MAITLAND CITY COUNCIL

HUNTER RIVER

BRANXTON TO GREEN ROCKS

FLOOD STUDY

SEPTEMBER 2010

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HUNTER RIVER: BRANXTON TO GREEN ROCKS FLOOD STUDY

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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.

The Hunter River: Branxton to Green Rocks Flood Study constitutes the first stage of the management process for this reach of the Hunter River catchment. It supersedes the previous Flood Study completed in 1998 which covered the Hunter River floodplain from Oakhampton to Green Rocks. This present study initially only included the Hunter River from Oakhampton to the Maitland/Cessnock local government boundary. Subsequently it was extended downstream to Green Rocks at the request of Maitland City Council and upstream at the request of Cessnock Council to near Branxton to include the lower part of the Black Creek floodplain.

Funding for this study was provided from the State Government's Flood Risk Management Program and Maitland and Cessnock Council on a 2:1 basis. The study has been developed for Maitland Council's Floodplain Risk Management Committee by WMAwater (formerly Webb, McKeown & Associates) for the future management of flood liable lands in this reach of the Hunter River. The results from this study supersede the previous Flood Study completed in 1998.

EXECUTIVE SUMMARY

The area around Maitland was first settled by non indigenous persons in around 1820 and these early residents experienced a major flood in 1820 with smaller events in subsequent years. It quickly became apparent that some form of mitigation measures was required to prevent the frequent inundation and resulting loss of homes, equipment, livestock and produce. By 1870 levees at Bolwarra and Oakhampton and partially around the town itself had been constructed to prevent inundation and divert floodwaters. These works were constructed in an un-coordinated manner by individual landowners and many failed.

The area has experienced many floods since 1820 but it was following the disastrous February 1955 event that the State Government passed the Hunter Valley Flood Mitigation Act (now termed the Water Management Act 2000) that facilitated the co-ordinated construction of flood mitigation works across the whole lower floodplain (downstream of Oakhampton).

Whilst flooding will have been experienced along the Hunter River in the reach from upstream of Branxton to Oakhampton the effect of floods would have been less damaging as the floodplain was not as extensively farmed as near Maitland. There are no mitigation works in this upstream reach.

LOWER HUNTER SCHEME

Under the Act the Lower Hunter Scheme was constructed by the then Public Works and subsequent State Departments continue to operate and maintain the Scheme today. The three main objectives of the Scheme are:

1. Reduce the frequency of flooding,
2. Control the direction and velocity of floodwaters in order to reduce the damage to farmlands and property,
3. Provide effective drainage after the peak of a flood has passed.

Whilst these objectives are still valid today the Scheme has subsequently encompassed additional objectives in response to environmental and related initiatives.

The Lower Hunter Scheme was designed in the 1960's using the best available techniques at the time which were scaled physical models. Subsequently the performance of the Scheme was evaluated using a computer model in the 1990's. There have been no significant changes to the Scheme since construction but spillways (Bolwarra) and control banks have been refurbished and levees raised (Wyburns). The Maitland and Lorn levees had major reconstruction works undertaken in 2000-2003. Post flood repair work has also been undertaken several times.

PREVIOUS DESIGN FLOOD LEVELS

Design flood levels for Maitland and the lower Hunter River floodplain were first defined in the early 1980's by the then Public Works and published in the Lower Hunter Floodplain Atlas. In this study it was assumed that the February 1955 flood approximated a 1% AEP event, though it was considered that the Lower Hunter Scheme would lower the 1955 flood levels by between 1.0m and 1.4m at the CBD and at Lorn.

In 1990 a state-of-the art computer model of the lower Hunter River floodplain was established and calibrated to historical events in order to review the previously adopted design flood levels. Subsequently the model was extensively revised and recalibrated as part of the Lower Hunter Valley Floodplain Management Study and a Supplementary Flood Study was prepared in 1998. This latter study provided a Compendium of Data which amalgamated all known flood levels, corrected for datum errors and listed all available data.

The Supplementary Flood Study undertook flood frequency analysis of the historical records at Gostwyck on the Paterson River and at Maitland and Singleton. Design flood levels for the 5%, 2%, 1% and 0.5% AEP events as well as an Extreme Flood were determined. The analysis indicated that the February 1955 flood approximated a 0.5% AEP event.

COMPUTER MODELLING

The computer model established for the 1990 study is termed a One Dimensional (1D) hydraulic model in that flow can only travel in one direction. The floodplain is represented as a series of cross sections linked together and flow can be “split” at a junction which has several downstream branches. This system is often termed a “quasi” Two Dimensional (2D) approach as it can account for flow in various directions through the use of One Dimensional branches.

Advances in computer technology, software development and the availability of extensive survey have led to the development of 2D hydraulic modelling. With this approach the floodplain is represented as a grid (10m by 10m cells) and the model determines the flow paths between the cells. The model used in this study is TUFLOW which is widely used in Australia and in the UK.

APPROACH

The approach adopted in this present study was determined by the quality and quantity of the available data. 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.

Design peak inflows on the Hunter River were obtained from flood frequency analysis based on the flood record at Maitland with the shape of the hydrograph based on the shape of the February 1955 event. For the tributary inflows to the Hunter River (the largest being the Paterson River) there is no recognised approach for establishing the joint probability of flooding on the two systems.

Through sensitivity analysis the 36 hour duration event was adopted for all tributaries together with the following joint probability approach.

Hunter River Design Event	Tributaries Design Event (36 hour duration)
Extreme	0.5% AEP
0.2% AEP	1% AEP
0.5% AEP	2% AEP
1% AEP	5% AEP
2% AEP	6.7% AEP
5% AEP	10% AEP
10% AEP	20% AEP
20% AEP	50% AEP
50% AEP	50% AEP

SENSITIVITY ANALYSIS

The following sensitivity analysis was undertaken:

- Co-incidence of tributary inflow timing,
- Design duration of tributary inflows,
- Joint probability of Hunter River and tributary inflows,
- Channel Manning's "n",
- Increased rainfall intensity,
- Starting level in Wallis and Fishery Creek swamps.

ACCURACY OF DESIGN FLOOD LEVELS

The accuracy of the design flood levels depends on many factors including:

- The accuracy of the survey data,
- The availability and quality of rainfall and flood height data to calibrate the models,
- Changes in the topography (sedimentation, erosion, vegetation removal and planting) of the Hunter River,
- The assumptions in the flood frequency analysis.

Where quality historical flood height data are available (mainly at the gauges) the accuracy of the reported design flood levels is of the order of +/- 0.3m. Elsewhere the accuracy is of the order of +/-0.5m. The accuracy will be improved over time as data from future flood events is collected and evaluated.

RESULTS

A comparison of design flood levels between the 1998 Supplementary Flood Study and the present study are provided in the table below.

Location Refer Figure E1 in Appendix E	Study	Peak Flood Level (mAHD)				
		Extreme	0.5%	1%	2%	5%
U/S Oakhampton No. 2 Site A	Previous	16.4	13.2	12.8	12.4	12.0
	Current	16.0	13.5	13.0	12.7	12.3
Adjacent to Bolwarra Spillway Site B	Previous	15.0	12.6	12.3	12.0	11.8
	Current	14.7	12.9	12.5	12.3	11.9
Belmore Bridge Site C	Previous	13.7	11.7	11.5	11.3	11.1
	Current	13.3	11.9	11.7	11.5	11.1
Powerhouse Control Site D	Previous	15.5	12.5	11.9	11.1	10.5
	Current	14.6	12.8	12.2	11.1	10.3
Mount Pleasant Street Site E	Previous	14.5	11.8	11.1	10.3	9.8
	Current	14.3	12.4	11.8	10.5	9.8
Long Bridge Site F	Previous	14.2	11.5	10.4	9.3	8.0
	Current	13.9	12.1	11.5	10.1	8.4
Dagworth Bridge Site G	Previous	13.4	11.1	10.3	9.3	7.5
	Current	12.2	10.8	9.7	8.5	7.6
Victoria Bridge Site H	Previous	12.9	10.8	10.2	9.3	7.5
	Current	11.9	10.7	9.7	7.7	
Pitnacree Road Site I	Previous	12.8	10.4	9.9	9.3	7.5
	Current	11.3	10.3	9.6	7.7	6.6
Lorn Site J	Previous	13.1	9.2	8.2	7.4	6.7
	Current	11.2	8.1	7.5	7.2	
Belmore/Paterson Road Site K	Previous	13.1	10.6	10.1	9.6	9.2
	Current	11.4	9.8	9.2	9.0	8.6
U/S Howes Lagoon Site L	Previous	12.7	10.2	9.6	8.5	8.4
	Current	11.1	10.2	9.6	7.7	6.6
D/S Howes Lagoon Site M	Previous	11.2	8.6	8.2	7.7	7.7
	Current	10.4	8.5	8.0	7.9	7.8
Pitnacree Site N	Previous	11.4	8.8	8.4	8.0	8.0
	Current	10.4	8.5	8.1	8.1	8.0
Kings Island Site O	Previous	11.1	8.2	7.3	6.9	6.5
	Current	10.1	7.8	7.3	7.0	6.5
Morpeth Bridge Site P	Previous	10.4	7.9	7.5	7.2	7.1
	Current	9.5	7.4	7.2	7.1	7.0
Green Rocks Gauge Site Q	Previous	7.4	6.0	5.6	4.9	4.6
	Current	8.2	6.0	5.7	5.5	4.7

There are some significant differences between the previous and current studies. This is to be expected due to the different modelling approaches (two dimensional versus the previous one dimensional hydraulic modelling), the use of more extensive and higher quality survey data and the inclusion of the June 2007 flood data (which altered the calibration in places and thus the resulting design flood levels).

1. INTRODUCTION

1.1. Background

The Hunter River has a catchment of some 16,500 km^2 to Singleton and 17,600km^2 to Maitland (Figure 1), which is approximately 50 kilometres straight line or 85 kilometres 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). Flood Studies have been completed for both Singleton (Reference 1) and Maitland (Reference 2) and this present Flood Study covers the Hunter River and its floodplain from approximately 3 kilometres upstream of the Black Creek tributary at Branxton to Green Rocks (approximately 8 kilometres downstream of Morpeth at the Maitland LGA boundary). Other flood studies and related flood information in the region is provided in References 3 to 9.

The original commission by Maitland City Council was for the Hunter River upstream of Oakhampton to the Maitland LGA boundary but the study has been extended to include the floodplain surrounding Branxton (Black Creek) which is within the Cessnock Council LGA and subsequently from Oakhampton to Green Rocks within Maitland LGA.

Cessnock Council requested the extension in order to obtain flood levels near Branxton (Black Creek). The extent of the study area within the Black Creek catchment was defined by the extent of inundation by flooding from the Hunter River, upstream of this point local catchment runoff from Black Creek dominates. The divide between the two flooding mechanisms will vary depending upon the magnitude of the respective floods. This present study includes the Hunter River floodplain to upstream of the New England Highway at Branxton.

The extension downstream of Oakhampton to Green Rocks was undertaken to update the previous 1998 Supplementary Flood Study (Reference 2) and in particular to make use of the available Airborne Laser Scanning (ALS) survey data and the June 2007 calibration data. Reference 8 had indicated that there were issues with the June 2007 model validation using the hydraulic model from the 1998 Supplementary Flood Study.

Oakhampton is the locality approximately 4 kilometres upstream (north) of Maitland where the north coast railway line crosses the Hunter River. From a flooding perspective Oakhampton is of importance as upstream of this point the Hunter River is confined to a defined valley with only a narrow floodplain. Immediately downstream the Hunter River enters an expansive floodplain extending up to five kilometres either side of the main channel. The floodplain downstream also contains the extensive Fishery and Wallis Creeks floodplain storage areas. Further downstream near Morpeth the Paterson River joins the Hunter River.

The Maitland LGA has experienced solid growth over the past 5 to 10 years and growth is expected to continue which will result in the expansion of existing urban areas and the development of previously un-developed areas. The floodplain of the Hunter River from Branxton to Oakhampton (Figure 2) is potentially one such area but at present there is limited information about the flood hazard within the area. Downstream of Oakhampton (Figure 2) as the floodplain widens there is the potential for significant urban development on the fringes of the floodplain. For this area design flood information is available from Reference 2.

1.2. Objectives

The key objective of this Flood Study is to develop a suitable hydraulic model that can 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. Downstream of Oakhampton this involves the updating of the existing hydraulic model established in Reference 2. Elsewhere no hydraulic modelling of the study area had been completed.

Additional objectives of the study are:

- to establish the effects on flood behaviour of future development,
- to test the impacts of specific development proposals on flooding,
- to assess the hydraulic categories and undertake provisional hazard mapping.

This report details the results and findings of the Flood Study investigations. The key elements include:

- a summary of available historical flood related data,
- calibration of the hydrologic and hydraulic models,
- definition of the design flood behaviour for existing catchment conditions.

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

1.3. Justification for Present Study

A comprehensive Flood Study of the Lower Hunter River was completed in October 1998 (Reference 2). This Supplementary Flood Study further developed a previous Flood Study completed in 1990 (Reference 3). This present Flood Study has been initiated for the following reasons:

- The continued development of computer technology and hydraulic modelling software has enabled the more widespread use of Two Dimensional (2D) computer models which more accurately represent the floodplain than the previously used One Dimensional (1D) "branched" models,
- 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,
- There have been advancements in flood frequency estimation which is used to determine design inflows 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 data therefore provides a suitable event for

model calibration,

- The June 2007 event equalled the January 1971 event at Singleton, exceeded the 1971 peak at Greta (by 0.7m) but was 0.4m 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 required some further investigation,
- There is a need to review the results of the October 1998 Flood Study (Reference 2) and establish a computer model for use in the evaluation of climate change scenarios as well as potential development options,
- To investigate issues with the model calibration to the February 1971 and June 2007 floods as described in Reference 8.

2. BACKGROUND

2.1. Catchment Description

The main catchment area of the Hunter River at Maitland (Oakhampton) is upstream of Singleton. The additional catchment area between Singleton and Maitland (Figure 3) is approximately 1,100 km^2 or 6% of the total catchment to Maitland. Upstream of Singleton the main catchments are:

- the Upper Hunter River - 4,200km^2 upstream of Muswellbrook,
- the Goulburn River – 7,800km^2,
- Fal Brook - 800km^2,
- Wollombi Brook - 1,700km^2.

There are two major dams (and many smaller dams) within the catchment; these are Glennies Creek Dam on Fal Brook and Glenbawn Dam on the Upper Hunter River. These dams were constructed for water supply but Glenbawn Dam has a significant flood mitigation component. A detailed study of the hydrologic impacts of these dams on the flow regime downstream of Singleton has not been undertaken. These dams will reduce the peak flow during times of flood at Singleton and downstream depending upon the available capacity within the dams at the time of the flood.

Glenbawn Dam was completed in 1958 (it was partially complete at the time of the February 1955 flood) but subsequently enlarged in 1987. It was primarily constructed for irrigation purposes but has a significant flood mitigation component. At Full Supply Level (FSL) of 276.25 mAHD the dam has a capacity of 750 gigalitres (GL). One gigalitre is the volume contained within an area 316 m square and 10 metres deep. By comparison Warragamba Dam has a storage capacity of 2000 GL and a much larger catchment area of 9000 km^2. Above the FSL there is an additional capacity of 120 GL of flood storage (this volume could contain approximately 90 mm of runoff over the entire catchment to the dam). The uncontrolled spillway with three bay fuse plugs is at 280.6 mAHD. No rigorous flood study has been undertaken to quantify the reduction in downstream flood levels due to the dam construction. The Singleton Flood Study (Reference 1) ignored the impact of the dams (the catchment to Glenbawn Dam is approximately 1,300km^2 or 8% of the total catchment at Singleton) on the flood record and the same approach is adopted for this present flood study.

At Singleton (Figure 2) the floodplain is up to 5 kilometres wide across Doughboy Hollow but becomes narrower downstream in the reach from near Branxton to Oakhampton. The Hunter River has extensive meanders in this reach with the river distance approximately twice the direct distance. Downstream of Oakhampton the Hunter River enters an expansive floodplain from Maitland to Newcastle. Within this lower area it is joined by the Paterson River (approximately 1000km^2) and the Williams River. The Hunter River enters the Pacific Ocean through Newcastle Harbour.

The upstream limit of the present study area was taken as approximately the lower limit of the Singleton Flood Study hydraulic model (Reference 1) and just upstream of the Black Creek confluence on the Hunter River. Green Rocks (approximately 8 kilometres downstream of Morpeth) was taken as the downstream limit and is the Maitland LGA boundary. This is the same downstream model extent as included within the hydraulic model in the Lower Hunter Valley (Oakhampton to Green Rocks) Supplementary Flood Study (Reference 2).

A comprehensive description of the Hunter River catchment and flood mitigation works is provided on the Hunter – Central Rivers Catchment Management Authority web site (www.hcr.cma.nsw.gov.au).

2.1.1. Floodplain Upstream of Oakhampton

The floodplain of the Branxton to Oakhampton reach of the Hunter River is entirely occupied by rural properties with urban settlements set back from the floodplain. Branxton is some 5 kilometres from the Hunter River but in a large event the Hunter River floodwaters will reach the outskirts of the town. Greta is on high ground above the floodplain but is of significance as water levels have been recorded since 1961 at Greta although continuous height records (from an automatic recorder) are only available since 1970. This gauge is primarily used for flood warning purposes linking up with the Singleton (upstream) and Maitland (downstream) recorders.

There are two major bridge crossings in the reach – Elderslie Bridge near Branxton and Luskintyre Bridge near Lochinvar. There is also a low level wooden bridge near Aberglasslyn (Melville Ford bridge).

2.1.2. Floodplain Downstream of Oakhampton

This part of the floodplain of the Hunter River has been subjected to major flooding since it was first settled by non indigenous persons in the early 1800s. The first reasonably accurate flood level is the 1820 event which probably equalled the February 1955 flood peak, although the accuracy of this 1820 level can never be ascertained. The early non indigenous settlers constructed a series of farm levees and uncoordinated river bank levees which were frequently overtopped and/or failed. Many were then subsequently modified. Some were constructed in an attempt to confine the flood to a defined river corridor. In the February 1955 flood many of these were overtopped and failed resulting in devastating flooding within the City of Maitland. Unfortunately there is no accurate record of these pre 1955 levees.

A recently completed book on flooding of the Hunter River at Maitland (Reference 4) provides the most detailed history of flooding at Maitland available.

The 1956 Hunter Valley Flood Mitigation Act (now the Water Management Act 2000) allowed for the construction of a comprehensive flood mitigation scheme for the City of Maitland and comprises a series of:

- *Floodways* that confine the flow to defined paths,
- *Spillways* that allow the controlled overtopping of levees,
- *Levees* that prevent inundation of areas,

- *Control structures* that reduce the velocity of flow,
- *Floodgates* that prevent the backflow of floodwaters through culverts within the levees, the culverts are required to drain the area during non flood times.

The Lower Hunter Scheme (as it is known) was constructed following physical model studies undertaken in the 1960s. Subsequently parts of the scheme have been refurbished but no substantive changes from the original scheme have occurred.

Further details of the Scheme are provided on the Hunter – Central Rivers Catchment Management Authority web site (www.hcr.cma.nsw.gov.au).

Downstream of Oakhampton there is the Oakhampton railway bridge, the vehicular Belmore Bridge at Maitland and the vehicular bridge at Morpeth. A third Hunter River crossing is currently (2010) being constructed opposite East Maitland.

2.2. Previous Studies

2.2.1. Singleton Flood Study – 2003

This report (Reference 1) provides design flood level data for the Hunter River from approximately 8 kilometres upstream of Singleton at Rockley to Lower Belford (near the mouth of Jumpup Creek) approximately 25 kilometres downstream. A TUFLOW hydraulic model was set up over this reach based on the following survey sources:

- Aerial photogrammetry at 1:6500 scale,
- Ground survey undertaken in 1939 within Glenridding/Doughboy Hollow,
- 26 surveyed river cross sections,
- 10m contour information from the Land Information Centre.

The model was set up using both a 1D (one dimension) and 2D layout. The 1D layout was used to represent the Hunter River channel outside the floodplain around Singleton. The inflow to the hydraulic model was a flow hydrograph which was not obtained from a runoff routing hydrologic model. It was considered that such a hydrologic model was inappropriate as it could not adequately represent the spatial distribution of rainfall over the 16,500 km^2 catchment. Instead for historical events an inflow hydrograph was derived using a rating curve (relationship between water level and flow) obtained from the then WRC (Water Resources Commission now incorporated into the Department of Water and Energy).

For design events the hydrograph shape was derived from an averaging of the historical flood hydrographs and then scaled up to match the design peak flow. The design peak flows were obtained by flood frequency analysis of the historical flood flow record (1893 to 2000) at Singleton (Dunolly Bridge). The peak flows were obtained from WRC records and it was noted that there were several anomalies with the data (notably due to inconsistencies between the relative peak levels and recorded flows for the 1913, 1930, 1949, 1952, 1971 and 1977 events). An Extreme Flow was adopted as 3 times the 1% AEP peak. The adopted design and historical peak flows at Singleton are given in Table 1.

Table 1: Adopted Peak Flows at Singleton

AEP	Inflow Peak (m^3/s)	Ratio to the 1% AEP	Outflow Peak (m^3/s)	Attenuation (%)	Lag between Peaks (h)
February 1955	12500	1.33	10350	17.2%	4.3
February 1971	5410	0.58	4820	10.9%	8.2
June 2007 (1)	5970	0.64	5586	6.4%	7.0
20% AEP	1730	0.18	1690	2.3%	3.9
10% AEP	2950	0.31	2750	6.8%	4.8
5% AEP	4480	0.48	4020	10.3%	8.3
2% AEP	7040	0.75	6680	5.1%	6.1
1% AEP	9390	1	8920	5.0%	5.4
0.5% AEP	12140	1.29	11430	5.9%	5.1
Extreme	28180	3	25730	8.7%	4.6

(1) Provided by WBM as part of this study

The TUFLOW hydraulic model was calibrated to recorded flood levels for the February 1955 (74 levels), February 1971 (18 levels) and June 1949 (19 levels) events by adjustment of the Manning's "n" parameter (Manning's "n" is a parameter used in hydraulic models to reflect the "roughness" of the channel as well as other factors such as the sinuosity of the channel. It is the principal parameter used to match the model results with the historic recorded levels). A relatively low "n" value for the river bed of 0.025 and for pasture of 0.036 was adopted. These values were required in order to match the adopted (by the WRC many years ago) peak flows to the recorded flood levels.

The report indicated that there had been changes to the levee system since 1955 and this may have affected the rating curve. It should be noted that this report was finalised prior to the June 2007 flood (3rd equal (with 1971) highest flood ever recorded at Singleton) and the inclusion of this event in the flood records may change the model calibration and/or the flood frequency analysis.

2.2.2. Lower Hunter Valley Supplementary Flood Study – 1998

This report (Reference 2) provided an update to the 1990 Flood Study of the Hunter River reach from Oakhampton to Green Rocks (Reference 3). A Mike-11 hydraulic model was established and calibrated to the February 1971, January 1972, March 1977, March 1978 and October 1985 events. A verification was undertaken using the February 1955 flood but this was limited by the poor quality of the flood height data.

A similar approach for obtaining a Hunter River inflow hydrograph at the upstream boundary was adopted in this study as for the Singleton Flood Study (i.e no runoff routing hydrologic model but the design peak flows based on flood frequency analysis). The only slight difference was that the inflows for historical events were derived through an iterative procedure by matching to the recorded stage hydrograph at Belmore Bridge (Maitland) assuming a "reasonable" Manning's "n" rather than the use of a rating curve (not available for Maitland).

For design events the peak flows were obtained from flood frequency analysis of the Singleton and Belmore Bridge flood record with the February 1955 hydrograph shape adopted. A similar flood frequency approach was adopted to derive peak inflows from the Paterson River. A hydrologic model was used to derive historical and design inflows from the Fishery and Wallis Creek systems (smaller tributary inflows). The adopted design and historical peak flows for the Hunter River at Oakhampton (the flow splits downstream so the flow under Belmore Bridge is of the order of a third of the total Hunter River flow depending upon the magnitude of the event) are given in Table 2.

Table 2: Adopted Peak Flows at Oakhampton

AEP	Peak Flow (m^3/s)	Ratio to the 1% AEP	Ratio to corresponding event at Singleton
February 1955	10,300	1.29	0.82
February 1971	3,500	0.44	0.65
June 2007 (not included in Reference 2)	3,200	0.40	0.53
20% AEP	1,900	0.24	1.20
10% AEP	2,700	0.34	0.92
5% AEP	4,000	0.50	0.89
2% AEP	5,500	0.69	0.78
1% AEP	8,000	1	0.85
0.5% AEP	10,300	1.29	0.85
Extreme	24,000	3	0.85

Taken from Reference 2

A comparison of the ratio of the design peaks to the 1% AEP at Singleton and Maitland indicates that the Extreme, 0.5% AEP (also 1955) and 5% AEP have very similar ratios. At Singleton the February 1971 flood was approximately a 3% AEP event but was slightly smaller than a 5% AEP at Maitland.

It should be noted that this report was finalised prior to the June 2007 flood and the inclusion of this event in the flood records may change the model calibration and/or the flood frequency analysis.

2.2.3. Black Creek Flood Study – 2004

This report (Reference 5) was undertaken to provide design advice to the RTA (Roads and Traffic Authority) for the demolition of the New England Highway road bridge and subsequent replacement with twin bridges on its upstream side. The objectives of the study were to:

- Ascertain the flood mechanism at the site and the relative importance of the flooding from the Hunter River and Black Creek,
- Estimate the magnitude and frequency of the February 1955 flood and compare the results to the 1% AEP event,

- Estimate the “afflux” in the 10% AEP event following construction of the new bridge.

The RORB hydrologic model and HEC-RAS hydraulic model were used. The study provided a compilation of flood levels for the February 1955 event along Black Creek and in the Hunter River. The February 1955 flood was approximately 3.0 metres above the deck of the bridge. The study concluded that the Hunter River was the dominant flood mechanism (producing greater flood levels than the flow emanating from Black Creek itself).

2.2.4. Greta Drainage Study – 1985

This report (Reference 6) undertook a hydraulic assessment for the proposed redevelopment of low lying areas. Mention was made of the February 1955 and other floods (June 1949 and January 1968) however as the ground levels of the study area were all above the recorded February 1955 level (approximately 29m AHD) it was concluded that the flood levels in the report relate to local catchment flooding and not flooding from the Hunter River. Consequently this report provides no useful information for this present study.

2.2.5. Black Creek Flood Study - 2008

This report (Reference 7) encompassed the 118 km^2 catchment of Black Creek to Lovedale Road Bridge (Bancroft’s Bridge) which is approximately 5 kilometres downstream of Cessnock. In the study a hybrid 1D/2D hydraulic model was developed and calibrated to the April 1974, March 1977, February 1990 and June 2007 floods. A 3m by 3m grid was developed for the 2D domain with over 700 cross sections in the 1D component.

The relevance of this study to the present study can be summarised as follows:

- The June 2007 event was approximately a 2% AEP event in Black Creek based on a comparison of the recorded and design rainfalls,
- The February 1990 event was calibrated to flow data at three gauges (subsequently abandoned). Initial losses of < 10mm and continuing losses of up to 4.5mm/h were adopted (the losses were varied between the catchments),
- The June 2007 event provided the most peak height data. This event was “unusual” in that it was assumed that up to 55 m^3/s of flow was diverted down a mineshaft just upstream of South Cessnock. This would have no significant impact on the peak flow or level at Greta.

2.2.6. Lower Hunter River Valley – Hydraulic Model: June 2007 Flood Validation

In this study (Reference 8) the hydraulic model adopted in Reference 2 was used to “verify” the June 2007 flood recorded data. The main conclusions from this verification were:

- the 2007 event did not accord with the 1971 peak height profile from Singleton to Maitland,
- the 2007, 1977 and 1971 events have different travel times of the flood peaks from Singleton to Maitland,

- the travel time of the flood peak from Singleton to Greta was similar for 1971 and 2007 but was longer in 2007 from Greta to Maitland,
- there is only a limited correlation between the peak gauge heights at the Singleton, Greta and Belmore Bridge gauges,
- the hydraulic model (MIKE-11) that was calibrated to the 1971 and 1977 events did not accurately replicate the 2007 peak height profile. Of particular note was the relatively good model match in 1977, an event which reached a similar level at Belmore Bridge to 2007. If the hydraulic model was matched closer to the 1971 data upstream of Oakhampton, the match to the 2007 data would be improved. It was possible to adjust parameters in the hydraulic model (notably the Manning's "n" value which accounts for the density of vegetation on the river banks) to achieve a match to the 2007 data but these adjustments would affect the calibration for the other events, particularly 1977 which has a reasonable amount of recorded data.

The recommendations from this study were:

- Further detailed survey is required of the Hunter River channel and floodways to verify the data in the hydraulic model (particularly in the reach from Oakhampton to Belmore Bridge). This may provide an insight into possible changes to the original data and an explanation for the differences in historical peak height flood profiles (to some extent this has been achieved with collection of the ALS).
- The BOM should review their flood warning system for Maitland in light of the 2007 data (already undertaken).
- The SES should review their gauge cards regarding the levels and timings of when roads, spillways and other essential structures are overtopped.
- Manly Hydraulics Laboratory (MHL) should review the data anomalies at Belmore Bridge and at the upstream/downstream Bolwarra gauges. This review may have implications for other gauges and records in NSW.

2.2.7. Paterson River Flood Study

This study (Reference 9) undertook a flood study of the 1000 km^2 Paterson River catchment with hydraulic modelling extending across the Hunter River floodplain to Hinton. The main stream flow gauging station is at Gostwyck which has records from 1928 to 1946 and 1969 to 1995 (date data obtained to). Unfortunately the record has a number of data anomalies and these needed to be resolved prior to undertaking the analysis.

A RAFTS-XP hydrologic runoff routing model and a MIKE-11 hydraulic model were established and calibrated to historical flow data (at Allyn, Gostwyck & Lostock Dam) and recorded flood levels for the March 1978, March 1977 and March 1995 events.

Design flows were obtained by both flood frequency analysis on the 46 years of record together with rainfall runoff modelling using RAFTS-XP. The results from the two approaches were reasonably consistent with the following adopted design peak flows at Gostwyck:

- Extreme = 3*1% AEP,

- 1% AEP = 2500m^3/s,
- 2% AEP = 2050m^3/s,
- 5% AEP = 1450m^3/s,
- 10% AEP = 1050m^3/s.

The shape of the design inflow hydrographs was based on the 36 hour Australian Rainfall & Runoff storm duration (i.e the RAFTS-XP flows at Gostwyck were factored to match the above adopted peak flows with the same factoring used on other tributary inflows). It was assumed that the design inflows occurred 12 hours prior to the peak on the Hunter River at Oakhampton.

The probability of combining a Hunter River design event with a similar magnitude Paterson River design event was considered unrealistic. The historical data indicates that a major flood can occur on the Paterson River (March 1978 and March 1995) in combination with only a small event on the Hunter River and vica versa (January 1971 and March 1977). To account for this joint probability of the two design events the following combinations of design events were adopted (the maximum level from either combination was adopted as the design flood level):

- **Extreme event** = Paterson Extreme + Hunter 1% AEP and
  Paterson 1% AEP + Hunter Extreme
- **1% AEP** = Paterson 1% AEP + Hunter 2% AEP and
  Paterson 2% AEP + Hunter 1% AEP
- **2% AEP** = Paterson 2% AEP + Hunter 5% AEP and
  Paterson 5% AEP + Hunter 2% AEP
- **5% AEP** = Paterson 5% AEP + Hunter 10% AEP and
  Paterson 10% AEP + Hunter 5% AEP

The above approach is arbitrary and can only be confirmed when sufficient future flood records become available (say a further 50 years of records). Sensitivity analysis was undertaken to test the relative importance of the design parameters.

3. 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.).

3.1. Hydraulic Model

The availability of high quality ALS and photographic data means that the study area is suitable for 2D hydraulic modelling. Various 2D software packages are available (SOBEK, TUFLOW) and the TUFLOW package (Reference 10) was adopted as it is widely used in Australia and was used in Reference 1.

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. The size of grid is determined as a balance between the model result definition required, the dimensions of the river channel (as a rough guide the channel should have over 4 cells widths in order to accurately define it) and the computer run time (depends on the number of grid cells).

The adopted approach was to establish two 10m by 10m grid TUFLOW models. The Upper model extends from the upstream limit of the study area to Belmore Bridge and the Lower model from upstream of Oakhampton to Green Rocks. Outflows from the Upper model were included at the upstream boundary of the Lower model. The overlapping area (Oakhampton to Belmore Bridge) was included in both models to eliminate boundary issues.

By modelling historical flood events and matching the model versus the recorded data the TUFLOW models can be "calibrated" or tuned to replicate actual flood events. This process is critical to the success of the approach and comprises the majority of the effort in the study.

3.2. Inflow Hydrographs

Flow hydrographs are required for the Hunter River and the various tributary catchments which enter between the upstream and downstream end of the two models. Typically in flood studies a rainfall-runoff hydrologic model is used to provide these inflows.

However, the use of rainfall runoff models become less reliable for design flow estimation when the catchment size becomes sufficiently large (the Hunter River catchment to Maitland is 17,500km^2) that many design assumptions are not seen in historical events. With large catchments many of the historical events occur over only parts of the catchment, there is no uniform or consistent spatial pattern between storms and the temporal pattern shape varies spatially over the catchment. For large catchments where these problems occur a design event generated from a rainfall runoff model tends to be "too uniform" and not to have many of the characteristics of the historical events. In these cases a more reasonable design event can be generated by a combination of flood frequency analysis which incorporates all of this variability and scaling a historical event close in magnitude to the desired frequency.

Whilst a hydrologic model could be used to establish historical inflows, design Hunter River inflows to the hydraulic model could not be obtained from a hydrologic model. It was therefore considered that a runoff-routing hydrologic model would not be practical as there is currently no accepted approach to represent this spatial variability of design rainfall over a catchment of this size.

The approach of using flood frequency analysis to determine design peak flows on the Hunter River (the shape of the hydrograph being based on the shape of the February 1955 event) together with the tributary inflows from the WBNM hydrologic model has therefore been adopted. The design storm duration for the WBNM model was based on sensitivity analysis and review of historical events.

For the historical events (used to calibrate the TUFLOW models) historical rainfall data was input to the WBNM model to obtain the tributary inflows with the inflow on the Hunter River "adjusted" to ensure a fit to the recorded stage (height) hydrograph at Greta and Maitland (Belmore Bridge). A similar approach for obtaining the Hunter River historical inflow hydrographs was adopted for the Singleton (Reference 1) and Lower Hunter Valley Flood Studies (References 2 and 3).

Automatic water level recorders (Greta, Belmore Bridge and elsewhere) provide a continuous record of the water level throughout a flood event and this data is used to compare to the results from the TUFLOW model. However it is preferable to use flow data for calibration purposes if that is available. Flow data can only be obtained if an authority has undertaken velocity measurements during a flood event and developed a rating curve (relationship between water level and flow).

At Singleton and Greta rating curves are available, however the Singleton data is too far upstream to be of value in the present study but results from the TUFLOW model compared to the stream gaugings at Greta have been compared. There are no other water level recording stations downstream on the Hunter River (e.g. Belmore Bridge) that have rating curves, though there are some velocity measurements available at Belmore Bridge.

The downstream limit of the Lower TUFLOW model is at Green Rocks and the downstream boundary condition was represented as a stage-discharge curve based upon normal flow conditions.

3.3. Flood Frequency Analysis

Flood frequency analysis 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,
- historic rainfall data are not required.

However this approach also has several limitations:

- there is no "perfect" distribution, 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 (at Maitland this is not a significant limitation due to the length of record). 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.

Both the Singleton and Lower Hunter Valley Flood Studies (References 1 and 2) adopted flood frequency analysis. This approach can only be used where there are long periods of flood record (say greater than 50 years), thus it is only applicable for Singleton and Maitland (Belmore Bridge). It could be undertaken at Greta but this was not considered worthwhile as:

- much longer records are available at Singleton and Maitland; and
- the Greta data does not include the March 1977 and February 1955 events.

For the present study flood frequency analysis has been undertaken on the flood record at Maitland (Belmore Bridge) using a rating curve at Oakhampton derived from the calibrated TUFLOW model. This approach was adopted as downstream of Oakhampton the flow is split between the Oakhampton floodway, the main channel and the Bolwarra floodway, thus a rating curve of the Hunter River at Belmore Bridge is not reflective of the total Hunter River flow.

The analysis was not undertaken at Singleton as this was completed in Reference 1.

At some locations in Australia there is the potential to extend the flood record through the use of paleo-flood records (determining peak levels from past evidence of flooding, e.g. debris in caves or sediment analysis). This is not possible (as far as we are aware) at Singleton, Greta or Maitland.

3.4. Calibration Events for TUFLOW

The choice of calibration events for flood modelling depends on a combination of the magnitude of the flood event and the quality and quantity of available height data. Clearly it is preferable to use the larger events (February 1955 and January 1971) as they are closer to the design flood events adopted by Council for flood related development control purposes. However, the more recent events generally have a higher quality and quantity of data.

3.4.1. Available Data

The quality and quantity of available data for each flood event has varied considerably over the years. The only locations to record all major events from February 1955 to date are Singleton, Belmore Bridge and Morpeth. Greta was not operating in 1955 and failed to record the March 1977 event. Other gauges have recorded some events but have subsequently not been used or the records lost. In some events only partial records are available and the peak may not have been recorded.

Records from an automatic gauge are generally superior to those from a manually read gauge. Belmore Bridge was only automated in 1992 and automatic records are only available since 1970 at Greta. There are now nine automatic gauges within the Hunter River floodplain between Oakhampton and Green Rocks with others at:

- **Paterson River:** Gostwck, Paterson Railway Bridge, Dunmore,
- **Williams River:** Seaham,
- **Lower Hunter River downstream of Green Rocks:** Raymond Terrace, Hexham Bridge and Stockton Bridge.

It is important to note that there is uncertainty associated with the water level data from manually read gauges as a result of the following possibilities:

- incorrect assumed gauge datums to Australian Height Datum (AHD), since most of the manual gauges were installed prior to adoption of AHD in 1971,
- incorrect transcription of gauge data into metres, since some data were obtained prior to the metric system being adopted in 1973/1974,
- improperly recorded changes to the gauge locations, or accidental raising/lowering of the gauge boards,
- human error in obtaining readings from the gauge boards during floods or other transcription errors.

Whilst every effort has been made to account for these errors, due to the passage of time, it is impossible to be sure that an accurate correction has been made for all records.

3.4.2. Choice of Calibration Events

Events prior to 1955 are of no value for model calibration as there are such limited data available. Figures 4 to 12 provide historical flood data in the study area. Table 3 lists all floods greater than 9m AHD at Belmore Bridge from 1955 to 2009 together with a brief description of the value of the data for model calibration.

Table 3: Peak Levels > 9m AHD at Belmore Bridge since 1955

Date of peak at Belmore Bridge	Height (m AHD)	Comments
25-Feb-55	12.10	Largest flood recorded with a large number of overbank peak levels (approximately 60) but only 4 hydrographs. No record at Greta.
2-Feb-71	11.14	2nd largest flood. No overbank data but 14 (including Greta) hydrographs available though only 8 indicate the peak. RAAF aerial photographs of the flood over Maitland also available.
5-Mar-77	10.81	No record at Greta, 12 hydrographs and 2 records of overbank inundation. No photographs or description of this event at Maitland. This event cannot be used for the calibration between Branxton and Oakhampton due to the lack of data in this reach.
11-Jun-07	10.70	13 automatic gauge records including Greta and over 30 overbank levels between Branxton and Maitland collected by Council as part of this study. Large number of video, oblique and aerial photographs.
12-Jun-64	10.40	12.0m recorded level at Singleton. No record at Greta but detailed records at Maitland and downstream. No indication that the spillways/levees were overtopped at Maitland.
14-May-62	10.38	9.8m at Singleton, 32.5 ft at Greta (gauge datum unknown but this corresponds to say 10m which is 3m lower than 2007), limited other records are available (Morpeth). Descriptions of the flood indicate that it did not overtop the spillways/levees at Maitland. It is of note that the travel time of the peak from Greta to Maitland was only 4.5 hours.
25-Jan-76	10.21	12.4m recorded level at Singleton but gauge failed at Greta and no other records available.
11-Feb-92	9.70	9.2m recorded level at Greta (3m lower than 1971) and thus of limited value. An extensive data search for this event has not been undertaken but it is presumed that automatic records are available downstream of Oakhampton. Unfortunately there is no automatic record at Belmore Bridge (gauge started in June 1992).
09-Aug-98	9.66	9.4m recorded level at Greta (approximately 3m lower than 1971) and thus of limited value.
21-Mar-78	9.61	9.2m recorded level at Greta (3m lower than 1971) and thus of limited value. Some stage hydrographs are available downstream of Oakhampton.
22-Jun-89	9.61	8.9m recorded level at Greta (>3m lower than 1971) and thus of limited value.
5-Jun-74	9.51	6.9m recorded level at Singleton but gauge failed at Greta and no other records available.
14-Oct-85	9.30	7.8m recorded level at Greta (>4m lower than 1971) and thus of limited value. There is some doubt about the peak level at Belmore Bridge as the gauge cards indicate a peak of only 8.9m AHD. This flood was 8m below the 2007/1971 peaks at Singleton and thus is not reflective of a major Hunter River flood. Possibly a greater proportion of the flow entered downstream of Singleton. There are reasonably good records available downstream of Oakhampton.

Ideally all large flood events (say greater than 10m AHD at Belmore Bridge) should be used for model calibration however due to the lack of data at Greta the June 1964, and January 1976 events cannot be used. The May 1962 event was also rejected due to datum issues at Greta and the limited peak levels available and no stage hydrographs. The four remaining events (1955, 1971, 1977 and 2007) can be used though 1977 cannot be used upstream of Oakhampton due to the lack of data at Greta and elsewhere in this reach.

Reference 2 included the 1972, 1978 and 1985 events for model calibration as some hydrograph data are available downstream of Oakhampton. As these events are all smaller than 10m AHD at Belmore Bridge and the quantity and quality of data is relatively poor these events have not been used in model calibration in the present study. Greater emphasis has been given to the February 1955 event in this present study than in Reference 2 due to the large number of peak levels recorded within the Upper TUFLOW model extent. Also the June 2007 event has provided high quality calibration data which negates the need to rely on the 1972, 1978 and 1985 events for model calibration.

3.4.3. Overtopping of Spillways at Maitland

The overtopping of the Oakhampton and Bolwarra spillways is of great significance at Maitland as it results in traffic disruption and potentially inundation of buildings. The January/February 1971 flood is notable as it is the largest event for which reliable water level data are available at several locations across the floodplain (data are available for February 1955 but the accuracy is doubtful in places). This 1971 event is also the only flood which has overtopped the Bolwarra spillway (in 2007 the floodwaters just lapped over it) since 1955, albeit only by approximately 0.3 m.

The Oakhampton spillways No. 1 (upstream) and No. 2 (downstream) were also overtopped in 1971 and again in June 2007. The March 1977 and the June 2007 events produced near identical peaks at Belmore Bridge (March 1977 was 0.1 m higher) and Figure 12 indicates that the Oakhampton No 1 spillway was overtopped (Oakhampton Road washed away) in March 1977 but there is very little information regarding whether the Oakhampton No. 2 spillway (or Bolwarra spillway) was or was not overtopped in March 1977. It is likely that they both were overtopped but as it caused little damage there are no records.

The Oakhampton No. 1 spillway was overtopped by approximately 0.15m in June 2007 and probably for a period of less than 6 hours. This estimate is based on limited data.

3.5. June 2007 Event

The Belmore Bridge record (Figure 5) indicates that the 2007 flood was the 12th largest flood on record and at least 23 floods have exceeded 10 mAHD at Belmore Bridge since 1820. A comparison between the data for the June 2007 event and other events highlighted a number of issues and these are summarised in the following sections.

3.5.1. Alterations to Belmore Bridge Readings

A discrepancy was observed at the Belmore Bridge gauge between the automatic gauge peak flood level and the observed peak level read from the adjoining manually read gauge boards. The flood peak was observed to be 10.70 mAHD according to the gauge boards but the peak of the automatic recorded levels was 10.47 mAHD. Observers from the gauge operators (MHL) noted this anomaly during the flood (and also to some extent at the Oakhampton Railway Bridge gauge) and can provide no explanation but agree that the automatic record is incorrect. Based on a review of the available data and discussions with MHL, it was decided that the data from the automatic gauge should be scaled up on a linear basis such that the recorded peak level matched the manually observed peak level.

All references to the recorded hydrograph at Belmore Bridge in this report should be taken to mean the scaled up data with a peak of 10.7 mAHD.

3.5.2. Comparison of Upstream and Downstream Bolwarra Automatic Gauge Records

The Upstream Bolwarra gauge is located approximately 450m downstream of the Oakhampton Railway Bridge whilst the Downstream Bolwarra gauge is located approximately 1450m downstream, or 1000m downstream of the Upstream Bolwarra gauge (refer Figure 3). A comparison of the recorded hydrographs from the Upstream and Downstream Bolwarra gauges indicates minimal difference in water level (less than 0.2m) with the Downstream gauge recording a <u>higher</u> peak than the Upstream gauge.

MHL have advised that this may be due to sediment build up or similar and the Downstream Bolwarra gauge recorded approximately 0.1m too high.

3.5.3. Comparison of Stage Hydrographs

A comparison of the stage (height) hydrographs for the 1971, 1977 (no record at Greta) and 2007 events, with the flood peaks at Singleton aligned, is provided below.

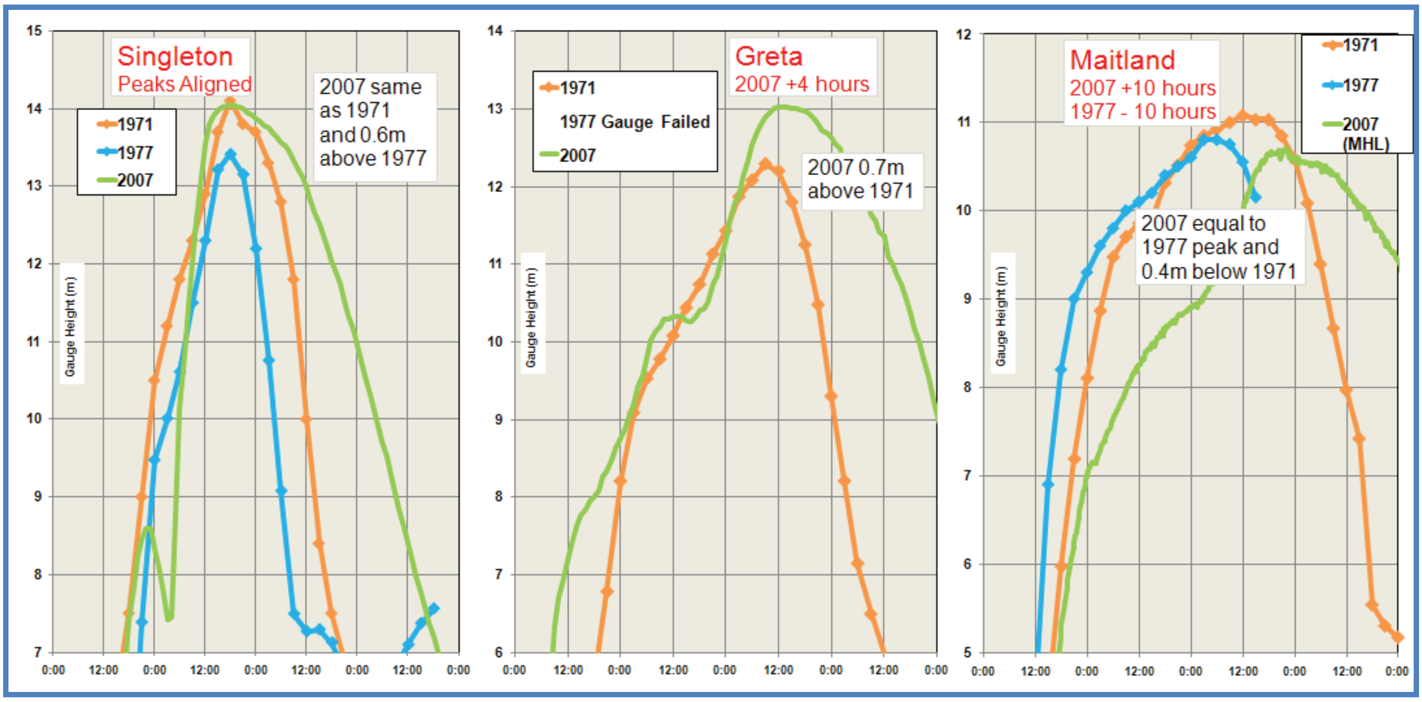


Table 4 provides a summary of the relative peak levels and timing for the three events at Singleton, Greta and Maitland.

Table 4: Summary of Data Upstream of Maitland

Event	Singleton	Greta (50kms d/s of Singleton)	Maitland (35 kms d/s of Greta)
	Peak Level (m)	Peak Level (m)	Peak Level (mAHD)
1971	14.1	12.3	11.1
1977	13.3	n/a	10.8
2007	14.0	13.0	10.7
	Time of Travel of Flood Peak from Singleton (hours)		
1971		15	18
1977		n/a	11
2007		19	28

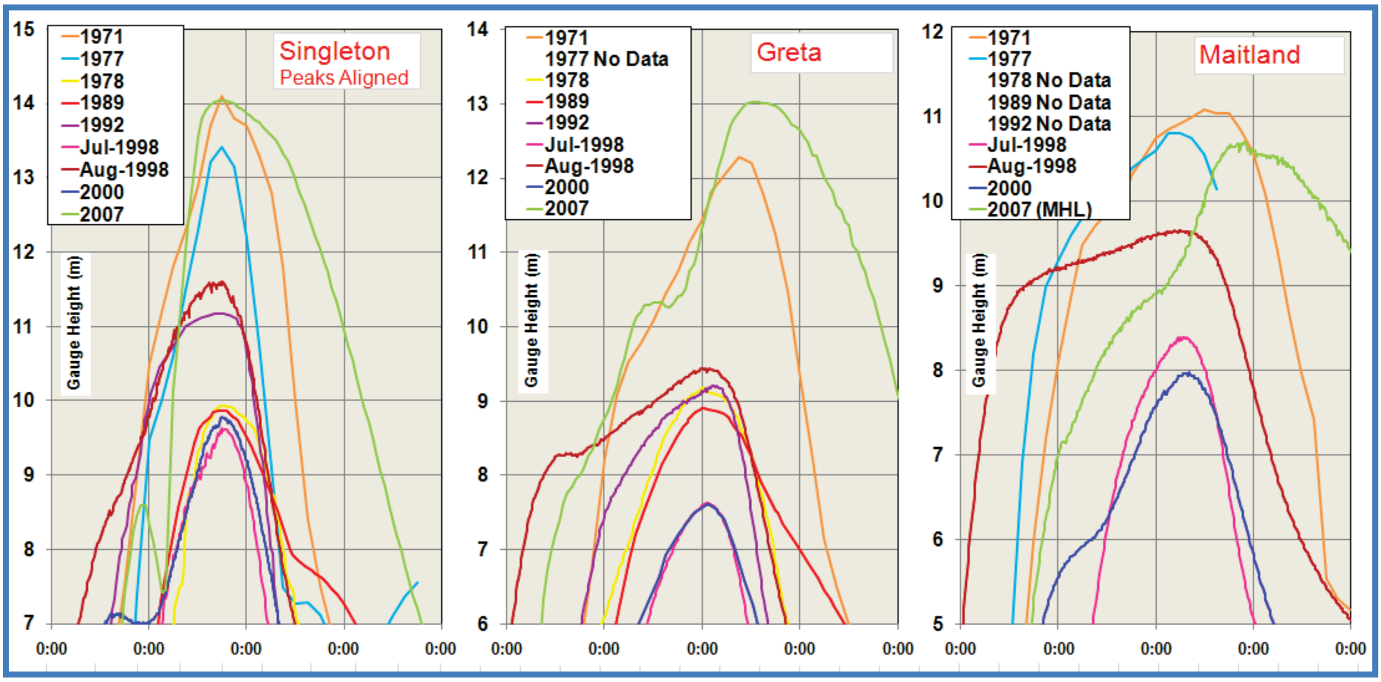
n/a - not available

The key features of the above are:

- at Singleton the 2007 flood peak approximately equalled the 1971 flood peak, at Greta the 2007 flood peak was approximately 0.7m above the 1971 flood peak, at Maitland the 2007 flood peak was 0.4m lower than the 1971 flood peak,
- at Singleton the 1977 flood peak was 0.7 m lower than the 1971 flood peak (no record at Greta for 1977), at Maitland the 1977 flood peak was 0.3m lower than the 1971 flood peak,
- the 2007 and 1971 flood peaks both reached Greta approximately 15-19 hours after the peak at Singleton,
- the 2007 flood peak reached Maitland 28 hours after the peak at Singleton while the 1971 flood peak took 18 hours and the 1977 flood peak took 11 hours.

Further to the above the peak gauge levels for all flood events (since automatic records are available) were obtained for Singleton, Greta and Maitland (Belmore Bridge). Hydrographs for the following large flood events were obtained and analysed (see below):

- March 1978 (Singleton and Greta only),
- June 1989 (Singleton and Greta only),
- February 1992 (Singleton and Greta only),
- July 1998,
- August 1998,
- November 2000.



The key features of the above comparisons are:

- for the 1978 and 1989 events the peak levels and times between the peaks at Singleton and Greta are very similar,
- in 1992 the peak at Greta was similar to 1978 and 1989 (9m) but the peak at Singleton was 1m higher than in 1978 or 1989. The time between the peaks was also slightly longer in 1992 although this is less definitive as the peak at Singleton was extended,
- in July 1998 the difference in peak gauge levels (2m) at Singleton and Greta was similar to 1992,
- in August 1998 the difference in peak levels (2m) and the difference in time of the peaks at Singleton and Greta was similar to 1992,
- in 2000 the peak levels and difference in time to peak at Singleton and Greta closely matched those recorded in July 1998,
- the 1978 and 1989 events showed similar differences in peak gauge level (1m) while all subsequent floods show a similar but greater difference (2m),
- the average difference in time to peak from Singleton to Greta is 7 hours,
- for the three events with data at Belmore Bridge (July 1998, August 1998 and November 2000) each show similar differences in time to peak between Greta and Maitland, though for August 1998 the timing is less well defined due to the extended peak. The differences in peak gauge levels for Greta and Maitland for August 1998 and November 2000 are similar (0.3m) but July 1998 shows a much greater difference (0.8m).

In conclusion there is only a limited correlation between the peak levels at the three gauges as shown in Figure 8.

3.5.4. Comparison of Flood Photographs - 1971 and 2007

Aerial photographs are available for the 1971 (Figure 12) and the 2007 (Figure 9) floods and have been examined to determine the extent of overtopping of the spillways. Of particular note are the following:

- the Bolwarra spillway was not overtopped in 2007 (to any significant extent though water did lap over) but was in 1971 (albeit by only approximately 0.3m),
- the Oakhampton No. 1 and No. 2 spillways were overtopped in 1971 and 2007 by what appears to be similar amounts, given the fact that the Mt Pleasant Street control was not overtopped in either event. If the 1971 flood overtopped the Oakhampton No. 1 spillway by a much greater amount than in 2007, the Mt Pleasant Street control would have been completely overtopped. Although it is noted that the Power House control was completely submerged in 1971 but it is unclear if it was in 2007 as the peak was during darkness and there are no observations available.

3.6. TUFLOW Calibration Approach

The steps in the calibration of the two TUFLOW models were as follows:

- The models were established based on the ALS data with the major inflow on the Hunter River at the upstream model extent and tributary inflows downstream (including the Paterson River),
- The tributary inflows (all inflows except the Hunter River) were obtained from a WBNM hydrologic model which was calibrated to the limited flow data available,
- For the 1971 and 2007 events the Hunter River inflow at the upstream boundary was adjusted in combination with the Manning's "n" friction factor to obtain a match to the recorded stage hydrograph data at Greta and downstream of Oakhampton. Due to the relative difference in levels at the Singleton, Greta and Maitland gauges this could only be achieved by having different Manning's "n" assumptions (most likely due to changes in the density of vegetation on the banks) for each event. The results were compared to the available recorded data and the TUFLOW model rating curve (height/flow relationship) at Greta compared to the historical gaugings,
- Once a satisfactory match had been achieved for the 1971 and 2007 events the 1977 event was input to the Oakhampton to Green Rocks model. This event was not included in the upper model as there is no calibration data (gauge at Greta failed). The Manning's "n" assumptions adopted for the 1971 event were also adopted for the 1977 event. The Hunter River inflow hydrograph was obtained by adjusting the inflow to provide the optimal match to the Belmore Bridge record. The results were compared to the available recorded data,
- Inflows for the 1955 event on the Hunter River upstream of Branxton were obtained by adjusting the inflow to provide the optimal match to the peak flood levels between Branxton and Oakhampton and the available recorded data downstream of Oakhampton. The Manning's "n" assumptions adopted for the 1971 event were also adopted for the 1955 event.

3.7. Design Flood Modelling

Following calibration and derivation of the peak Hunter River inflows at Oakhampton (through flood frequency analysis) the following steps were undertaken:

- Design tributary inflows were obtained from the WBNM hydrologic model and included in the TUFLOW model,

- Inflows for the design events on the Hunter River upstream of Branxton were obtained by adjusting the inflow to match the peak design flows at Oakhampton obtained from the flood frequency analysis. The “shape” of the Hunter River inflow hydrograph was based on the shape of the February 1955 flood. It is considered that the “shape” of the hydrograph was possibly influenced by the failure of “Cummins/Commerfords” dam/levee upstream and the spillway on the Bolwarra levee,
- Sensitivity analysis was undertaken to assess the effect of changing model parameters.

4. AVAILABLE DATA

4.1. Rainfall Stations

4.1.1. General

Rainfall data is required for the calibration of hydrologic models. Whilst hydrologic modelling of the Hunter River itself has not been undertaken (the upstream inflows are based on matching to recorded levels at Greta for the historical events and flood frequency analysis for the design events). The intermediate inflow catchments to the Hunter River, between Branxton and Green Rocks, need to be included in the hydraulic model.

For this reason rainfall data has been collected from the relevant rainfall stations (Figure 3). This data collection has focussed on the intermediate area between Branxton and Oakhampton as downstream the tributary creeks are either large systems (Paterson River) which has been analysed previously (Reference 9) or the Fishery and Wallis Creek catchments where there are no gauging stations. Rainfall data were obtained for the following dates (these were the largest events recorded at Greta plus the February 1955 (occurred prior to installation of the gauge) and March 1977 (gauge failed):

- February 1955,
- 29th January to 1st February 1971,
- 2nd February to 5th March 1977,
- 18th to 21st March 1978,
- 7th to 10th February 1992,
- 6th to 9th August 1998,
- 7th to 9th June 2007.

Table 5 indicates the total number of rainfall stations (where data are available) for each flood event. Table 6 lists the continuously read (pluviometer) stations that have data available.

Table 5: Availability of Rainfall Data for each Flood Event

		Flood Event						
Type	**Total**	**1955**	**1971**	**1977**	**1978**	**1992**	**1998**	**2007**
Daily	58	18	47	36	35	23	23	19
Continuous	8	0	4	8	6	3	5	4

Table 6: Continuously Read Rainfall Stations

Station No	Station name	Opened	Closed	Data Available						
				1955	1971	1977	1978	1992	1998	2007
61158	Glendon Brook (Lilyvale)	30/03/1964		n	y	y	y	y	y	n
61174	Millfield Composite	1/01/1958	1/01/1983	n	y	y	y	n	n	n
61238	Pokolbin (Somerset)	1/01/1962		n	y	y	y	y	y	y
61250	Tocal AWS	1/01/1975		n	n	y	y	y	y	y
61288	Lostock Dam	29/09/1969		n	y	y	y	n	y	y
61314	Mount View Range	14/11/1972	24/07/1985	n	n	y	y	n	n	n
210022	Allyn R @Halton	9/08/1976		n	n	y	n	n	y	y
210095	Bucks Ck @Vacy	31/10/1975	4/06/1991	n	n	y	n	n	n	n

n = data NOT available, y = data available

Table 7 lists the daily read stations that had data available for at least one flood event.

Table 7: Daily Read Rainfall Stations

Station No	Station Name	Opened	Closed	Station No	Station Name	Opened	Closed
61001	Allandale (Tingara)	Jan 1902	Dec 1971	61188	Broke (Sentry Box)	Jan 1959	Feb 1996
61005	Branxton Post Office	Jan 1886	Dec 1969	61197	Broke (Vere)	Jan 1959	Dec 1986
61008	Campbells Hill	Jan 1912	Dec 1965	61200	Warkworth Homestead	Jan 1959	Dec 1980
61009	Cessnock Post Office	Jan 1903	Oct 1992	61232	Singleton Pitt Street	Jan 1964	Dec 1975
61014	Branxton (Dalwood Vineyard)	Jan 1863		61238	Pokolbin (Somerset)	Jan 1961	
61024	Gresford Post Office	Jan 1895		61242	Cessnock (Nulkaba)	Jan 1966	
61032	Lochinvar	Jan 1896	Dec 1973	61243	Oaklands (Ravens Worth)	Jan 1920	Dec 1965
61034	East Maitland Bowling Club	Jan 1902	Mar 1994	61249	Gresford East (Strathisla HMSD)	Jan 1965	Dec 1972
61044	Mitchells Flat	Jan 1937	Dec 1976	61250	Paterson (Tocal AWS)	Nov 1967	
61047	Mount Olive (Fairholme)	Jan 1947	Dec 1983	61257	Mirannie	Jan 1894	Dec 1980
61048	Mulbring (Stone Street)	Jan 1932		61259	Maitland West Aero	Jan 1968	Dec 1974
61050	Sedgefield (Bundajon)	Jan 1903		61265	Kurri Kurri Bowling Club	May 1968	Jan 2006
61052	Muscle Creek (Clendinning)	Jan 1901	Dec 1976	61270	Bowmans Creek (Grenell)	Jan 1969	
61056	Pokolbin (Ben Ean)	Aug 1905		61271	Branxton Station Street	Jan 1969	Dec 1978
61070	Singleton Post Office	Jan 1881	Dec 1969	61272	Glennies Creek (Sydenham)	Jan 1969	Dec 1974
61077	Weston	Jan 1948	Dec 1957	61275	Singleton Army	Jul 1969	Dec 1990
61092	Elderslie (Elderslie Farm)	Jan 1927		61288	Lostock Dam	Jan 1969	
61100	Broke (Harrowby)	Jan 1887		61289	Quorrobolong Post Office	Jan 1959	Dec 1981
61121	Lostock Post Office	Jan 1952	Dec 1971	61293	Bulga Police Station	Jan 1968	Dec 1975
61129	Halton (Kinross)	Jan 1960	Dec 1985	61295	Nulkaba (O'Connors Road)	Jan 1970	
61143	Bulga (Down Town)	Jan 1960		61298	Pokolbin (Bellevue)	Jan 1970	
61146	Carrow Brook	Jan 1960		61307	Rothbury (Brooklands)	Jan 1965	Dec 1971
61150	Bulga (Charlton)	Jan 1959	Dec 1973	61313	Millfield (Cedar Creek)	Jan 1971	Dec 1982
61158	Glendon Brook (Lilyvale)	Jan 1960		61326	Cessnock (O'Connor)	Jan 1965	Dec 1979
61159	Wollombi (Rosedale)	Jan 1959	Dec 2005	61327	Pokolbin (Myrtledale)	Jan 1965	
61174	Millfield Composite	Jan 1959	Dec 1983	61329	Pokolbin (Jacksons Hill)	Jan 1961	
61180	Rothbury (Mistletoe)	Jan 1959	Dec 1977	61371	Singleton Water Board	Sep 1991	Nov 2002
61181	Broke (Oakley)	Jan 1959	Dec 1974	61388	Maitland Visitors Centre	Jun 1997	
61183	Pokolbin (Mount Bright)	Jan 1961	Dec 1971	61397	Singleton STP	Nov 2002	

4.1.2. Analysis of Daily Read Data

The rainfall record for six of the daily read stations with the longest period of record was analysed in order to provide an indication on the magnitude of historical rainfall events. This was undertaken by determining the maximum 1 day, 2 day and 3 day totals. The results are provided in Table 8. It should be noted that there are many possible anomalies with this data, including:

- The rain may fall over the 9am period and thus be distributed over 2 days and thus may not pick up the 24h, 48h or 72 h peaks,
- For many events the gauge may have failed (vandalism, over flowed, out of service). It is noted, for example, that at Carrow Brook the BOM readings were not considered reliable for June 2007 (even though values were given) and at Elderslie Farm the gauge did not operate in February 1955,
- In the past rainfall over the weekend was combined into the Monday reading.

Table 8: Highest Daily Read Rainfall Readings (mm) for 1-day, 2-day and 3-day events

Branxton (Dalwood Vineyard)						Gresford Post Office					
1day (mm)		2day (mm)		3day (mm)		1day (mm)		2day (mm)		3day (mm)	
193	9/06/2007	308	8/06/2007	322	7/06/2007	199	11/09/1929	272	19/01/1971	327	19/01/1971
192	18/06/1949	296	17/06/1930	314	17/06/1930	172	13/10/1985	244	11/09/1929	289	2/02/1990
179	18/06/1930	276	17/06/1949	314	8/06/2007	159	19/01/1971	244	13/10/1985	272	18/01/1971
160	9/07/1904	239	3/02/1990	303	16/06/1930	155	24/08/1899	235	9/07/1904	260	17/06/1930
145	3/02/1990	211	18/06/1949	295	17/06/1949	145	24/02/1955	230	3/02/1990	257	12/10/1985
145	10/06/1964	206	13/10/1985	278	16/06/1949	135	8/06/2007	210	8/06/2007	249	24/02/1955
143	4/12/1958	201	13/05/1962	254	2/02/1990	128	19/03/1963	203	27/09/1903	244	10/09/1929
132	29/12/1926	199	9/06/2007	239	3/02/1990	126	16/04/1927	201	24/08/1899	244	11/09/1929
132	4/03/1977	197	18/06/1930	218	12/05/1962	125	20/03/1978	200	17/06/1930	244	13/10/1985
124	14/10/1985	183	6/08/1952	215	18/06/1949	122	9/03/1967	199	10/09/1929	238	3/02/1990

Sedgefield (Bundajon)						Pokolbin (Ben Ean)					
1day (mm)		2day (mm)		3day (mm)		1day (mm)		2day (mm)		3day (mm)	
147	24/02/1955	242	8/06/2007	268	17/06/1930	245	9/06/2007	283	17/06/1949	296	17/06/1949
141	18/06/1949	207	17/06/1930	256	24/02/1955	178	18/06/1949	255	9/06/2007	286	16/06/1949
132	8/06/2007	191	18/06/1930	250	7/06/2007	155	4/03/1977	232	28/12/1926	256	23/04/1931
130	18/06/1930	190	24/02/1955	247	8/06/2007	143	29/12/1926	225	17/06/1930	255	9/06/2007
128	6/02/1950	187	3/02/1990	207	16/06/1930	140	16/04/1927	194	23/04/1931	251	27/12/1926
116	17/02/1932	174	19/01/1951	205	18/03/1978	127	2/10/1916	191	18/06/1949	234	28/12/1926
113	20/01/1951	173	23/04/1931	202	19/01/1951	127	23/04/1931	186	14/05/1913	232	17/06/1930
110	9/06/2007	168	18/06/1949	199	2/02/1990	126	18/06/1930	176	1/10/1916	230	16/06/1930
109	4/02/1990	166	17/06/1949	196	23/04/1931	126	24/02/1955	173	19/01/1951	219	24/02/1955
107	23/02/1908	163	14/05/1913	195	18/01/1951	125	18/02/1962	172	24/02/1955	216	18/01/1951

Elderslie (Elderslie Farm)						Carrow Brook					
1day (mm)		2day (mm)		3day (mm)		1day (mm)		2day (mm)		3day (mm)	
136	10/06/1964	202	23/04/1931	247	23/04/1931	156	13/10/1985	260	19/03/1978	310	18/03/1978
133	23/04/1931	183	3/02/1990	225	22/04/1931	155	20/03/1978	230	3/02/1990	300	19/01/1971
114	6/02/1950	182	13/05/1962	201	21/04/1931	142	19/03/1963	227	20/01/1971	261	20/01/1971
109	17/01/1988	163	4/03/1977	199	3/03/1977	128	4/02/1990	204	19/03/1963	260	19/03/1978
102	2/02/1934	163	13/10/1985	198	2/02/1990	125	20/01/1971	198	19/01/1971	241	25/12/1962
101	3/02/1990	159	10/06/1964	192	3/02/1990	124	7/11/1984	197	13/10/1985	239	2/02/1990
100	1/09/1934	155	22/04/1931	191	18/03/1978	114	9/03/2001	188	25/12/1962	238	3/02/1990
98	13/05/1962	149	9/06/1964	191	12/05/1962	114	25/12/1962	175	24/01/1972	225	3/03/1977
95	18/02/1962	139	6/02/1950	182	13/05/1962	109	16/05/1977	165	6/11/1984	225	18/03/1963
94	4/03/1977	130	3/03/1977	172	12/10/1985	109	9/03/1967	163	18/03/1963	213	19/03/1963

Table 8 indicates that the greatest 1 day total was 199 mm, the greatest 2 day was 308 mm and the greatest 3 day was 327 mm. By examining the dates of the peak rainfall totals it is noted that some correlate with major floods in the Hunter River but many do not. The above values should be used with caution as high rainfall events may be missing for the record for various reasons.

It is also noted that the June 2007 rainfall at Branxton (over 100 years of record) was the highest ever recorded at the gauge for 1 to 3 days.

4.2. Flood Levels

4.2.1. Water Level Recorders on the Hunter River

The main source of flood level data relevant to this study is the water levels recorders (Figures 3 and 4) at Singleton (Dunolly Bridge) (Figure 6), Greta (Figure 7) and Maitland (Belmore Bridge – Figure 5). Singleton and Maitland have records going back over 100 years whilst Greta has automatic gauge records since 1969 and possibly some prior records but these have not been sighted. It should be noted that the records at Singleton prior to 1969 and at Maitland prior to 1992 may be incomplete as the records are from manual readings which will certainly have missed some minor events.

A comparison between the recorded peak levels at these three gauges is provided on Figure 8. This indicates that there is a relatively poor correlation between the levels at the three gauges. It is presumed this is largely due to the effect of runoff from the intermediate catchment (approximately 1,100 km^2) between Singleton and Maitland or possibly changes in the conveyance of the Hunter River (largely vegetation).

The locations of all water levels recorders along the Hunter River from Singleton to Green Rocks are shown on Figure 3 and with the peak level for major events on Table 9.

Table 9: Water Level Recorders on the Hunter River

NAME	Type	Opened	**1955**	**1971**	**1972**	**1977**	**1978**	**1985**	**2007**
Singleton (Dunolly Bridge)	Auto/Manual	1891	42.2	41.7	35.6	40.9	37.6	33.8	41.7
Greta	Auto/Manual	1961		22.9			19.8	18.5	23.7
Oakhampton Railway	Auto	1996							12.28
Bolwarra DS	Auto	1980							11.92
Bolwarra US	Auto	1990							11.81
Belmore Bridge	Auto/Manual	1992	12.1	11.1	8.9	10.8	9.6	8.9	10.7
Wallis Ck DS	Auto/Manual	1979		N/P	8.3	9.4			9.58
McKimms Corner	Auto/Manual	1980						7.4	8.22
Morpeth	Auto/Manual	1989	7.5	6.4		6.8	6.4	6.1	6.52
Wallis Ck US	Auto	1990							6.26
Louth Park	Auto	Unknown							6.07
Green Rocks	Auto/Manual	1979	6.1	N/P				3.9	3.98
U/S Cummins Dam	Manual	1968		12.9		12.1	10.6		
OakHampton Spillway D/S	Manual	Unknown		N/P	9.5	11.7	10.3	N/P	
OakHampton (Penstock Tower)	Manual	Unknown		N/P		11.3			
Bolwarra Spillway D/S	Manual	Unknown		N/P		10.9		9	
Hinton Bridge	Auto/Manual	Unknown	7.2	5.7	5.5	6.3	5.9	N/P	5.78
Dunmore Bridge	Auto/Manual	Unknown			6.3	6.3	6.4	6.3	6.36
Trappaud Road Bridge	Single level	Unknown				6.2			
Victoria Bridge	Manual/Single level	Unknown		N/P		6.1			
Scotts Dam	Manual	Unknown		5.8	5.5	6		N/P	
Duckenfield	Manual	Unknown		4.4		5.2	5	N/P	
Gardiners	Manual	Unknown		4	3.7	4.2	4.1		
Porters Hollow	Manual	Unknown		N/P					
Victoria Bridge U/S	Manual	Unknown		N/P					
Victoria Bridge D/S	Manual	Unknown		N/P					
Hinton Hill	Manual	Unknown					5.6		
Notes 1. All Levels to m AHD. Gauge zero at Singleton is 27.63m AHD at Greta is 10.649m AHD.									
2. Opening dates are approximate and records may be available outside those periods.									
3. Where blanks are shown no reliable record can be found (in some instances there may be a record but the data is unreliable).									
4. For many of the manual gauges no further flood readings will be taken but there is no official closing date.									
5. N/P = No peak shown on record.									

4.2.2. Flood Levels from Debris or Other Marks

Apart from the water level recorders the other source of flood peaks are the surveying of flood marks recorded during/after the flood. Generally these are debris marks and for this reason are probably only accurate to +/- 0.3 to 0.5 m depending upon the source of the mark. There are over 60 of these levels for the February 1955 flood as shown on Figure 4 and listed in Appendix C. These levels were provided by DECCW for use in this study and were surveyed by the then Water Resources Commission following the flood but the original source and accuracy of many of these levels is unknown. These, together with the stage hydrographs are the only available records of the February 1955 flood within the study area.

Peak flood levels are also available for the June 2007 event and these are also shown on Figure 4 and in Appendix C. These levels were recorded by Maitland City Council (Figures 9, 10 and 11) as part of the present study in response to a Questionnaire sent out to residents fronting the Hunter River between Branxton and Oakhampton.

Aerial photographs were taken by the RAAF during the January 1971 flood and one showing flow over the Oakhampton and Bolwarra spillways is shown as Figure 12.

4.3. Flow Measurements

4.3.1. Streamflow Gaugings

For calibration of a hydrologic model and to a lesser extent a hydraulic model, a recorded flow (in m^3/s) in the river is required. The estimated flow at a given water level is obtained from a rating curve which provides a relationship between the water level and flow. This relationship is derived from velocity readings (obtained from 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.

It is relatively easy to obtain "low flow" gaugings as small rises in water level 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. Thus all rating curves have few "high flow" gaugings and there is therefore 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, from this an estimate of the accuracy of the high flows can be made. Generally there are no gaugings taken at the peak of a flood and thus the highest gaugings may be several metres below the peak and the rating curve must be extrapolated.

Gaugings are usually taken from a bridge over the river with several velocity measurements at various depths and distances across the river. These velocity measurements are averaged and the flow calculated (flow {m^3/s} =mean velocity {m/s}*waterway area {m^2}).

It is generally not physically possible or practical to undertake gaugings on large rivers such as the Hunter River and thus at Maitland there is no "official" rating curve. At Singleton rating curves exist however their accuracy at high river levels is doubtful due to the considerable extension of the rating curve beyond the high level recordings.

At Greta over 300 gaugings have been taken at Luskintyre Bridge (5 kilometres downstream) and these are shown on Figure 13. A review of this data indicates the following:

- All the high flow gaugings are for the 1961, 1962 or 1977 events,
- The automatic gauge commenced at Greta in 1969 and it is unclear if the heights for the 1961 and 1962 gaugings relate to the same location and datum as the other gaugings.

4.3.2. Water Level Recorders with a Rating Curve

Apart from Greta there are six other water level recorders that have had velocity gaugings undertaken and a rating curve derived. These are all on the tributary creeks entering the Hunter

River between Singleton and Oakhampton. These are shown in Table 10 together with the peak flow recorded for each of the 7 flood events (data obtained from the State Government funded Pinneena CD that lists water records in NSW).

Table 10: Water Level Recorders on the Tributary Creeks

Name	Catchment Area (km^2)	Opened	Closed	Peak Recorded Flow m^3/s						
				1955	1971	1977	1978	1992	1998	2007
First Creek at Pokolbin Site 1	14.3	18/05/1961	27/09/1978	n/r	22	50	14	n/r	n/r	n/r
Middle Creek at Pokolbin Site 2	8.0	11/12/1963	1/08/1978	n/r	13	22	13	n/r	n/r	n/r
Pokolbin Creek at Pokolbin Site 3	25.2	12/11/1963		n/r	54	180	109	22	6	164
Muggyrang Creek at Pokolbin Site 4	4.8	12/11/1963	25/06/1993	n/r	5	27	20	3	n/r	n/r
Glendon Brook at Glendon Brook	275.0	10/08/1964	6/07/1978	n/r	495	788	769	n/r	n/r	n/r
West Brook at U/S Glendon Brook	80.0	29/04/1969		n/r	n/r	n/r	5	55	245	666

Note: n/r = no record

An analysis was undertaken to determine the largest flood events recorded at these gauges and the results are shown in Table 11.

Table 11: Largest Events Recorded on Tributary Creeks

First Creek at Pokolbin Site 1		Middle Creek at Pokolbin Site 2		Pokolbin Creek at Pokolbin Site 3	
Catchment	14 km^2	**Catchment**	8.0 km^2	**Catchment**	25 km^2
Duration	18/05/61 to 27/09/78	**Duration**	11/12/63 to 1/08/78	**Duration**	12/11/63 to current
Flow m^3/s	**Date**	**Flow m^3/s**	**Date**	**Flow m^3/s**	**Date**
50	4/03/1977	22	4/03/1977	180	4/03/1977
31	5/06/1974	13	1/02/1971	164	9/06/2007
22	1/02/1971	13	20/03/1978	109	20/03/1978
21	7/08/1967	10	7/08/1967	107	9/02/1990
14	20/03/1978	10	22/04/1974	81	15/03/1982
13	11/06/1964	9	22/06/1975	57	28/01/1978
11	25/01/1978	9	28/01/1978	54	1/02/1971
11	25/01/1976	7	11/01/1974	52	5/06/1974
no record	Feb-1955	7	11/06/1964	51	3/04/1989
no record	Feb-1992	no record	Feb-1955	49	22/04/1974
no record	Aug-1998	no record	Feb-1992	no record	Feb-1955
no record	Jun-2007	no record	Aug-1998	no record	Jun-2007

Muggyrang Creek at Pokolbin Site 4		Glendon Brook at Glendon Brook		West Brook at U/S Glendon Brook	
Catchment	4.8 km^2	**Catchment**	275 km^2	**Catchment**	80 km^2
Duration	12/11/63 to 25/96/93	**Duration**	10/08/64 to 6/07/78	**Duration**	29/04/69 to current
Flow m^3/s	**Date**	**Flow m^3/s**	**Date**	**Flow m^3/s**	**Date**
27	4/03/1977	788	5/03/1977	844	1/02/1988
20	20/03/1978	769	20/03/1978	798	14/10/1985
16	9/02/1990	550	22/01/1971	666	8/06/2007
12	3/04/1989	508	4/03/1977	364	4/02/1990
8	5/06/1974	495	29/01/1971	323	9/03/2001
8	15/03/1982	476	22/06/1975	250	19/08/1987
6	22/04/1974	470	5/06/1974	245	8/08/1998
5	21/06/1989	445	4/04/1972	225	22/03/2000
5	7/07/1988	440	25/01/1976	116	5/01/1987
5	11/01/1974	no record	Feb-1955	no record	Feb-1955

no record	Feb-1955	no record	Feb-1992	no record	Jan-1971
no record	Aug-1998	no record	Aug-1998	no record	Feb-1977
no record	Jun-2007	no record	Jun-2007	no record	Mar-1978

During large flood events it is possible that the recorder failed and thus no data is collected. For this reason the above records should be viewed with caution. For example there is no record for 1971 at West Brook.

The records at Glendon Brook and West Brook are the most valuable for use in this study due to their large catchment size. The records for the smaller catchments are of less value as they are more influenced by a localised thunderstorm rather than a rainfall event than causes flooding on the Hunter River.

4.3.3. Other Streamflow Gauging Data

Reference 2 undertook a review of flow gauging data under by the then Department of Land and Water Conservation. This data was obtained in the 1952, 1964, 1979, 1984, 1987 and 1992 events. Unfortunately the majority are for relatively small flows and thus provides little insight into the magnitude of flows in major floods. Of significance is the estimate of the flow during the August 1952 flood at 11.01m AHD of 3,265m^3/s. This estimate was included as part of the calibration of the hydraulic model in Reference 2 (1971 flood reached 11.1m AHD with an estimated peak flow of 3500m^3/s – refer Table 2). Similarly the estimate of Manning's "n" in the August 1952 and June 1964 events indicated a range of 0.02 to 0.025 and similar values were adopted in Reference 2.

No stream velocity measurements have been found for the February 1971 event.

Just prior to the flood peak in the March 1977 event the following velocity measurements were obtained at Belmore Bridge:

2nd span 4.02 m/s,
3rd span 4.16 m/s,
4th span 3.4 m/s,
5th span 1.72 m/s,
6th span 1.66 m/s,
Average = 3 m/s.

4.4. Flood Photographs

At Maitland and at Singleton aerial photographs were taken in the 1955, 1971 and 2007 floods but in the intermediate reaches no aerial photographs are available for any flood event. Downstream of Oakhampton there are many oblique June 2007 flood photographs taken by local residents, Council, SES, DECC (as they were known at the time) and journalists. Many are available on web sites. Figure 9 provides a selection of the June 2007 photographs and Figure 12 provides one of a series of aerial photographs taken by the RAAF during the February 1971 flood.

4.5. Survey

Airborne laser survey (ALS) was obtained as part of this study 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 no greater than 0.15m
- The mean of the error is not greater than +/- 0.1m

Aerial photogrammetry for the Maitland LGA and part of Cessnock LGA was obtained from SKM and used to verify ground features.

The ALS did not pick up “below water levels” and the following approach was adopted to include this data in the model. Upstream of Oakhampton it was considered that the cross sectional area below the water surface was so small that it could be omitted (in places the water was <1m deep at the time the ALS was taken). Downstream of Oakhampton the “below water levels” were included in the ALS dataset by incorporating the data from the hydraulic model river cross sections used in Reference 2.

Whilst the original source of these river cross sections is field survey it is likely that there have been significant changes over the years (it is understood that the survey was undertaken in 1984 and at approximately 350m spacing). River cross sections vary considerably over the years and most probably during a flood as erosion occurs during the event followed by sedimentation as the river level and velocities fall. It is likely that the river cross sections will have changed between floods, however there is no data to confirm this assumption.

The approach taken to include the “below water levels” is therefore imprecise. However, it should be noted that whilst a change in the river cross section will have a large impact in a small event, it will have only a minor impact in the 1% AEP or similar events when 50% or more of the flow is in the overbank areas. To date there is no satisfactory procedure for ensuring a more precise approach.

The use of ALS has meant that the crest levels of the spillways and levee banks have been established with a much higher degree of accuracy than achieved previously in Reference 2. Typical crest levels along these structures are provided in Table 12.

Table 12: Crest Dimensions of Major Spillways

Spillway	Crest Level (m AHD)	Crest length (m)
Oakhampton No 1	11.60	400
Oakhampton No 2	11.65	850
Bolwarra (zig zag)	11.35	1200

5. INFLOW HYDROGRAPHS TO TUFLOW

5.1. WBNM

The WBNM hydrologic runoff-routing model was used to determine inflows from the local catchments (including the Paterson River) to the Hunter River. The model layout is shown as Figure 14. This model is widely used throughout NSW and was also used in Reference 2 for the same purpose. The model input parameters are a storage lag factor (termed C) and the rainfall initial and continuing loss.

If data is available the model can be "calibrated" to historical flow records by including the historical rainfall data and adjusting the model parameters until a good match to the recorded data is achieved. The main issue with this approach is the limited amount of pluviometer records available. Pluviometer data is required to provide a temporal pattern to be applied to the daily rainfall records. It is known that the rainfall temporal patterns can vary greatly across even a small area and thus over these relatively large catchments the availability of only a few pluviometers means that the resulting "accuracy" of the calibrated model is low.

5.2. Calibration

There are flow records for historical events at 6 water level recording stations (Figure 3) and these have been used for model calibration. The approach used was to adopt the "default" C parameter of 1.7 and vary the losses to obtain a fit. The results are provided in Appendix B and Table 13. The quality of fit for each calibration event was qualitatively assessed as either "good" (indicating a match for peak flow and for hydrograph shape), "fair" (indicating a satisfactory match, but with some discrepancies), or "poor" (indicating an unsatisfactory match).

Table 13: WBNM Calibration Results

Station	Event	Initial Loss (mm)	Continuing Loss (mm/hr)	Quality of Calibration Fit
Pokolbin	Jan 1971	20	2.5	Good
	Mar 1977	20	2.5	Good
	Mar 1978	50	2.5	Fair
	Jun 2007	60	2.5	Fair
Glendon Brook	Jan 1971	20	2.5	Poor[1]
	Mar 1977	20	2.5	Poor[1]
	Mar 1978	50	2.5	Poor[1]
U/S Glendon Brook	Aug 1998	20	2.5	Poor[1]
	Jun 2007	60	2.5	Poor[1]
Paterson	Jun 2007	60	2.5	Good

[1] There appear to be errors in the streamflow records from Glendon Brook and U/S Glendon Brook (including large recorded flows when no rain had been recorded), that suggest either the recording equipment or the rating curve used to derive flows at these stations may be erroneous. The "poor" calibration obtained at these locations is therefore not considered to be of significance.

5.3. Design

For the design the following model parameters were adopted:

C = 1.7
Initial Loss = 20mm
Continuing Loss = 2.5mm/h

The approach to obtain the design critical storm duration for the tributary creeks used in conjunction with the Hunter River design inflows is detailed in Section 6.3.3.

5.4. Paterson River

Modelled inflows from the Paterson River at Gostwyck were compared to the hydrological modelling undertaken for the Paterson River Flood Study (Reference 9). The modelled peak design flows were generally in agreement with those modelled using RAFTS for Reference 9, although reduced flows were adopted for that study based on areal reduction factors. Table 14 shows comparisons between the modelled flow estimates at Gostwyck bridge.

Table 14: Paterson River Peak Design Flows at Gostwyck Bridge

Event	Present Study WBNM model	Paterson Flood Study RAFTS model	Diff (%)	Paterson Flood Study Adopted flows	Diff (%)
50% AEP	600				
20% AEP	1060	-	-	-	-
10% AEP	1350	1471	-8%	1050	29%
5% AEP	1825	1863	-2%	1450	26%
2% AEP	2350	2334	1%	2050	15%
1% AEP	2830	2773	2%	2500	13%

As the Paterson River Flood Study did not provide peak flows for all required events modelled in the present study, and as modelled results were found to be in good agreement for both studies, the WBNM results were adopted for the design event inflows. A discussion on the sensitivity of the modelling results to the assumed tributary inflows, including those from the Paterson, is provided in Section 6.4.2.

6. HYDRAULIC MODELLING

6.1. TUFLOW

Two TUFLOW 2D hydraulic models were established as part of this Flood Study. The Upper model extended from approximately 3 kilometres upstream of the Black Creek junction with the Hunter River to Belmore Bridge and the Lower model extended from Oakhampton to Green Rocks. The overlap between the two models ensures that there are minimal boundary issues between the two models. For all flood events the upstream model was run first and the outflow hydrograph at Oakhampton included as the Hunter River inflow to the Lower TUFLOW model.

Both models were setup using a 10m by 10m grid based on the ALS with the inclusion of "below water topography" obtained from the cross sections used in Reference 2. Spillways and levee banks were included as specific structures in the Lower TUFLOW model.

Each grid cell is assigned a ground level and a Manning's "n" value which reflects the hydraulic roughness of the topography.

Since 1955 the channel and overbank have experienced significant changes, including:

- Increase/decrease in sedimentation and erosion,
- Change in level of key structures such as levees, spillways, control banks, railway lines etc. There is insufficient information available to accurately document these changes. However is many cases works have not changed the crest levels. For example the Bolwarra spillway was refurbished in the 1990's and the same crest level and dimensions were adopted. We are aware that the crest of the railway line between Maitland and East Maitland has changed but again there is insufficient information to accurately document the changes and the period they applied for. Railway tracks are also subject to rise and fall due to re-ballasting,
- Farming practices and land use will have changed the hydraulics of the floodplain but again these changes cannot be accurately documented,
- Change in vegetation along the river banks,
- Redevelopment has also occurred around the Maitland CBD including Les Darcy Drive and Ken Tubman Drive as well as several commercial redevelopments.

Whilst many changes have occurred to the channel and floodplain will have affected the riverine hydraulics there is insufficient data to accurately model these changes. For this reason one topographic model has been adopted but with two sets of Manning's "n" values (pre 2007 historical events and June 2007/design flood events) as detailed in the following section.

6.2. Calibration and Verification

6.2.1. Outline

The calibration process was based on matching the TUFLOW results to produce the best fit to the February 1955, February 1971 and June 2007 events. The February 1971 and June 2007 events were chosen as they are the only large floods recorded at the Greta gauge. Both events had to be used as the recorded flood height data (refer Section 3.5.3) at Singleton, Greta and Maitland (Belmore Bridge) indicates that the conveyance along the river has changed over time. February 1955 was chosen as it is the largest event recorded on the Hunter River. The resulting calibrated model was then verified using the March 1977 event.

6.2.2. Change in Channel Conveyance

It was apparent from a comparison of the recorded flood height data at Singleton, Greta and Maitland (Belmore Bridge) as discussed in Section 3.5.3 that different channel conveyances had to be adopted to replicate the recorded changes in relative gauge heights at the three locations between 1971 and 2007. The change in conveyance could be due to a change in channel dimensions (erosion and/or sedimentation) or channel friction (represented by the Manning's "n" parameter). There is no conclusive evidence in this regard however a comparison of aerial photographs taken in 1974 and 2009 (refer Appendix D) indicates that there is considerably more vegetative growth along the banks in 2009 than in 1974. This is confirmed (at many locations) by anecdotal evidence from local landowners.

Thus a different set of Manning's "n" values has been adopted to simulate the pre 2007 flood events compared to the 2007 and design events.

6.2.3. Calibration

Upper TUFLOW Model: Branxton to Oakhampton

For the tributary creeks inflows from the calibrated WBNM hydrologic model were included into TUFLOW at the locations as shown on Figure 14. For the 1971 and 2007 events the Hunter River inflow hydrograph at the upstream point of the Upper TUFLOW model was adjusted so that the modelled stage hydrograph at the Greta gauge matched the recorded hydrograph. This was an iterative procedure and also included different sets of Manning's "n" along the bank for each event to reflect the change in conveyance (refer Section 6.2.2). The results are provided on Figure 17 and the adopted Manning's "n" values are provided in Table 15. However it should be noted that other combinations of hydrologic and hydraulic parameters could produce similar results.

Table 15: Adopted Manning's "n" Values – Upper TUFLOW model

Description	Events prior to 2007	2007 and Design Events
River Bed	0.025	0.03
River Banks	0.04	0.07
General Floodplain	0.04	0.04

Figure 13 provides a comparison between the "rating curve" from TUFLOW for the 2007 and 1971 events and the recorded gaugings. These results indicate that the gaugings indicate a greater flow (for a given height) than that obtained from the TUFLOW model. Section 4.3.1 indicates that this may be due to anomalies with the high flow gaugings.

There are no other available flood height data for the 1971 event upstream of Oakhampton but there are for 2007. For 2007 this includes approximately 20 levels (Figure 4) obtained as a result of the questionnaire survey (Section 4.2.2) and field survey of a debris line obtained by Singleton Council. A comparison between the model and observed data for 2007 is provided on Figure 15 (peak height profile upstream of Oakhampton) and Figure 22 (comparison of flood extents).

For the February 1955 event there are insufficient rainfall data to accurately describe the temporal pattern for the tributary creeks (the nearest pluviometer was Williamstown), though there is a reasonably adequate daily rainfall record. There is also no flood height record at Greta but there are approximately 40 peak height records in this reach (Figure 4). Whilst this dataset is inconsistent in parts (range of recorded levels at the same location) it does provide a relatively well defined peak height profile along the river. This dataset is of particular importance as it relates to the largest recorded flood on the Hunter River, which was of similar magnitude to events adopted for establishing flood related development controls.

The inflows for the 1955 event were obtained for the Upper TUFLOW model iteratively (running the Lower and Upper TUFLOW models) in order to meet the following criteria:

- Approximates a peak flow of 10,300 m^3/s at Oakhampton. This peak flow for the February 1955 event has been adopted in both References 2 and 3,
- Replicate the shape of the recorded 1955 stage hydrograph at Belmore Bridge.

A comparison between the model and recorded peak height profile for the February 1955 event is provided on Figure 15 and a comparison between the model peak flows at the downstream limit of the Singleton Flood Study model, at Greta and Oakhampton for the historical events is provided on Table 16.

Table 16: Historical Peak Flows from the Upper TUFLOW and Singleton Flood Study (Reference 1)

	Singleton Flood Study	From the Upper TUFLOW model	
Historical Event	Peak Flow at downstream end (m^3/s)	Peak Flow at Greta (m^3/s)	Peak Flow at Oakhampton (m^3/s)
February 1955	10,350	11,100	10,300
February 1971	4,820	3,350	3,100
March 1977	Not known	n/a [1]	2,700
June 2007	5750	2,800	2,700

[1] The 1977 event was not run for the upstream model as no calibration data were available

It is interesting that the Singleton Flood Study has a much greater flow in 2007 than 1971 (although no account was made of any vegetation changes – if required), however at Maitland 2007 produced a lower peak at Belmore Bridge than 1971 and thus a lower peak flow is required to match the data at Oakhampton. A detailed study would be required to investigate how and where the peak flows from these two events change.

Lower TUFLOW Model: Oakhampton to Green Rocks

For the tributary creeks inflows from the calibrated WBNM hydrologic model were included into TUFLOW at the locations as shown on Figure 14. For the 1955, 1971 and 2007 events the Hunter River flow hydrograph at Oakhampton, near the downstream limit of the Upper TUFLOW model, was taken as the Hunter River inflow to the Lower TUFLOW model. The Manning's"n" values were then adjusted to replicate the observed data and the results are provided on Figures 16 (peak height profile) and Figures 18 to 21 (stage hydrographs). Similar to the Upper TUFLOW model, two sets of Manning's "n" parameters were adopted as provided in Table 17. However it should be noted that other combinations of hydrologic and hydraulic parameters would produce equally valid results.

Table 17: Adopted Manning's "n" Values – Lower TUFLOW model

Description	Events prior to 2007	2007 and Design Events
River Bed	0.03	0.03
River Banks	0.06	0.07
General Floodplain	0.04	0.04

A comparison between the model peak flows at Oakhampton for the historical events is provided on Table 16.

6.2.4. Verification

The March 1977 event was used as a model verification event (event was simulated using the adopted pre 2007 calibration parameters with no model adjustment undertaken). The Upper TUFLOW model was not run for the March 1977 event as there is no recorded data within this reach. Thus this is not a "true" verification event as an inflow hydrograph at Oakhampton was generated (based on matching to the recorded Belmore Bridge stage hydrograph). The results are provided on Figures 16 and 20 with the model peak flow at Oakhampton provided in Table 16.

6.2.5. Calibration Discussion

It should be noted that the emphasis in calibration / verification of the computer models was to find the optimal balance of model parameters (such as roughness) that gave the overall best match to observed historic flood behaviour. This set of parameters could then be used to estimate design flood behaviour. It would be possible to improve the match between modelled and observed flood behaviour for the historic events by adjusting the model parameters and assumed inflows separately for each event, but then an arbitrary decision would need to be made about which parameters to use for the design flood estimation. Additional information about land-use and geomorphologic changes would then be required (if available) to justify selection of different parameters for different events.

For this study, a relatively large amount of historic flood data was available for the calibration process, across a large study area and several flood events. While the addition of more observation data generally improves confidence in the outcomes of the calibration (as it has in this case), it often means that obtaining an excellent match to every observation for all historic events is unachievable. This can result from:

- inconsistency between the observations (such as two different flood levels at similar locations, or inadequate rainfall data). It is likely that some of the historic data has been inaccurately recorded through errors in transcription or conversion between datum conventions. Even with today's automatic water level recorders errors can occur, as happened at Belmore Bridge in June 2007, when the peak flood level was incorrectly recorded as 0.2m below the actual level, a reading which would stand if the anomaly had not been identified by comparison with another source;
- physical changes to the study area between events (such as scour of the river bed, meandering of the river channel, development of the catchment, or changes to riparian vegetation); and / or
- limitations of the computational models used.

Table 18 summarises the results of the calibration process. The terms "Upper" and "Lower" refer to the separate models upstream and downstream of Oakhampton railway bridge respectively.

Table 18: Calibration Summary

Flood Event	Model	Quality of Calibration	Comments
June 2007	Upper	Excellent	• Good fit to water level hydrograph at Greta • Good fit of peak water level profile to observed levels • Good fit of mapped extent at Branxton
	Lower	Excellent	• Good fit to several water level recorders in Hunter River • Fair fit to water level recorders in Louth Park and Wallis Creek • Good fit to observed extent and flood behaviour from aerial photographs
March 1977	Upper	–	• No calibration data available in upper reach
	Lower	Good	• Good match to recorded water level hydrographs in Hunter River
February 1971	Upper	Fair	• Fair fit to water level hydrograph at Greta
	Lower	Good	• Good fit to water level hydrograph at Belmore Bridge • Matched observed overtopping of Bolwarra and Oakhampton Spillways in aerial photographs • Fair fit to other water level hydrographs in Hunter River
February 1955	Upper	Fair	• Peak flood levels track the higher range of recorded levels along the Hunter River, notably at Branxton
	Lower	Good	• Good match to water level hydrograph at Belmore Bridge, and fair match at other stations • Good match to observed peak floodplain levels

The quality of match was lower in the Upper model for the February 1971 and February 1955 floods than for the other results. In both cases estimated peak flood levels were slightly higher than the observed levels. Attempts to reproduce lower flood levels in the Upper model led to significantly poorer calibration performance in reproducing observed flood behaviour in the Lower model at Maitland, Bolwarra, and Oakhampton for example. It was considered that observed flood data at Maitland were likely to be more reliable than in the upper study area, and the final outcome of the calibration was the best balance that could be achieved across the study area. Flexibility of the calibration was limited somewhat by the constraint of estimated peak discharges at Oakhampton (most notably 10,300 m^3/s at Oakhampton for February 1955), which was a fundamental component of the flood frequency analysis.

In light of the results, it is considered likely that there were significant changes to channel conveyance in the Hunter River upstream of Oakhampton between 1955 and 2007, as a result of geomorphologic processes and riparian vegetation programs. The topographic data used to build the model was obtained in 2008, and aerial photographs from a similar period were available. It is therefore unsurprising that a more comprehensive match was obtained for modelling of the June 2007 flood. Some evidence of changes to riparian vegetation justified the use of slightly different Manning's "n" roughness values between 1955/1971 and 2007, but overall it was considered preferable to determine a consistent set of modelling parameters and assumptions that would provide the best estimate of design flood behaviour under present conditions.

6.3. Design

6.3.1. Flood Frequency Analysis

As detailed in Section 3.3 flood frequency analysis was undertaken using the historical flood height record at Maitland (Belmore Bridge – Figure 5). Whilst some flood velocity measurements have been undertaken in this reach (refer Section 4.3.3) no "official" rating curve has been developed. The recorded flood velocity measurements that are available (average of 3m/s) were comparable to the velocities from TUFLOW (average of 2.5 m/s) and this provides confidence that the combination of Manning's "n" and cross sectional waterway area in the TUFLOW model are of the correct order. This is important as it provides the only independent verification of the peak flows in this reach of the Hunter River.

On completion of the model calibration the following approach was adopted for undertaking the flood frequency analysis:

1. Obtain the entire flood height record at Maitland (Belmore Bridge – Figure 5) after checking the record against the BOM's data,
2. Develop a rating curve based on the water level at Belmore Bridge versus the flow at Oakhampton from the Lower TUFLOW model. This was obtained by running floods of varying magnitude and plotting the peak level at Belmore Bridge versus the peak flow at Oakhampton. The flow was obtained at Oakhampton as downstream the flow becomes divided between the main channel, the Oakhampton floodway and the Bolwarra floodway. This rating curve is given in Figure 23c,
3. Curve fitting relationships were determined to describe this rating curve. The rating curve was fitted using power relationships, with a different relationship used for events smaller than the 20% AEP, events between the 20% AEP and the 10% AEP, and

events greater than 10% AEP. The development of the rating curve involved some iteration since it relied on estimates of AEP. The rating curve was used to convert the historical flood height record at Maitland to an annual peak flow record,

4. Flood frequency analysis was undertaken on this derived historical peak flow record at Maitland, in accordance with Australian Rainfall & Runoff (Reference 11).

The analysis was undertaken using Monte Carlo Bayesian inference techniques (Reference 12) to fit the data to both Log-Pearson III (LP3) and Generalised Extreme Value (GEV) probability distributions (Figures 23a and 23b). A threshold of 700m^3/s was used, below which annual peaks were censored (by this technique the year is still included in the analysis, but the influence on the fit to larger events is reduced). The 1820 event was also included, assuming a minimum flow of 9,500m^3/s for that event. Both assumed distributions gave similar results. The GEV distribution was adopted for determining peak design event flows, as it was considered to provide the best fit to the data.

The results of the flood frequency analysis are provided in Table 19. It should be noted that the peak flows in Table 19 refer to Oakhampton and not Maitland (where the flood levels used to derive the historical series were obtained).

Table 19: Flood Frequency Analysis – Oakhampton

AEP	Peak Flow from Reference 2 (m^3/s)*	Adopted Peak Flow (m^3/s)*	Ratio to the 1% AEP	Ratio of Adopted to corresponding event at Singleton (Inflow Peak – Table 1)
20% AEP	1,900	1,700	0.21	0.98
10% AEP	2,700	2,600	0.33	0.88
5% AEP	4,000	3,800	0.48	0.85
2% AEP	5,500	5,800	0.73	0.82
1% AEPI	8,000	8,000	1	0.85
0.5% AEP	10,300	10,300	1.29	0.85
Extreme	24,000	24,000	3	0.85

6.3.2. Hunter River Inflows to TUFLOW

The Hunter River design inflows to the Upper TUFLOW model were determined iteratively, in conjunction with determination of the tributary inflows, so that after running the design event through the Upper TUFLOW model the resulting peak flow at Oakhampton matched the adopted flood frequency analysis peak flow in Table 19. The shape of the design flood hydrograph was adopted as the shape of the February 1955 flood event. This Hunter River flow at Oakhampton (near the downstream limit) in the Upper TUFLOW model was then used as the inflow to the Lower TUFLOW model.

6.3.3. Tributary Inflows to TUFLOW

Flooding on the Hunter River floodplain is a combination of the flow in the Hunter River in conjunction with inflow from the tributary creeks (Figure 14). For a small tributary catchment the contribution to the total flow is a very small percentage and thus will make little difference to the resulting flood levels. However in larger tributary catchments (Black Creek and the Paterson River) the tributary inflow will have a much greater impact, particularly in the lower parts of the tributary creeks rather than in the Hunter River itself. Flows in Fishery and Wallis Creeks can also have a significant impact on the peak levels in the low lying areas surrounding Maitland as they can “fill” the areas prior to the arrival of flows down the Oakhampton floodway.

An approach is therefore required to consider the relative magnitude, timing and duration of the tributary inflows. To date there is no adopted rigorous approach to resolving this issue. A detailed joint probability analysis based on historical data will not be conclusive due to the lack of observed data. In the Paterson River Flood Study (Reference 9) the following joint coincidence (Table 20) was adopted.

Table 20: Design Flood Matrix – Paterson River Flood Study

	Hunter River Flood				
Paterson River Flood	Extreme	1% AEP	2% AEP	5% AEP	10% AEP
Extreme		EXTREME			
1% AEP	EXTREME		1% AEP		
2% AEP		1% AEP		2% AEP	
5% AEP			2% AEP		5% AEP
10% AEP				5% AEP	

For example the 1% AEP flood level is the greater of the 1% AEP Paterson in combination with the 2% AEP Hunter or the 2% AEP Paterson in combination with the 1% AEP Hunter.

For the present study the scope does not include providing design flood levels within the tributary creeks upstream of the influence of the Hunter River. Thus only the magnitude of the tributary creek flows in combination with the Hunter River flow is required.

The timing of the coincidence of the peaks and the duration of the events is also of significance though little information is available for historical events. For June 2007 the rainfall event was relatively short (say 36 hours) and the peak flows in the tributaries occurred in advance of the peak flow in the Hunter River. In Reference 9 a 12 hour lag (between the peaks at Oakhampton and Gostwyck on the Paterson River) was adopted for design. The duration of events was not considered in Reference 9

For the present study the joint coincidences shown in Table 21 were adopted assuming a 36 hour critical duration on the tributary creeks. The start of the 36 hour design rainfall was adjusted so that the peak of the tributary inflows occurred approximately 24 hours prior to the peak in the Hunter River upstream of Oakhampton (based on data for the June 2007 event).

Table 21: Design Flood Matrix

Hunter River Design Event (AEP)	Extreme	0.2%	0.5%	1%	2%	5%	10%	20%	50%
Tributary Inflows (AEP)	0.5%	1%	2%	5%	6.7%	10%	20%	50%	50%

For the smaller events (up to the 20 year ARI / 5% AEP) these are the same as for the Paterson River Flood Study, however for the larger events a slightly smaller design event from the tributary creeks was adopted. This approach was taken as the Paterson River Flood Study approach assumes very little change in the Paterson River inflow from the 1% AEP in the Hunter River (combined with a 50 year ARI /2% AEP in the Paterson River) to the Extreme in the Hunter River (combined with a 100 year ARI / 1% AEP in the Paterson River). Thus using this approach there would be difficulty in obtaining a Paterson River design inflow for the 200 year and 500 year ARI (0.5% and 0.2% AEP) Hunter River events. Also given the size of the Hunter River catchment to Maitland it is unrealistic that the meteorologic event that produces a 1% AEP flow on the Hunter River will also produce a large design event (such as a 2% AEP) on the much smaller tributary catchments. The coincidence of events is largely subjective and has been evaluated with sensitivity analysis.

The design flood contours, velocities and extents are provided on Figures 24 to 48. The flood hazard and hydraulic categorisation for the extreme and 1% AEP events are provided on Figures 49 to 52.

6.4. Sensitivity Analyses

Whilst there is a considerable amount of reliable historical flood level data and some streamflow data available, a number of assumptions have been made during the model calibration phase and in determination of the design approach/parameters. The following sensitivity analyses were undertaken for the 1% AEP event to establish the variation in design flood level that may occur if different assumptions were made. However it should be noted that many of the parameters are not independent and adjustment of one parameter (Manning's "n") require adjustment of another (such as inflows) in order for the model to match the recorded historical data.

6.4.1. Variation in Manning's "n"

Flood levels are very sensitive to the adopted "n" value, an increase in "n" will increase flood levels, however as noted above a combination of "n" values and peak flows is required to match the recorded historical levels. An infinite combination is possible, although there is a generally accepted view regarding the range of possible "n" values. Different "n" values have been used for model calibration for the 1971 and 2007 events, with the 2007 values being higher in the river and river banks than for 1971. The sensitivity of "n" values was tested by assuming the alternate set of values for each event.

The results indicate that flood levels in the model upstream of Oakhampton are quite sensitive to changes in “n”. For the 1971 flood, using the higher “n” values adopted for the 2007 event was found to increase flood levels by an average of 0.8m at several representative locations within the floodplain. Using the lower values for the 2007 event was found to lower flood levels by a similar amount. The significant influence of varying “n” on flood levels upstream of Oakhampton was an important aspect of the model calibration (refer to Sections 3.5.3 and 6.2.2). Confidence in the values eventually adopted was increased by the large amount of calibration data available.

In the floodplain downstream of Oakhampton, variation of the “n” values was found to have significantly less influence on results. Peak flood levels were found to vary by less than 0.1m at most locations in the floodplain, for all calibration events and the 1% AEP design flood, with the biggest change being 0.2m in the Oakhampton Floodway at Long Bridge.

6.4.2. Variation in Tributary Inflows

Altering the shape or the peak of the main Hunter River inflow will affect the results but as noted above this is not an independent variable. However the contribution of the other inflows during a design event is unclear (the issue of whether the 1% AEP flow on the Hunter River should be combined with the 2%, 5% or 10% AEP events on the other tributaries for example is open to discussion). Table 21 provides the design approach adopted. The sensitivity of this assumption was tested by assuming the 1% AEP event on the Hunter River occurs in conjunction with the 2% AEP as opposed to the 5% AEP.

The results indicate that changes to the magnitude of local tributary inflows do not have a significant bearing on the results, with changes to peak flood levels of less than 0.05m observed at most locations. The areas around South Maitland and Pitnacree were found to be the most sensitive to this change, with increases to peak flood levels of up to 0.15m when tributary flows were increased from the 5% to the 2% AEP.

The effect of varying the magnitude of the design duration (36 hours was adopted) was also undertaken by testing a 72 hour duration event for the 1% AEP Hunter River flood. The results indicate that this assumption has a negligible influence on peak flood levels, with changes of less than 0.02m observed at most locations in the study area.

The effect of altering the timing of the peak of the inflows was evaluated by modelling a +24 hour shift in the start time of the tributary inflows, such that they coincided with the peak of the Hunter River flow. The change resulted in slight increase across the floodplain of between 0.05m and 0.1m at most locations. The most sensitive areas were the floodplain between Morpeth and Green Rocks (largely due to the influence of the Paterson River flows), and the Oakhampton Floodway.

It is noted that since the adopted flood frequency approach was to estimate Hunter River flows at Oakhampton, and then iterate inflows to the upstream model to match the estimated design flows, the choice of relative inflows from the tributaries is not a significant concern with respect to flood magnitude at Oakhampton and Belmore Bridge. If a larger event magnitude was adopted for the tributaries, it would have resulted in an equivalent reduction of Hunter River flow in the upstream model, to produce the same total flow at Oakhampton.

6.4.3. Variation in Starting Level in Wallis and Fishery Creek Swamps

Local catchment runoff can fill the Wallis and Fishery Creek swamps to a depth of several metres in the absence of inflow from the Hunter River down the Oakhampton floodway. This is largely what occurred in June 2007. For design it is assumed that the swamps have a water level of 0.3 mAHD at the start of the design event and fill from local catchment runoff before being inundated by runoff down the Oakhampton floodway. The sensitivity of this assumption was tested by assuming the swamps started at a level of 3.0mAHD, and alternatively by assuming an increase of 50% in the available flood storage in the swamps.

The effect of increasing the initial water level by 2.7m (corresponding to a significant increase in water volume in the swamps at the start of the flood) was to increase peak flood levels by up to 0.3m in the areas near Louth Park, South Maitland, and Pitnacree. Increasing the assumed flood storage by 50% in the swamp areas where survey was unavailable resulted in a comparable decrease in peak flood levels of 0.3m in those areas. Peak flood levels in other areas such as the Oakhampton Floodway, Bolwarra, Lorn, Morpeth and Duckenfield were found to not vary significantly (less than 0.02m) due to changes in Wallis and Fishery Creek.

6.4.4. Hydraulic Energy Losses at Bridge Structures

The abutments, piers, decks and railings of bridges cause an obstruction to flow which results in afflux upstream of the bridge, and potentially a change in floodplain flow distribution. The influence of bridges on the Hunter River and tributaries in the study area was included in the model through the use of energy loss parameters. The values used were based on typical bridge performance, and reflect assumptions about the hydraulic efficiency of the bridges and likely levels of blockage.

The sensitivity of the model results to the assumed energy loss at bridges was tested by halving and doubling the assumed parameters. The peak flood levels were found not to vary significantly with the changes, with a change of less than 0.1 m generally observed over the floodplain. The most significant change was observed in the Oakhampton Floodway due to the influence of Long Bridge. Long Bridge is a relatively low structure flanked on the downstream side by poplar trees. The results suggest that flood levels in this area could change with varying levels of blockage of Long Bridge.

6.4.5. Climate Change

DESCRIPTION

The earth's surface temperature is due to the presence of certain gases in the atmosphere which allow the sun's rays to penetrate to the earth but reduce the amount of energy being radiated back. It is this trapping of the reflected heat which has enabled life to exist on earth.

Since the early 1980's there has been concern that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) resulting from human activity may be raising the average earth surface temperature. As a consequence, this may affect the climate and sea level. The extent of any permanent climatic or sea level change can only be established 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,
- the balance of evidence suggests human interference has resulted in climate change over the past century,
- 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.

The best available estimate of the projected sea level rise (including ice melt) along the NSW coast is from 0.2 m to 0.9 m between the years 2090 and 2100.

DISCUSSION

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 possible mechanisms are far from clear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. Even if an increase in total annual rainfall does occur, the impact on design rainfalls may not be adverse. There is some recent literature by CSIRO that suggests rainfalls may increase by up to 30% in parts of NSW (in other places the increases are much less), however this information is not of sufficient accuracy for use as yet.

Any change 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.

Any change in the sea level will have an immediate impact but this will largely only affect Hunter River flood levels within Newcastle Harbour. Sea level rise will raise the normal water level in the Hunter River at Maitland but will have no impact on design flood levels (unless sea level rises of several metres occur). The issue of sea level rise is complicated by other long term influences on mean sea level changes. The available literature suggests that a gradual increase in sea level is likely to occur with a rise of perhaps up to 0.9 m within the next 80 years along the NSW coast.

The effect of increasing the design rainfall inflows by 10%, 20% and 30% has been evaluated for the 1% AEP event, resulting in a relatively significant impact on peak flood levels in the study area. Generally speaking, each incremental 10% increase in flow results in a 0.4 m increase in peak flood levels upstream of Oakhampton, and a 0.2 m increase in flood levels downstream of Oakhampton, with localised increases in peak flood level of approximately twice that amount.

6.5. Summary

From the sensitivity analysis, it was concluded that the principal factors that influence the modelled flood behaviour are the magnitude of flow and, particularly upstream of Oakhampton, the Manning's "n" roughness parameter. This finding supports the variation of these two model inputs as the primary calibration method. Peak flood levels were found to vary slightly as a result of variation of other model inputs, including:

- magnitude and timing of tributary inflows;
- level of initial flood storage, and total flood storage in Wallis Creek / Wentworth Swamp;
- energy loss at bridge structures in the floodplain.

It is considered that the design flood levels adopted reflect the best estimate of the model inputs with available information, and based on experience with other studies. However it is noted that variation of some of the above assumptions could result in localised changes to the estimated flood levels.

As mentioned above, there are limitless combinations of parameters, and a considerable effort was made to verify that the values used brought about the optimal match of modelled flood behaviour with each of the historical calibration events. There is a reasonable level of confidence in the discharge values adopted due to the extensive flood record at Maitland and the Manning's "n" values adopted were supported by historical aerial photography. The model is considered to reproduce observed historical flood behaviour well, for a wide range of events.

Where quality historical flood height data are available (mainly at the gauges) the accuracy of the reported design flood levels is of the order of +/- 0.3m. Elsewhere the accuracy is of the order of +/-0.5m. The accuracy will be improved over time as data from future flood events is collected and evaluated.

7. ACKNOWLEDGEMENTS

This study was carried out by WMAwater and funded by Maitland and Cessnock Councils and the Department of Environment, Climate Change and Water. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Maitland City Council,
- Cessnock Council,
- Department of Environment, Climate Change and Water,
- City of Maitland Floodplain Management Committee,
- Residents of the Hunter River floodplain within the study area.

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Figures

Appendix A

APPENDIX A: GLOSSARY of TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a

relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas The remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

flood mitigation standard The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain Area of land which is subject to inundation by floods up to and including the

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

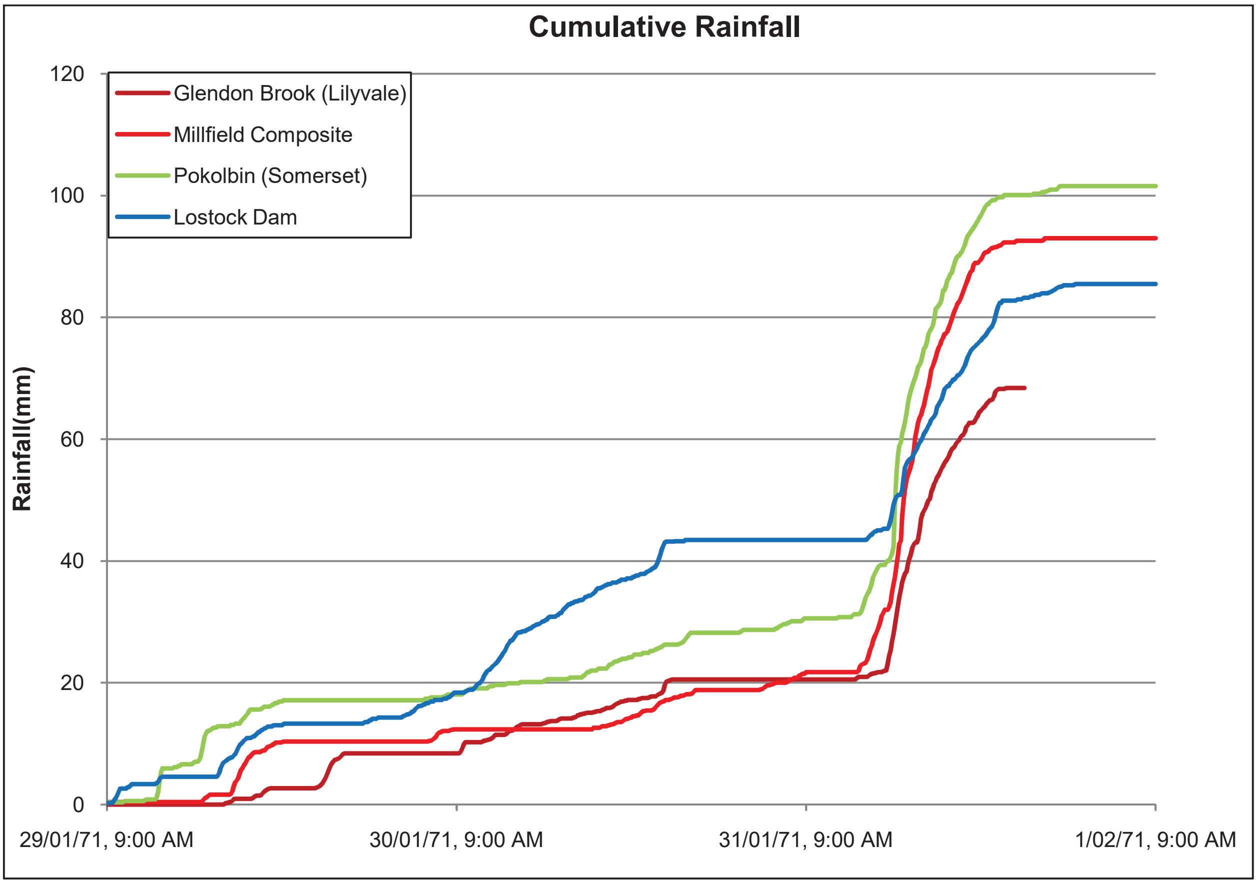
	flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor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

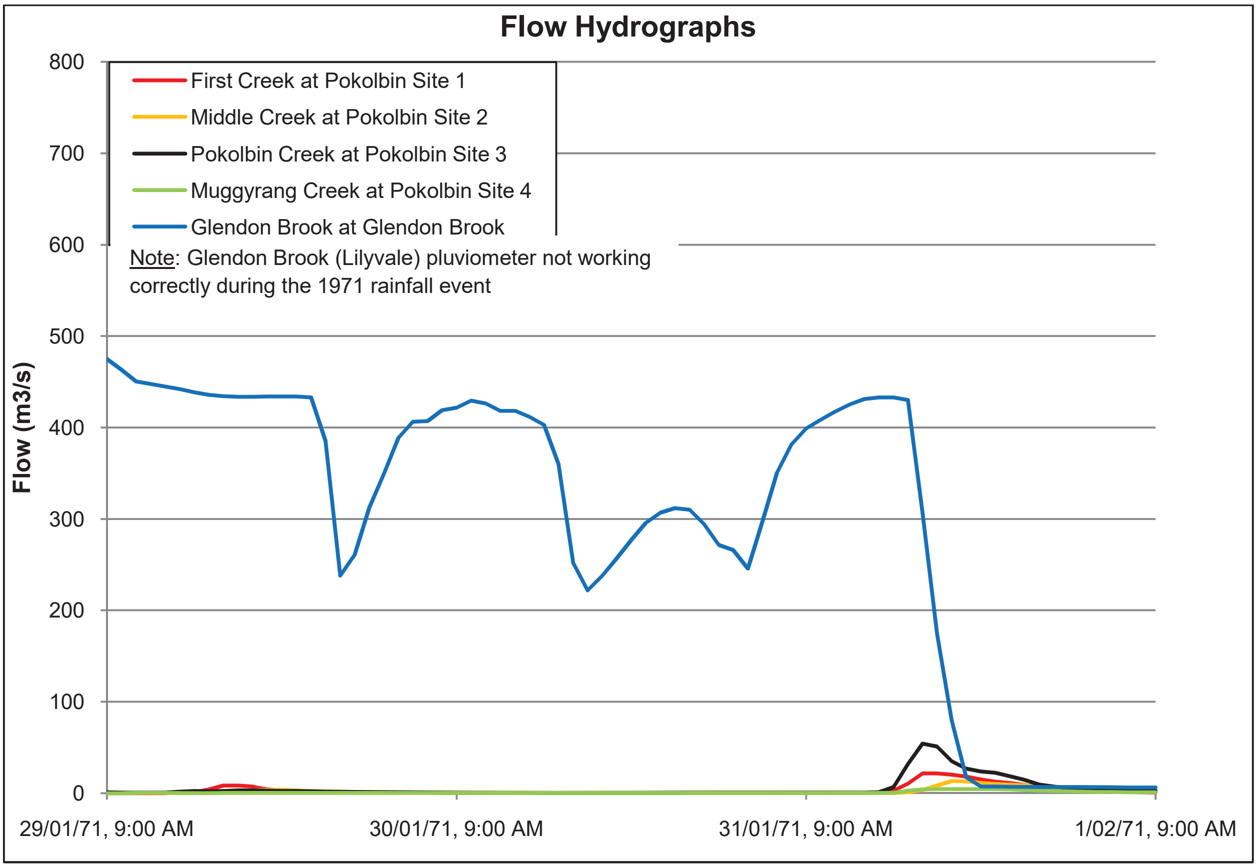
	The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific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

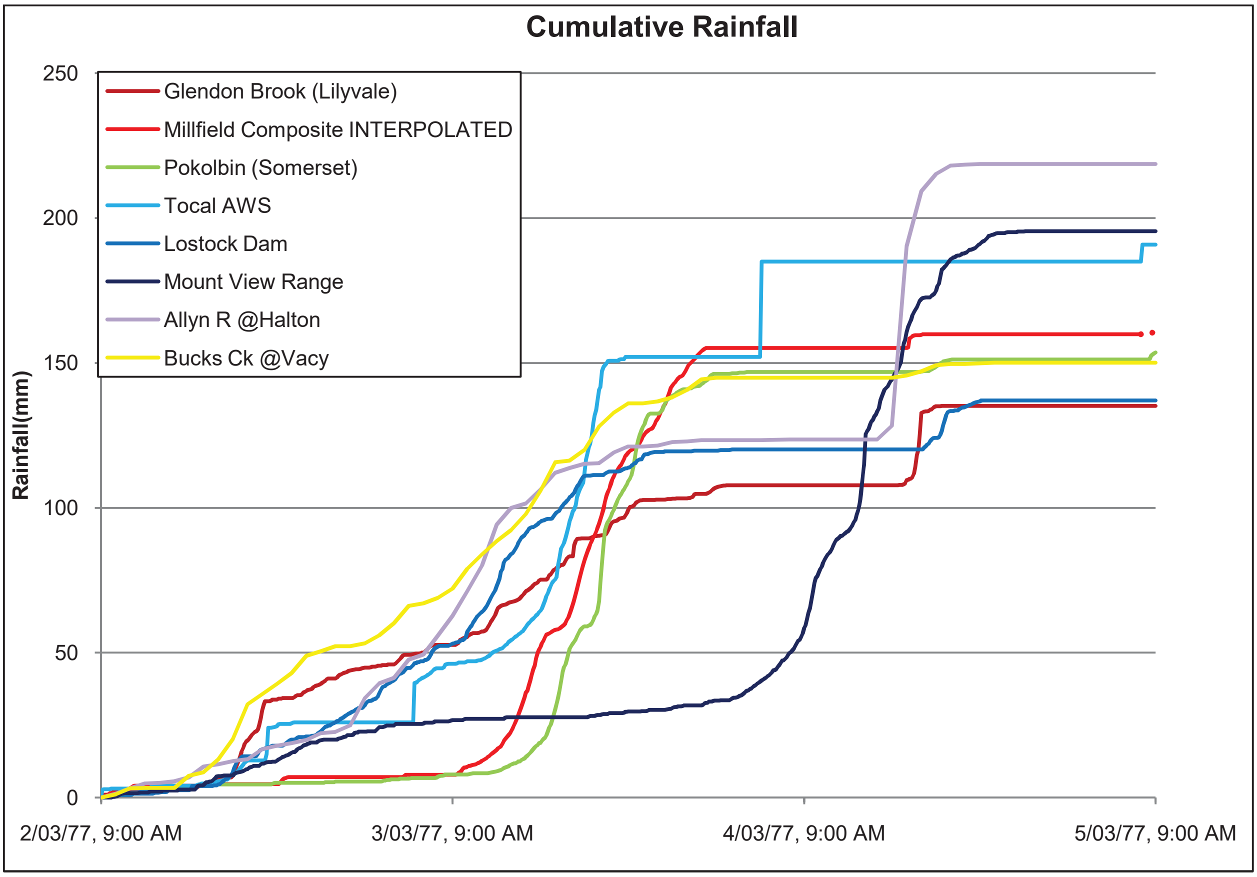
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

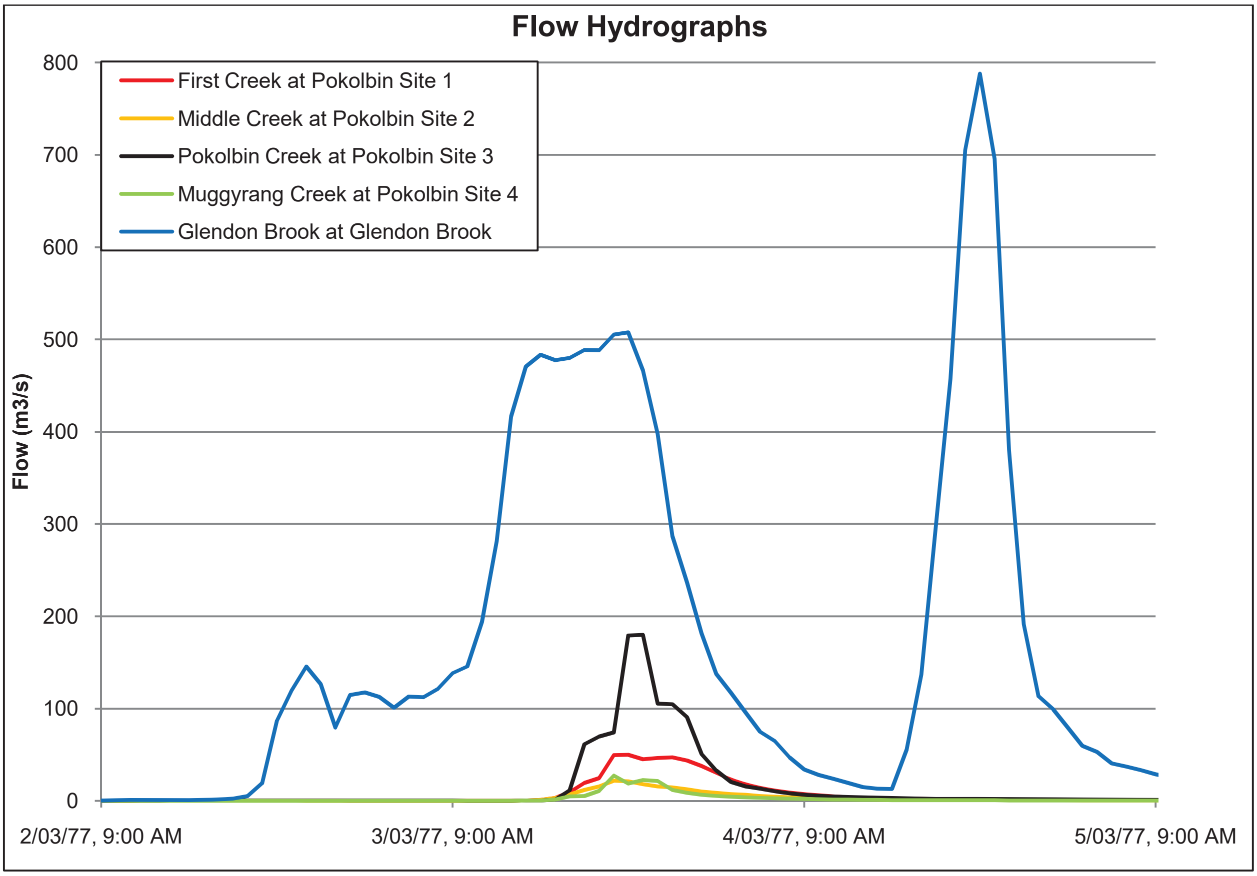
Appendix B

STREAMFLOW AND PLUVIOMETER DATA
1971 EVENT

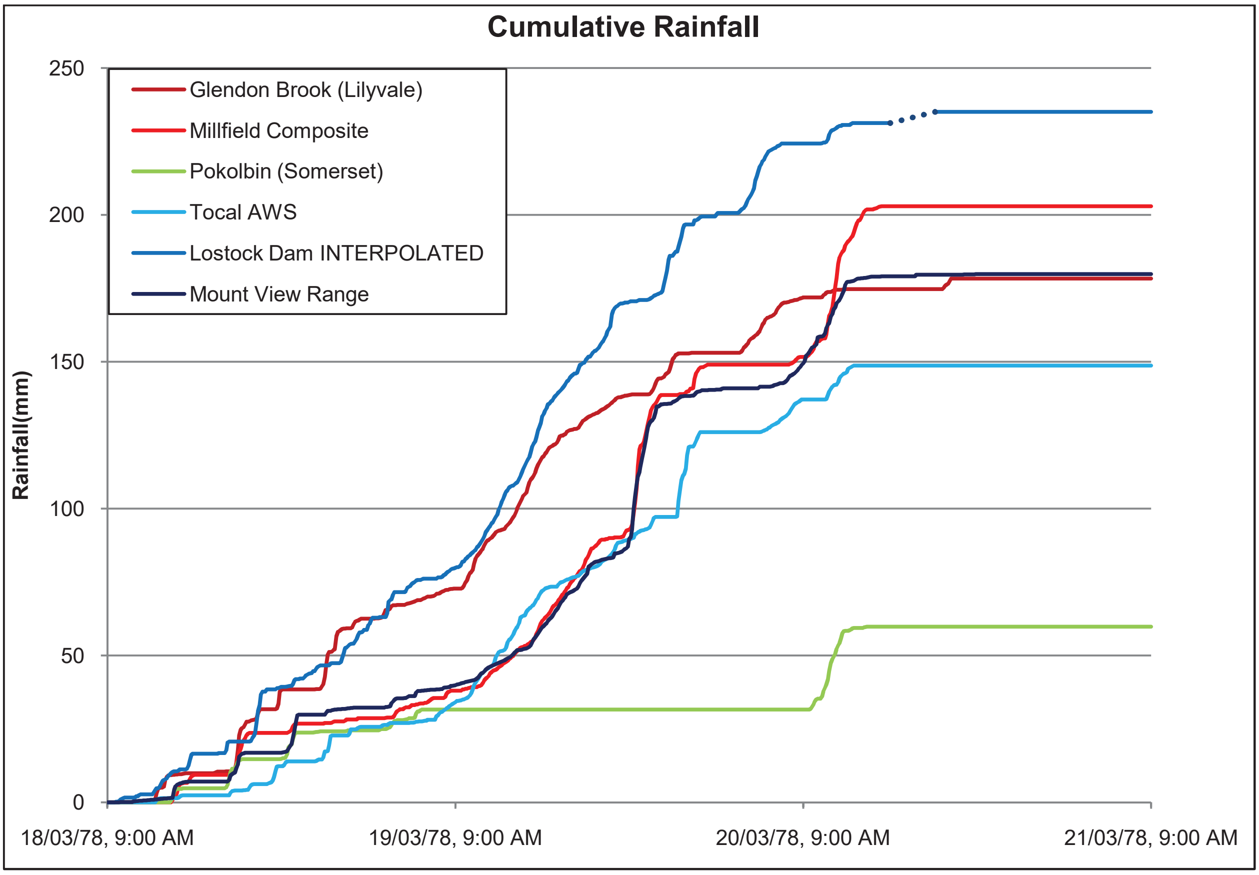


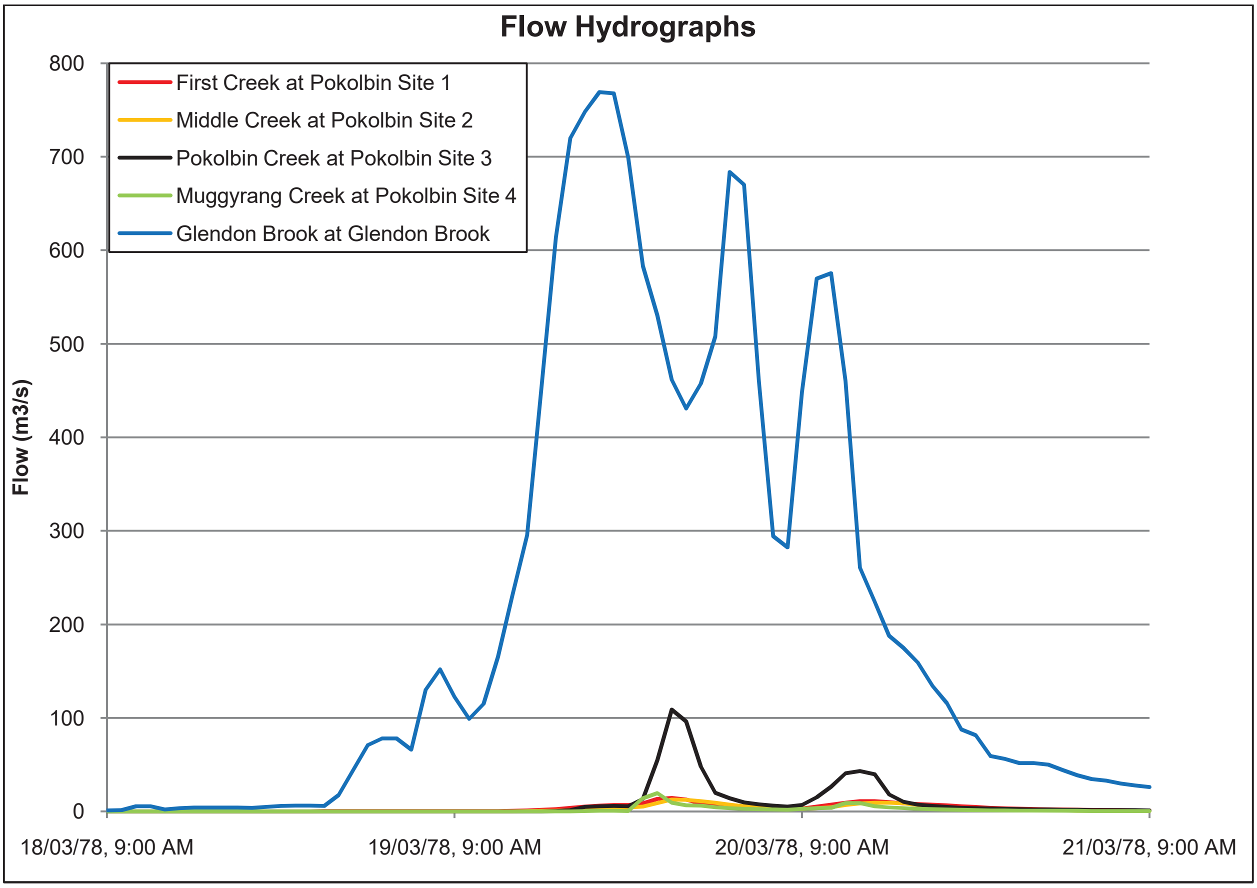



Cumulative Rainfall
Rainfall(mm)
250
200
150
100
50
0
Glendon Brook (Lilyvale)
Millfield Composite INTERPOLATED
Pokolbin (Somerset)
Tocal AWS
Lostock Dam
Mount View Range
Allyn R @Halton
Bucks Ck @Vacy
2/03/77, 9:00 AM
3/03/77, 9:00 AM
4/03/77, 9:00 AM
5/03/77, 9:00 AM

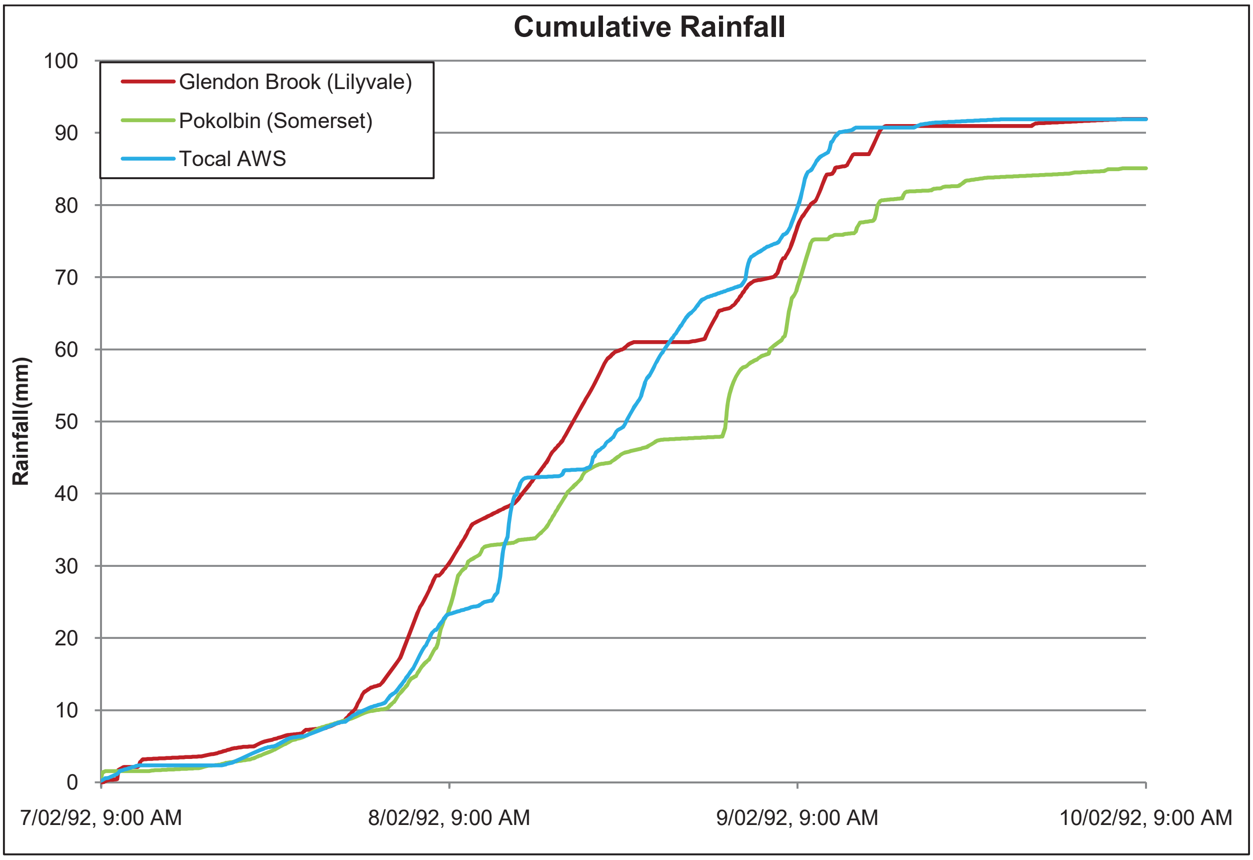

Flow Hydrographs
Flow (m3/s)
800
700
600
500
400
300
200
100
0
First Creek at Pokolbin Site 1
Middle Creek at Pokolbin Site 2
Pokolbin Creek at Pokolbin Site 3
Muggyrang Creek at Pokolbin Site 4
Glendon Brook at Glendon Brook
2/03/77, 9:00 AM
3/03/77, 9:00 AM
4/03/77, 9:00 AM
5/03/77, 9:00 AM

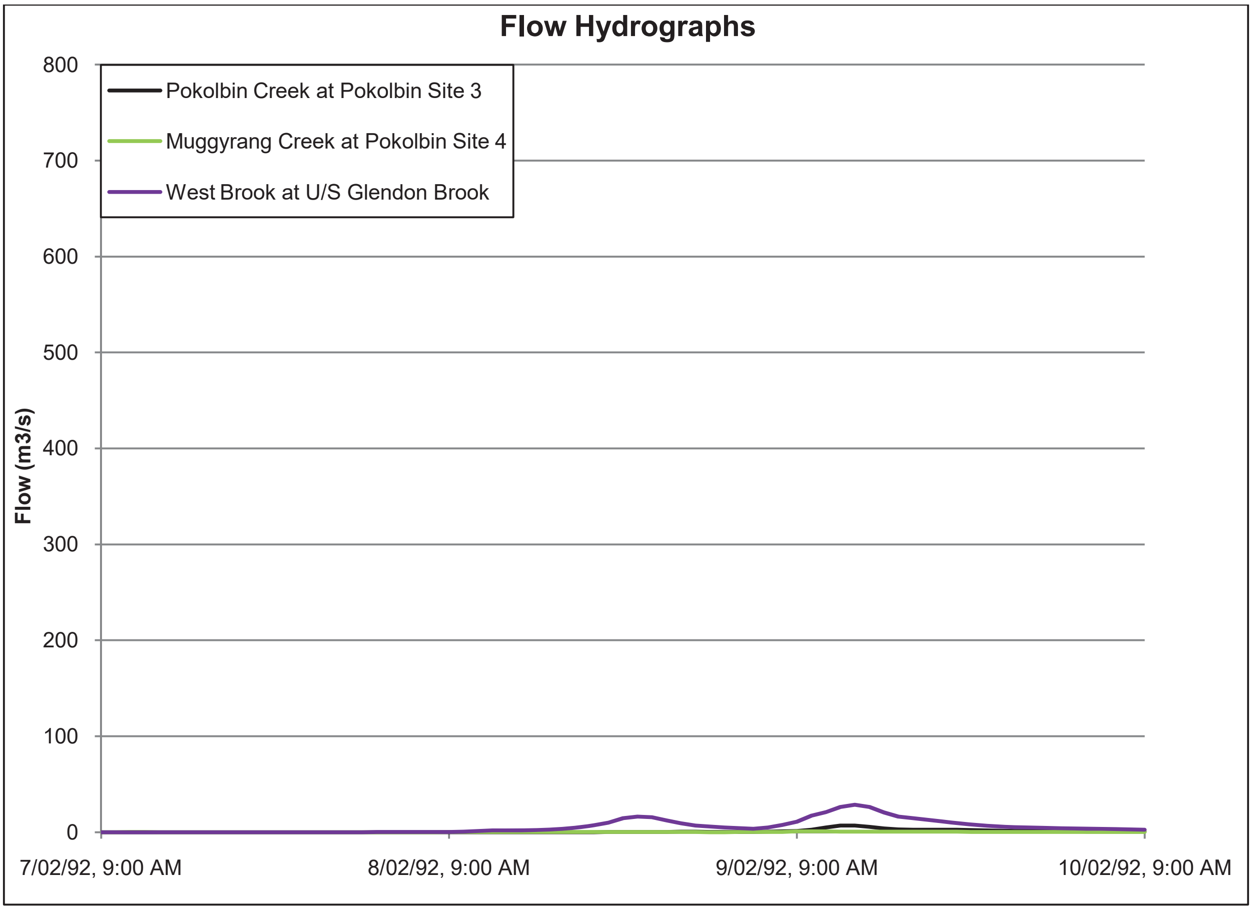
STREAMFLOW AND PLUVIOMETER DATA 1978 EVENT



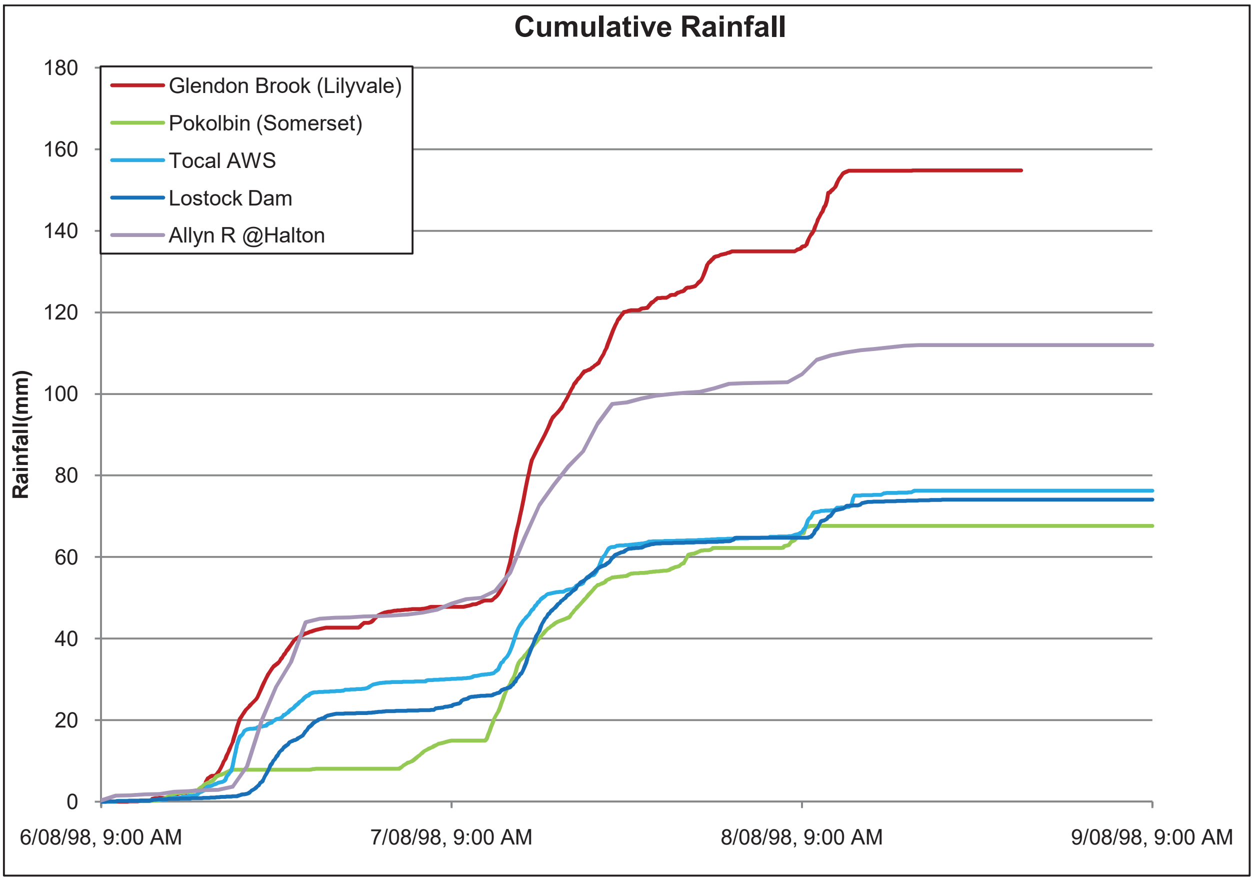


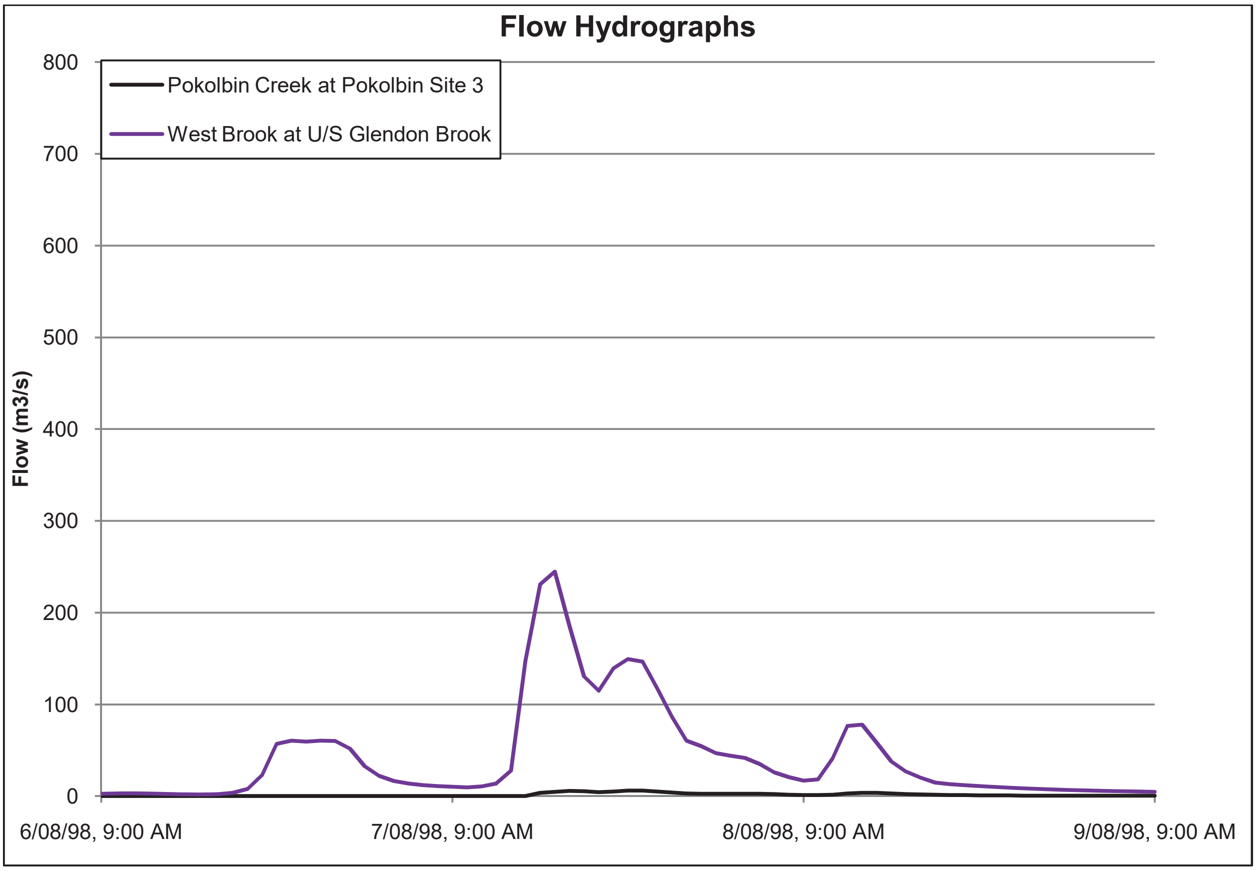
STREAMFLOW AND PLUVIOMETER DATA
1992 EVENT



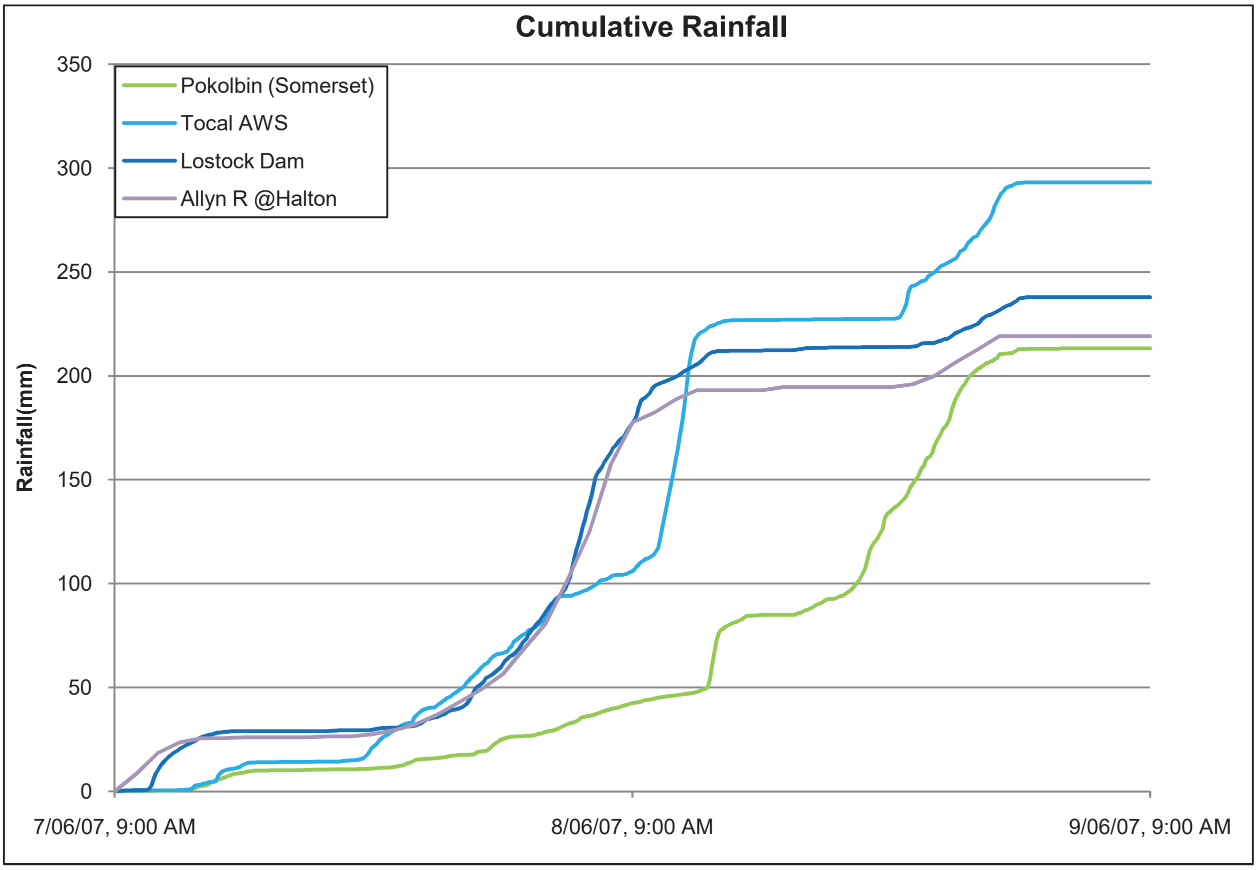


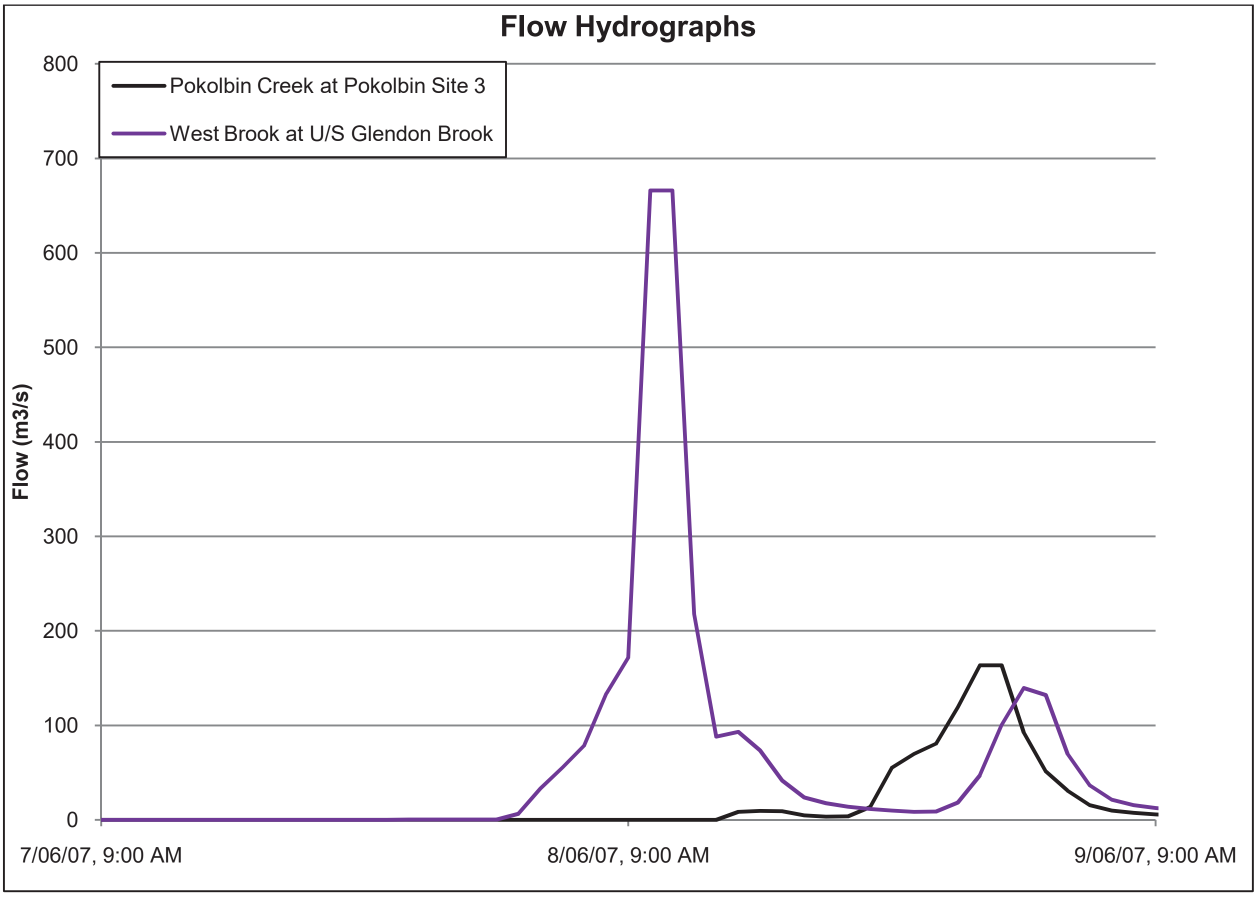
STREAMFLOW AND PLUVIOMETER DATA 1998 EVENT





STREAMFLOW AND PLUVIOMETER DATA
2007 EVENT





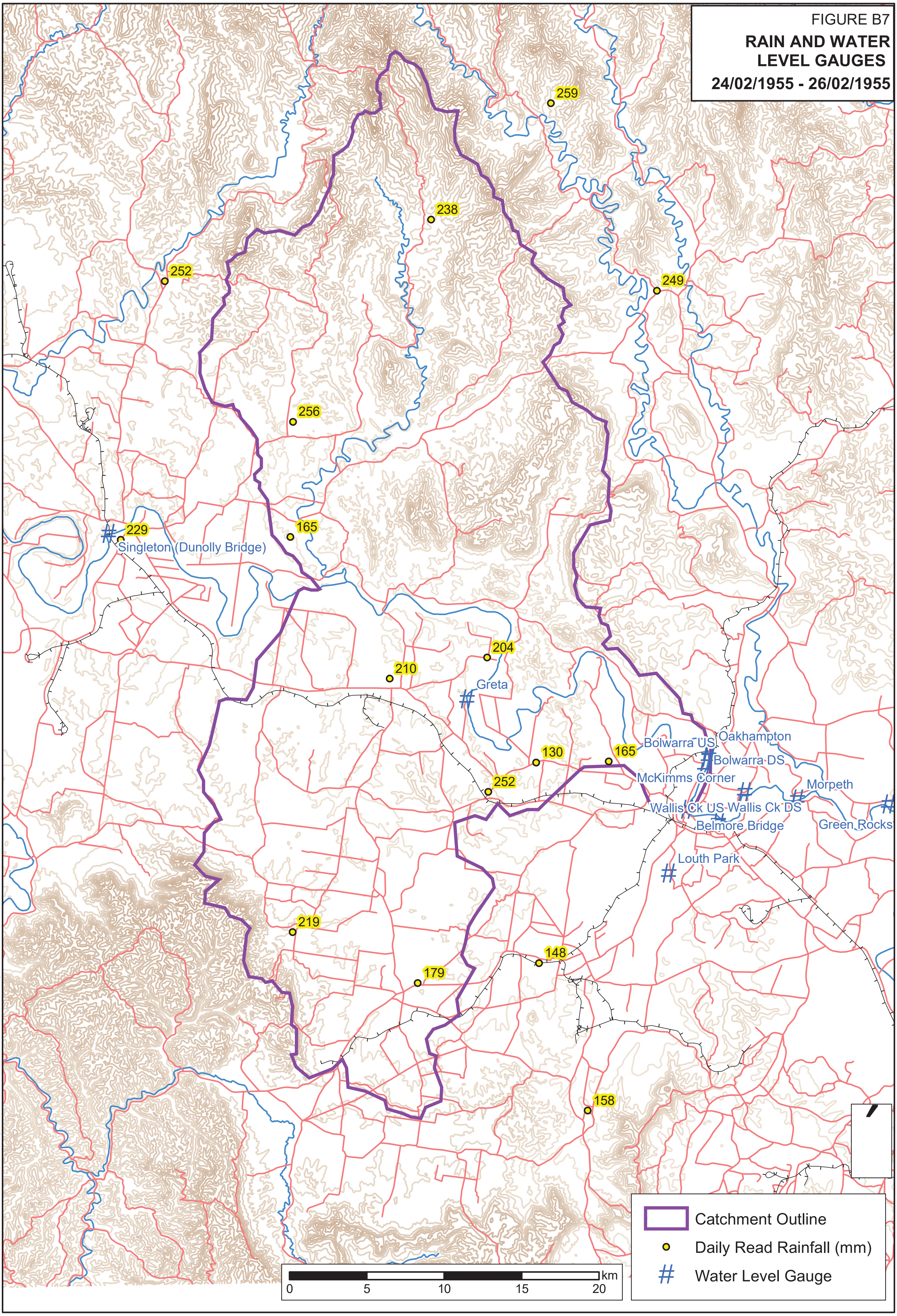


FIGURE B7
RAIN AND WATER LEVEL GAUGES
24/02/1955 - 26/02/1955

J:\Jobs\27036\ArcGIS\Maps\Pluvis_StreamGauges1955.mxd

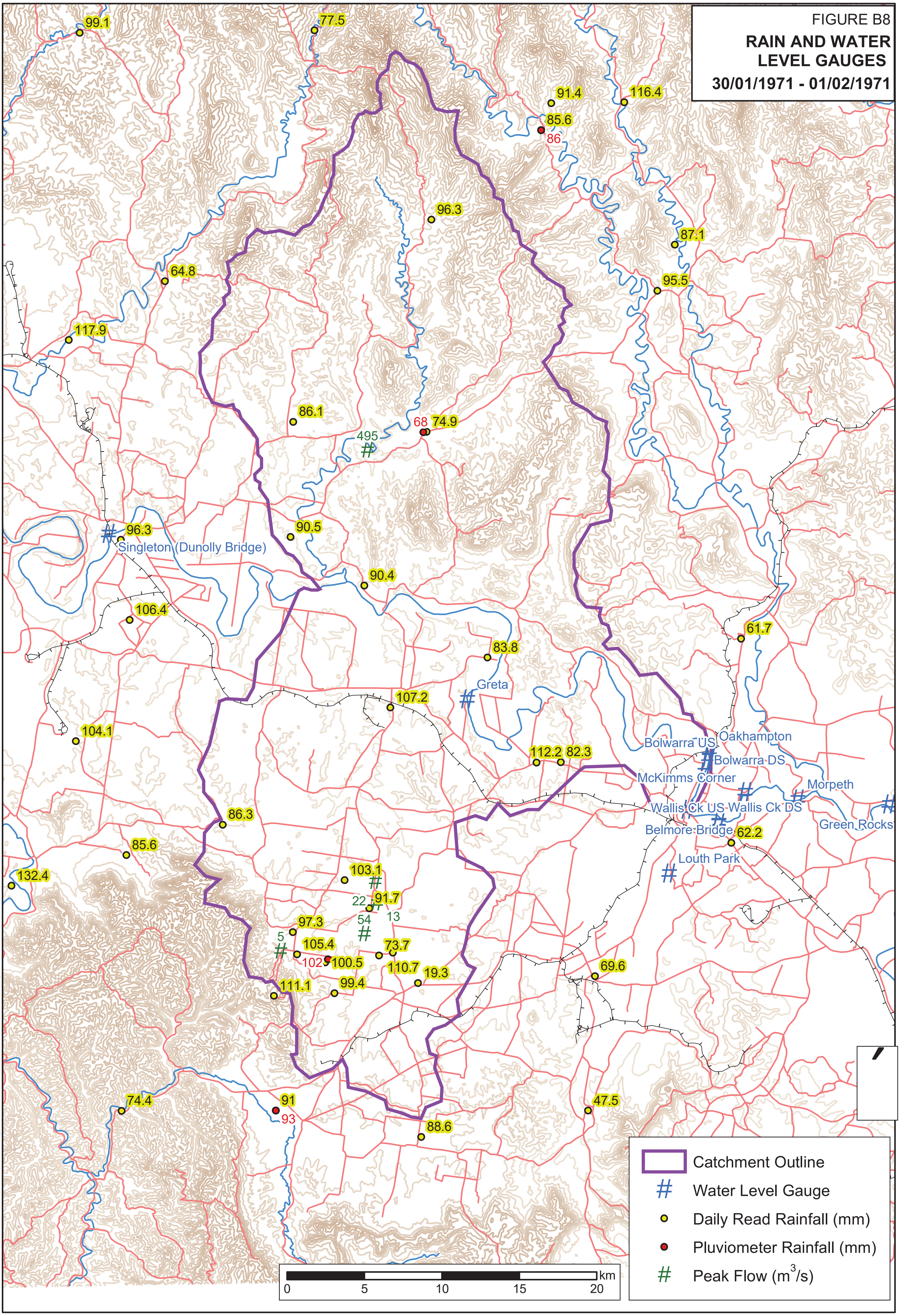


FIGURE B8
RAIN AND WATER LEVEL GAUGES
30/01/1971 - 01/02/1971
99.1
77.5
91.4
116.4
85.6
86
96.3
87.1
64.8
95.5
117.9
86.1
68
74.9
495
96.3
Singleton (Dunolly Bridge)
90.5
90.4
106.4
61.7
83.8
Greta
107.2
104.1
Bolwarra US
Oakhampton
112.2
82.3
Bolwarra DS
McKimms Corner
Morpeth
Wallis Ck US
Wallis Ck DS
86.3
Belmore Bridge
62.2
Green Rocks
85.6
Louth Park
132.4
103.1
22
91.7
54
13
97.3
5
105.4
73.7
102
100.5
110.7
19.3
69.6
111.1
99.4
74.4
91
93
47.5
88.6
Catchment Outline
Water Level Gauge
Daily Read Rainfall (mm)
Pluviometer Rainfall (mm)
Peak Flow (m3/s)
0
5
10
15
20
km
J:\Jobs\27036\ArcGIS\Maps\Pluvis_StreamGauges1971.mxd

FIGURE B9
RAIN AND WATER LEVEL GAUGES
03/03/1977 - 05/03/1977

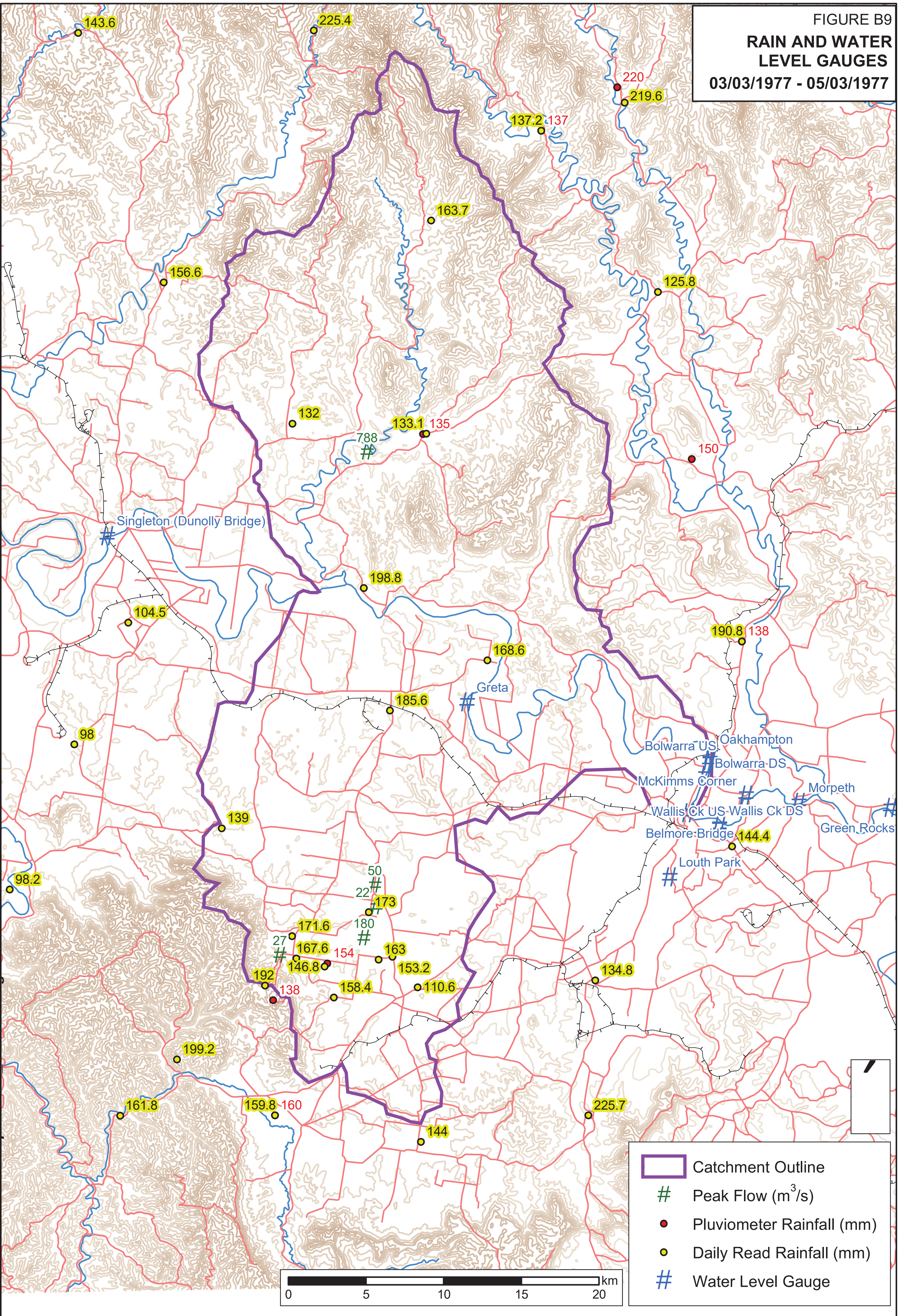


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FIGURE B10
RAIN AND WATER LEVEL GAUGES
19/03/1978 - 21/03/1978

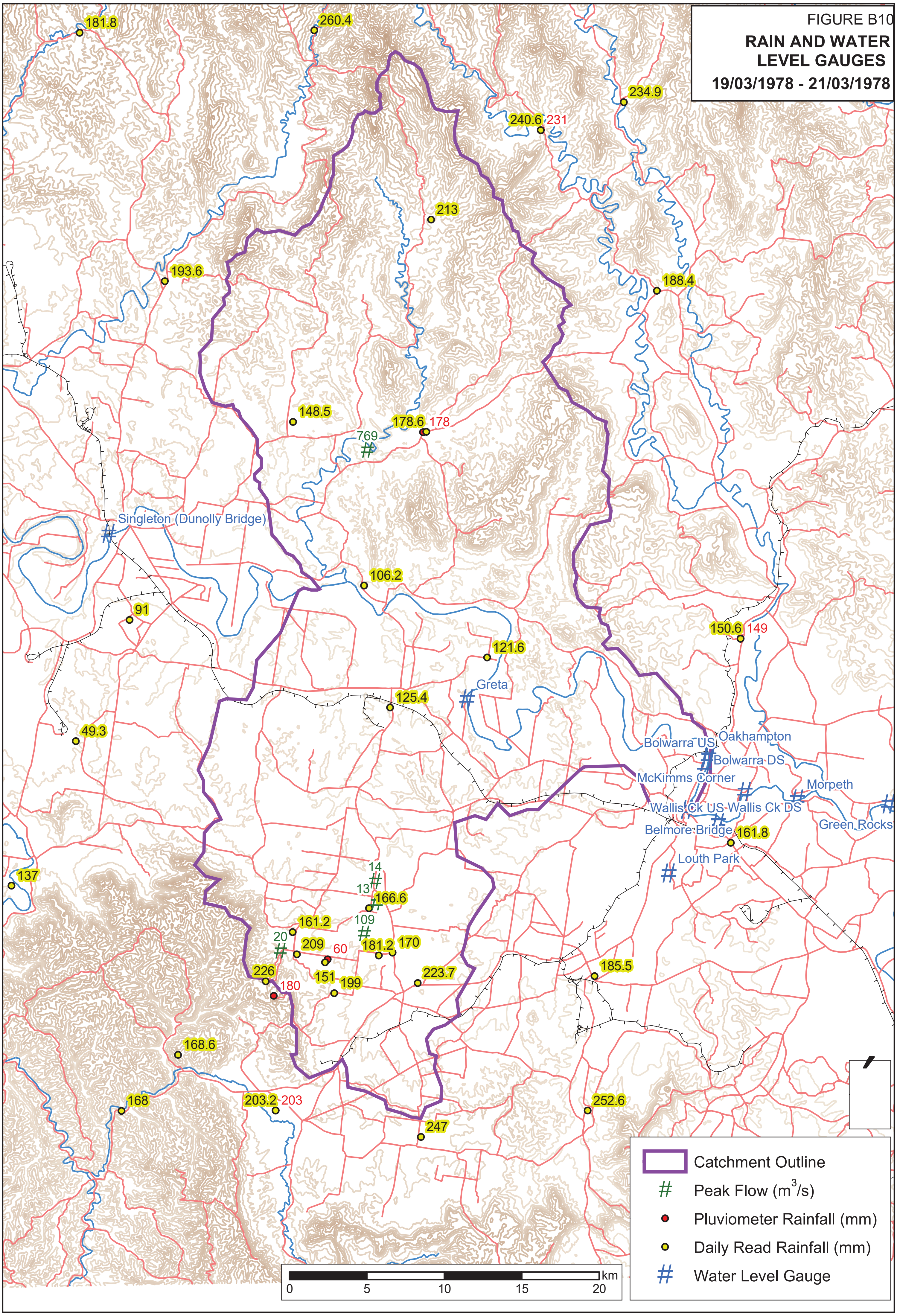
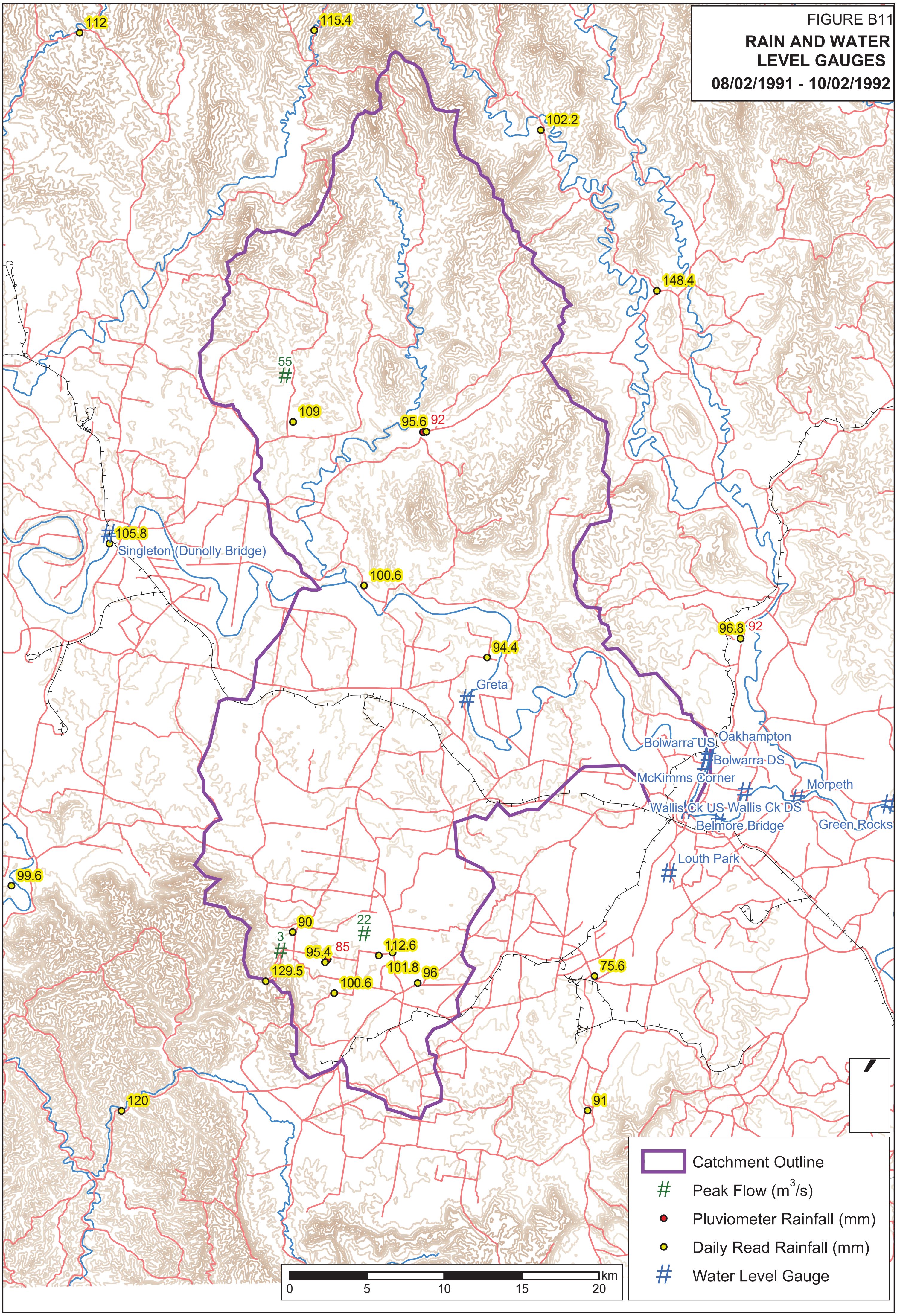


FIGURE B11
RAIN AND WATER LEVEL GAUGES
08/02/1991 - 10/02/1992



J:\Jobs\27036\ArcGIS\Maps\Pluvis_StreamGauges1992.mxd

FIGURE B12

RAIN AND WATER LEVEL GAUGES

07/08/1998 - 09/08/1998

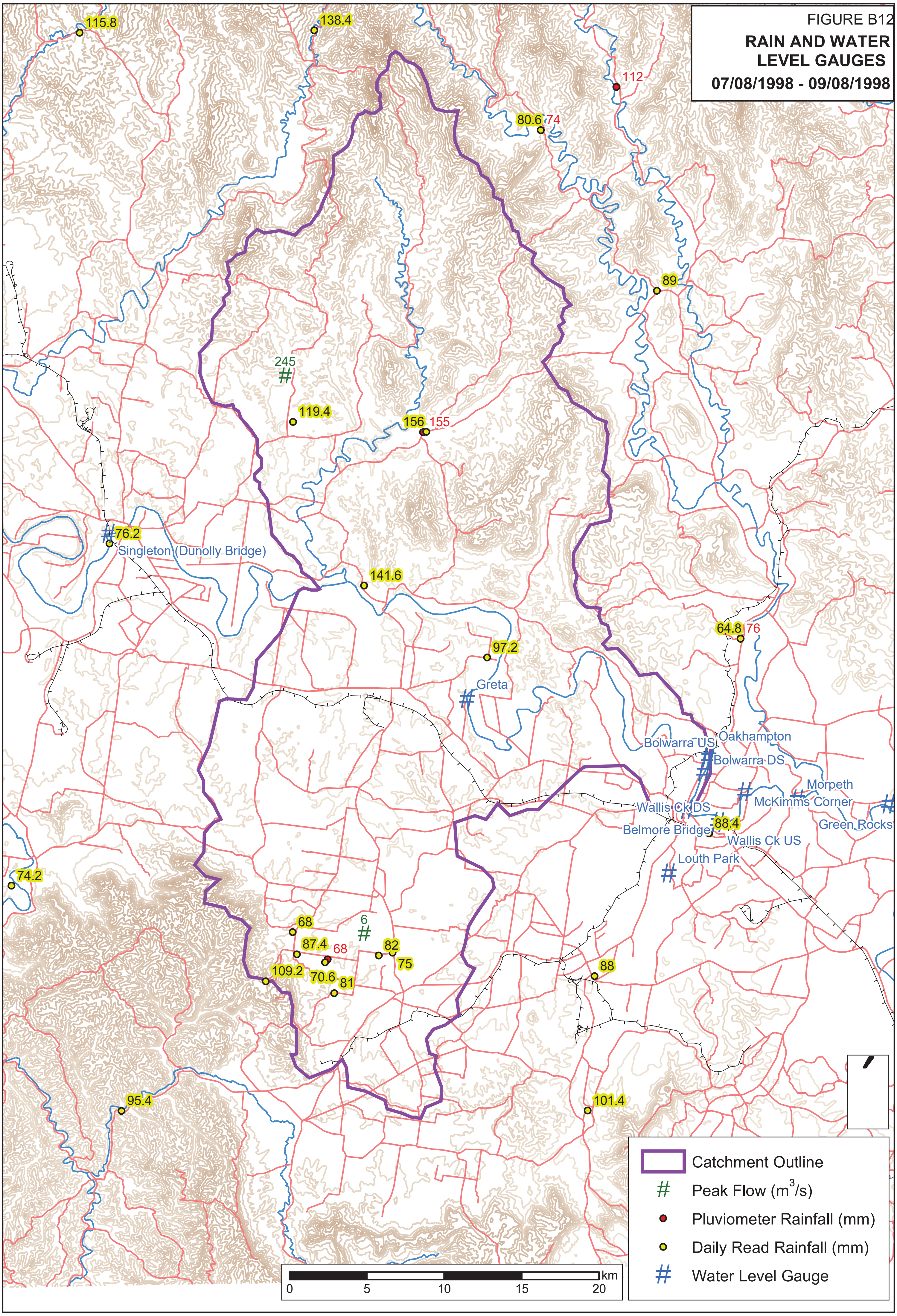


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FIGURE B13
RAIN AND WATER LEVEL GAUGES
07/06/2007 - 09/06/2007

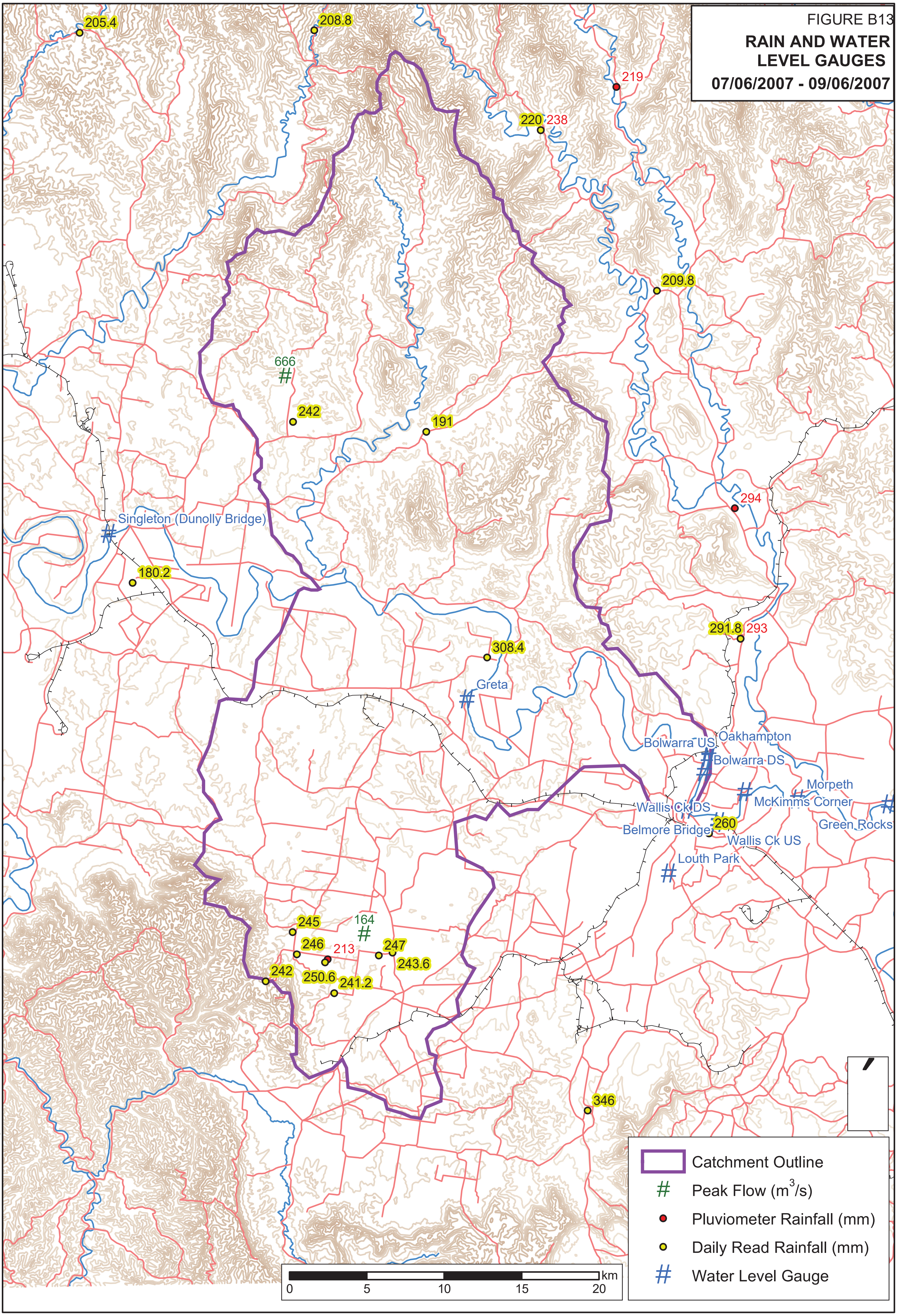

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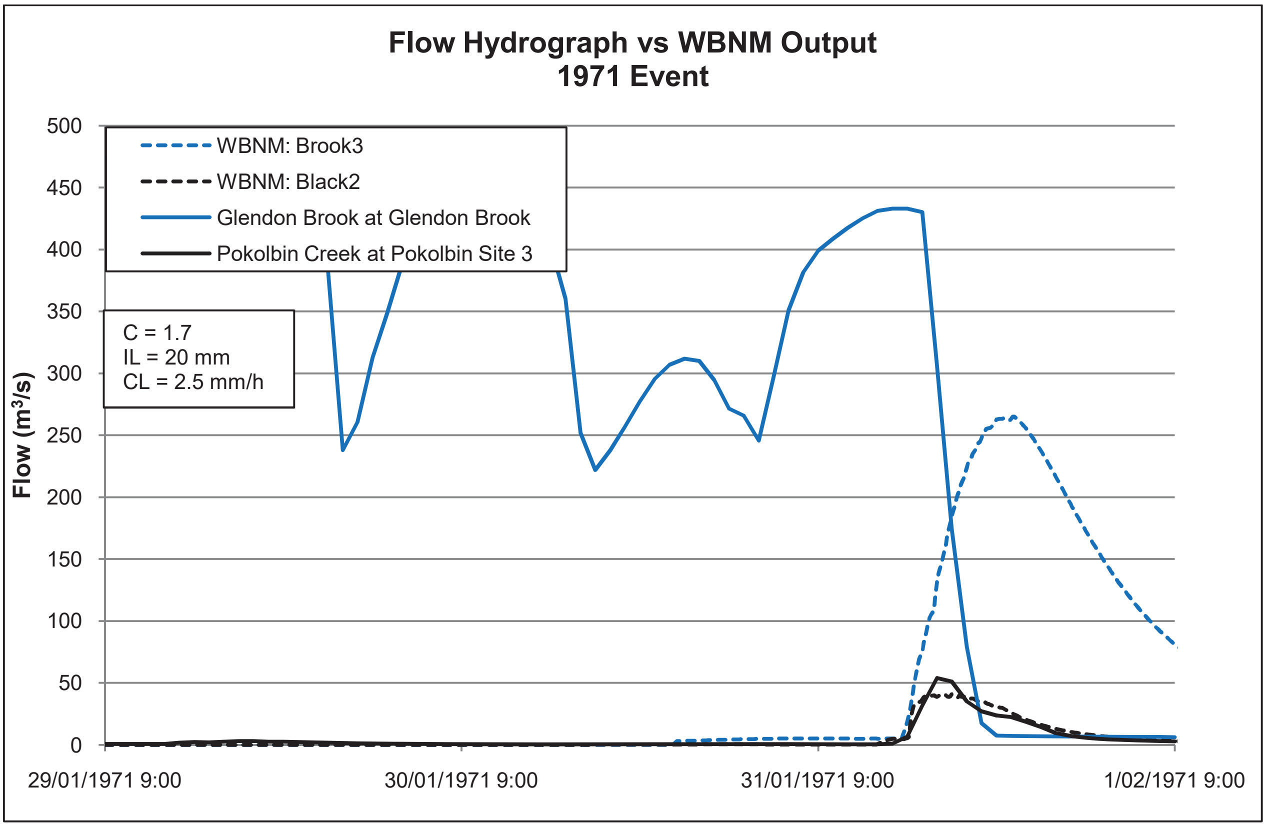
FIGURE B14

FLOW HYDROGRAPH VS WBNM OUTPUT

1971, 1977



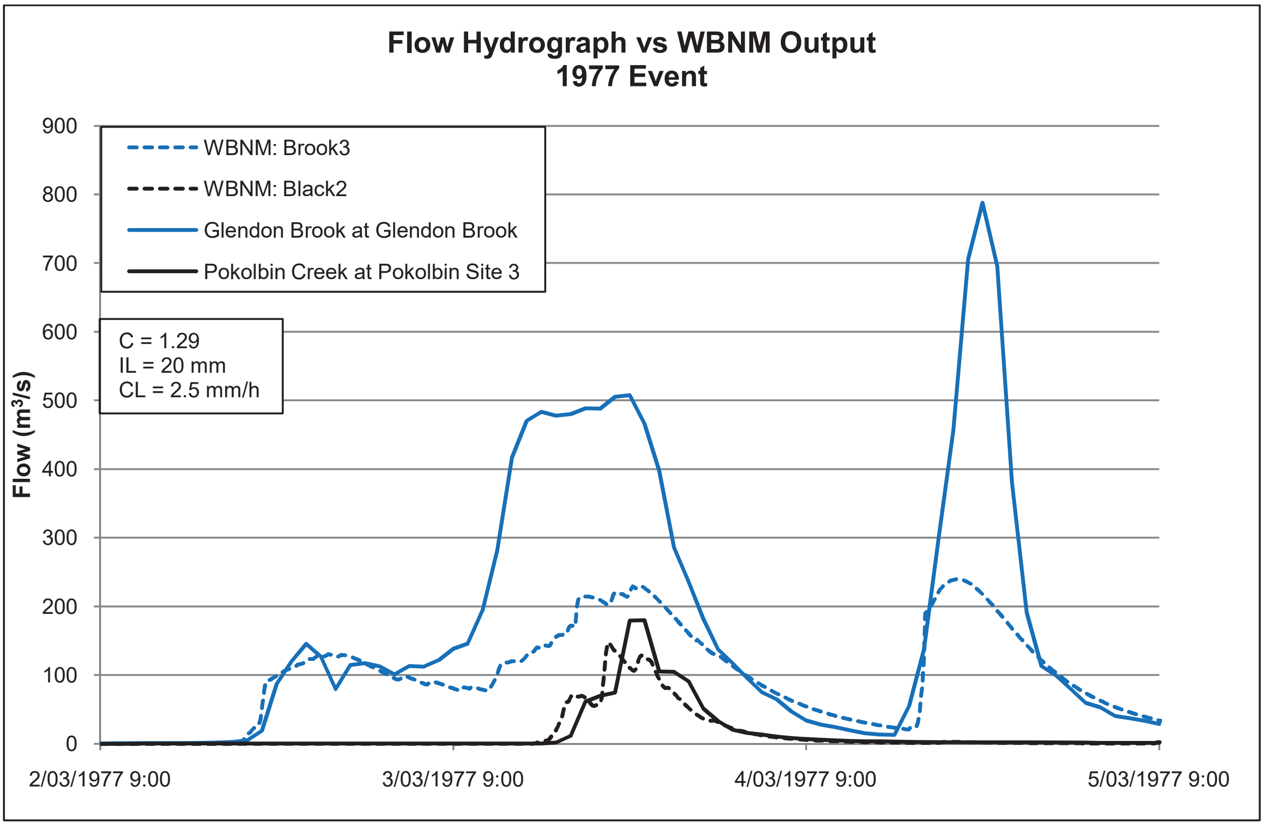
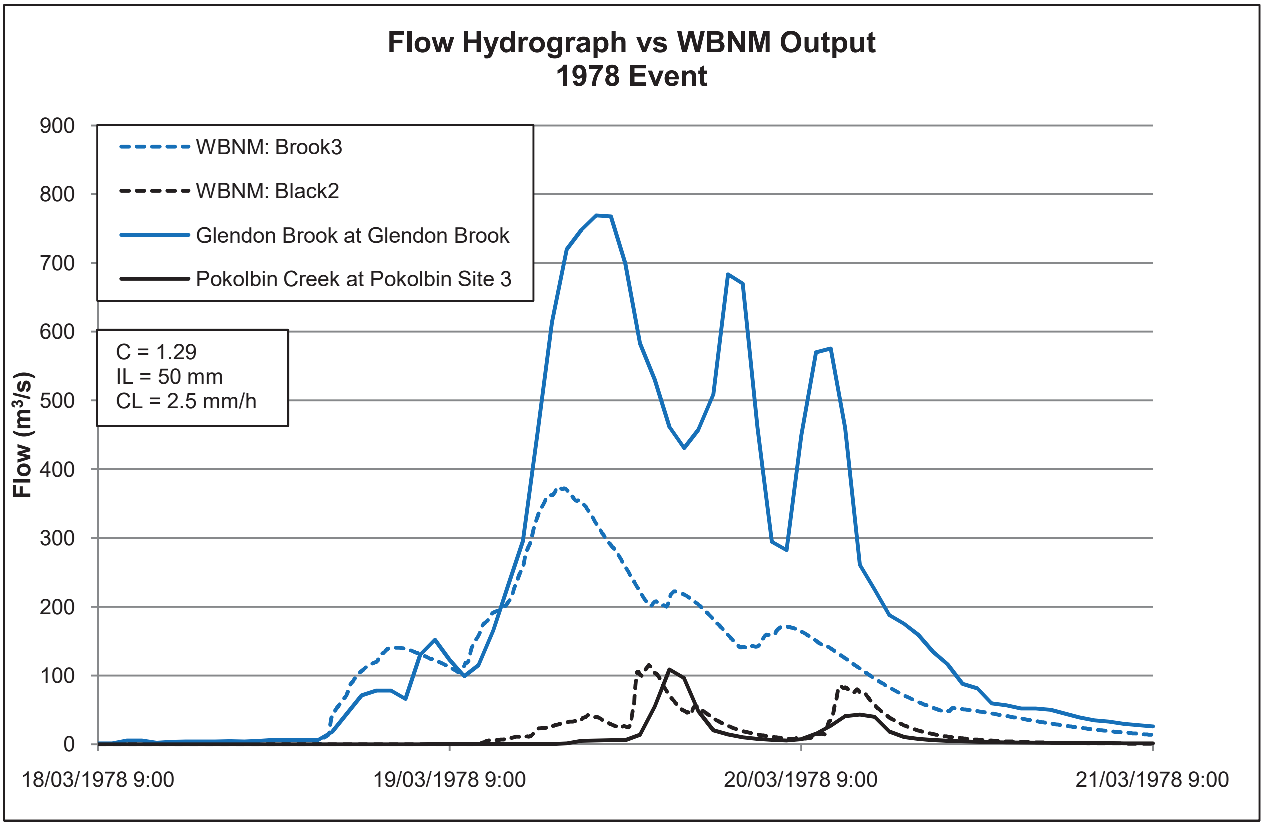


FIGURE B15

FLOW HYDROGRAPH VS WBNM OUTPUT

1978, 1998



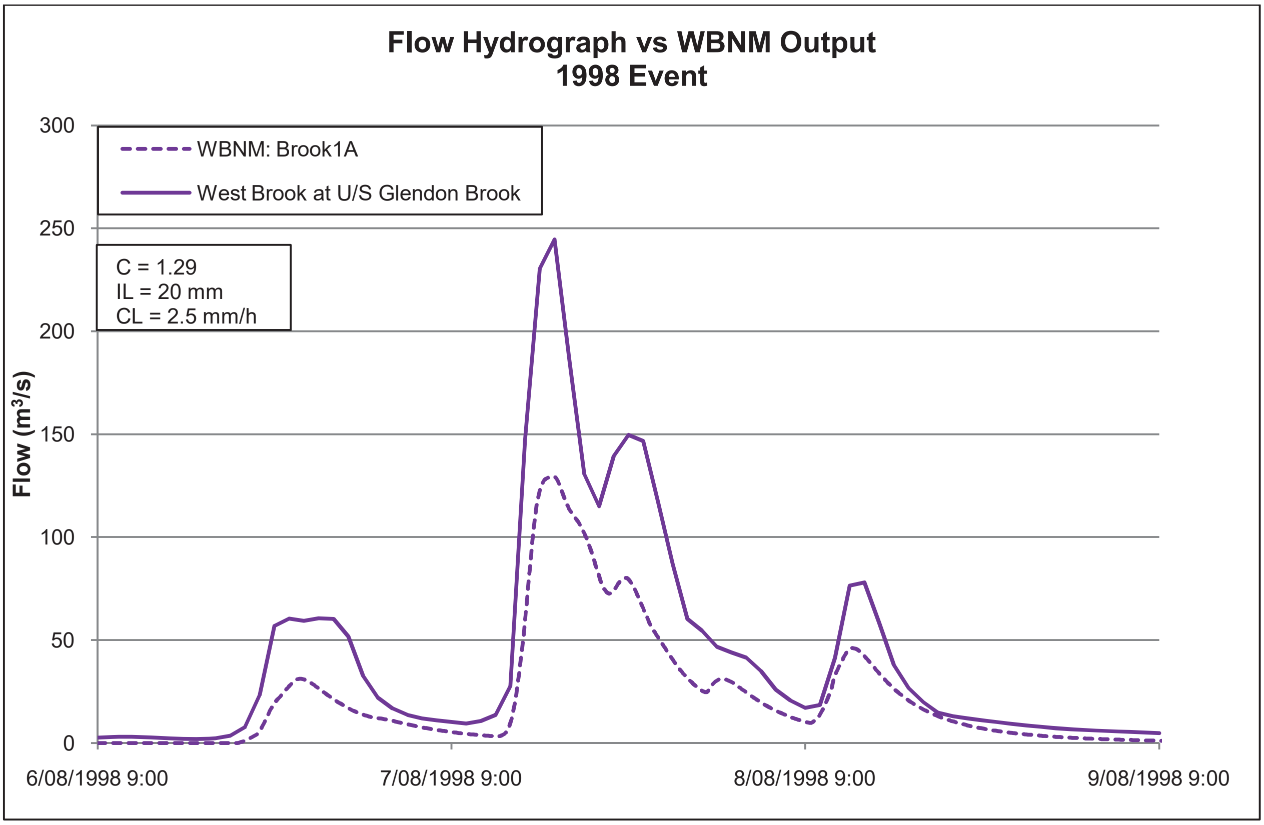
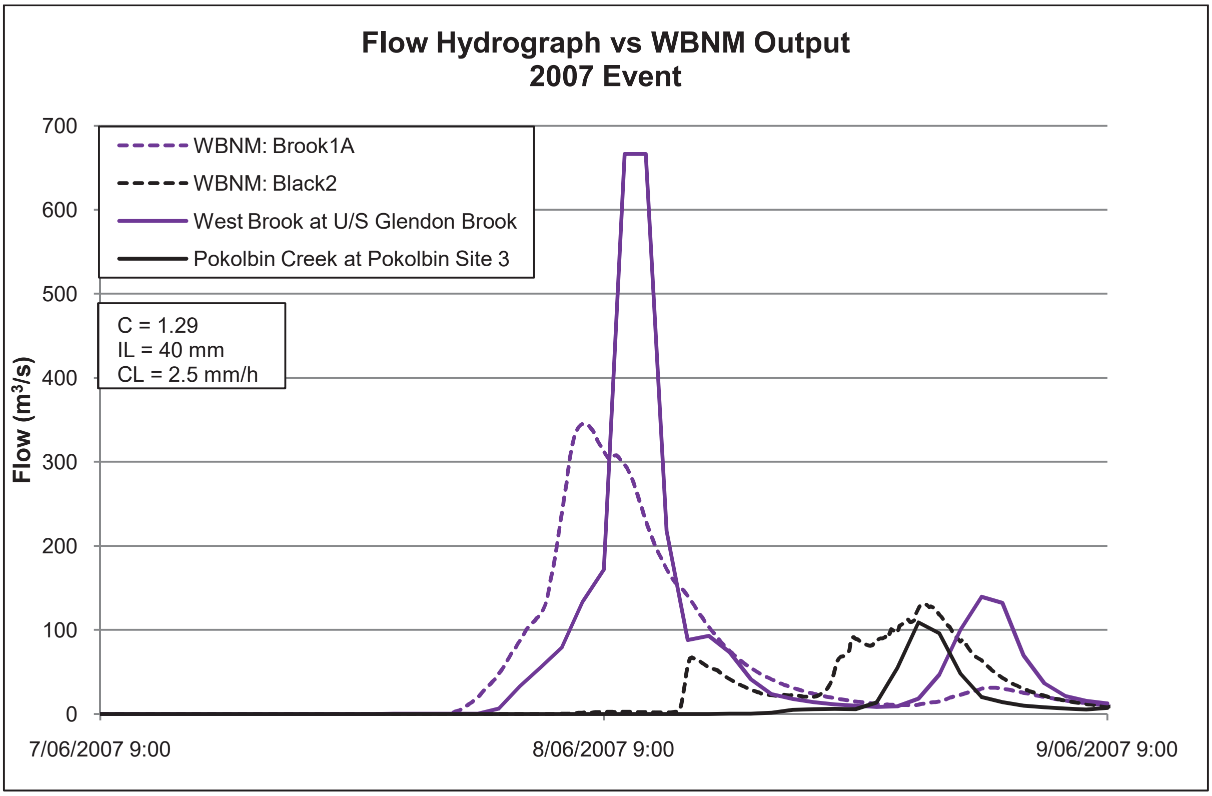


FIGURE B16
FLOW HYDROGRAPH VS WBNM OUTPUT
2007



Appendix C

APPENDIX C: PEAK FLOOD LEVEL DATA

February 1955 level (mAHD)	Location	Comments	Source	x	y
35.60	Hunter River	Near confluence with Jump Up Creek	DECC	340823.02	6392078.69
35.50	Hunter River	Northern floodplain, southern side of Glendon Lane	DECC	339625.28	6392172.69
35.2	Hunter River	U/S Elderslie Bridge	RTA	344813.29	6390575.57
34.63	Commercial Hotel		RTA	345559.74	6385664.30
34.40	Black Creek	Western floodplain near Standen Drive 1 km U/S confl with Hunter River	RTA	344234.02	6389514.13
34.30	Black Creek	Western floodplain near Standen Drive 1 km U/S confl with Hunter River	RTA	344234.02	6389514.13
34.23	Branxton cnr N-E Hwy and Bowen Street	Flood level was 2.55 m above PM 214414	DECC	345208.50	6385638.10
34.23	Blacks Garage	Exact location unknown	RTA	345282.60	6385653.28
34.22	Bank of NSW	Exact location unknown	RTA	345263.87	6385652.47
34.00	Black Creek	Western floodplain near Standen Drive 1 km u/s confluence with Hunter River	DECC	344234.07	6389514.14
33.70	Hunter River	Northern floodplain near intersection Elderslie/Stanhope Road	RTA	345037.42	6391184.03
33.61	N-E Hwy Bridge over Black Creek	Level taken from 1958 Bridge Design Drawing	RTA	343264.72	6385671.93
33.49	Black Creek	Western floodplan at Homestead 1 km U/S N-E Highway Bridge	DECC	342646.09	6385118.66
33.00	Hunter River	U/S Elderslie Bridge	DECC	344813.42	6390575.58
32.14	Hunter River	Near corner of Luskintyre and Stanhope Road	DECC	352973.96	6390173.07
31.30	Hunter River	Flood level northern floodplain near Stanhope Bridge	DECC	348300.67	6391280.90
30.76	Hunter River	Near Stanhope Road	DECC	350243.26	6390806.98
30.63	Hunter River	Near corner of Luskintyre and Stanhope Road	DECC	353278.72	6390038.97
29.79	Hunter River	East bank near end of Dalwood Road	DECC	352620.43	6387222.94
29.77	Hunter River	Source unknown	DECC	352096.23	6386442.74
28.96	Hunter River	Source unknown	DECC	351230.70	6385369.96
28.86	Hunter River	Near corner of Luskintyre and Stanhope Road	DECC	352815.48	6390258.40
28.83	Hunter River	Source unknown	DECC	350694.31	6383248.79
27.32	Hunter River	Source unknown	DECC	352705.76	6382297.93
26.47	Hunter River	Source unknown	DECC	354814.74	6384041.19
26.09	342 Windemere Road	Flood level taken at house floor	Maitland Council	354887.15	6383855.59
24.54	Hunter River	Source unknown	DECC	355741.23	6385223.67
21.68	Hunter River	Source unknown	DECC	357191.91	6386576.83
21.31	Hunter River	Source unknown	DECC	359032.69	6387271.70
20.81	Hunter River	Source unknown	DECC	360739.38	6384492.24
20.65	Hunter River	Source unknown	DECC	359630.03	6386162.35

19.49	Hunter River	Source unknown	DECC	360276.14	6385235.87
19.46	Hunter River	Source unknown	DECC	360288.33	6382529.55
19.34	Hunter River	Source unknown	DECC	363226.27	6383480.42
18.99	Hunter River	Source unknown	DECC	361641.49	6382139.45
18.95	Hunter River	Source unknown	DECC	361495.20	6381932.21
15.83	Hunter River	Source unknown	DECC	364420.95	6382529.55
15.81	Hunter River	Source unknown	DECC	364725.71	6382383.26
13.00	Hunter River	Source unknown	DECC	365542.48	6380213.33
12.10	Hunter River	Source unknown	DECC	364433.14	6377787.40
10.9	Hunter River floodplain	Figure 3	Oct98 Flood Study	364125.83	6376710.33
9.2	Hunter River floodplain	Figure 3	Oct98 Flood Study	365622.35	6378491.91
9.1	Hunter River floodplain	Figure 3	Oct98 Flood Study	365230.40	6377886.17
9.2	Hunter River floodplain	Figure 3	Oct98 Flood Study	365266.04	6377672.39
11	Hunter River floodplain	Figure 3	Oct98 Flood Study	365768.89	6376013.01
9.2	Hunter River floodplain	Figure 3	Oct98 Flood Study	366904.65	6378514.76
8.8	Hunter River floodplain	Figure 3	Oct98 Flood Study	366536.29	6378054.31
9.2	Hunter River floodplain	Figure 3	Oct98 Flood Study	366981.39	6378038.96
9	Hunter River floodplain	Figure 3	Oct98 Flood Study	367273.00	6377716.65
10.3	Hunter River floodplain	Figure 3	Oct98 Flood Study	367380.44	6376013.01
10.3	Hunter River floodplain	Figure 3	Oct98 Flood Study	367395.79	6375736.74
10.1	Hunter River floodplain	Figure 3	Oct98 Flood Study	367733.45	6376074.40
10.3	Hunter River floodplain	Figure 3	Oct98 Flood Study	367610.66	6375874.88
10.2	Hunter River floodplain	Figure 3	Oct98 Flood Study	367441.83	6375905.57
7.3	Hunter River floodplain	Figure 3	Oct98 Flood Study	371294.22	6378622.19
7.7,7.7,7.5	Paterson River	Figure 3	Oct98 Flood Study	369391.05	6383441.51
7.4	Paterson River	Figure 3	Oct98 Flood Study	371723.97	6380602.11
7.5	Paterson River floodplain	Figure 3	Oct98 Flood Study	372061.63	6380187.71
8.1	Paterson River floodplain	Figure 3	Oct98 Flood Study	372322.54	6379942.13
7.2	Paterson River	Figure 3	Oct98 Flood Study	373274.13	6379497.04

June 2007 level (mAHD)	Location	Comments	Source	x	y
30.86	Elderslie Bridge	Refer to Figure 11 - approx below bridge	Maitland Council	344900.81	6390545.83
29.79	New England Highway Lochinvar	Refer to Figure 11 - in paddock	Maitland Council	355536.10	6381004.07
27.90	122 Stanhope Road	Refer to Figure 11 - blade of bulldozer	Maitland Council	345067.64	6391358.67
26.08	674 Stanhope Road	Fence line	Maitland Council	350254.06	6391009.91
26.06	Intersection Mvale/Luskintyre	Refer to Figure 11 - bottom of P on sign	Maitland Council	353527.82	6390256.67
25.52	993 Luskintyre Road	Refer to Figure 11 - near starpickets	Maitland Council	353040.00	6388621.39
24.24	506 Stanhope Road	Fence line	Maitland Council	348501.03	6390688.40
23.24	255 Pywells Road	Refer to Figure 11 – fence line nearly opposite Greta Gauge	Maitland Council	350387.69	6384668.96
22.12	204 Luskintyre Road	Down from power pole near Luskintyre Bridge	Maitland Council	352825.57	6382502.64
20.70	342 Windemere Road	Refer to Figure 11 – fence line	Maitland Council	354696.42	6383913.92
18.88	90 Hillsborough Road	Refer to Figure 11 - top of steps	Maitland Council	356967.88	6386320.09
18.62	66 Hillsborough Road	Refer to Figure 11 – fence line	Maitland Council	357278.61	6387181.02
18.12	90 Hillsborough Road	Refer to Figure 11 – fence line near river	Maitland Council	357145.71	6386328.16
17.64	Hillsborough Road	Refer to Figure 11 - road	Maitland Council	357003.14	6387716.94
17.26	723 Anambah Road	Refer to Figure 11 - near shed	Maitland Council	358424.03	6386556.68
15.87	Hillsborough Road	Refer to Figure 11 - road	Maitland Council	356919.95	6387895.49
15.38	26 Daniel Avenue	Refer to Figure 11 – fence line	Maitland Council	360806.07	6380820.45
14.62	236 Melvilleford Road	Refer to Figure 11 - in shed	Maitland Council	361024.51	6382363.09
14.50	29 Bluegum Drive Aberglassyn	Refer to Figure 11 – fence line	Maitland Council	361755.06	6381736.09
14.41	96 Melvilleford Road	Refer to Figure 11 – fence line	Maitland Council	360680.21	6383880.96
13.13	Melville Ford bridge	South side - level taken in trees	Maitland Council	361811.32	6382248.10
12.40	Melville Ford bridge	North side - level taken in trees	Maitland Council	361775.85	6382304.85
12.28	Hunter River	Oakhampton Railway	DECC	365860.91	6381589.82
11.92	Hunter River	D/S Bolwarra	DECC	365540.70	6380211.92
11.81	Hunter River	U/S Bolwarra	DECC	365822.10	6381148.31
11.52	Near Oakhampton No 2 spillway	Level taken at a paint mark on pumphouse	Maitland Council	365206.94	6379765.56
10.70	Hunter River	Belmore Bridge	DECC	364429.65	6377786.05

9.58	Hunter River	Wallis Creek floodgate downstream	DECC	366447.97	6377009.77
8.22	Hunter River	McKimms Corner	DECC	368155.79	6378931.06
6.52	Hunter River	Morpeth bridge	DECC	371556.87	6378470.14
6.26	Hunter River	Wallis Creek floodgate Upstream	DECC	366428.57	6376936.99
5.91	Maitland Railway	Point 9 - WL @ 2:50 pm	Maitland Council	364220.95	6376863.40
5.90	Maitland Railway	Upstream of Cessnock Road	Maitland Council	364214.26	6376499.83
5.89	Maitland Railway	Point 19 - WL 2 headwall @ 2:50 pm	Maitland Council	364256.08	6376881.34

Appendix D

FIGURE D1

COMPARISON OF 1974 & CURRENT STREAMBANK VEGETATION
ZONE A

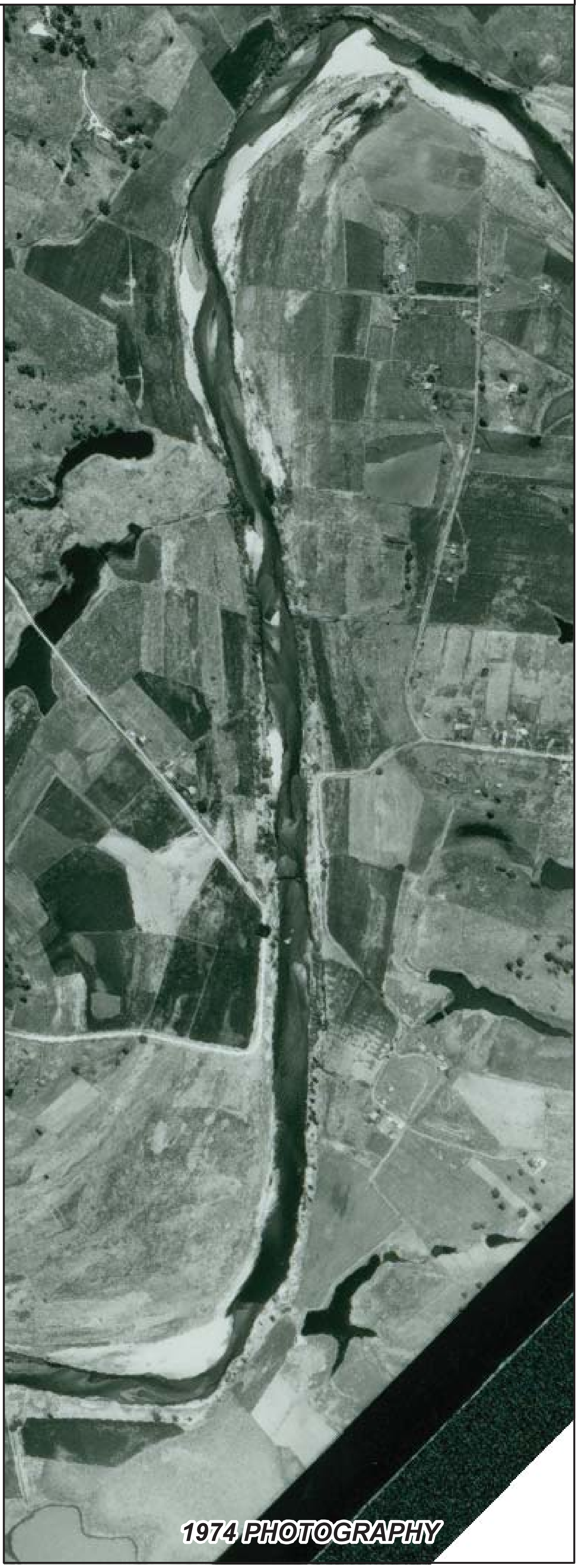


FIGURE D2

COMPARISON OF 1974 & CURRENT STREAMBANK VEGETATION ZONE B

FIGURE D3

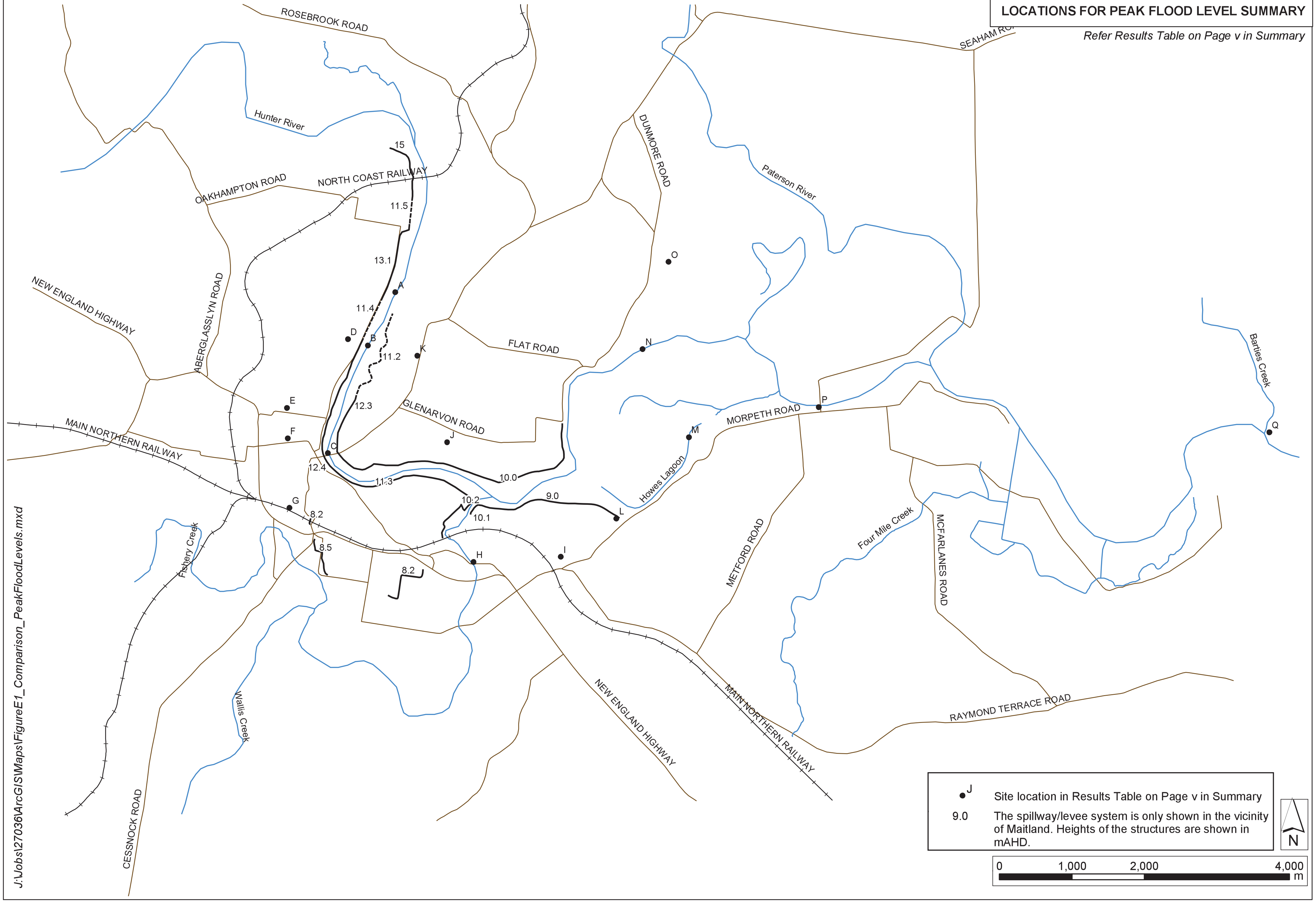
COMPARISON OF 1974 & CURRENT STREAMBANK VEGETATION ZONE C

Appendix E

FIGURE E1

LOCATIONS FOR PEAK FLOOD LEVEL SUMMARY

Refer Results Table on Page v in Summary



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Figures

FIGURE 1
HUNTER RIVER CATCHMENT

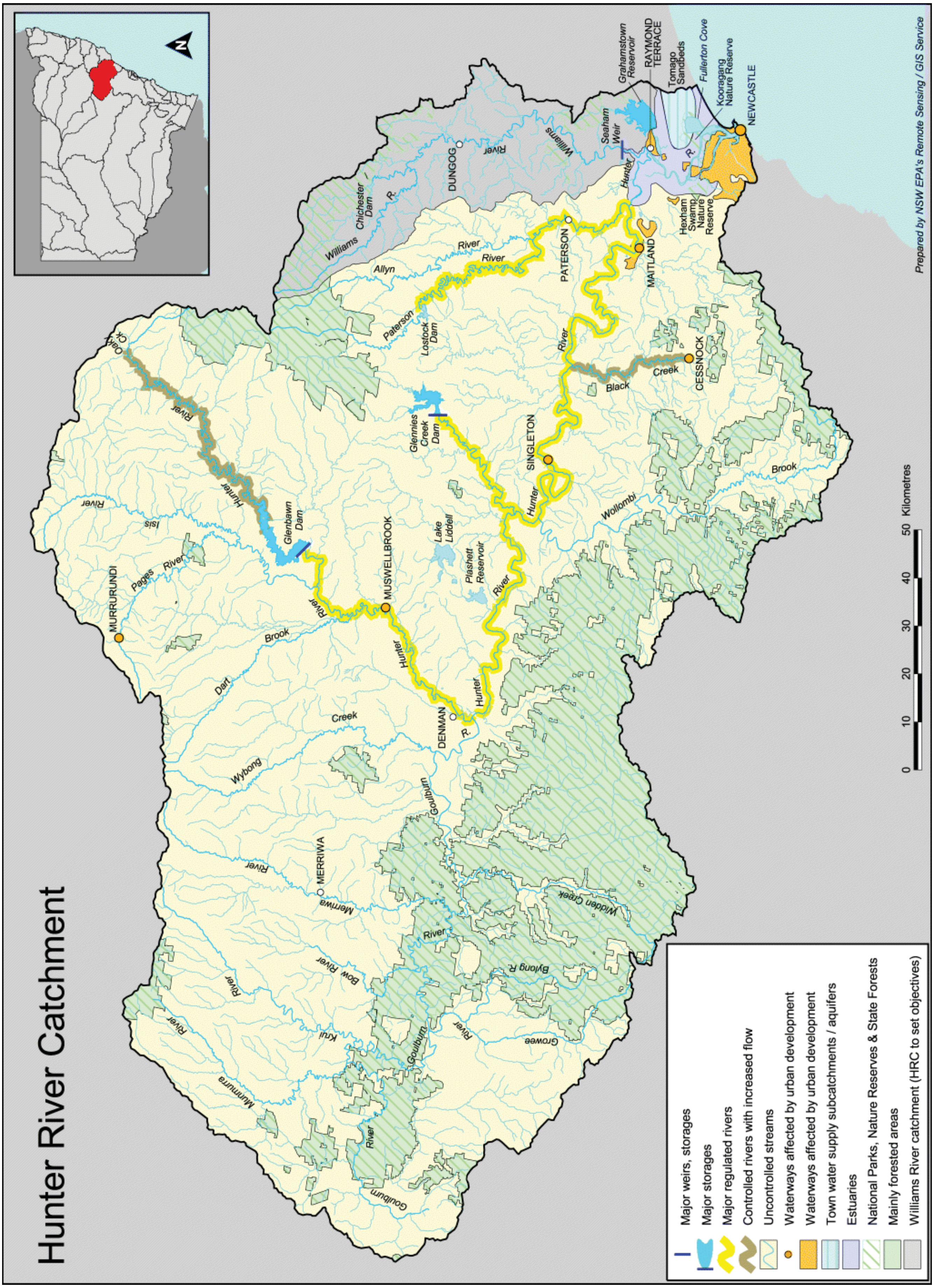

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FIGURE 2
STUDY AREA

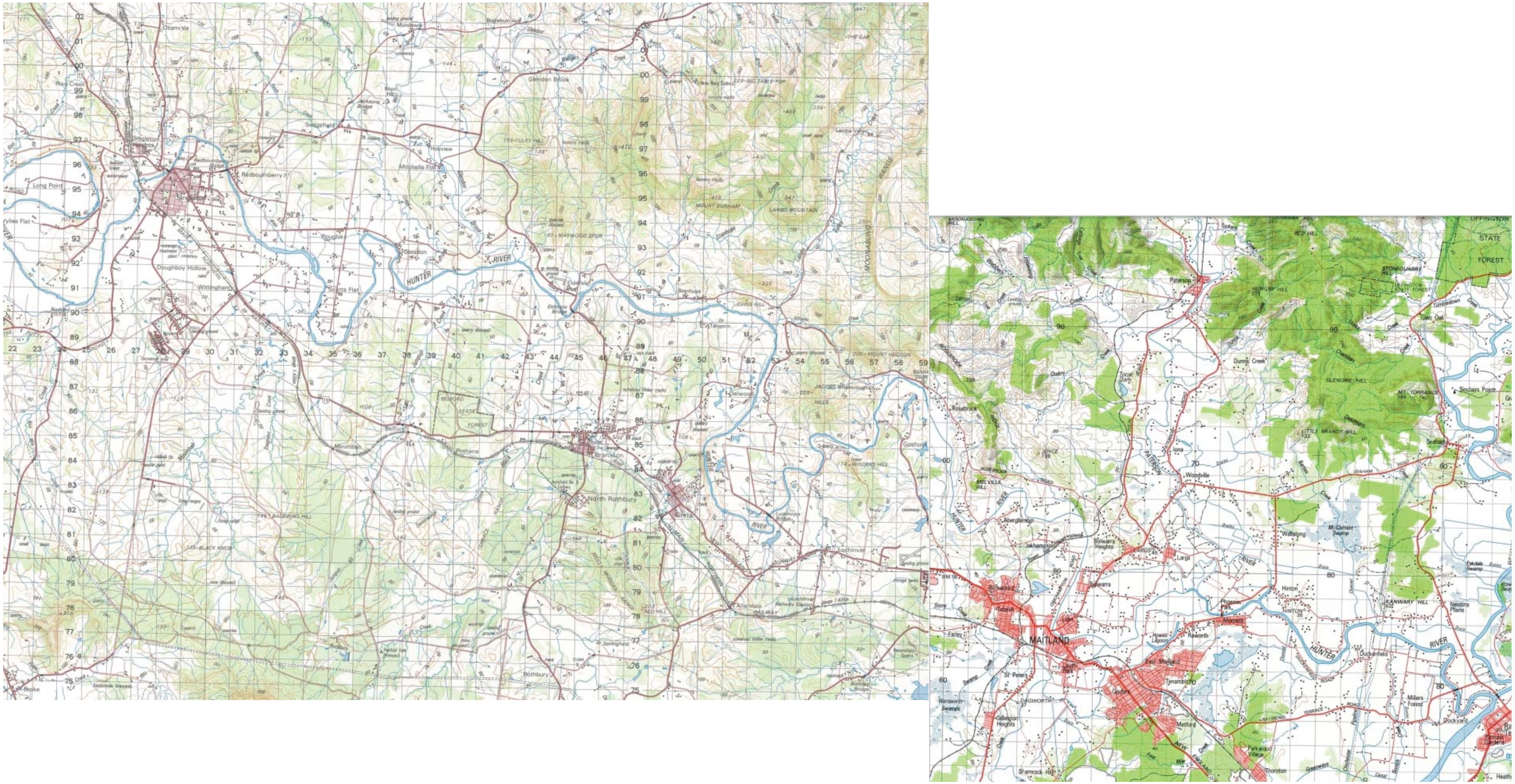

FIGURE 3
RAINFALL AND WATER LEVEL GAUGES

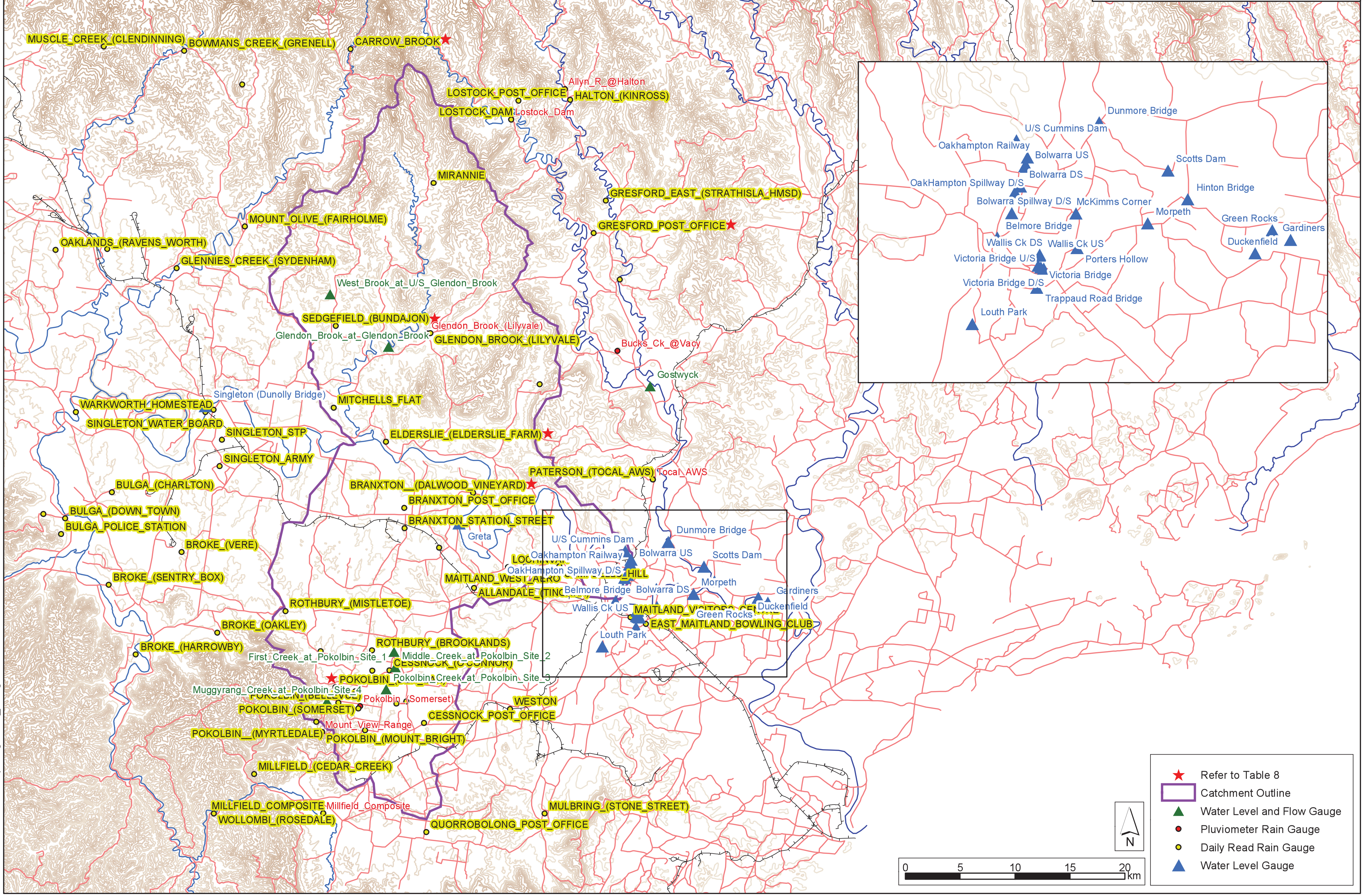

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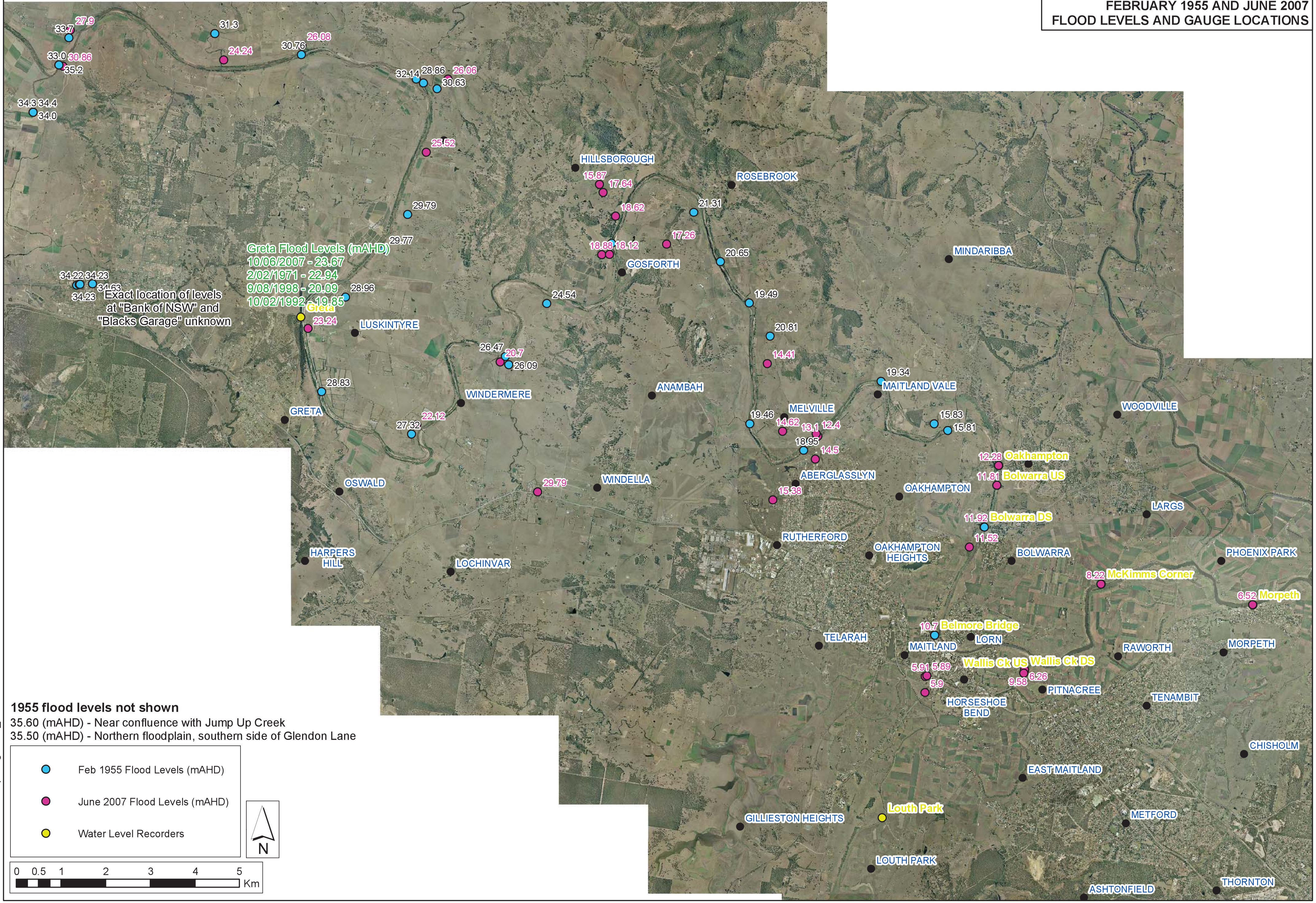
FIGURE 4
FEBRUARY 1955 AND JUNE 2007
FLOOD LEVELS AND GAUGE LOCATIONS



1955 flood levels not shown
35.60 (mAHD) - Near confluence with Jump Up Creek
35.50 (mAHD) - Northern floodplain, southern side of Glendon Lane

Feb 1955 Flood Levels (mAHD)
June 2007 Flood Levels (mAHD)
Water Level Recorders

N

0 0.5 1 2 3 4 5 Km

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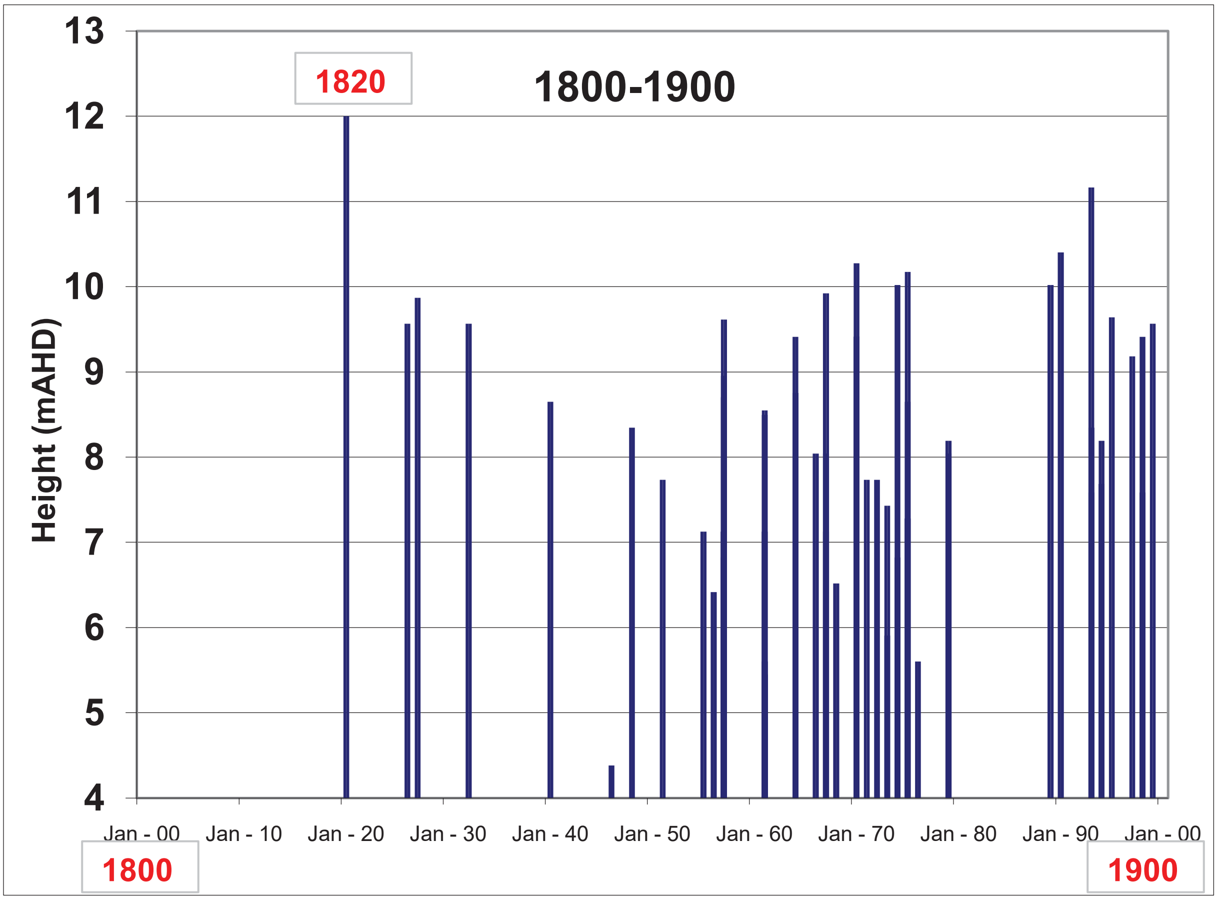
FIGURE 5

FLOOD RECORDS AT MAITLAND



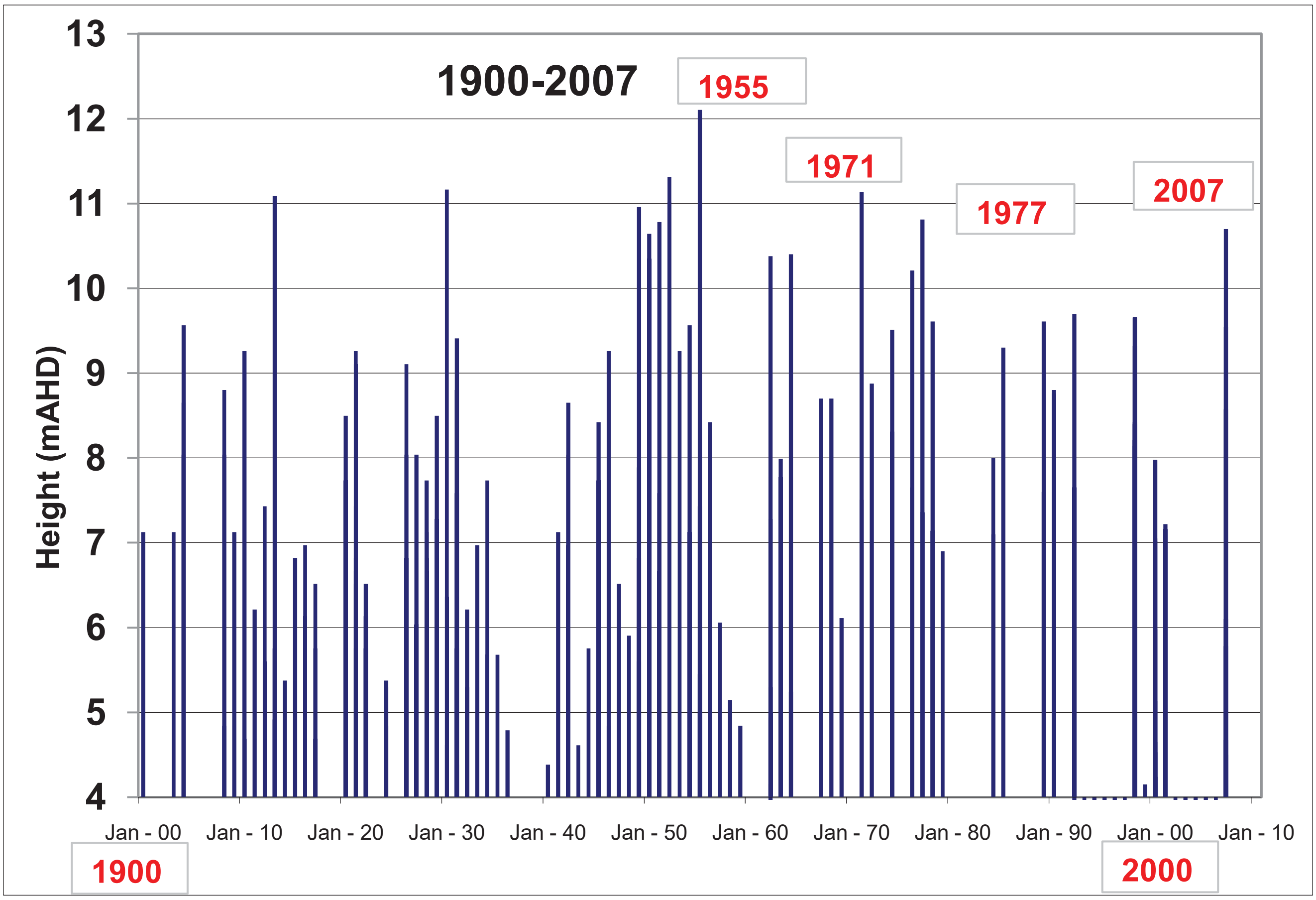
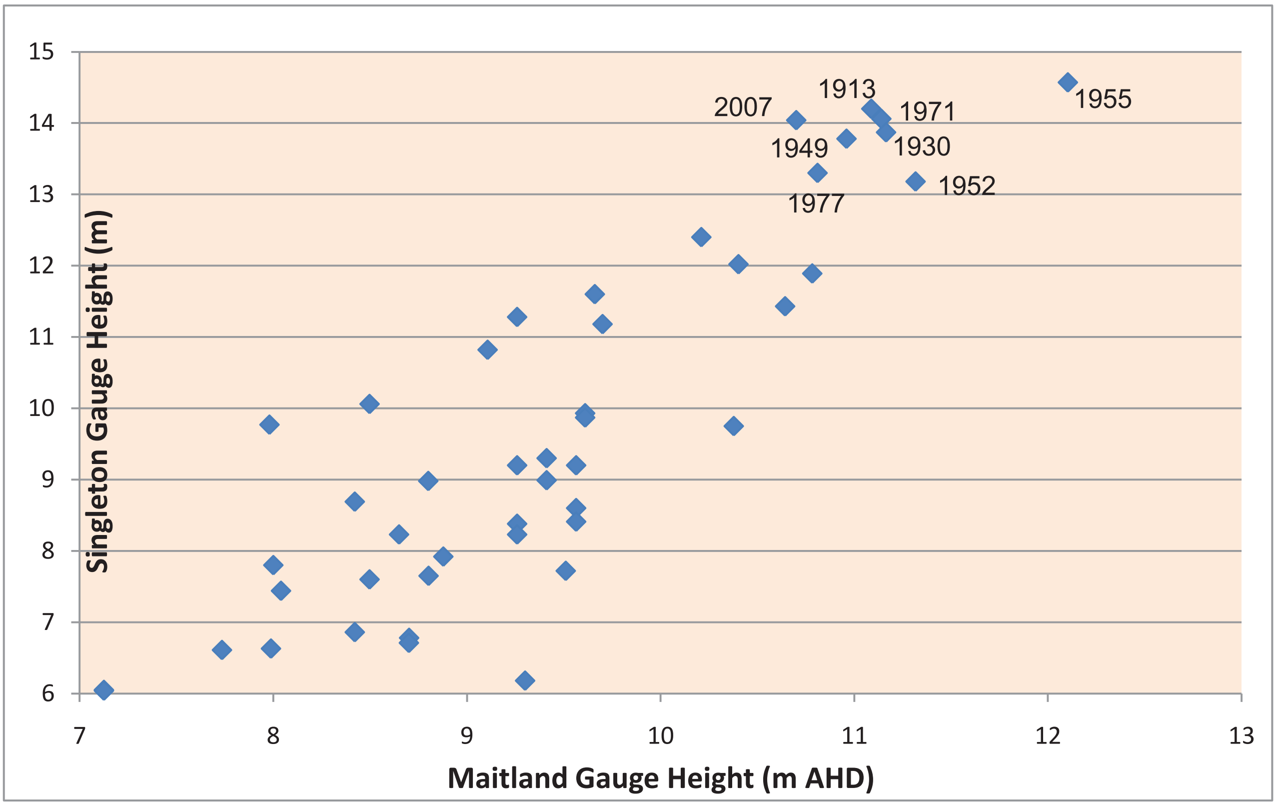


FIGURE 6
FLOOD RECORDS AT SINGLETON



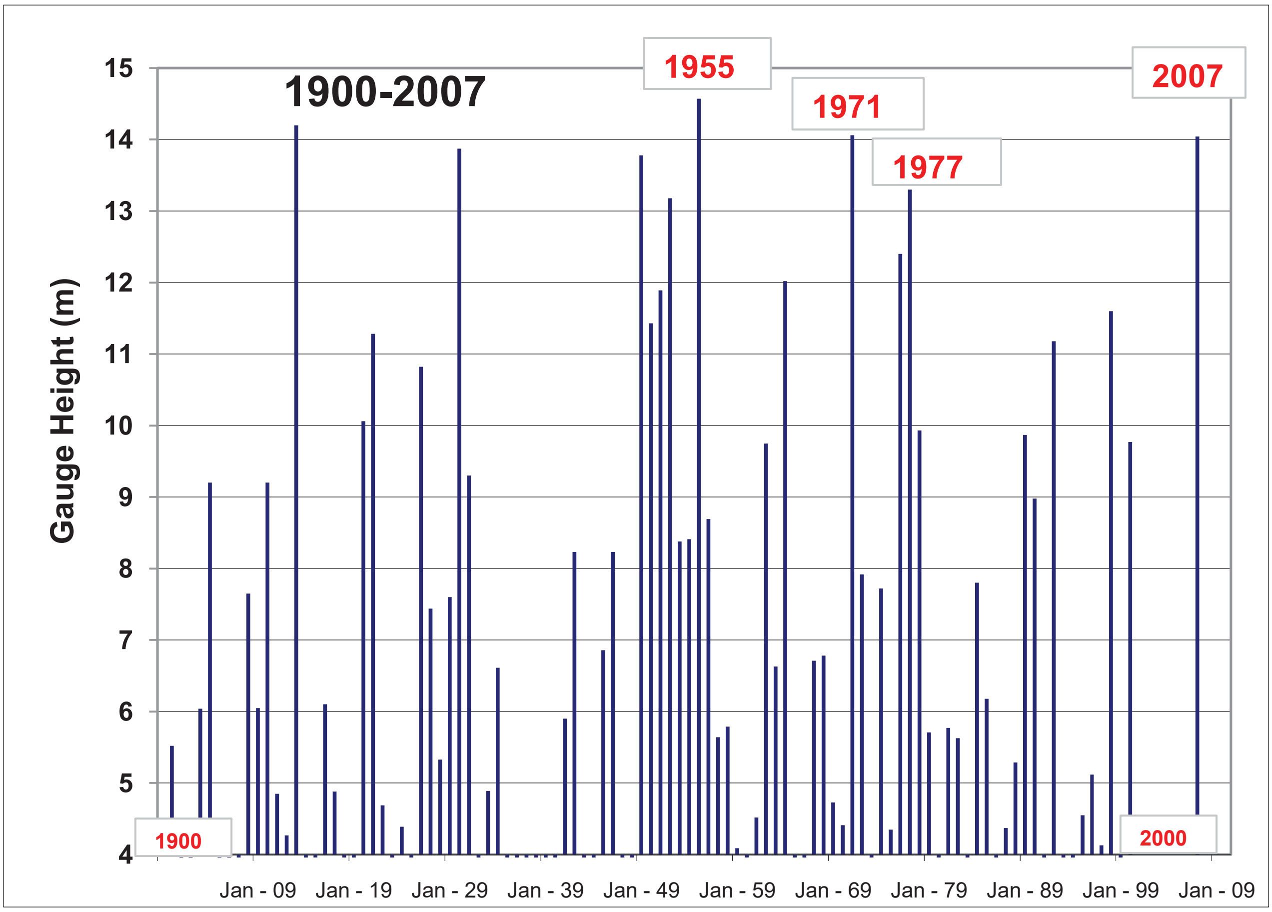


FIGURE 7
FLOOD RECORDS AT GRETA

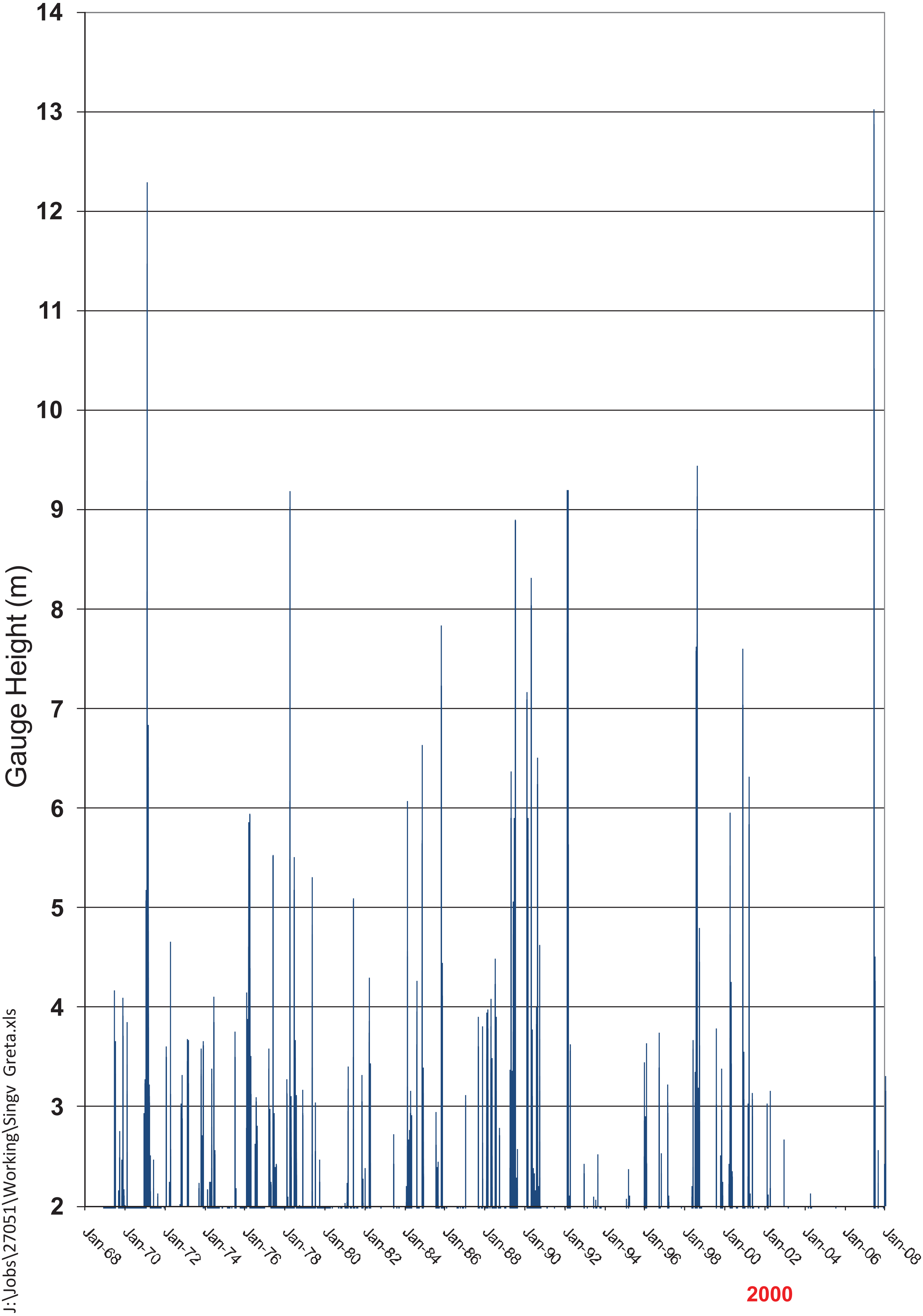


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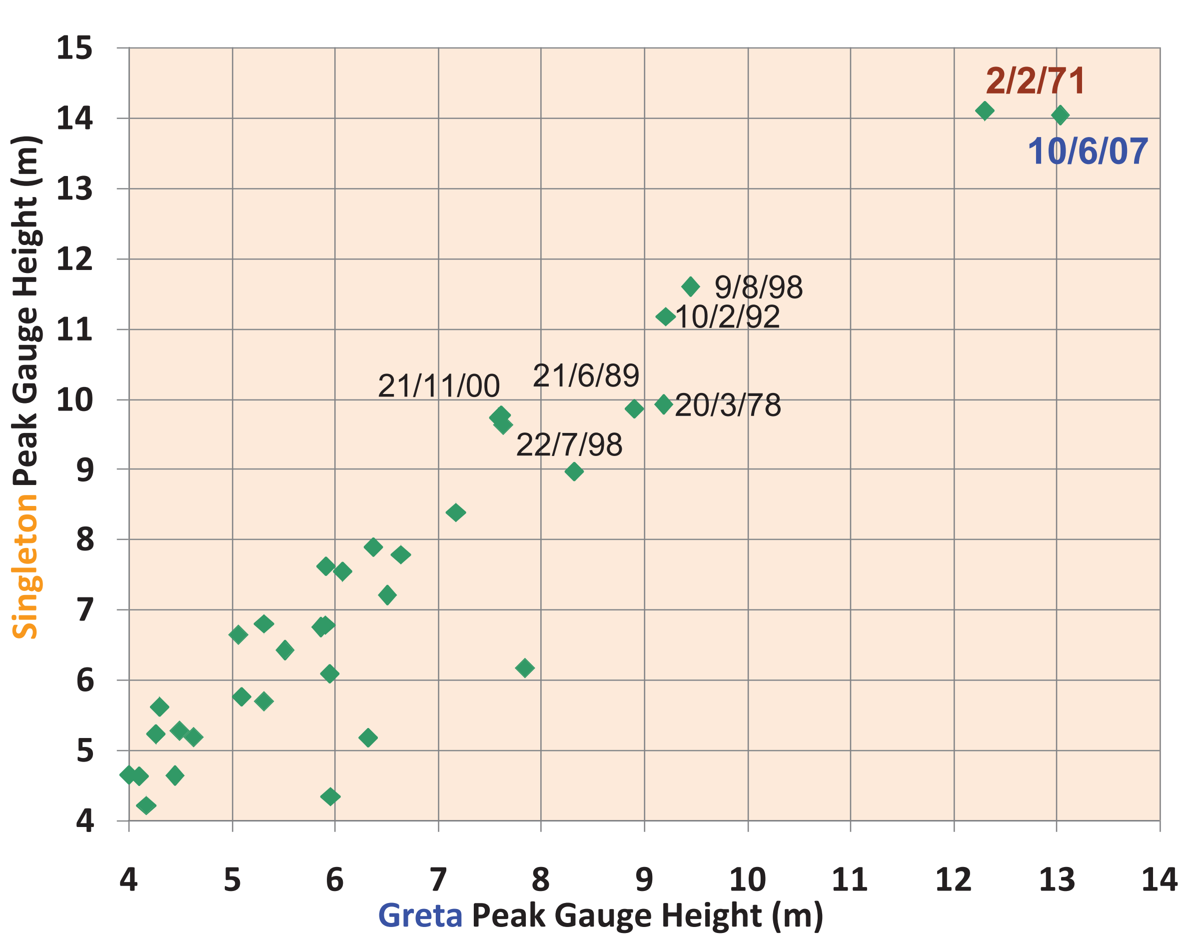
FIGURE 8

COMPARISON OF RECORDED PEAK GAUGE HEIGHTS



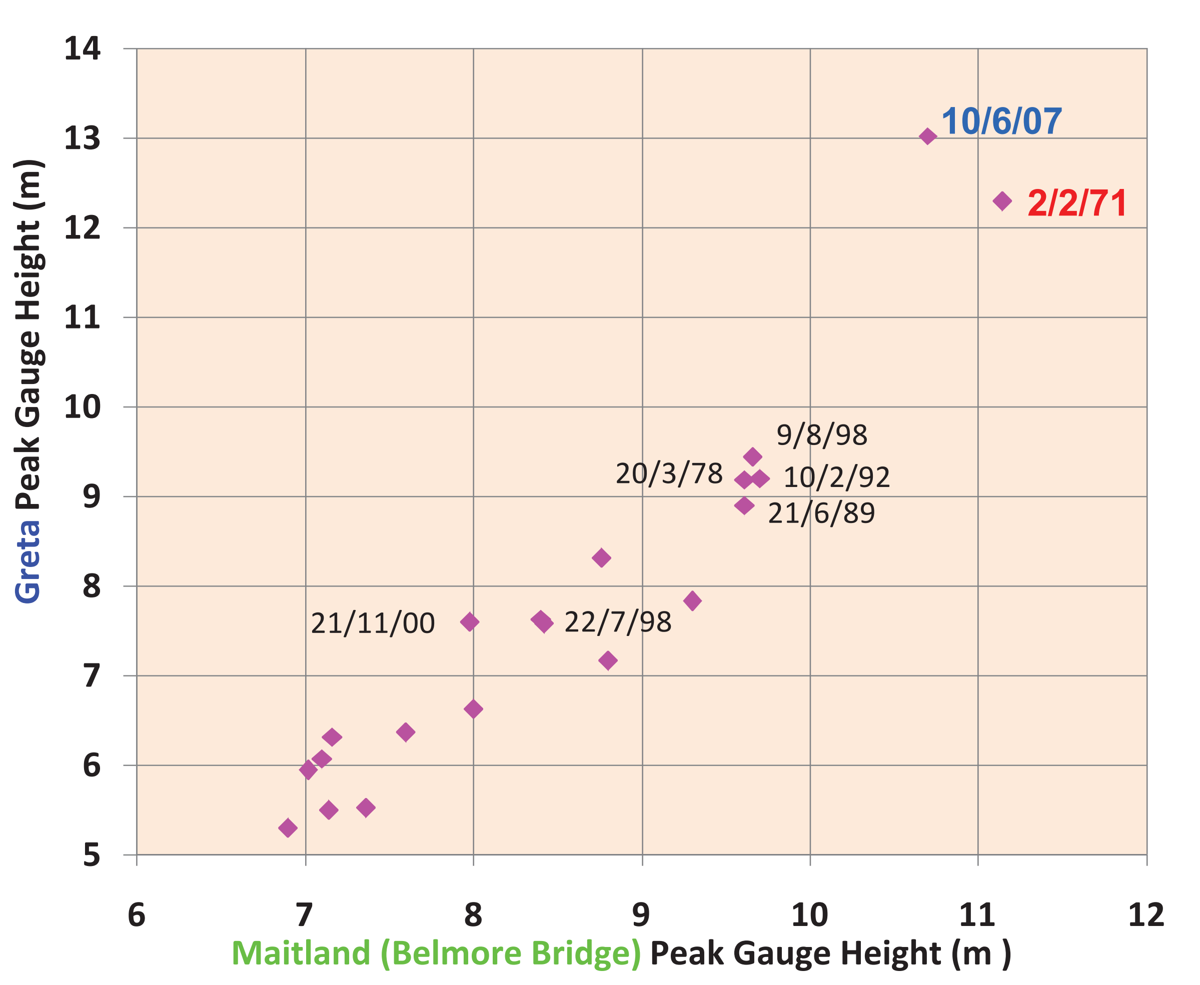
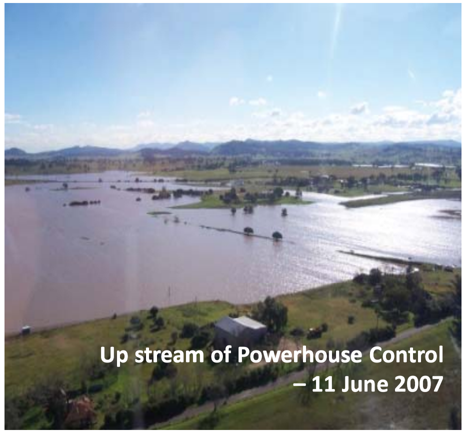
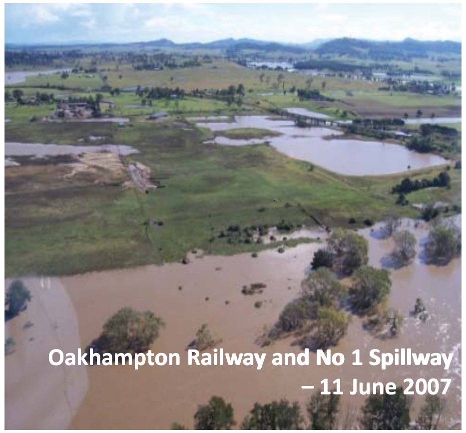


FIGURE 9
JUNE 2007 FLOOD PHOTOGRAPHS
SET A


Up stream of Powerhouse Control – 11 June 2007


Oakhampton Railway and No 1 Spillway – 11 June 2007


Oakhampton Road Control – 11 June 2007


Powerhouse Control – 11 June 2007


Mt Pleasant Street Control – 11 June 2007


New England Highway - 11 June 2007


View to Fishery Creek – 11 June 2007


East Maitland – 11 June 2007


Melbourne Street, East Maitland – 11 June 2007


Down stream of East Maitland Railway Line – 11 June 2007


No Overtopping of the Bolwarra Spillway – 10 June 2007


Overtopping of the Oakhampton Spillway No.1 – 10 June 2007

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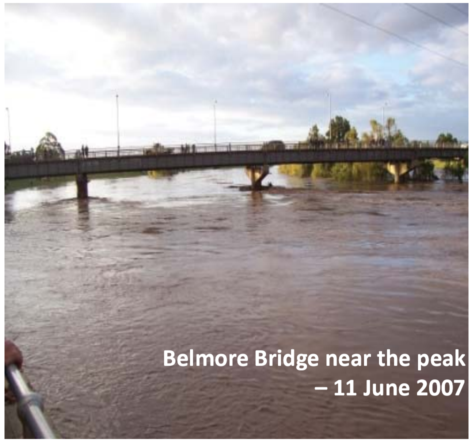
FIGURE 9
JUNE 2007 FLOOD PHOTOGRAPHS
SET B

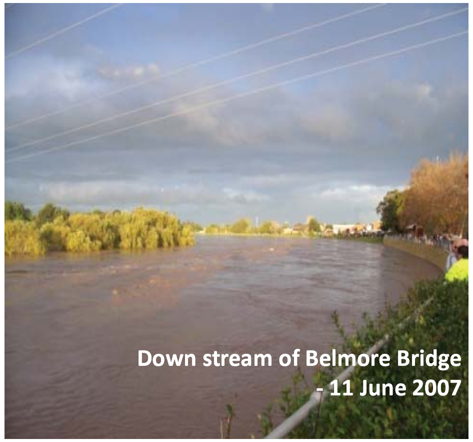

Oakhampton Road Failure – 13 June 2007


Erosion down stream of Belmore Bridge – 11 June 2007


Long Bridge – 11 June 2007


Long Bridge – 11 June 2007


Belmore Bridge near the peak – 11 June 2007


Down stream of Belmore Bridge – 11 June 2007


View to East Maitland – 11 June 2007


Wallis Creek – 11 June 2007


Maitland Railway Station – 11 June 2007


New England Highway – 11 June 2007


Mt Pleasant Street Control – 11 June 2007


Powerhouse Control – 11 June 2007

FIGURE 9
JUNE 2007 FLOOD PHOTOGRAPHS
SET C


Hunter River at Melville Ford Bridge – 13 June 2007


Oakhampton Road – 13 June 2007


Maitland Railway Station – 13 June 2007

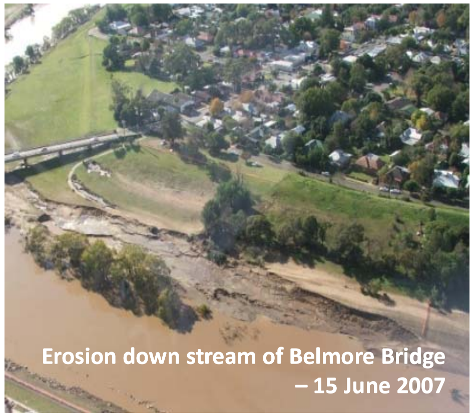

Wallis Creek Floodgates – 13 June 2007


Looking down stream towards Melville Ford Bridge – 15 June 2007


Oakhampton Floodway – 15 June 2007


Oakhampton Floodway – 15 June 2007


Long Bridge – 15 June 2007


Erosion down stream of Belmore Bridge – 15 June 2007


Hunter River & Oakhampton Floodway in background – 15 June 2007


Oakhampton Floodway – 15 June 2007


Wallis Creek Floodgates – 15 June 2007

FIGURE 9
JUNE 2007 FLOOD PHOTOGRAPHS
SET D

Hunter River at Luskintyre Bridge
– 13 June 2007

Branxton
– 13 June 2007

Singleton
– 12 June 2007

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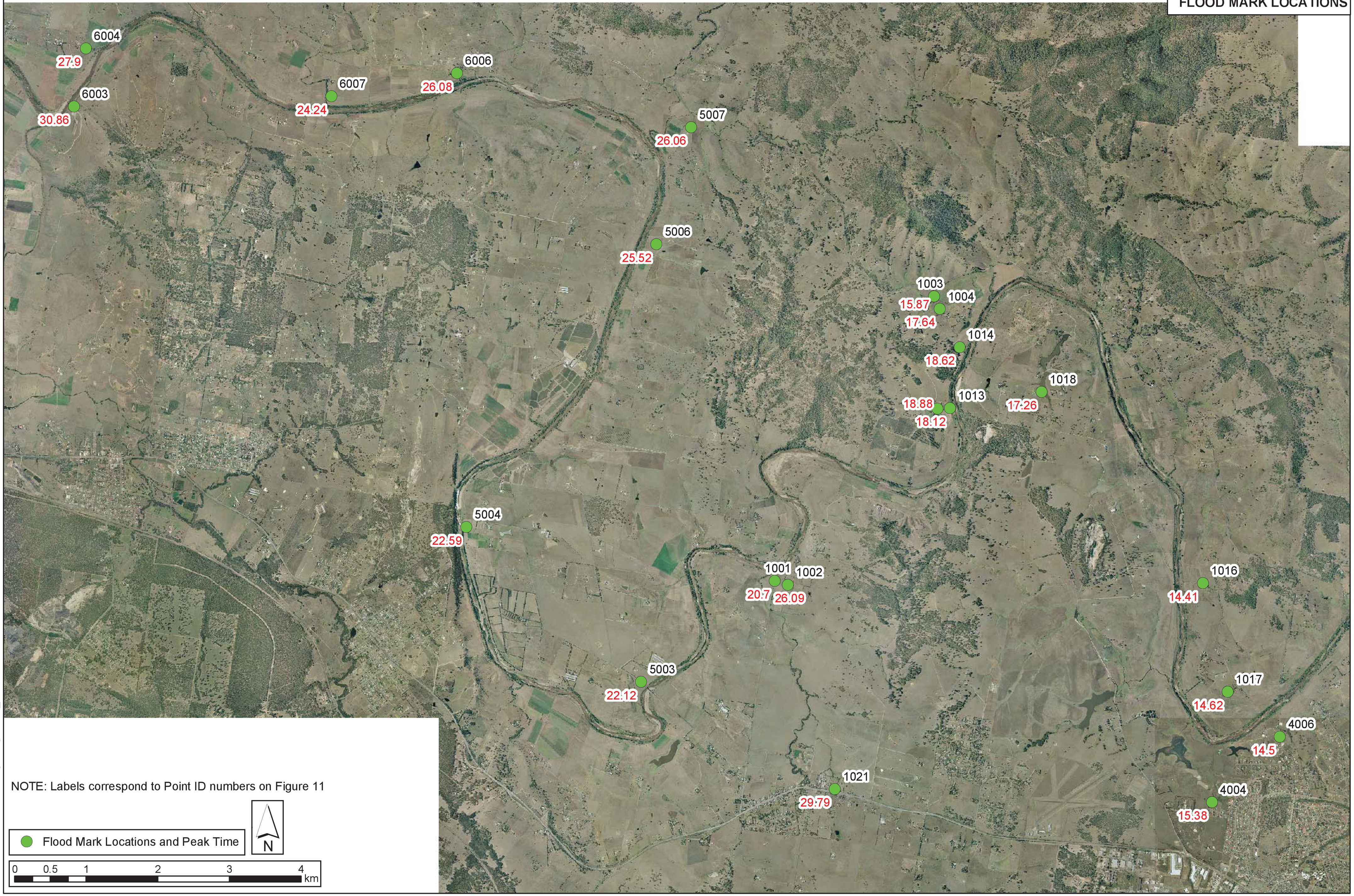
FIGURE 10

JUNE 2007

FLOOD MARK LOCATIONS



NOTE: Labels correspond to Point ID numbers on Figure 11

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1.90 Hillsborough Rd

1.90 Hillsborough Rd 2

26 Daniel Av

29 Blue Gum Dr Aberglasslyn

66 Hillsborough Rd, White spray painted dot location of peak flood level

66 Hillsborough Rd


96 Melville Ford Rd, Peak flood level located at 'notch' half way between gate and post


236 Melville Ford Rd, Black texta mark on shed door location of peak level, roughly peaked midnight 10.11-06-07


122 Stanhope Rd


674 Stanhope Rd


255 Pywells Rd

723 Anambah Rd

993 Luskintyre Rd, 'teepee' shaped stakes location of peak flood level


Elderslie Bridge

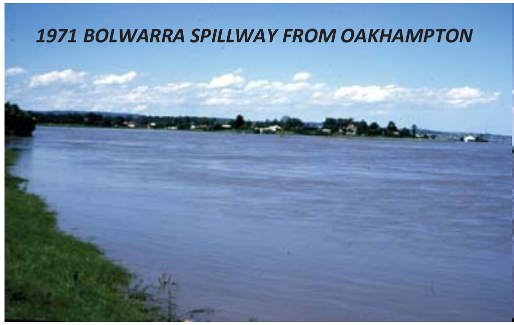
Intersection Maitvale Luskintyre

St Joseph Lochinvar

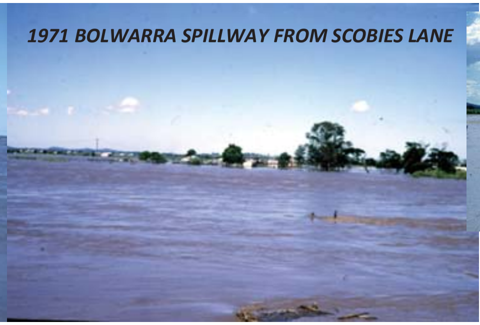
FIGURE 12

AERIAL PHOTOGRAPHS

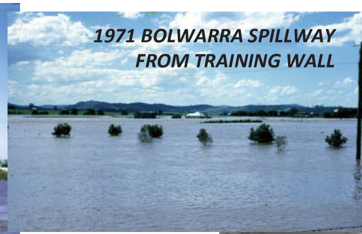
JAN/FEB 1971 & MARCH 1977 FLOODS



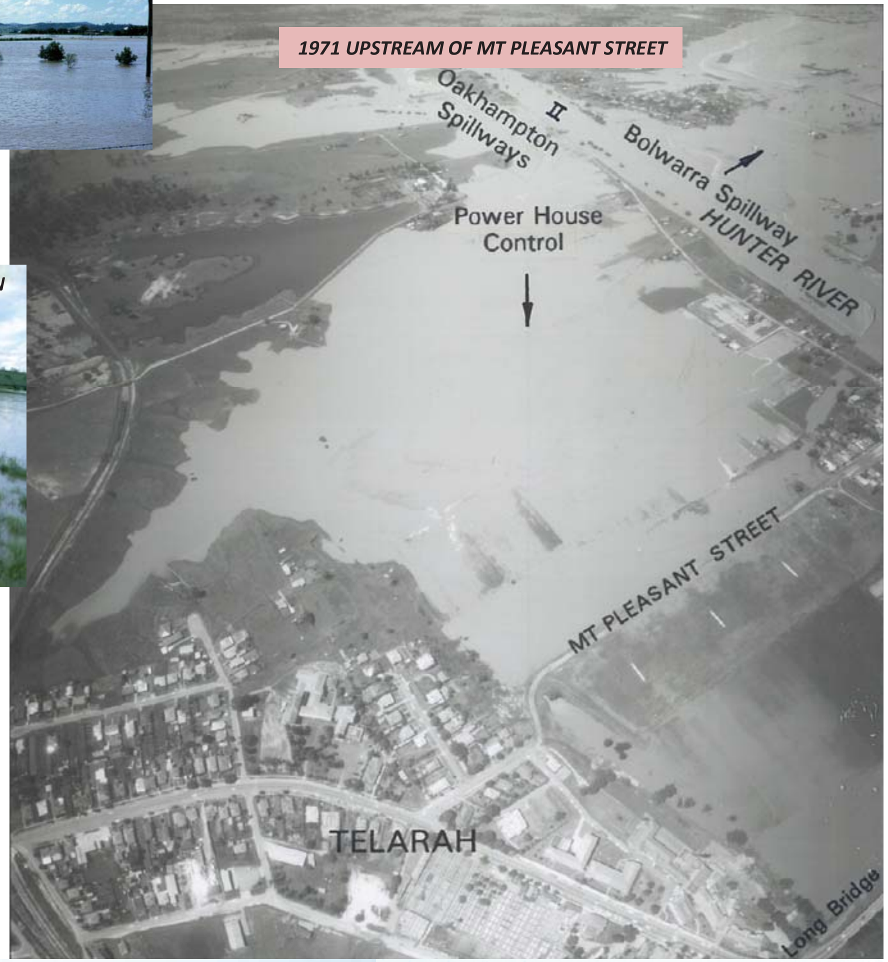
1971 BOLWARRA SPILLWAY FROM OAKHAMPTON



1971 BOLWARRA SPILLWAY FROM SCOBIES LANE

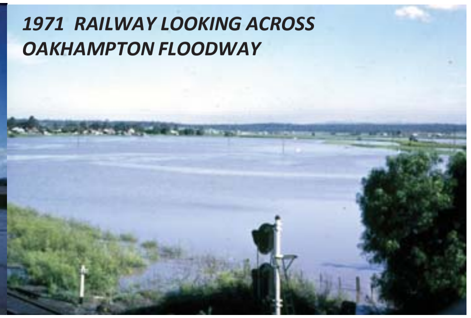


1971 BOLWARRA SPILLWAY FROM TRAINING WALL

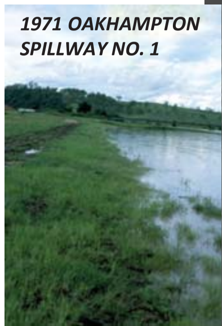


1971 UPSTREAM OF MT PLEASANT STREET

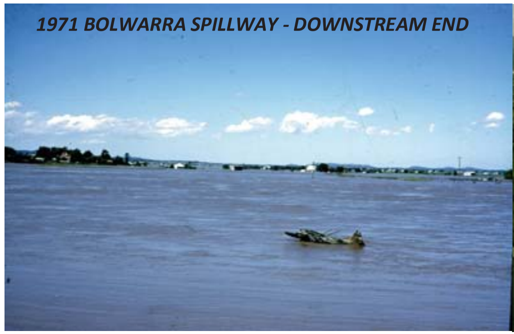
1971 POWERHOUSE CONTROL OVERTOPPING



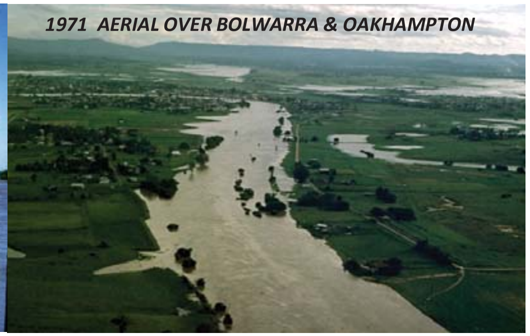
1971 RAILWAY LOOKING ACROSS OAKHAMPTON FLOODWAY



1971 OAKHAMPTON SPILLWAY NO. 1

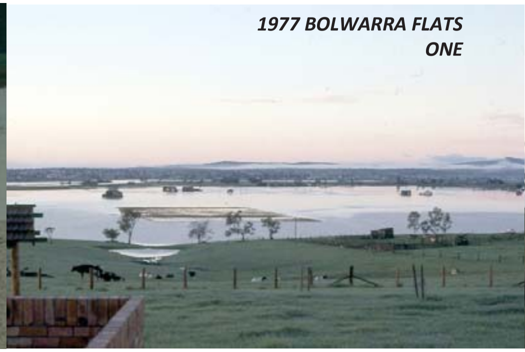


1971 BOLWARRA SPILLWAY - DOWNSTREAM END



1971 AERIAL OVER BOLWARRA & OAKHAMPTON

OAKHAMPTON ROAD 1977 FLOOD

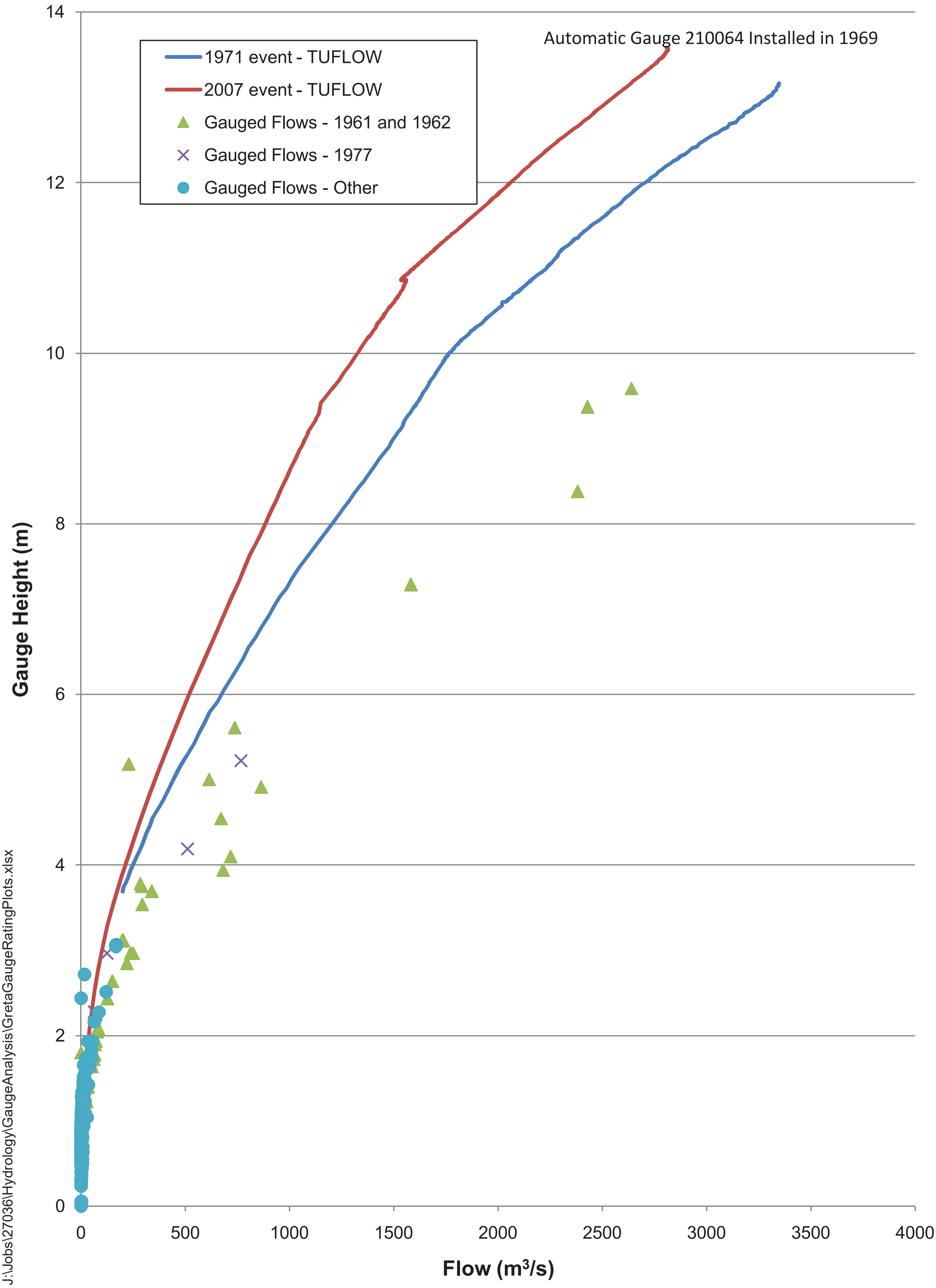


1977 BOLWARRA FLATS ONE

1977 BOLWARRA FLATS TWO

1977 BOLWARRA FLATS THREE

FIGURE 13
FLOW GAUGINGS AT GRETA



J:\Jobs\27036\Hydrology\GaugeAnalysis\GretaGaugeRatingPlots.xlsx

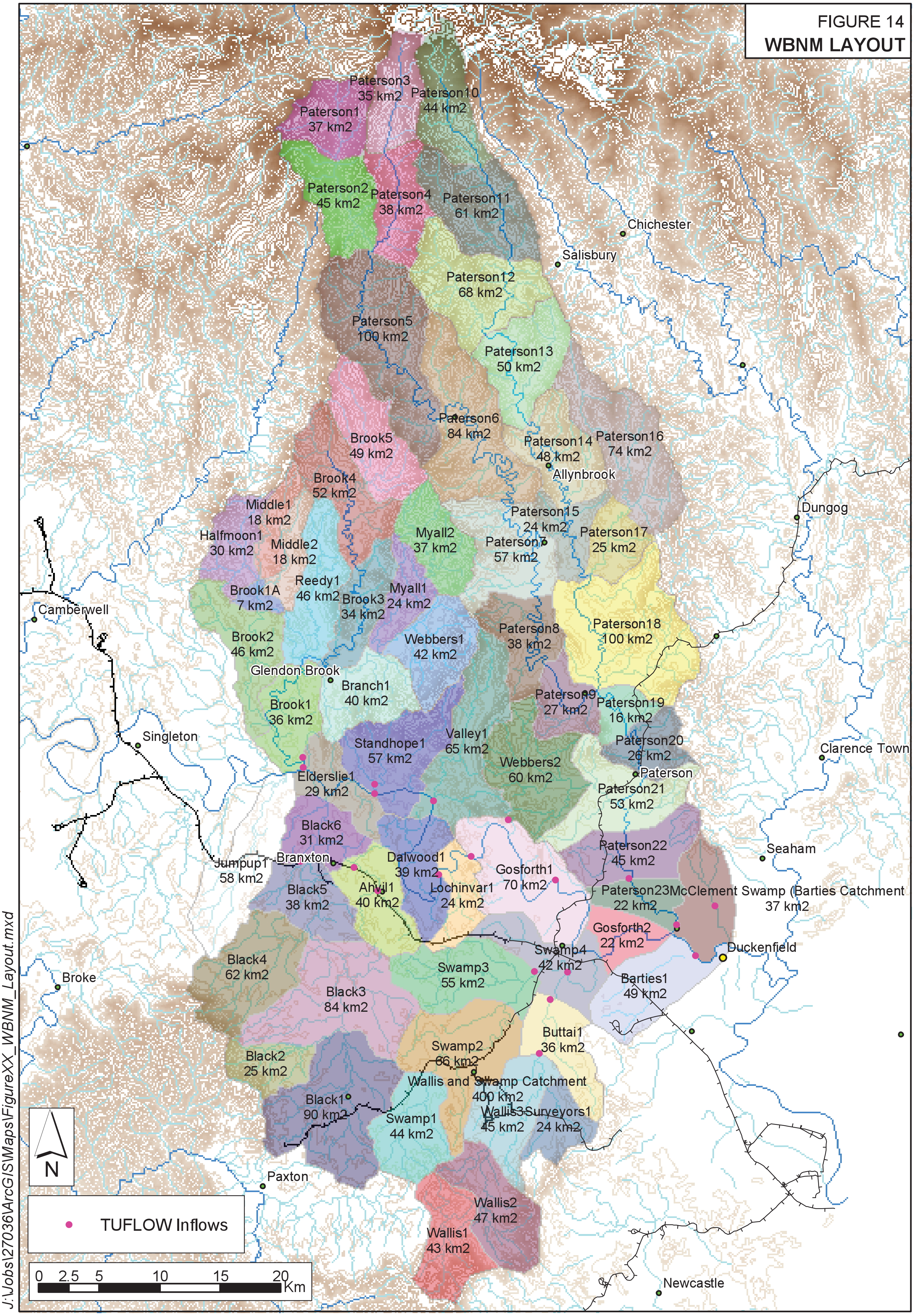


FIGURE 14
WBNM LAYOUT
Paterson3 35 km2
Paterson10 44 km2
Paterson1 37 km2
Paterson2 45 km2
Paterson4 38 km2
Paterson11 61 km2
Chichester
Salisbury
Paterson12 68 km2
Paterson5 100 km2
Paterson13 50 km2
Paterson6 84 km2
Brook5 49 km2
Paterson14 48 km2
Paterson16 74 km2
Allynbrook
Brook4 52 km2
Middle1 18 km2
Dungog
Paterson15 24 km2
Halfmoon1 30 km2
Middle2 18 km2
Myall2 37 km2
Paterson7 57 km2
Paterson17 25 km2
Reedy1 46 km2
Brook1A 7 km2
Brook3 34 km2
Myall1 24 km2
Camberwell
Paterson18 100 km2
Brook2 46 km2
Webbers1 42 km2
Paterson8 38 km2
Glendon Brook
Branch1 40 km2
Brook1 36 km2
Paterson9 27 km2
Paterson19 16 km2
Singleton
Valley1 65 km2
Standhope1 57 km2
Paterson20 26 km2
Clarence Town
Elderslie1 29 km2
Webbers2 60 km2
Paterson
Paterson21 53 km2
Black6 31 km2
Paterson22 45 km2
Seaham
Jumpup1 58 km2
Branxton
Dalwood1 39 km2
Gosforth1 70 km2
Black5 38 km2
Anvil1 40 km2
Lochinvar1 24 km2
Paterson23 22 km2
McClement Swamp (Barties Catchment 37 km2
Gosforth2 22 km2
Duckenfield
Swamp4 42 km2
Black4 62 km2
Swamp3 55 km2
Barties1 49 km2
Broke
Black3 84 km2
Buttai1 36 km2
Swamp2 66 km2
Black2 25 km2
Wallis and Swamp Catchment 400 km2
Black1 90 km2
Swamp1 44 km2
Wallis3 45 km2
Surveyors1 24 km2
N
Paxton
Wallis2 47 km2
TUFLOW Inflows
Wallis1 43 km2
0 2.5 5 10 15 20 Km
Newcastle
J:\Jobs\27036\ArcGIS\Maps\FigureXX_WBNM_Layout.mxd

FIGURE 15

HISTORICAL PEAK HEIGHT PROFILES UPSTREAM OF OAKHAMPTON

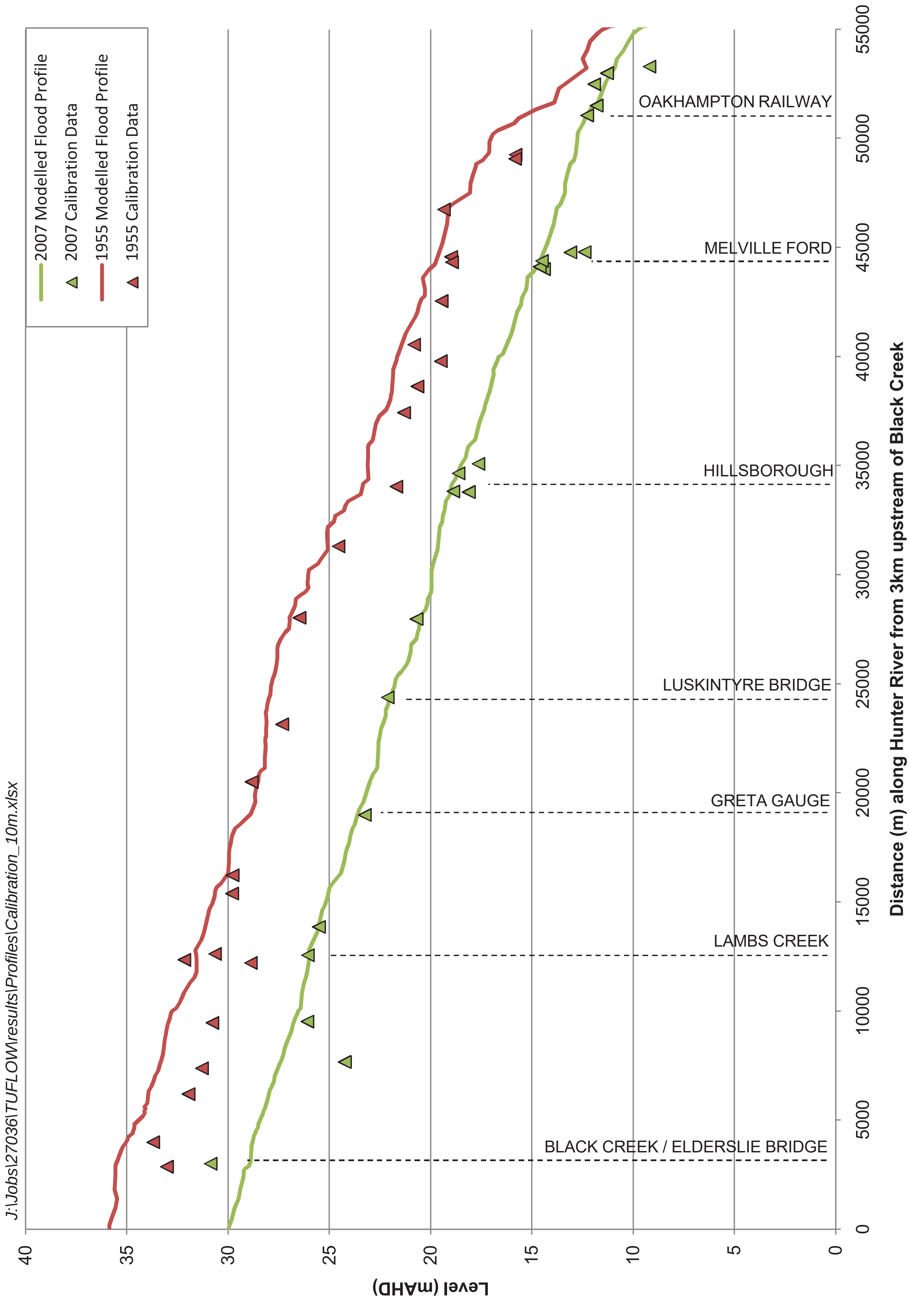


FIGURE 16
HISTORICAL PEAK HEIGHT PROFILES
DOWNSTREAM OF OAKHAMPTON

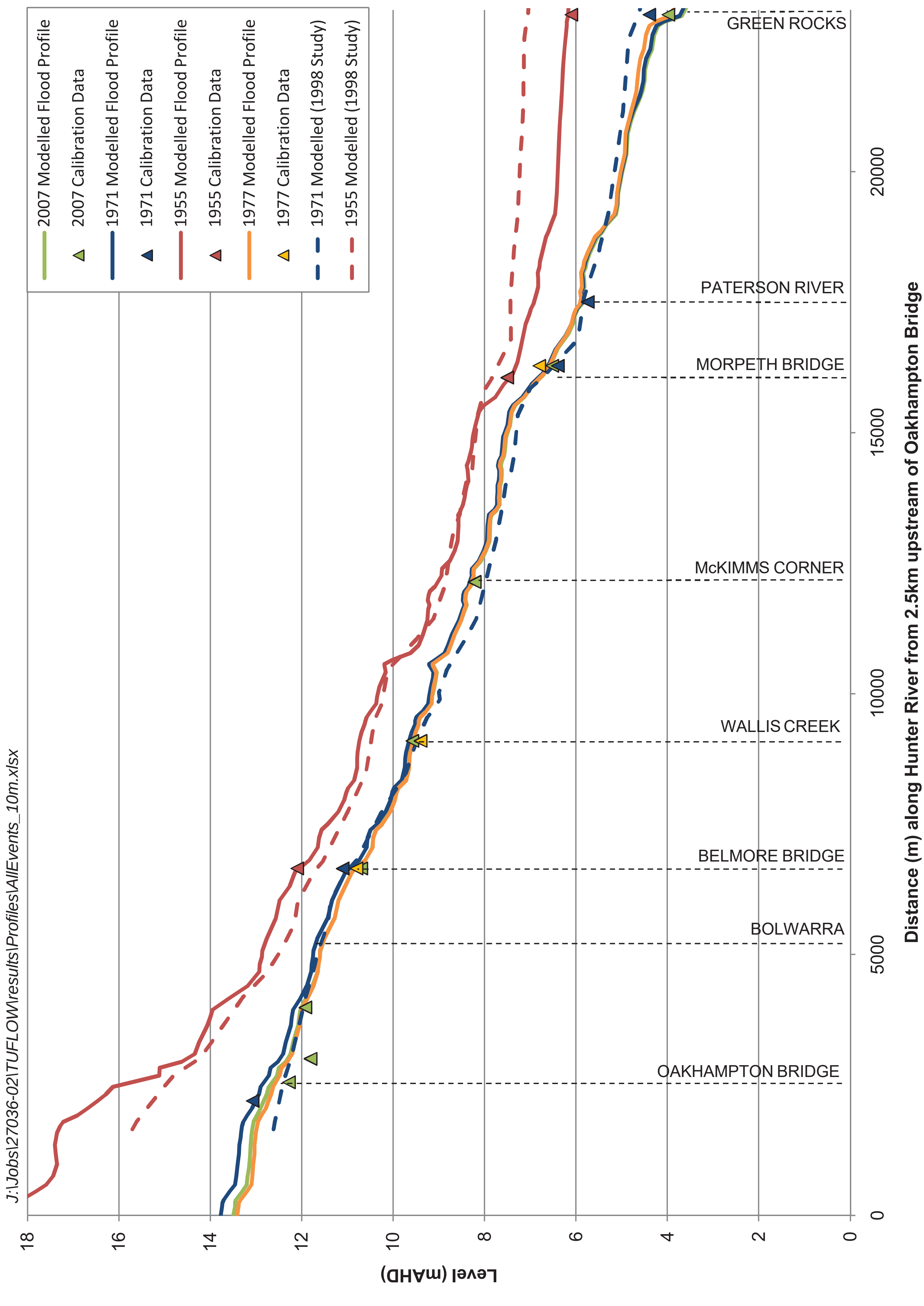


FIGURE 17a
STAGE HYDROGRAPH
1971 EVENT
GRETA GAUGE

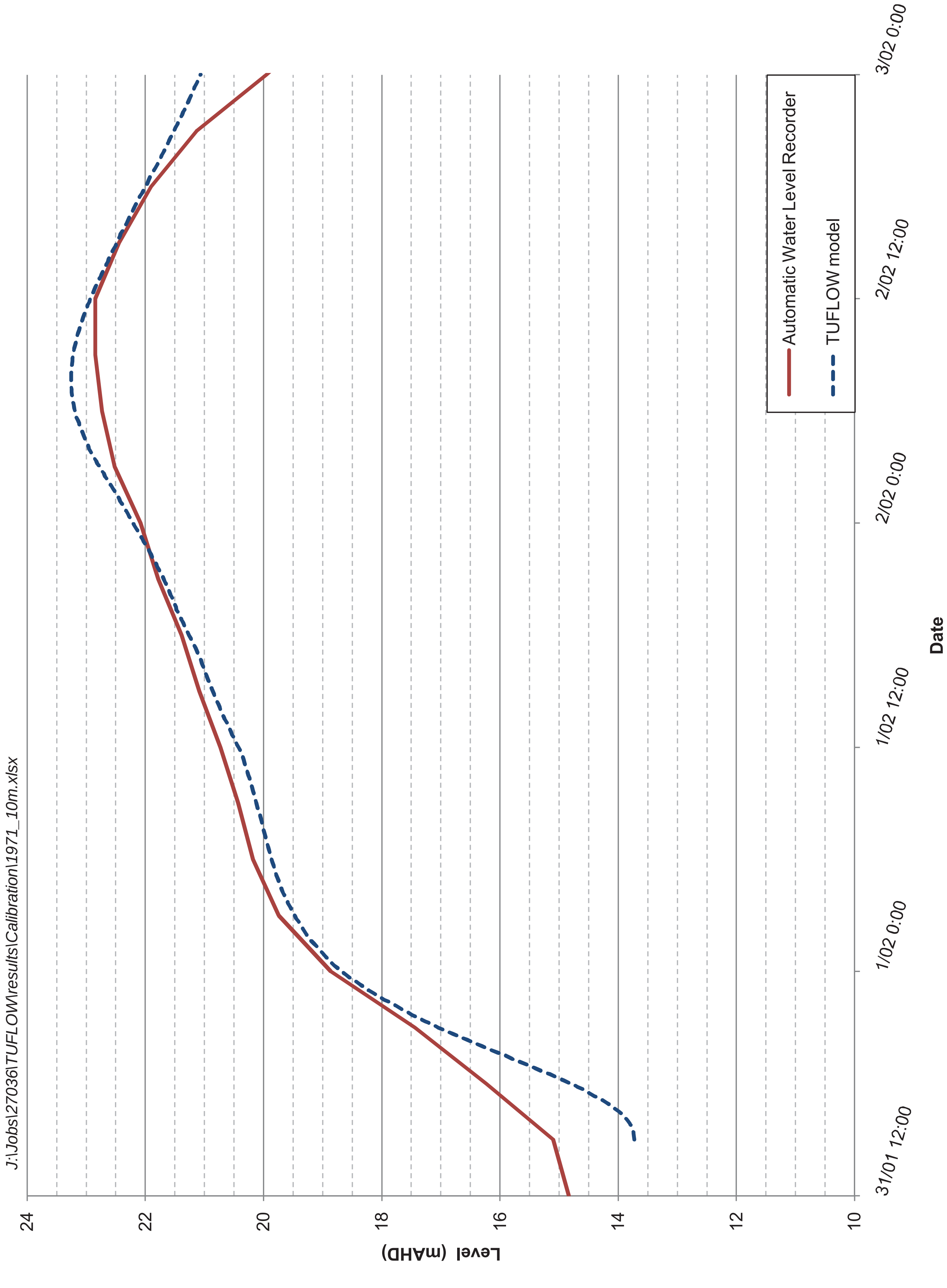


FIGURE 17b

STAGE HYDROGRAPH
JUNE 2007 EVENT
GRETA GAUGE

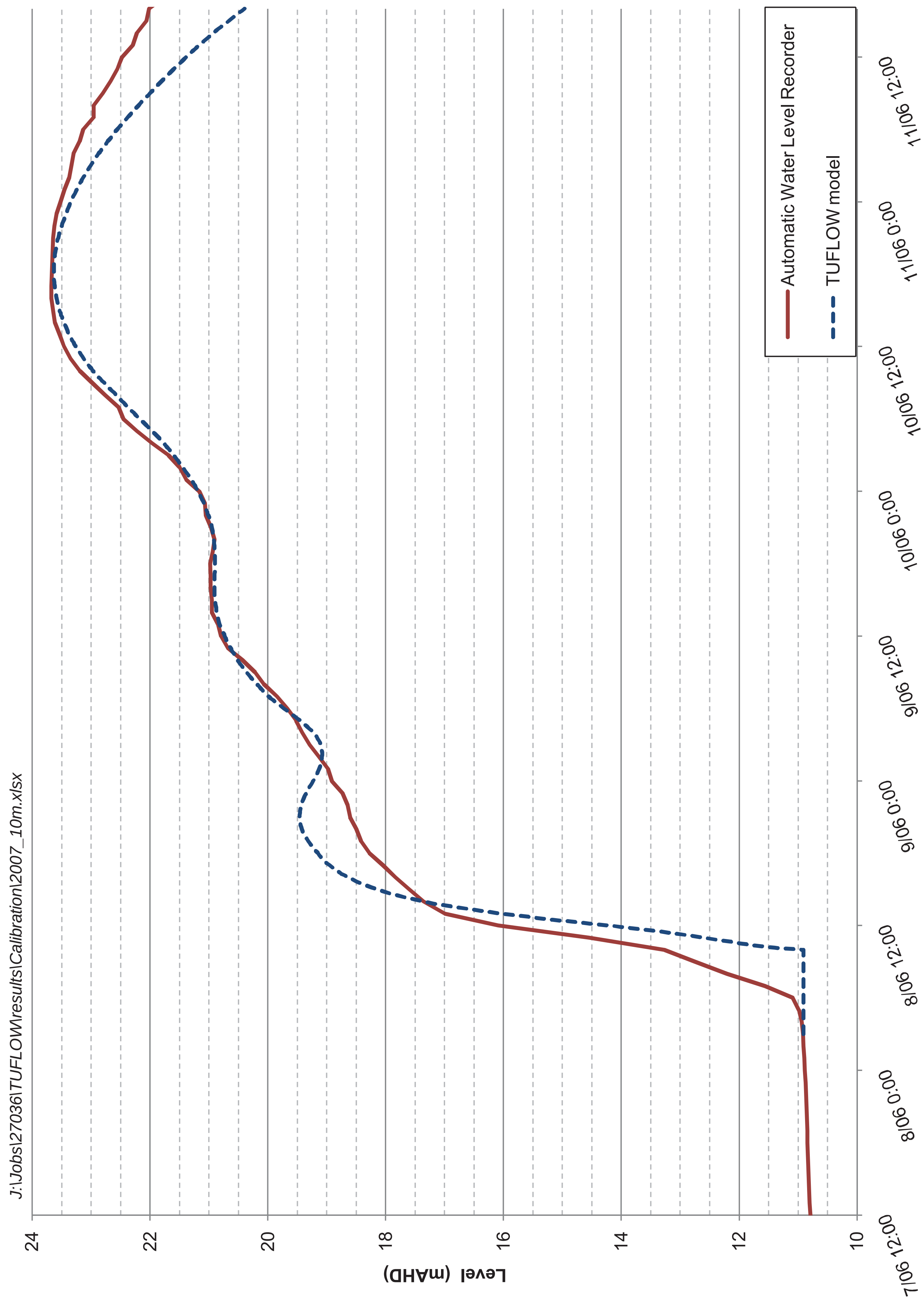


FIGURE 18

STAGE HYDROGRAPHS

FEBRUARY 1955

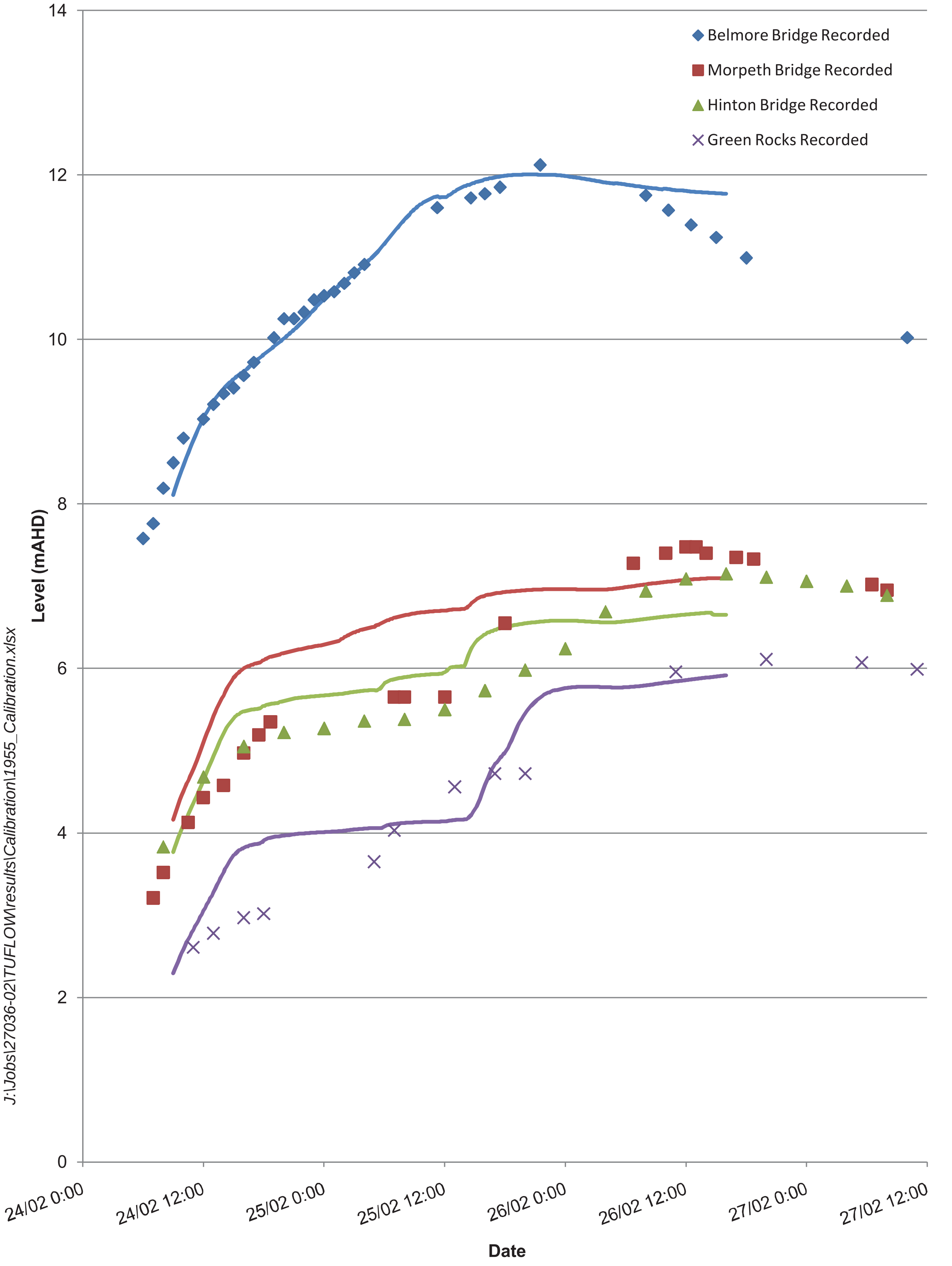
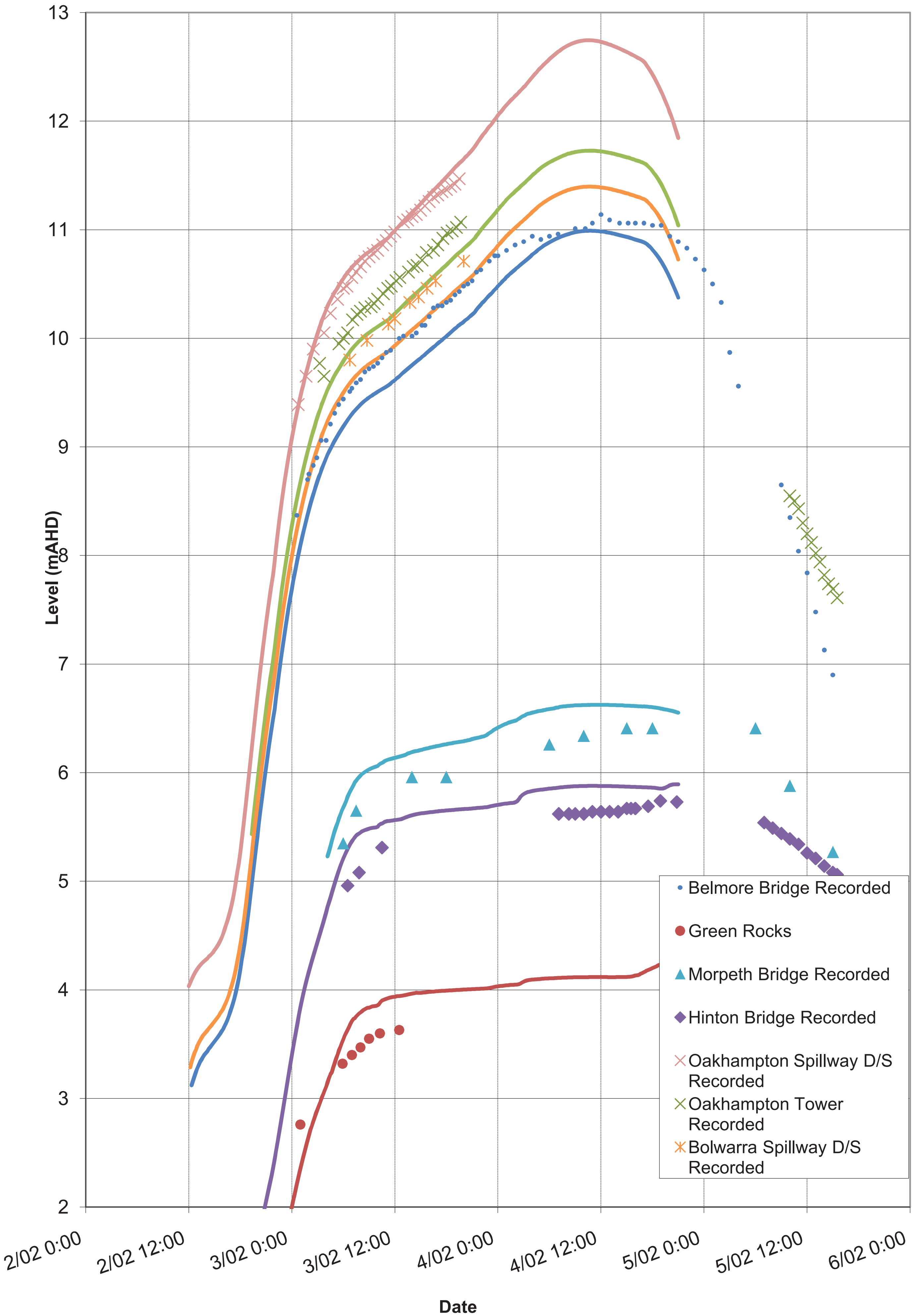


FIGURE 19
STAGE HYDROGRAPHS
FEBRUARY 1971



J:\Jobs\27036-02\TUFLOW\results\Calibration\1971\Calibration_1971.xlsx

FIGURE 20
STAGE HYDROGRAPHS
MARCH 1977

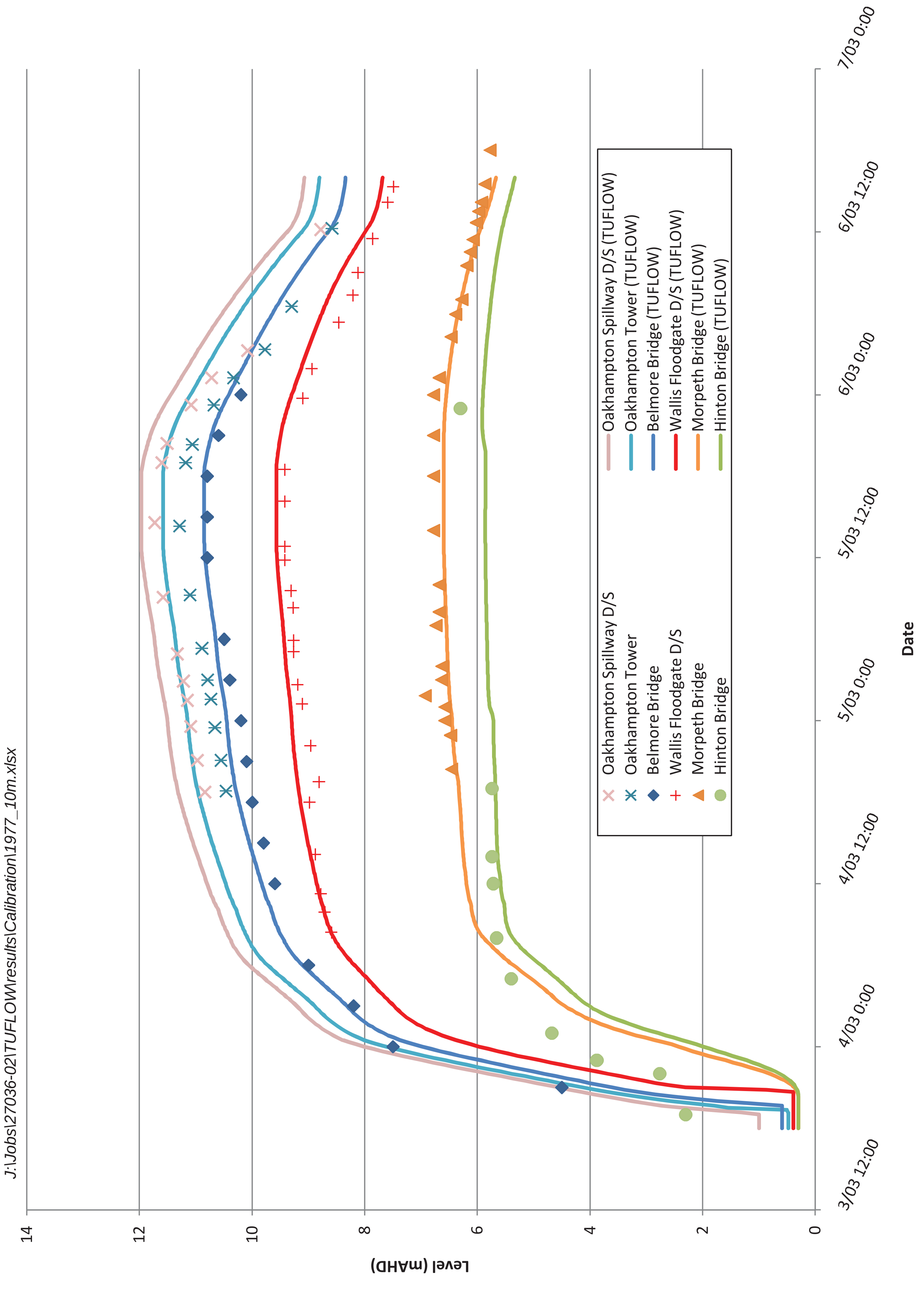


FIGURE 21a
STAGE HYDROGRAPHS
JUNE 2007

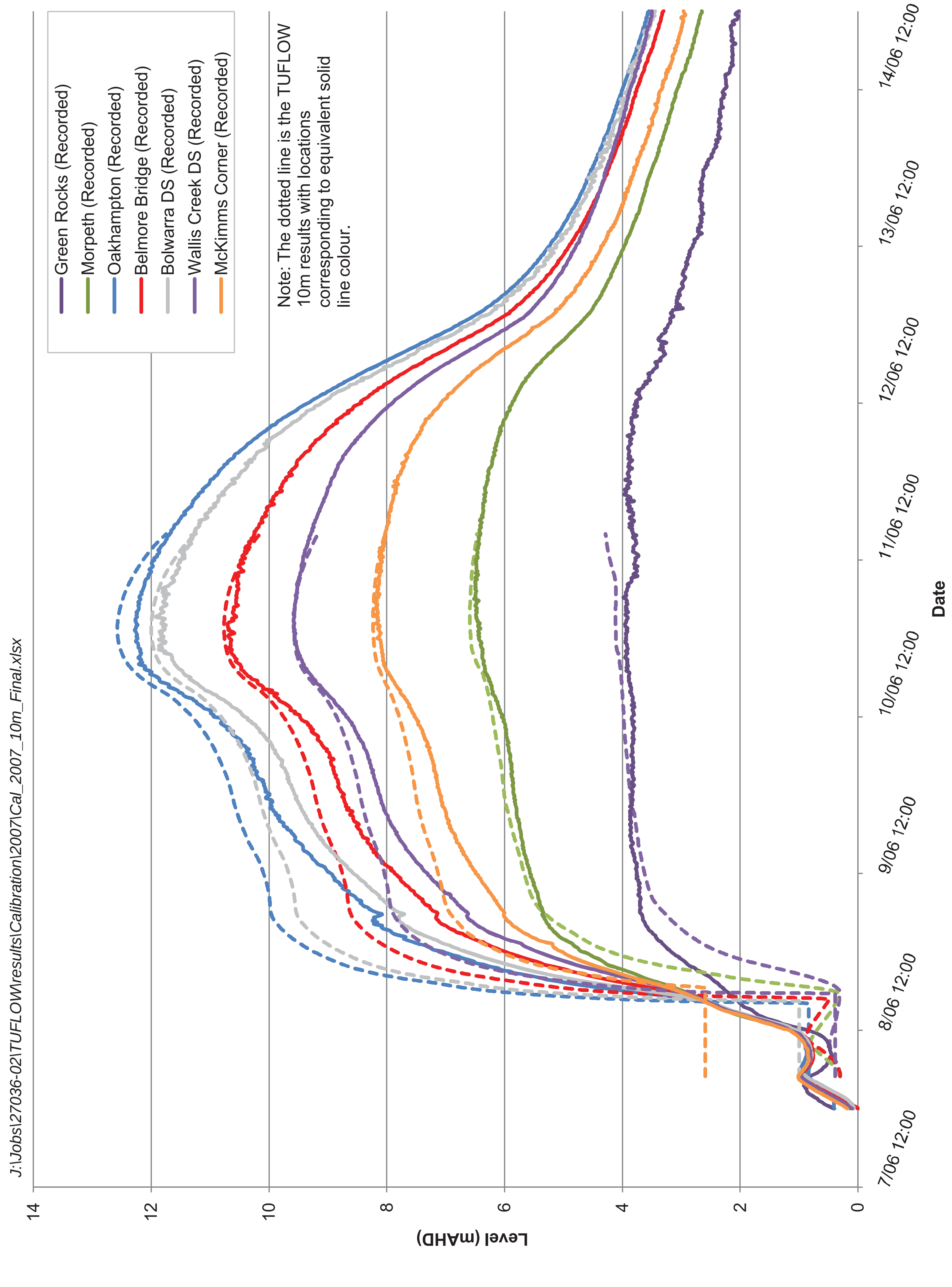
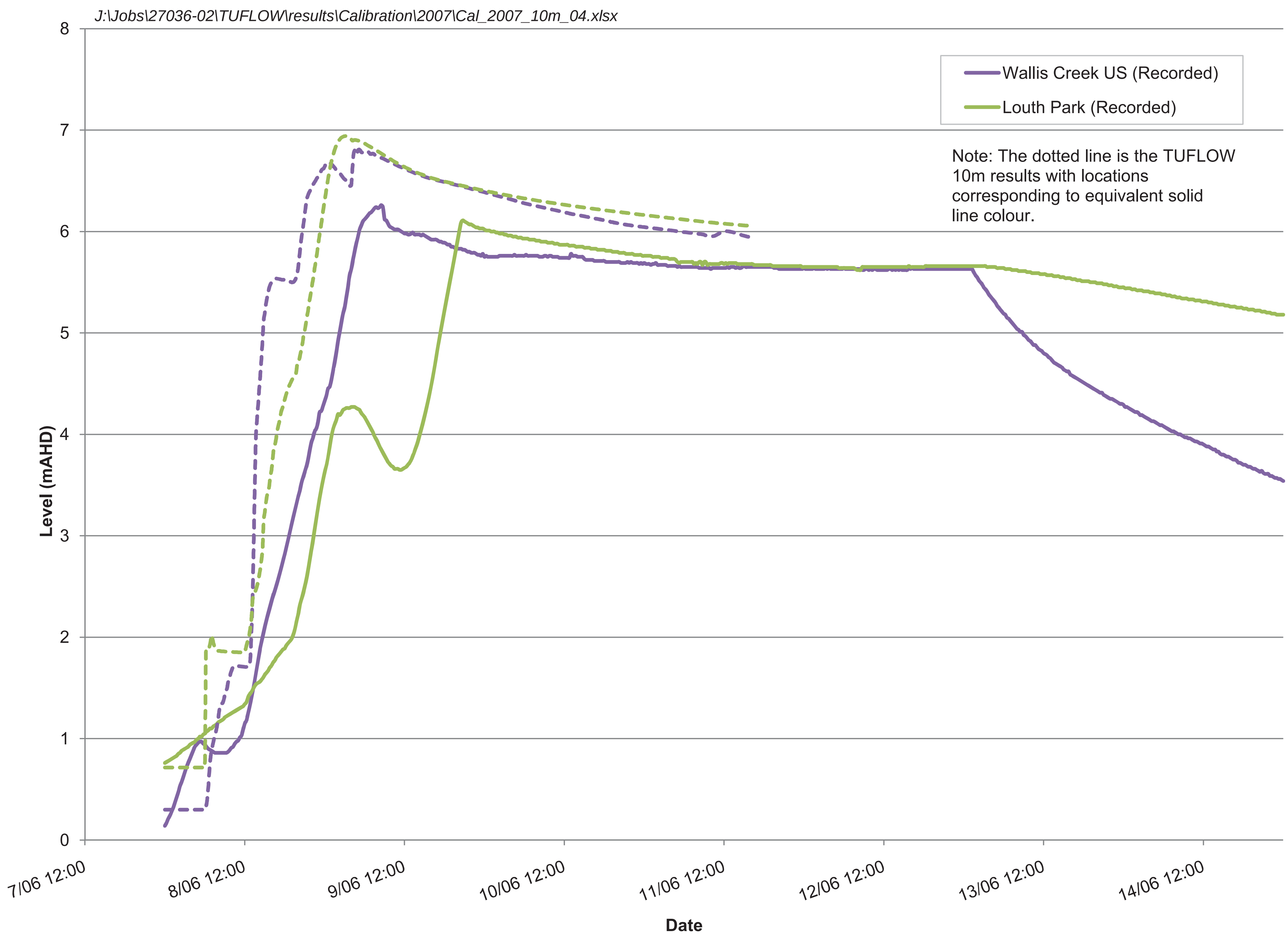


FIGURE 21b
STAGE HYDROGRAPHS
JUNE 2007



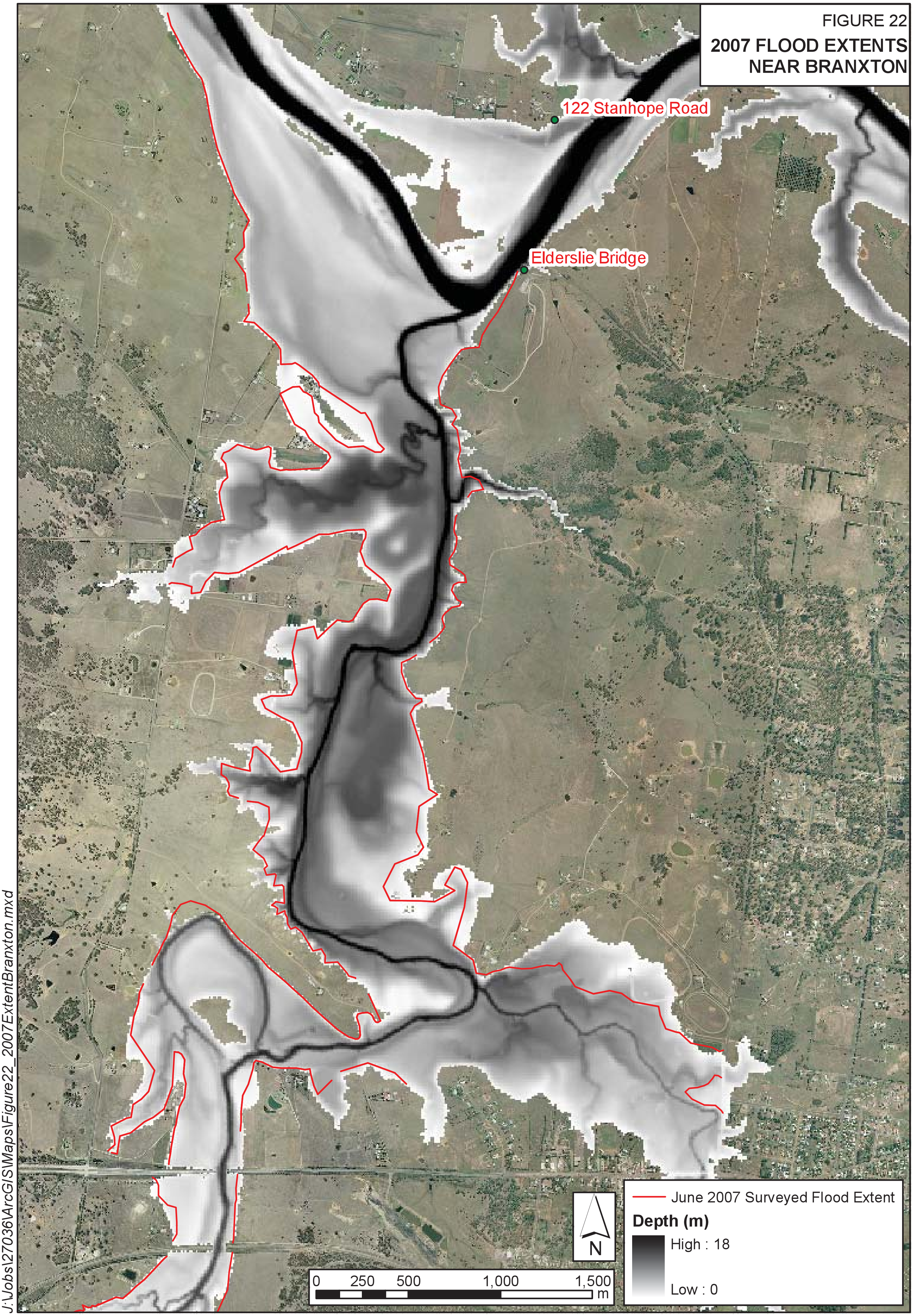


FIGURE 22
2007 FLOOD EXTENTS
NEAR BRANXTON
122 Stanhope Road
Elderslie Bridge
June 2007 Surveyed Flood Extent
Depth (m)
High : 18
Low : 0
N
0
250
500
1,000
1,500
m
J:\Jobs\27036\ArcGIS\Maps\Figure22_2007ExtentBranxton.mxd

FIGURE 23a

FLOOD FREQUENCY ANALYSIS
OAKHAMPTON/BELMORE BRIDGE
LP3 DISTRIBUTION

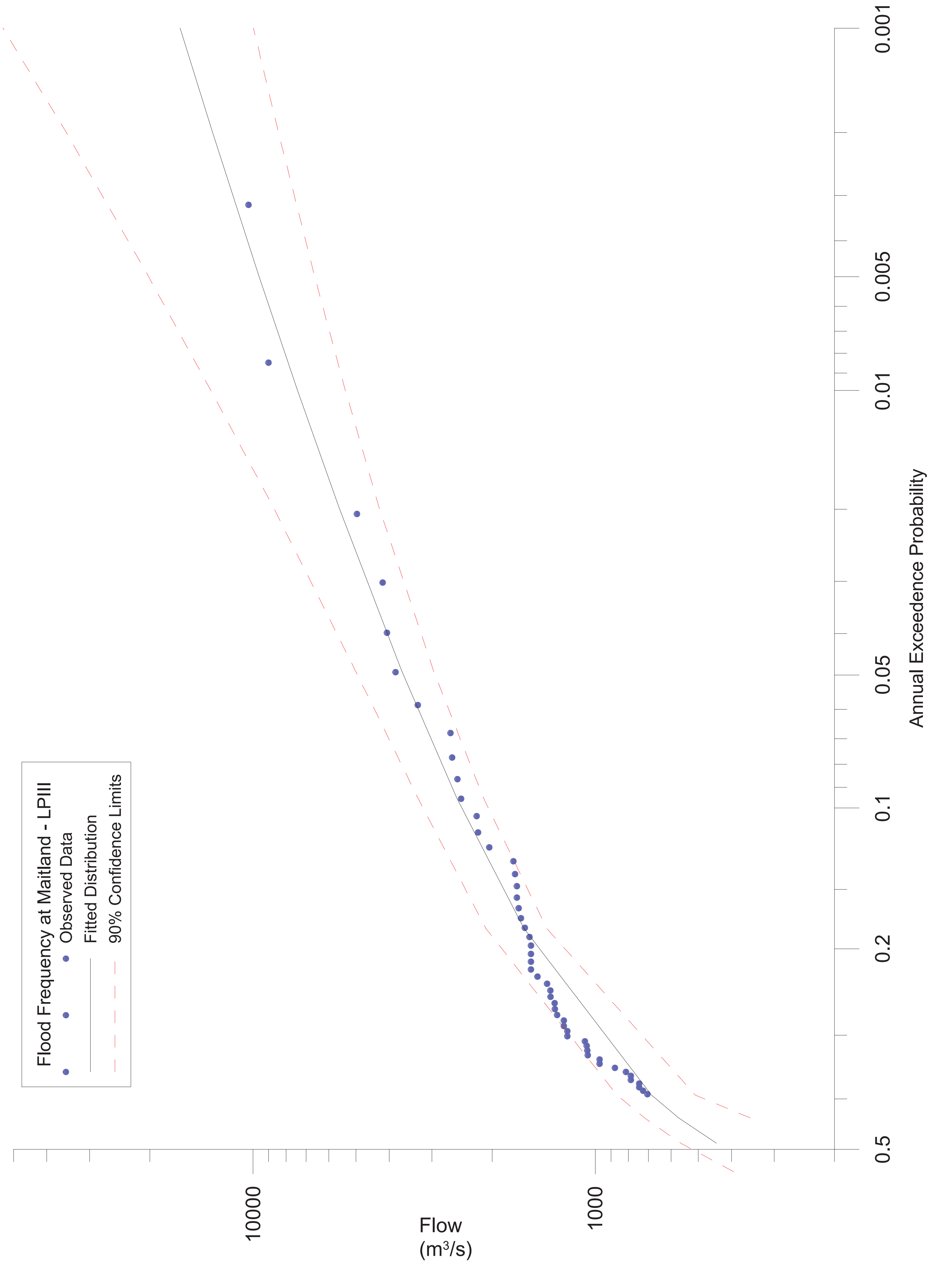


FIGURE 23b

FLOOD FREQUENCY ANALYSIS
OAKHAMPTON/BELMORE BRIDGE
GEV DISTRIBUTION

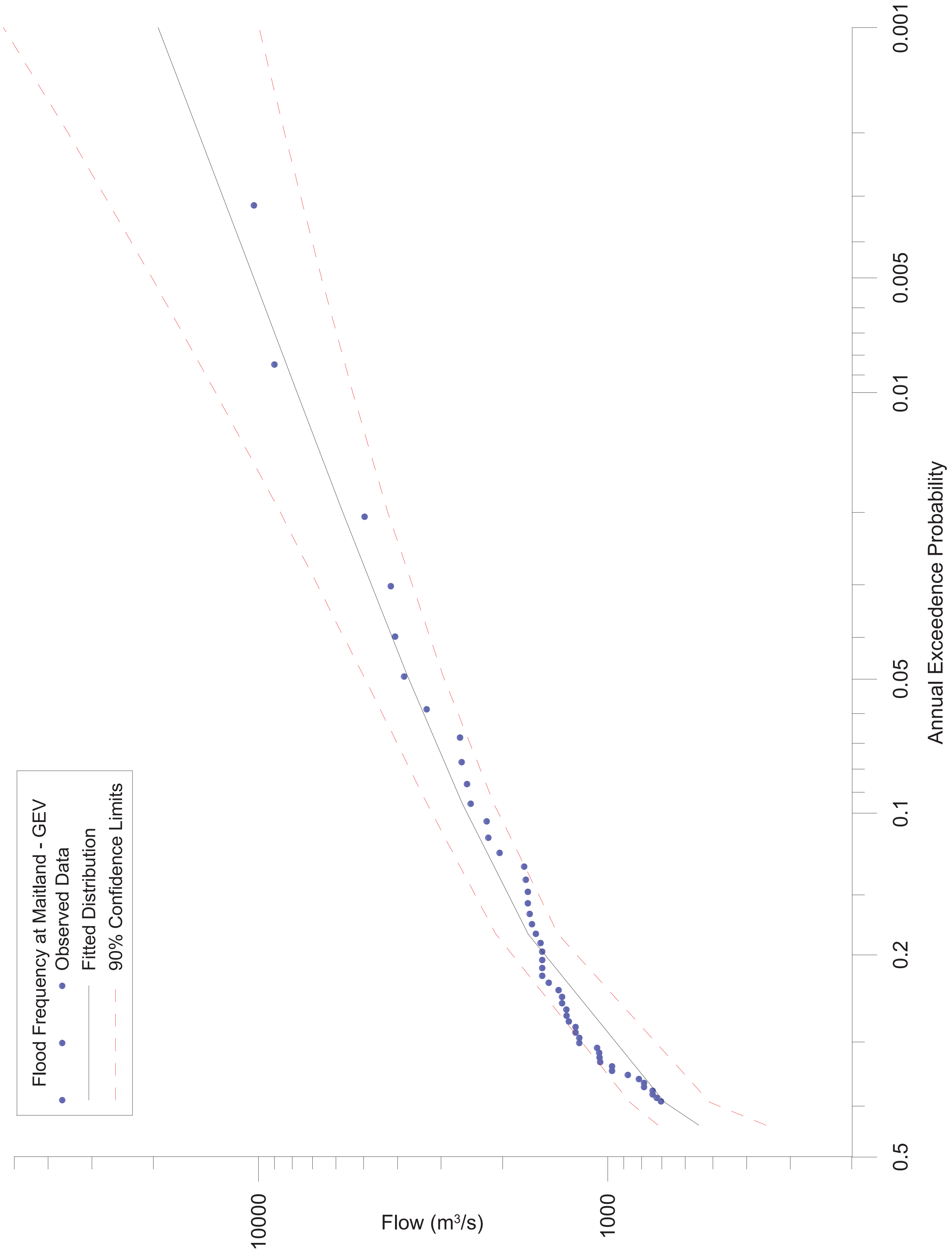


FIGURE 23c
FLOOD FREQUENCY ANALYSIS
OAKHAMPTON / BELMORE BRIDGE RATING CURVE

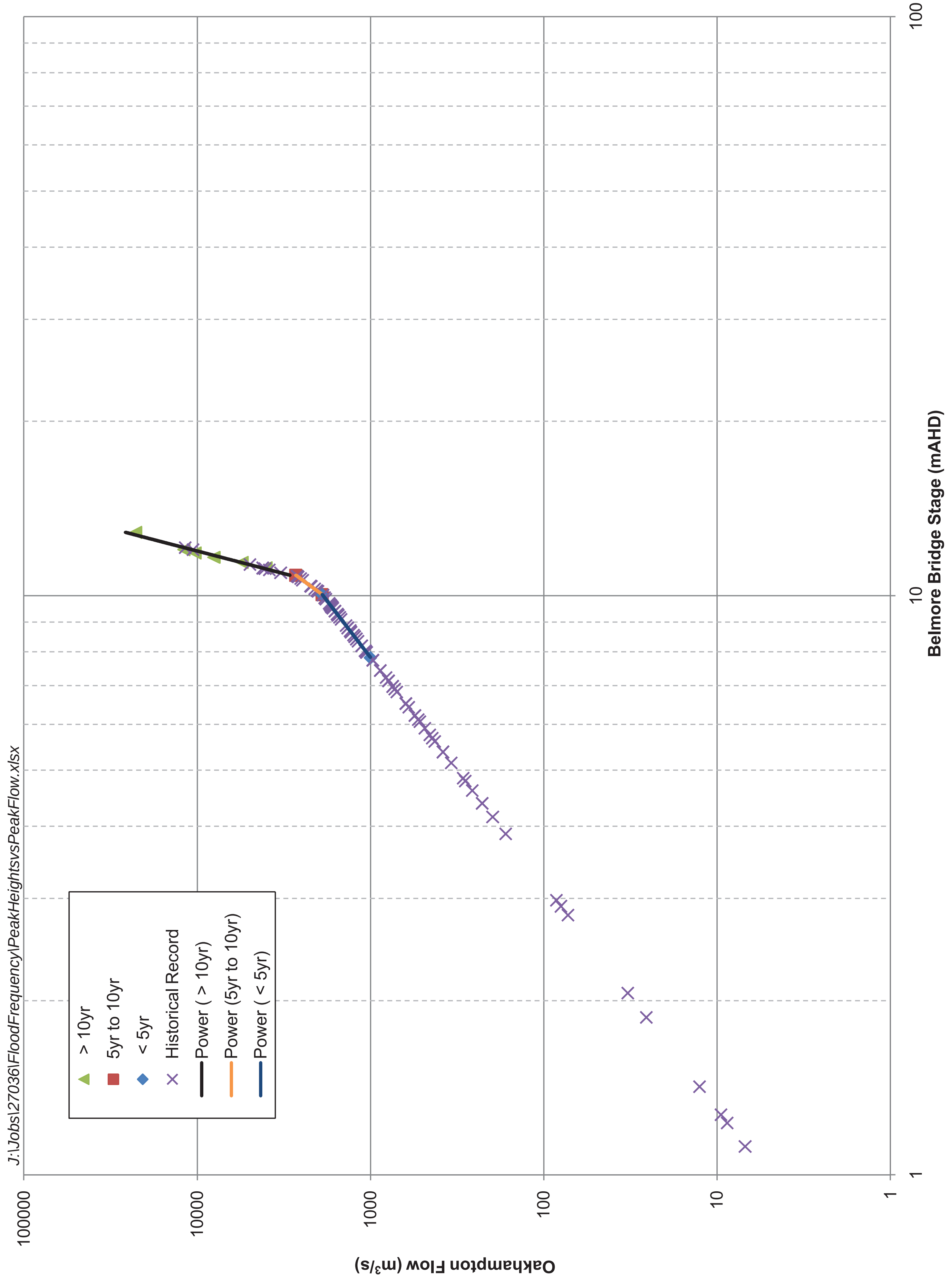


FIGURE 24
DESIGN PEAK HEIGHT PROFILES UPSTREAM OF OAKHAMPTON

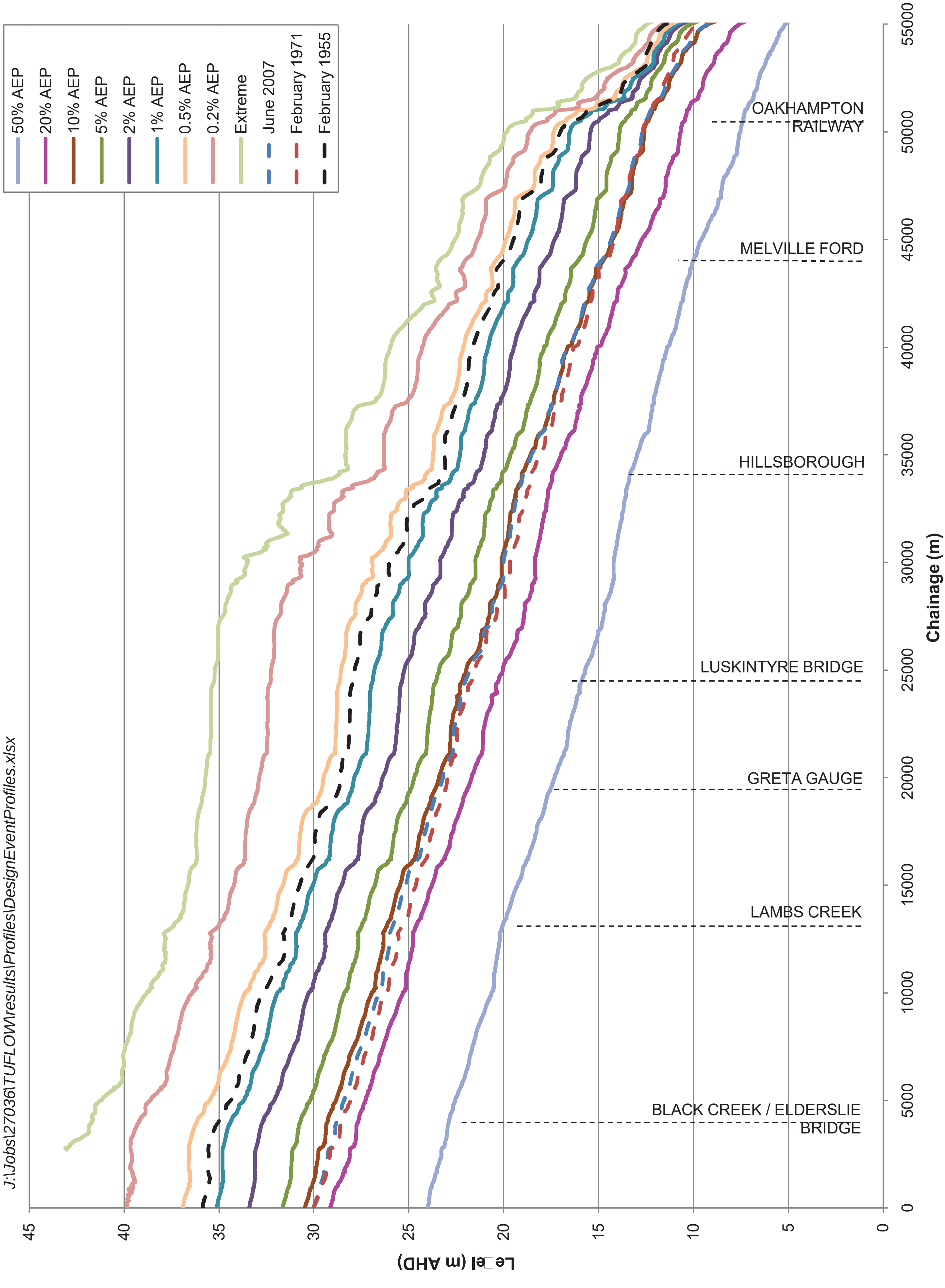
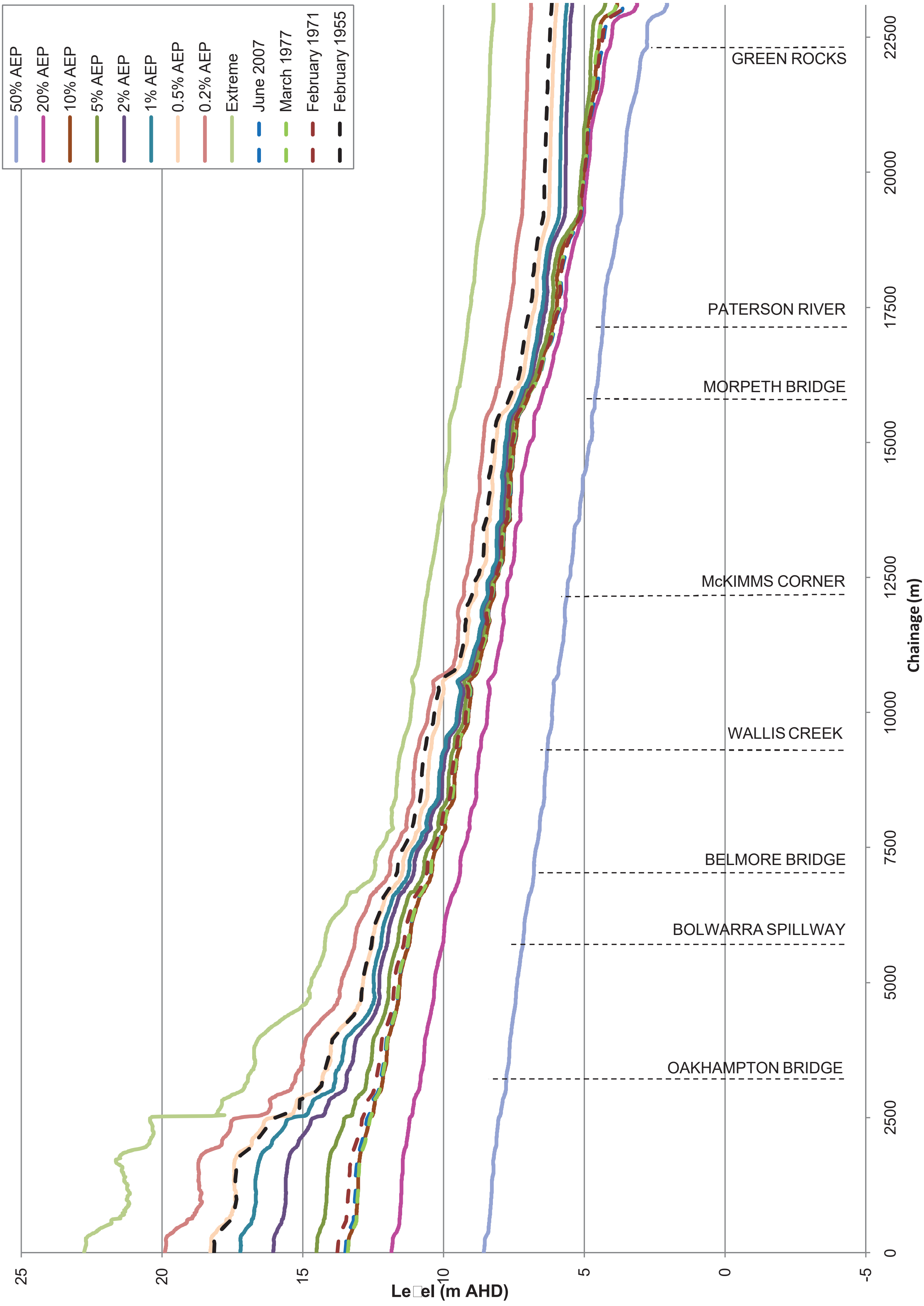


FIGURE 25
DESIGN PEAK HEIGHT PROFILES
DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\-02\TUFLOW\results\Profiles\DesignEventProfiles.xlsx

FIGURE 25a

□□□□STUDY PROFILE COMPARISON

DO□ NSTREAM OF OAKHAMPTON

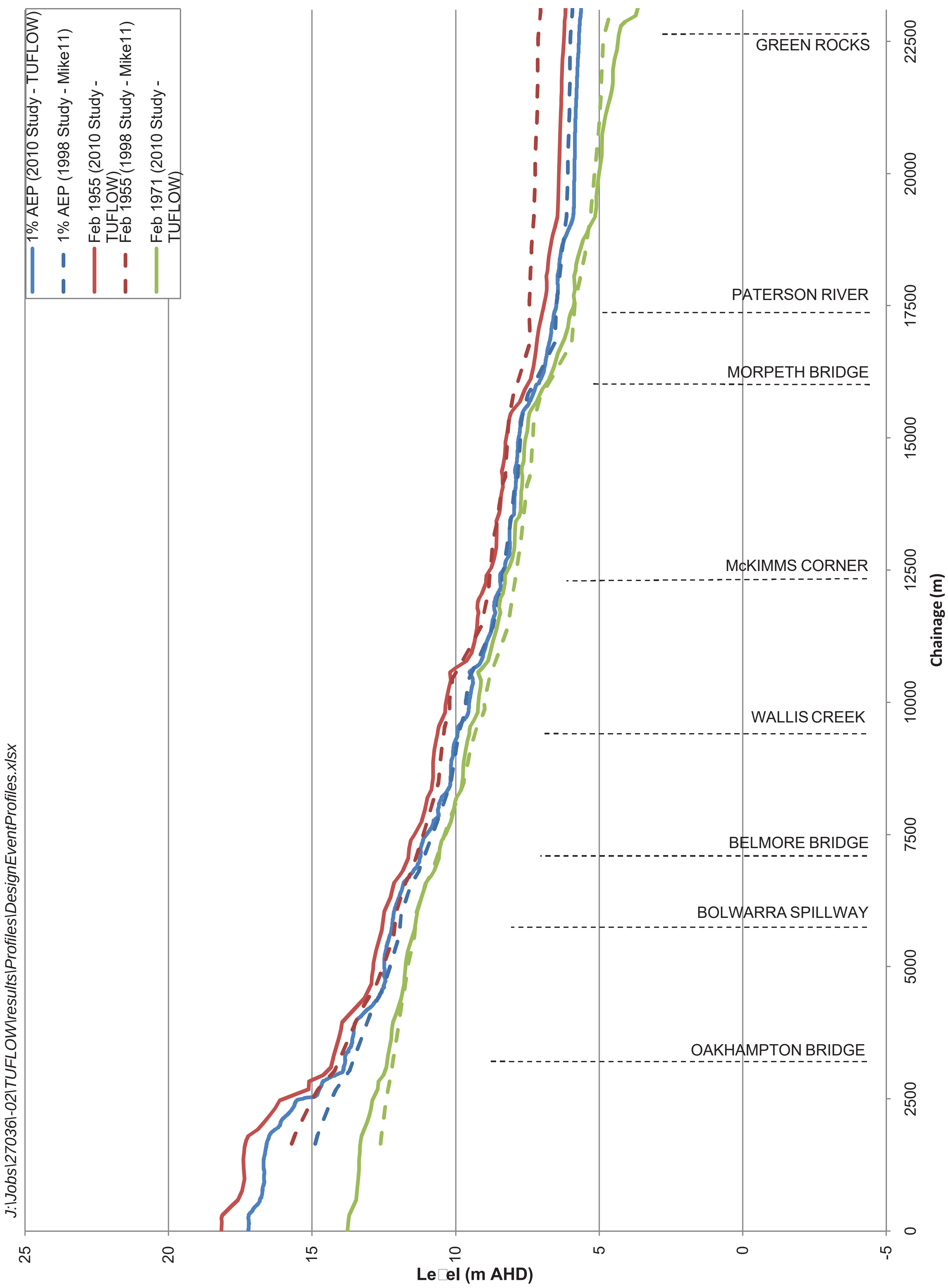


FIGURE 26a
DESIGN STAGE HYDROGRAPHS
BELMORE BRIDGE

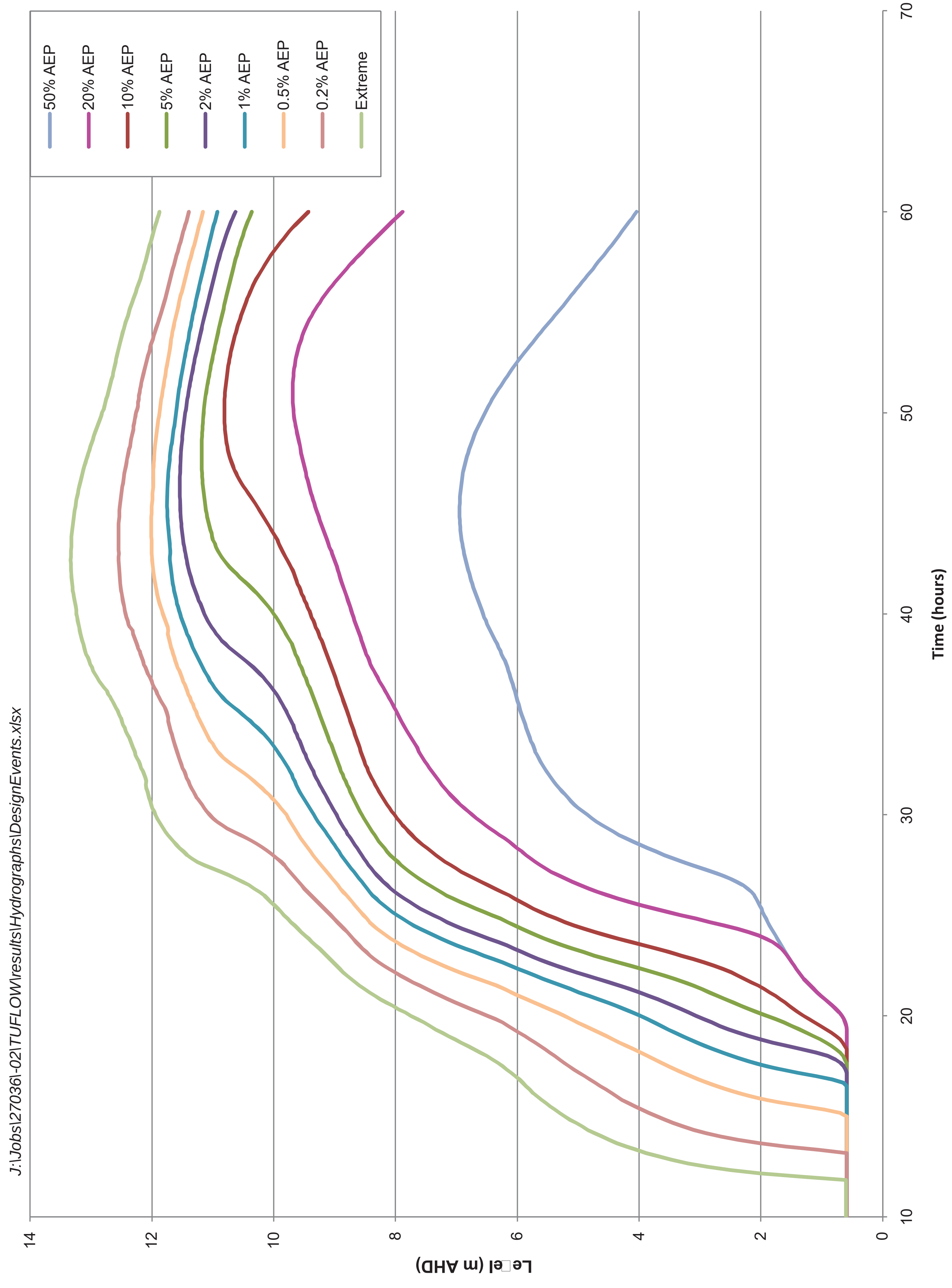


FIGURE 26b
DESIGN STAGE HYDROGRAPHS
OAKHAMPTON

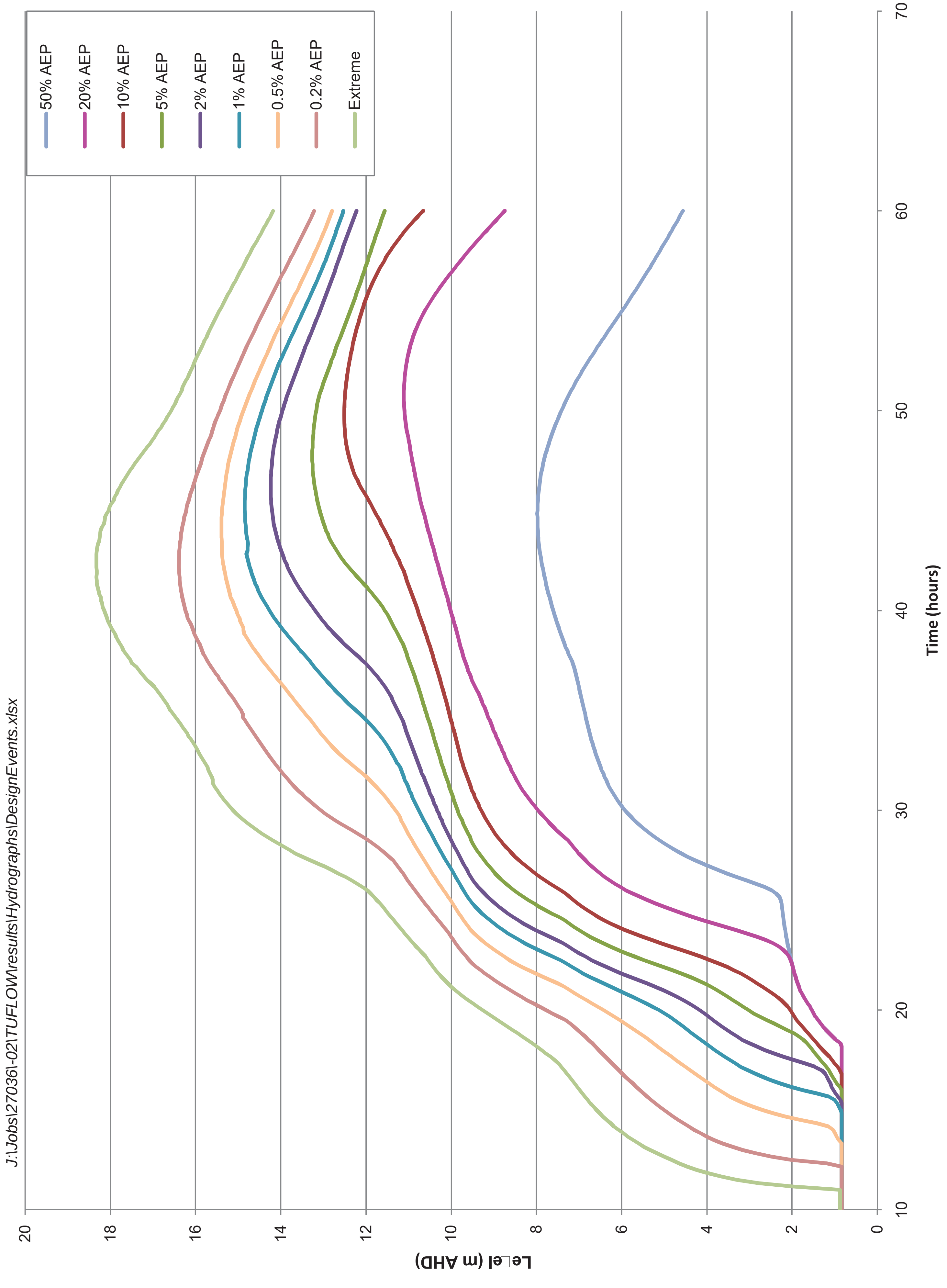


FIGURE 26c

DESIGN STAGE HYDROGRAPHS
PORTERS HOLLO□

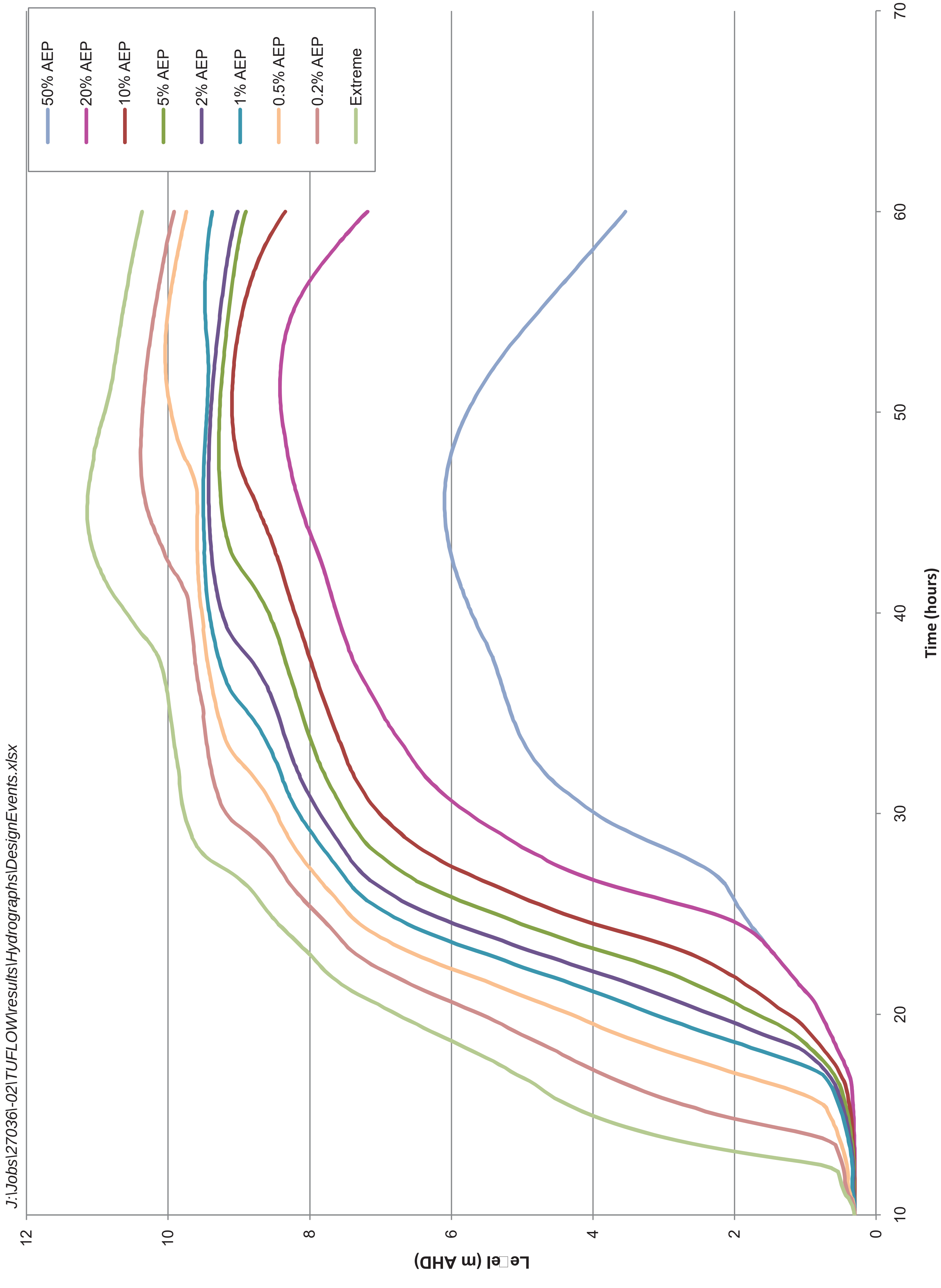
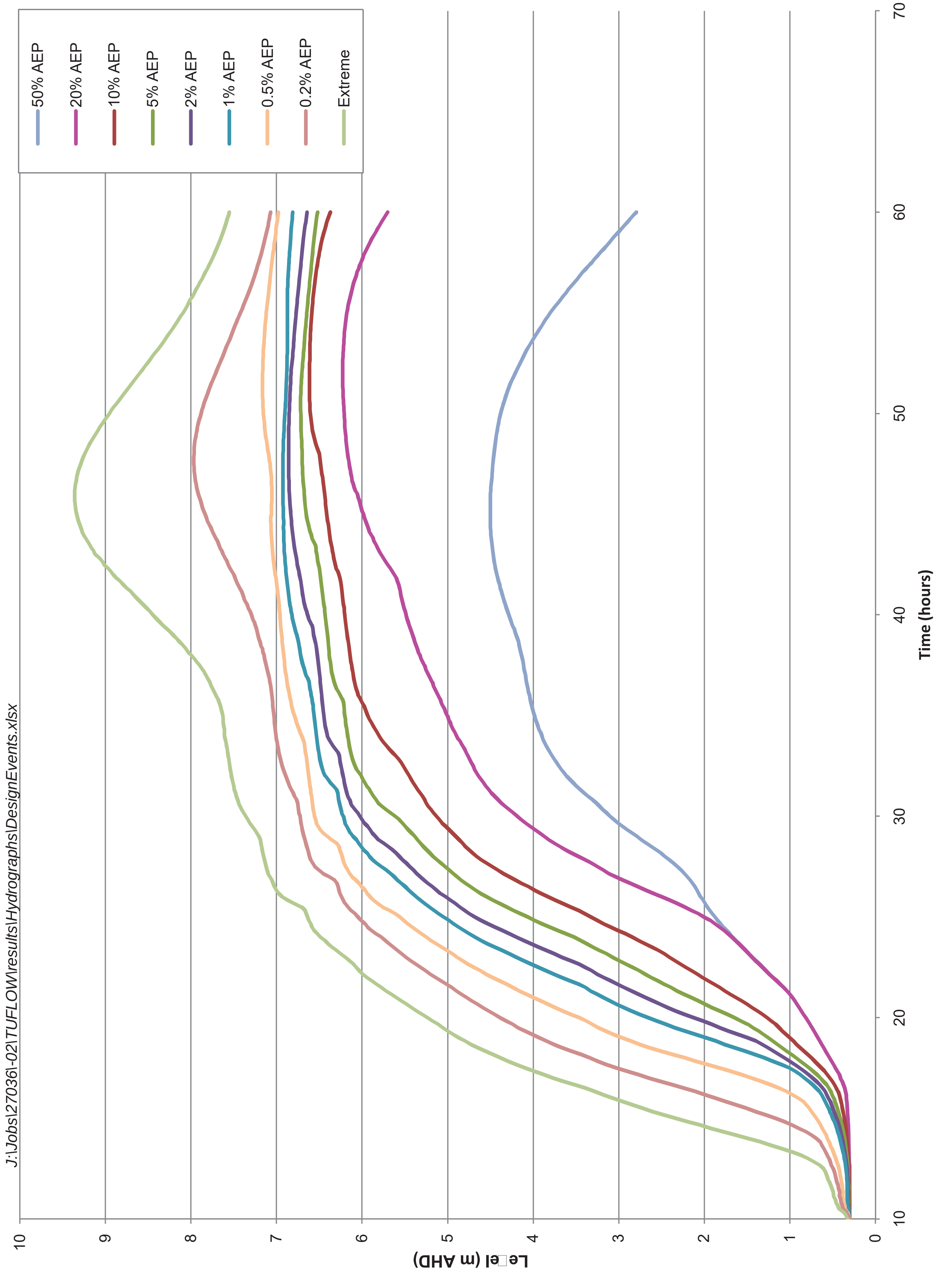


FIGURE 26d
DESIGN STAGE HYDROGRAPHS
MORPETH



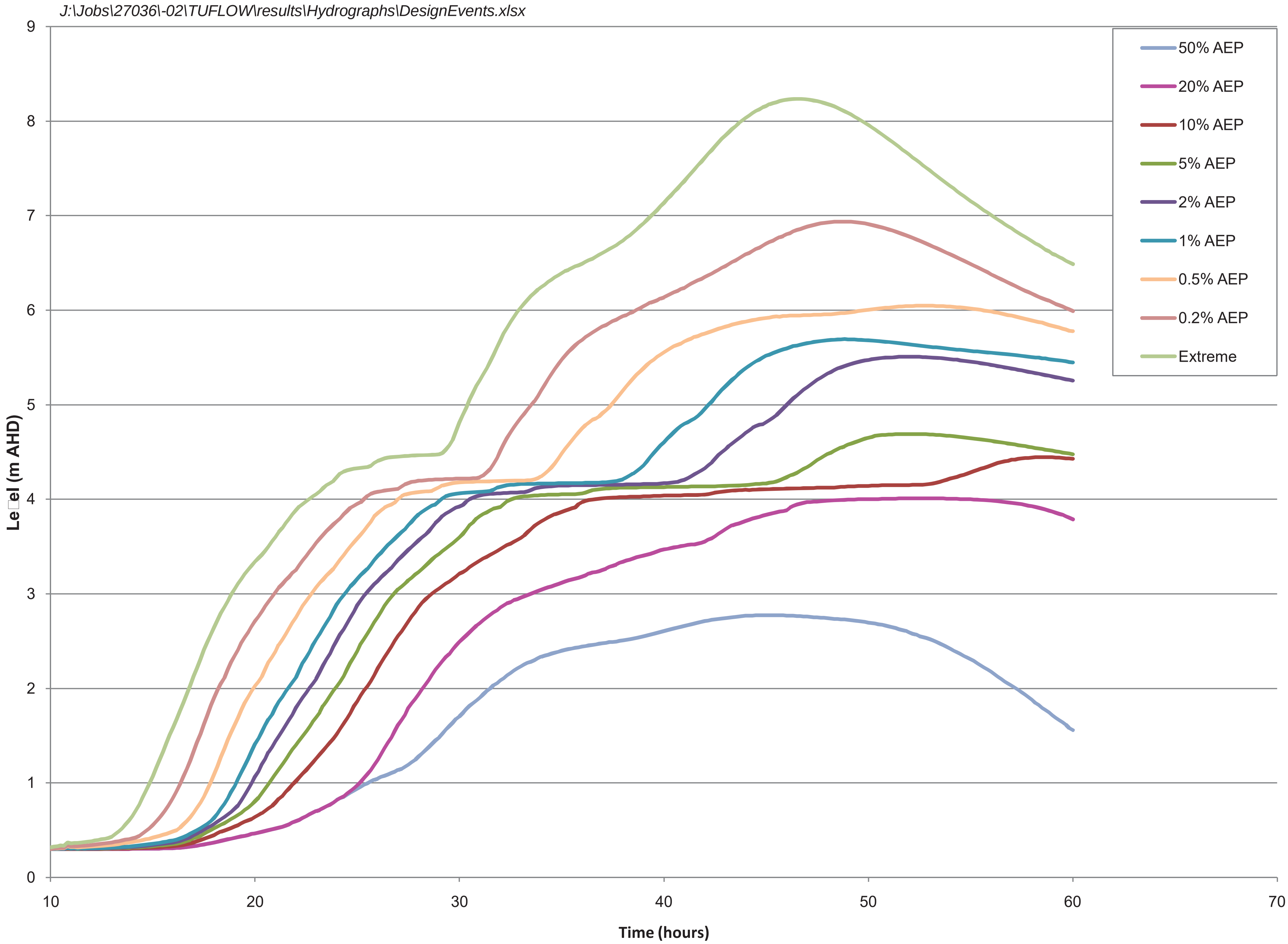


FIGURE 26e
DESIGN STAGE HYDROGRAPHS
GREEN ROCKS

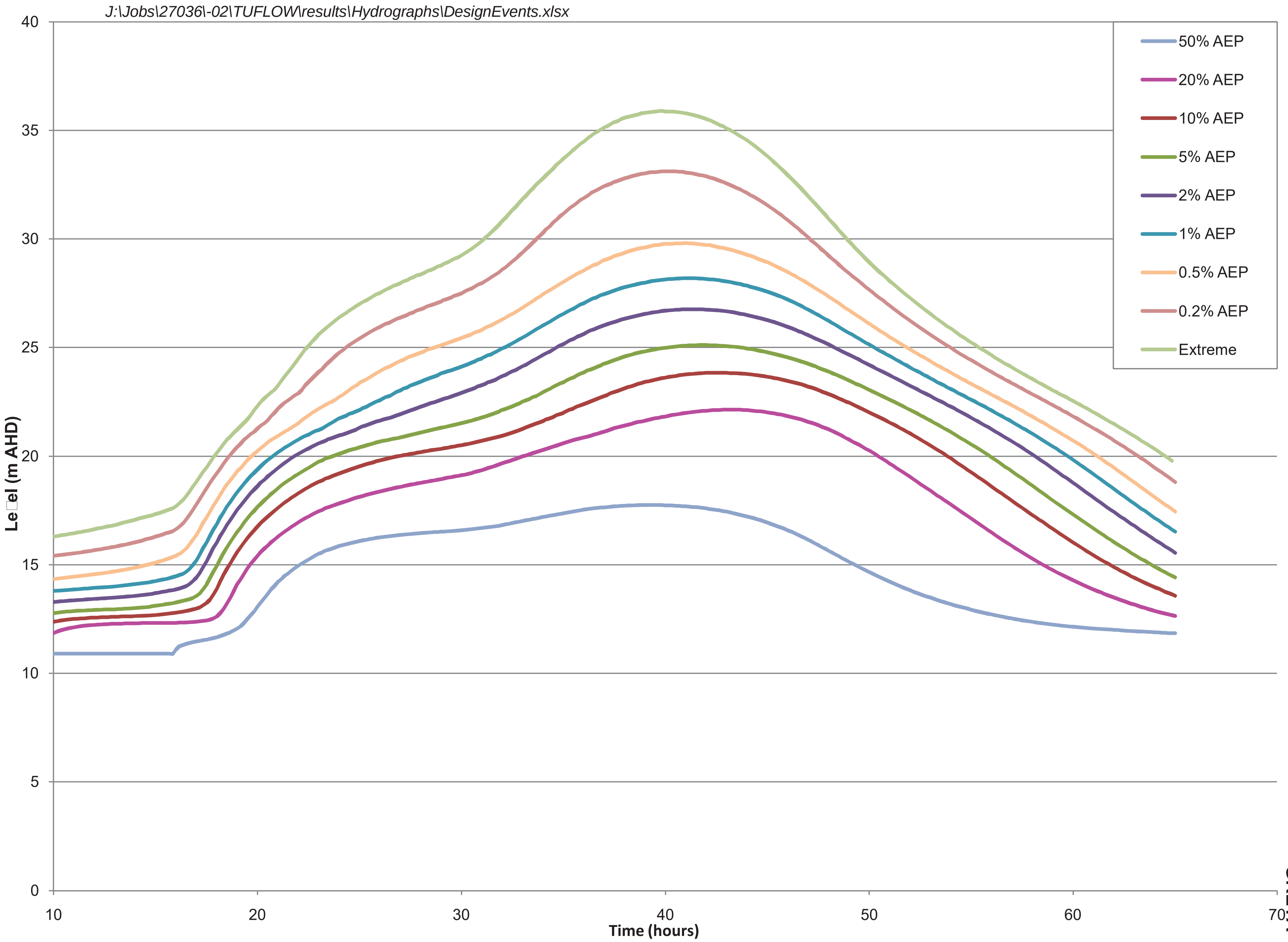


FIGURE 26f
DESIGN STAGE HYDROGRAPHS
GRETA

J:\Jobs\27036\-02\TUFLOW\results\Hydrographs\DesignEvents.xlsx

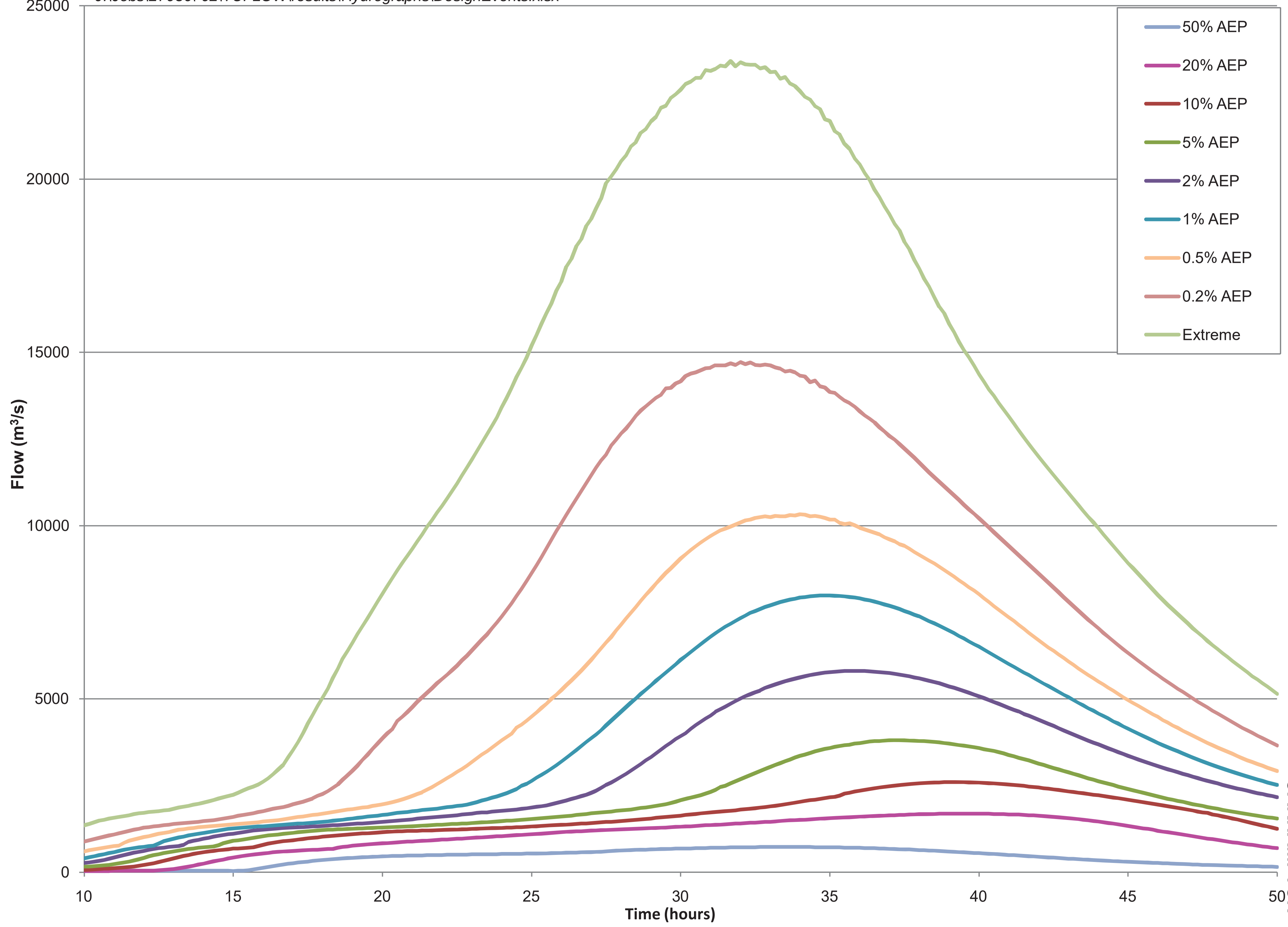
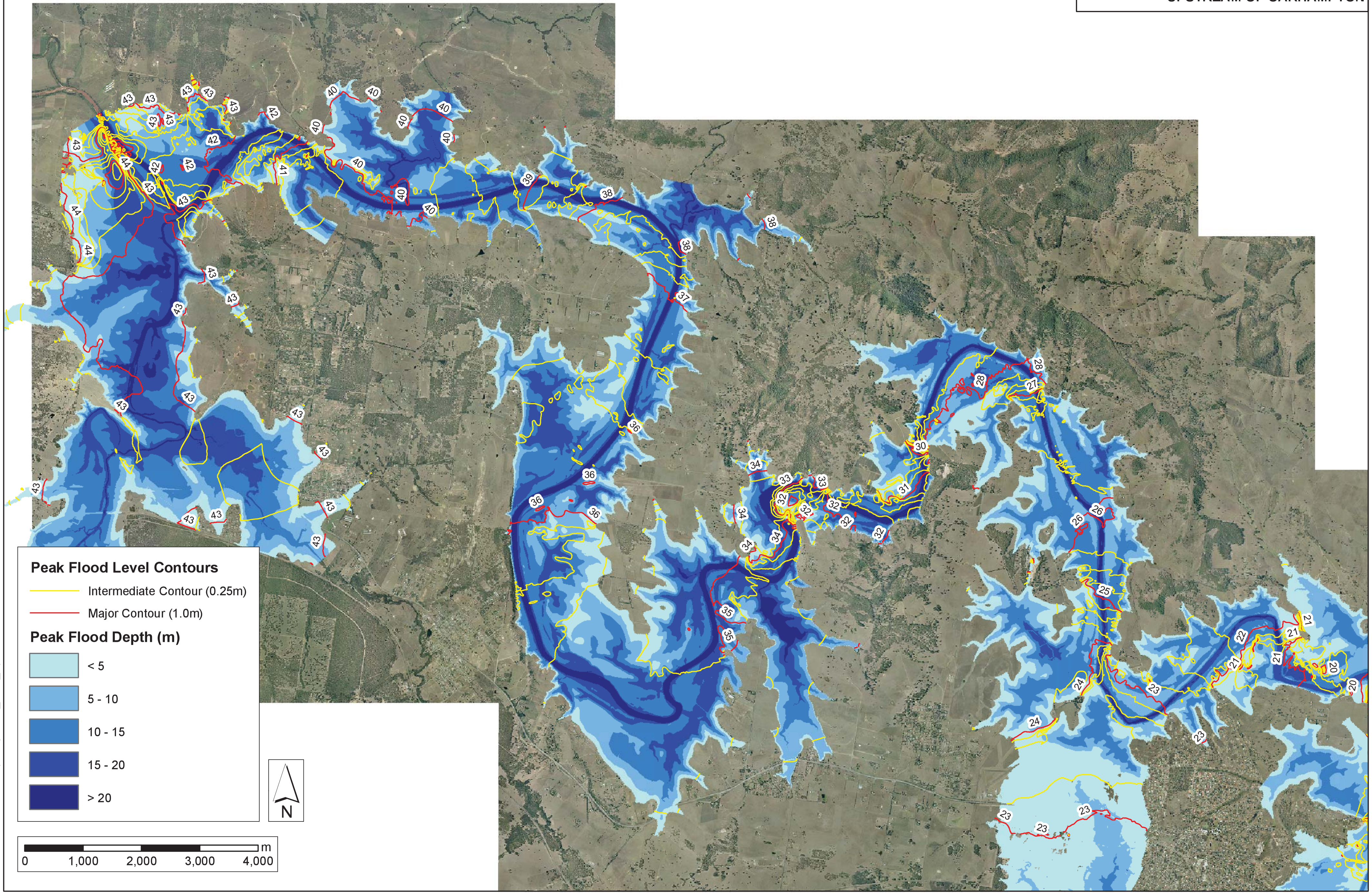


FIGURE 26g
DESIGN FLO□ HYDROGRAPHS
OAKHAMPTON

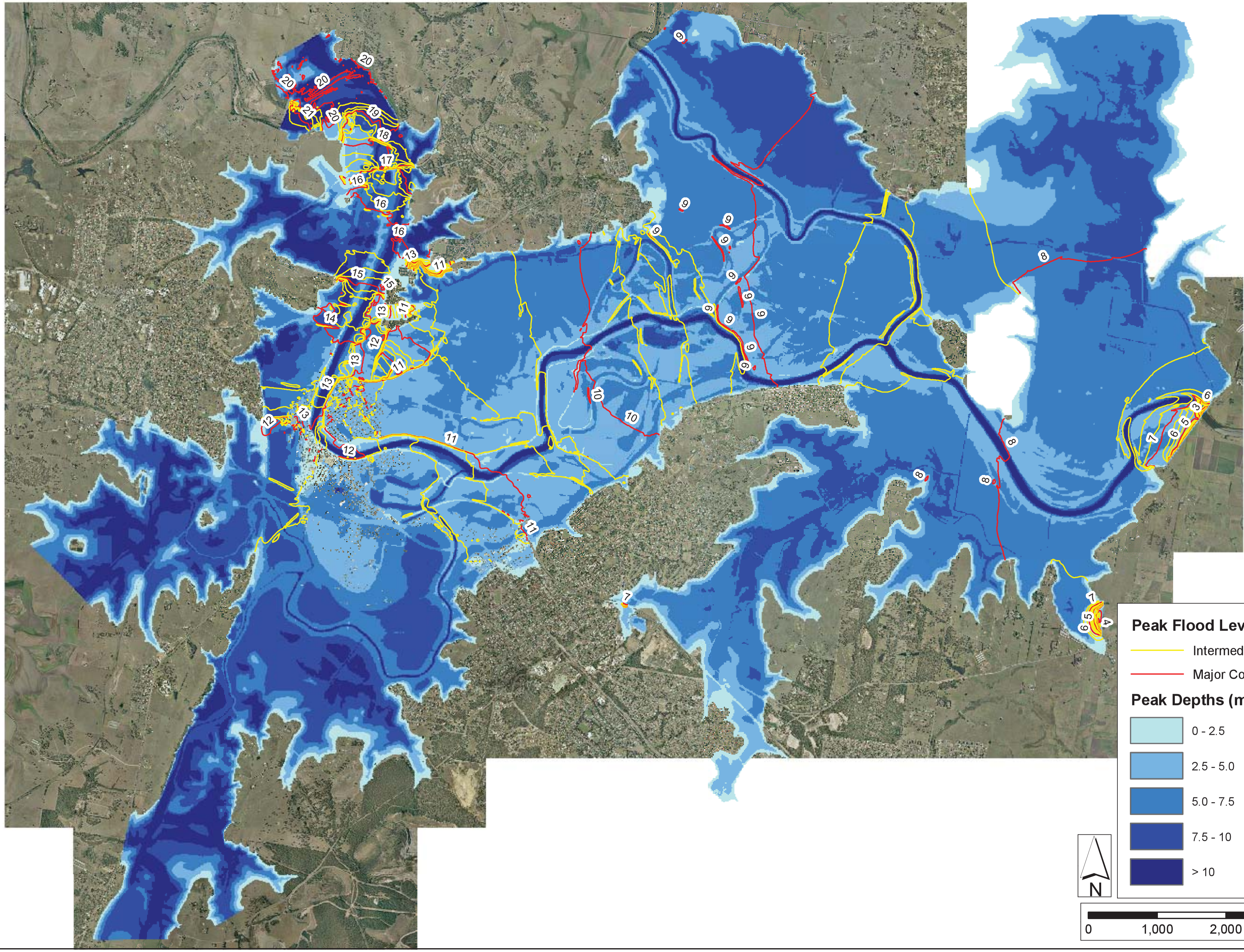
FIGURE 27

EXTREME FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure27_PMF_Upstream.mxd

FIGURE 28
EXTREME FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



Peak Flood Level Contours
- Intermediate Contours (0.25m)
- Major Contours (1.0m)

Peak Depths (m)
- 0 - 2.5
- 2.5 - 5.0
- 5.0 - 7.5
- 7.5 - 10
- > 10

N

0 1,000 2,000 3,000 4,000 m

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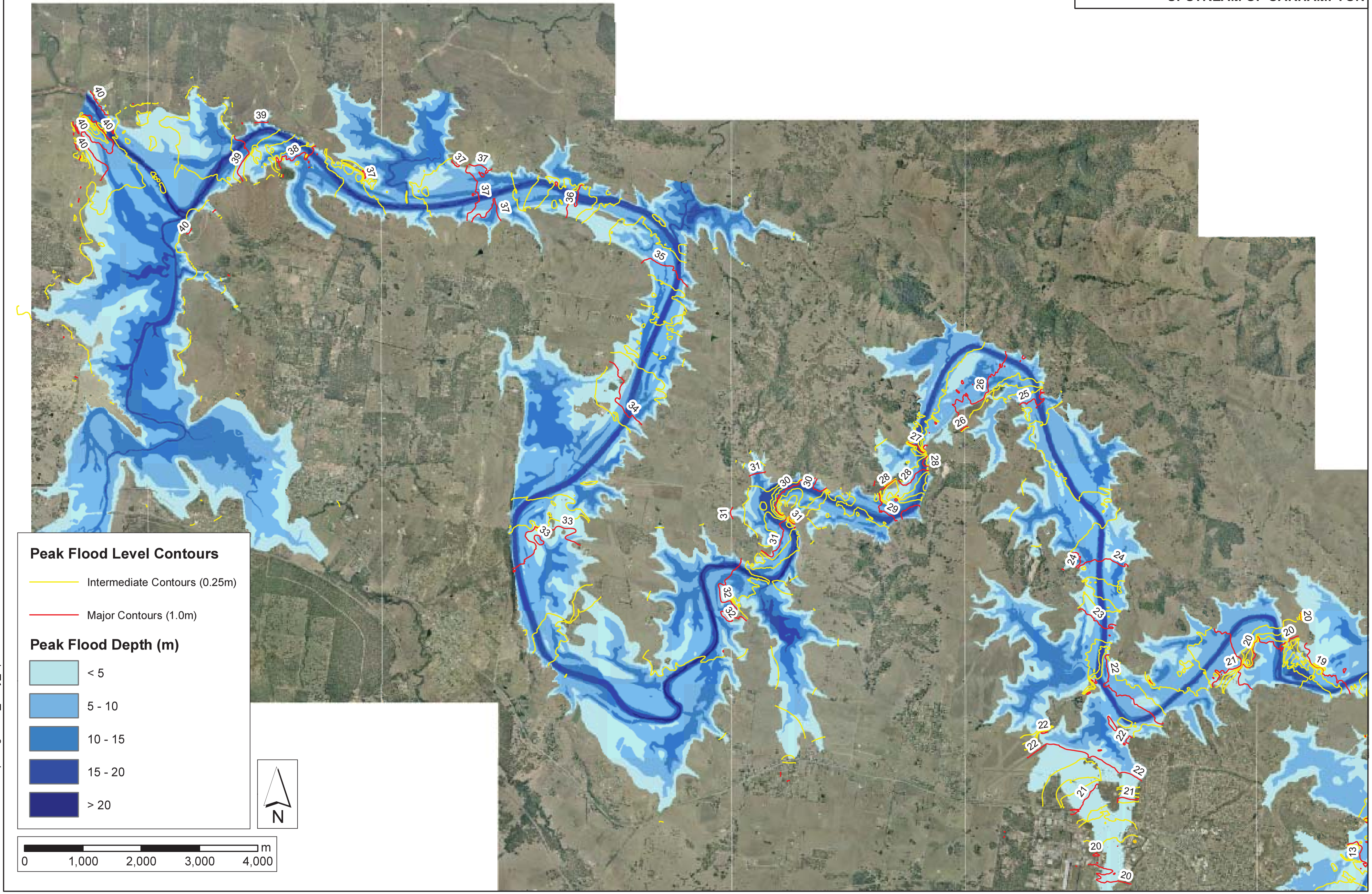
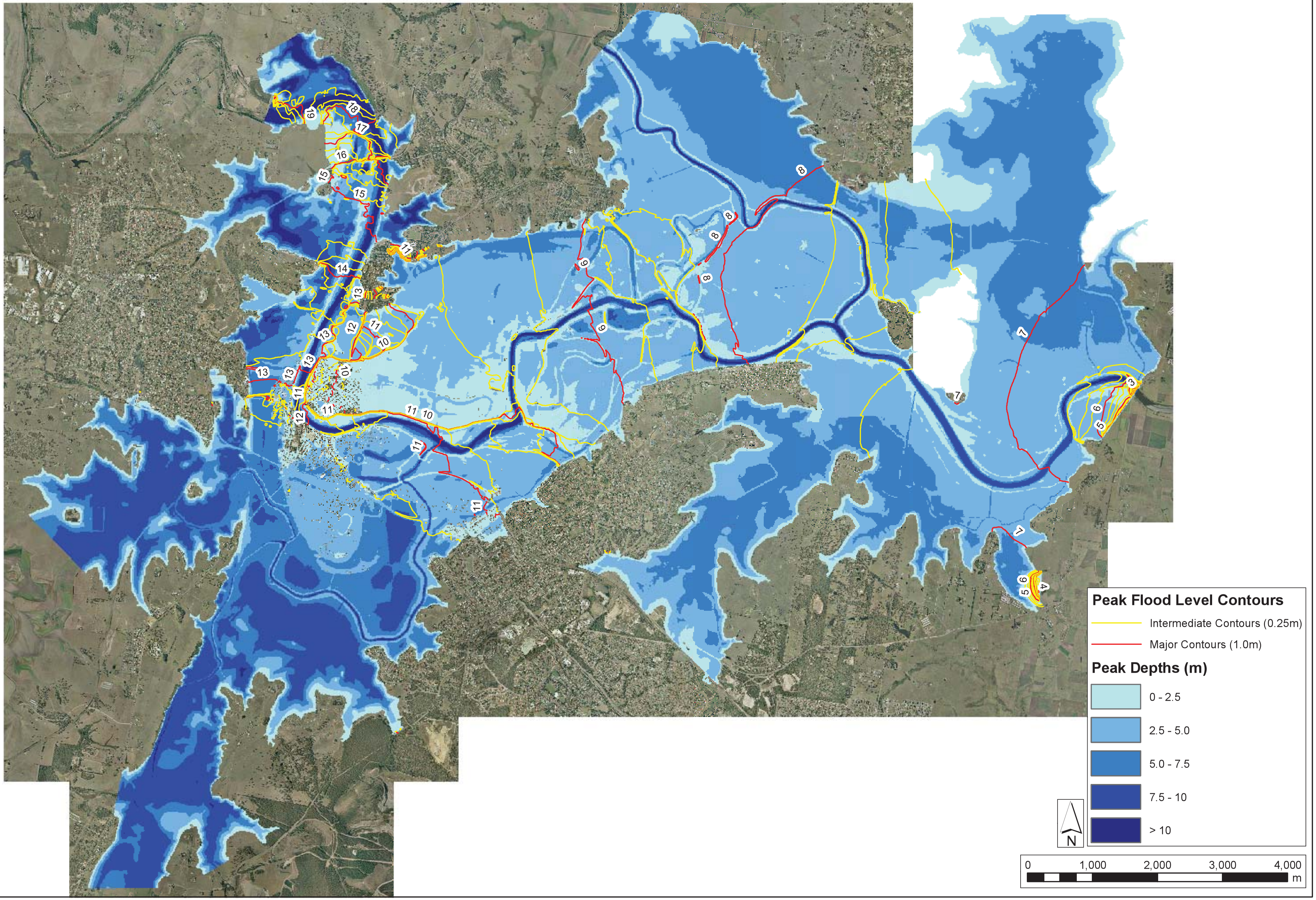
FIGURE 29

0.2% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure29_500y_Upstream.mxd

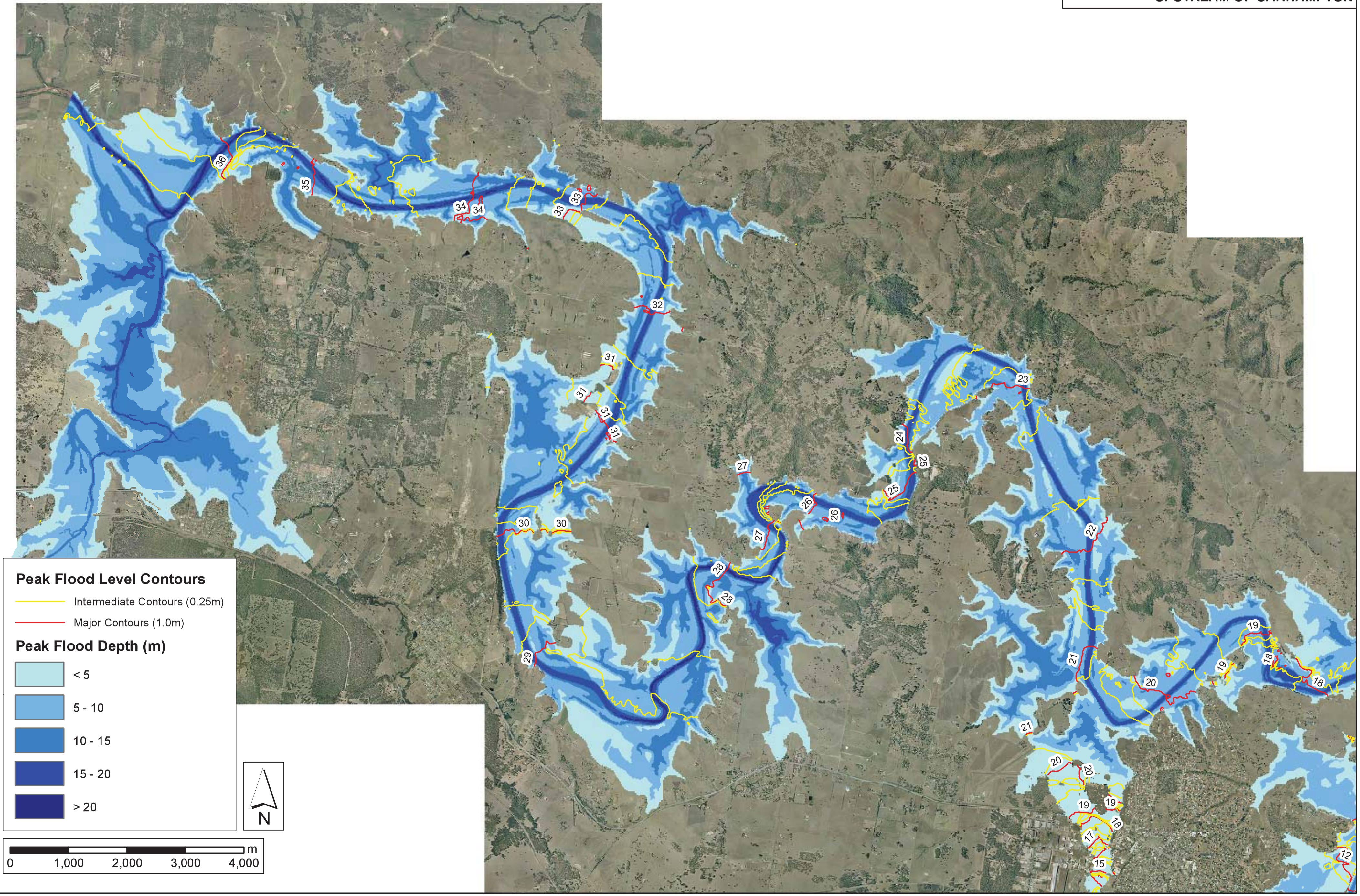
FIGURE 30
0.2% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure30_500y_Downstream.mxd

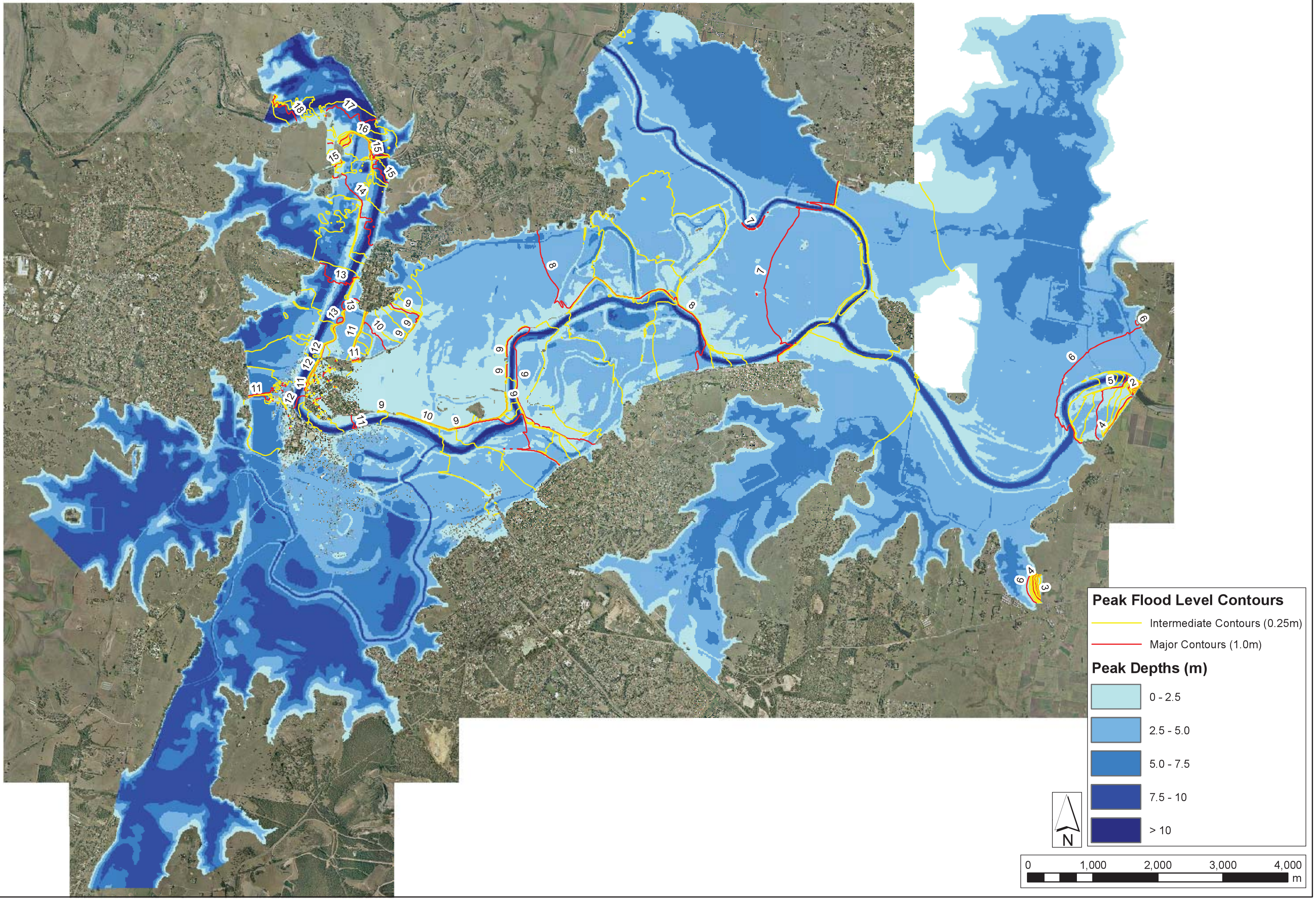
FIGURE 31

0.5% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure31_200y_Upstream.mxd

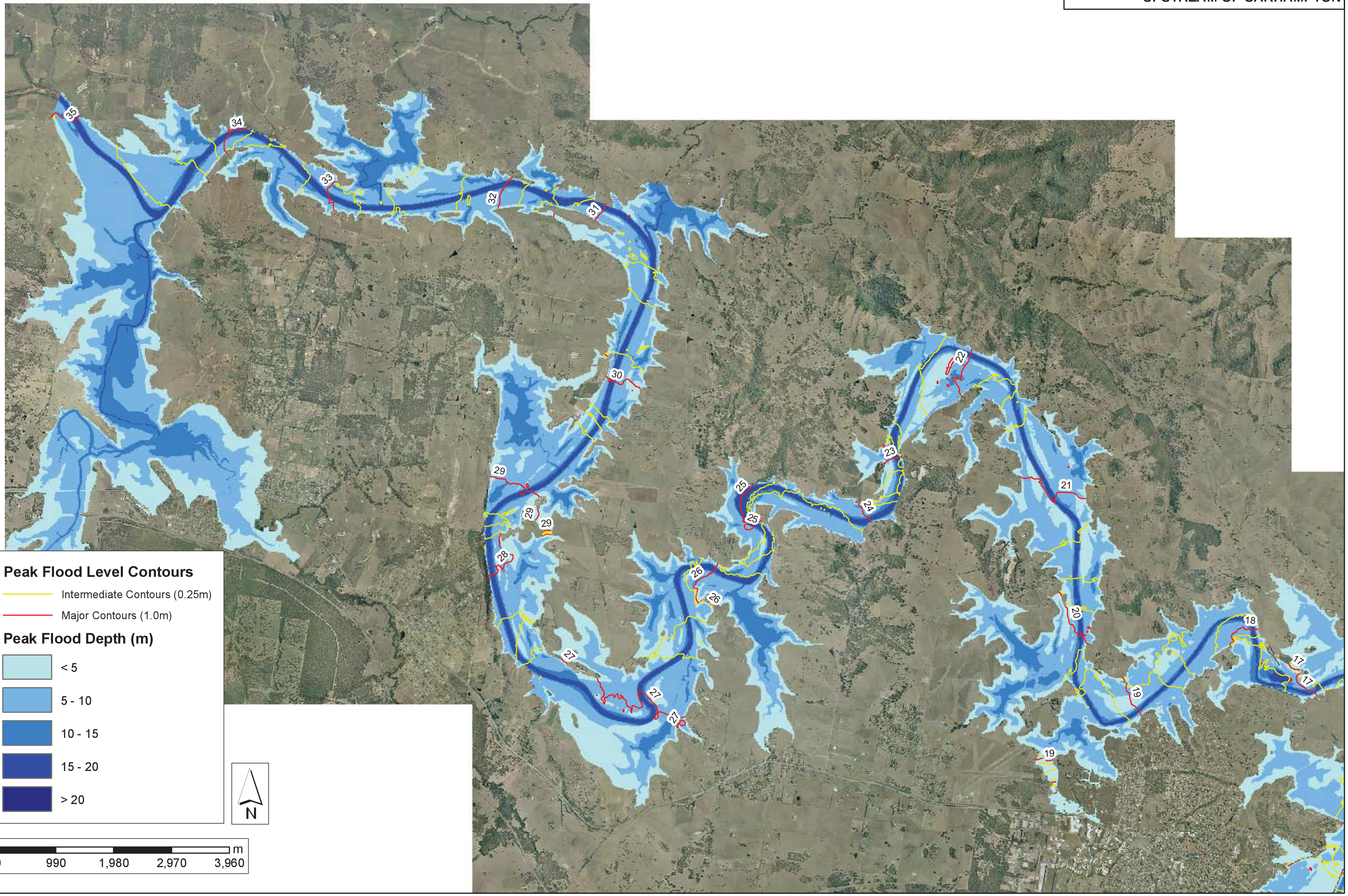
FIGURE 32
0.5% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure32_200y_Downstream.mxd

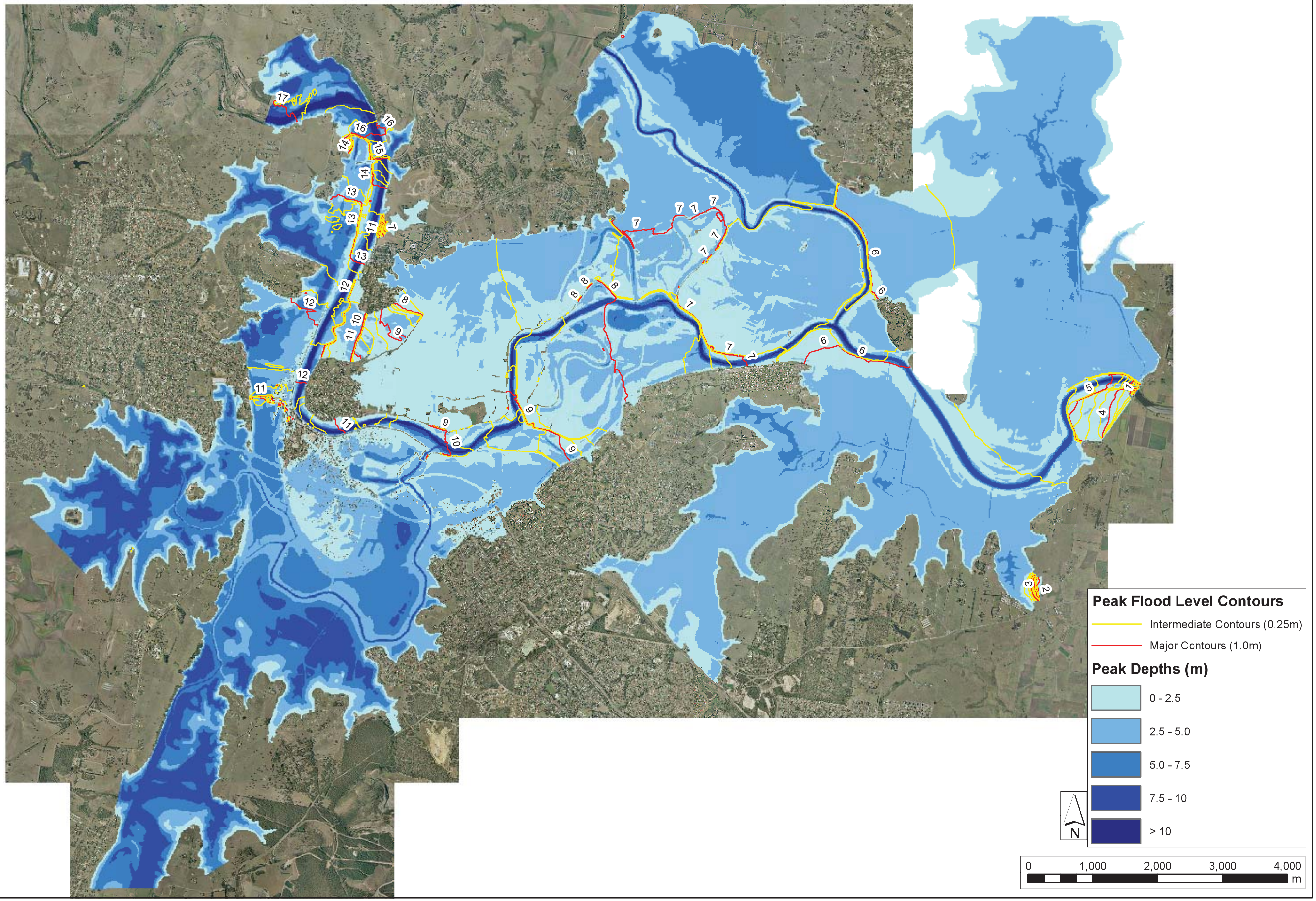
FIGURE 33

1% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure33_100y_Upstream.mxd

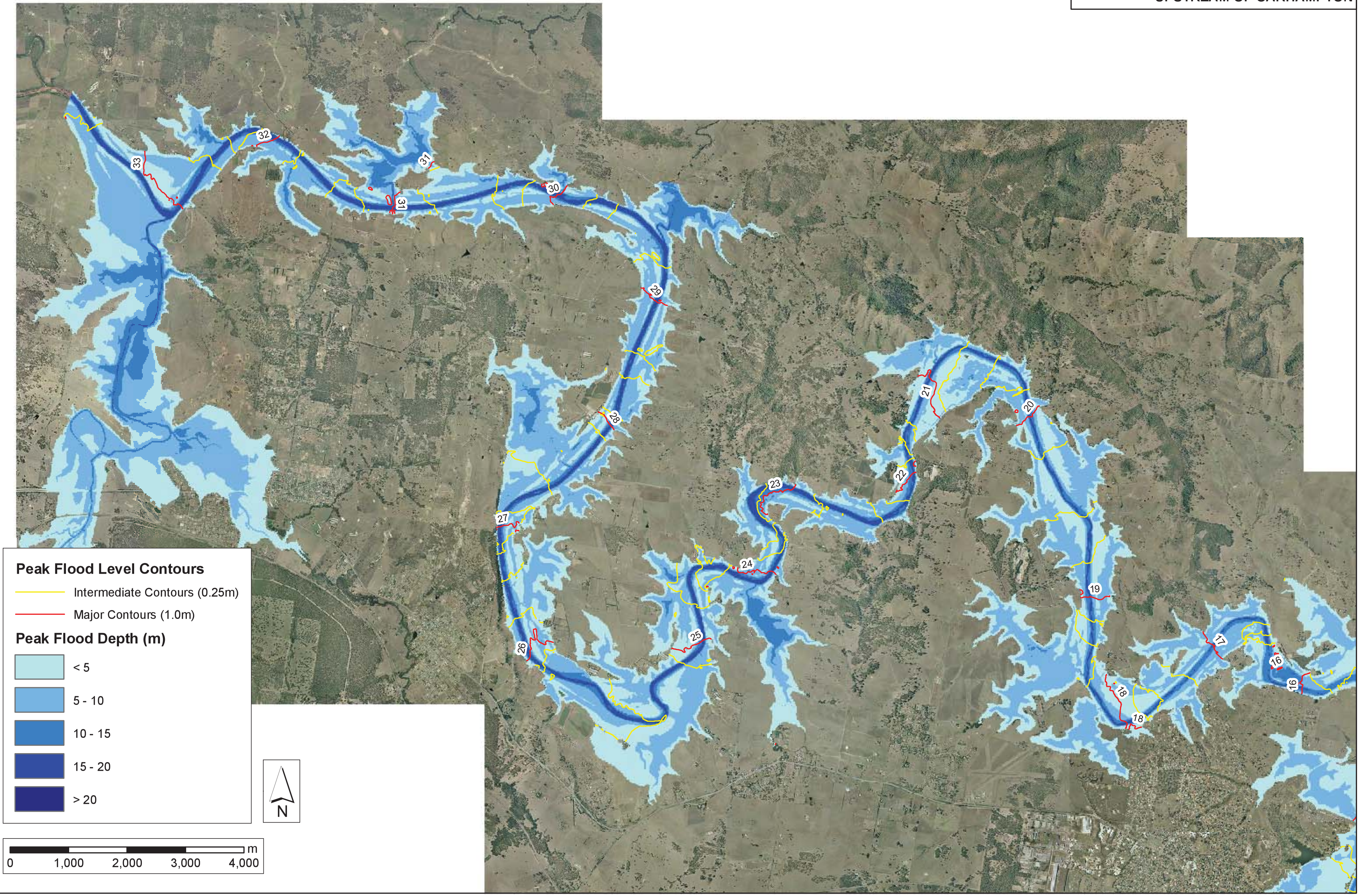
FIGURE 34
1% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure34_100y_Downstream.mxd

FIGURE 35

2% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure35_050y_Upstream.mxd

FIGURE 36
2% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON

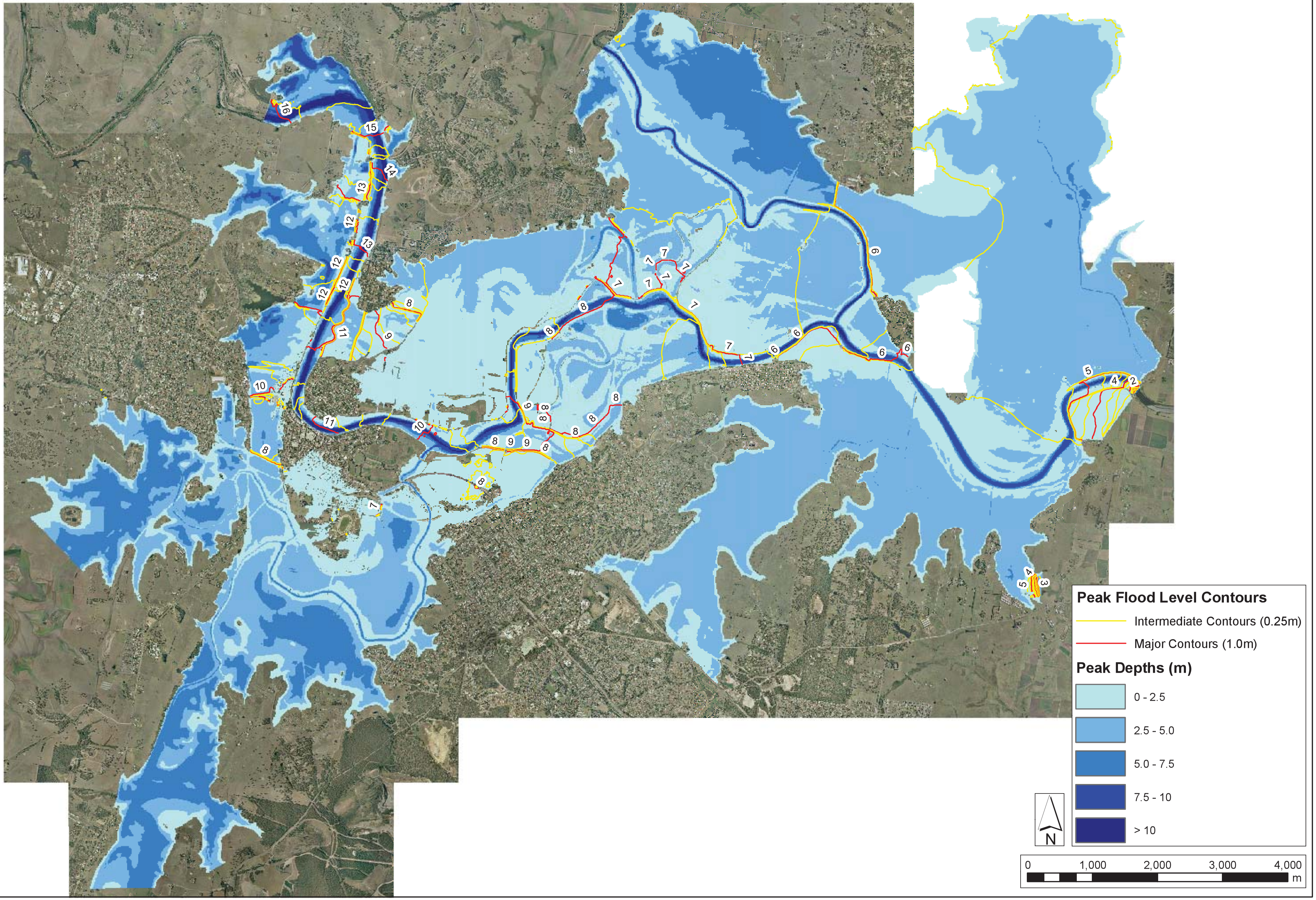
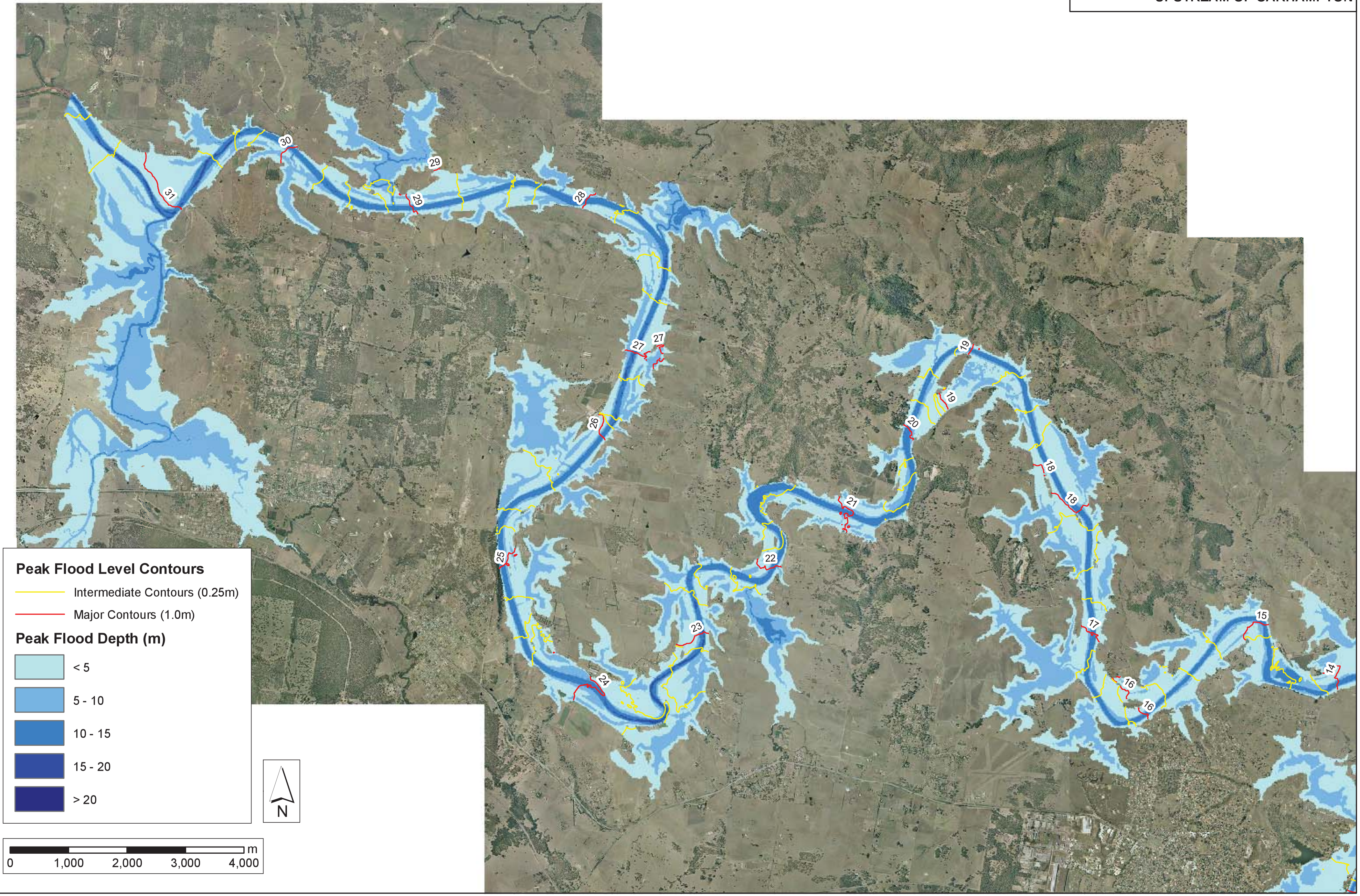


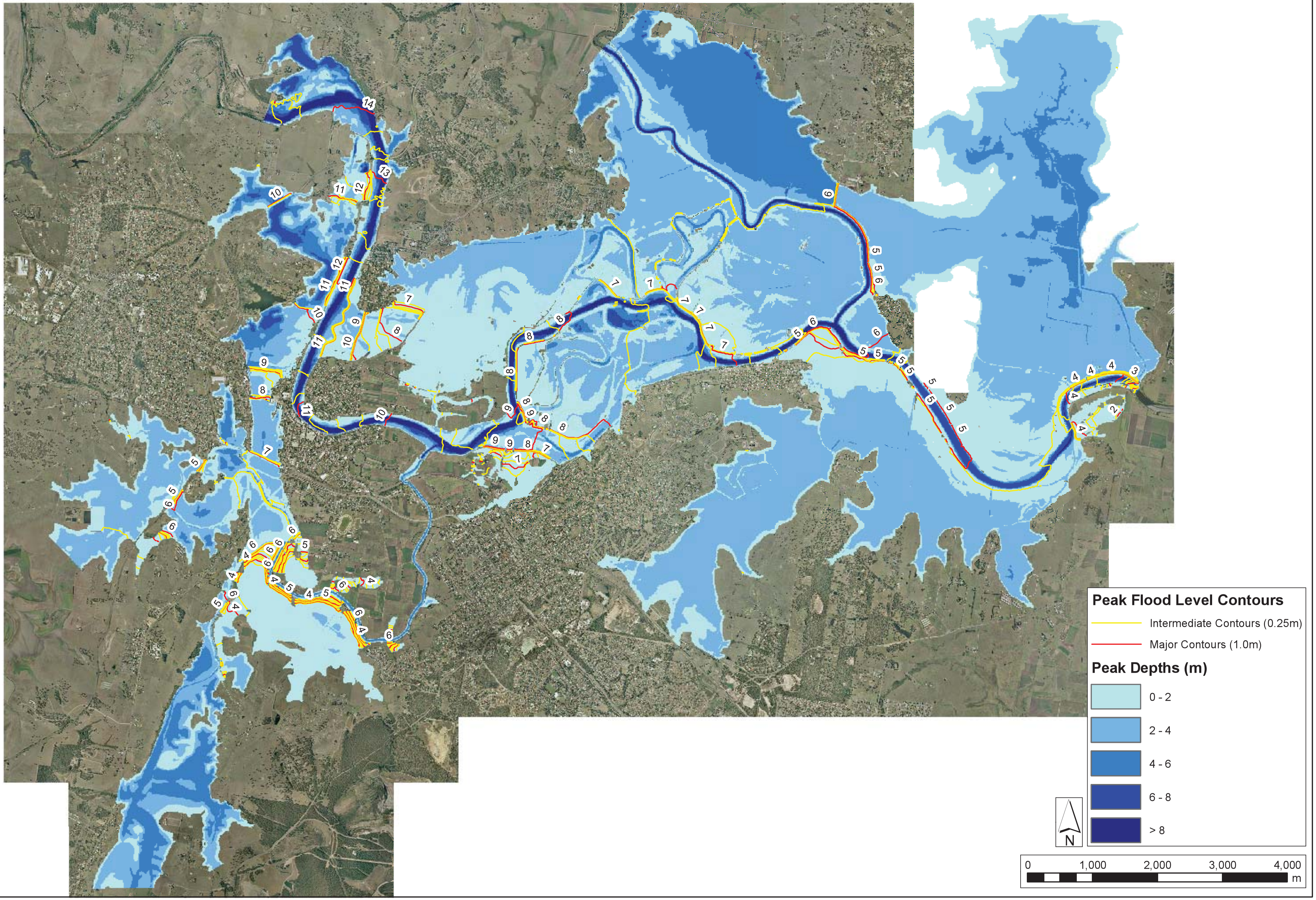
FIGURE 37

5% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure37_020y_Upstream.mxd

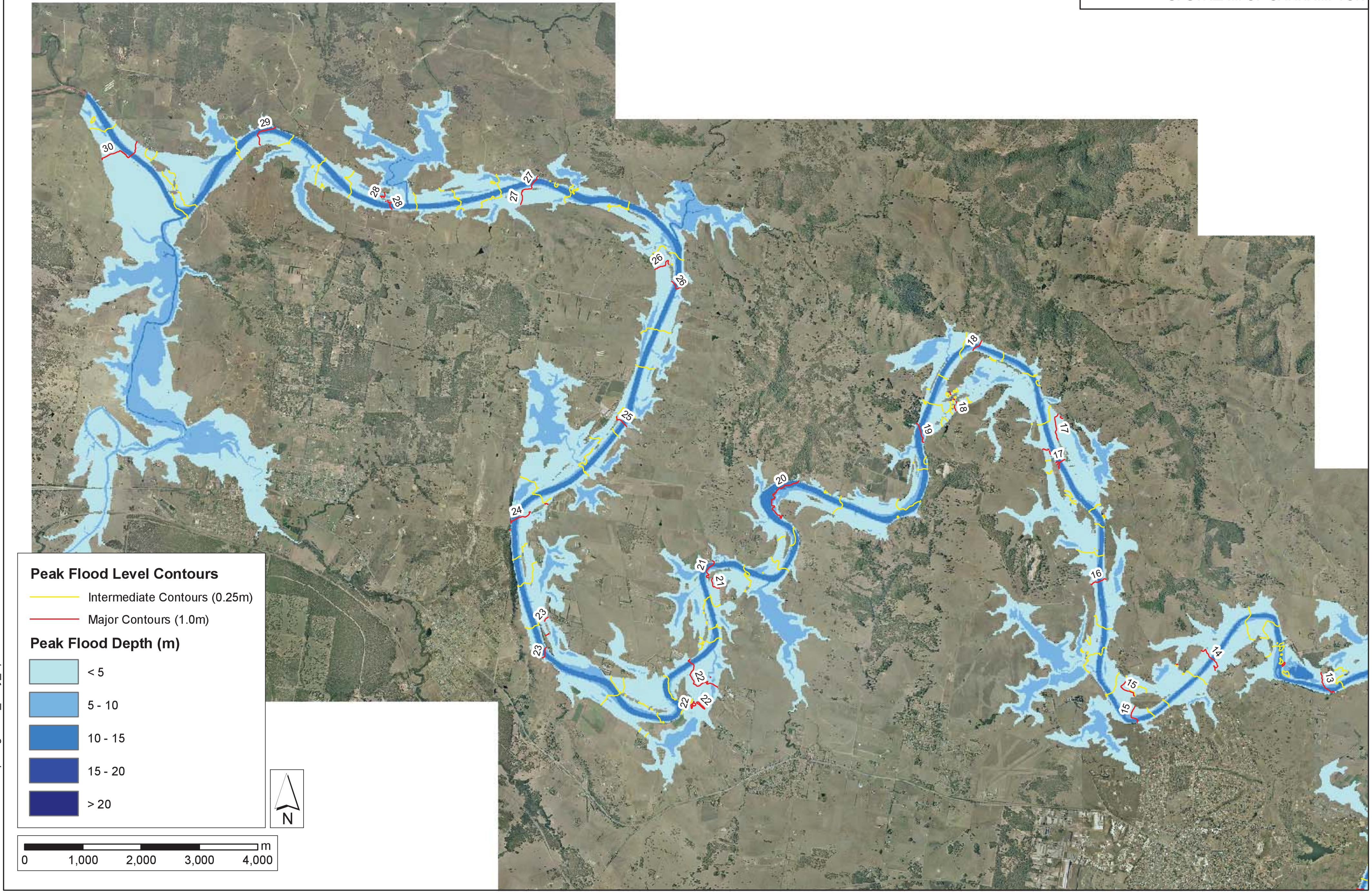
FIGURE 38
5% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure38_020y_Downstream.mxd

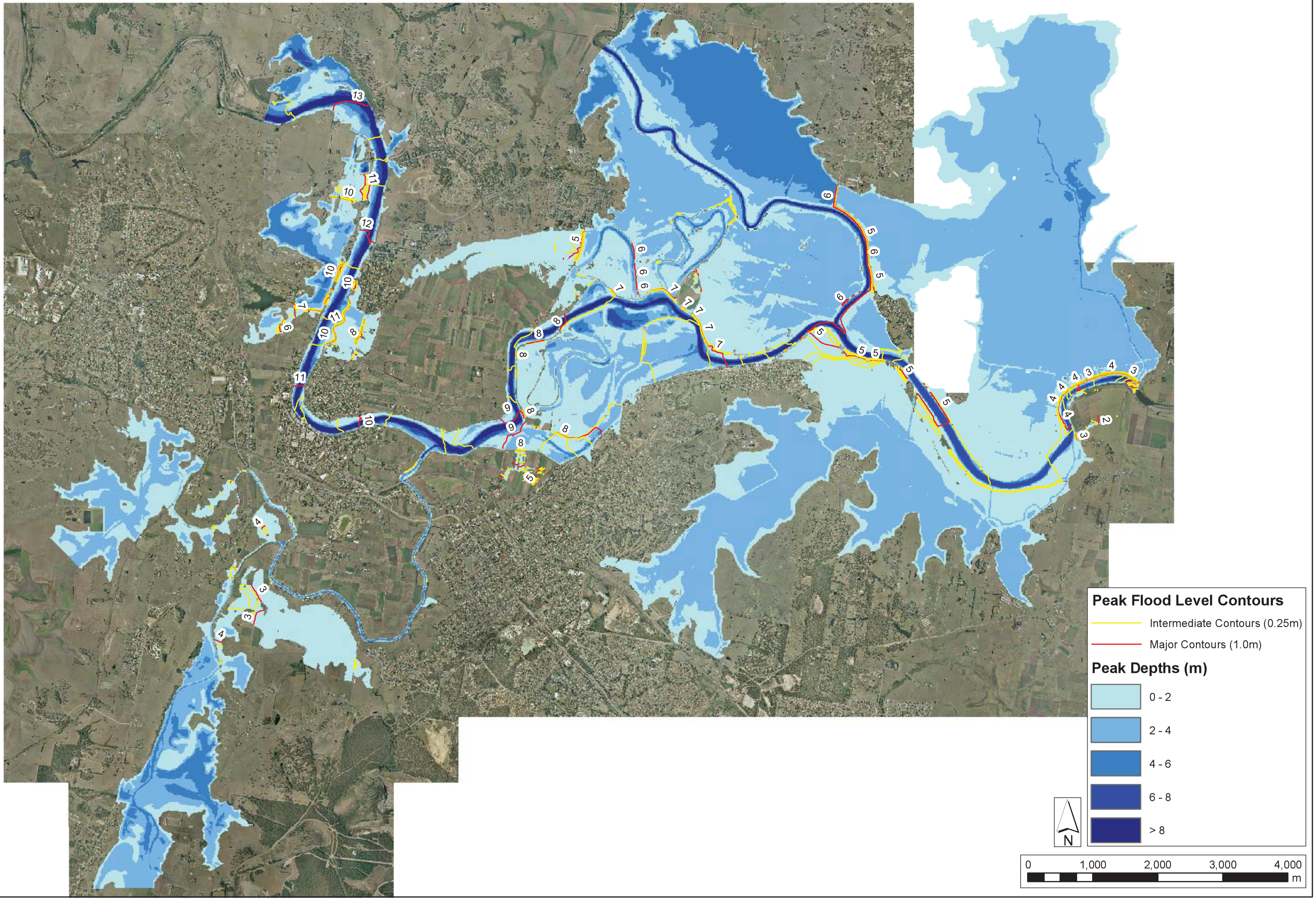
FIGURE 39

10% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure39_010y_Upstream.mxd

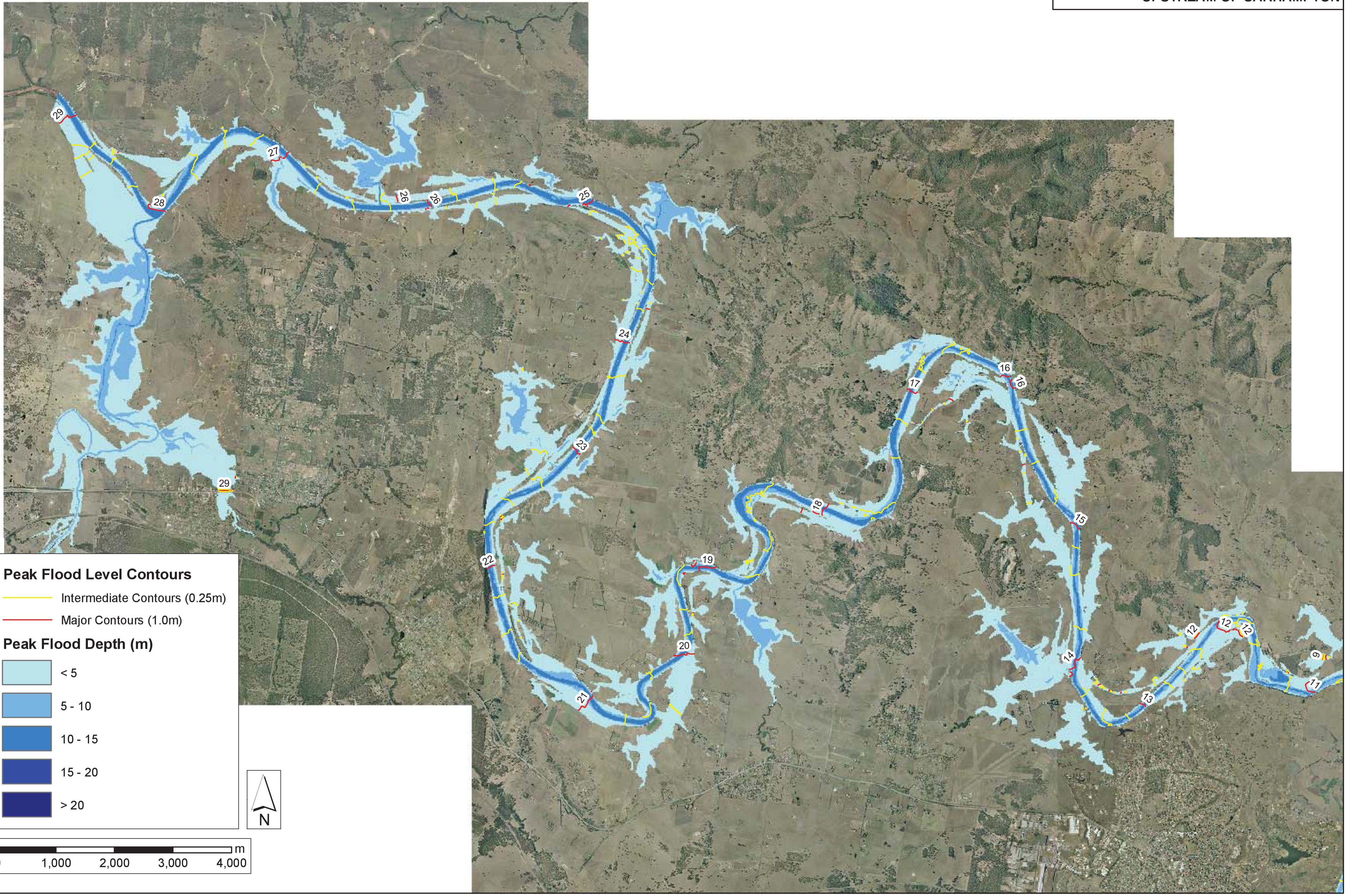
FIGURE 40
10% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure40_010y_Downstream.mxd

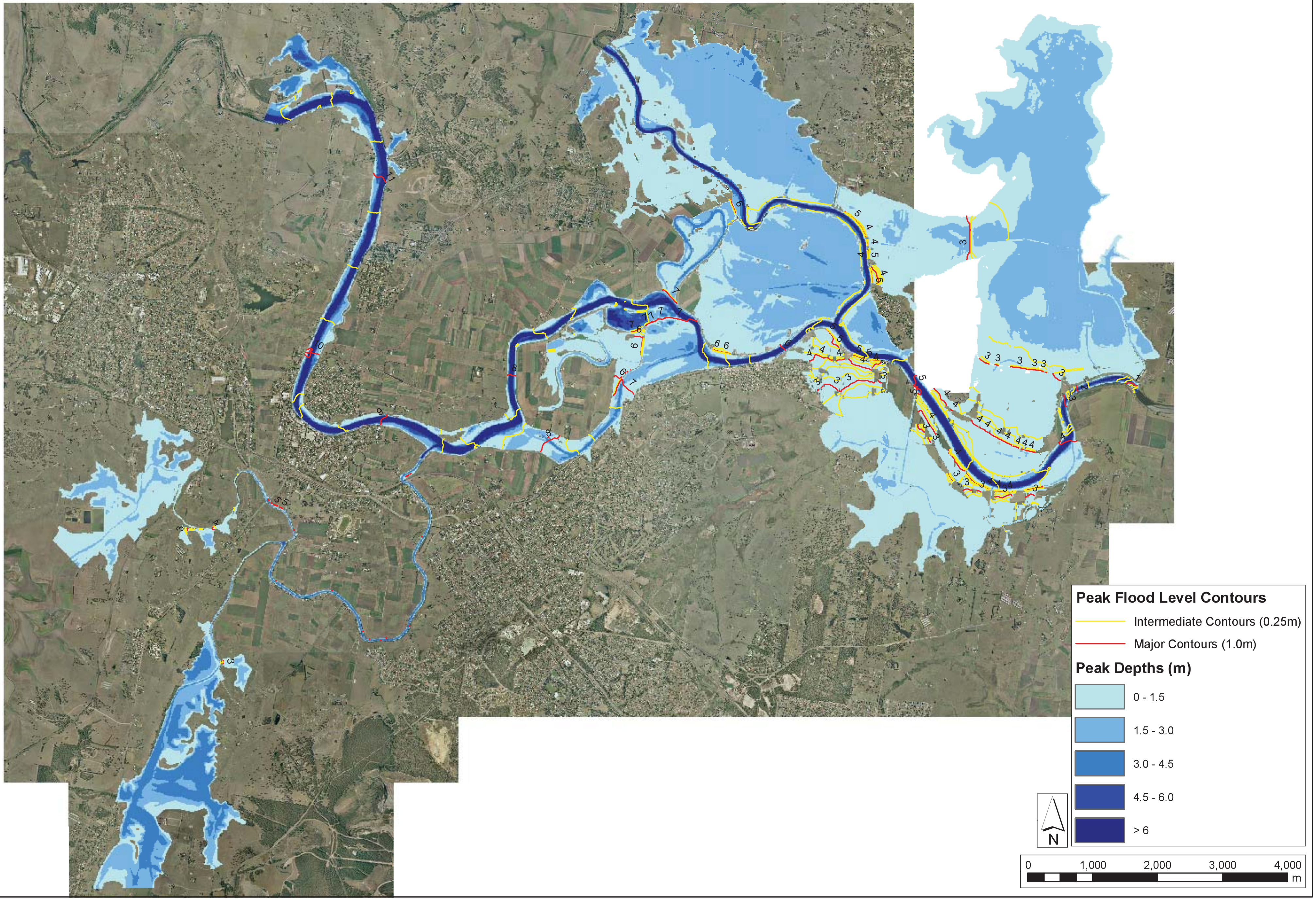
FIGURE 41

20% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure41_005y_Upstream.mxd

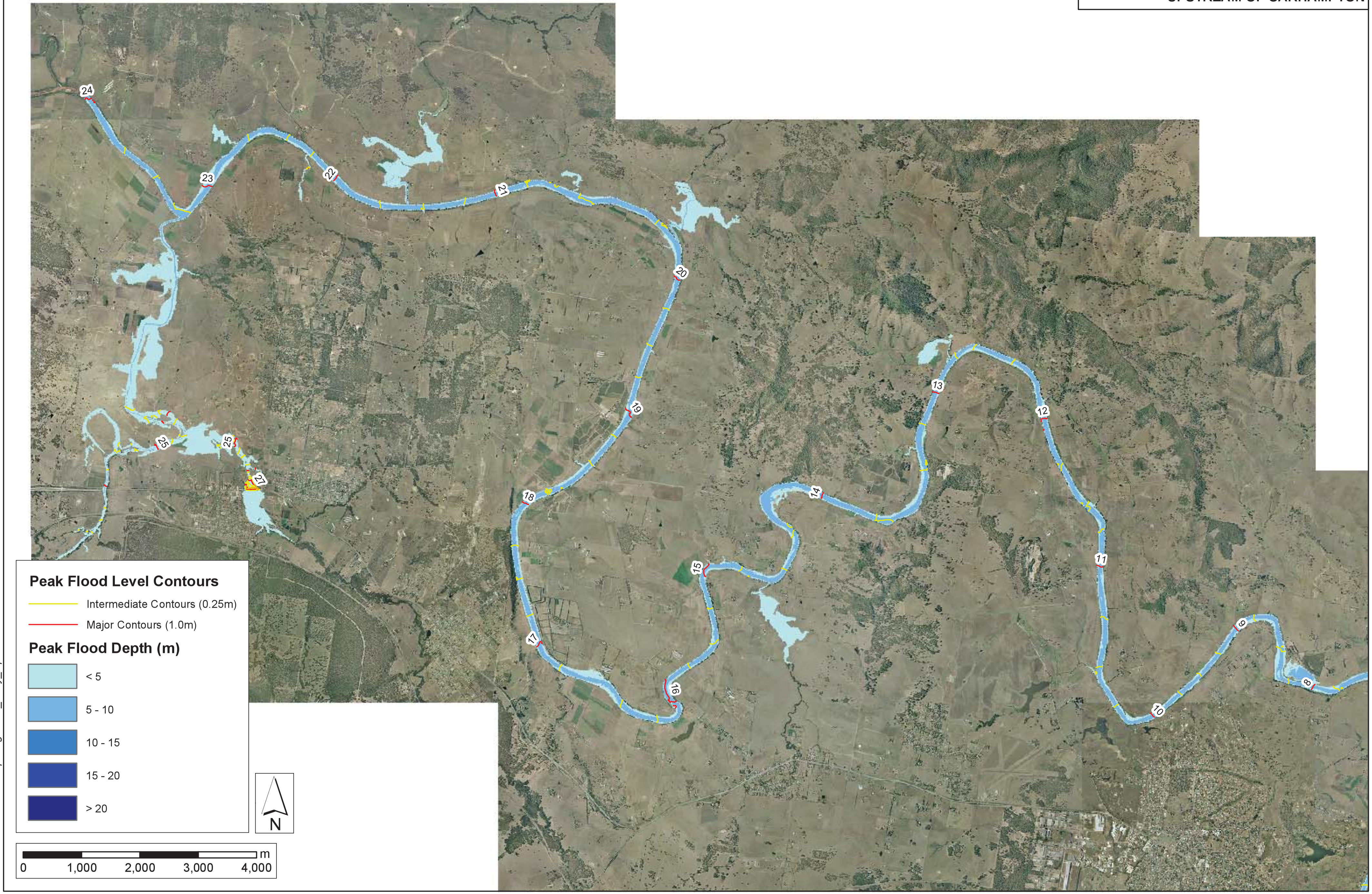
FIGURE 42
20% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure42_005y_Downstream.mxd

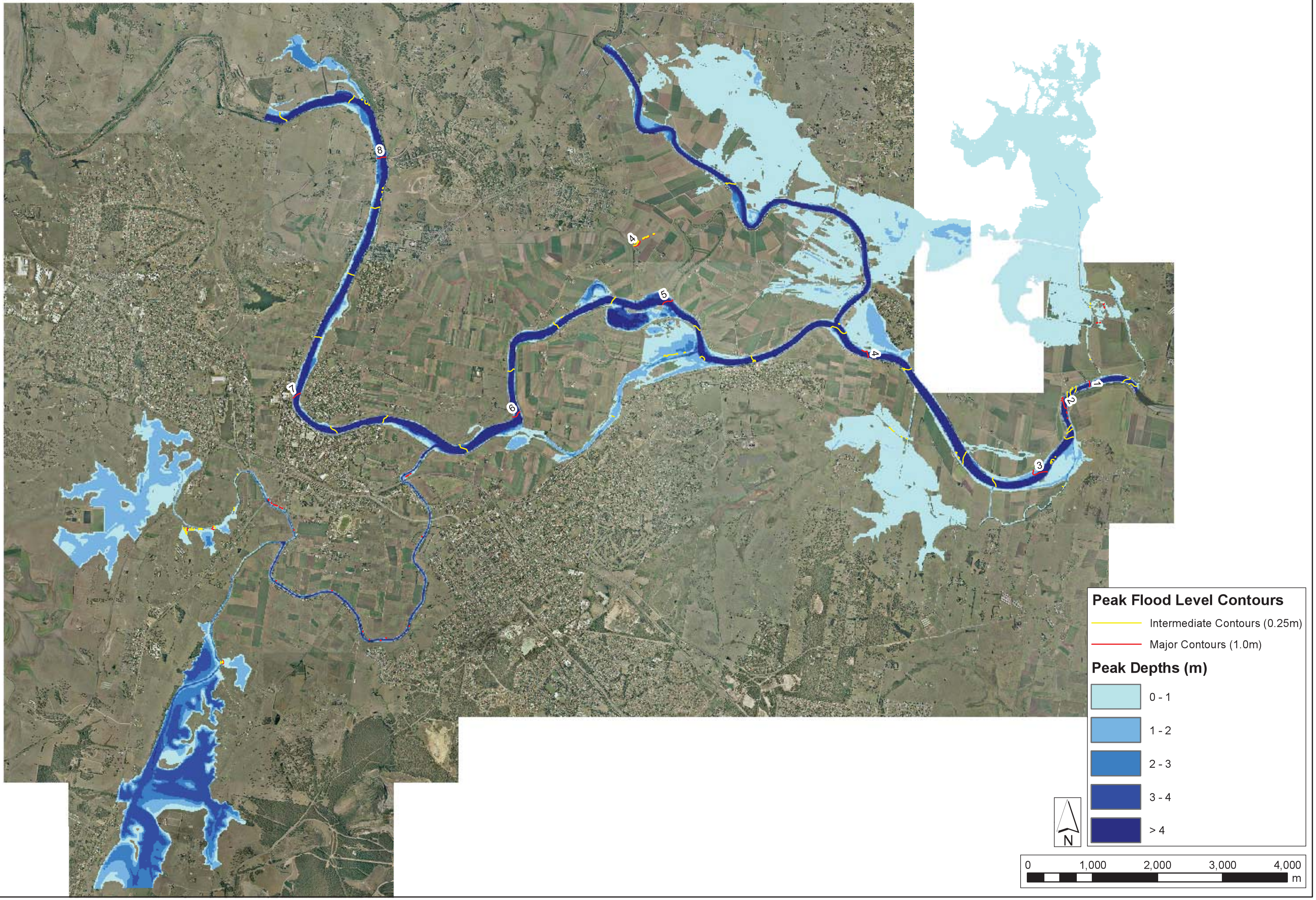
FIGURE 43

50% AEP FLOOD CONTOURS AND DEPTHS UPSTREAM OF OAKHAMPTON



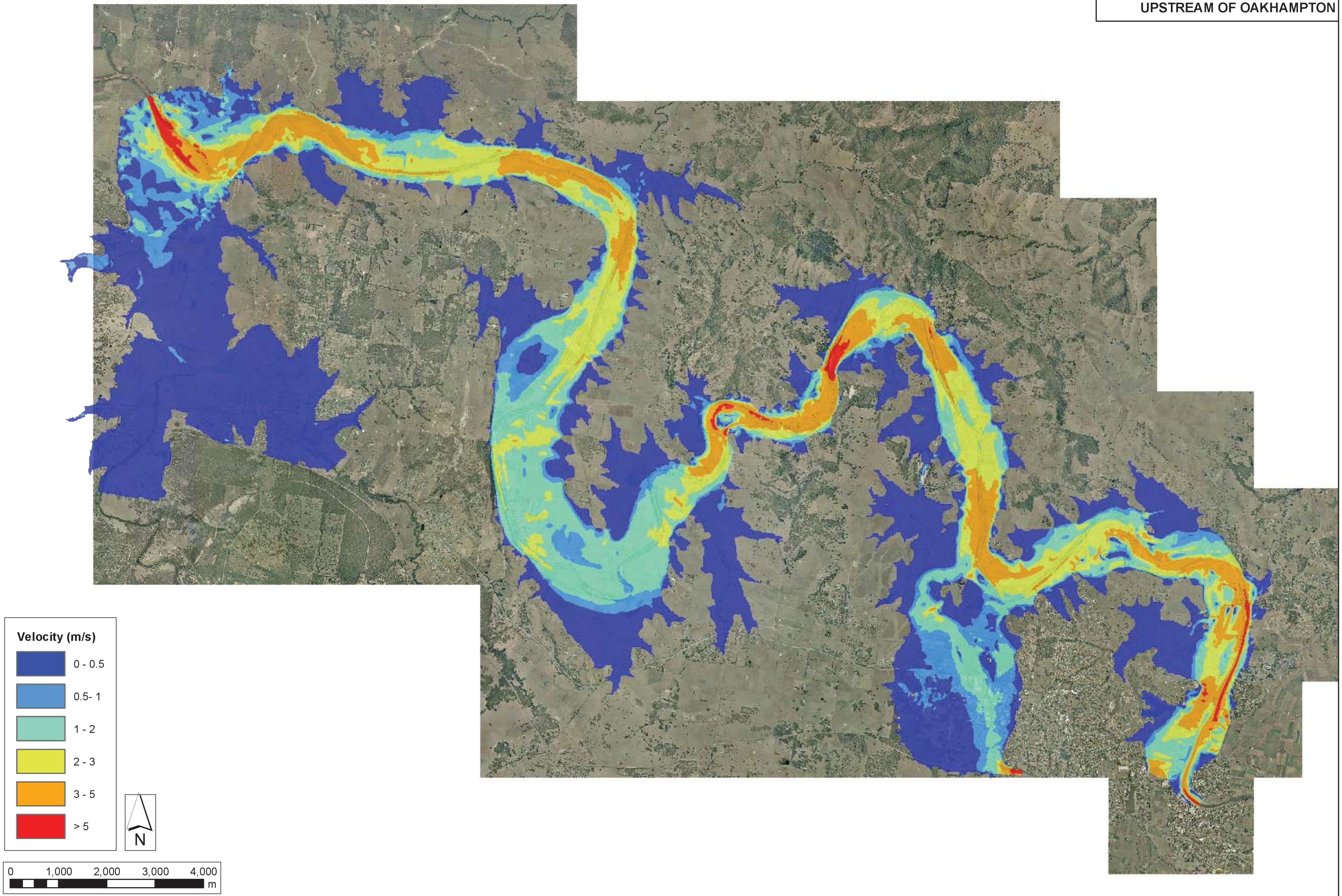
J:\Jobs\27036\ArcGIS\Maps\Figure43_002y_Upstream.mxd

FIGURE 44
50% AEP FLOOD CONTOURS AND DEPTHS DOWNSTREAM OF OAKHAMPTON



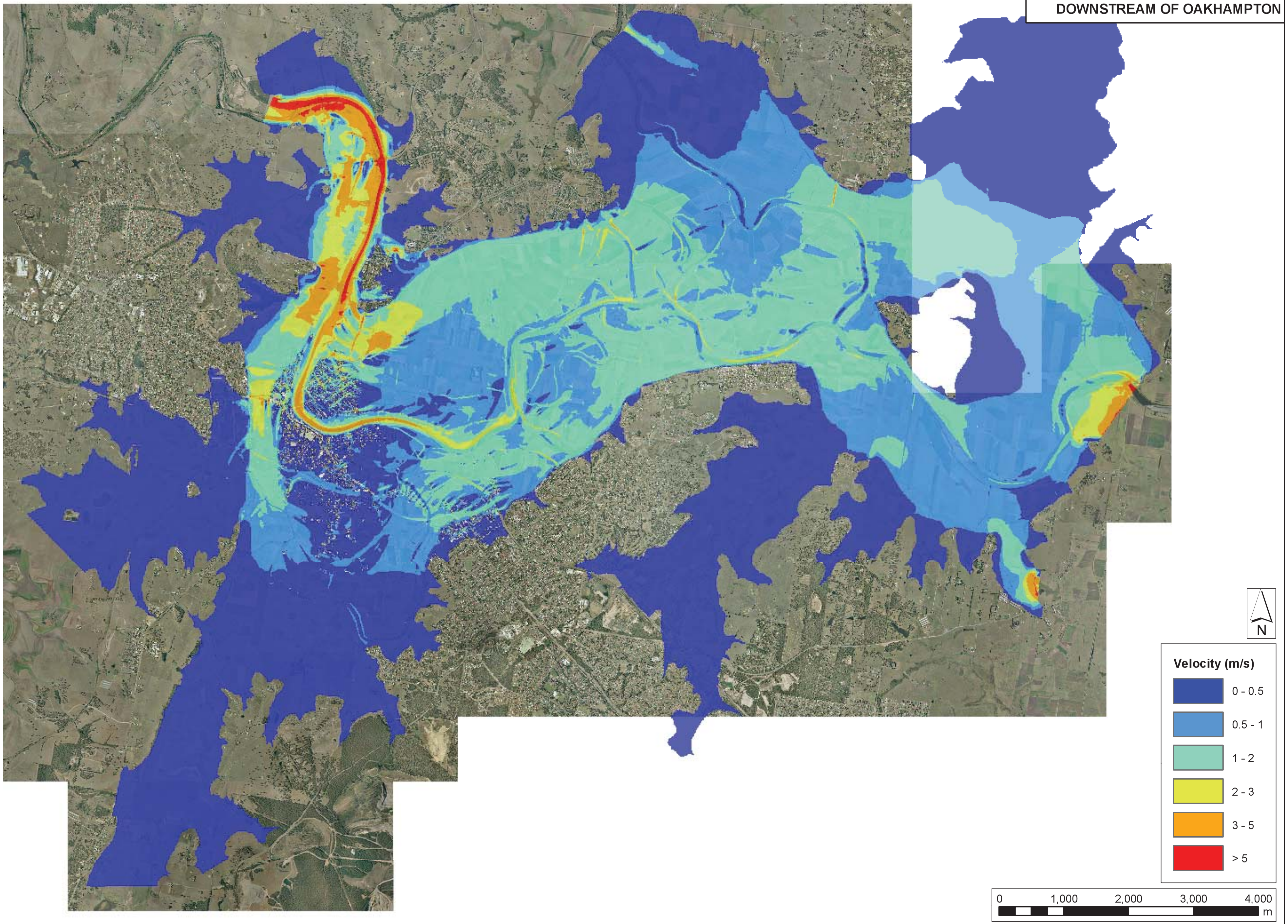
J:\Jobs\27036\ArcGIS\Maps\Figure44_002y_Downstream.mxd

FIGURE 45
EXTREME PEAK FLOOD VELOCITIES UPSTREAM OF OAKHAMPTON



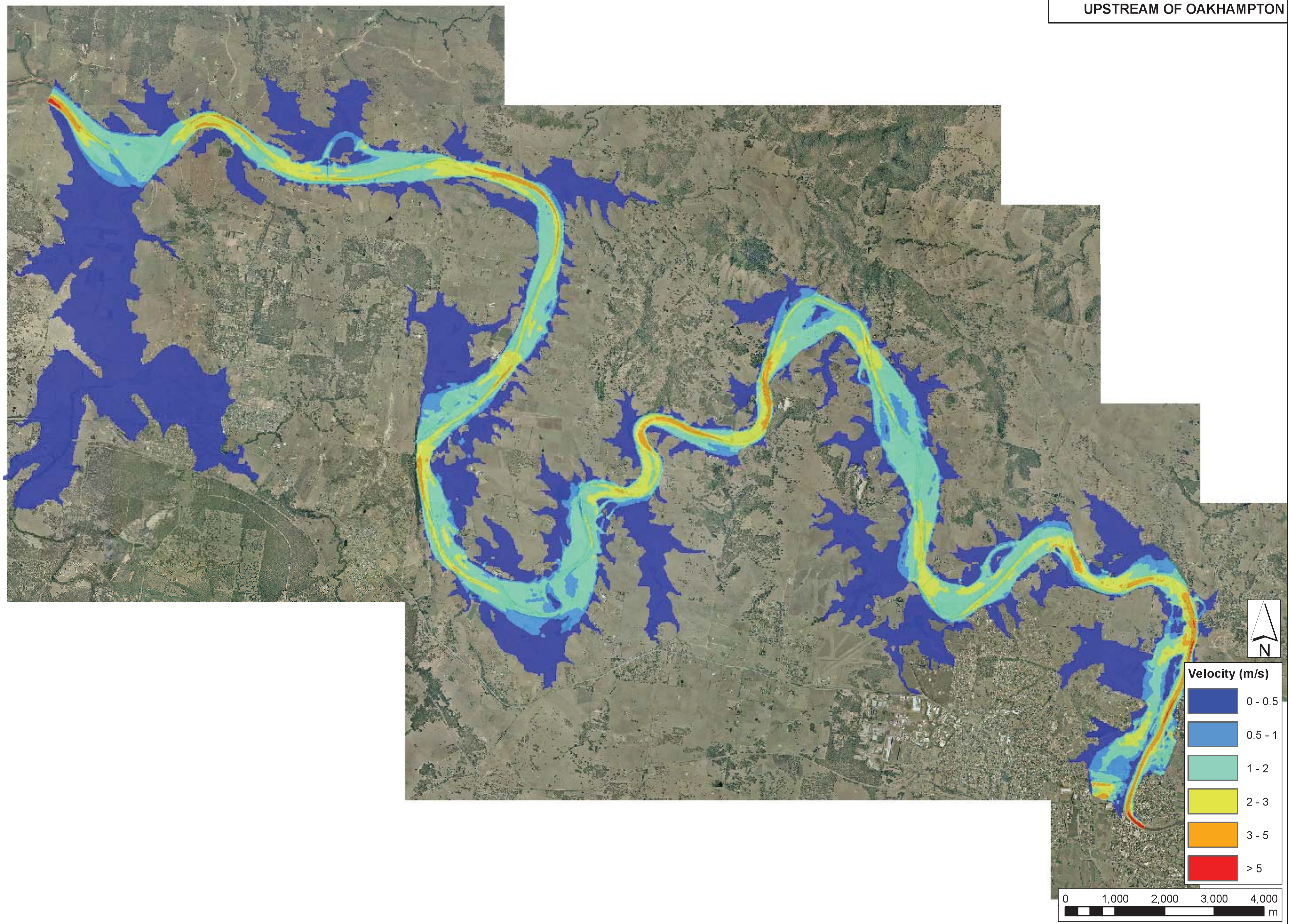
J:\Jobs\27036\ArcGIS\Maps\Figure45_PMF_Upstream.mxd

FIGURE 46
EXTREME PEAK FLOOD VELOCITIES DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure46_PMF_Downstream.mxd

FIGURE 47
1% AEP PEAK FLOOD VELOCITIES UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure47_100y_Upstream.mxd

FIGURE 48
1% AEP PEAK FLOOD VELOCITIES DOWNSTREAM OF OAKHAMPTON

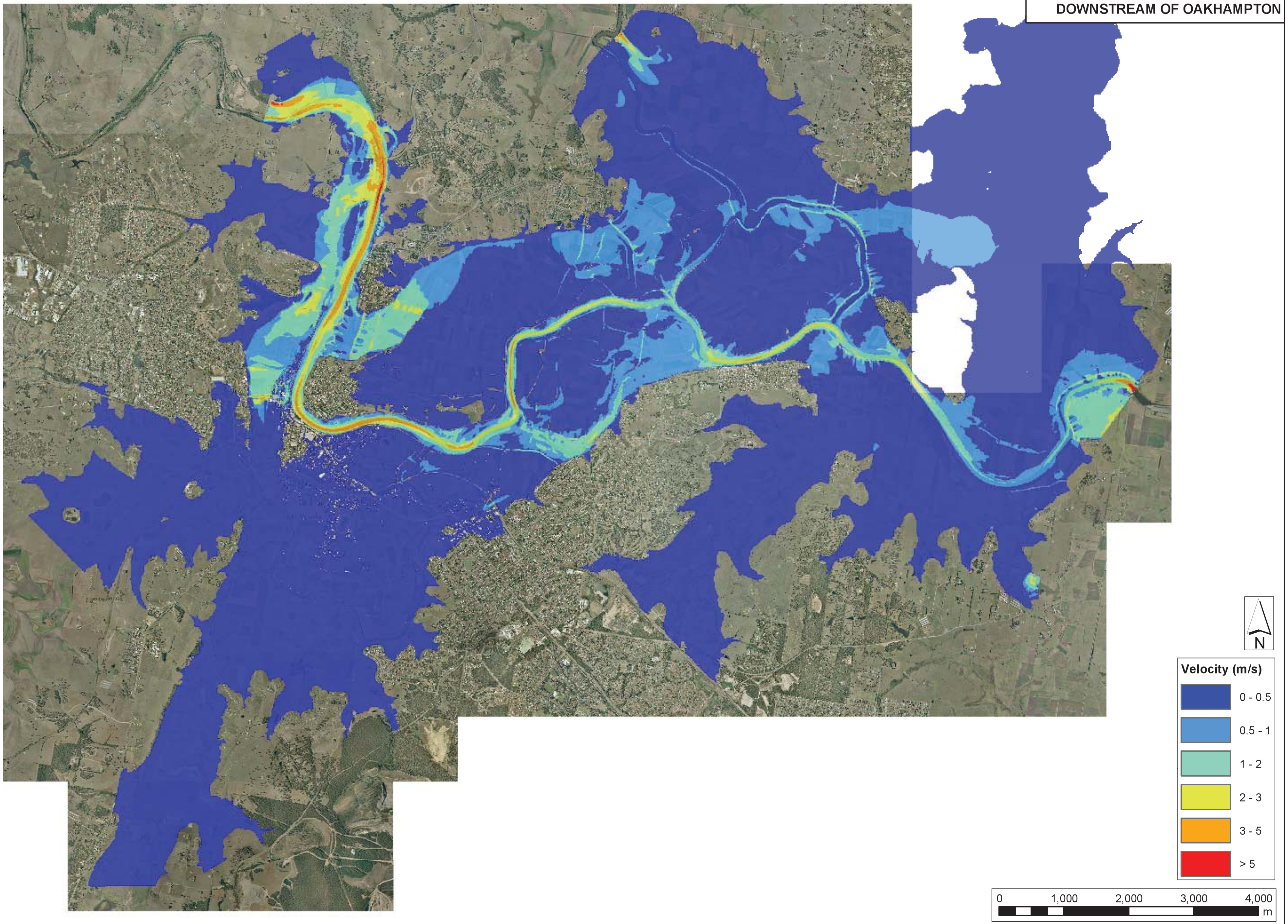


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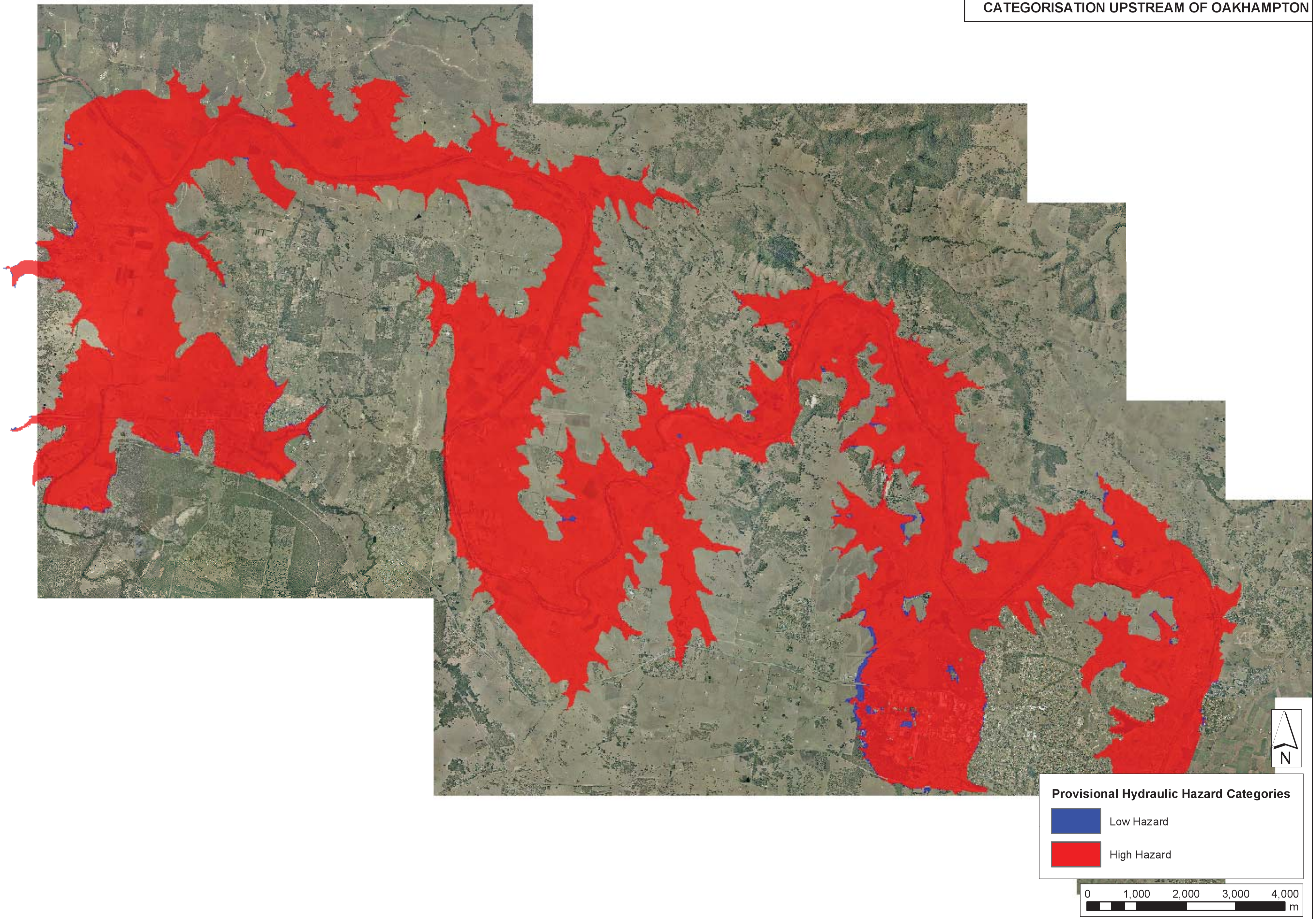
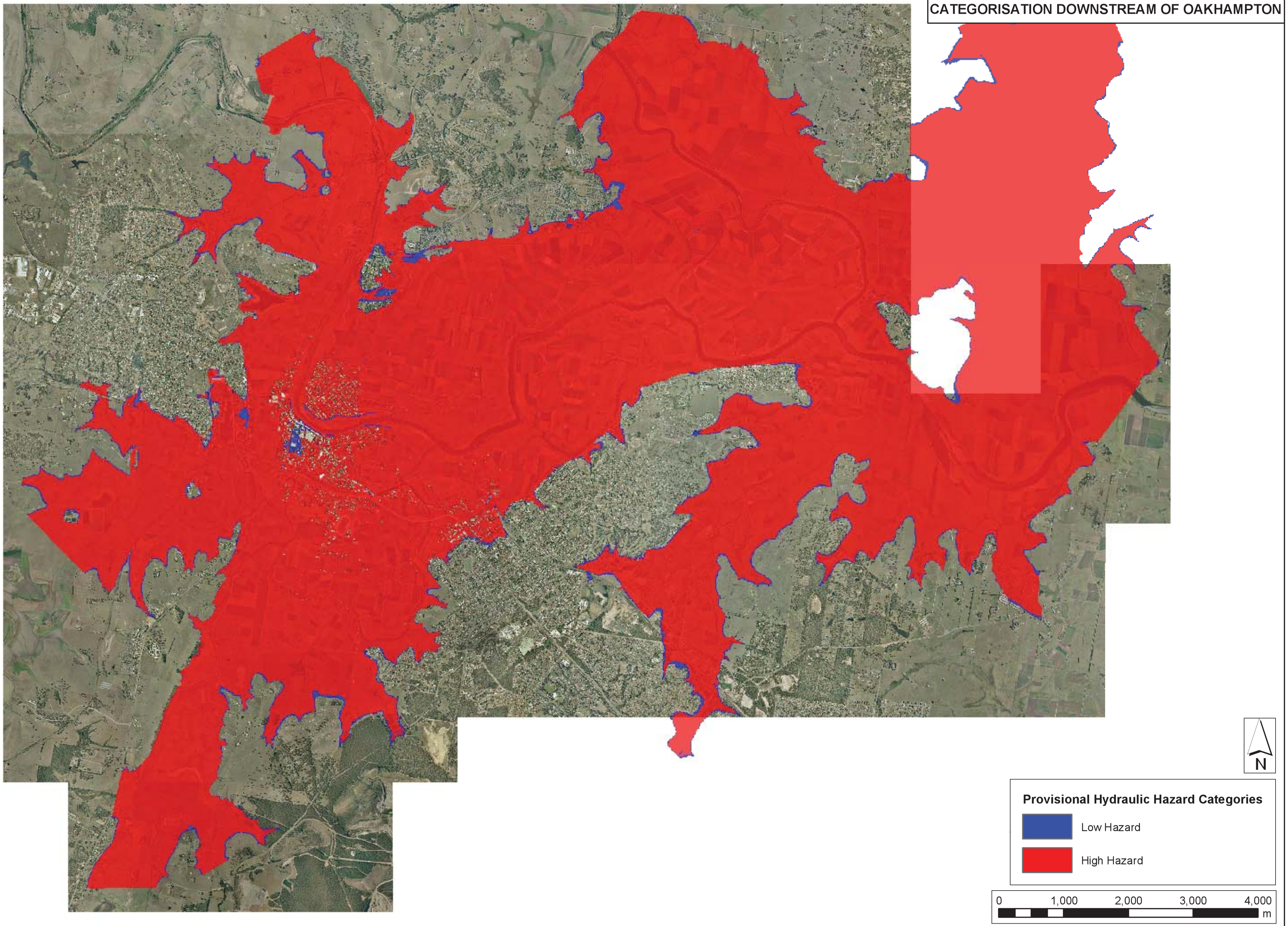
FIGURE 49
EXTREME FLOOD HAZARD AND HYDRAULIC CATEGORISATION UPSTREAM OF OAKHAMPTON



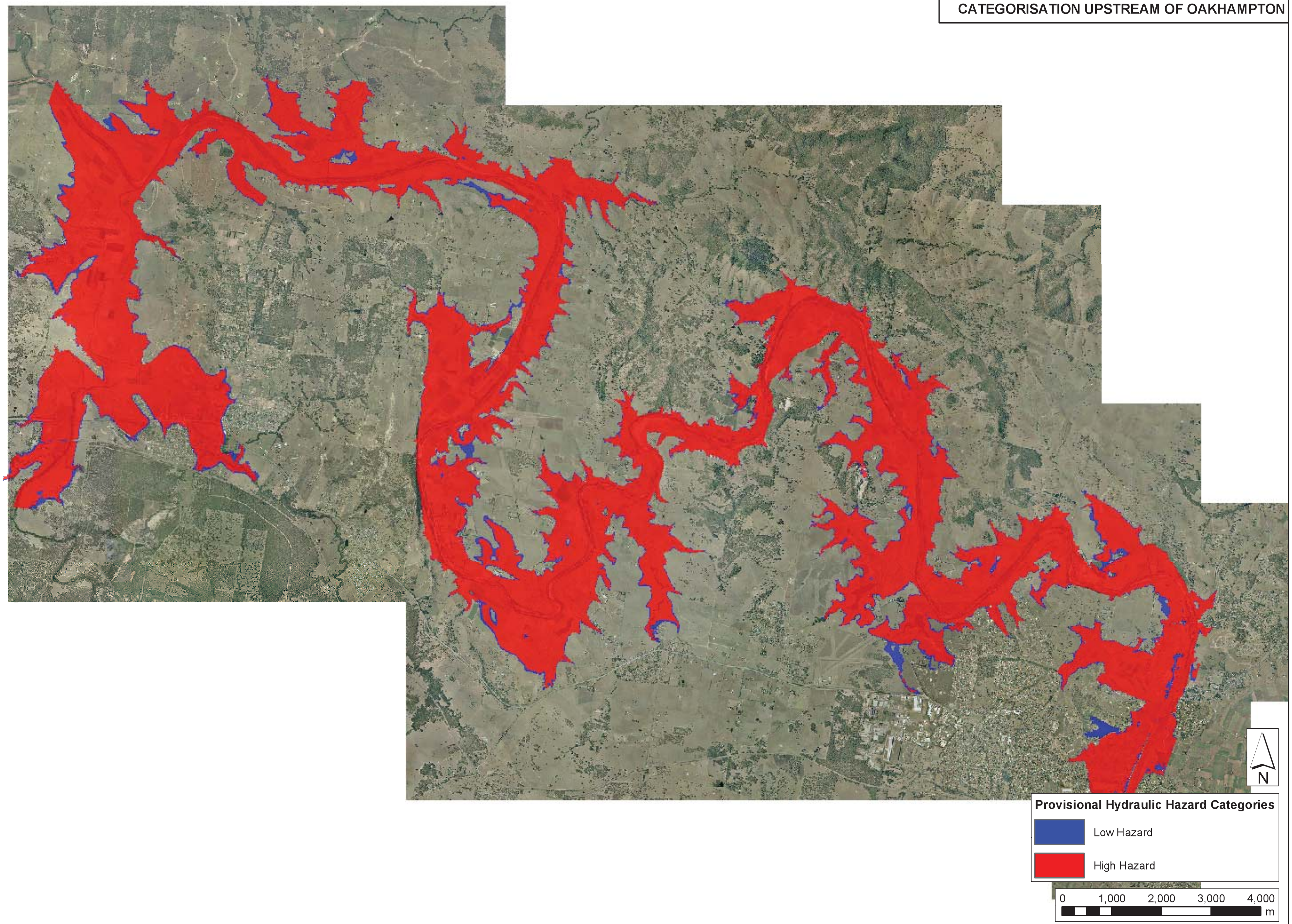
J:\Jobs\27036\ArcGIS\Maps\Figure49_PMF_Upstream.mxd

FIGURE 50
EXTREME FLOOD HAZARD AND HYDRAULIC CATEGORISATION DOWNSTREAM OF OAKHAMPTON



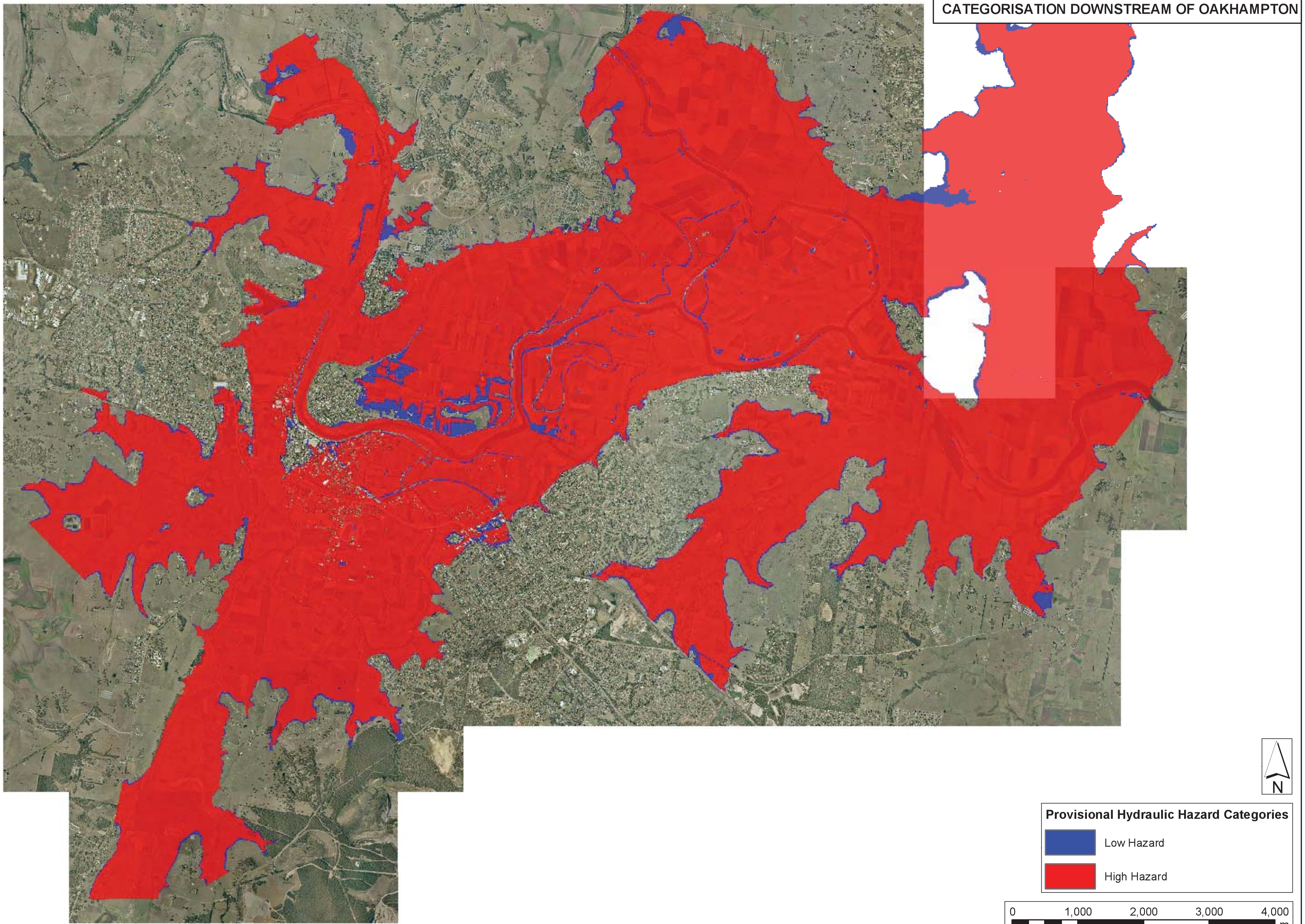
J:\Jobs\27036\ArcGIS\Maps\Figure50_PMF_Downstream.mxd

FIGURE 51
1% AEP FLOOD HAZARD AND HYDRAULIC CATEGORISATION UPSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure51_100y_Upstream.mxd

FIGURE 52
1% AEP FLOOD HAZARD AND HYDRAULIC CATEGORISATION DOWNSTREAM OF OAKHAMPTON



J:\Jobs\27036\ArcGIS\Maps\Figure52_100_Downstream.mxd