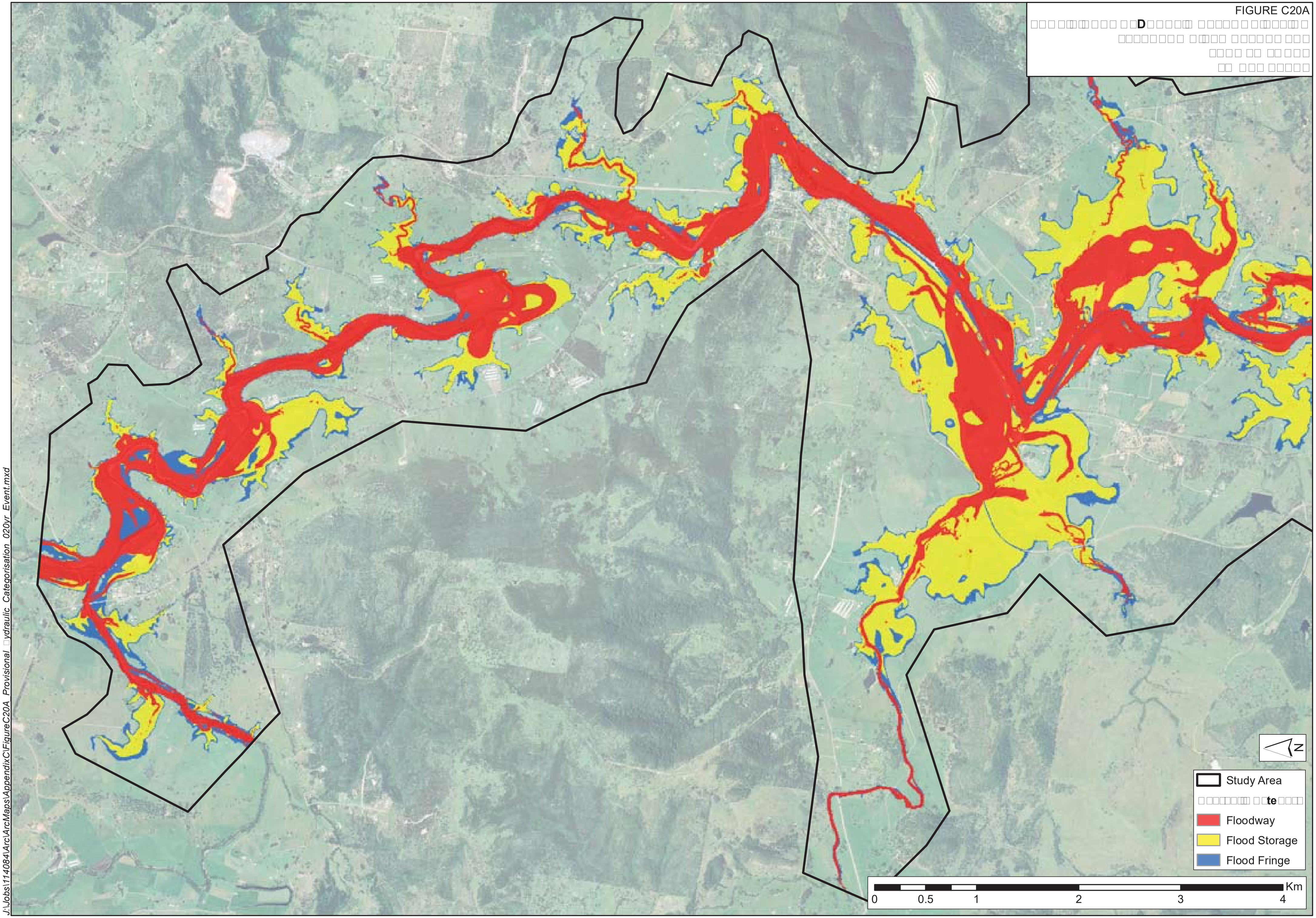
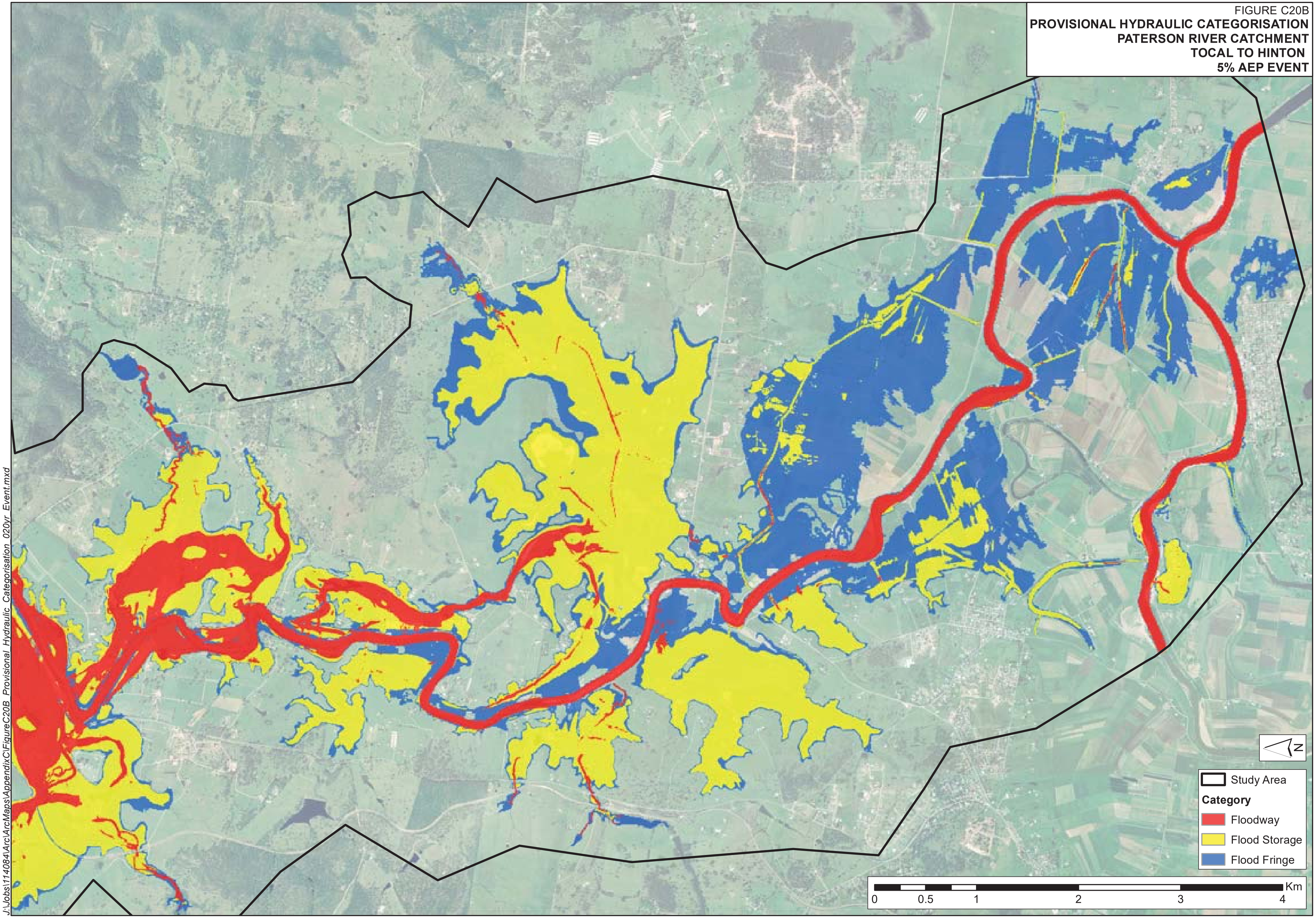


FIGURE C20A

J:\Jobs\114084\ArcArcMaps\AppendixC\FigureC20A_Provisional_ydraulic_Categorisation_020yr_Event.mxd

FIGURE C20B

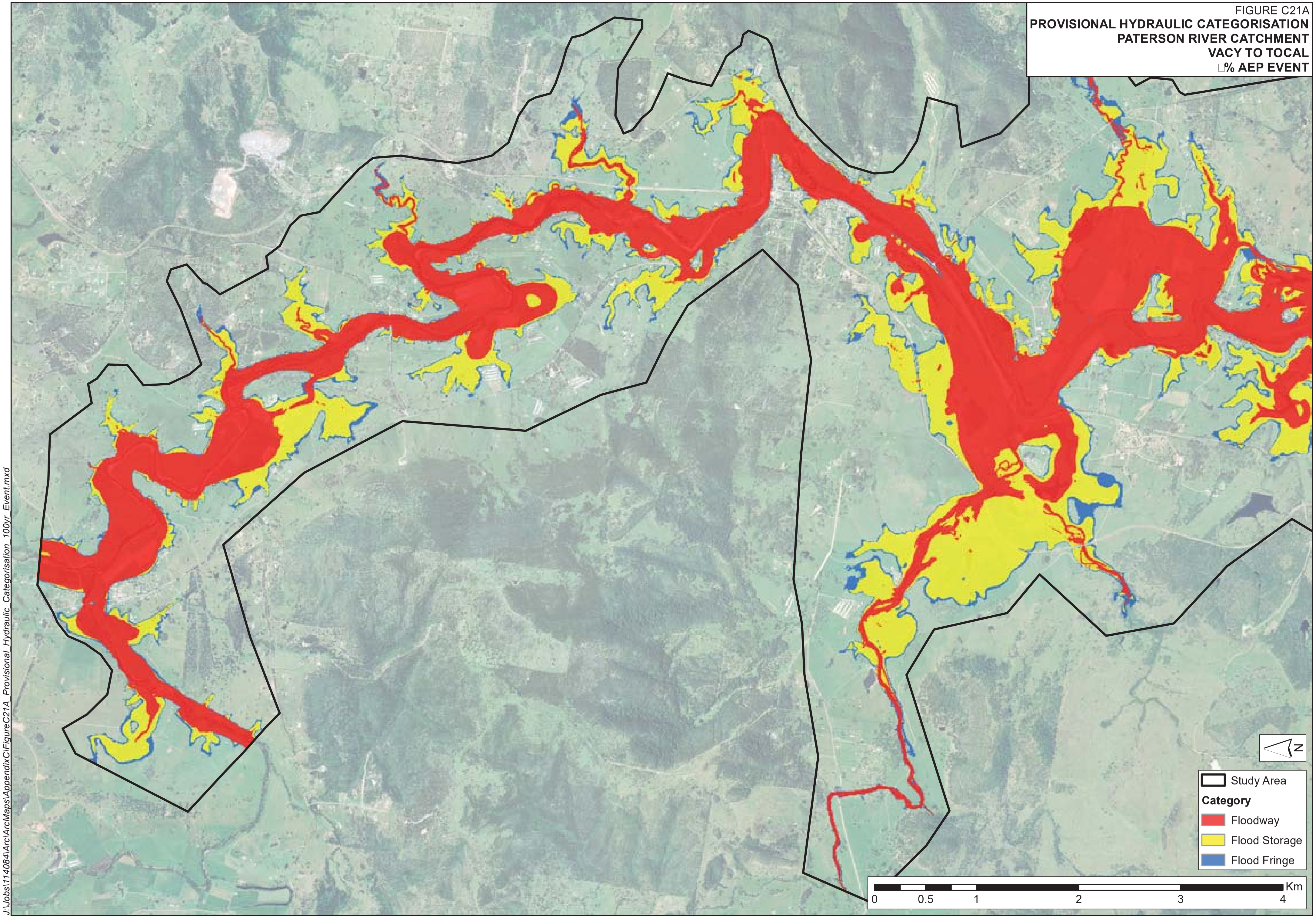
PROVISIONAL HYDRAULIC CATEGORISATION
PATERSON RIVER CATCHMENT
TOCAL TO HINTON
5% AEP EVENT



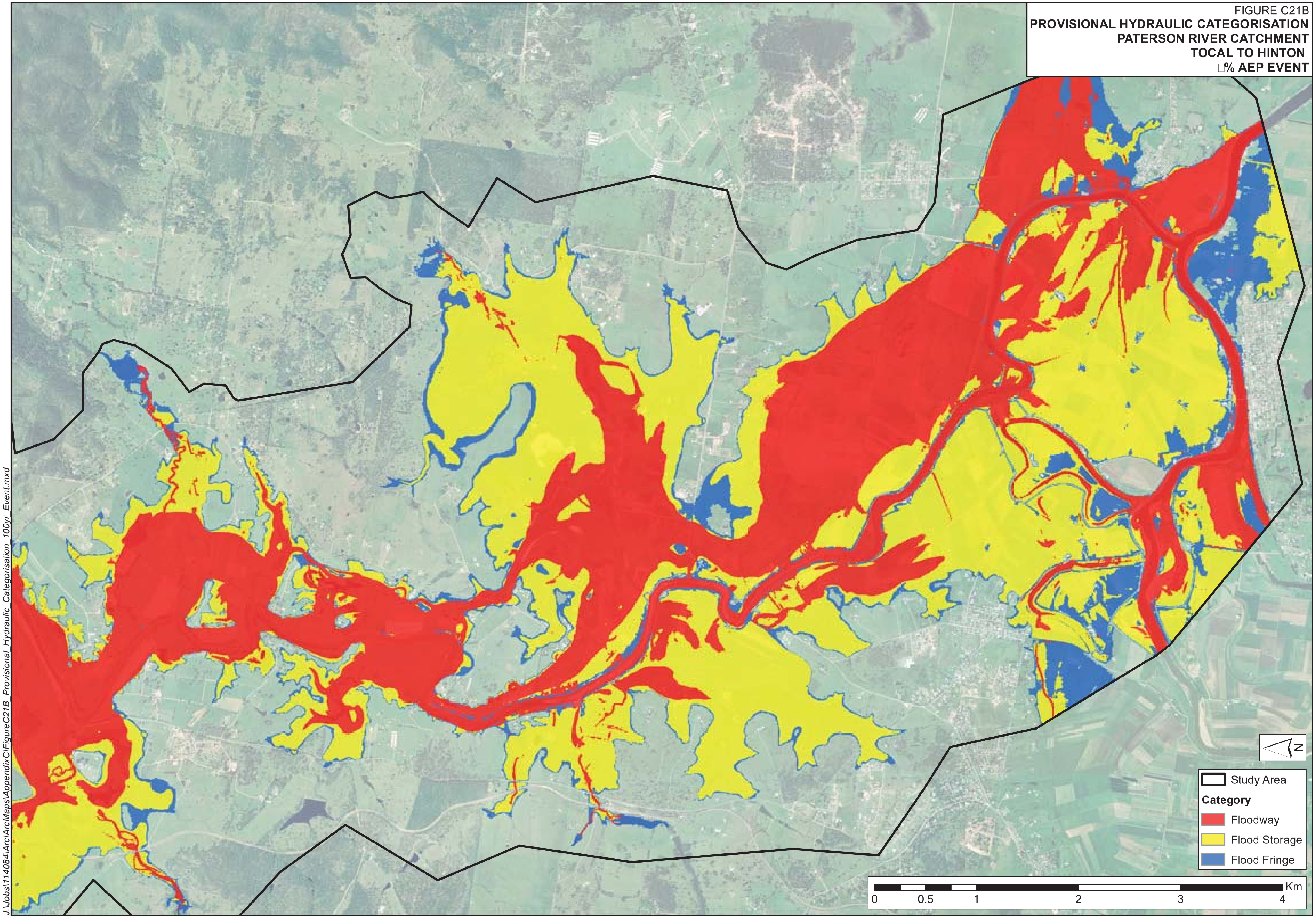
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC20B_Provisional_Hydraulic_Categorisation_020yr_Event.mxd

FIGURE C21A

PROVISIONAL HYDRAULIC CATEGORISATION
PATERSON RIVER CATCHMENT
VACY TO TOCAL
□% AEP EVENT



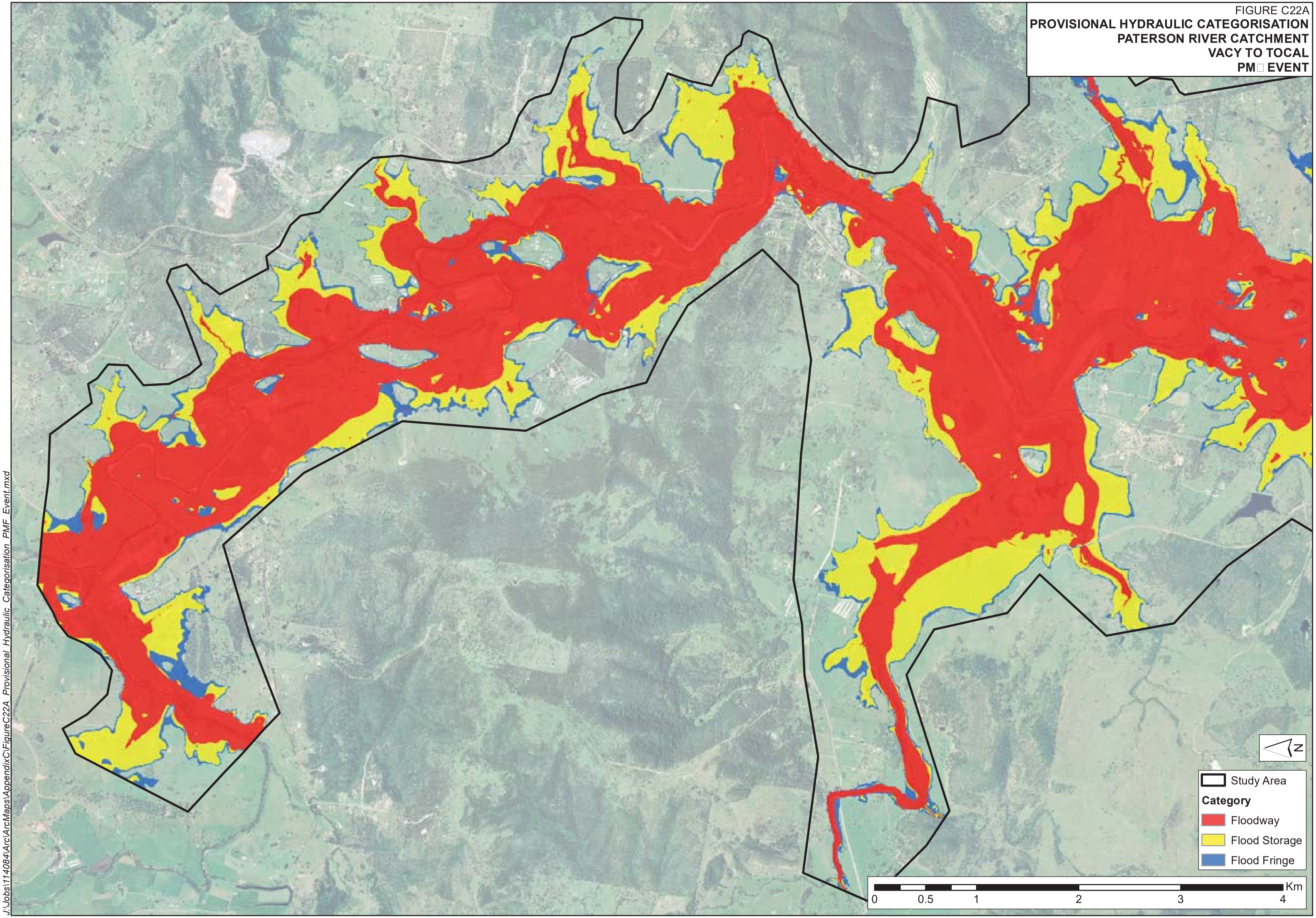
J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC21A_Provisional_Hydraulic_Categorisation_100yr_Event.mxd



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC21B_Provisional_Hydraulic_Categorisation_100yr_Event.mxd

FIGURE C22A

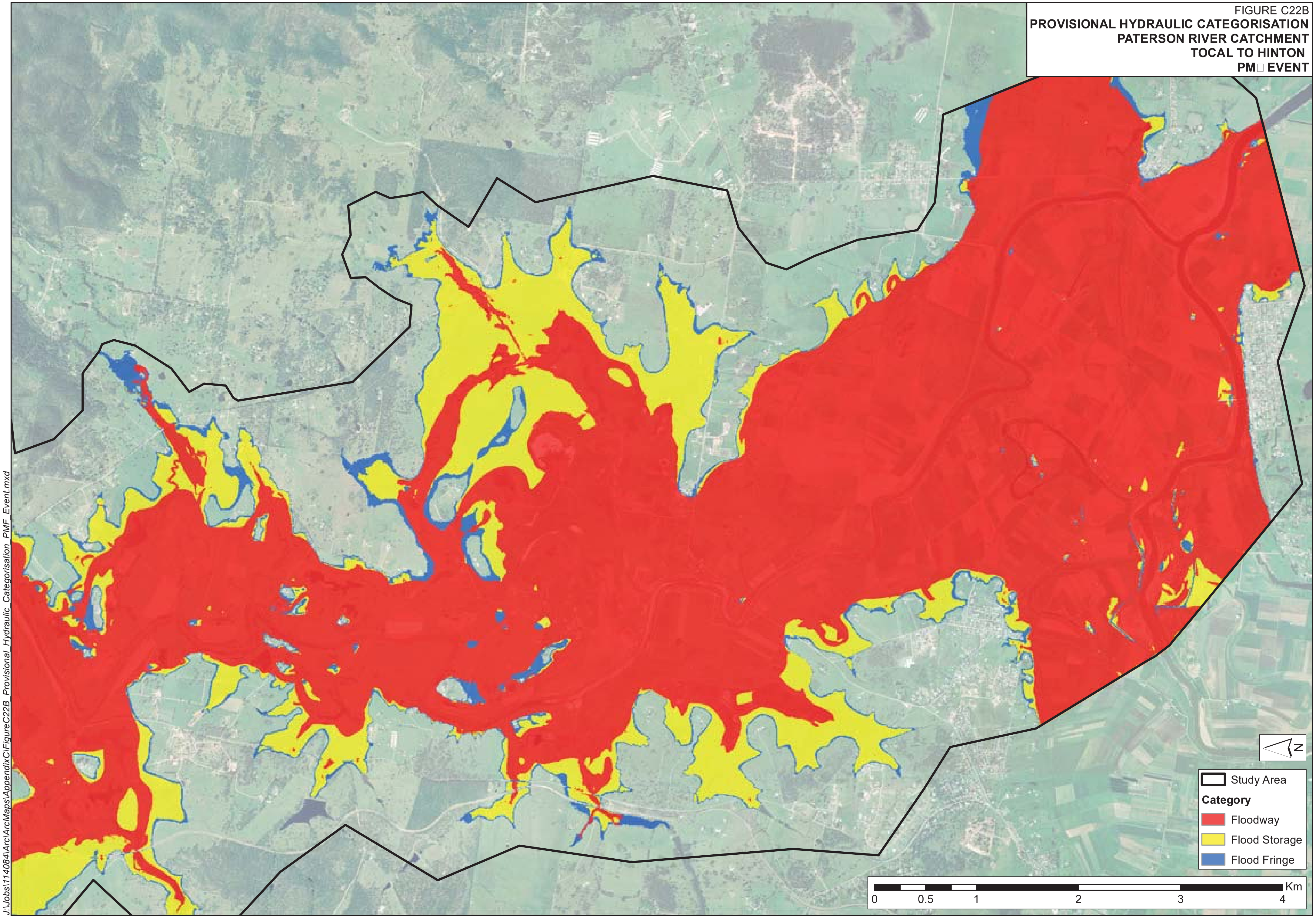
PROVISIONAL HYDRAULIC CATEGORISATION
PATERSON RIVER CATCHMENT
VACY TO TOCAL
PM□ EVENT



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC22A_Provisional_Hydraulic_Categorisation_PMF_Event.mxd

FIGURE C22B

PROVISIONAL HYDRAULIC CATEGORISATION
PATERSON RIVER CATCHMENT
TOCAL TO HINTON
PM□ EVENT



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC22B Provisional Hydraulic Categorisation PMF Event.mxd

FIGURE C23A

PRELIMINARY FLOOD PLANNING AREA
PATERSON RIVER CATCHMENT
VACY TO TOCAL

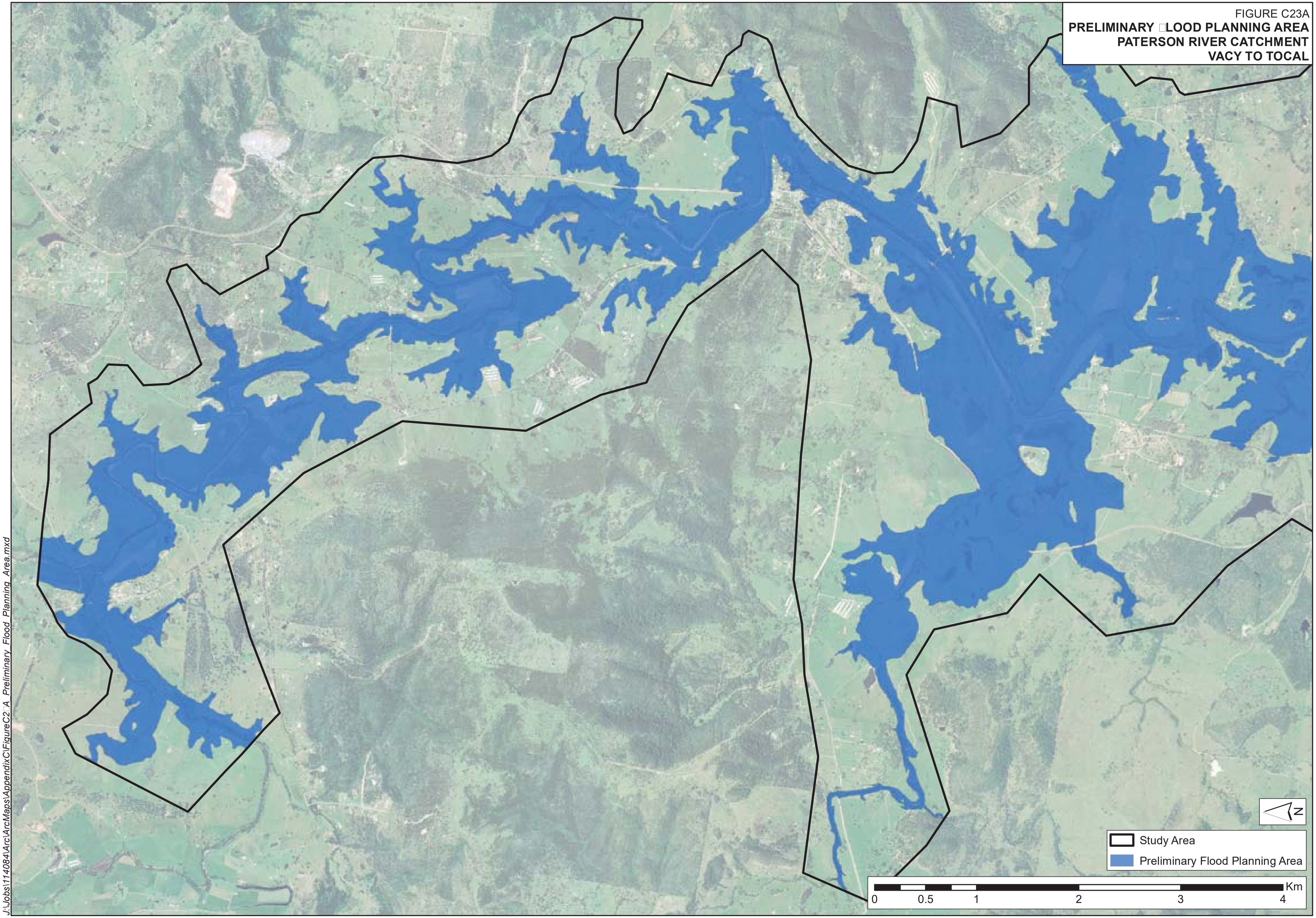


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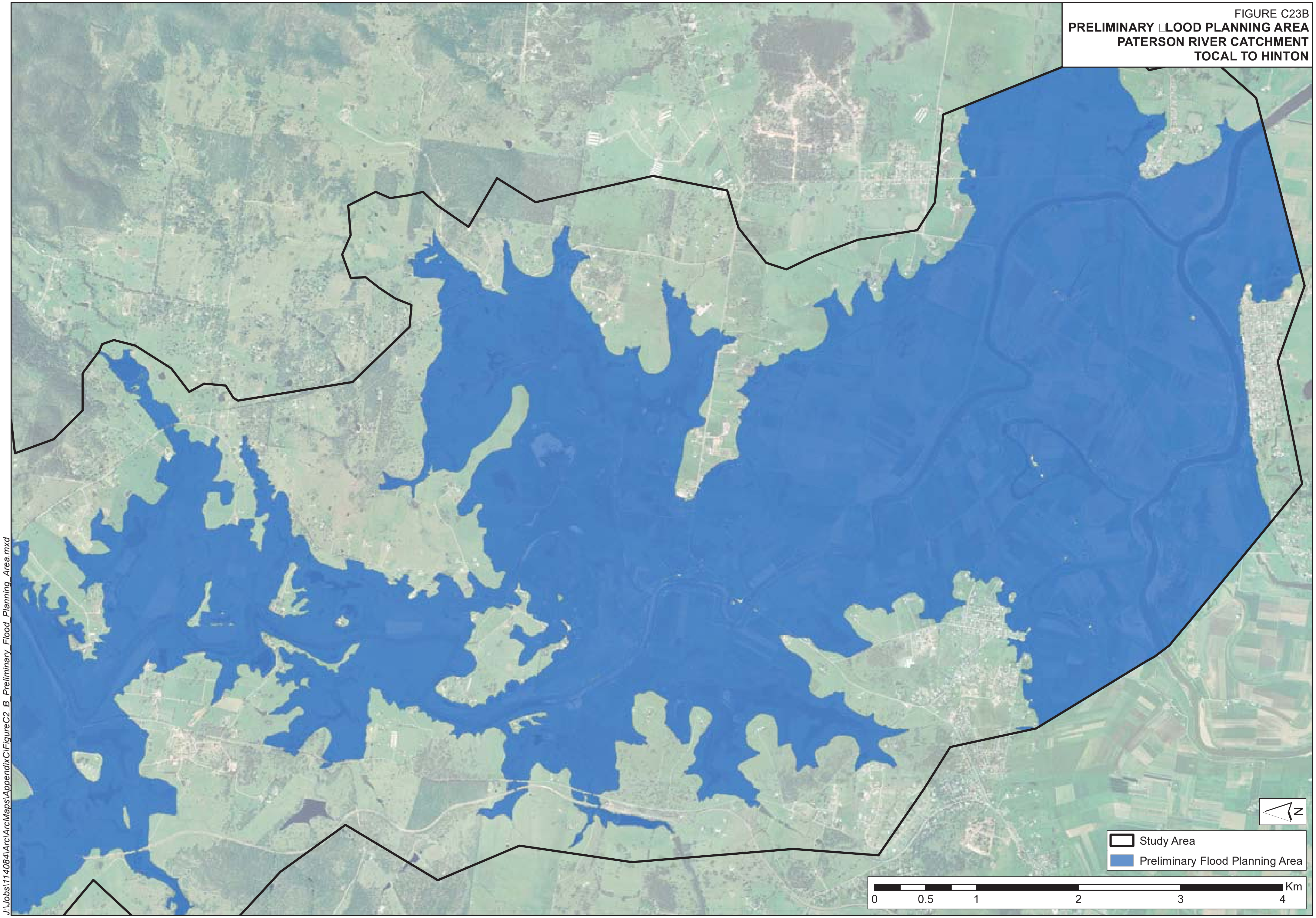
FIGURE C23B
PRELIMINARY □LOOD PLANNING AREA
PATERSON RIVER CATCHMENT
TOCAL TO HINTON



J:\Jobs\114084\Arc\ArcMaps\AppendixC\FigureC2_B_Preliminary_Flood_Planning_Area.mxd

FIGURE C24

PATERSON RIVER LEVEL PRO□ILE
5%□□% AEP EVENT AND PM□

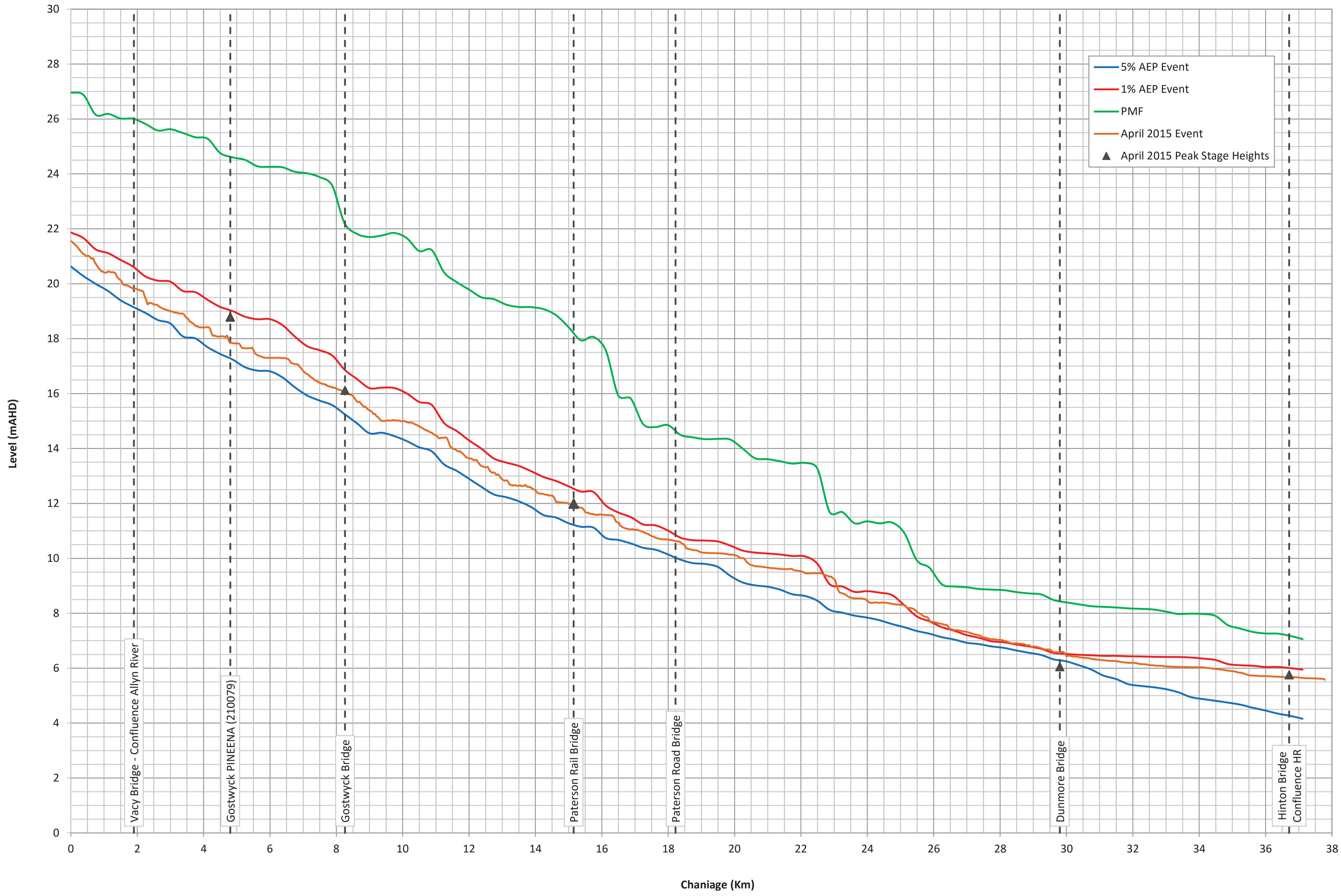
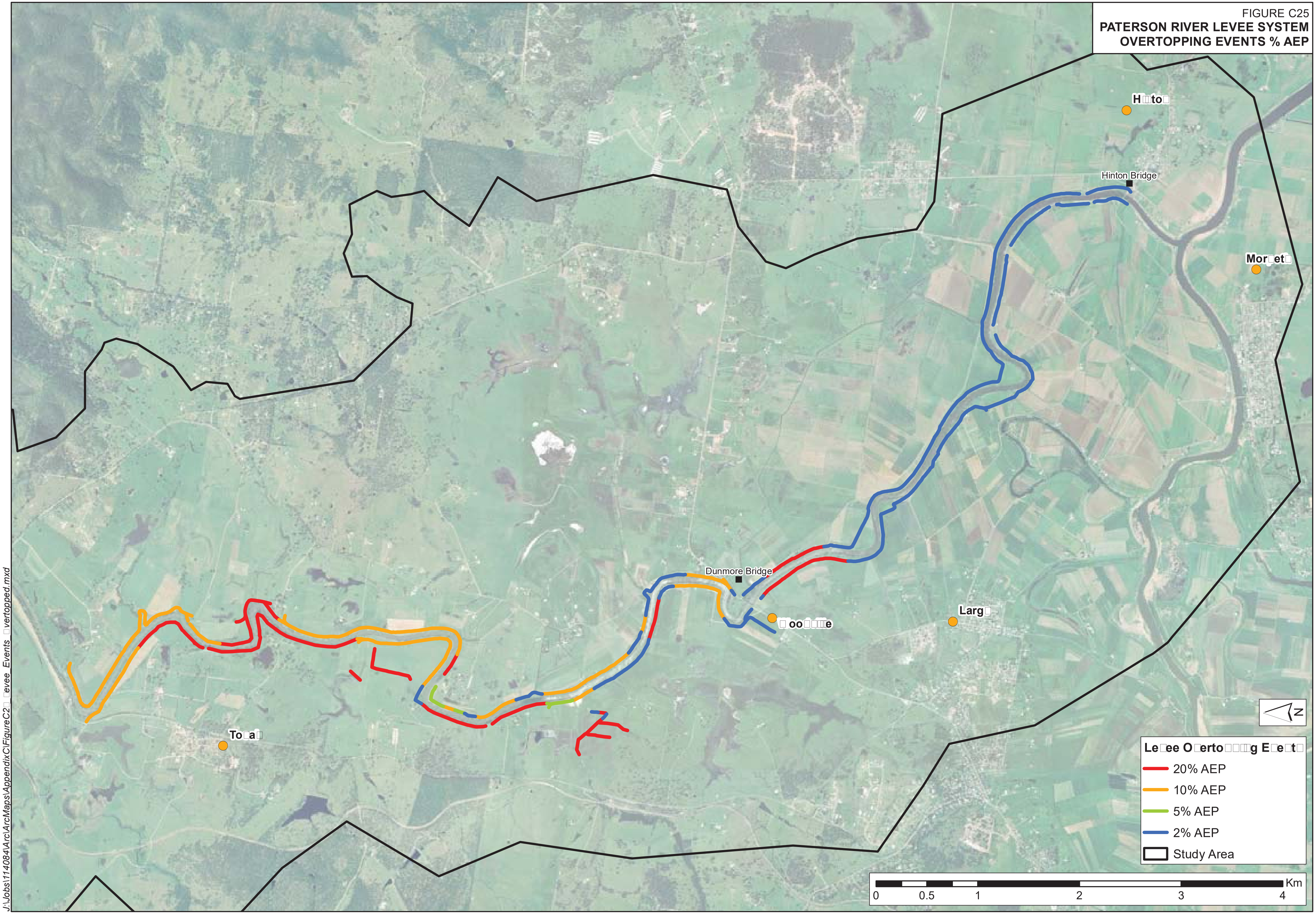
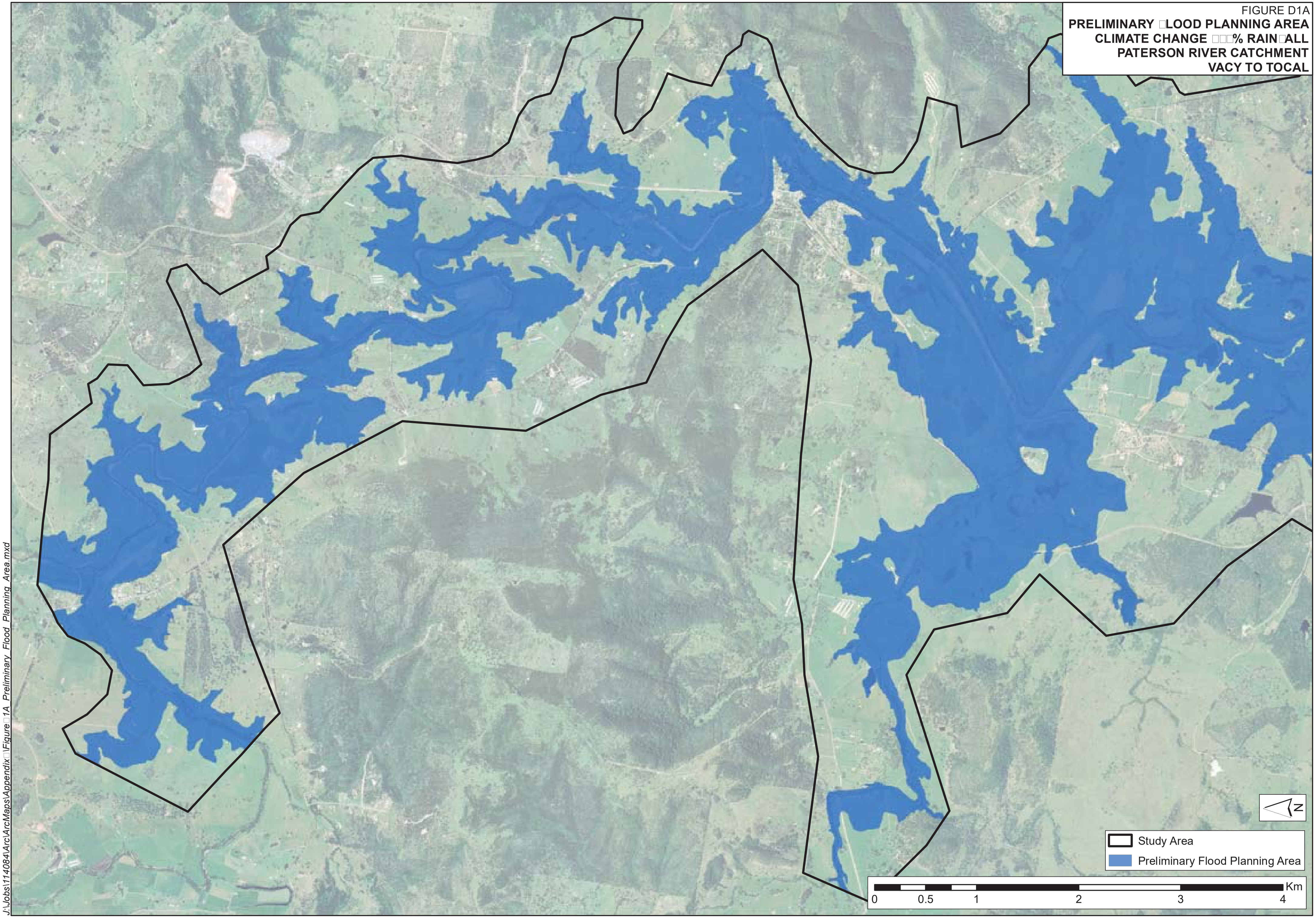


FIGURE C25

PATERSON RIVER LEVEE SYSTEM
OVERTOPPING EVENTS % AEP



Appendix D



J:\Jobs\114084\ArcGIS\ArcMaps\Appendix□\Figure□1A_Preliminary_Flood_Planning_Area.mxd

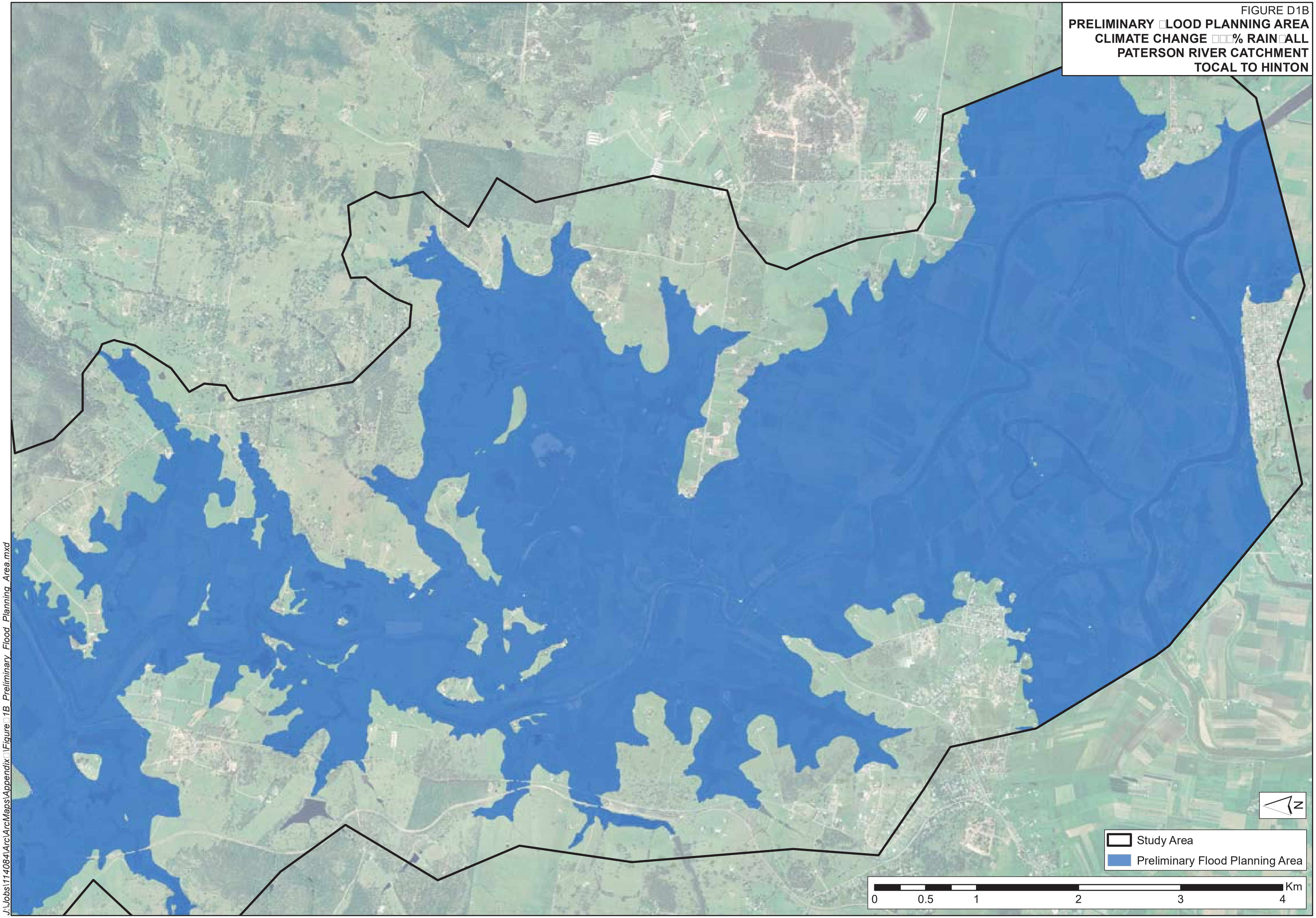
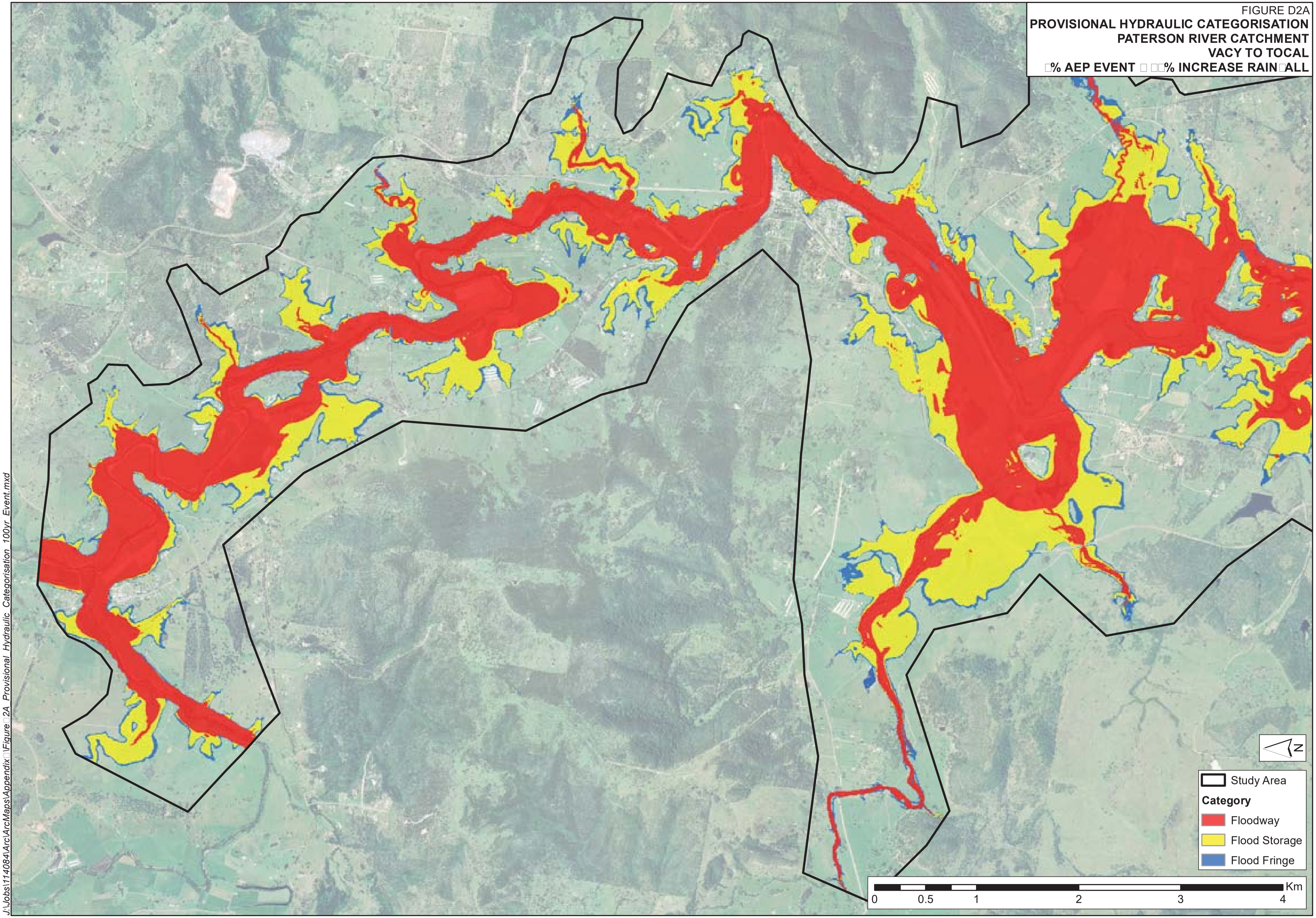


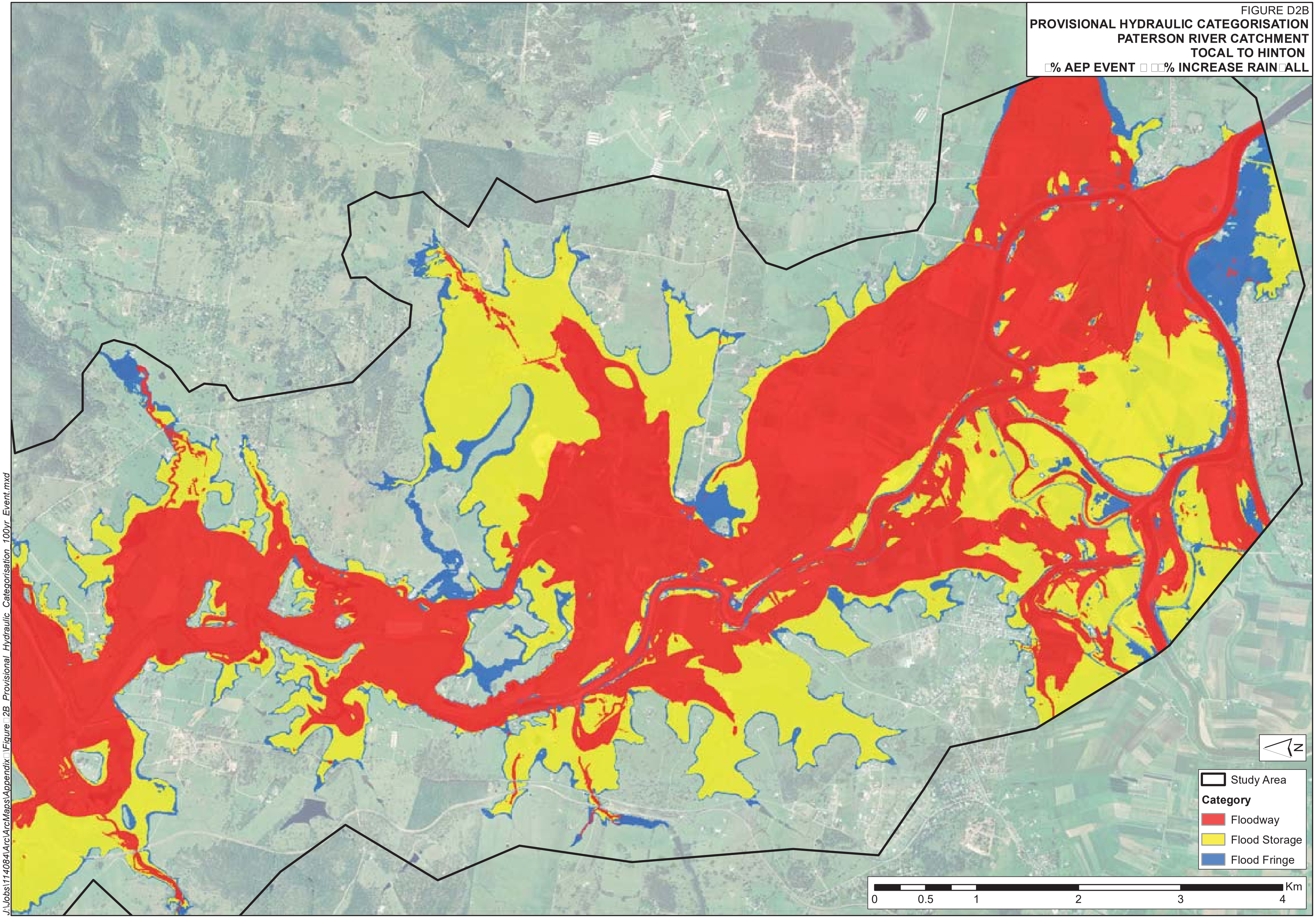
FIGURE D1B
PRELIMINARY □LOOD PLANNING AREA
CLIMATE CHANGE □□□% RAIN□ALL
PATERSON RIVER CATCHMENT
TOCAL TO HINTON
N
Study Area
Preliminary Flood Planning Area
Km
0
0.5
1
2
3
4
J:\Jobs\114084\Arc\ArcMaps\Appendix□\Figure□1B_Preliminary_Flood_Planning_Area.mxd



J:\Jobs\114084\ArcMaps\Appendix□\Figure□2A Provisional Hydraulic Categorisation 100yr Event.mxd

FIGURE D2B

PROVISIONAL HYDRAULIC CATEGORISATION
PATERSON RIVER CATCHMENT
TOCAL TO HINTON
□% AEP EVENT □ □□% INCREASE RAIN□ALL



J:\Jobs\114084\ArcArcMaps\Appendix□\Figure□2B Provisional Hydraulic Categorisation 100yr Event.mxd