GOSFORD CITY COUNCIL

ERINA CREEK

FLOOD STUDY REVIEW

Final Report

August 2013

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ERINA CREEK FLOOD STUDY REVIEW

FINAL REPORT
AUGUST, 2013

Project **Erina Creek Flood Study Review**	**Project Number** **29040**
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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 and use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Erina Creek Flood Study Review constitutes the first stage of the management process for the areas adjacent to Erina Creek and has been prepared for Gosford City Council by WMAwater. This report supersedes the previous Erina Creek Flood Study Review 1990 and provides the basis for the future management of flood liable lands along Erina Creek.

In the next stage a Floodplain Risk Management Study will be undertaken which will use the design flood level information developed in the Flood Study to determine the extent of the flood problem and then to evaluate management measures. The Floodplain Risk Management Plan provides the approaches to be undertaken for the future management of the Erina Creek floodplain.

This Flood Study has been undertaken in accordance with the guidelines provided in the NSW Government's Floodplain Development Manual (April 2005).

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SUMMARY

This Erina Creek Flood Study Review was undertaken to determine the design flood levels applicable to the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events. Whilst the study area for hydrologic modelling was taken as the entire catchment, detailed hydraulic modelling and definition of design flood levels was limited to the floodplain where there is a defined creek channel. Thus in the heavily vegetated areas in the upper part of the catchment where the channel is ill defined (based on the ALS survey) flood levels are not provided, although an indicative flood extent has been determined in these areas along the major drainage lines.

This present Flood Study Review updates and supersedes the Erina Creek Flood Study Review 1990 completed in 1991 and uses current hydraulic modelling techniques (a 2D hydraulic model) as well as the inclusion of Airborne Laser Scanning (ALS) survey data. The modelling approach has also benefited from being verified against the June 2007 flood as well as the other historical events (February 1990) used in the Erina Creek Flood Study Review 1990 report.

Erina Creek has a catchment area of approximately 32 square kilometres to its confluence with Brisbane Water which exits into Broken Bay. Flood levels in the lower reaches of Erina Creek are influenced by flood levels in Brisbane Water. For this reason it was necessary to consider the interaction of flooding from Brisbane Water with the local Erina Creek catchment flows.

Significant flooding of Erina Creek is known to have occurred in:

- March 1977,
- January 1978,
- February 1981,
- November 1984,
- October 1985,
- April 1988,
- January 1989,
- 4th and 7th February 1990,
- February 1992,
- 8th June 2007.

A hydrologic model (WBNM) was used to calculate run-off hydrographs from rainfall. A 1D/2D hydraulic model (TUFLOW) was used to calculate flood levels and velocities based on the calculated inflow hydrographs. The modelling approach was able to be calibrated to historical flood data included in the Erina Creek Flood Study Review 1990 and collected for the June 2007 event as part of the present study. The latter was obtained from a post flood survey undertaken by Gosford City Council and as a result of a newsletter mailed to local residents seeking details of past floods.

Design rainfall intensities and temporal pattern were obtained from Australian Rainfall and Runoff (1987) and applied to the catchment to determine the relevant design flood hydrographs for each of the tributary creeks. Rainfall and ocean level increases due to potential climate change are based upon the current Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water) guidelines.

The peak flood levels for Erina Creek were obtained using an envelope of the Brisbane Water

and Erina Creek design flood levels. Design flood levels at the confluence with Brisbane Water were taken from the 2009 Brisbane Water Flood Study. These levels were obtained from the critical design storm of 9 hour duration over Brisbane Water. Critical duration storms for Erina Creek were the 6 and 9 hour durations with the tributaries to Erina Creek obtained from the 2 hour duration (all events except the PMF). The critical storm duration for Erina Creek for the PMF event was found to be 2.5 hours and for all tributary creeks 1 hour.

This report provides design flood levels, contours, peak flows, flood extents and velocities for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events, as well as hydraulic and hazard categorisation.

The main factor affecting the accuracy of the design flood levels is the availability of historical flood height data. It is imperative therefore that following each future flood event Gosford City Council and government authorities collect as much data (peak levels, extents) as possible immediately following the flood. This was successfully undertaken for the June 2007 event.

Due to the limited quality and quantity of the calibration data available and in view of the sensitivity analysis, it is estimated that the order of accuracy of absolute flood levels is up to ±0.3m for the main Erina Creek channel and ±0.5m within the tributary creeks. These orders of accuracy are typical for such studies and can only be improved upon with additional observed flood data to refine the model calibration. The flood extent mapping (Appendix D) is considered of high accuracy due to the use of ALS.

1. INTRODUCTION

1.1. General

The 32km^2 Erina Creek catchment is one of the major tributaries entering Brisbane Water at East Gosford (Figure 1). Figure 2 shows a digital terrain image of the study area and Figures 3 to 5 show further detail of the study area. Figure 6 indicates the current land use zones.

The Erina Creek Flood Study Review 1990 was completed in 1991 (Reference 1), which utilised information available and current at the time hydrologic and hydraulic models to produce design flood profiles along the lower parts of Erina Creek. The aim of the present study is to update the Erina Creek Flood Study Review 1990 with currently available data, notably the use of airborne laser scanning (ALS) data and more sophisticated hydraulic modelling techniques as well as verification to the June 2007 event.

All earlier flood studies of Erina Creek were superseded with completion of the Erina Creek Flood Study Review 1990.

1.2. Objectives

WMAwater was engaged by Gosford City Council to undertake the Erina Creek Flood Study Review utilising current technology and data. The information and results obtained from the study will provide a basis for development of targeted stormwater management strategies and a subsequent Floodplain Risk Management Study and Plan.

The study was developed in order to meet the primary objective of defining the flood behaviour (50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and the Probable Maximum Flood (PMF) design events) along the major tributaries in the Erina Creek catchment. The study area was significantly greater than for the previous 1991 Flood Study.

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

- a summary of available historical flood related data,
- discussion on the calibration of the hydrologic and hydraulic models,
- definition of the design flood behaviour for existing conditions through the analysis and interpretation of model results,
- sensitivity and climate change analysis.

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

2. BACKGROUND

2.1. Study Area

Erina Creek discharges into Brisbane Water in East Gosford and has a catchment area of 32 square kilometres. The catchment land use is a mixture of rural and residential with significant light industrial and commercial areas in the lower reaches. The catchment has been extensively urbanised over the last 20 years with the development of residential areas and Erina Fair in the east.

Erina Creek rises in the hills of the Ridgeway District, approximately 5 kilometres inland from the coast. The creek flows in a south-westerly direction discharging into Brisbane Water at the Punt Bridge. The catchment includes the suburbs (part or all) of Matcham, Erina Heights, Holgate, Mount Elliot, Erina, Springfield, Green Point and East Gosford.

The upper portion of the Erina Creek catchment is fairly steep and the slopes are largely heavily vegetated. The lower portion is an area of general low relief, particularly surrounding the tidal extent downstream of the Central Coast Highway crossing of the Worthing Road Creek catchment.

There are two major tributaries to Erina Creek, Worthing Road Creek catchment which enters downstream of Carlton Road and Nunns Creek which enters downstream of Karalta Road under the Central Coast Highway. Flooding is a known concern in the floodplain and significant hardship and damage were experienced in floods prior to the mid 1990's namely:

- March 1977
- January 1978,
- February 1981,
- November 1984,
- October 1985,
- April 1988,
- January 1989,
- 4th and 7th February 1990,
- February 1992.

Since 1992 the only flood of any significance was on 8th June 2007 (known in the Newcastle area as the Pasha Bulker storm).

An extensive floodplain develops downstream of Milina Road as the topography flattens out. The creek is tidal to nearly the confluence with the Worthing Road Creek (unofficial name) catchment at the Central Coast Highway with the reach downstream of Barralong Road lined by mangroves and approximately 10 to 20m wide. The northern bank in this reach is heavily vegetated in a semi natural state.

2.2. Works Undertaken in the Catchment that have Affected the Flood Regime

Human activities in the catchment have had a significant effect on the flood regime in the catchment. These can be broadly categorised into two types, those that increase the quantity of runoff entering the floodplain areas and those that affect the hydraulics of the floodplain.

The former includes works such as land clearing which have increased the rate and quantity of runoff and thus increased peak flows downstream. Similarly, urban development will have increased the amount of impervious area and produced a similar impact. These activities have been occurring since the time of white settlement, however it is probably only in the last 50 years that the quantity of the activities has been such that it has been of significance. Unfortunately there is no “accurate” means of assessing these impacts, though technical papers provide a general indication.

No large land clearing has occurred since the early 1990’s but major urban growth areas have occurred adjacent to Terrigal Drive and Karalta Road which drain into Worthing Road Creek. However some compensation measures such as the retarding basin in the lands of the Tarragal Retirement Village have been designed to mitigate the peak flow increases and will also provide some water quality benefit.

All works on the floodplain (filling, stream clearing, re-vegetation, road works) will have affected the hydraulics of the floodplain to some extent. These impacts can be evaluated with the use of hydraulic models. Since completion of References 1 to 3 Gosford City Council has ensured that all major works on the floodplain require a flood study to evaluate the potential hydraulic impacts. Considerable minor works are continually being undertaken, the following provides a description of the major works known to have occurred since the early 1990’s.

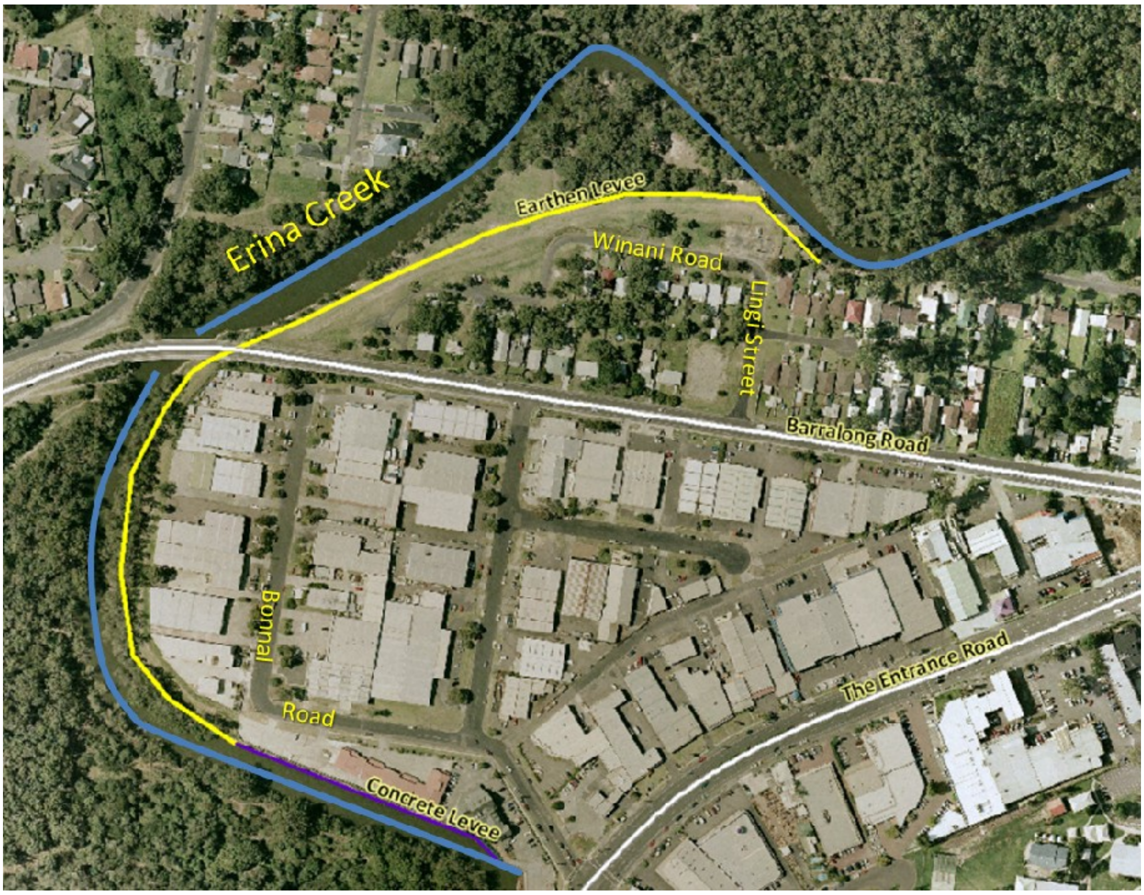
All major works on the floodplain (as described above and in the following sections) have been incorporated in the hydrologic/hydraulic modelling process as far as is possible. Thus for the modelling of the historical events the models represent the catchment at the time of the flood event rather than as it is today. However as there was no detailed survey of the floodplain undertaken prior to this study, it is impossible to accurately define the floodplain and catchment at the time of the historical flood events (e.g changes in the density of vegetation or fences in the floodplain). The modelling process, whilst the most up to date that is available, is limited in its ability to accurately represent small scale or subtle changes to the catchment.

2.2.1. Barralong Road Levee

Following on from the 1991 Erina Creek Flood Study Review 1990, the Erina Creek Floodplain Management Study and Plan were completed in 1991 (References 2 and 3). One of the recommendations was construction of the Barralong Road levee system. The earthen and concrete wall levee was completed in the late 1990’s and protects the majority of the urban areas near Barralong Road, Winani Road, Bonnal Road and Aston Road (refer to Photograph

1). A bridge was also constructed across Erina Creek connecting Barralong Road to Wells Street.

Reference 3 indicates that the 1% AEP flood levels would be increased by approximately 0.1m due to its construction. Four houses upstream of the Central Coast Highway in the Worthing Road Creek catchment were purchased as part of the works so that the owners would not be affected by increased flood levels as a result of the works.



Photograph 1: Earthen and concrete levees close to Barralong Road

2.2.2. Works Upstream of Terrigal Drive

Significant urban development has occurred in this southern tributary of the Worthing Road Creek catchment (refer to Photograph 2) including;

- Erina Fair,
- Terrigal Glen retirement village,
- Residential developments,
- Landscaping of the creek.

Photograph 2: Urban development in the vicinity of Worthing Road Creek

However hydrologic studies were undertaken prior to the construction of these works to ensure that any increases in peak flows were mitigated through construction of the Worthing Road Creek retarding basin (refer to Photograph 8).

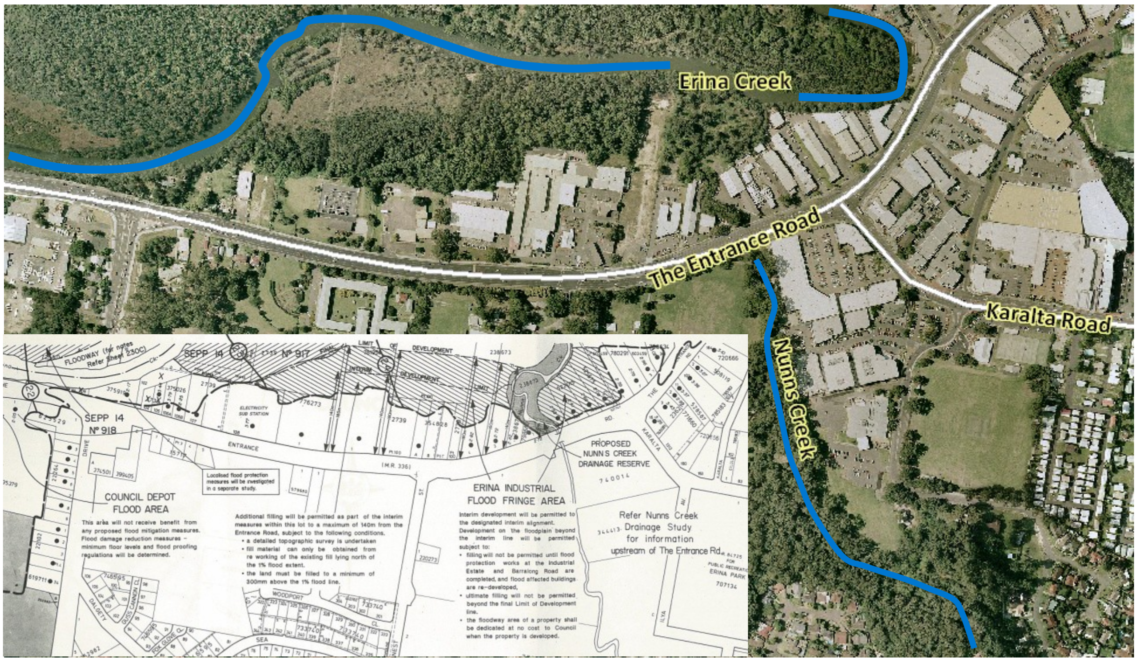
2.2.3. Redevelopment along Nunns Creek

Nunns Creek enters Erina Creek under the Central Coast Highway immediately downstream of Karalta Road. Extensive residential, commercial and tourist developments (refer Photograph 3) have occurred along this tributary since the 1990's. Flood studies have also been undertaken to assess the possible impacts upon downstream developments.

Photograph 3: Redevelopment along Nunns Creek

2.2.4. Re-development along the Central Coast Highway

The northern side of the Central Coast Highway (refer to Photograph 4) is occupied by large commercial and light industrial sites. There has been pressure to build out into the floodplain of Erina Creek but this has been limited to a "development line" established in Reference 3.



Photograph 4: Redevelopment along the Central Coast Highway

2.2.5. Other Major Works on the Floodplain

It is known that RTA road works at the Worthing Road Creek culverts under the Central Coast Highway have affected flood levels but mitigation measures have been incorporated in the design for events up to the 1% AEP flood standard for development (approximately). However in a flood that overtops the road (larger than the 1% AEP) the concrete crash barriers along each side will prevent the overflow of floodwaters and so impact on flood levels greater than the 1% AEP as there are no mitigation measures. For events that just overtop the road the barriers will restrict floodwaters from entering Erina Creek on the western side of the Central Coast Highway. However in much larger events, such as the PMF, it is possible that the barriers may fail or divert floodwaters. The precise consequences of such an event have not been accurately assessed as part of this study as this would require a detailed review of the structural integrity of the barriers and is outside the scope of this study.

The school grounds of the Central Coast Grammar School off Arundel Road have also been modified however no detailed survey is available to quantify the impacts on flood levels.

A mini golf course has been constructed on the floodplain immediately north of Erina Creek at Karwin Avenue. These works are generally of a nature that will have minimal (if any) affect on flood levels however it appears that the access road may have been raised and this may have produced a localised affect on flood levels upstream of this location. Again no detailed survey is available to accurately define the extent of the works.

2.3. Photographs

Photographs of key sites along Erina Creek and the tributary creeks are shown below.

Photograph 5: Earthen levee, west of Bonnal Road, looking downstream

Photograph 6: Earthen levee, west of Bonnal Road, looking upstream

Photograph 7: Concrete levee, Erina Creek.

Photograph 8: Retarding basin at Worthing Road Creek

Photograph 9: Nunns Creek – triple box culvert at the Central Coast Highway

Photograph 10: Worthing Road Creek - obstructed culvert at Jessie Hurley Drive near Stringybark Close

Photograph 11: Nunns Creek - Paved channel inside Tourist Park

2.4. Previous Studies

2.4.1. Erina Creek Flood Study Review 1990 – June 1991 (Reference 1)

In this study a WBNM hydrologic (converts rainfall to runoff) model was established as well as a RUBICON 1 Dimensional hydraulic (converts runoff to levels and velocities) model. These models were calibrated in tandem to the events of (in order of importance):

- 7th February 1990,
- 4th February 1990,
- January 1989,
- April 1988,
- October 1985,
- November 1984,
- February 1981 and
- January 1978.

Subsequently the models were used to determine design flood levels for the 20%, 10%, 5%, 2% and 1% AEP events and an Extreme Flood (assumed as a peak flow twice the 1% AEP). Sensitivity analyses to changes in the model parameters and design rainfalls were also undertaken.

2.4.2. Erina Creek Floodplain Management Study and Plan June 1991 (References 2 & 3)

The Management Study assessed various floodplain management measures and the preferred measures were incorporated into the Management Plan. The plan divided the floodplain into 11 areas, namely:

0. Erina Creek Floodway
1. Council Depot Flood Area,
2. Erina Industrial Flood Fringe Area,
3. Erina Industrial Flood Protection Area,
4. Worthing Road Creek Flood Area,
5. Carlton and Milina Roads Flood Fringe Areas,
6. Old Erina Estate Floodway and Acquisition Area,
7. Barralong Road, Winani Road and Lingi Street Levee and Acquisition Area,
8. Clarence Road Flood Fringe Area,
9. Springfield Wetland Flood Storage Area,
10. Upstream Catchment.

3. AVAILABLE DATA

3.1. Water Levels in Brisbane Water

Flooding in the lower parts of Erina Creek is largely influenced by the water level in Brisbane Water. This is in turn affected by the ocean tide, wave setup, wave runup and storm surge activities. It may also be affected by flooding in the Hawkesbury River but only to a very minor extent which has been ignored in this study.

Design water levels for Brisbane Water have been investigated as part of the Brisbane Water Foreshore Flood Study (Reference 4) and are provided in Table 1.

Table 1: Brisbane Water Design Flood Levels at the mouth of Erina Creek

AEP	Peak Water Level (mAHD)
20%	1.35
10%	1.42
5%	1.50
2%	1.59
1%	1.67
0.5%	1.75
PMF	2.08

Taken from Point 30 Table G1 of Reference 4

For historical events a water level in Brisbane Water was obtained either from the Wharf Street or Punt Bridge recorder if they were operating (refer following section). For the January 1978 event data was available from a temporary gauge at Saratoga but for February 1981 and November 1984 no local data was available.

For design flood estimation it would be unrealistic to assume that the (say) 1% AEP event in Brisbane Water and the 1% AEP event in Erina Creek would occur together (the AEP of such an event would be rarer such as say a 0.2% AEP). Table 6.3 and Figure H6 of Reference 4 refers to the 1% Probability of Exceedance level (i.e is only exceeded 1% of the time) and indicates that this is an appropriate downstream water level for design flood analysis. This level is not equivalent to the 1% AEP flood level in Brisbane Water which defines an event that has a 1% probability of occurrence of being equalled or exceeded in any year.

3.2. Rainfall

Reference 1 indicates that the Bureau of Meteorology (BOM) operated eight daily read gauges and Manly Hydraulics Laboratory (MHL) operated approximately nine pluviometers (installed in 1984) within 10 kilometres of the catchment boundary. Details of these gauges are provided in Reference 1. Up until approximately 2005 there was no official rainfall gauge located within the Erina Creek catchment, subsequently a pluviometer was installed at Punt Bridge and at Paul Oval off Milina Road.

Experience has shown that the rainfall patterns in this area can vary significantly over a short distance (less than 5 kilometres), thus it is probably impossible to determine an “accurate” assessment of the rainfall over the Erina Creek catchment for historical events.

Design rainfalls and temporal patterns for events up to the Probable Maximum Flood (PMF) were taken from Australian Rainfall and Runoff (Reference 5) and from the Computerised Design IFD Rainfall System (CDIRS, Reference 6). For the PMF design rainfall data were taken from Reference 7.

3.3. Survey

3.3.1. Cross Sections

The Erina Creek Flood Study Review 1990 (Reference 1) used a RUBICON hydraulic model to determine the flood levels and velocities within the catchment. This model incorporated river cross-sections (inbank and overbank) for Erina Creek.

As a check on whether there had been any change in the sedimentation/erosional regime of the creek since 1991, 18 cross sections surveyed as part of the Erina Creek Flood Study Review 1990 (Reference 1) were re-surveyed and the cross sectional areas compared (Appendix E). It was concluded that there was no significant change in the channel dimensions since 1990. The current 18 cross sectional data was used to derive the bathymetry of Erina Creek in the present study. Outside of the re-survey area the inbank component of the cross sections from Reference 1 were used as the available survey data for the present study (ALS) did not include data below water levels.

A comparison of the previous overbank survey with the ALS was also undertaken (Appendix E) and the results indicated that the two approaches are comparable. It should be noted that the locations of the surveyed sections used in Reference 1 cannot be accurately re-located, for this reason there are differences in the width of some of the sections as the alignments are not comparable.

3.3.2. Topography for 2D Domain

ALS ground levels were provided for the study area by Gosford City Council and were used to create a DEM (Digital Elevation Model) at a 1 m grid resolution. This information is shown on Figure 2.

3.4. Historical Flood Data

Erina Creek is tidal in low flow conditions up to approximately the confluence with Worthing Road Creek. However during flood times the tidal influence is dominated by the flow along Erina Creek and is a lesser factor in determining the peak water level. Peak flood levels from historical events are available from various recorders and surveying of debris marks as described in the following sections.

3.4.1. Maximum Height Recorders

Following the January 1978 flood the then Public Works had a program of installing Maximum Height Recorders (MHR) along the major creek systems in the Gosford area (refer Figure 3 for gauges on Erina Creek). The MHR consisted of a series of poles (to cover the range of floods heights) painted with dye that left a “tide mark” when inundated. After a flood the height of the mark above the base (m AHD level previously known) would be measured and thus the peak flood level obtained. Whilst a very simple concept the data obtained from the MHRs has been of poor quality for a number of reasons including,

- infestation by ants or similar preventing the inflow of water to the painted pole,
- rainwater infiltration,
- the dye mark was not clear,
- vandalism,
- confusion about which pole was read,
- if two floods occurred in a short period of time then unless a reading was taken between the events it is unclear which event was the largest,
- the database maintained by Manly Hydraulics Laboratory (MHL) requires rigorous checking to eliminate errors.

In July 2009 advice from MHL is that the MHR gauges have not been read since approximately 2000. A listing of all MHRs in the catchment is provided in Table 2.

Table 2: MHRs in the Erina Creek Catchment

Station No.	Station	Stream	Eastings	Northings
M11001	Marcus Close	Erina Creek	371853	6266231
M11002	Avoca Drive	Erina Creek	372621	6266549
M11003	Bonnal Rd	Erina Creek	374173	6265953
M11004	Barralong Rd	Erina Creek	373904	6266874
M11006	Central Coast Hgw Bridge	Erina Creek	372862	6267785
M11007	Nerissa Road	Worthing Rd Creek	375175	6268123
M11008	Nerissa Road	Worthing Rd Creek	375187	6267199
M11009	Chiltern Av	Erina Creek	375171	6268431
M11010	Carlton Rd Bridge	Erina Creek	375943	6268441
M11011	Milina Rd	Erina Creek	376703	6269375
M11012	Oak Rd/Coachwood	Erina Creek	378493	6270322
M11013	McGarrity Av	Oak Rd Creek	378232	6270627
M11014	Giraween	Fires Creek	378193	6273707
M11091	Chetwynd Rd	Worthing Rd Creek	376715	6268451
M11092	Matcham Rd	Erina Creek	380803	6270967

Whilst in theory the MHRs recorded all flood events the data issues listed above has meant that no data is available for some events. Table 3 lists the peak levels recorded at the gauges for the various flood events.

Table 3: Peak Height Data (m AHD) from MHRs in the Erina Creek Catchment

	Maximum Height Recorders in Erina Creek catchment (prefix M110)														
Event	**01**	**02**	**03**	**04**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**91**	**92**
Feb-81		0.75	0.77	1.87		2.13	2.49	2.62	4.00	6.46	8.07	11.07			
Nov-84	0.81	0.91	1.29	1.62	2.51	2.66	2.77	3.24	4.38	7.23					
Oct-85		1.05	1.52	1.94	2.58	2.81	2.72	3.39	4.40	6.83	8.53	11.22	16.55		
Apr-88	1.07	1.31	2.13	2.22	2.99	3.15	3.13		4.19	6.02	8.48	11.04	16.47		
Jan-89	0.85	0.84		2.07	2.05	2.98	3.07		4.37	6.27	8.71	11.19	16.87		
4-Feb-90	No data as gauge picked up the larger 7 Feb 1990 peak.														
7-Feb-90	1.23	1.33		2.23	2.88	2.99		3.66	4.31	6.50					
Feb-92			1.72	2.10	2.84	2.93	2.97	3.35	4.31	6.76	8.62			3.30	

Note: Data only shown where available

3.4.2. Water Level Recorders

Water level recorders (Figure 3) can be either automatic or manually read (during a flood) and differ to the MHRs as they can provide water levels continuously during the flood. Three manual (read by local residents) gauges were installed in 1980, namely:

- Gauge 212424 approximately 250m upstream of Milina Road,
- Gauge 212412 on Erina Creek opposite the Worthing Road Creek culverts under the Central Coast Highway,
- Gauge 212425 approximately 250m upstream of the Barralong Road bridge.

Automatic gauges have also been installed: in 1985 in Brisbane Water (termed Wharf Street - 212421), at Punt Bridge in 1984, at Erina (old) in 1996 and Erina (new) in 2007. Data are available from these gauges as shown in Table 4. Gauge 212421 represents the tidal level in Brisbane Water and thus the peak level may or may not correspond with the time of the peak outflow from Erina Creek. For this reason the peak levels for this gauge are not provided in Table 4.

Table 4: Peak Height Data (m AHD) available from Water Level Recorders

	Manual Gauge			Automatic Gauge			
Event	**212424**	**212412**	**212425**	**212421**	**Punt Bridge**	**Erina old**	**Erina new**
Feb 81		2.45					
Nov 84		2.7					
Apr 88	12.32	3.13	2.63	tidal			
Jan 89		2.91		tidal			
4 Feb 90			2.43	tidal			
7 Feb 90		3.04	2.53	tidal			
Feb 92				tidal			
June 2007				tidal	1.15		2.21

Note: Data only shown where available

In 2009 an automatic water level recorder was installed at the Carlton Road bridge (Figure 3).

3.4.3. Non Gauge Flood Marks

Reference 1 lists peak flood levels collected during the course of that study (particularly 4th and 7th February 1990). Since 1992 there has been no significant flood event on Erina Creek until June 2007. Whilst this event produced major flooding at Newcastle and on the Hunter River, as well as at Wyong (greater than 1% AEP rainfalls recorded) this was a relatively small event on Erina Creek. Council undertook a data collection study immediately following the event and obtained five peak levels on Erina Creek at:

- Milina Road,
- Carlton Road,
- opposite Worthing Road Creek,
- Hammersmith Road,
- Winani Road.

In addition a hydrograph was available for the June 2007 event from the Erina (new) gauge and the Punt Bridge gauge.

A listing of all available historical peak height data is provided in Appendix B.

3.4.4. Questionnaire

As part of the present study questionnaires were sent out to approximately 770 property owners in the catchment (refer Appendix C for details). The objective of the questionnaire was to advise residents of the study and if possible obtain additional flood level data. 136 responses were obtained, the majority of which were from residential property owners. Among the responses that were received 65 could not identify the peak level reached and 14 did not list an answer to this question.

Of those that could identify peak levels reached, 11 included photographs of flood waters at the time and 2 included photographs with identifying marks the peak flood level reached. If applicable, survey was undertaken to obtain the peak water level (in mAHD).

Appendix C provides a summary of the results from the questionnaire. Overall the results are typical of such surveys taken approximately 3 years after the last flood. A more effective response is obtained immediately following a flood event.

4. APPROACH ADOPTED

4.1. General

As there is no stream flow data and limited historical flood level data for the study area the hydrologic and hydraulic models were “calibrated” in tandem. The following sections provide details of the procedures adopted to obtain design flood flows and levels. Diagram 1 indicates the flood study process.

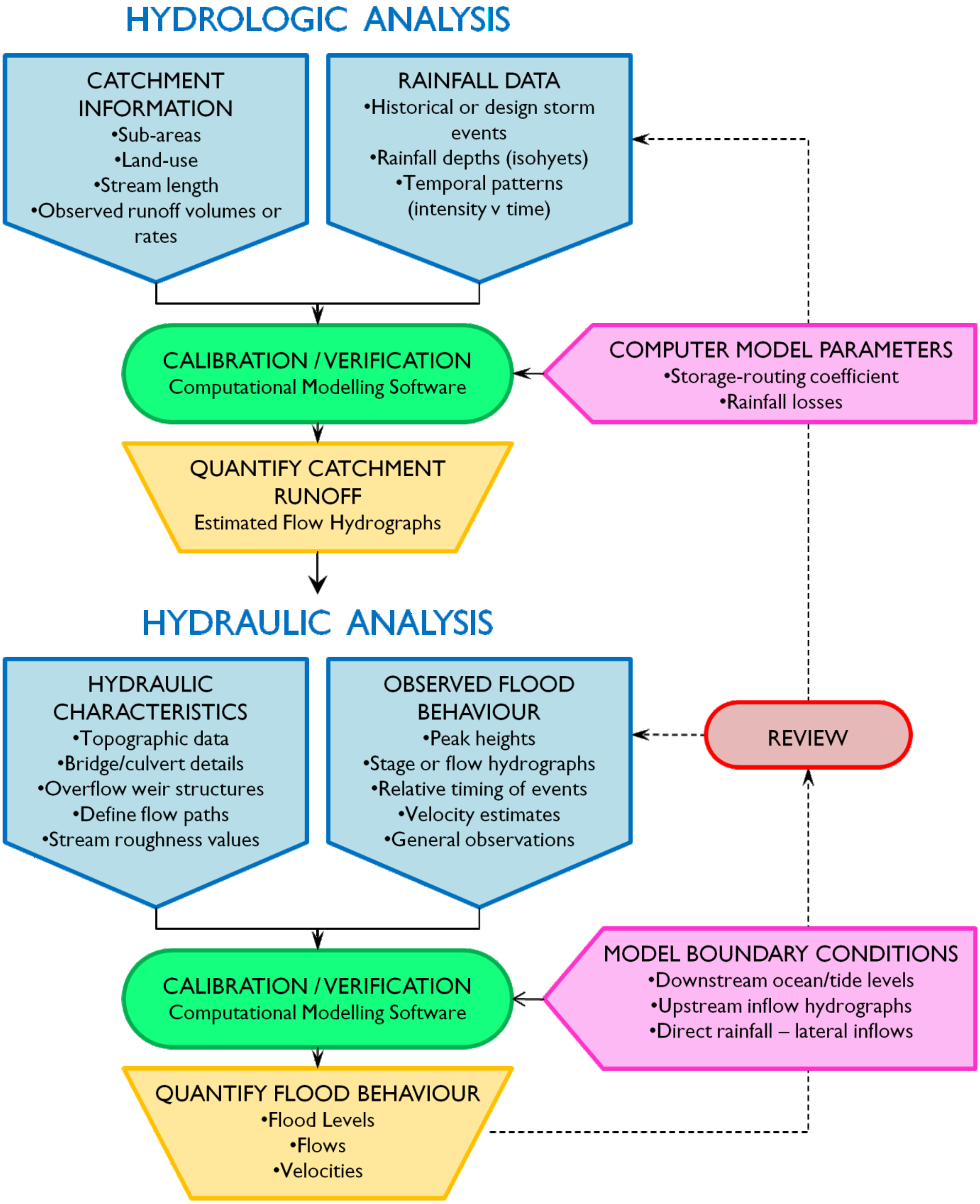


Diagram 1: Flood Study Process

4.2. WBNM Hydrologic Model

As the Erina Creek catchment is heavily developed in the lower reaches, the adopted model had to be able to accommodate the effects of urbanisation and provide inflow hydrographs for each of the tributaries.

Of the models which satisfy these requirements, the one considered most suitable for this study is the Watershed Bounded Network Model (WBNM – Reference 8). This model was originally based on rural data but has been substantially modified to account for the effects of urbanisation. Equally suitable would be XP-RAFTS or RORB (refer Reference 5). WBNM was adopted as it was the hydrologic model used in the Erina Creek Flood Study Review 1990 (Reference 1). The sub-catchment number and configuration in the present WBNM model are different to the ones in Reference 1 as sub-catchments had to be delineated again due to changes in the hydraulic model layout. The layout of the WBNM model is shown on Figure 4.

4.3. TUFLOW Hydraulic Model

4.3.1. Upper and Lower Models

Downstream of the Punt Bridge, Erina Creek discharges into Brisbane Water where the water level is primarily dominated by the tides. Thus flood levels in Erina Creek are determined by a combination of the Brisbane Water level and the inflows from the tributary catchments.

The hydraulic model must therefore include the varying downstream water level in Brisbane Water as well as inflows from the tributaries. The model must also simulate the considerable floodplain storage area in the lower reaches as well as the behaviour of the tributary creeks. Due to the complex nature of the interaction between channels and floodplain flow, as well as obstructions by buildings, the flow is most accurately represented by a two-dimensional (2D) unsteady flow hydraulic model.

The two-dimensional model TUFLOW (Reference 9) model developed by WBM met the requirements of the brief and was adopted as the hydraulic modelling approach.

Inflows from the WBNM model were included into TUFLOW together with a downstream water level in the Brisbane Water and flood levels, flows and velocities determined.

In this study, two separate hydraulic models (both 3m by 3m grids) were developed to cover the floodplain of the Erina Creek catchment. The main reasons for doing this were to manage computational running times and achieve a high level of topographic detail. The Erina Creek catchment was divided into a “lower” and “upper” Erina Creek model (refer Figures 5a and 5b). The models were separated at a suitable location for making the transfer of flows between the models simple and reliable. This separation occurs approximately 150m upstream of the manual gauge 212424 (refer Figures 5a and 5b).

4.3.2. Events Adopted for Model Calibration

Data are available in the catchment for 10 floods in the last 30+ years (earliest is March 1977). Prior to this floods would have occurred but no records are available. The data for each event varies. For the events prior to 1988 the main limitation is the lack of pluviometer rainfall data. Mt Elliot is the nearest pluviometer and was installed in 1985 but no records are available for flood events prior to the February 1990 floods. The quality and quantity of flood height data varies between events. The January 1978 event has some 26 peak flood levels with most of the other events having less than 15. The February 1990 events (4th and 7th) provide the best flood height record (as the flood occurred during the preparation of the Erina Creek Flood Study Review 1990 - Reference 1) with 13 for the 4th and 35 for the 7th February 1990 event. June 1992 has only 10 levels and June 2007 only 6.

The relative magnitude of the known flood events are (from largest to smallest):

1. January 1978,
2. April 1988,
3. 7th February 1990,
4. 1977,
5. 4th February and February 1992 equal,
6. January 1989,
7. October 1985,
8. February 1981,
9. November 1984,
10. June 2007.

An analysis of the annual peak rainfall intensities recorded at the Mt Elliot pluviometer was undertaken and the results are shown in Table 5.

Table 5 indicates that the peak rainfall intensities at the Mt Elliot pluviometer occurred in 1994 (3 May) but it would appear that a flood did not eventuate in Erina Creek. The second greatest intensity was in February 1990. June 2007 had a low intensity which accords with the relatively low recorded peak flood levels. It is interesting to note that the peak intensity in June 2007 was at 3am on 9 June which was some 12 hours after the peak intensities causing flooding in Newcastle.

Table 5: Peak Annual Rainfall Intensities (mm) at Mt Elliot

Year	max 30 min	max 1 hour	max 1.5hour	max 2 hour	max 3 hour
1988	**Gauge not working for April 1988**				
1989	**Gauge not working for Jan 1989**				
1990	39	63	86	102	111
1991	9	15	20	24	31
1992	31	41	51	58	74
1993	27	27	27	31	33
1994	66	95	109	122	148
1995	40	48	52	54	65
1996	13	25	33	39	51
1997	21	34	37	38	38
1998	15	26	30	36	43
1999	21	28	33	36	51
2000	23	24	27	31	36
2001	32	51	59	64	72
2002	21	32	41	46	57
2003	57	71	73	73	74
2004	25	45	64	77	91
2005	18	22	23	24	25
2006	41	58	68	78	81
2007	21	35	46	50	64
2008	18	21	26	29	41
MAXIMUM	**66**	**95**	**109**	**122**	**148**

Based on the above, the model calibration event was taken as 7th February 1990 event as it was one of the largest recorded events and had the highest quality and quantity of rainfall/flood height data. The January 1978 event was the largest of all these events but as there is no suitable pluviometer data available it cannot be used. The 4th February 1990 was used as a model verification event as it was well recorded. The June 2007 event was also used but only to a very limited extent as it was a relatively small event. The events of January 1978, February 1981, November 1984, October 1985, April 1988 and January 1989 were also used but due to the limited rainfall data these events were more used to verify the shape and slope of the profiles rather than the absolute flood levels. The results for these events are not reported as the poor quality of the rainfall data and the assumptions necessary to derive rainfall means that the results are of very limited value.

4.3.3. "Rainfall on the Grid" Approach

The TUFLOW 2D hydrodynamic package has capabilities to carry out "rainfall on the grid" modelling. This approach applies rainfall as inflows at each 2D cell. This approach was used for the tributary creek system upstream of the main creek system within the upper TUFLOW model (Figure 5b). Computational time and grid size are some of the limitations of undertaking this type of approach for a catchment of this size. Taking into consideration the size of the catchment and modelling time, a model with a 3m x 3m grid size was used. In this approach, no 1D tributaries need to be identified during the model setup since all the tributaries are implicitly defined in the 2D topography.

The purpose of this model was to identify drainage paths in the upper catchment (upstream of the main creek system within upper model layout (Figure 5b) based on the ALS and obviously the results are not used where the floodplain is included within the main creek system TUFLOW model shown on Figure 5b. It was not possible to calibrate this model due to the complete absence of historical data in this study area.

5. HYDROLOGIC ANALYSIS

5.1. General

The Watershed Bounded Network Model (WBNM) is a runoff-routing model (Reference 8) which provides for both areal and temporal distribution of rainfall as well as non-linear flood routing. It has been modified to simulate the effects of catchment urbanisation. Parameters recommended for use on an ungauged catchment are provided in Reference 8 and are as follows:

C (storage routing) = 1.7
Continuing Loss = 2.5 mm/h

The only parameter changed from those used in the Erina Creek Flood Study Review 1990 (Reference 1) was the storage routing parameter from 1.29 to 1.7 which is consistent with the recommendations of the current WBNM manual (Reference 8). The C parameter affects the catchment travel time and thus the peak flow (an increase will increase the travel time and so reduce the peak flow).

The initial loss value was specified individually for each of the calibration and verification events, as indicated below:

- 4th February 1990: 50 mm,
- 7th February 1990: 20 mm,
- 8th June 2007: 30 mm.

In the absence of recorded flow data it is impossible to accurately determine the initial loss for historical events and thus the above values are based on judgement and experience. For design the initial loss was taken as 10mm and the continuing loss as 2.5mm/h.

The WBNM sub-catchments are shown on Figure 4. A description of the rainfall patterns and depths for the February 1990 event is provided in the Erina Creek Flood Study Review 1990 (Reference 1) and the figures are replicated in Appendix B of this study.

5.2. Design Flows

Design rainfalls were obtained from Reference 5 for a series of storm durations and frequencies. These were run through the WBNM model to produce design inflow hydrographs at the tributary creeks. The critical design storm duration (produced the largest peak flow) for the main Erina Creek channel within the Lower Erina Creek model was found to be 9 hours for all events except the PMF.

The critical duration for the majority of tributary creeks to the main creek in the Lower Erina Creek model was found to be 2 hours. For a small number of tributaries the critical duration was found to differ from the 2 hour event; however, the difference in peak levels for those durations compared to the 2 hour event was less than 50 mm. As the difference in flood peak, in the majority of the creeks, is small and to provide a consistent modelling approach the 2 hour flood event was adopted for all tributary creeks. The critical duration for the Upper Erina Creek model was found to be 6 hours.

The contributing catchment area is the key factor in determining critical storm duration. The larger the area of the catchment, the longer the critical duration; therefore, it is reasonable to expect a longer duration for the main channel within the Lower Erina Creek than the Upper Erina Creek.

For the PMF the critical durations were determined as the 2.5 hour event for the Lower Erina Creek model and the 2 hour event for the Upper Erina Creek model. For the tributaries within the Lower Erina Creek model the critical duration for the PMF was the 1 hour.

The critical durations adopted for the present study are slightly different to those given in the 1990 Flood Study (Reference 1). This is not unexpected given the different modelling approaches adopted and is not of significance. In many locations the difference between design storm durations (say the 6 and 9 hour) is a few millimetres and at some locations is the 9 hour and some the 6 hour. A single critical storm duration is adopted for ease of use.

A table in Appendix D indicates the peak 1% AEP flood levels obtained at the mouth of each tributary creek for the various design durations. Figure D65 in Appendix D provides the same information (as peak height profiles) along Erina Creek for the various design durations.

Design inflow hydrographs for the critical storm durations were obtained for the 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events as well as the PMF.

6. HYDRAULIC ANALYSIS

6.1. General

The TUFLOW model schematisation was set up as shown on Figure 5a and 5b. The model included the large tributary creeks and the estuarine reach of Erina Creek. The upstream limits for the Lower Erina Creek hydraulic model are indicated in Figure 5a, which corresponds to the model extent used in Reference 1. As previously stated in Section 4.3, two TUFLOW models (Upper Erina Creek and Lower Erina Creek, refer to Figures 5a and 5b) were established in this study. In the Lower Erina Creek model, the downstream end is located at the confluence of Erina Creek with Brisbane Water, while the upstream boundary is located approximately 150m upstream of gauge 212424. In the Upper Erina Creek model, the model extends from the upstream boundary of the Lower Erina model and covers the remaining upstream extent of the "defined" floodplain. Upstream of this point the "rainfall on the grid" TUFLOW hydraulic model was established.

For the Upper Erina Creek model only a 2D domain was used to represent the topography of the catchment, whereas the Lower Erina Creek model included both 1D and 2D domains (refer Figure 5a). The small and undefined tributaries in the Upper Erina Creek model were not represented hydraulically due to limitations with the ALS data over highly vegetated areas. These tributaries were represented in the "rainfall on the grid" TUFLOW hydraulic model but the results have only been used to define an approximate flood extent and no peak levels or depths are provided due to the limitations of the ALS and modelling approach.

For the Lower Erina Creek model, a 1D/2D domain was implemented. Tributaries located in upper areas were modelled in 1D. The cross sectional information for these creeks was obtained at 10m intervals from the ALS. The re-survey of the cross-sectional survey data (refer Section 3.3.1) was used for deriving the 2D bathymetry of Erina Creek in conjunction with the overbank ALS data.

Within the Lower Erina Creek 2D model domain the topography was defined using a regular grid of 3m x 3m cells. This resolution was needed to properly define significant localised ground details and other features expected to function as hydraulic controls. Culverts and pipes with a diameter of 600 mm or greater and located within a flowpath were modelled in 1D. Culverts with diameters smaller than 600m and/or not located within a flowpath were not included since they convey insignificant flows during large events and are often blocked by debris. Inflows were included from the major tributaries to the main creek and at several locations downstream to represent flows from local catchments. Building footprints were obtained from aerial photography and site inspection and modelled as impervious flow barriers where it was considered that this level of model detail was required. The majority of these buildings are in the Erina industrial area adjoining Barralong Road where any flow across the area will generally be confined to the road network.

6.2. Flow Verification between Hydrologic and Hydraulic Model

A comparison was carried out to assess the consistency of inflow transfer between the hydrologic and hydraulic models. The flow verification consisted of obtaining the 1% AEP 9-hour design event peak flow at the downstream end of the Upper Erina Creek in the WBNM model and measuring the peak flow in the TUFLOW model at the same location.

The WBNM model peak flow was 171 m^3/s and the TUFLOW model peak flow was 186 m^3/s. This represents a relative difference of 8% between peak flows. The resulting peak flow difference is caused by two different routing types between the hydrologic and hydraulic models. WBNM uses an implicit catchment slope whereas TUFLOW employs the actual topography of the catchment. The Upper Erina Creek catchment is located in a coastal area with steep terrain surrounding the floodplain and it is presumed that this causes the difference in peak flow. This small difference in peak flow has therefore been ignored.

6.3. Boundary Conditions

Inflows obtained from the WBNM hydrologic model were introduced into the TUFLOW model by equally distributing inflows to all the cells that are located along each tributary. In the case of the 1D tributaries the flow was equally distributed in each node. This approach has been successfully undertaken in other hydraulic studies.

The downstream boundary conditions for this model were the water levels at Brisbane Water. For each calibration and verification event, the water level time series used was obtained from the Brisbane Water (212421) gauge. For design runs, the water level was assumed to be static at 0.74 mAHD (refer to Table 6.3 and Figure H6 of Reference 4 which corresponds to the 1% Probability of Exceedance level – *this level is not equivalent to the 1% AEP flood level in Brisbane Water and indicates the water level that is equalled or exceeded 1% of the time*). A static tide was adopted as a varying tide introduces issues with the timing of the peak water level and the peak flow from Erina Creek. This approach assumes the design rainfall over Erina Creek occurs when Brisbane Water is not in flood. This is to be expected as a design rainfall event over Erina Creek would not cause any significant elevation of Brisbane Water and it is unrealistic to expect that a rainfall event producing flooding on Brisbane Water (say 2 days of rain) would also include a much shorter (9 hour) rainfall intensity of the same design magnitude over Erina Creek.

This issue of joint probability of the two mechanisms should be investigated further when sufficient data is available to make reasonable predictions.

6.4. Land Use - Roughness

The Manning's 'n' factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features that may affect hydraulic efficiency. Manning's 'n' values were adopted by reference to recommended texts. A list of the adopted values is given in Table 6 with the regions shown on Figure 6.

Table 6: Manning's 'n' values adopted for the TUFLOW model

Description	'n' value
Natural channel	0.025
Roads	0.02
Mangroves	0.12
Grassed areas	0.04
Residential Low – High Density	0.055/0.065
Tributaries (Low/High vegetated)	0.06/0.08
Industrial	0.035

6.5. Model Calibration and Verification

The results of the calibration and verification are provided on Figures 7 to 13. These figures show the flood extent and the peak height profiles of Erina Creek for each calibration and verification event. For the calibration and verification events it was assumed that there was no blockage in any culverts or bridges (this is a different assumption to that adopted for design). The extent of blockage in any historical event on Erina Creek is unknown. The corresponding observed and modelled peak heights, for the historical events, are provided in Tables 7 to 9.

Table 7: Peak Water Level Heights for Verification Event – 2nd to 4th February 1990

Point ID	Location	Observed Peak Height (mAHD)	Model Peak Height (mAHD)	Difference (Model-Observed) (m)
11	212425	2.43	2.40	0.0
12	Lot 40A Bonnal Rd	1.82	2.0	0.2
13	3 Winani St	2.16	2.4	0.2
14	59 Barralong Rd	2.30	2.4	0.1
15	24 Nerissa Rd	2.89	2.9	0.0
16	45 Kuburra Rd	2.93	2.9	0.0
17	Lot 53 Arundel Rd	5.51	5.3	-0.2
28	55 Barralong Rd	2.31	2.4	0.1

Table 8: Peak Water Level Heights for Verification Event – 7th June 2007

Point ID	Location	Observed Peak Height (mAHD)	Model Peak Height (mAHD)	Difference (Model-Observed) (m)
1	96 Chetwynd Rd	3.43	3.3	-0.1
2	21 Narrawa Ave	2.37	2.3	-0.1
3	51 Kuburra Rd	3.17	3.0	-0.2
4	18-20 Erina Valley Rd	5.66	5.6	-0.1
5	65 Barralong Rd	1.47	1.5	0.0

Table 9: Peak Water Level Heights for Calibration Event – 7th February 1990

Point ID	Location	Observed Peak Height (mAHD)	Model Peak Height (mAHD)	Difference (Model-Observed) (m)
1	212412	3.04	3.1	0.0
2	M11001	1.23	1.1	-0.1
3	M11002	1.33	1.3	0.0
4	M11003 (Does not agree with 3 nearby levels)	1.50	2.0	0.5
5	M11004	2.23	2.3	0.1
6	M11006	2.88	2.8	-0.1
7	M11007	2.99	3.0	0.0
8	M11009	3.66	3.3	-0.4
9	M11010	4.31	4.4	0.1
10	M11011	6.50	6.7	0.2
11	212425	2.53	2.4	-0.1
12	Lot 40A Bonnal Rd	1.90	2.0	0.1
13	3 Winani St	2.32	2.4	0.1
14	59 Barralong Rd	2.44	2.4	0.0
15	24 Nerissa Rd	3.00	3.0	0.0
16	45 Kuburra Rd	3.17	3.1	-0.1
17	Lot 53 Arundel Rd	5.80	5.8	0.0
18	57 Barralong Rd	2.47	2.4	-0.1
19	O'Brien Glass	2.56	2.5	-0.1
20	Lot 12 Bonnal Rd	2.24	2.0	-0.2
21	Lot 14 Bonnal Rd	2.24	2.0	-0.2
22	Lot 1 Bonnal Rd	2.25	2.1	-0.2
23	89 Barralong Rd	2.29	2.4	0.1
24	34 Winani St	2.50	2.5	0.0
25	1 Lingi St	2.53	2.5	0.0
26	Hammersmith Rd	2.84	2.7	-0.1
27	Central Coast Hgw cnr Karwin Ave	3.80	3.6	-0.2

The results indicate that a reasonable match to the recorded data has been obtained using a consistent and reasonable set of model parameters. It is acknowledged that there is not a 100% match at each of the recorded points. This could be due to a number of reasons, including:

- The recorded point is in slightly the wrong position (the precise locations of some gauges are unknown),
- Local hydraulic effects may affect both the model and recorded results,
- The topography is not accurately represented in the hydraulic model (a wall or building affects the pattern of flow,
- The catchment rainfall distribution (temporal and areal) is not accurately represented by the recorded data,
- The recorded point is in error (wrong datum, incorrect datum conversion or reading).

The modelling approach and calibration is suitable for design flood estimation but should be reevaluated immediately following the next large flood. One component within the freeboard included within the Flood Planning Level for setting the minimum residential floor levels is to take into account any inaccuracies in the modelling approach (other components are wave action, local hydraulic effects, climate change and the cumulative effects of future development on the floodplain).

6.6. “Rainfall on the Grid” Analysis

For the creek system upstream of that modelled by the Upper Erina Creek 2D TUFLOW approach with WBNM inflows a “rainfall on the grid” TUFLOW model (Figure 5b) was established. The results of this approach are provided on Figure 14. In this approach, the 1% AEP 2-hour design rainfall was adopted. This approach was implemented only as an indicative assessment for locating flowpaths over this area.

As seen on Figure 14, the definition of the tributaries after obtaining peak water levels is not clearly defined and the extent of flooding appears to be widespread (which is probably not the case). One of the reasons for this is that the 3m grid does not properly represent the topography on these tributaries. The most likely reason for this is because of the limitations of the ALS data to properly sample ground points around these highly vegetated areas. In some cases the tributaries’ natural flow path may be interrupted by uneven terrain causing “ponding” in some areas.

One of the approaches for improving the rainfall on the grid modelling would be decreasing the model’s grid size, which implicates longer running times (more than twice the modelled one). However, this solution does not solve the limitations caused by ALS data in highly vegetated areas. Therefore, the “rainfall on the grid” approach was not considered reliable enough for providing design flood levels or extents but used only as a guide to whether part of the property was flood liable or not.

6.7. Design Analysis

6.7.1. Approach

Flood levels along Erina Creek are influenced by a combination of runoff from the local catchment (short duration storm event) and elevated levels in Brisbane Water (longer duration storm event). Thus the 1% AEP design flood levels along Erina Creek are determined as an envelope of the 1% AEP peak flood levels from the critical duration design storms over the Erina Creek catchment and the Brisbane Water catchments (Table 1). This present study has determined the design flood levels along Erina Creek as a result of rainfall over the Erina Creek catchment and Reference 4 has determined the design flood levels for Brisbane Water.

Initially durations from 1 hour to 36 hours for all AEP events were run. The results indicate that the design critical storm duration for the lower section of Erina Creek is 9 hours and this was adopted for all design events except the PMF where the 2.5 hour event was adopted as critical (refer to Section 5.2 for more detail regarding critical durations).

6.7.2. Blockage of Culverts and Bridges

Recent floods in August 1998 in North Wollongong and Newcastle in June 2007 have highlighted the significance of blockage in elevating flood levels at hydraulic structures (bridges, culverts). Some Councils have implemented a "blockage" policy that must be adopted for all design flood analysis. In other local government areas this issue has been addressed on a case by case basis. Unfortunately there is no "industry standard" approach for blockage and this issue is being reviewed as part of the current review of Australian Rainfall and Runoff (Reference 5).

It should be noted that blockage can occur as a result of natural (wind, rain, lightening) and human (car crash) causes and may involve both natural (trees) and manmade (cars, fencing) debris. Also blockage may not necessarily occur in all flood events in the same catchment.

For design runs the following blockage scenario has been assumed:

- **Nunns Creek:** 3 box culverts, 3 m x 1.2 m, below the Central Coast Highway, blocked 50% of their capacity,
- **downstream of Newcastle Street corner with Spring Avenue**, 2 x 1.05 m diameter culverts, blocked 50% of their capacity,
- **Worthing Road Creek:** (3 culverts, 3 m x 3 m) below the Central Coast Highway, blocked 50% of their capacity, and
- **Remaining culverts** in the model blocked 25% of their capacity.

It was considered that the larger culverts were more likely to have a higher percentage of blockage as they are on "open" channels and thus affected by vegetative, fencing and possibly vehicle debris. There is no absolute justification for the above scenario and other combinations would be equally as suitable. However a fundamental issue is that some form of blockage should be included for design flood analysis based on the data available from recent floods in similar type catchments in NSW (North Wollongong in August 1998, Newcastle in June 2007 and Coffs Harbour in March 2009).

6.7.3. Results

Results from the design flood analysis are shown in the form of maps, tables and profile graphs.

Design peak profiles along Erina Creek for the 50% AEP to PMF events are shown on Figure 15. A comparison with the peak flood level profiles from the Erina Creek Flood Study Review 1990 (Reference 1) is provided on Figure 16. Maps indicating flood depths, contours of peak flood levels and velocity are provided in Appendix D.

Peak level profiles have been derived for a number of tributaries within the Lower Erina Creek model. These creeks are identified on Figure 17 with the peak profiles shown on Figures 18 to 30.

A tabulation of peak levels, flows and velocities at each cross section within the 1D extent of the hydraulic model is shown in Appendix D.

6.7.4. Hazard and Hydraulic Classification

The risk to life and potential damages to buildings during floods varies both in time and place across the floodplain. In order to provide an understanding of the effects of a proposed development on flood behavior and the effects of flooding on development and people the floodplain can be sub-divided into hydraulic (effects of development) and hazard (effects of flooding) categories. This categorization should not be used for the assessment of development proposals on an isolated basis, rather they should be used for assessing the suitability of future types of land use and development in the formulation of a floodplain risk management plan.

Hazard is a measure of the overall harm caused by flooding and should consider a number of factors (depth of flooding, velocity of flood waters, access to escape routes, duration etc.). In the first instance Provisional hazard categories can be defined based on the depth and velocity of floodwaters. Provisional flood hazard categories were defined in this study in accordance with the *Floodplain Development Manual - Figure L2* (Reference 10) as indicated below.

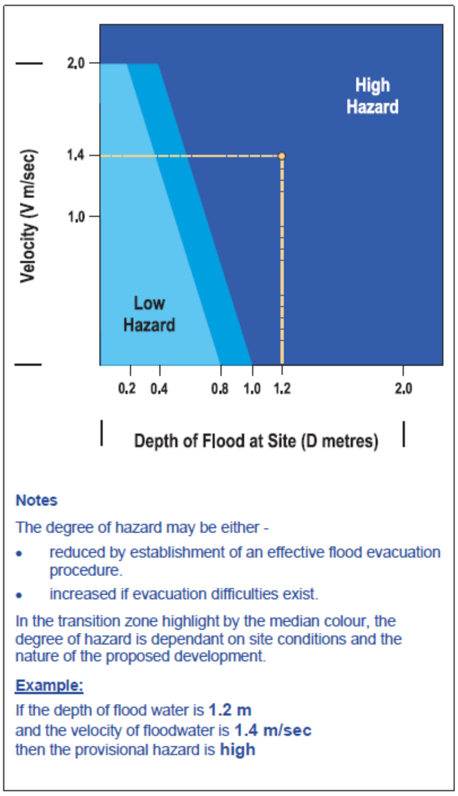


FIGURE L2 - Provisional Hydraulic Hazard Categories

The hazards are provisional because they only consider the hydraulic aspects of flood hazard. Using model results the hazard was calculated from the envelope of the velocity and depth results calculated for each time step. High and low provisional hazard areas were defined for the range of design flood events and provided in Appendix D. The *Floodplain Development Manual* (Reference 10) requires that other factors be considered in determining the "true" hazard such as size of flood, effective warning time, flood readiness, rate of rise of floodwaters, depth and velocity of flood waters, duration of flooding, evacuation problems, effective flood access, type of development within the floodplain, complexity of the stream network and the inter-relationship between flows.

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The *Floodplain Development Manual* (Reference 10) defines flood prone land to fall into one of the following three hydraulic categories (refer definition in Appendix A taken from Reference 10):-

- Floodway,
- Flood Storage,
- Flood Fringe.

Floodways are areas of the floodplain where a significant discharge of water occurs during floods and by definition if blocked would have a significant affect on flood flows, velocities or depths. Flood storage are areas of importance for the temporary storage of floodwaters and if filled would significantly increase flood levels due to the loss of flood attenuation. The remainder of the floodplain is defined as flood fringe. There is no technical definition of hydraulic categorisation and different approaches are used by different consultants and authorities.

For this study hydraulic categorisation was defined according to the approach adopted in Reference 4, namely:

Floodway = *Velocity * Depth > 0.25m²/s AND Velocity > 0.25m/s OR Velocity > 1m/s*

The remainder of the floodplain outside the Floodway becomes either Flood Storage or Flood Fringe. Reference 4 defines Flood Storage if the depth is greater than 0.2m and Flood Fringe if the depth is less than 0.2m. As the floodplain rises relatively steeply on the perimeter of the Erina Creek floodplain there is very little area defined as Flood Fringe using this approach. At Windsor on the Hawkesbury River floodplain, where flood levels rise some 17m, the depth used to define flood storage from flood fringe will be much greater. In this study Flood Storage was defined as the land outside the Floodway if the depth is greater than 0.5m and Flood Fringe if the depth is less than 0.5m. As noted in Reference 10 *"it is impossible to provide explicitly quantitative criteria for defining floodways and flood storage areas, as the significance of such areas is site specific"*.

Hydraulic categorization is provided in Appendix D for the 5% AEP, 1% AEP and PMF events.

6.7.5. Comparison of Results with Previous Studies

A number of previous flood studies have been undertaken on Erina Creek and its tributaries. The most comprehensive of these was the Erina Creek Flood Study Review 1990 (Reference 1) but earlier studies have also been completed. A comparison of the design flood results from the present study and from Reference 1 is provided in Appendix F and on Figure 16. In places there are significant differences whilst in other areas there are minimal differences. The following sections provide some general explanation into why these differences occur.

General: The determination of design flood levels (or the magnitude of most other natural disasters) is complex and unable to be defined to a high level of precision. For example, in order to accurately estimate the 1% AEP (100 year ARI) design flood level at a location there would need to be approximately 500 years of accurate flood height data in order to undertake a statistical analysis. This data would also have to be available at all other locations throughout the catchment where accurate flood levels are required. Clearly no such data exists for Erina Creek where the earliest known extent of flooding was in the 1970s.

The approach adopted in the majority of flood studies undertaken in NSW is therefore to establish computer models of the catchment. The modelling systems are very sophisticated but are dependant upon a number of factors for their accuracy. Over the years the accuracy of these systems have increased due to the inclusion of additional data (survey, rainfall, historical flood height data, computer technology) and thus it is expected that the most recent studies will be more accurate than the previous studies. Thus each new study should increase our knowledge of flooding.

However rainfall events (and consequent flood events) can occur (Dapto 1984, Coffs Harbour 1996, North Wollongong 1998, Newcastle 2007) which result in a change in the overall methodology. These changes are reflected in the guidelines used in design flood estimation and documented in Australian Rainfall and Runoff (Reference 5). This document was last updated in 1987 and is currently in the process of being updated at present (2009 to 2012).

Rainfall Data: Since completion of Reference 1 there have only been minor changes to the design rainfall estimates over the Erina Creek catchment, however, different loss rates have been assumed for calibration and design in this study than in the past. The change in the initial loss of 0mm to 25mm (from Reference 1 to the present study) has changed the relative difference between the 7th February 1990 calibration event and the 1% AEP event. This is because the higher assumed initial loss in this present study has a greater impact on the peak flow in the short duration 7th February 1990 event than the longer duration 1% AEP event. The result is that the difference between two events is greater in this present study.

Hydrologic Modelling: The same hydrologic model has been used as for Reference 1 but there have been changes to the modelling software as well as the recommended parameters adopted (storage routing parameter). More detailed sub-catchment definition in the present study will also have changed inflows at locations compared to Reference 1.

Hydraulic Modelling: Since 1990 there has been a significant change to the type of computer model used for design flood estimation. This has largely arisen due to technological and computer advancements. Flood levels are estimated on a 3m by 3m grid system in the present study whereupon in Reference 1 they were calculated at cross sections spaced say 200m apart (some were closer and some further apart). The use of a different hydraulic model will have made significant changes to the resulting design flood levels. Importantly the funnelling of floodwaters under the Barralong Road bridge is more accurately simulated in the present model than in Reference 1 as the existing model can more accurately represent the topography.

Survey Data: A key factor affecting the accuracy of the results across the catchment is the survey data used to define the floodplain. In Reference 1 this was cross sections spaced at intervals greater than 100m. For the present study ALS has been used which provides ground levels at approximately 1m spacing over the entire catchment. The use of ALS is expected to provide a significant increase in model accuracy.

A check was undertaken to assess whether the in bank and over bank survey used in Reference 1 is comparable to that obtained used in the present study. The results are provided in Appendix E and indicate a high degree of correlation (as would be expected).

Calculation of Flow through Culverts: Hydraulic models use different formulae for estimation of flow through culverts and this can make a significant difference to the flood levels upstream. This is likely to be one of the reasons for the difference between the peak levels upstream of the Central Coast Highway on Worthing Road Creek. The formulae are constantly being updated as the software developers incorporate advancements.

Historical Flood Data used for Model Calibration: The inclusion of accurate peak flood levels from a recent large event (say greater than a 5% AEP event) is likely to significantly improve the accuracy of the design flood levels as this enables accurate "calibration" of the modelling system. However since 1990 there have been no large events in the catchment (June 2007 was only a minor flood) and thus this is not a factor in explaining the difference between the results herein and in Reference 1. However the calibration of the models to the data is different between the two studies and this will account for some difference in the design flood levels.

Modelling Assumptions: A large number of model assumptions are incorporated in the modelling process. Each of these assumptions will impact on the design flood levels. One of the key assumptions is the effect of blockage in culverts. In Reference 1 no blockage was assumed. However review of floods since 1990, particularly North Wollongong 1998, has indicated that culverts can become blocked by debris and thus this should be accounted for in the modelling assumptions. Whilst blockage occurred in the past it was not well documented and certainly the use of colourbond fencing (as opposed to paling fencing) and cars that now float (as they are of lighter construction and well sealed) has increased the likelihood of culvert blockage in recent floods (also containers that float). Some Councils have adopted a strict blockage policy for all culverts of less than 6m width (Wollongong Council), however a review of blockage across Australia (as part of the review of Reference 5) indicates that the inclusion of a blockage strategy is complex. Examples are provided of creeks that experience minimal blockage and others major blockage and even some which block in some past floods but have not in others. Thus there is no definitive position regarding blockage assumptions in design flood analysis, for this reason sensitivity analysis has been undertaken (Section 7).

Increased Catchment Development: Potentially changes to land use (particularly increased density of development) will change the amount of runoff into the creek system and thus flood levels. Whilst significant changes to the catchment have occurred since 1990 (documented in

Section 2.2) the majority of these have not impacted on flood levels as studies have been undertaken as part of the design to ensure mitigation measures are incorporated (e.g construction of Worthing Road Retarding basin). However some works have increased levels (construction of the Barralong Road levee) and this has been accounted for in the modelling process. The comparison shown on Figure 16 and in Appendix F includes the construction of the Barralong Road levee, thus the “old” levels are greater than those shown in Reference 1 (study undertaken before construction of the levee).

Assumed Water Levels in Brisbane Water: Slightly different assumptions have been made in this regard but these will have made minimal impact except within a few hundred metres of the Punt Road bridge.

SUMMARY: The results from the present Erina Creek Flood Study Review incorporates best practice in design flood estimation at this time but it is acknowledged that changes in approach in the future will cause changes to design flood levels. A good example of this is the collection of rainfall data which forms the basis of design flood estimation. As more and more rainfall data is collected and analysed (and particularly from continuously read gauges termed pluviometers) the Bureau of Meteorology will be providing new estimates of design rainfalls and design temporal patterns over NSW within the next 2 to 5 years. An updated Reference 5 will also introduce new approaches and guidelines which may change design flood levels.

7. SENSITIVITY ANALYSES

The hydrologic/hydraulic models established for this study rely on a number of assumed parameters, the values of which are considered to be the most appropriate for the study area. As only a limited model validation was performed and no validation of the design flows (due to the complete absence of flow data) a range of sensitivity analysis was undertaken on different key parameters in order to quantify potential variations corresponding to different modelling assumptions.

The sensitivity analyses were carried out by modelling the 1% AEP 9-hour design event which corresponds to the critical duration of the main channel within the Lower Erina Creek model.

7.1. Modelled Scenarios and Assumptions

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

- rainfall and tailwater (ocean level) increases due to climate change,
- ± 50% change in loss rates in the WBNM hydrologic model,
- ± 20% change in the C storage routing parameter in the WBNM hydrologic model,
- ± 20% change in Manning's 'n' value,
- 100% blockage of culverts.

7.2. Climate Change

The 2005 Floodplain Development Manual (Reference 10) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change on flood behaviour. The then Department of Environment and Climate Change (DECC) – Floodplain Risk Management Guideline 2007 (Reference 11) indicated climate change scenarios for rainfall by the year 2070 (shown below) and ocean level rise by the year 2100 (not shown as now superseded):

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

A high level rainfall increase of up to 30% is recommended for consideration due to the uncertainties associated with this aspect of climate change. It is understood that work currently being undertaken by CSIRO and the Sydney Catchment Authority should provide better direction on the possible impacts on rainfall.

Since commencement of this study the NSW Government has updated its advice regarding ocean level rise from that provided in Reference 11 and now advises a 0.4m ocean level rise by the year 2050 and 0.9m ocean level rise by the year 2100 (References 12 and 13).

7.3. Results

In order to undertake the sensitivity analysis key locations have been selected within Erina Creek catchment to obtain peak flood levels. These locations are shown on Figure 31.

Results from the sensitivity analyses for the 1% AEP event are shown in Table 10 and Table 11.

Table 10: Sensitivity Analyses Results

		Change in level in m						
Location	**1% AEP (mAHD)**	**100% Culvert Blockage (Relative Level)**	**Hydrological losses decrease (Relative Level)**	**Hydrological losses increase (Relative Level)**	**Manning's 'n' decrease (Relative Level)**	**Manning's 'n' increase (Relative Level)**	**Routing C decrease (Relative Level)**	**Routing C increase (Relative Level)**
Nunns Ck U/S The Central Coast Highway	3.53	+0.14	+0.01	-0.01	-0.01	+0.01	+0.01	-0.01
Worthing Rd Ck Retarding Basin	7.99	+0.97	+0.00	+0.00	+0.11	+0.05	0.00	+0.01
Terrigal Dr. @ Nunns Ck	7.72	+0.03	+0.01	+0.00	+0.01	+0.00	+0.02	-0.01
Worthing Rd. Ck U/S The Central Coast Highway.	4.03	+0.92	+0.09	-0.10	-0.09	+0.03	+0.06	-0.08
Erina Ck U/S Barralong Rd	2.95	+0.04	+0.05	-0.06	-0.11	+0.09	+0.04	-0.04
Erina Ck nr Bonnal Rd cnr The Central Coast Highway	2.69	+0.01	+0.04	-0.04	-0.07	+0.06	+0.03	-0.02
Erina Ck U/S Punt bridge	1.14	-0.03	-0.02	-0.06	-0.06	-0.05	-0.03	-0.05
Drainage channel U/S Ilya Ave	8.25	-0.06	0.00	+0.01	-0.01	+0.01	+0.01	0.00

As seen in Table 10 culvert blockage has a significant impact on peak flood levels in Erina Creek with the peak flood depths in major roads such as the Central Coast Highway near Worthing Road Creek and at the Worthing Road retarding basin increased by up to 1m.

However Table 10 also indicates that any change in design losses, Manning's "n" or the storage routing factor - C will have only a relatively minor impact (maximum of 0.1m) on the 1% AEP design flood level.

Table 11: Climate Change Results

		Change in level in m				
Location	**1% AEP (mAHD)**	**10% rainfall increase (Relative Level)**	**20% rainfall increase (Relative Level)**	**30% rainfall increase (Relative Level)**	**0.4m ocean rise (Relative Level)**	**0.9m ocean rise (Relative Level)**
Nunns Ck U/S The Central Coast Highway	3.53	+0.04	+0.07	+0.11	0.00	0.00
Worthing Rd Ck Retarding Basin	7.99	+0.02	+0.10	+0.16	0.00	0.00
Terrigal Dr. @ Worthing Rd Ck	7.72	+0.05	+0.08	+0.13	0.00	0.00
Worthing Rd. Ck U/S The Central Coast Highway.	4.03	+0.22	+0.41	+0.57	0.00	+0.03
Erina Ck U/S Barralong Rd	2.95	+0.11	+0.26	+0.37	+0.02	+0.04
Erina Ck nr Bonnal Rd cnr The Central Coast Highway	2.69	+0.09	+0.22	+0.33	+0.03	+0.05
Erina Ck U/S Punt bridge	1.14	+0.01	+0.06	+0.10	+0.36	+0.59
Drainage channel U/S Ilya Ave	8.25	+0.01	+0.02	+0.06	0.00	0.00

Table 11 indicates the variation in peak levels as a consequence of future climate changes in the catchment (also refer Figures D63 and D64 in Appendix D). The most significant impact can be seen upstream of the Central Coast Highway near Worthing Road Creek, where the maximum impact can reach approximately 0.6m for a 30% rainfall increase. It is important to note that the change in peak level at this location is influenced by the assumed culvert blockage of 50% capacity. In other locations the impacts are much less.

Whilst Erina Creek is tidal under low flow conditions, during a flood the Brisbane Water level has much less impact on water levels. For this reason the increase in ocean level tapers off rapidly upstream of Brisbane Water (less than 0.1m at the corner of Bonnal Road/the Central Coast Highway).

Gosford City Council has adopted sea level rise planning levels of 0.9m by the year 2100.

8. ACKNOWLEDGEMENTS

This study was funded by Gosford City Council and the State Government and was undertaken by WMAwater. The assistance of the following in providing data and guidance to the study is gratefully acknowledged.

- Gosford City Council,
- Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water),
- NSW State Government,
- Residents of the Erina Creek catchment.

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New South Wales Government, October 2009

13. **Flood Risk Management Guide**
Department of Environment Climate Change and Water NSW, August 2010

Figures

FIGURE 1
STUDY AREA

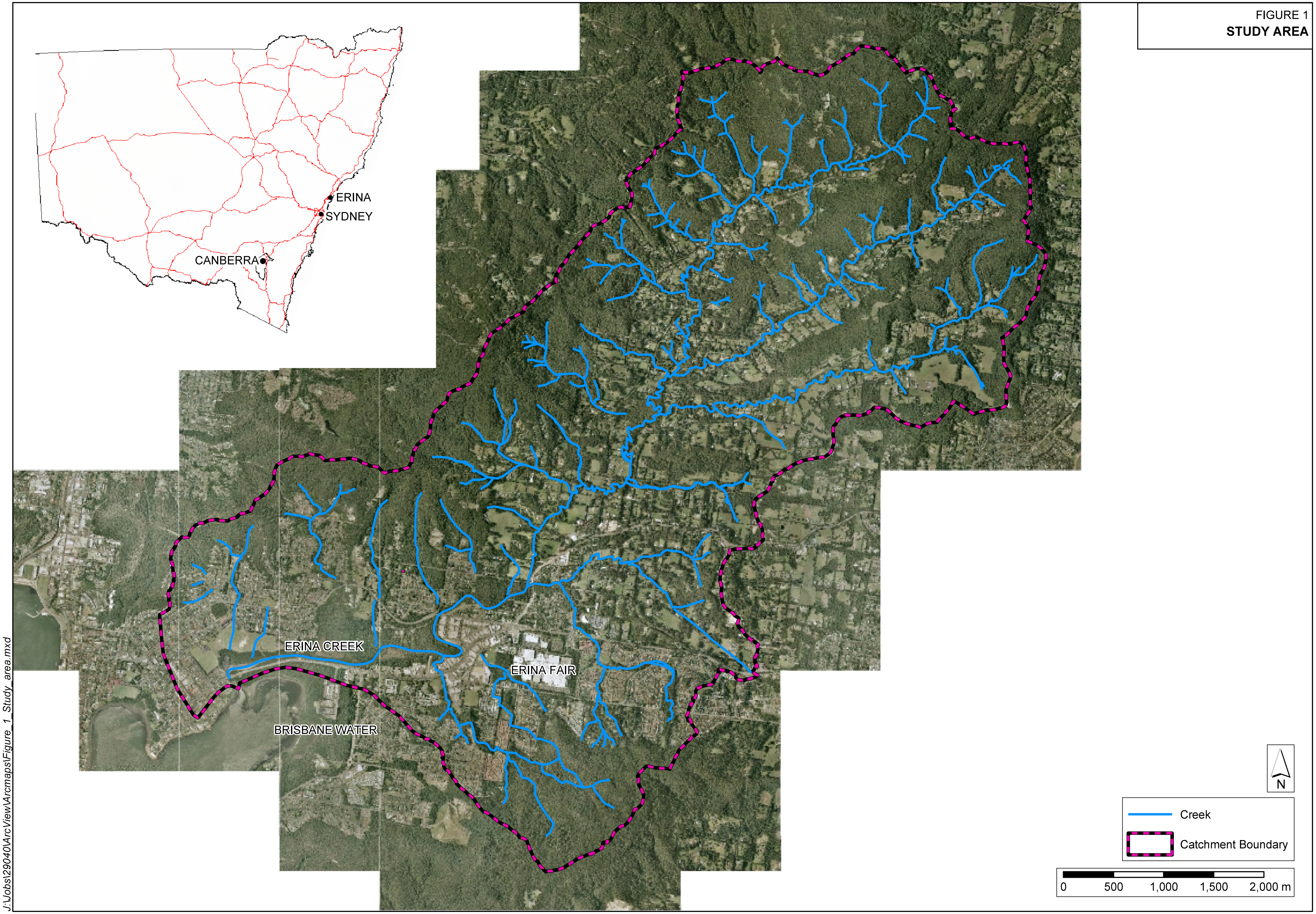

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FIGURE 2
DIGITAL ELEVATION MODEL

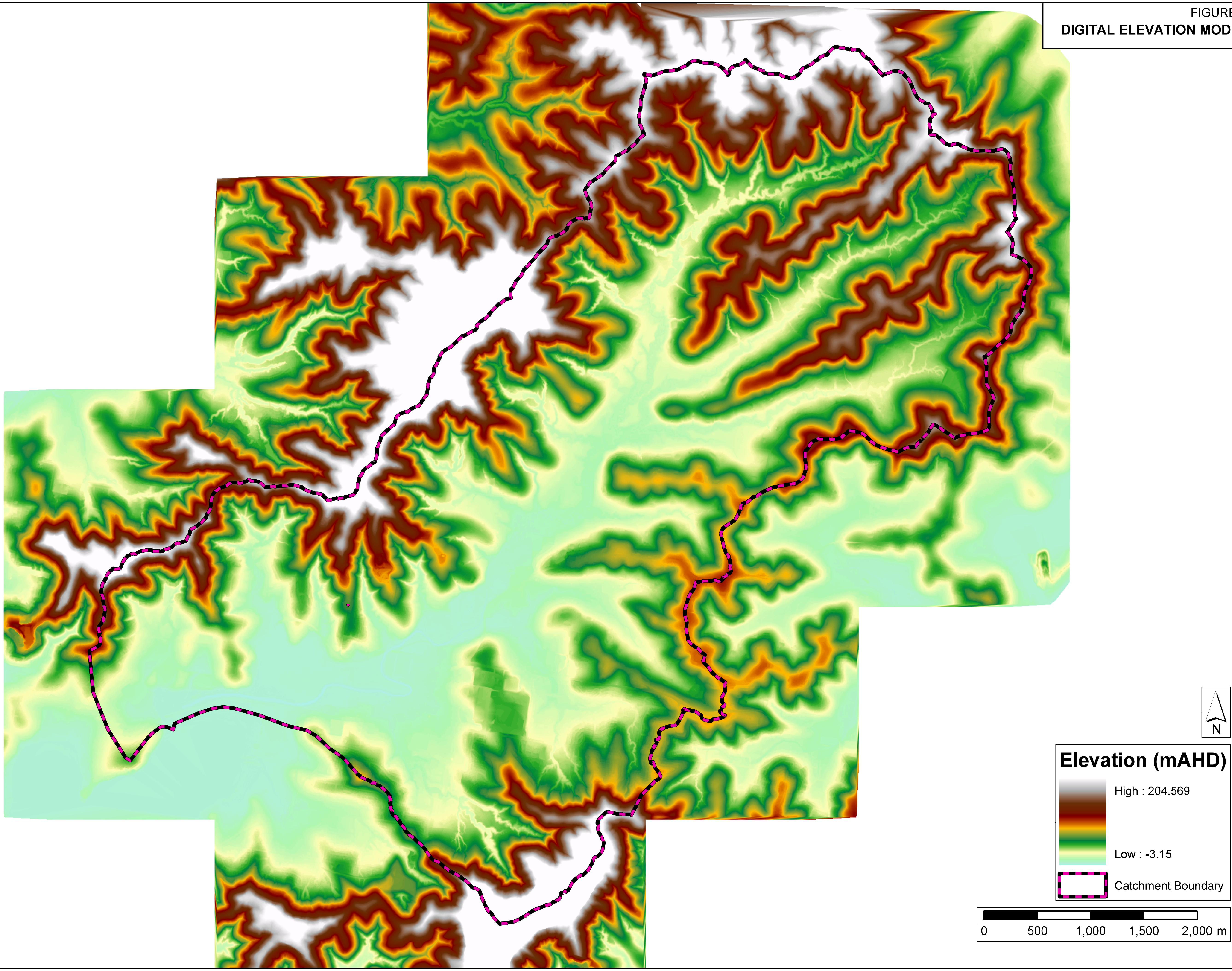

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FIGURE 3
WATER LEVEL HEIGHT RECORDERS

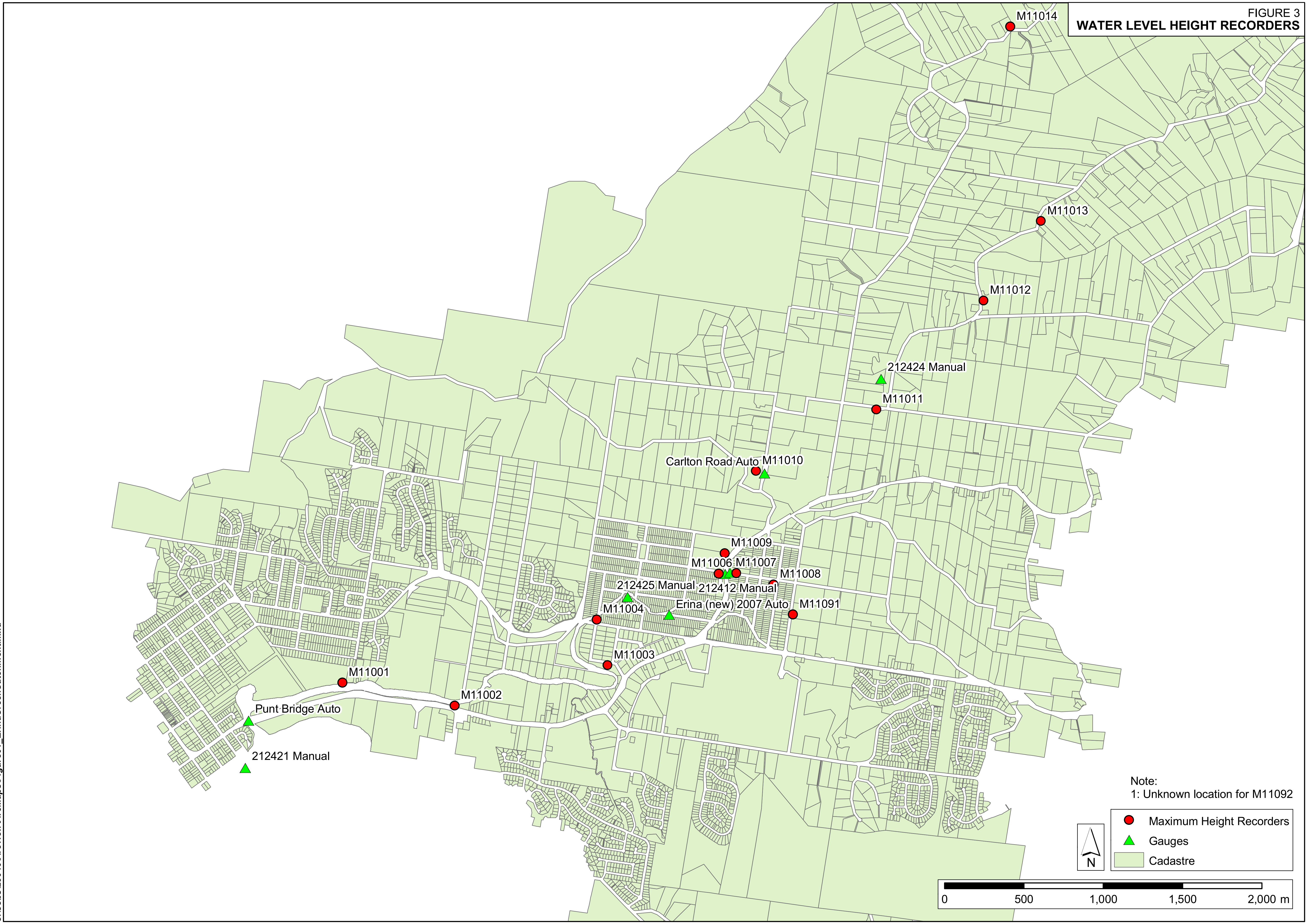

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FIGURE 4
WBN MODEL SUB-CATCHMENTS

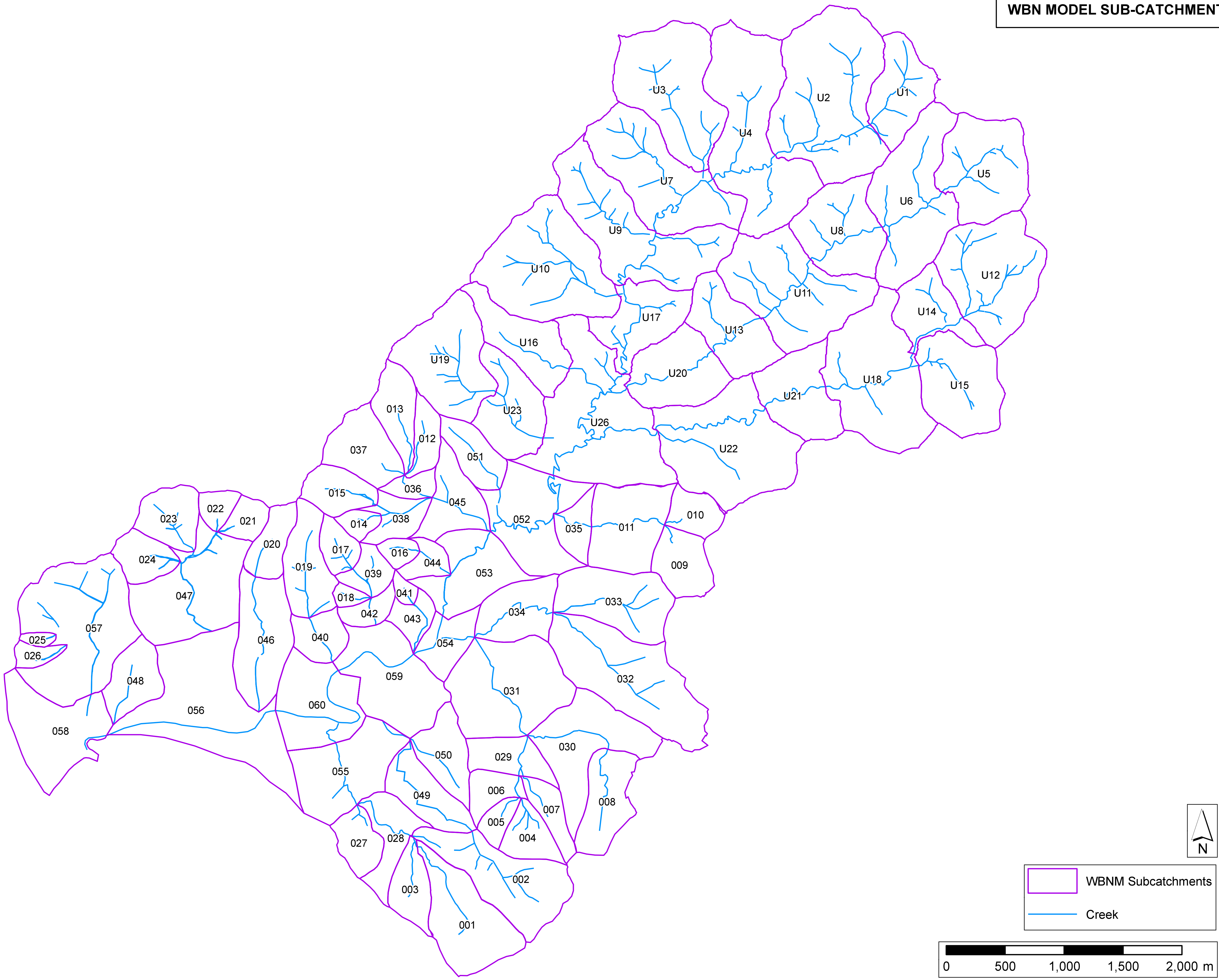

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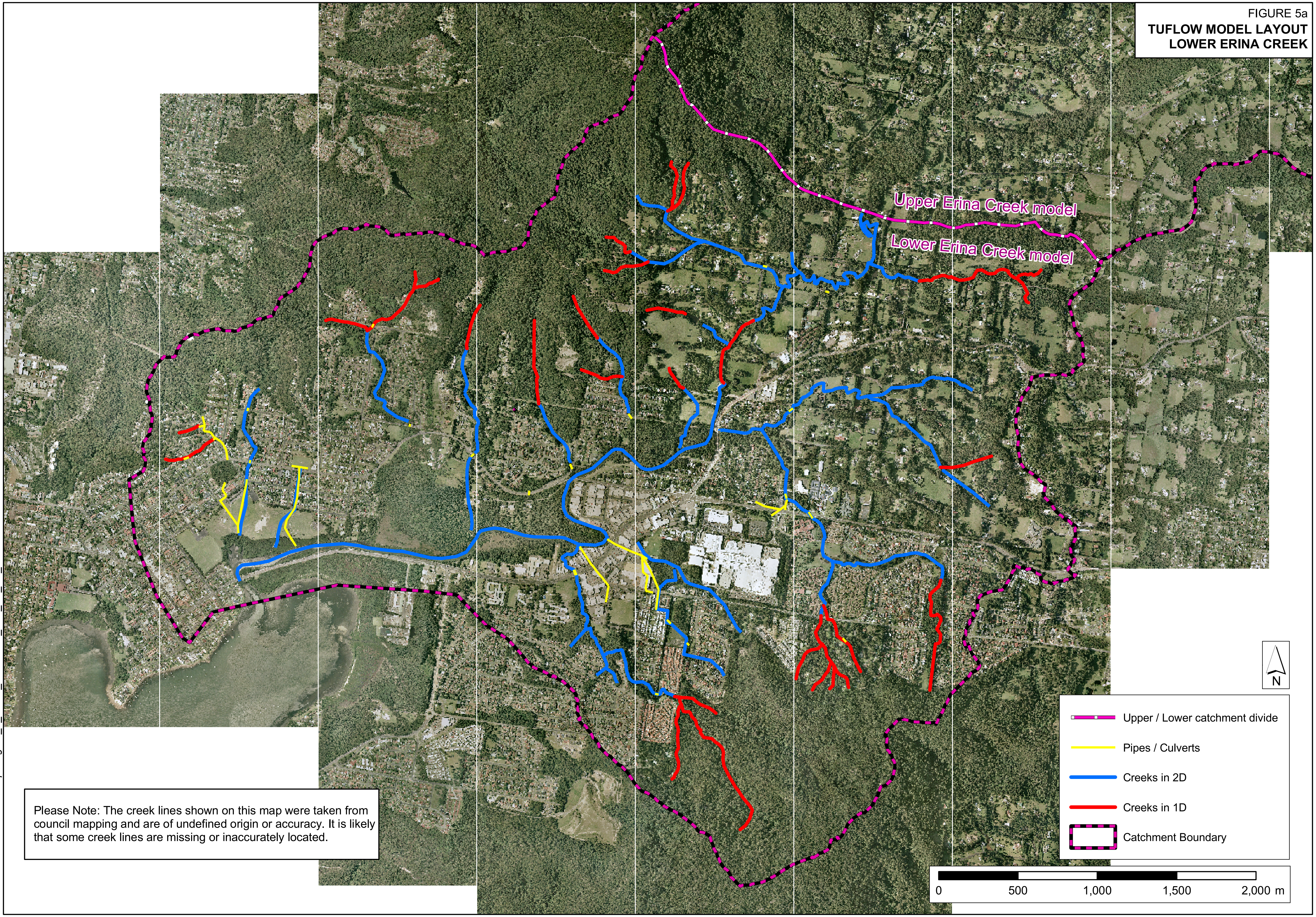
FIGURE 5a
TUFLOW MODEL LAYOUT
LOWER ERINA CREEK



Please Note: The creek lines shown on this map were taken from council mapping and are of undefined origin or accuracy. It is likely that some creek lines are missing or inaccurately located.

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FIGURE 5b

TUFLOW MODEL LAYOUT
UPPER ERINA CREEK

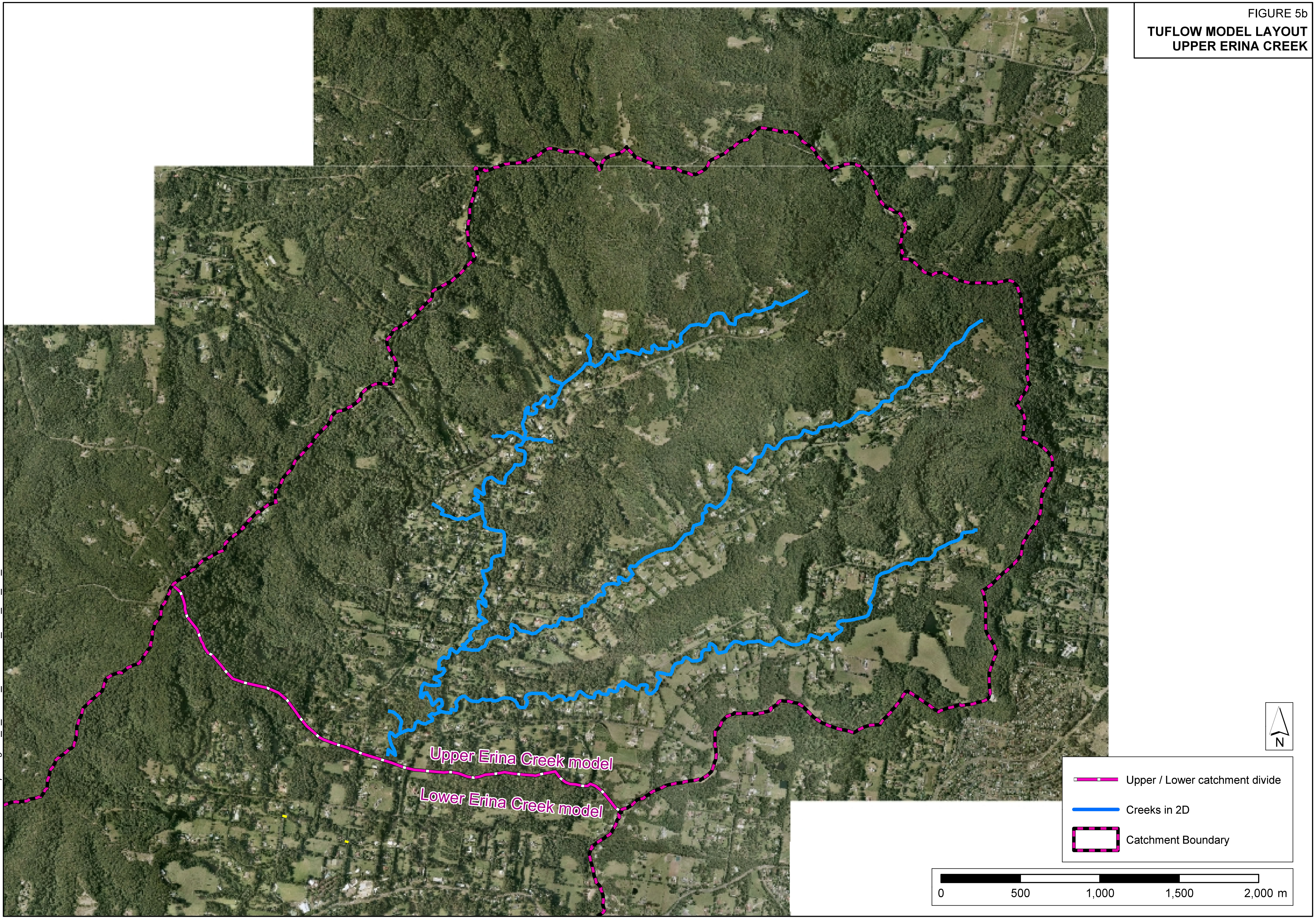

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FIGURE 6
LAND USE

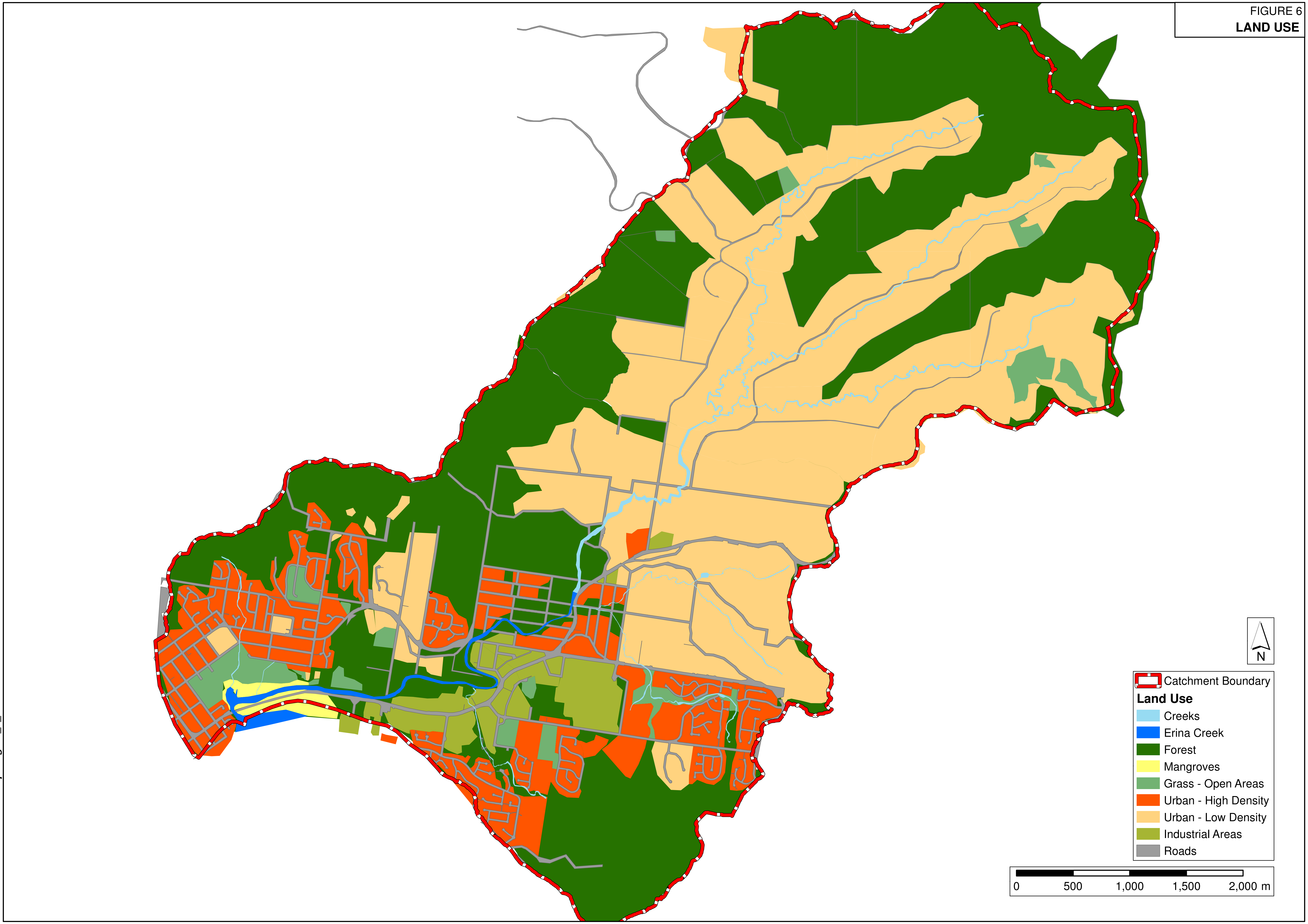

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FIGURE 7
VERIFICATION EVENT
2 TO 4 FEBRUARY 1990

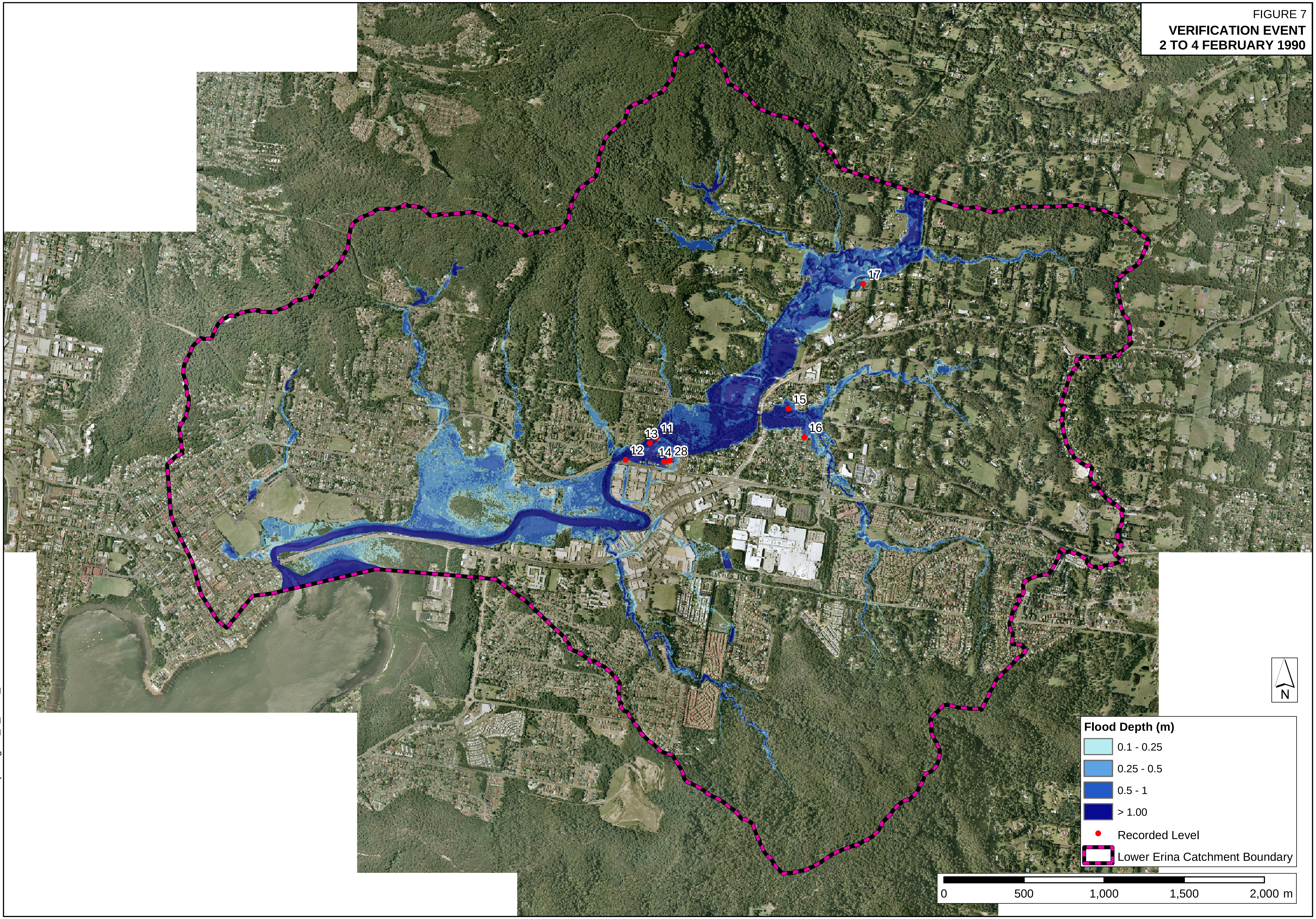

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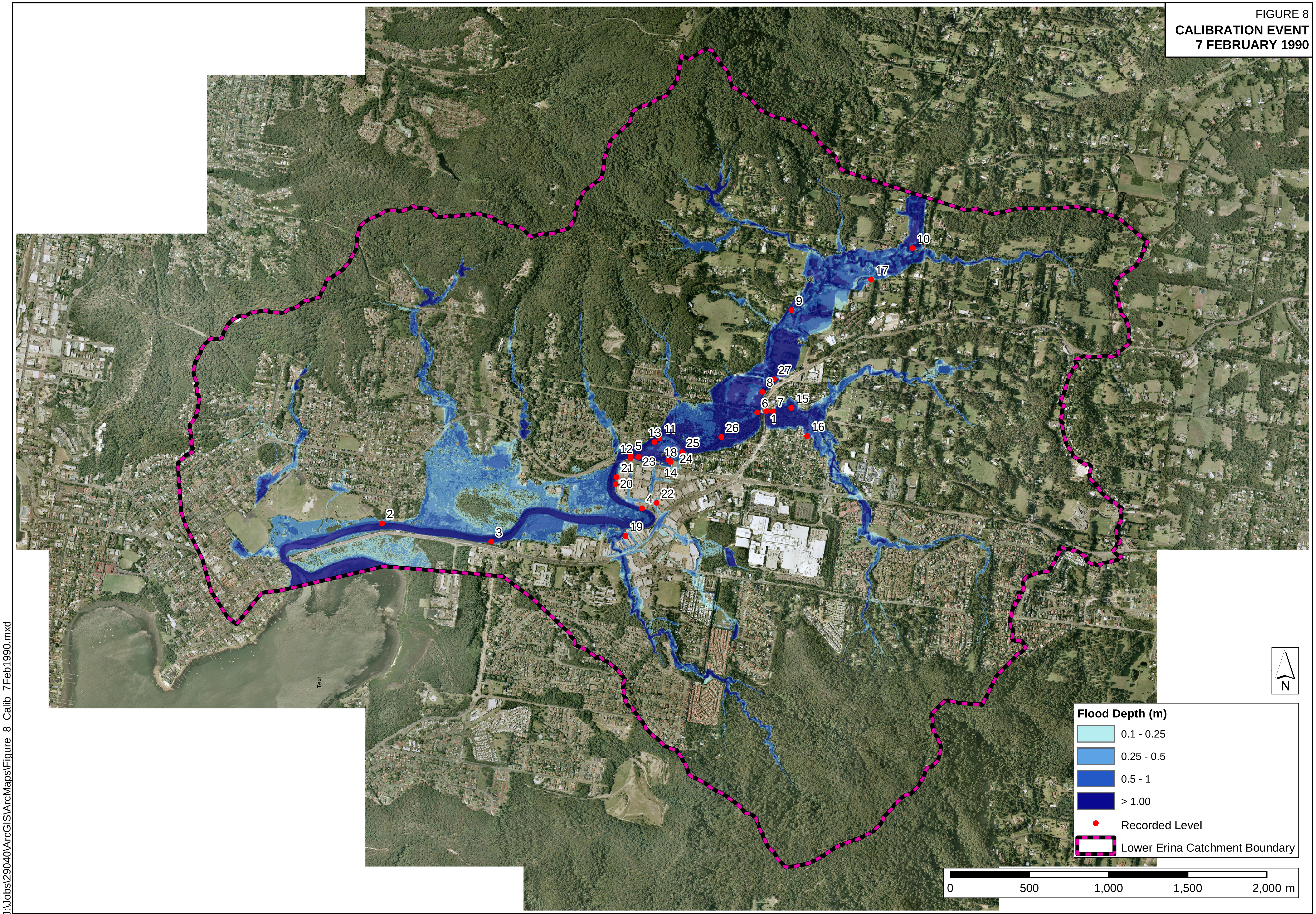
FIGURE 8
CALIBRATION EVENT
7 FEBRUARY 1990



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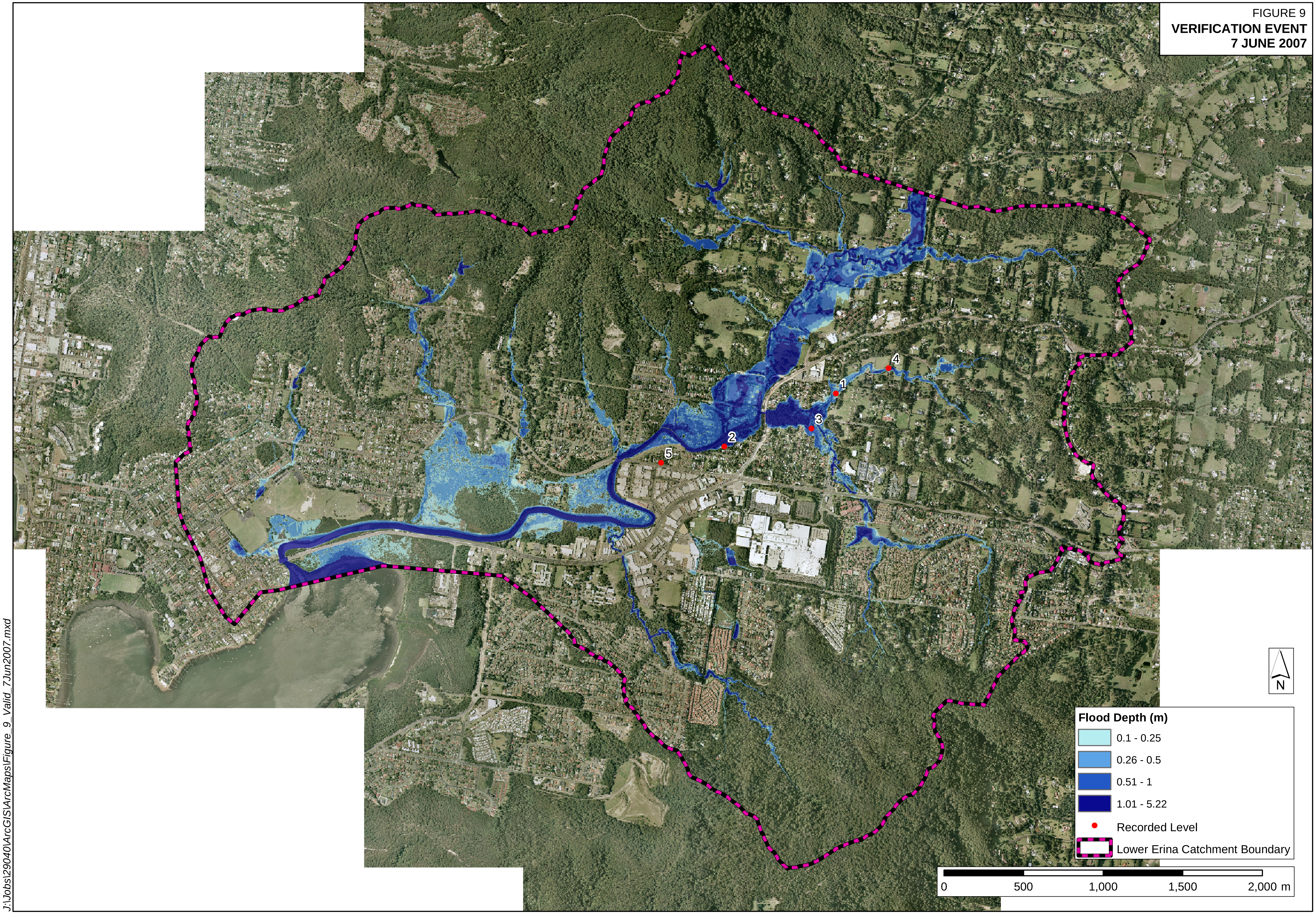

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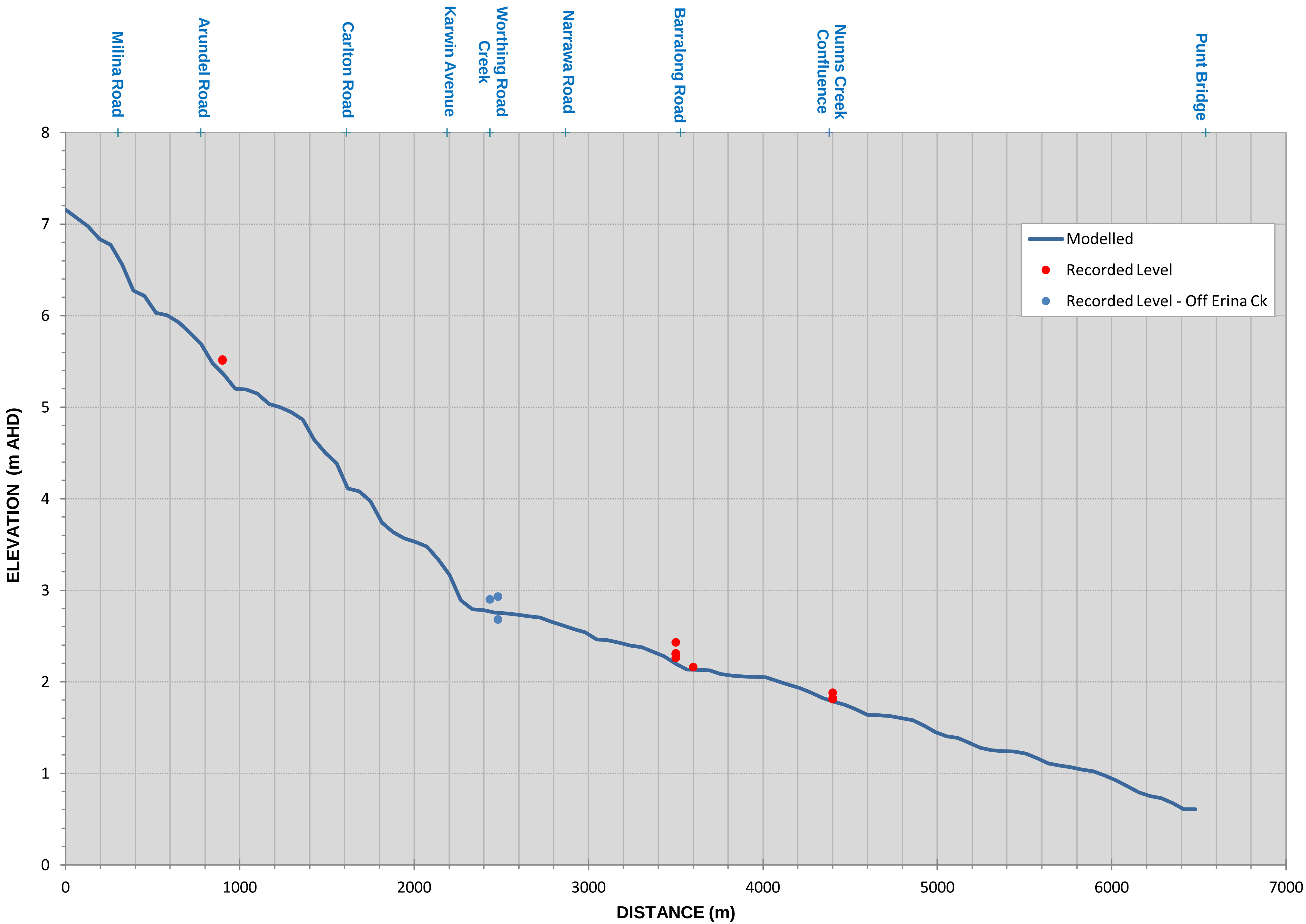

FIGURE 10
VERIFICATION EVENT
2 TO 4 FEBRUARY 1990

FIGURE 11
CALIBRATION EVENT
7 FEBRUARY 1990

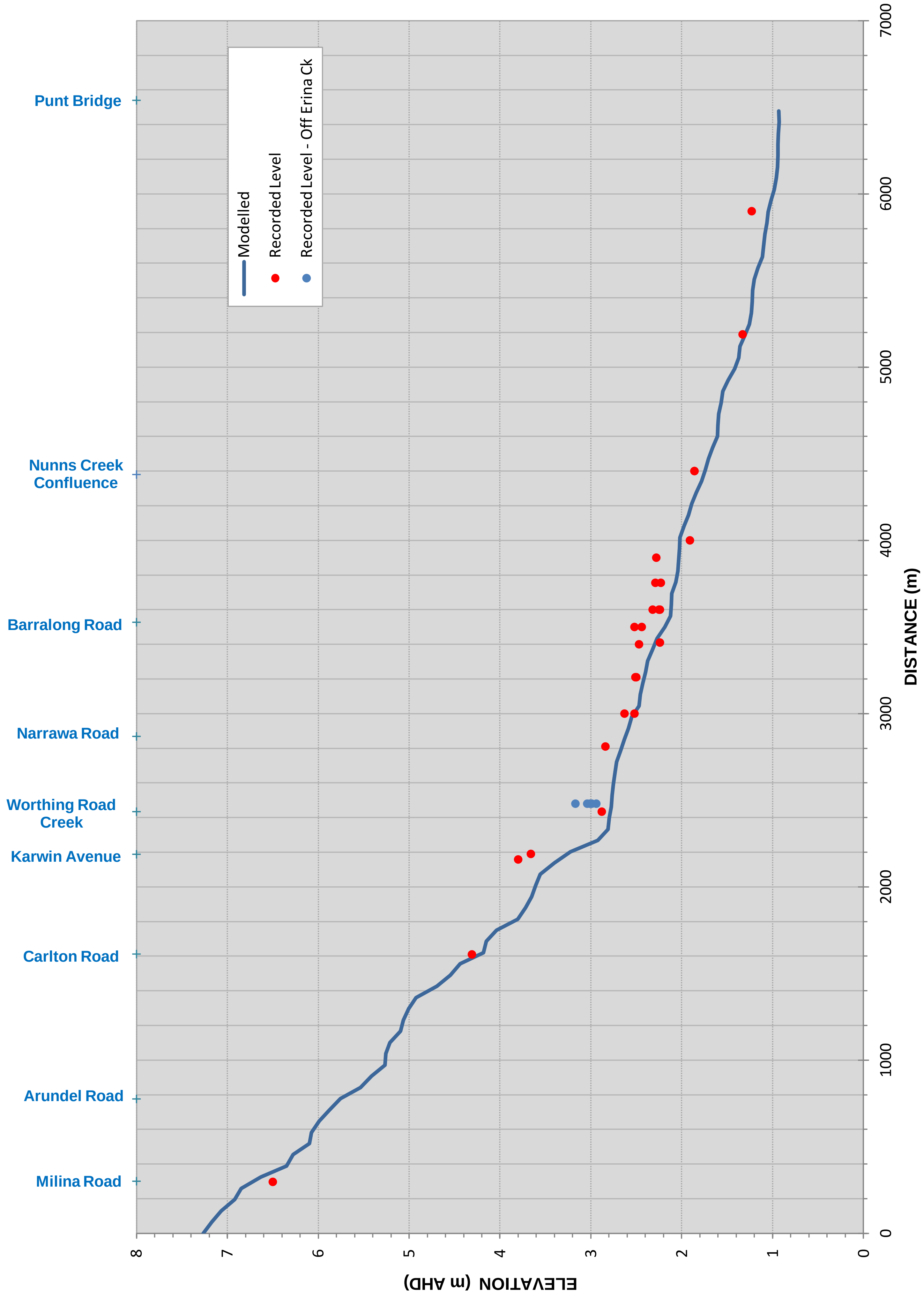

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FIGURE 12

STAGE HYDROGRAPHS

7 FEBRUARY 1990

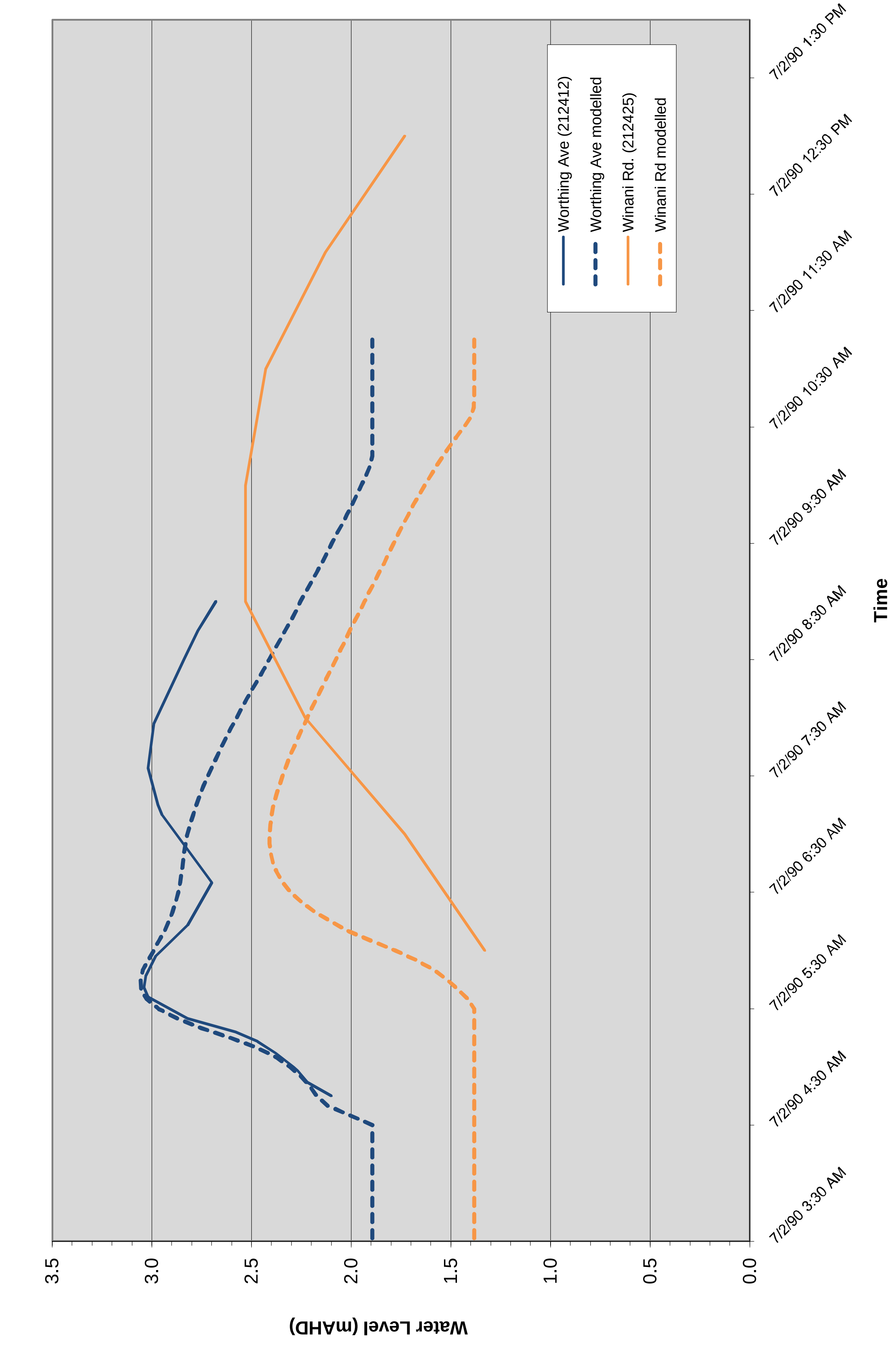

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FIGURE 13
VERIFICATION EVENT
7 JUNE 2007

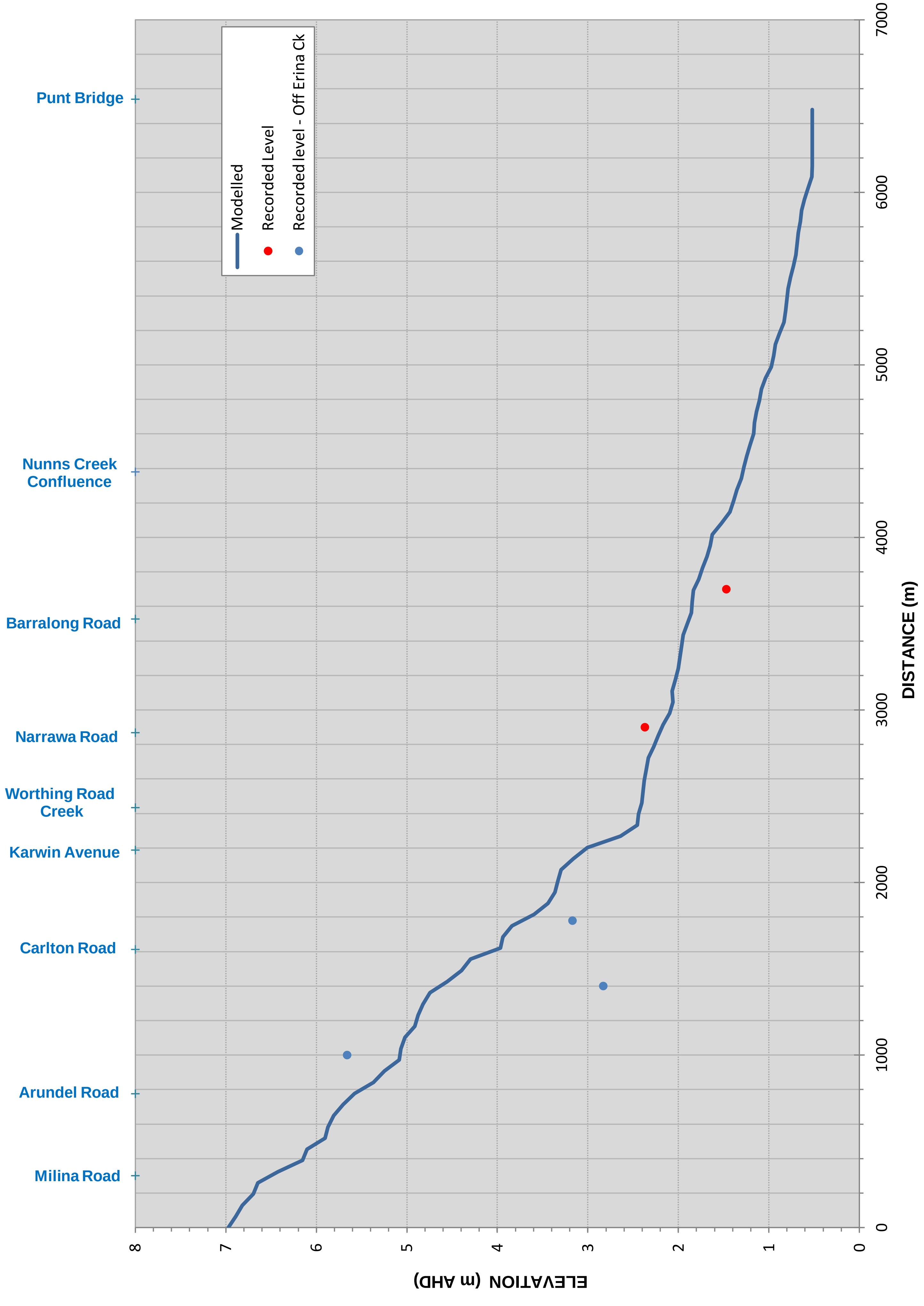

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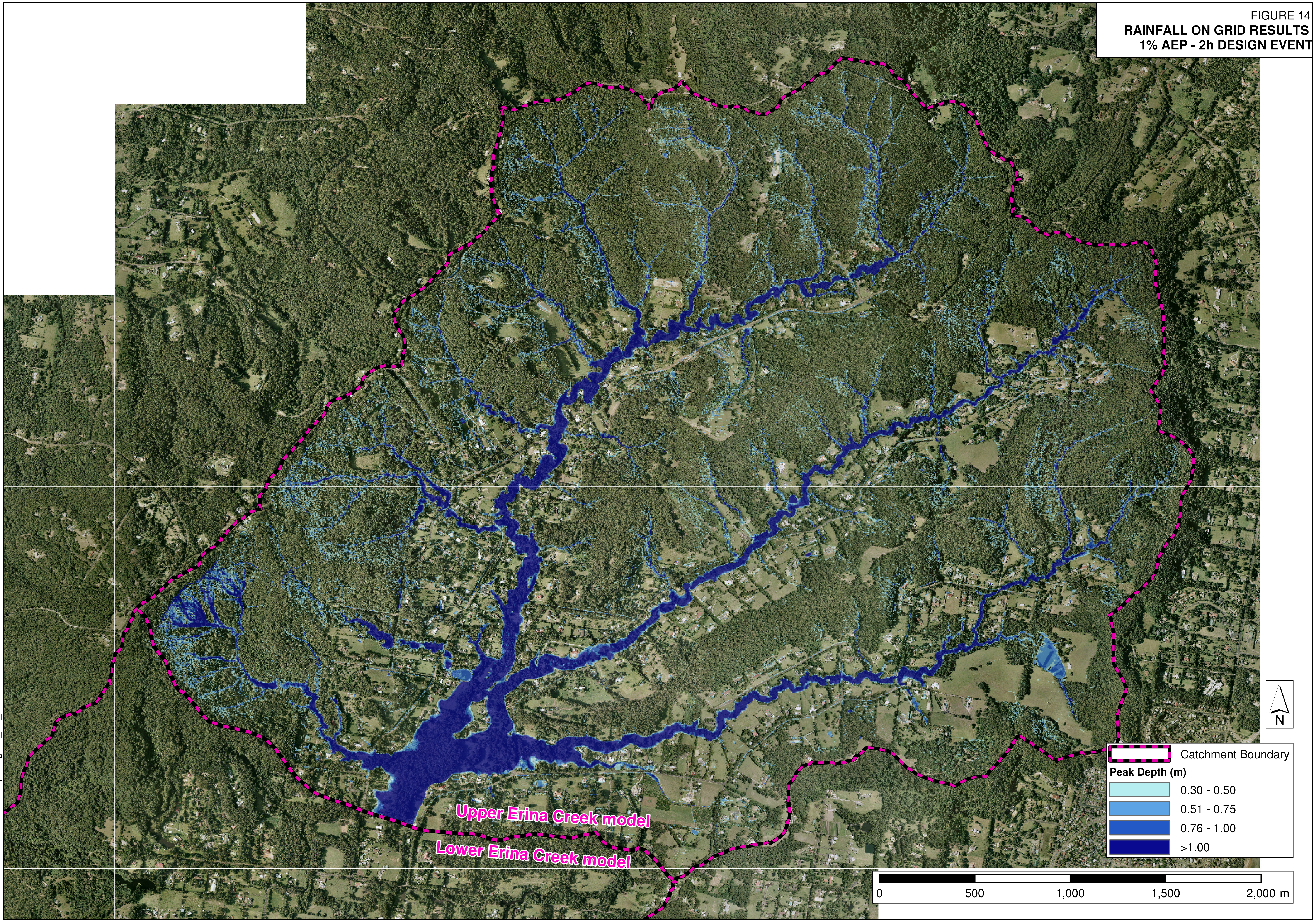
FIGURE 14

RAINFALL ON GRID RESULTS
1% AEP - 2h DESIGN EVENT



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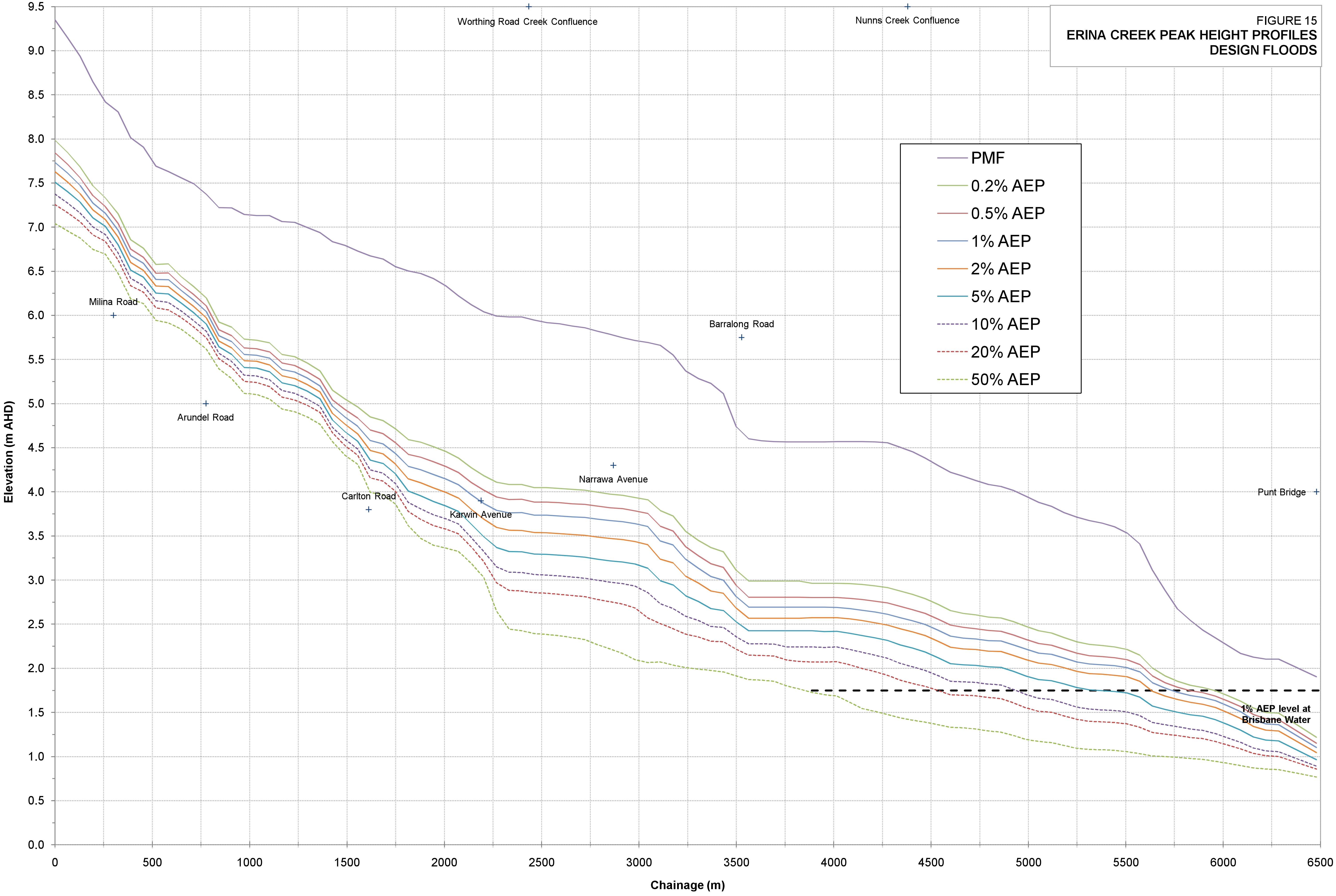


FIGURE 15
ERINA CREEK PEAK HEIGHT PROFILES
DESIGN FLOODS
Worthing Road Creek Confluence
Nunns Creek Confluence
PMF
0.2% AEP
0.5% AEP
1% AEP
2% AEP
5% AEP
10% AEP
20% AEP
50% AEP
Milina Road
Arundel Road
Barralong Road
Narrawa Avenue
Carlton Road
Karwin Avenue
Punt Bridge
1% AEP level at Brisbane Water
Elevation (m AHD)
Chainage (m)
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500

FIGURE 16

ERINA CREEK HEIGHT PROFILES

OLD VS NEW

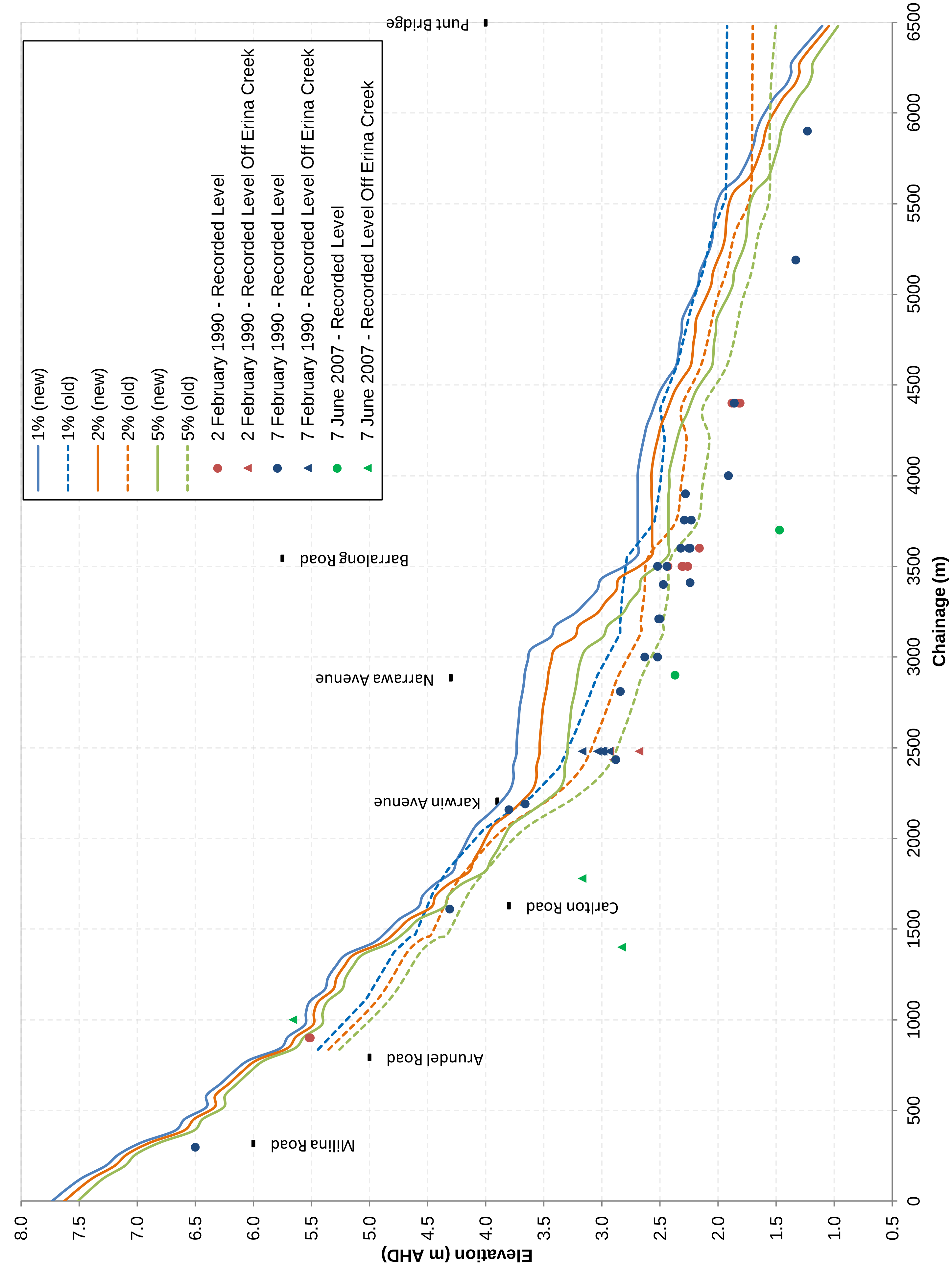
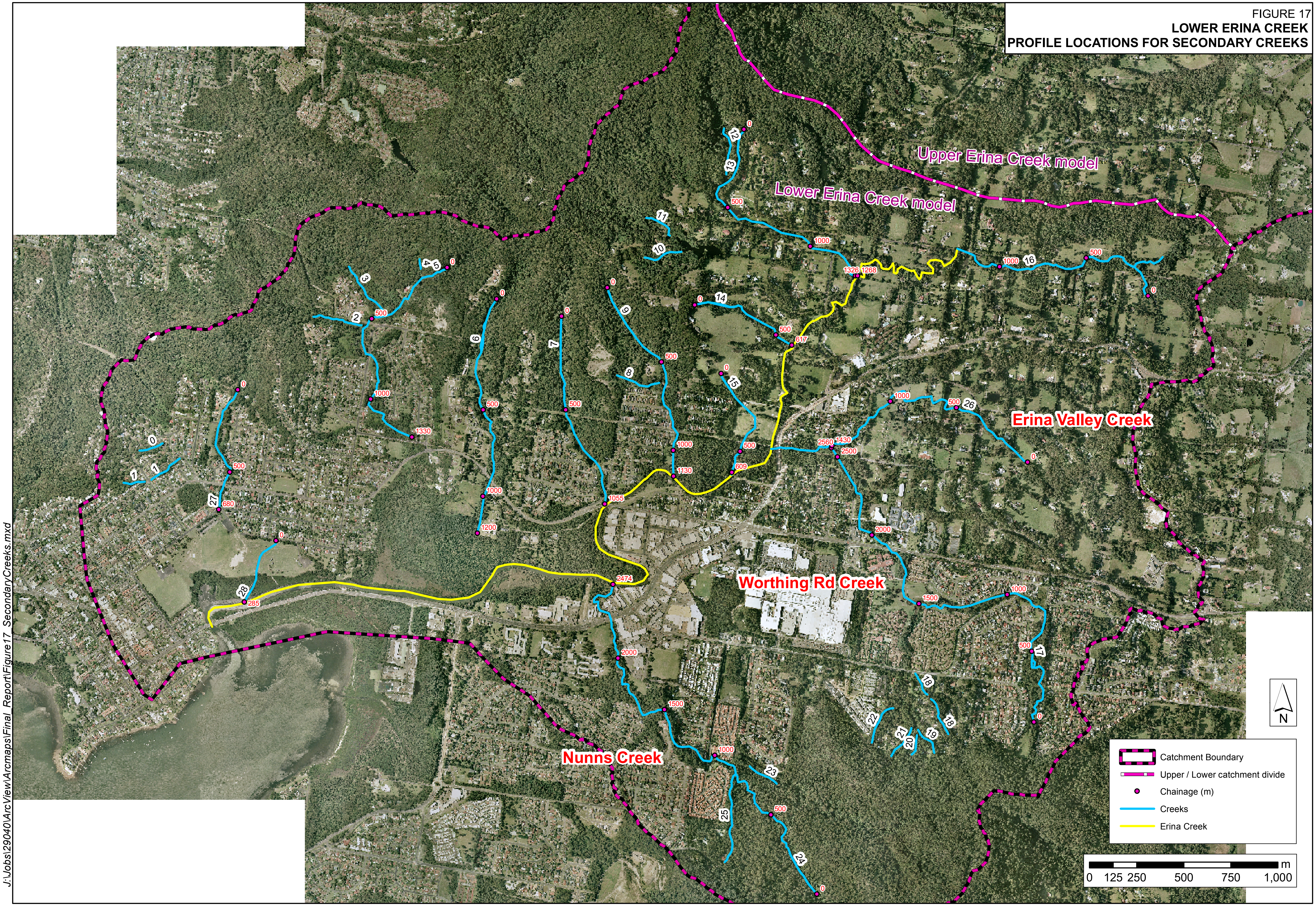


FIGURE 17
LOWER ERINA CREEK
PROFILE LOCATIONS FOR SECONDARY CREEKS



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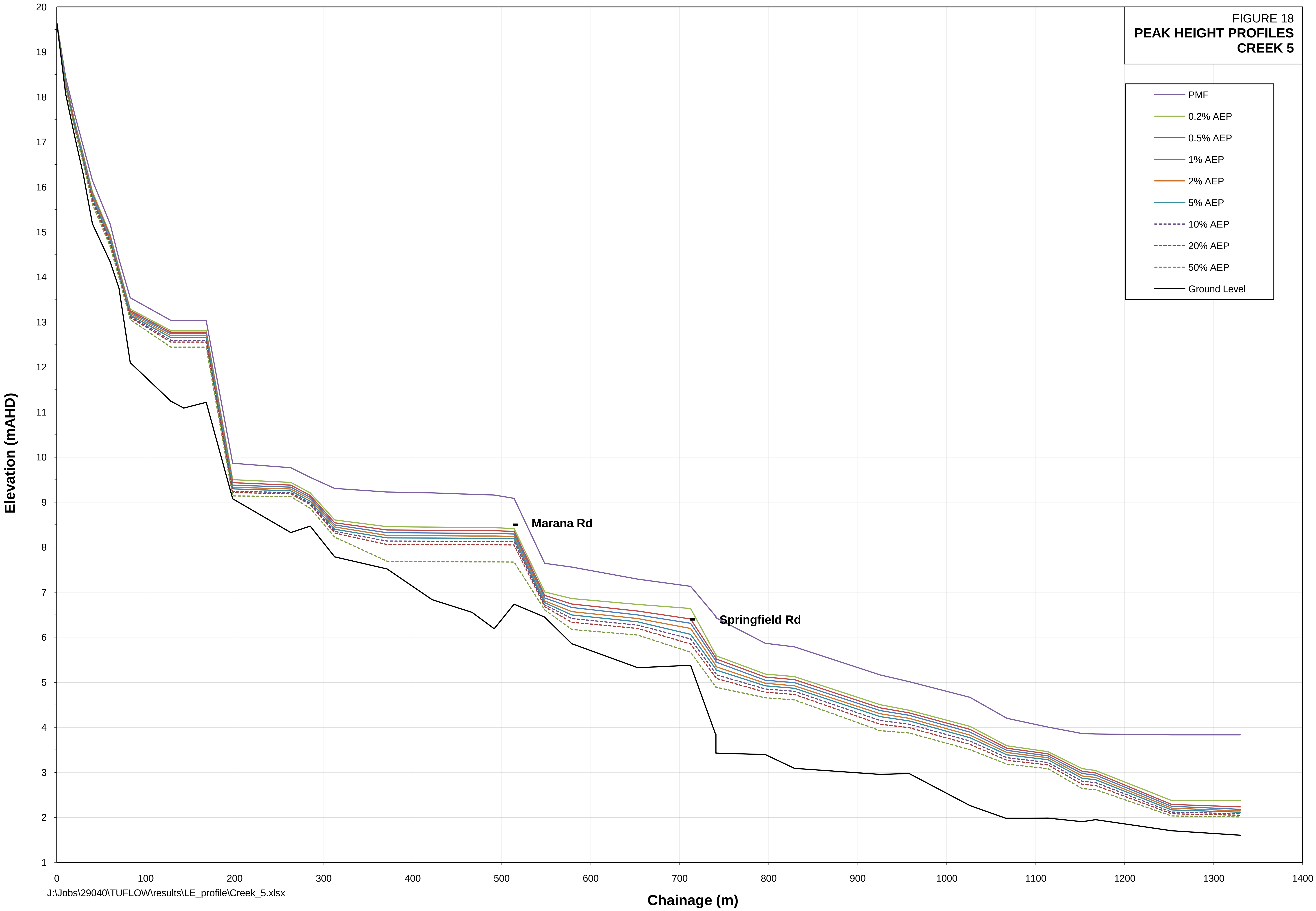

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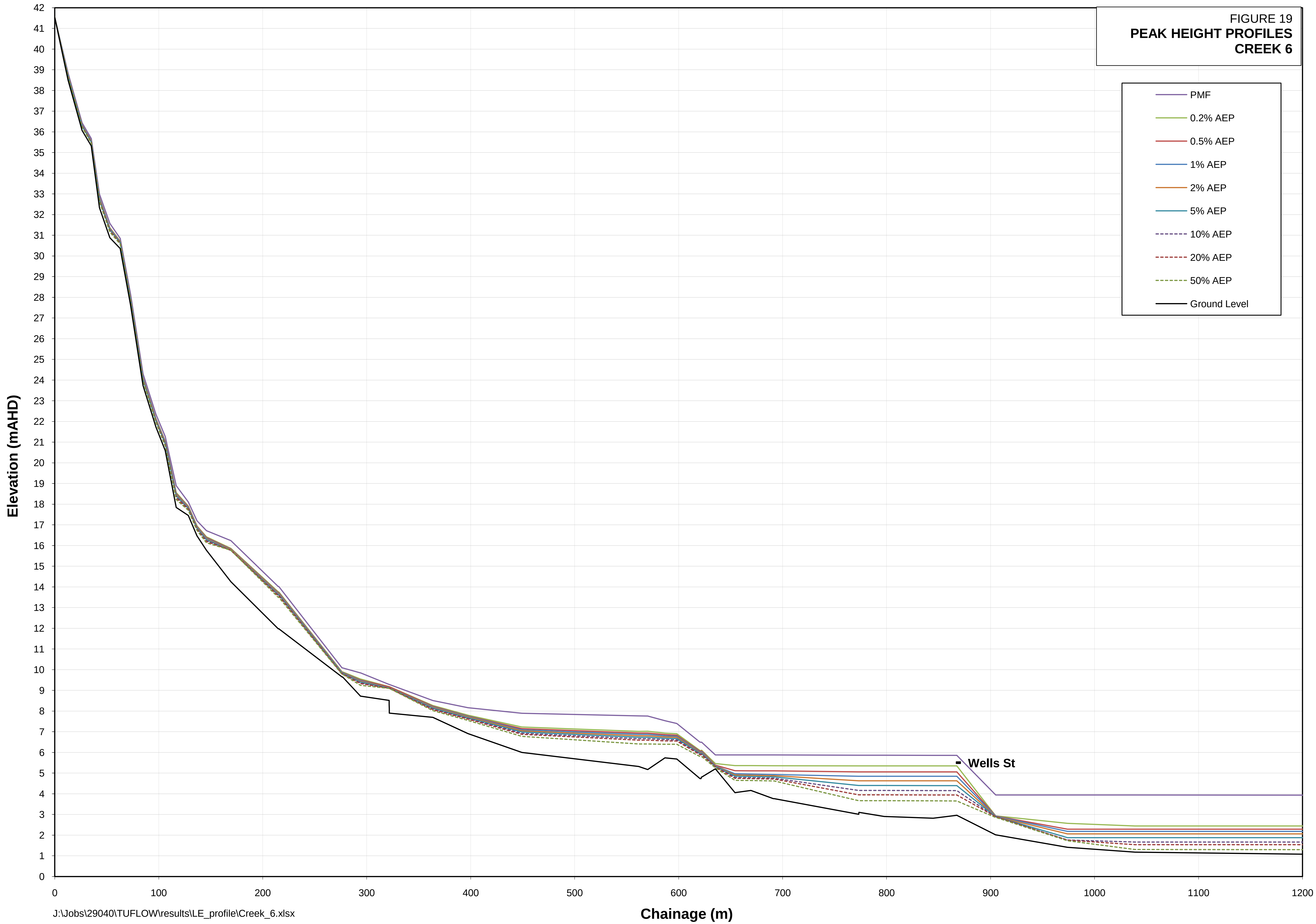

FIGURE 19
PEAK HEIGHT PROFILES
CREEK 6
PMF
0.2% AEP
0.5% AEP
1% AEP
2% AEP
5% AEP
10% AEP
20% AEP
50% AEP
Ground Level
Wells St
Elevation (mAHD)
Chainage (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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42
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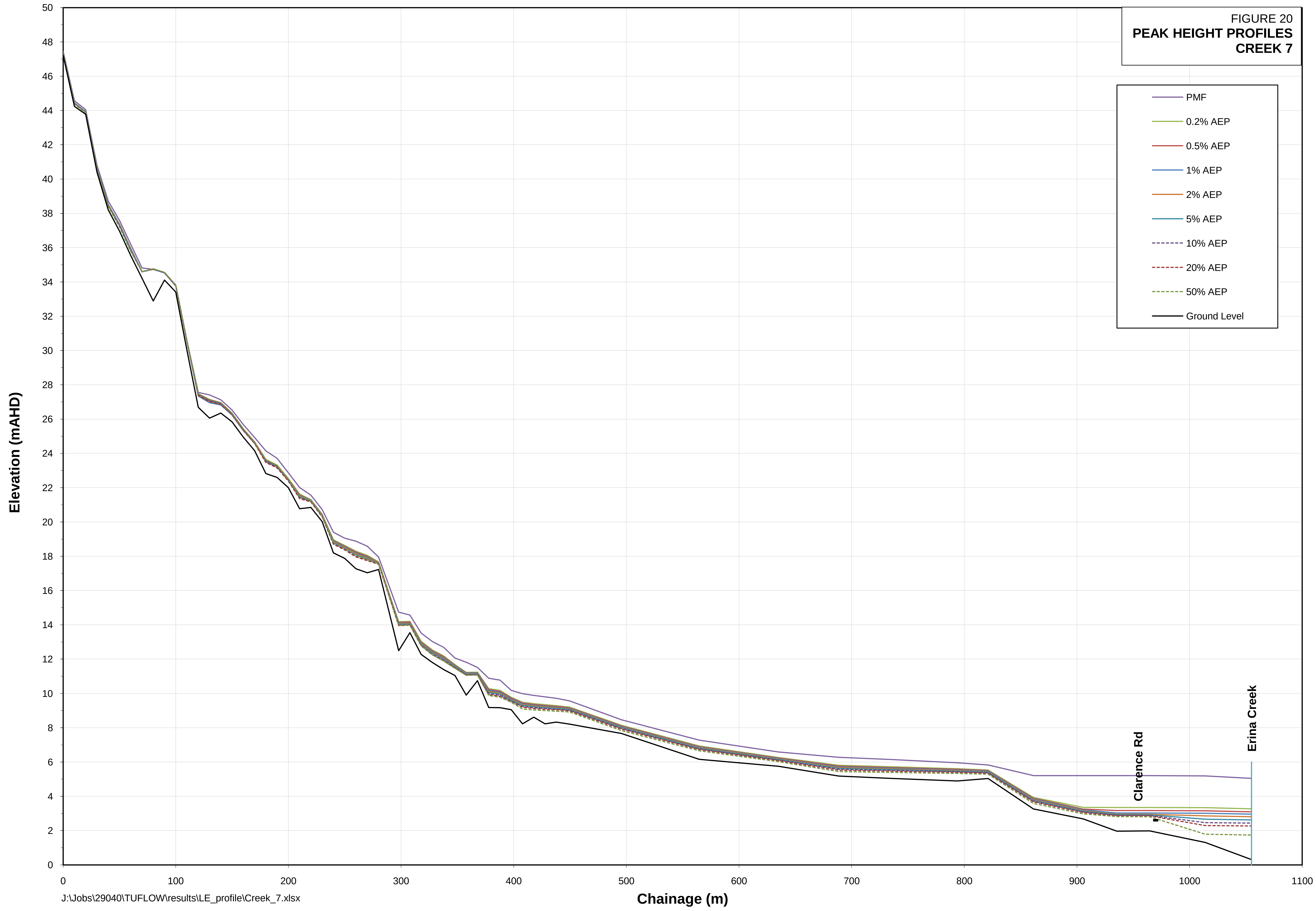
FIGURE 20
PEAK HEIGHT PROFILES
CREEK 7
PMF
0.2% AEP
0.5% AEP
1% AEP
2% AEP
5% AEP
10% AEP
20% AEP
50% AEP
Ground Level
Elevation (mAHD)
Chainage (m)
Clarence Rd
Erina Creek
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
0
100
200
300
400
500
600
700
800
900
1000
1100
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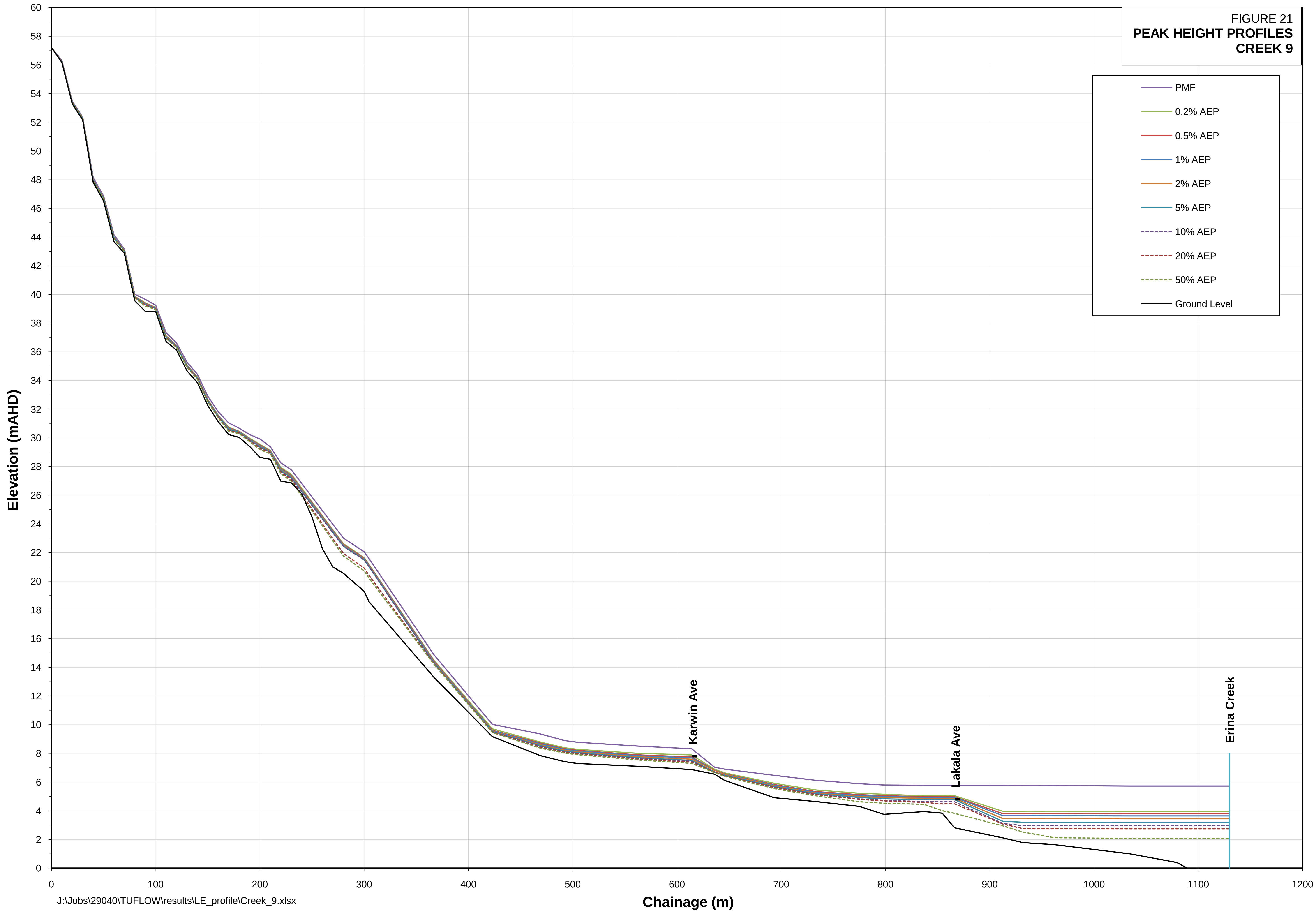

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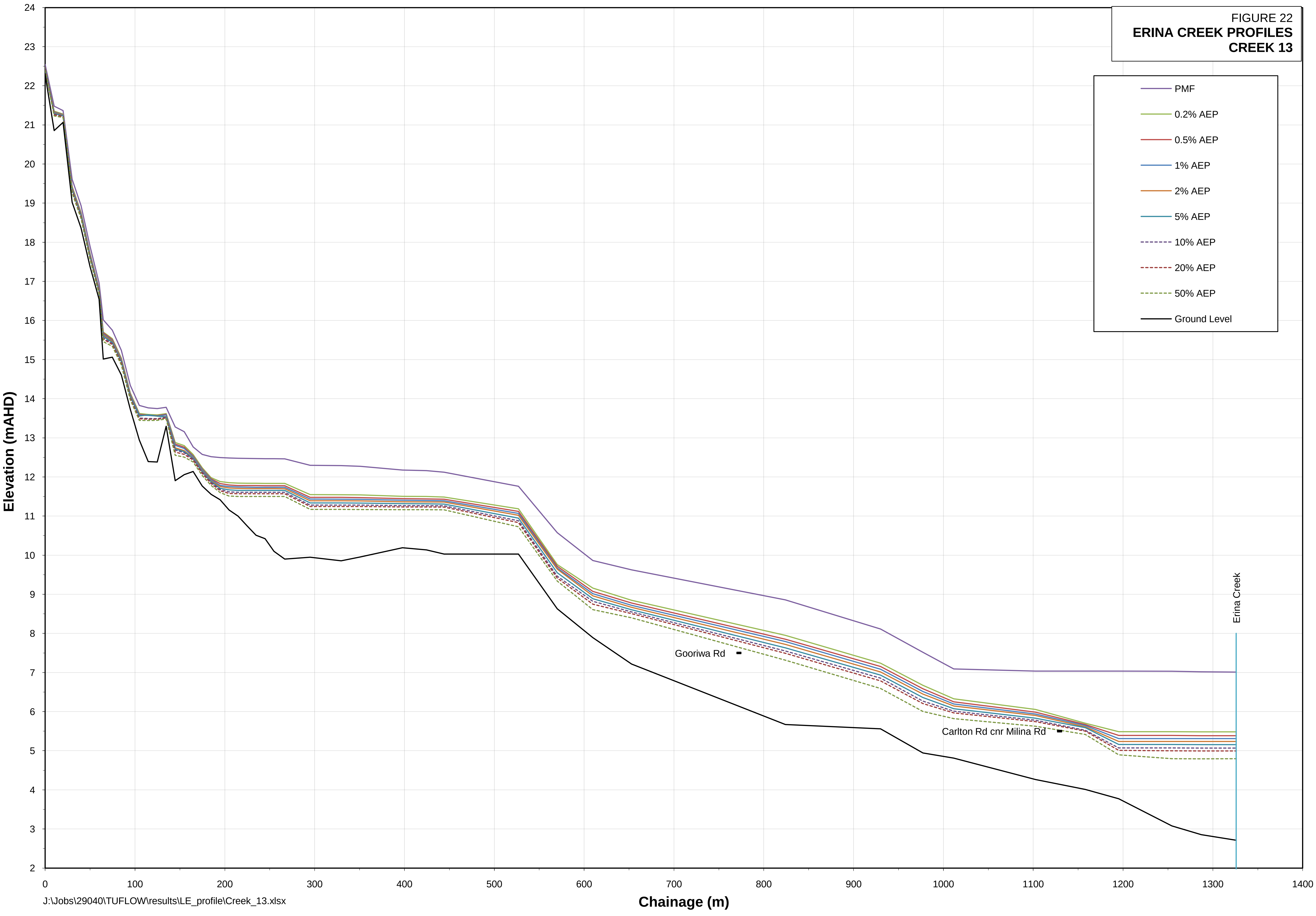

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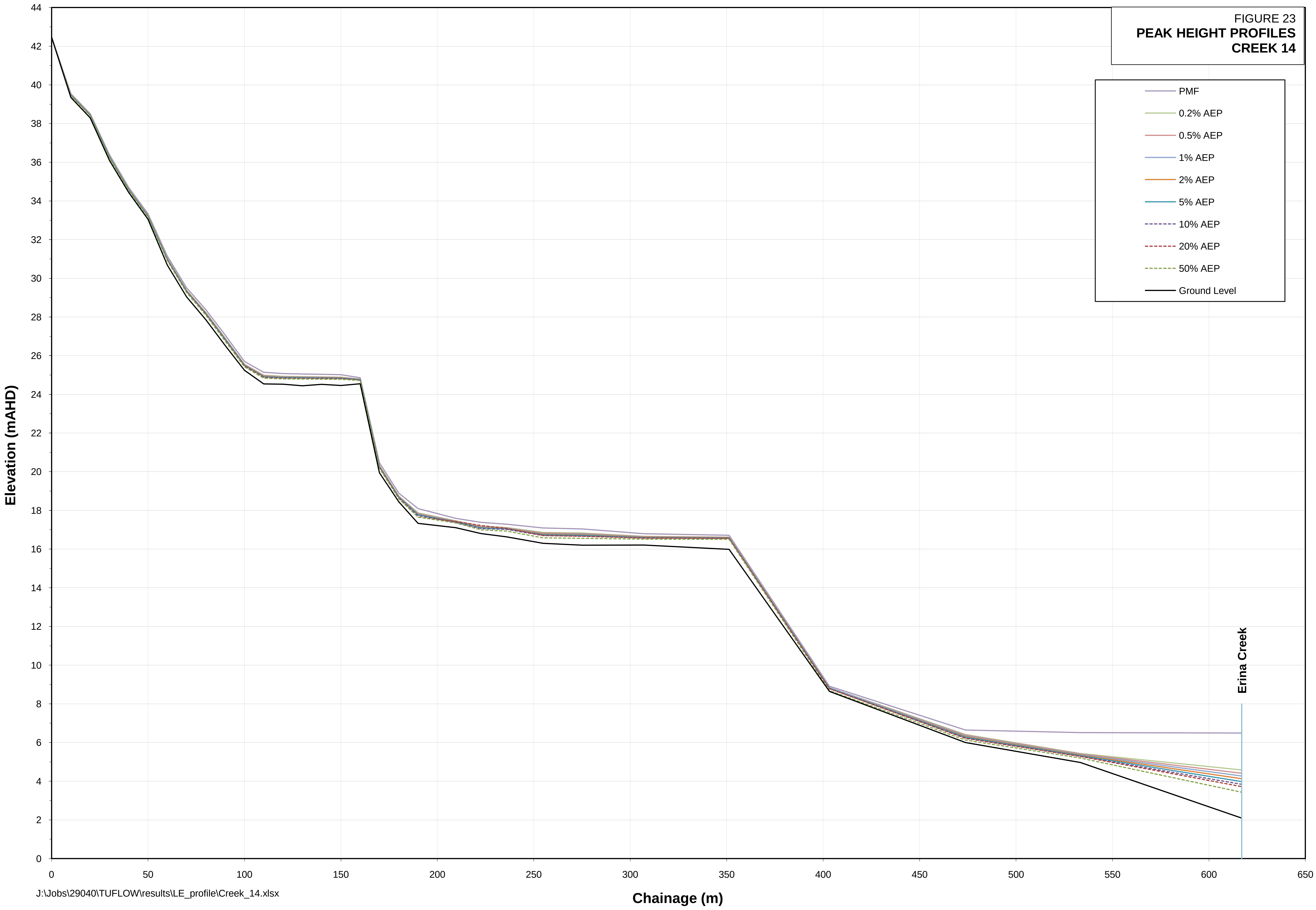

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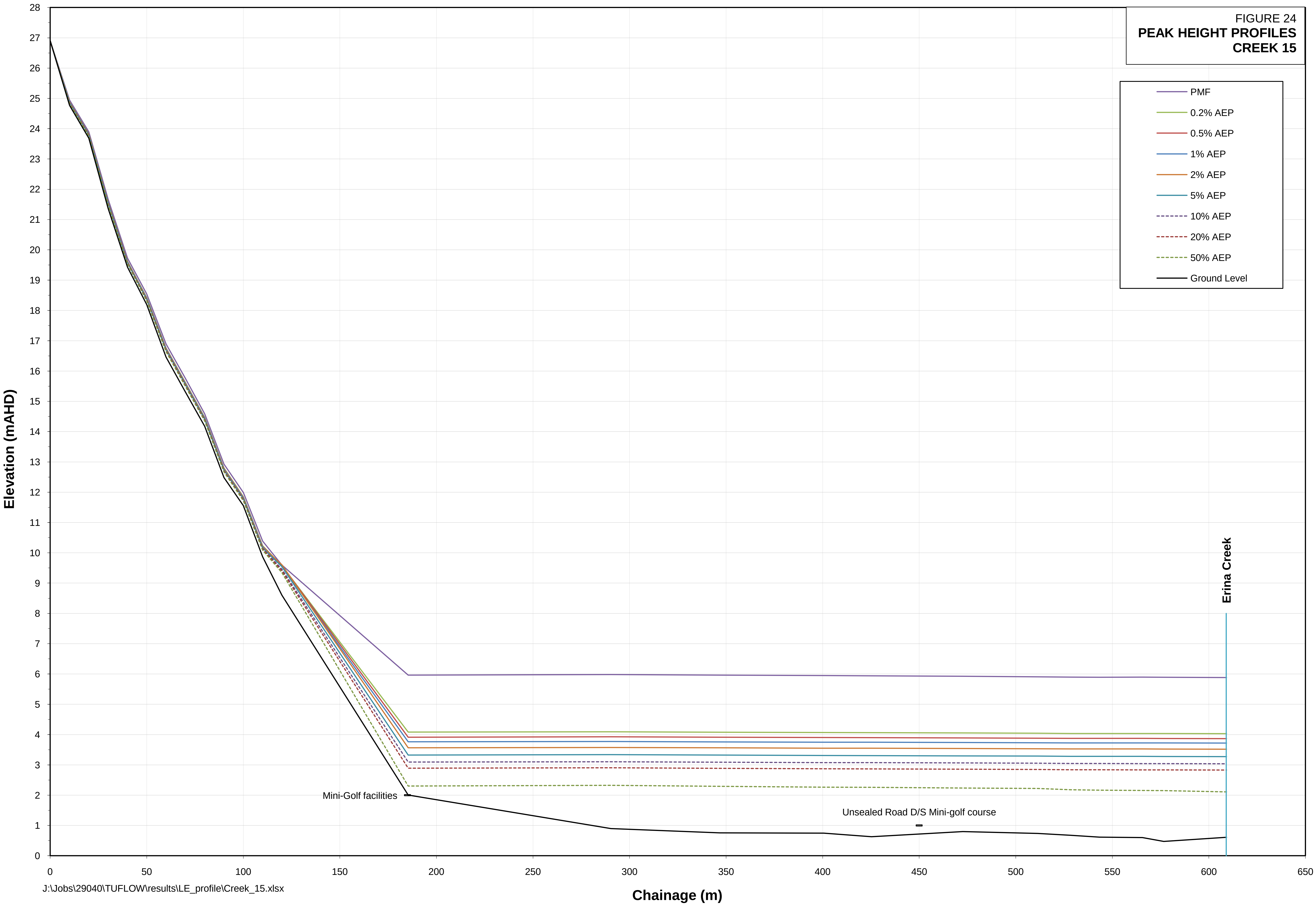
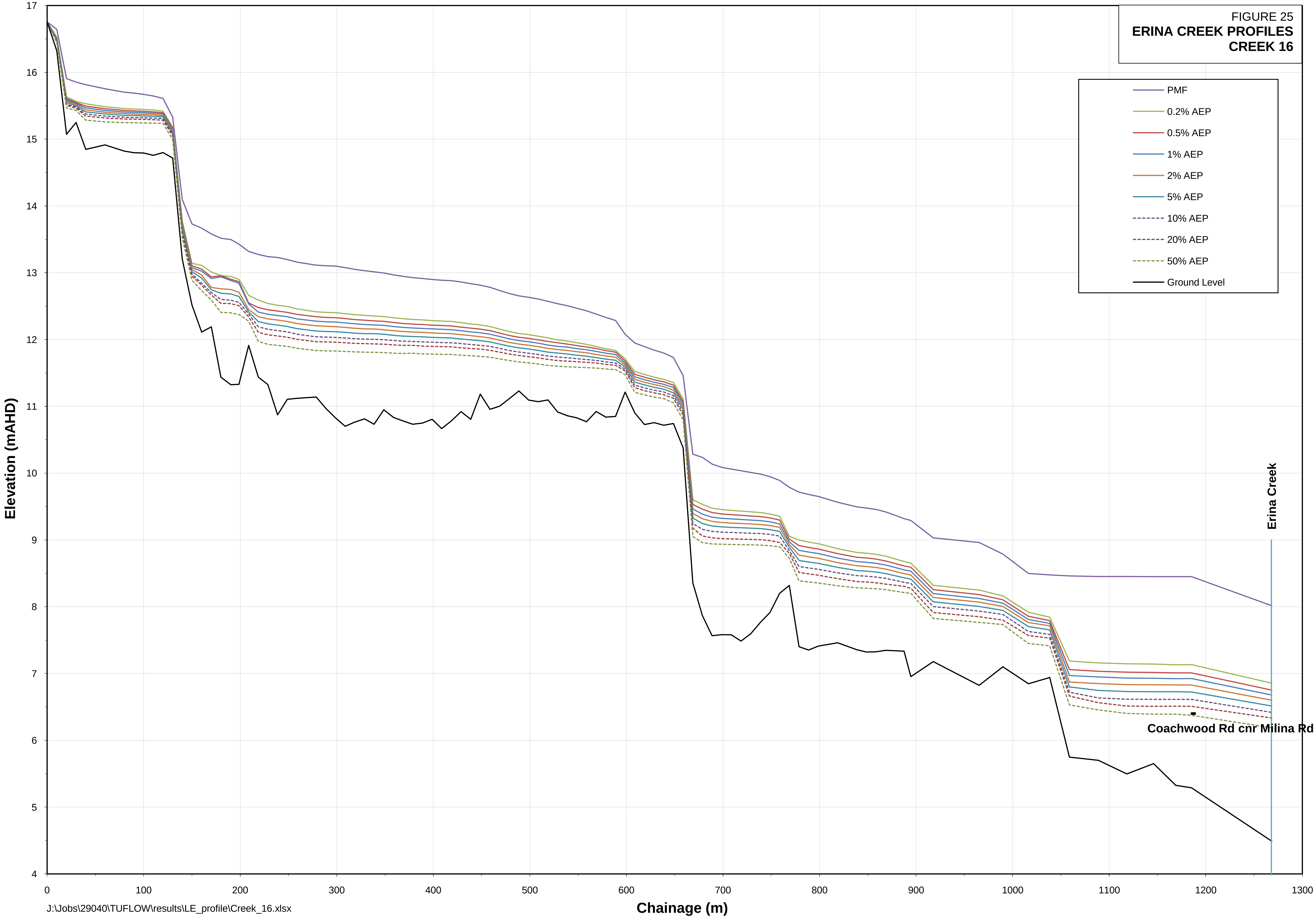


FIGURE 24
PEAK HEIGHT PROFILES
CREEK 15
PMF
0.2% AEP
0.5% AEP
1% AEP
2% AEP
5% AEP
10% AEP
20% AEP
50% AEP
Ground Level
Erina Creek
Mini-Golf facilities
Unsealed Road D/S Mini-golf course
Elevation (mAHD)
Chainage (m)
J:\Jobs\29040\TUFLOW\results\LE_profile\Creek_15.xlsx



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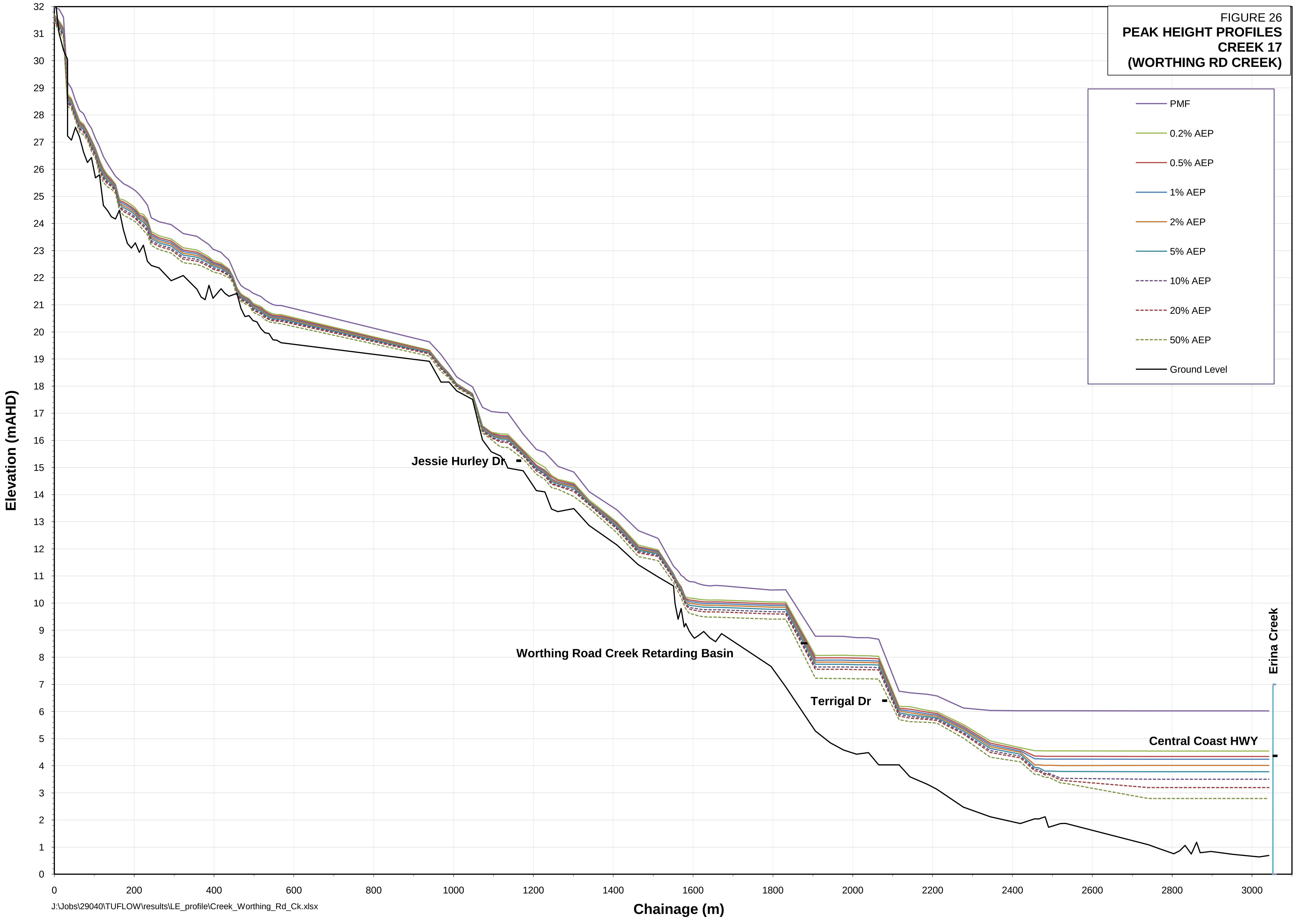
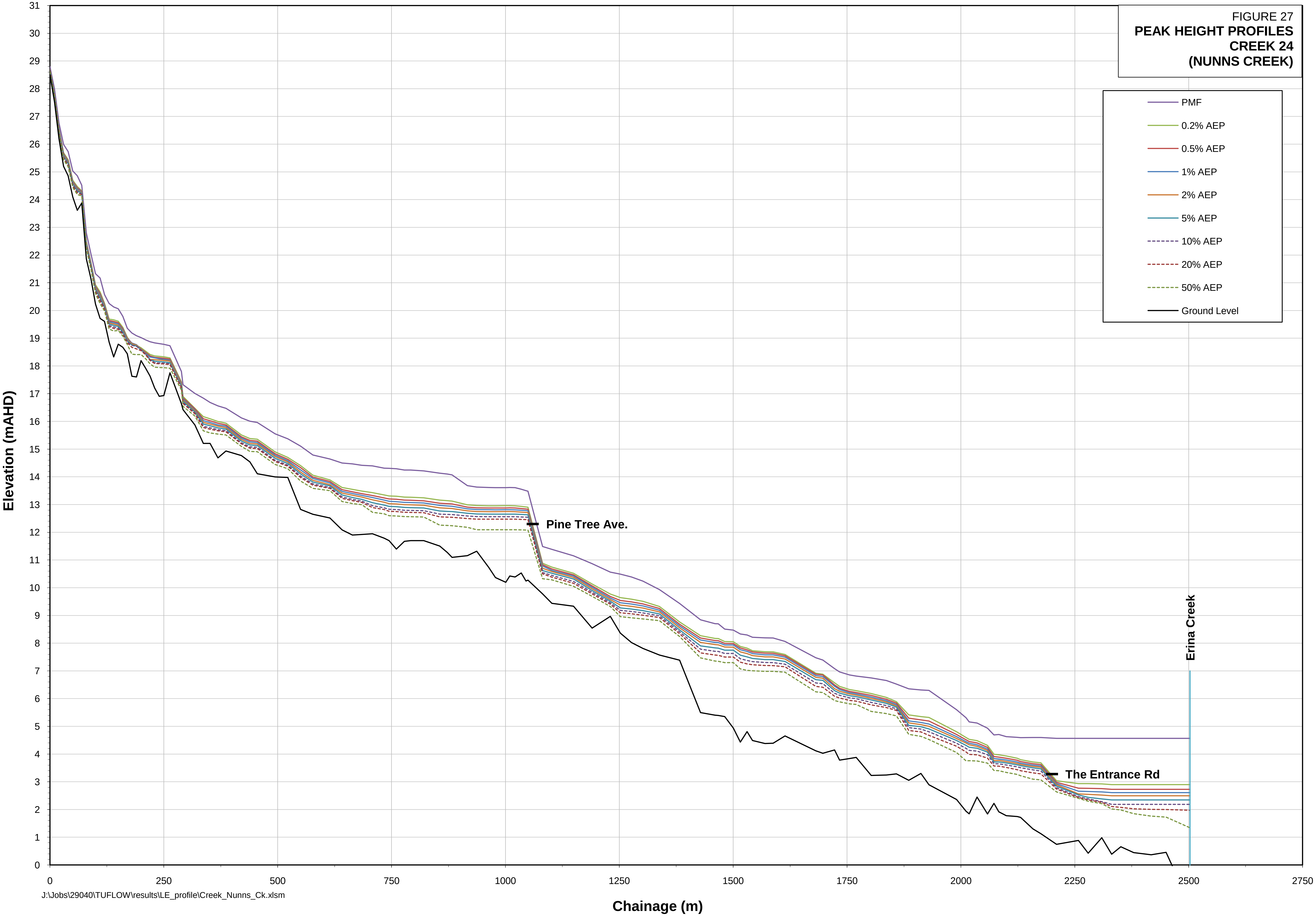


FIGURE 26
PEAK HEIGHT PROFILES
CREEK 17
(WORTHING RD CREEK)
PMF
0.2% AEP
0.5% AEP
1% AEP
2% AEP
5% AEP
10% AEP
20% AEP
50% AEP
Ground Level
Jessie Hurley Dr
Worthing Road Creek Retarding Basin
Terrigal Dr
Central Coast HWY
Erina Creek
Elevation (mAHD)
Chainage (m)
J:\Jobs\29040\TUFLOW\results\LE_profile\Creek_Worthing_Rd_Ck.xlsx



J:\Jobs\29040\TUFLOW\results\LE_profile\Creek_Nunns_Ck.xlsm

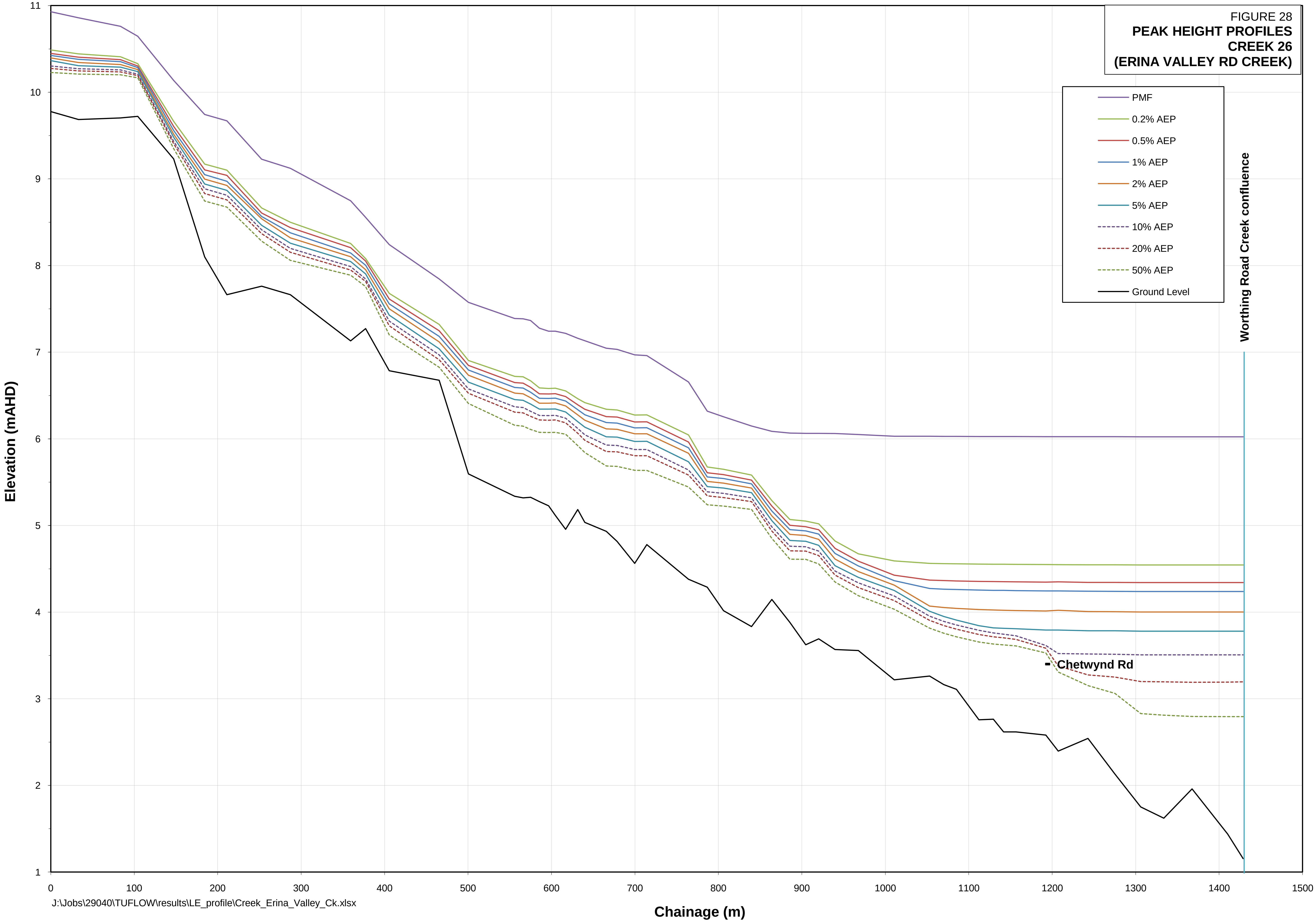


FIGURE 28
PEAK HEIGHT PROFILES
CREEK 26
(ERINA VALLEY RD CREEK)
PMF
0.2% AEP
0.5% AEP
1% AEP
2% AEP
5% AEP
10% AEP
20% AEP
50% AEP
Ground Level
Worthing Road Creek confluence
Chetwynd Rd
Elevation (mAHD)
Chainage (m)
11
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
J:\Jobs\29040\TUFLOW\results\LE_profile\Creek_Erina_Valley_Ck.xlsx

FIGURE 29
PEAK HEIGHT PROFILES
CREEK 27

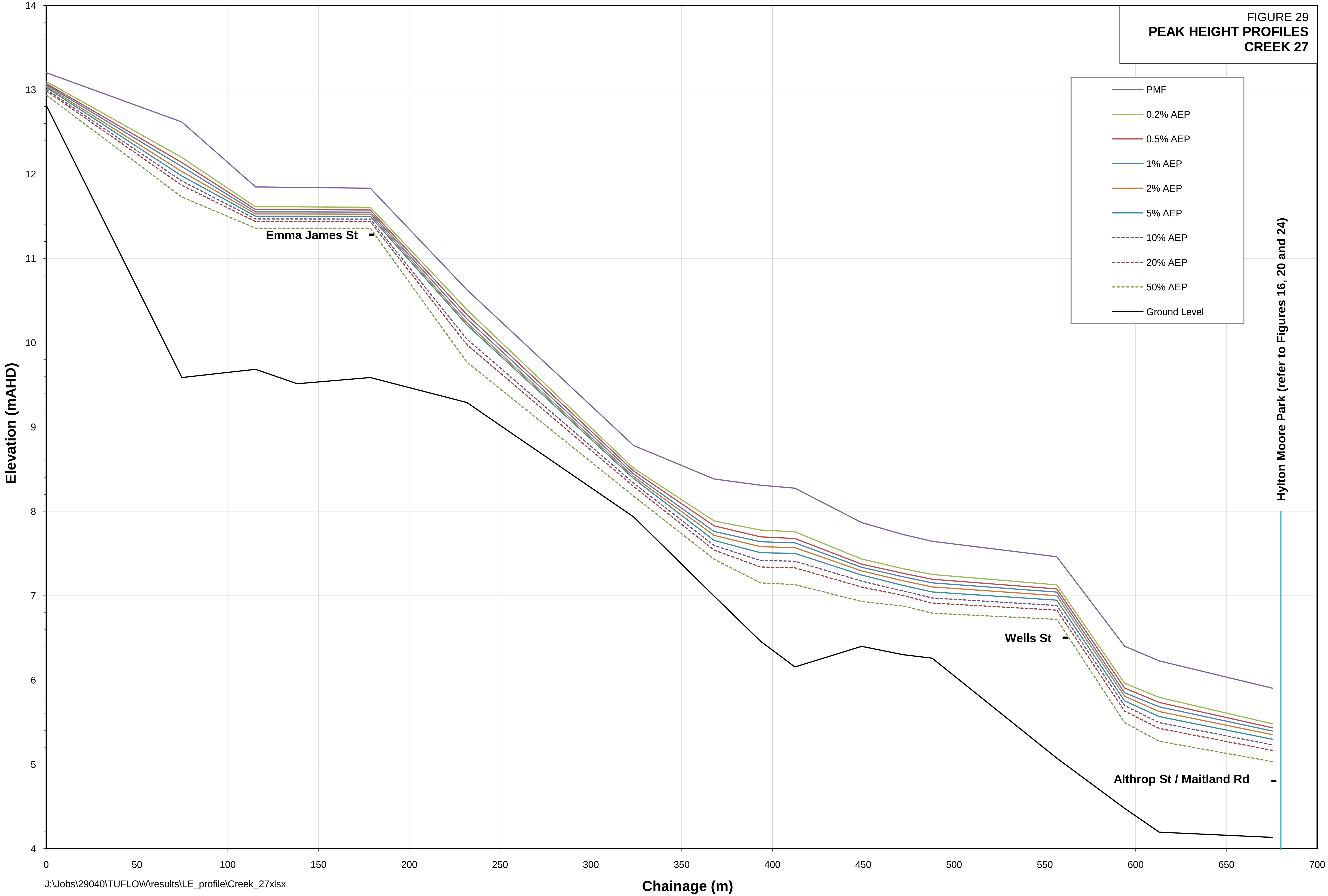


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FIGURE 30
PEAK HEIGHT PROFILES CREEK 28

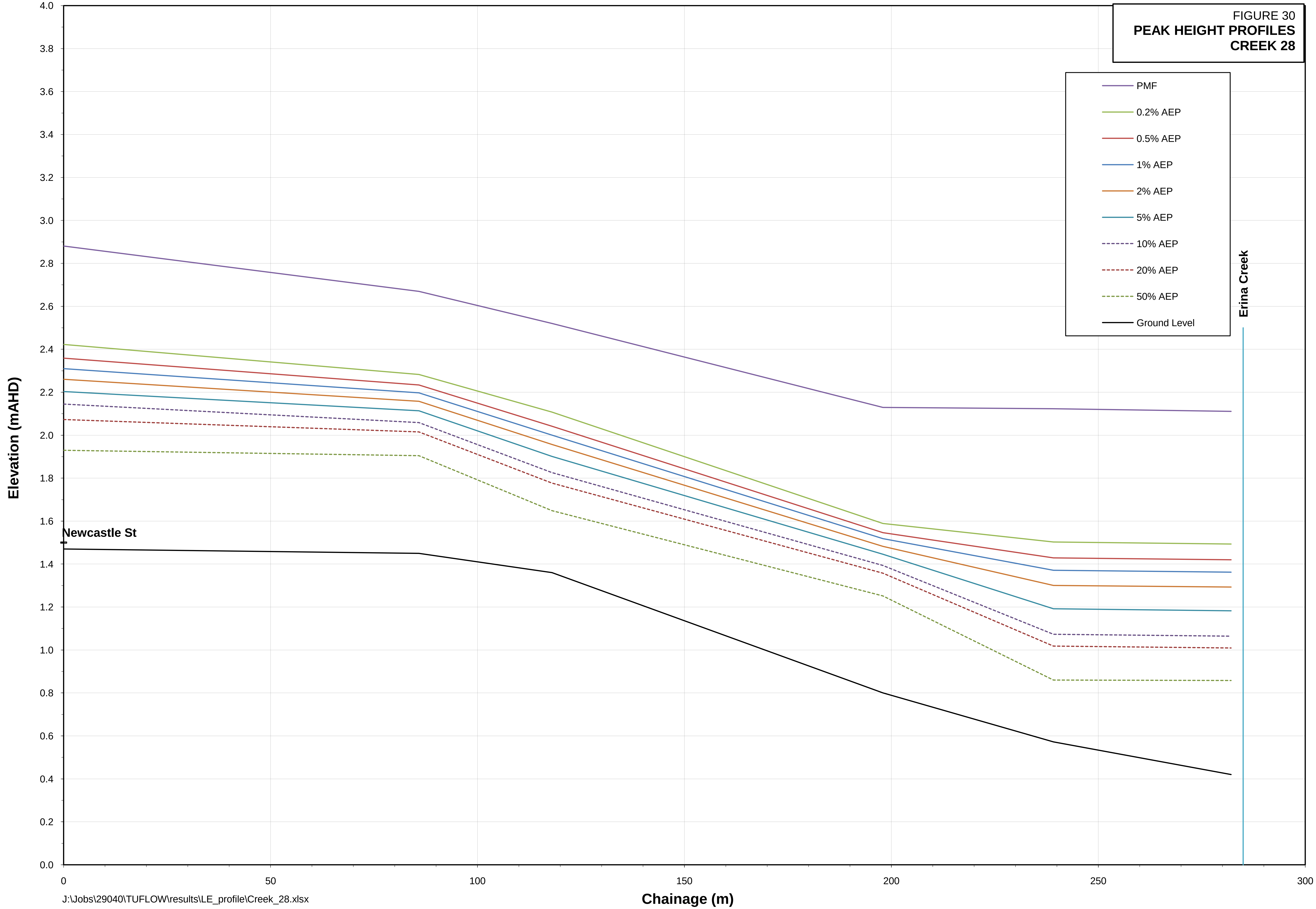

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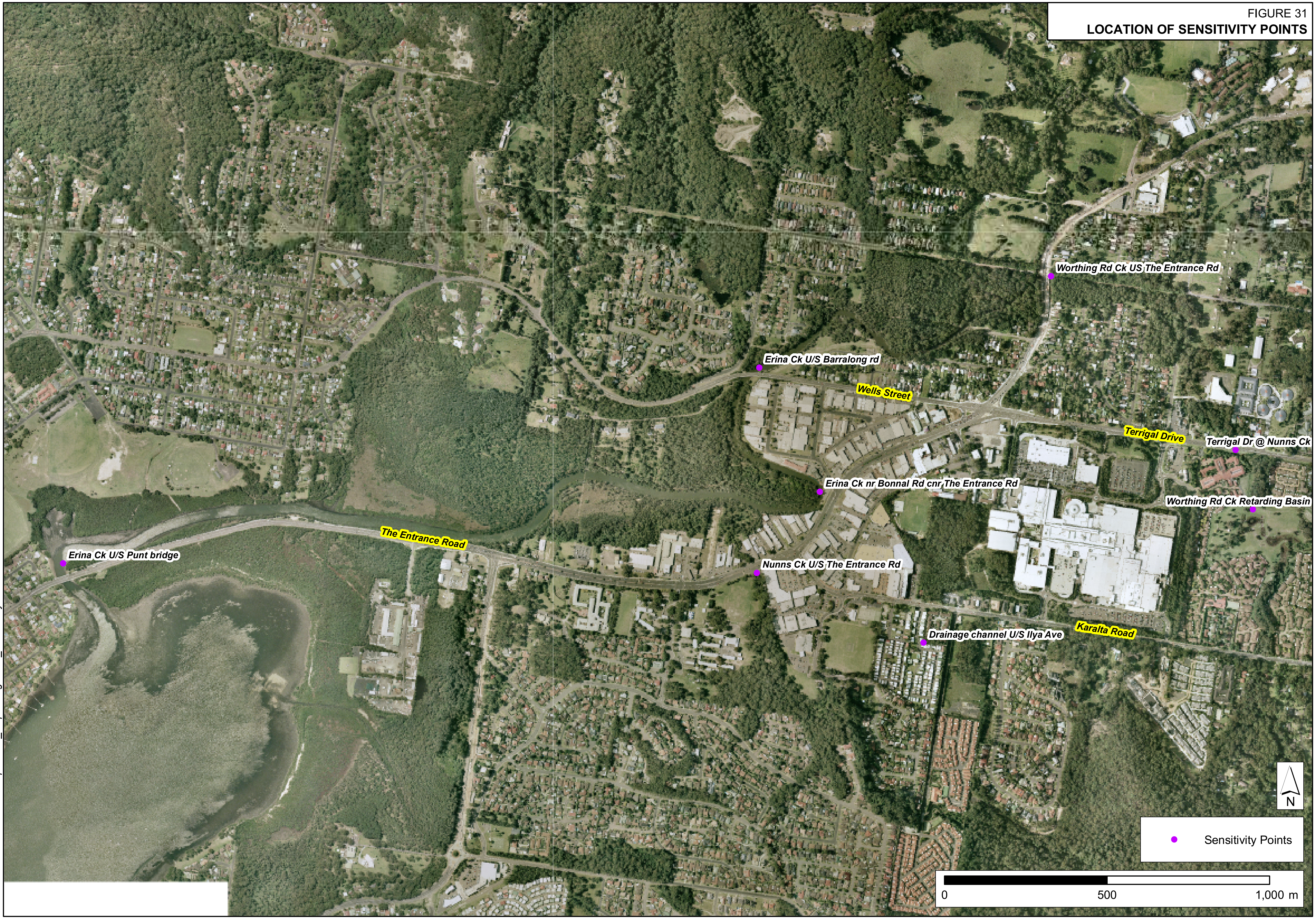
FIGURE 31
LOCATION OF SENSITIVITY POINTS



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Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

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

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

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

	floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
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

APPENDIX B: Historical Flood Data

DAY	MONTH	YEAR	RIVER CHAINAGE * km	FLOOD HEIGHT m AHD	GAUGE No.	COMMENTS
	3	1977	2.69	1.9		Table A3 - Erina Creek F.S.
	3	1977	3.19	2.25		Table A3 - Erina Creek F.S.
	3	1977	3.6	2.37		Table A3 - Erina Creek F.S.
29	1	1978		1.79		42 Narrawa Avenue
29	1	1978	0.97	1.45		Lot 27 Wells Street
29	1	1978	2.6	2.27		Lot 40a Bonnal Road
29	1	1978	2.69	2.2		Table A1 - Erina Creek F.S.
29	1	1978	2.83	2.41		Lot 19 Aston Road
29	1	1978	2.87	2.5		Lot 18 Aston Rd.
29	1	1978	2.88	2.5		Lot 24 Marinus Place
29	1	1978	2.95	2.45		Lots 13,14 Bonnal Road
29	1	1978	2.96	2.59		Lot 15 Aston Road
29	1	1978	2.99	2.48		Table A1 - Erina Creek F.S.
29	1	1978	2.99	3.2		32 Winani Street
29	1	1978	3.14	2.55		Lot 2 Barralong Road
29	1	1978	3.14	3.41		Lot 2 Barralong Road
29	1	1978	3.28	2.63		3 Winani Street
29	1	1978	3.57	2.73		1 Lingi Street
29	1	1978	3.65	2.74		Table A1 - Erina Creek F.S.
29	1	1978	3.69	2.22		34 Narrawa Avenue
29	1	1978	3.8	2.95		Lot 19 Narrawa Street
29	1	1978	4.52	3.35		Portion 2 Karwin Avenue
29	1	1978	4.52	3.5		Portion 2 Karwin Avenue
29	1	1978	4.54	3.42		Portion 2 Karwin Avenue
29	1	1978	4.55	3.56		Portion 1 The Entrance Rd.
29	1	1978	4.58	4.21		335 The Entrance Road
29	1	1978	4.62	3.86		31 The Entrance Road
29	1	1978	4.64	4.23		347 The Entrance Road
29	1	1978	4.86	4.55		Portion 27 Clyde Road
6	2	1981	1.45	0.75	M11002	Table A2 - Erina Creek F.S.
6	2	1981	2.61	0.77	M11003	Table A2 - Erina Creek F.S.
6	2	1981	3.14	1.87	M11004	Table A2 - Erina Creek F.S.
6	2	1981	4.17	2.13	M11007	Table A2 - Erina Creek F.S.
6	2	1981	4.17	2.45	212412	
6	2	1981	4.17	2.49	M11008	Table A2 - Erina Creek F.S.
6	2	1981	4.41	2.62	M11009	Table A2 - Erina Creek F.S.
6	2	1981	5.03	4	M11010	Table A2 - Erina Creek F.S.
6	2	1981	6.24	6.46	M11011	Table A2 - Erina Creek F.S.
6	2	1981	7.69	8.07	M11012	Table A2 - Erina Creek F.S.
6	2	1981	8.24	11.07	M11013	Table A2 - Erina Creek F.S.
15	3	1982	7.69	7.612	M11012	
15	3	1982	8.24	10.04	M11013	
3	8	1982	0.75	0.86	M11001	
3	8	1982	1.45	0.863	M11002	

DAY	MONTH	YEAR	RIVER CHAINAGE * km	FLOOD HEIGHT m AHD	GAUGE No.	COMMENTS
3	8	1982	2.61	0.855	M11003	
3	8	1982	4.13	0.885	M11006	
3	8	1982	5.03	2.811	M11010	
3	8	1982	6.24	4.863	M11011	
3	8	1982	7.69	6.942	M11012	
3	8	1982	8.24	9.755	M11013	
19	10	1982	1.45	0.678	M11002	
19	10	1982	2.61	0.664	M11003	
22	10	1982	5.03	2.72	M11010	
22	10	1982	7.69	7.042	M11012	
22	10	1982	8.24	9.755	M11013	
24	10	1982	6.24	4.818	M11011	
25	10	1982	4.13	0.776	M11006	
26	10	1982	0.75	0.675	M11001	
17	2	1983	4.13	0.651	M11006	
17	2	1983	4.41	1.549	M11009	Not read Upper/Lower 1.20 ?
1	3	1983	2.61	0.639	M11003	
1	3	1983	6.24	3.488	M11011	
1	3	1983	8.24	9.49	M11013	
3	3	1983	0.75	0.655	M11001	
21	3	1983	2.61	0.494	M11003	
21	3	1983	4.13	1.131	M11006	
21	3	1983	4.17	1.997	M11007	
21	3	1983	4.41	2.034	M11009	No reading Upper
21	3	1983	5.03	3.36	M11010	
21	3	1983	6.24	5.403	M11011	Reading 1.97 0.080 ?
21	3	1983	6.24	5.388	M11011	Reading 1.97 0.080 ?
21	3	1983	7.69	7.372	M11012	
21	3	1983	8.24	10.01	M11013	
26	9	1983	4.41	1.929	M11009	
26	9	1983	5.03	3.245	M11010	
26	9	1983	6.24	5.198	M11011	
26	9	1983	7.69	7.167	M11012	
26	9	1983	8.24	9.875	M11013	
25	10	1983	1.45	0.798	M11002	
10	11	1983	5.03	3.595	M11010	
30	11	1983	0.75	0.795	M11001	
30	11	1983	4.13	1.066	M11006	
16	12	1983	1.45	0.663	M11002	
16	12	1983	6.24	5.403	M11011	Reading 1.97 0.360 ?
16	12	1983	6.24	5.668	M11011	Reading 1.97 0.360 ?
16	12	1983	7.69	7.772	M11012	
16	12	1983	8.24	10.29	M11013	
10	5	1984	0.75	0.865	M11001	
10	5	1984	4.13	1.491	M11006	
5	10	1984	0.75	1.015	M11001	

DAY	MONTH	YEAR	RIVER CHAINAGE * km	FLOOD HEIGHT m AHD	GAUGE No.	COMMENTS
5	10	1984	1.45	0.963	M11002	Not Clear
	11	1984	0.75	0.81	M11001	
	11	1984	1.45	0.913	M11002	
	11	1984	2.61	1.289	M11003	
	11	1984	3.14	1.623	M11004	
	11	1984	4.13	2.511	M11006	
	11	1984	4.17	2.662	M11007	
8	11	1984	4.17	2.7	212412	
	11	1984	4.17	2.771	M11008	
	11	1984	4.41	3.239	M11009	
	11	1984	5.03	4.375	M11010	
	11	1984	6.24	7.227	M11011	1.45 2nd gauge ?
	11	1984	7.69	8.237	M11012	
	11	1984	8.24	11.2	M11013	Overtop
	11	1984	9.49	17.064	M11014	
29	8	1985	1.45	0.933	M11002	
29	8	1985	2.61	0.919	M11003	
29	8	1985	5.03	3.295	M11010	
29	4	1985	6.66	10.8	212424	
4	10	1985	8.24	11.22	M11013	
14	10	1985	1.45	1.053	M11002	
14	10	1985	2.61	1.524	M11003	
14	10	1985	3.14	1.923	M11004	
14	10	1985	3.14	1.938	M11004	
14	10	1985	4.13	2.221	M11006	Lower MHR not accessible - 1.83 Presumed
14	10	1985	4.13	2.581	M11006	Indistinct
14	10	1985	4.17	2.721	M11008	
14	10	1985	4.17	2.812	M11007	
14	10	1985	4.41	3.389	M11009	
14	10	1985	5.03	3.545	M11010	Lower rod Pt. submerged
14	10	1985	5.03	4.395	M11010	
14	10	1985	6.24	6.717	M11011	On Pole
14	10	1985	6.24	6.828	M11011	On Upper Bridge
14	10	1985	7.69	8.072	M11012	
14	10	1985	7.69	8.527	M11012	
14	10	1985	9.49	16.554	M11014	
21	10	1985	4.17	1.95	212412	
23	1	1986	6.66	10.7	212424	
5	8	1986	6.66	10.7	212424	
13	10	1986	1.45	1.073	M11002	
13	10	1986	3.14	0.953	M11004	
13	10	1986	4.13	3.161	M11006	High (Probably Nov 1985 ?)
13	10	1986	4.41	1.149	M11009	Not distinct
13	10	1986	5.03	3.475	M11010	Low rod completely washed

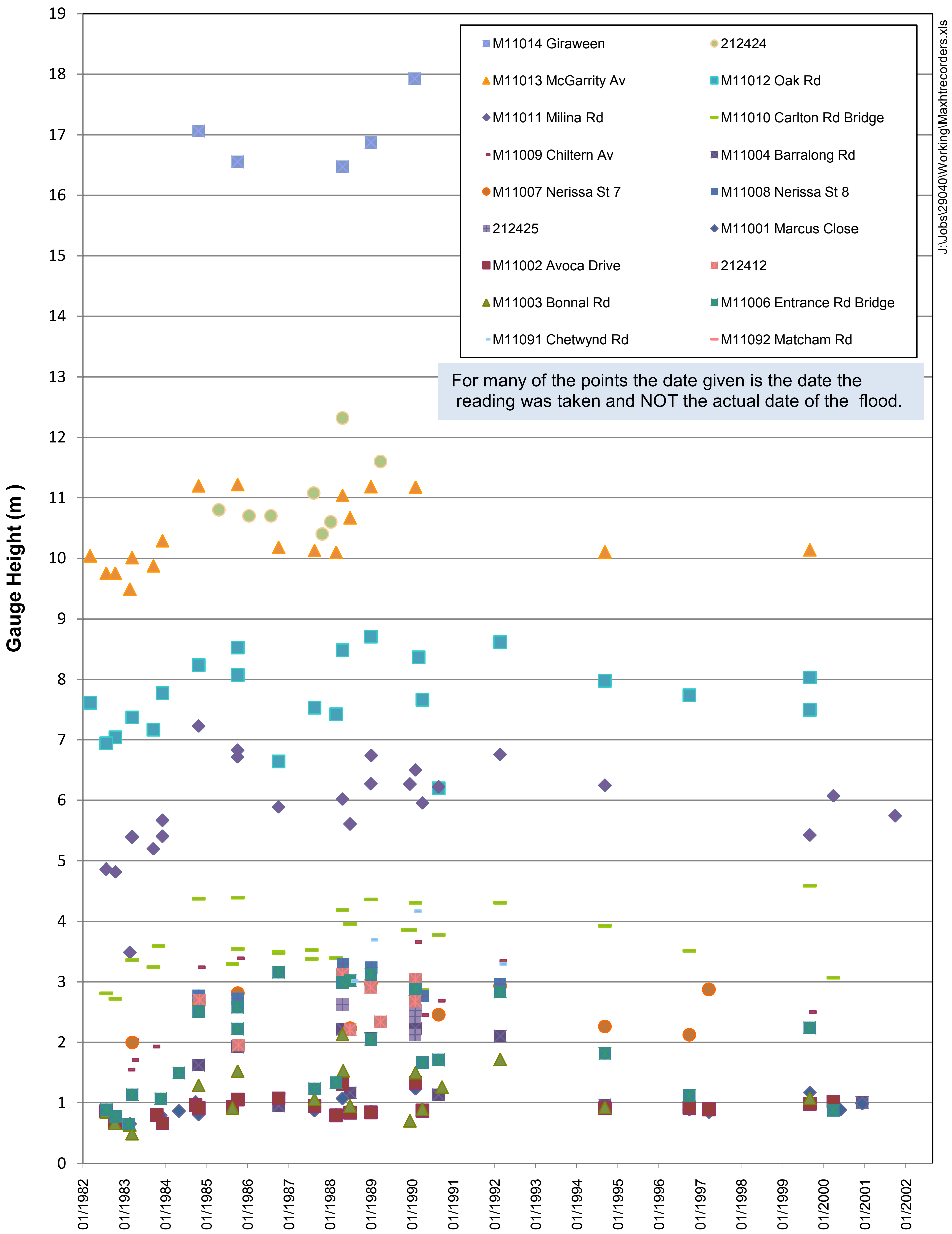
DAY	MONTH	YEAR	RIVER CHAINAGE * km	FLOOD HEIGHT m AHD	GAUGE No.	COMMENTS
13	10	1986	5.03	3.495	M11010	2 readings given - not sure which
13	10	1986	6.24	5.888	M11011	Low rod gone. Upper read
13	10	1986	7.69	6.642	M11012	
13	10	1986	8.24	10.18	M11013	
	8	1987	5.03	3.38	M11010	
	8	1987	5.03	3.525	M11010	
18	8	1987	6.66	11.08	212424	
25	8	1987	0.75	0.875	M11001	
25	8	1987	1.45	0.953	M11002	
25	8	1987	2.61	1.059	M11003	
25	8	1987	4.13	1.231	M11006	
25	8	1987	7.69	7.532	M11012	
25	8	1987	8.24	10.13	M11013	
	11	1987	6.66	10.4	212424	
17	1	1988	6.66	10.6	212424	
4	3	1988	0.75	0.8	M11001	
4	3	1988	1.45	0.793	M11002	
4	3	1988	4.13	1.331	M11006	
4	3	1988	5.03	3.395	M11010	Appeared washed (1.8m)
4	3	1988	7.69	7.422	M11012	
4	3	1988	8.24	10.1	M11013	
30	4	1988	0.75	1.07	M11001	
30	4	1988	1.45	1.308	M11002	
30	4	1988	2.58	1.9		Lot 40A Bonnal Rd - Coastal Prod.
30	4	1988	2.61	2.04		Lot 40A Bonnal Rd - Panel Beater
30	4	1988	2.61	2.129	M11003	
30	4	1988	3.14	2.218	M11004	
30	4	1988	3.33	2.625	212425	
30	4	1988	4.13	2.991	M11006	
30	4	1988	4.17	3.13	212412	
30	4	1988	4.17	3.131	M11008	
30	4	1988	4.17	3.152	M11007	
30	4	1988	5.03	4.19	M11010	
30	4	1988	6.24	6.018	M11011	
30	4	1988	6.66	12.32	212424	
30	4	1988	7.69	8.482	M11012	
30	4	1988	8.24	11.04	M11013	
30	4	1988	9.49	16.474	M11014	
6	7	1988	1.45	0.838	M11002	
6	7	1988	2.61	0.949	M11003	
6	7	1988	3.14	1.163	M11004	
6	7	1988	4.13	3.021	M11006	
6	7	1988	4.17	2.21	212412	Approx. - peaked pre-dawn

DAY	MONTH	YEAR	RIVER CHAINAGE * km	FLOOD HEIGHT m AHD	GAUGE No.	COMMENTS
6	7	1988	4.17	2.232	M11007	
6	7	1988	5.03	3.96	M11010	
6	7	1988	6.24	5.608	M11011	
6	7	1988	8.24	10.67	M11013	
7	1	1989	0.75	0.85	M11001	
7	1	1989	1.45	0.843	M11002	
7	1	1989	3.06	2.16		Approx. Bonnal Rd. - factory owner
7	1	1989	3.14	2.066	M11004	
7	1	1989	4.13	2.046	M11006	Good debris mark on Lower
7	1	1989	4.13	3.131	M11006	High - believe Lower
6	1	1989	4.17	2.91	212412	
7	1	1989	4.17	2.982	M11007	
7	1	1989	4.17	3.071	M11008	
7	1	1989	5.03	4.365	M11010	
7	1	1989	5.84	5.31		Approx. Arundel Rd - from photo
7	1	1989	6.24	6.273	M11011	
7	1	1989	7.69	8.707	M11012	
7	1	1989	8.24	11.185	M11013	
7	1	1989	9.49	16.874	M11014	
2	4	1989	4.17	2.34	212412	Peak just below floors Nerissa Rd.
2	4	1989	6.66	11.6	212424	
	2	1990		4.83		Milina Rd
3	2	1990	3.33	2.125	212425	
3	2	1990	4.17	2.68	212412	
4	2	1990	2.58	1.82		Lot 40A Bonnal Rd - Coastal Prod.
4	2	1990	2.59	1.88		Lot 40A Bonnal Rd - Plumbers
4	2	1990	2.61	1.81		Lot 40A Bonnal Rd - Panel Beater
4	2	1990	2.67	1.81		Lot 40A Bonnal Rd - Fencing Yard
4	2	1990	3.28	2.16		3 Winani St
4	2	1990	3.33	2.425	212425	
4	2	1990	3.45	2.26		59 Barralong Rd
4	2	1990	3.45	2.3		59 Barralong Rd
4	2	1990	3.45	2.31		55 Barralong Rd
4	2	1990	4.17	2.89		24 Nerissa Rd
4	2	1990	4.17	2.93		45 Kuburra Rd
4	2	1990	5.81	5.51		Lot 53 Arundel Rd
4	2	1990	5.84	5.52		Lot 53 Arundel Rd - below window
7	2	1990	0.75	1.227	M11001	
7	2	1990	1.45	1.332	M11002	

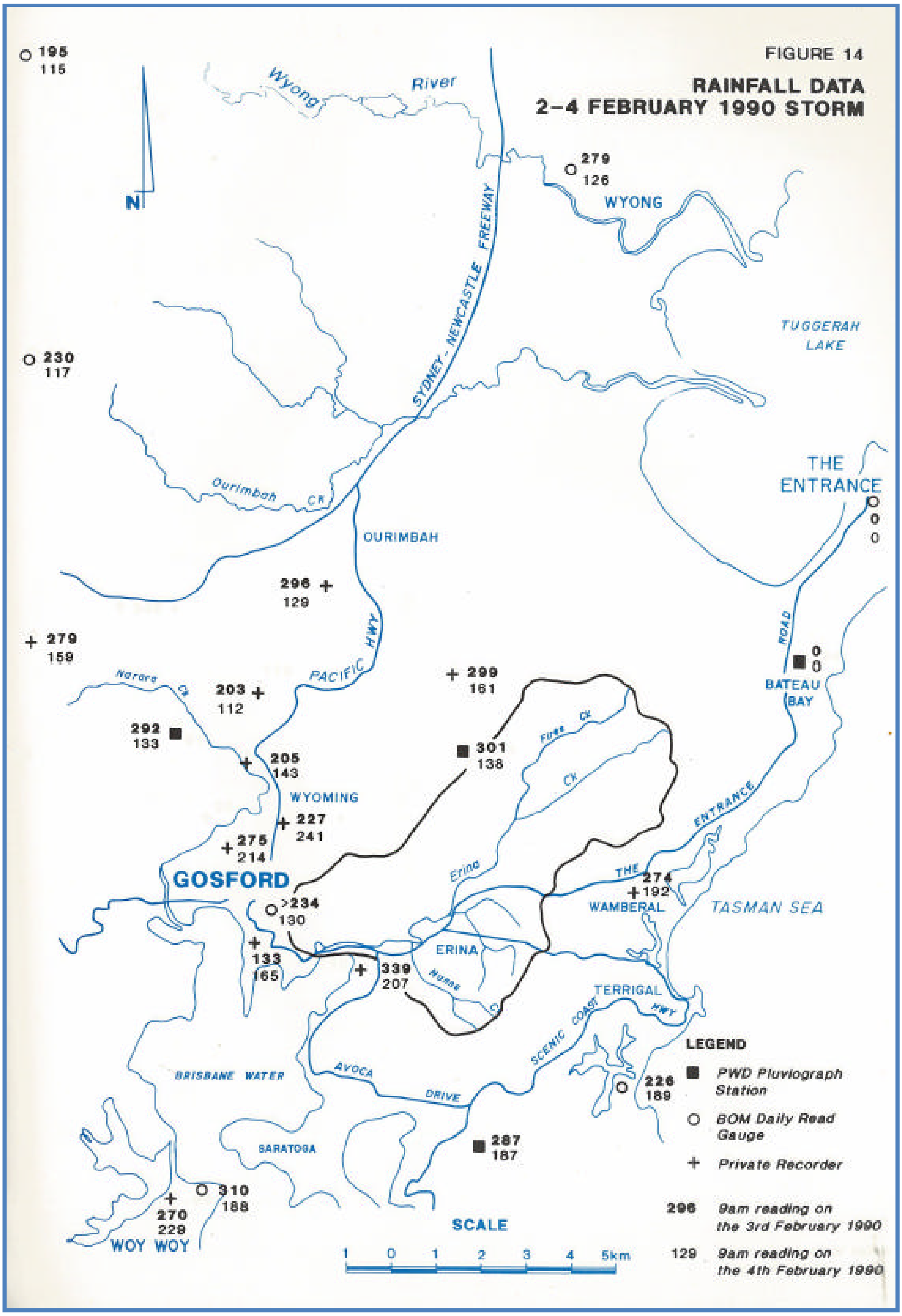
DAY	MONTH	YEAR	RIVER CHAINAGE * km	FLOOD HEIGHT m AHD	GAUGE No.	COMMENTS
7	2	1990	2.35	2.56		O'Brien Glass
7	2	1990	2.59	1.91		Lot 40A Bonnal Rd - Plumbers
7	2	1990	2.61	1.497	M11003	Does not agree with 3 nearby levels
7	2	1990	2.61	1.86		Lot 40A Bonnal Rd - Panel Beater
7	2	1990	2.67	1.86		Lot 40A Bonnal Rd - Fencing Yard
7	2	1990	2.99	2.24		Lot 12 Bonnal Rd - Debri mark Hylite Blinds
7	2	1990	3.05	2.24		Lot 14 Bonnal Rd - Benchmark Hardware at door
7	2	1990	3.05	2.25		Lot 1 Bonnal Rd - approx. level Timber Yard
7	2	1990	3.05	2.29		89 Baralong Rd
7	2	1990	3.13	2.28		77 Barralong Rd
7	2	1990	3.14	2.229	M11004	
7	2	1990	3.15	2.44		59 Barralong Rd
7	2	1990	3.15	2.47		57 Barralong Rd
7	2	1990	3.28	2.32		3 Winani St
7	2	1990	3.33	2.525	212425	
7	2	1990	3.54	2.5		34 Winani St
7	2	1990	3.54	2.51		34 Winani St
7	2	1990	3.58	2.52		1 Lingi St
7	2	1990	3.6	2.63		Lot 2 Lingi St
7	2	1990	3.84	2.84		Hammersmith Rd
7	2	1990	4.13	2.88	M11006	
7	2	1990	4.17	2.936	M11007	
7	2	1990	4.17	2.988	M11007	
7	2	1990	4.17	3		24 Nerissa Rd - at front
7	2	1990	4.17	3.01		24 Nerissa Rd - on fence
7	2	1990	4.17	3.04	212412	
7	2	1990	4.17	3.17		45 Kuburra Rd
7	2	1990	4.41	3.66	M11009	
7	2	1990	4.49	3.8		Lot 1 The Entrance Rd-Karwin Ave cnr
7	2	1990	5.03	4.309	M11010	
7	2	1990	5.84	5.8		Lot 53 Arundel Rd - at sill
7	2	1990	5.85	5.83		Lot 53 Arundel Rd – top front fence
7	2	1990	5.85	5.92		Lot 53 Arundel Rd - front gate
7	2	1990	6.24	6.499	M11011	
	6	2007		3.43		96 Chetwynd Rd – under driveway
	6	2007		2.42		21 Narrawa Ave – at back
	6	2007		5.66		18 – 20 Erina Valley Rd – access bridge covered once
	6	2007		1.52		65 Barralong Rd

* The value of River Chainage corresponds to the model in Reference 1. Not the present stud

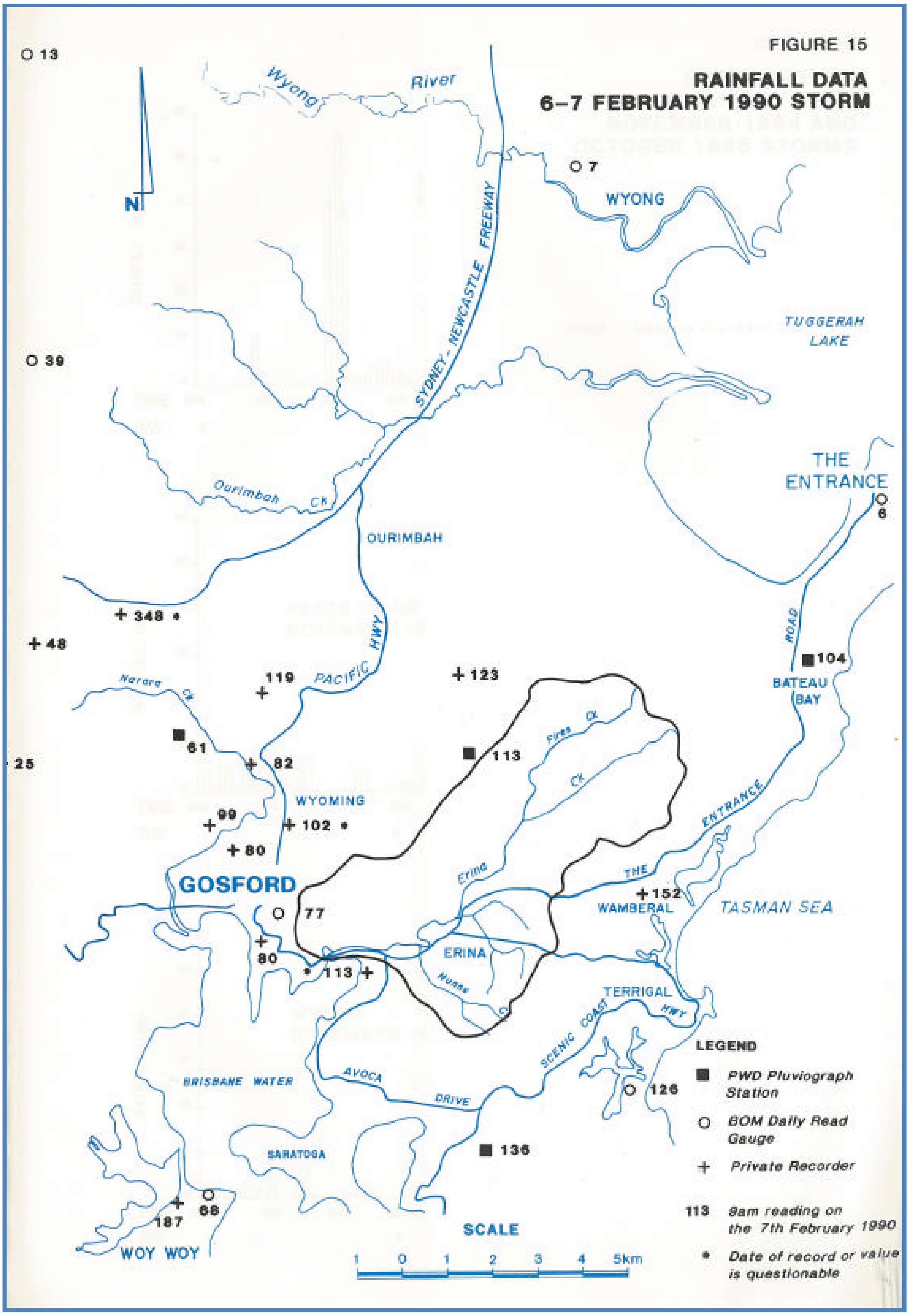
FIGURE B1
GAUGE HEIGHT RECORDS
MAXIMUM HEIGHT RECORDERS & STAFF GAUGES



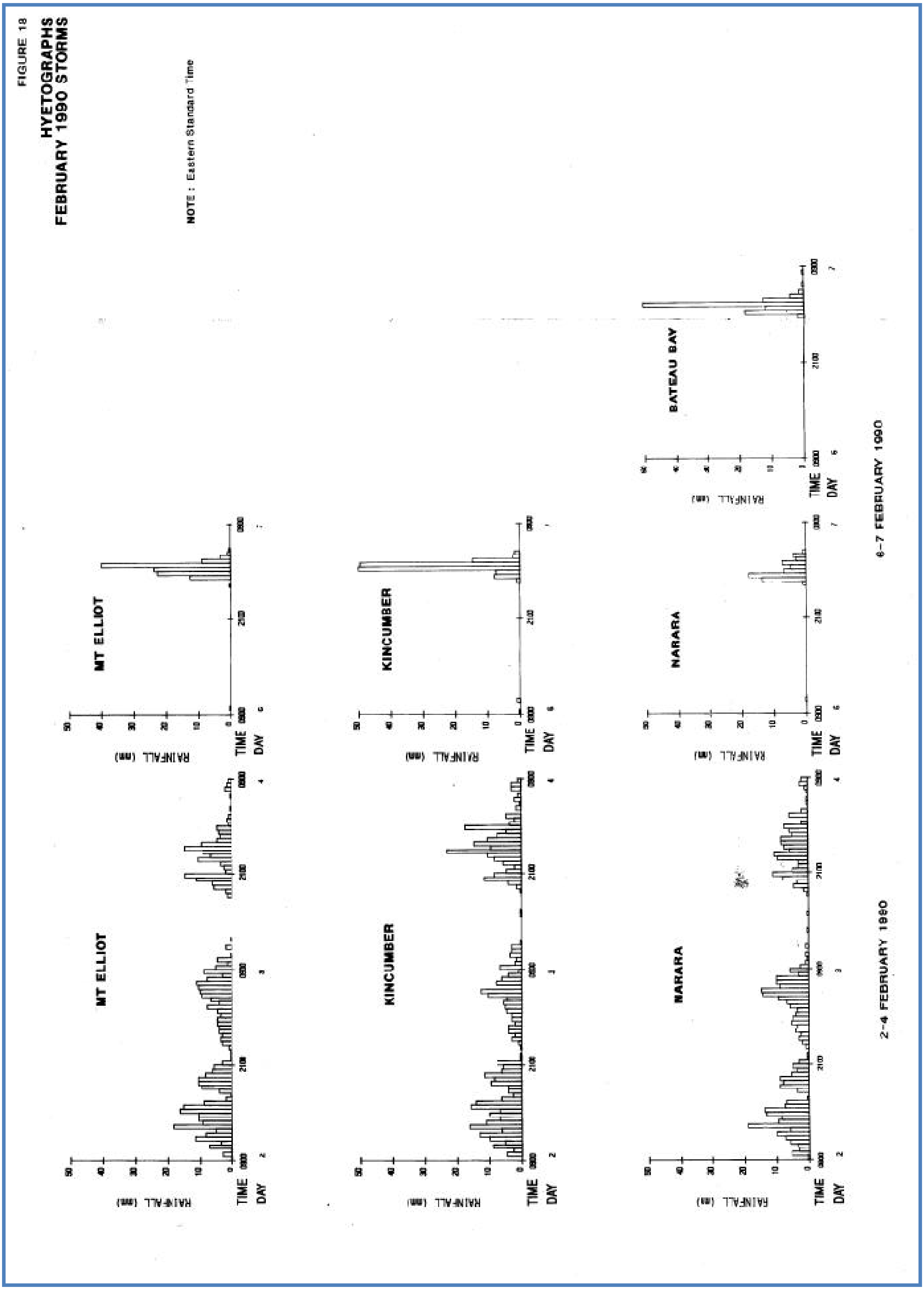
Copy of Figure taken from Erina Creek Flood Study Review 1990



Copy of Figure taken from Erina Creek Flood Study Review 1990



Copy of Figure taken from Erina Creek Flood Study Review 1990



Appendix C

How Do I Get Involved?

Community input to the Flood Study and the subsequent Floodplain Risk Management Study is essential. To make a comment, provide any flood information that you think would be of relevance, or to seek clarification on any issue, please contact us.

The Project Manager is: **Richard Dewar:**

WMAwater
Level 2, 160 Clarence Street
SYDNEY NSW 2000
Telephone: 9299 2855
Facsimile: 9262 6208
Email: dewar@wmawater.com.au

The relevant Council Officer is

Mrs Erensa Shrestha,
Flooding and Drainage Section,
Environment and Planning Directorate,
Gosford City Council
Level 9, 49 Mann Street
Telephone: 4304 7087
Facsimile: 4323 2528
Email: erensa.shrestha@gosford.nsw.gov.au

During the latter stages where management and planning strategies are outlined, it is important to get community input and feedback to ensure proposed measures meet the needs of the local community.

The importance of community involvement is recognised through the implementation of a community consultation program that is an integral part of each stage of the Floodplain Management Process.

At the Flood Study stage information on actual flooding or drainage problems that have taken place is very helpful in ascertaining the performance of the existing creek system and identifying problem areas.

At the Floodplain Risk Management Stage members of the community will be asked by local newspaper advertisement to provide information and feedback in planning the best way to improve the management of the catchment with regard to minimising flood risk.

Review of Erina Creek Flood Study, Floodplain Risk Management Study and Plan

Community Information Sheet No. 1 August 2009

Introduction

Under the NSW Government's Flood Prone Land Policy, management of flood prone land is primarily the responsibility of councils.

Gosford City Council has appointed WMAwater - *Water and Environmental Engineers* to carry out a Flood Study of Erina Creek. There has been a previous Flood Study of Erina Creek completed in 1991 using the latest available techniques at that time.

The Flood Study will define the nature and extent of flooding. It will provide a basis for sound floodplain management planning for the catchment, whilst recognising the demands for development and change, the need for good urban and environmental outcomes, and the social and economic benefits of reducing flood damage.

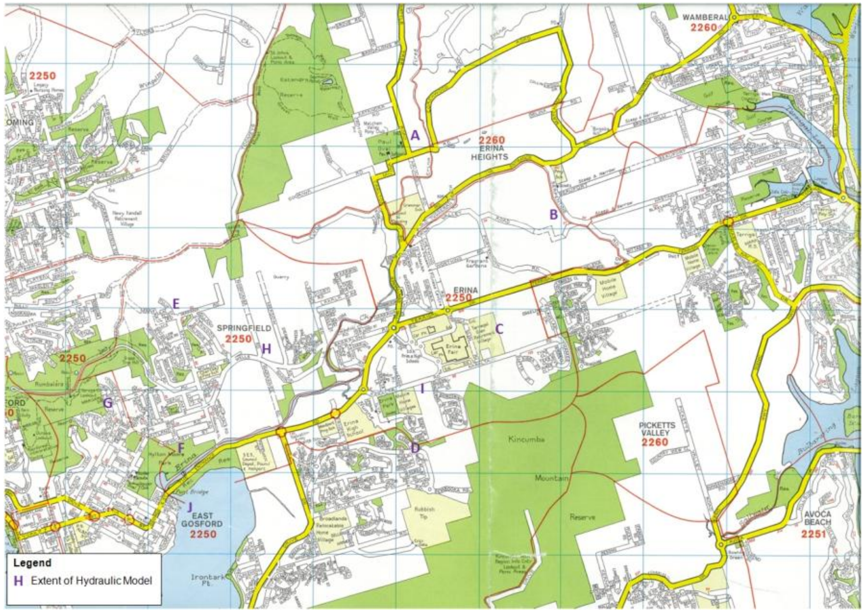
The Flood Study and Floodplain Risk Management Study Review are funded under the NSW Government's Floodplain Management Program. On completion of the study any mitigation measures recommended may be eligible for State and/or Federal government funding.

The Study Area

Erina Creek has a catchment area of approximately 32 square kilometres which adjoins Brisbane Water downstream of the Punt Bridge (Figure 1). It includes the suburbs of Springfield, Holgate, Matcham, Erina Heights, Erina and part of the suburbs of Terrigal, East Gosford and Green Point.

The terrain of the catchment is relatively steep and the slopes are heavily vegetated. A considerable portion of the floodplain has been subject to major flood events in 1978, 1990, 1992 and 2007. In the last 60 years, there has been significant urban and industrial development within the catchment area.

FIGURE 1: Catchment Area



Floodplain Management Process

The first step in the process (Diagram 1) is data collection and preparation of the Flood Study.

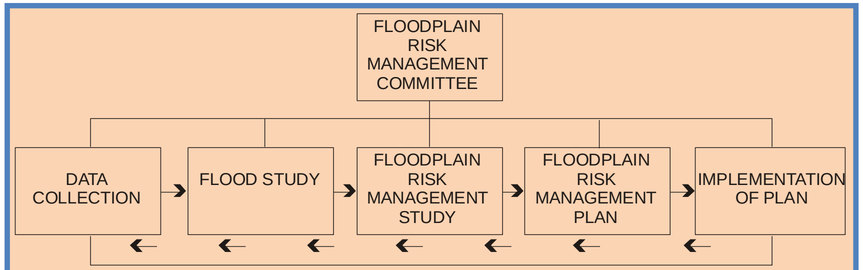


DIAGRAM 1: The Floodplain Risk Management Process

The Flood Study

The Flood Study involves a comprehensive technical investigation of the nature and extent of flooding within the study area.

PHOTOGRAPH 1: Nunns Creek at The Entrance Road

PHOTOGRAPH 2: Flap gated culverts preventing high water levels in Erina Creek from affecting upstream properties near Karalta Rd.

Floodplain Risk Management Study

The second step (preparation of the Floodplain Risk Management Study (FRMS)) identifies a range of management measures to address the problem.

PHOTOGRAPH 3: Concrete levee preventing inflow at Bonnal Road

PHOTOGRAPH 4: View to Barralong Road bridge along earthen levee protecting industrial properties on the right of the photo.

Floodplain Risk Management Plan

The third stage involves preparation of a Plan that documents how the proposed measures identified in the FRMS are to be implemented in terms of resources and timing. The final stage of the process is the undertaking of the works.

PHOTOGRAPH 5: Golf Course adjoining Erina Creek

Community Consultation Program Public Exhibition of Draft Reports

Once the Flood Study has been completed, and the flood behaviour of the catchment is defined, Council will then commence the next stage of the project, the Floodplain Risk Management Study.

We will inform you of this and provide contacts for you to give input or voice any questions or concerns you may have in due course in a further information sheet and in the local newspaper.

Drafts of the studies will be placed on public exhibition for comments and questions prior to finalisation. Again you will be advised of this in a further information sheet and in the local newspaper.

PHOTOGRAPH 6: Example of flood debris mark picked up by Council following the June 2007 flood on Erina Creek.

Information Sought from Residents

Please provide any information that you think would be of use in the preparation of the Flood Study.

This information might include:

- photographs of flooding,
- memory/description of flooding,
- records of flood heights (see photo).

We welcome any information, however minor. Please contact WMAwater or Council by phone or email (contacts shown over page).

PHOTOGRAPH 7: Buildings and services built on elevated pads above the level of flood waters.

PHOTOGRAPH 8: Carlton Road bridge over Erina Creek showing flood depth indicator on left.

Erina Creek Flood Study, Floodplain Risk Management Study & Plan
PROPERTY OWNER QUESTIONNAIRE – August 2009

Dear Resident,

As you will be aware from the attached community information sheet, Council has engaged WMAwater to undertake a review of the existing Flood Study & Floodplain Risk Management Study for Erina Creek. The purpose of this study is to accurately define the nature and extent of flooding, and provide a basis for sound floodplain management planning for the catchment. The study will recognise the demands for development, the social and economic benefits of reducing flood damage, and the need for good urban and environmental outcomes.

In order to ensure this study adequately addresses these issues, we have prepared this questionnaire. Please take time to answer the following questions as accurately as possible. If you have any photographs of flooding in your area, it would be greatly appreciated if you could email them to dewar@wmawater.com.au. Please mail the completed questionnaire by 30th August, 2009 using the prepaid self-addressed envelope provided, fax to 9262 6208, or scan and email to dewar@wmawater.com.au.

Contact Details

Please note that the return of the completed questionnaire is voluntary and any personal information included in the questionnaire will be subject to the Privacy & Personal Information Protection Act 1998. This information will only be used as an input into the Erina Creek Floodplain Risk Management Study & Plan.

Contact Name: ______________________ Tel No: ______________________

Address: ______________________ E-Mail ______________________

☐ Residential Property ☐ Non-Residential Property

Flooding Related Information

How long have you lived at this address?

☐ Less than 5 Years ☐ 5 – 10 Years ☐ 10 – 15 Years ☐ 15 – 30 Years ☐ More than 30 Years

Are you aware of the following flood events?

☐ February 1990 ☐ February 1992 ☐ June 2007

Has your property ever been inundated, if so when? ______________________

And were any buildings inundated? ☐ House ☐ Building other than house

Can you identify the peak level reached by floodwaters? An example of a peak level may be a debris mark, a water line, or say you recall the water reached the top of the 2nd step. Please be as accurate as possible as it is important.

☐ No ☐ Yes, on my property ☐ Yes, outside my property

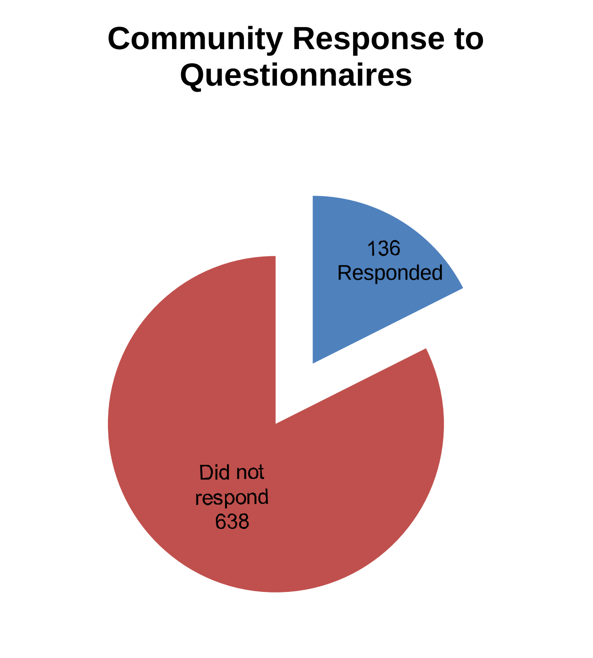
If yes, please provide a brief description over the page or photograph the flood mark & email it to us.

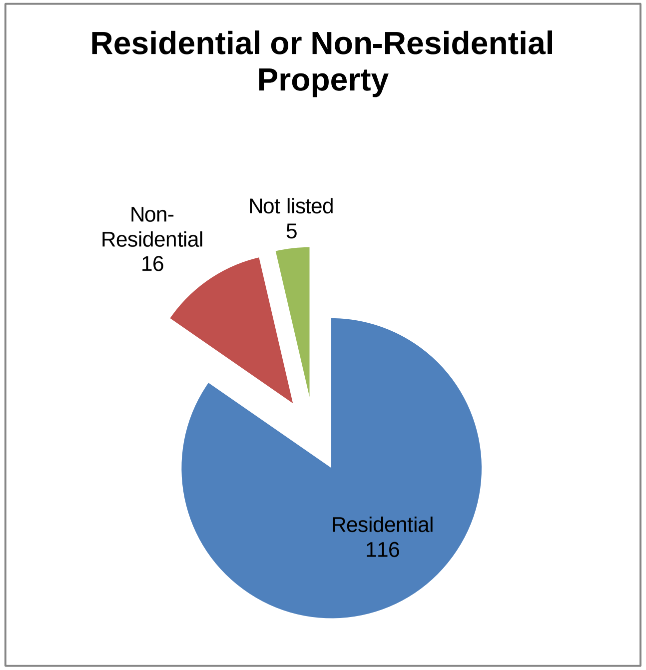
Do you have any photographs of local flooding? ☐ Yes ☐ No

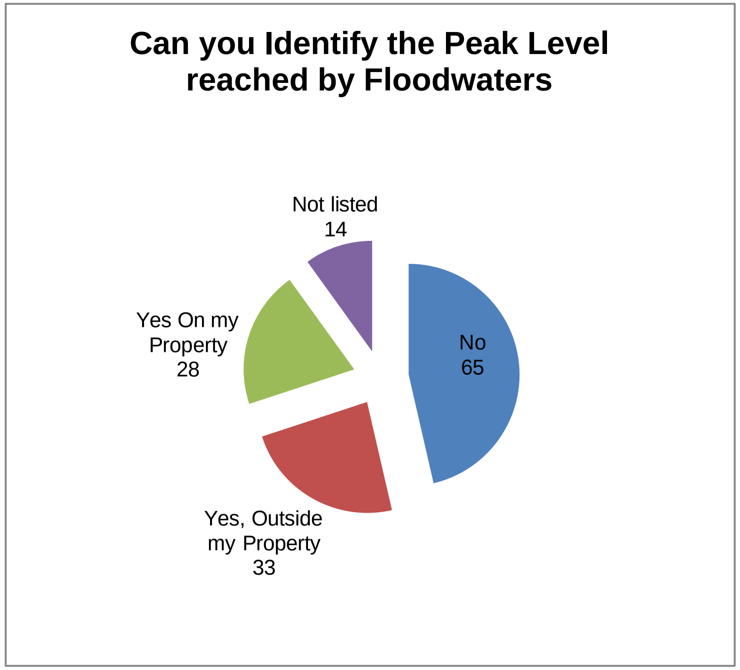
Can we contact you for more information? ☐ Yes ☐ No

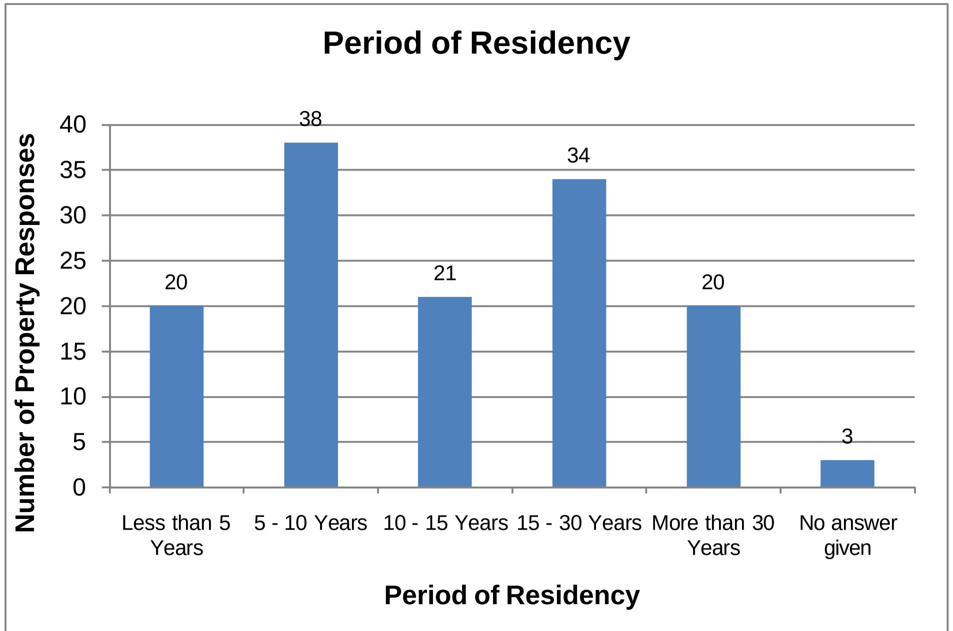
FIGURE C1
QUESTIONNAIRE RESULTS

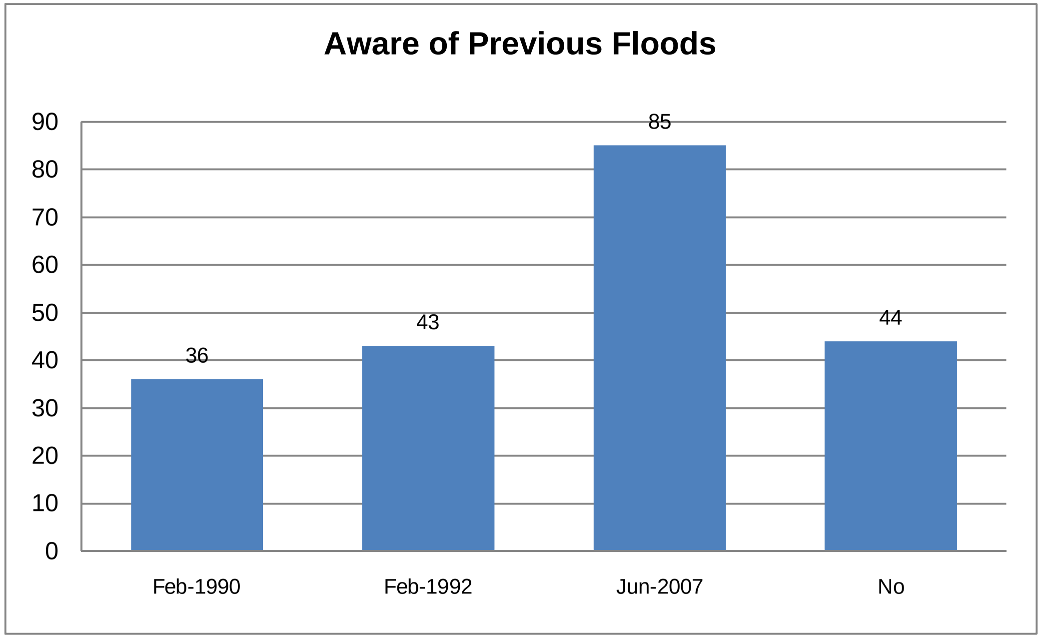
J:\Jobs\29040\Admin\Questionnaire\Questionnaire_Results.xls











Community Response to Questionnaires

Number of Questionnaires sent out	Responded	Did not respond
774	136	638

Residential or Non-Residential Property

Residential	Non-Residential	Not Listed	Both Residential and Non-Residential
116	16	5	1

Can You Identify the Peak Level Reached by Floodwaters

No	Yes, Outside my Property	Yes On my Property	Not listed	Both on and outside
65	33	28	14	5

Aware of Previous Floods (Many Ticked Multiple Events)

Feb-1990	Feb-1992	Jun-2007	No
36	43	85	44

Period of Residency

Less than 5 Years	5 - 10 Years	10 - 15 Years	15 - 30 Years	More than 30 Years	No answer given
20	38	21	34	20	3 (including 1 that said rental)

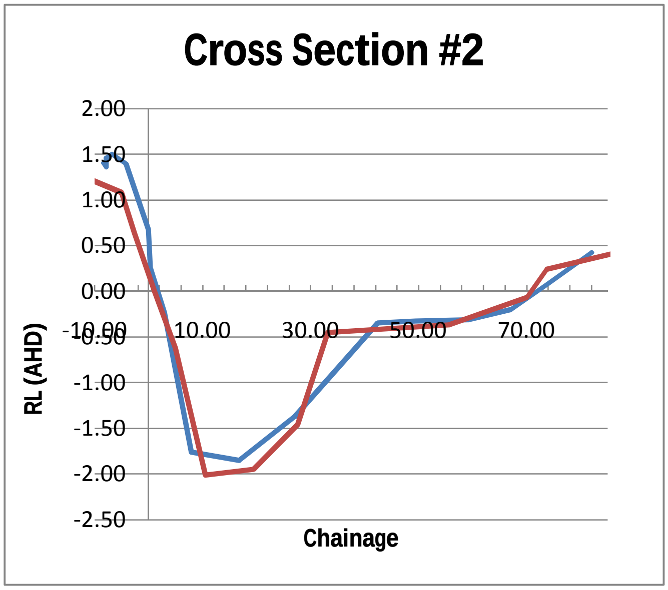
Suburb	Survey Description	Flood Event
ERINA	Under house driveway and storage room floods up to 2 feet (approx. 600mm) high	Assume 2007 flood event
ERINA	The water came up to 5cm from the top of the small retaining wall (but didn't overtop it) at the back of 21 Narrawa Avenue, Erina	Assume 2007 flood event.
ERINA NSW 2250	In 1990 water level overflowed landscape divider barrier	1990 flood event
ERINA NSW 2250	Resident in 51 Kuburra Road has painted on fence the high water marks for the last 12 years	Flood event date unknown
ERINA NSW 2250	Access bridge was covered once by the floods	Assume 2007 flood event
ERINA NSW 2250	Approximately 50mm above lower floor level. See following Photographs	June 2007 flood event
EAST GOSFORD 2250	Approximately halfway up timber fence. See following Photographs	February 1990 flood event

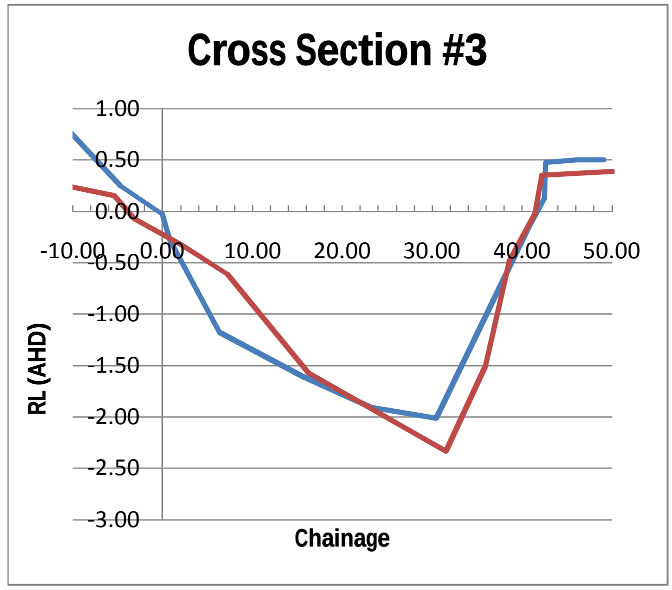
Appendix D

Appendix E

FIGURE E1
ERINA CREEK CATCHMENT
SURVEY LOCATIONS

J:\Jobs\29040\Arcview\ArcMaps\FigureXX_SurveyCrossSections.mxd


Cross Section #2
RL (AHD)
Chainage
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-10.00
10.00
30.00
50.00
70.00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RL (AHD)
Chainage
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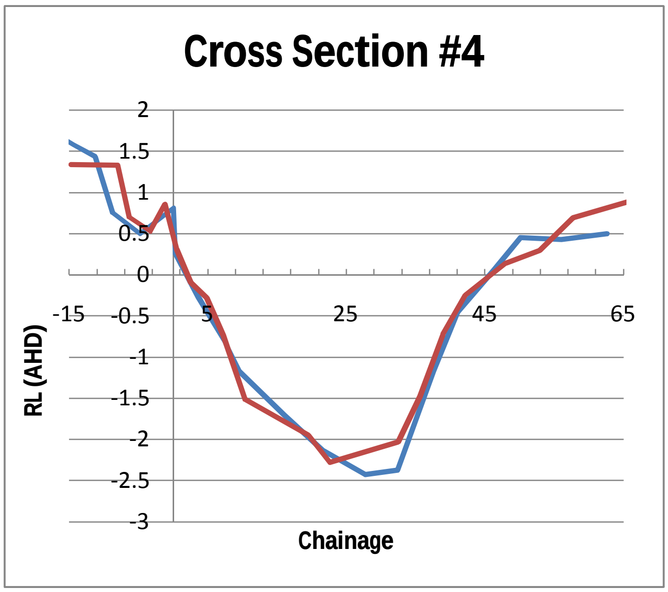
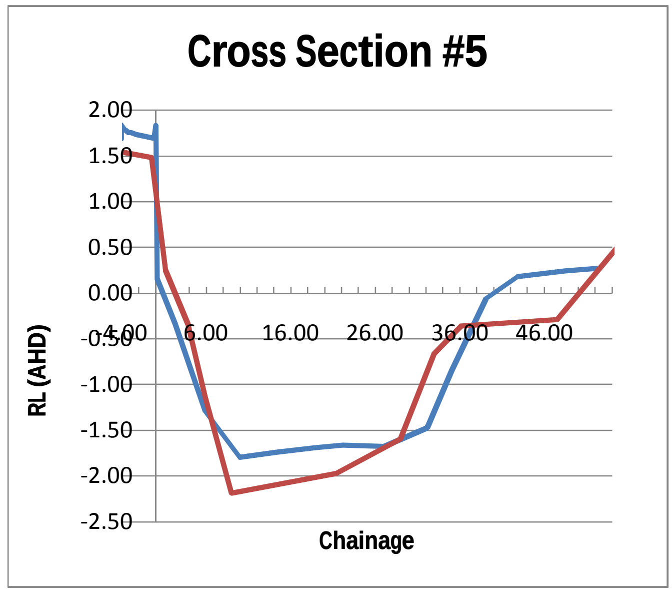
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-10.00
0.00
10.00
20.00
30.00
40.00
50.00


Cross Section #4
RL (AHD)
Chainage
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-15
5
25
45
65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RL (AHD)
Chainage
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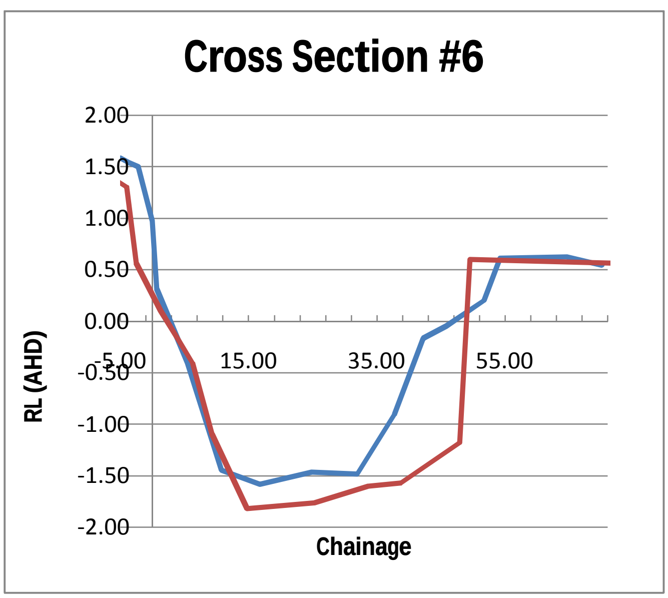
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-4.00
6.00
16.00
26.00
36.00
46.00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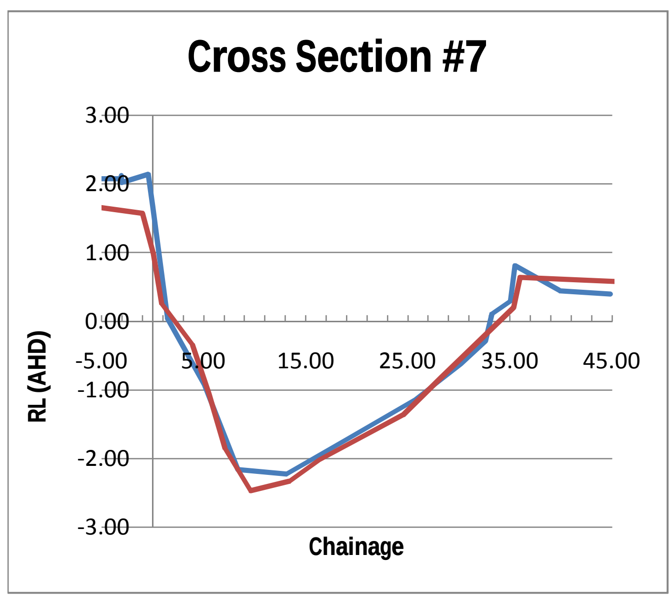
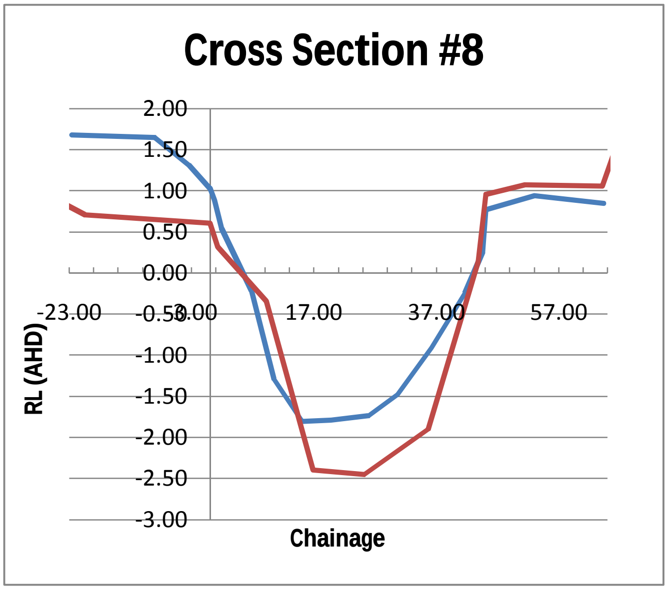
RL (AHD)
Chainage
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-5.00
15.00
35.00
55.00


Cross Section #7
RL (AHD)
Chainage
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-5.00
5.00
15.00
25.00
35.00
45.00

OLD NEW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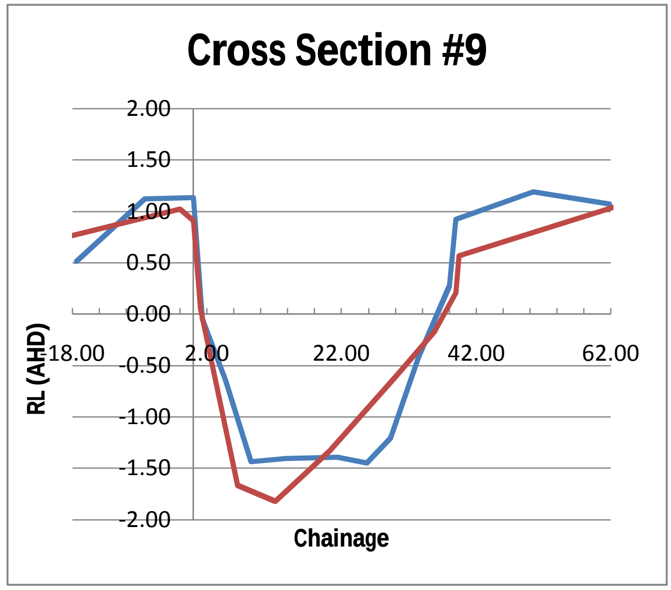
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-23.00
-3.00
17.00
37.00
57.00
RL (AHD)
Chainage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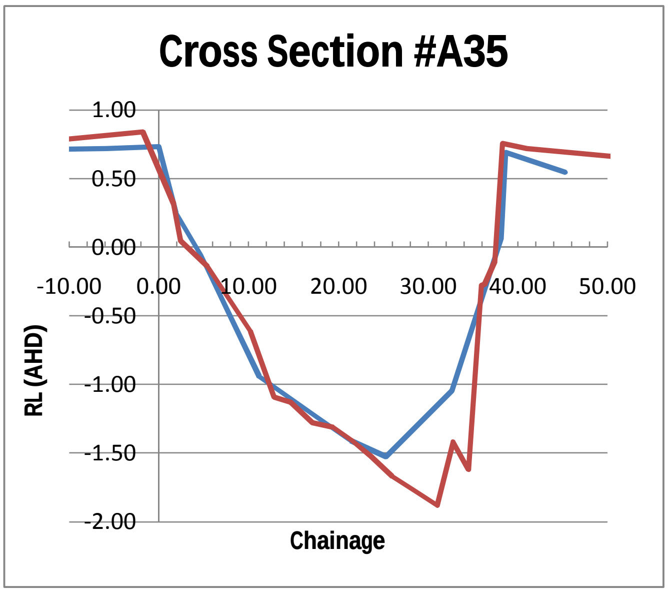
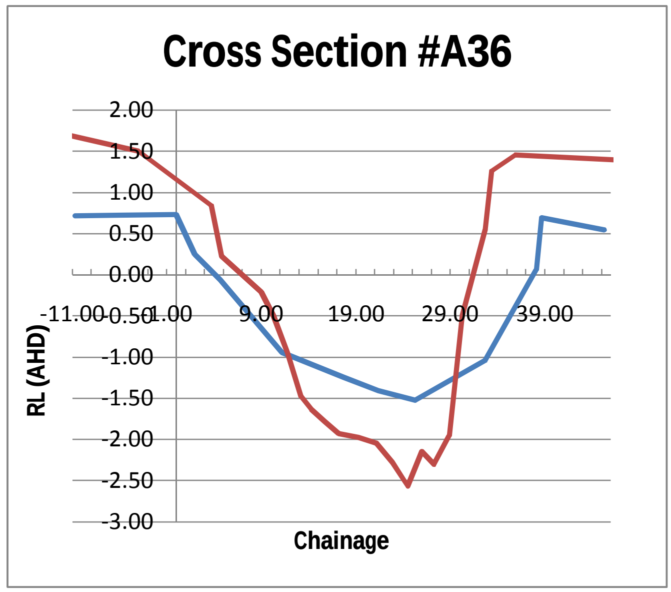
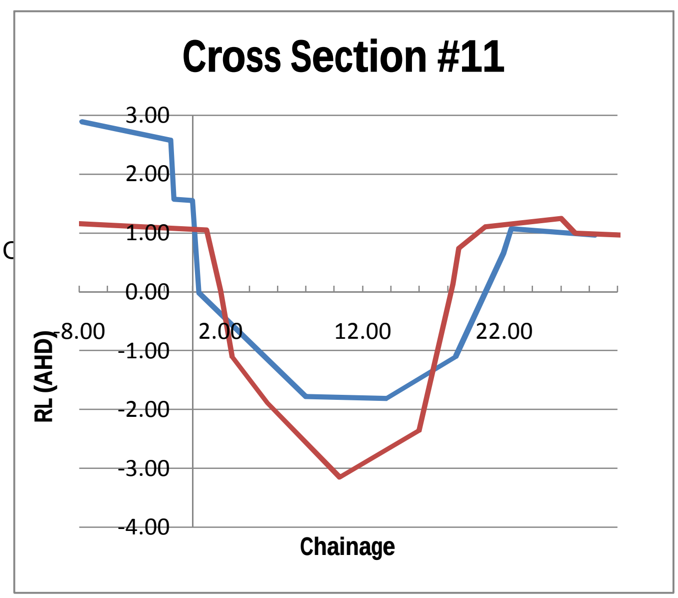
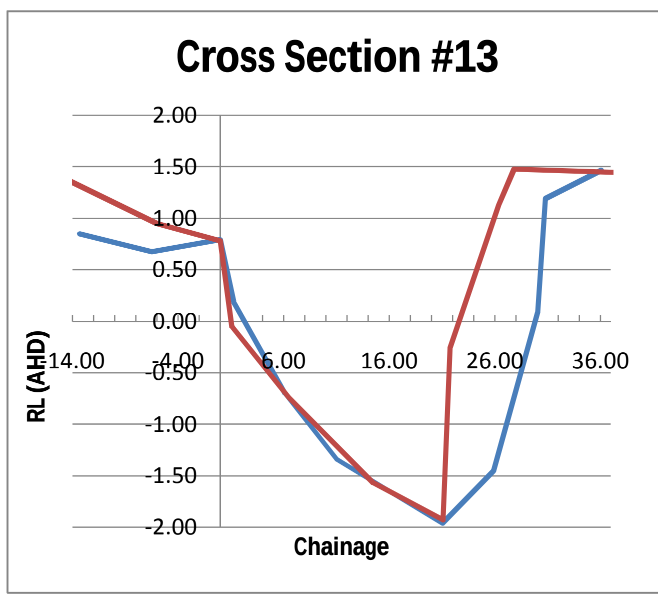
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-18.00
2.00
22.00
42.00
62.00
RL (AHD)
Chainage

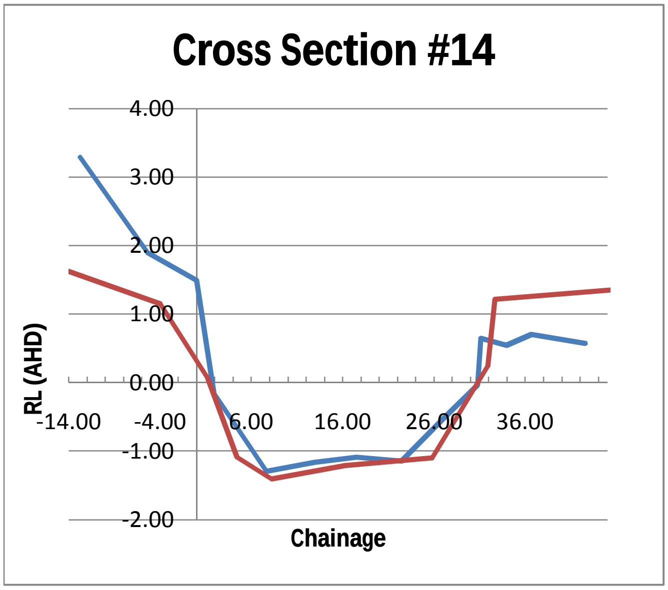

Cross Section #A35
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-10.00
0.00
10.00
20.00
30.00
40.00
50.00
RL (AHD)
Chainage

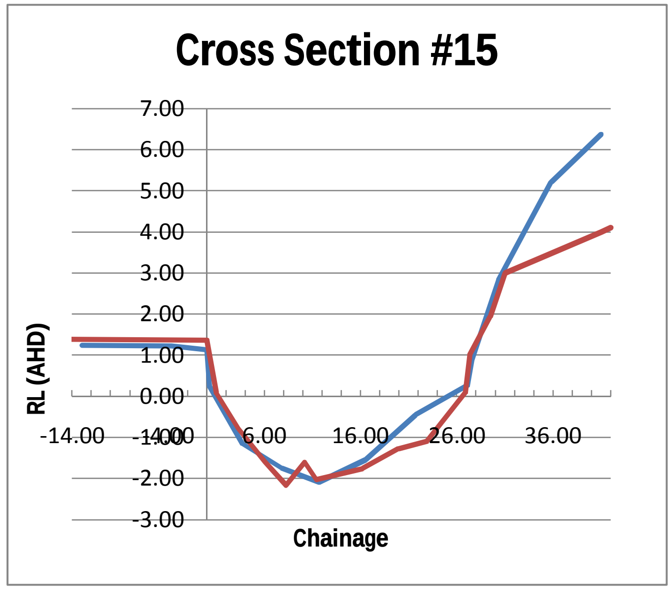

Cross Section #A36
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-11.00
-1.00
9.00
19.00
29.00
39.00
RL (AHD)
Chainage

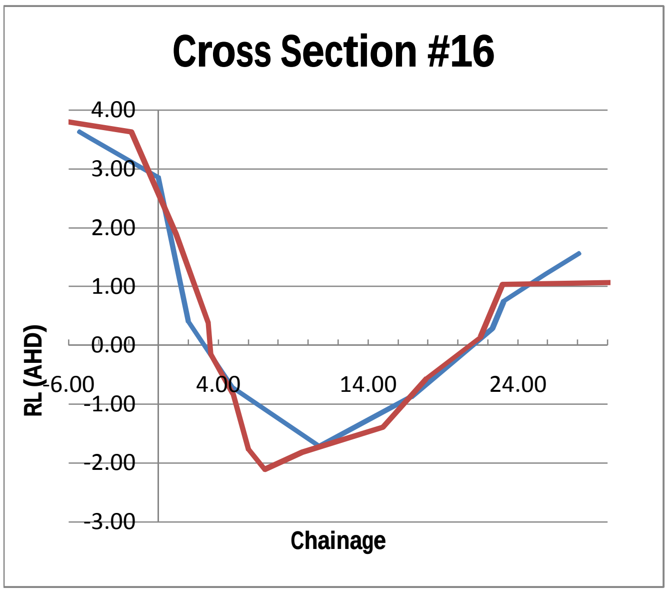

Cross Section #11
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-8.00
2.00
12.00
22.00
RL (AHD)
Chainage

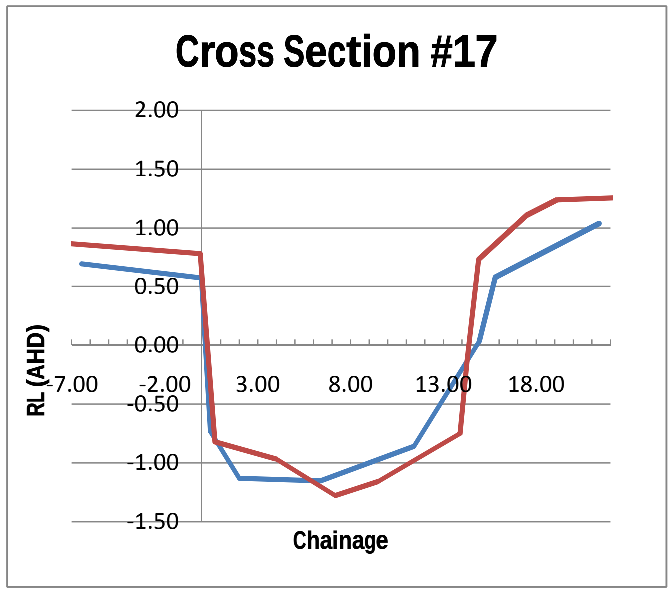

Cross Section #13
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-14.00
-4.00
6.00
16.00
26.00
36.00
RL (AHD)
Chainage

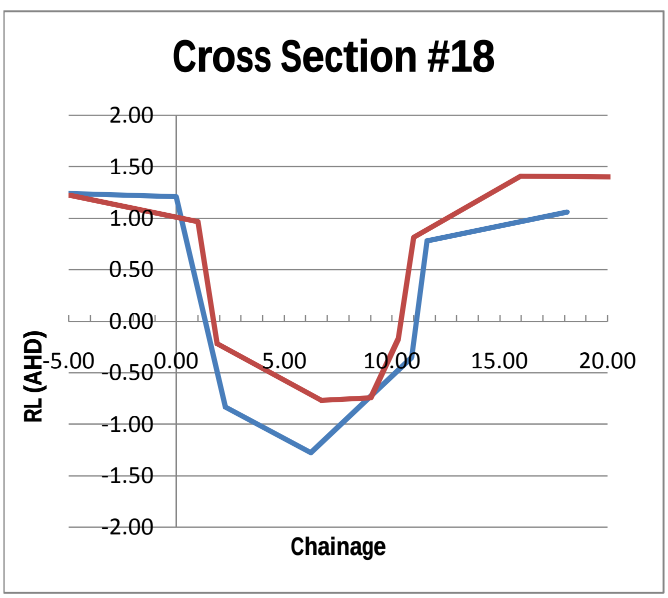
OLD NEW

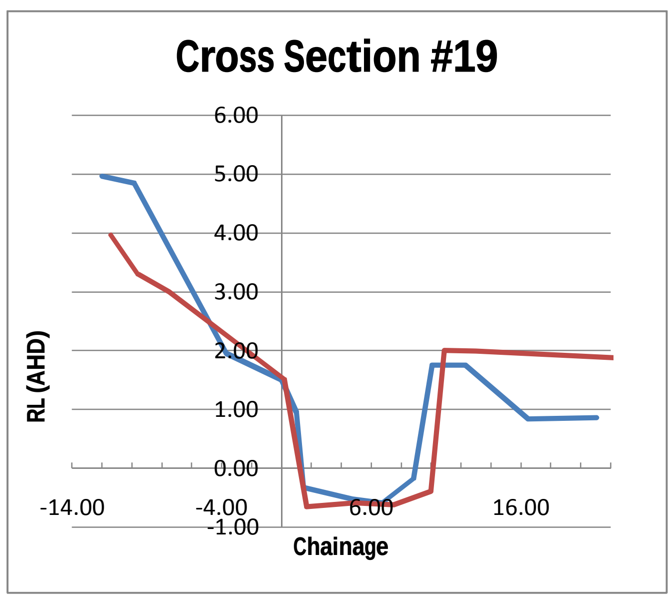

Cross Section #14
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-14.00
-4.00
6.00
16.00
26.00
36.00
RL (AHD)
Chainage


Cross Section #15
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-14.00
-4.00
6.00
16.00
26.00
36.00
RL (AHD)
Chainage


Cross Section #16
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-6.00
4.00
14.00
24.00
RL (AHD)
Chainage


Cross Section #17
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-7.00
-2.00
3.00
8.00
13.00
18.00
RL (AHD)
Chainage

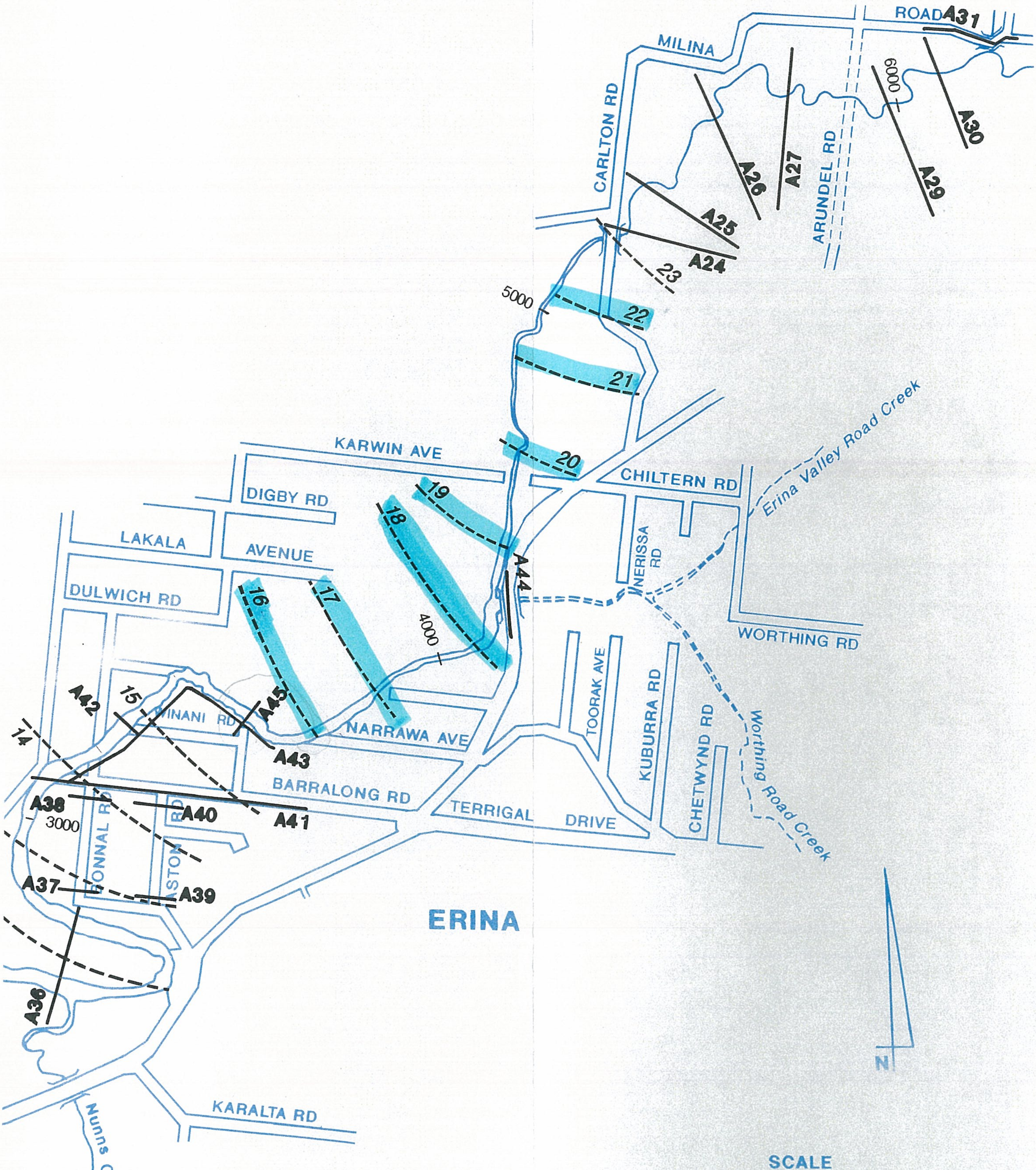

Cross Section #18
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-5.00
0.00
5.00
10.00
15.00
20.00
RL (AHD)
Chainage

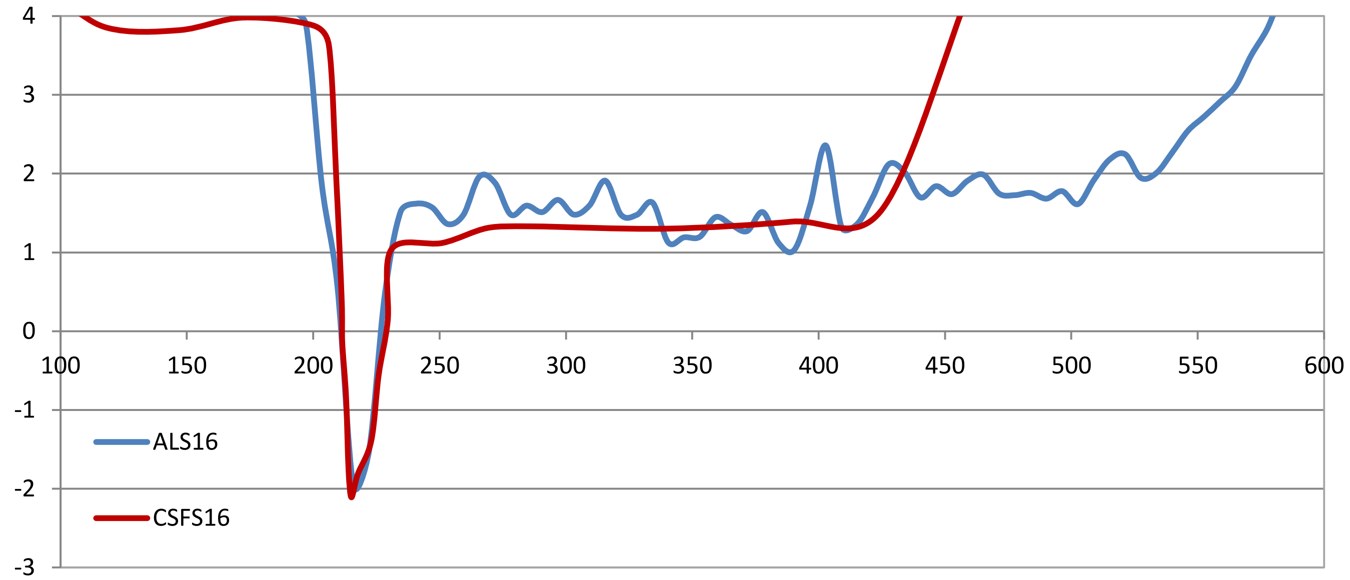

Cross Section #19
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-14.00
-4.00
6.00
16.00
RL (AHD)
Chainage

OLD NEW

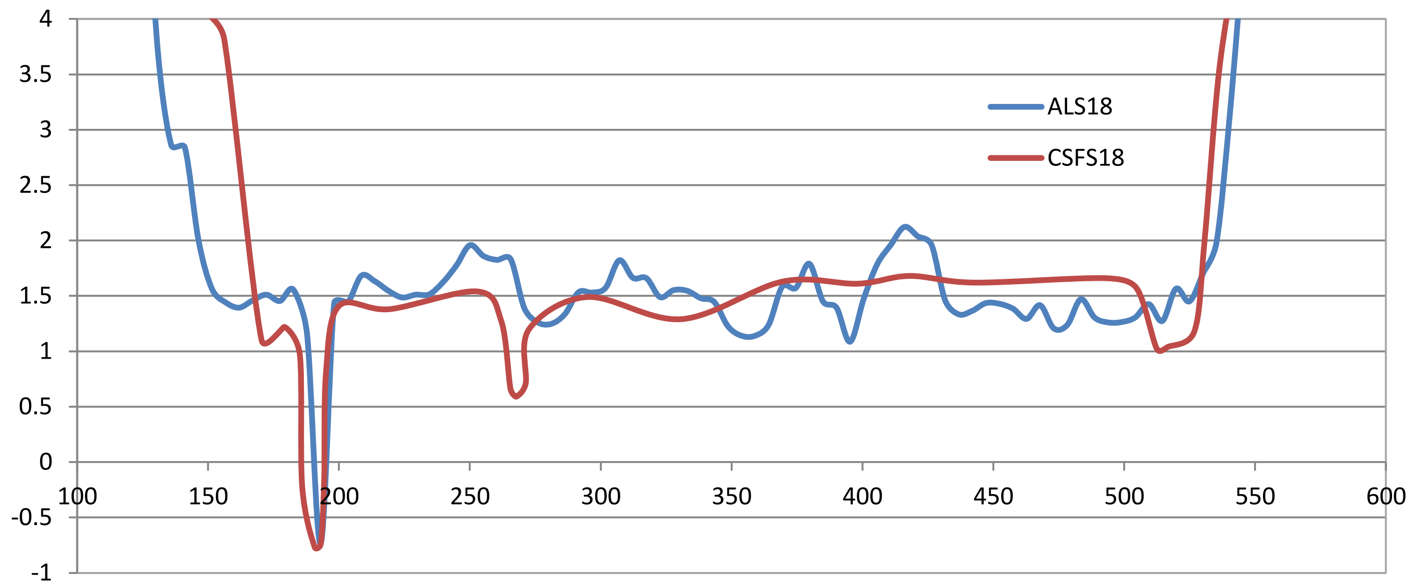
FIGURE 5

SURVEY DATA

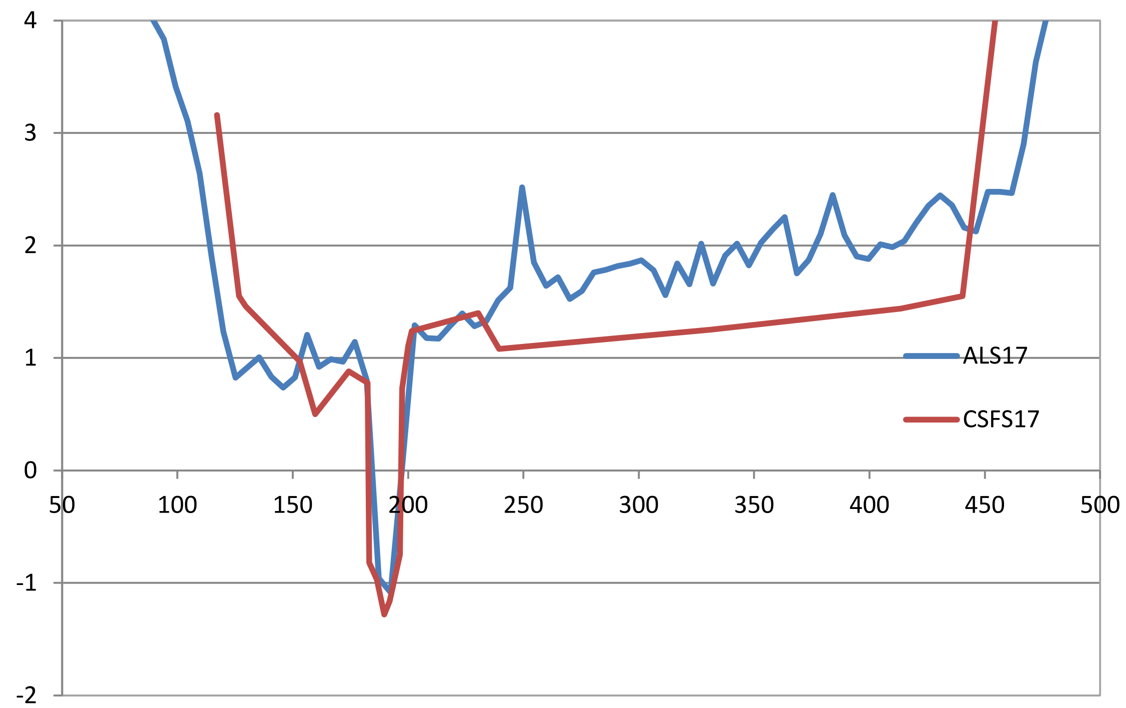




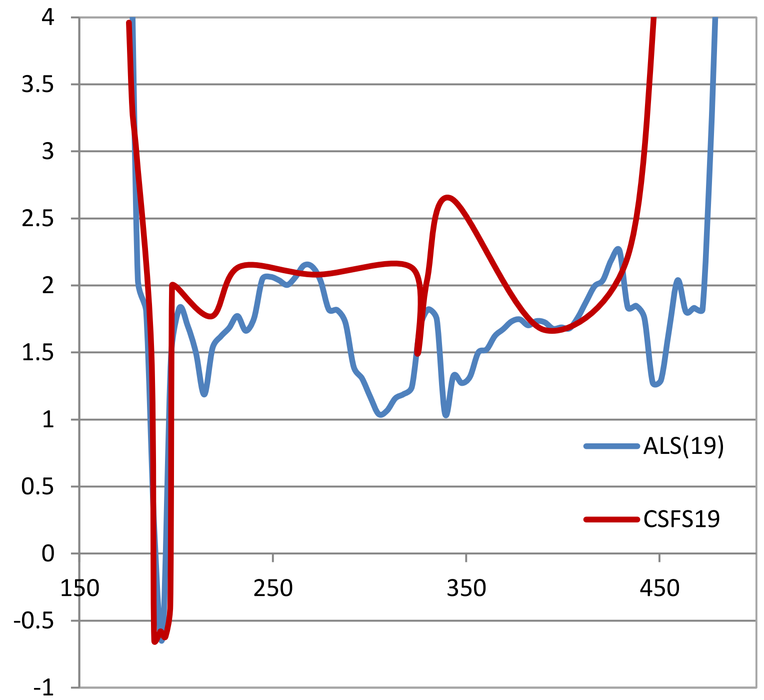
4
3
2
1
0
-1
-2
-3
100
150
200
250
300
350
400
450
500
550
600
ALS16
CSFS16



4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
100
150
200
250
300
350
400
450
500
550
600
ALS18
CSFS18

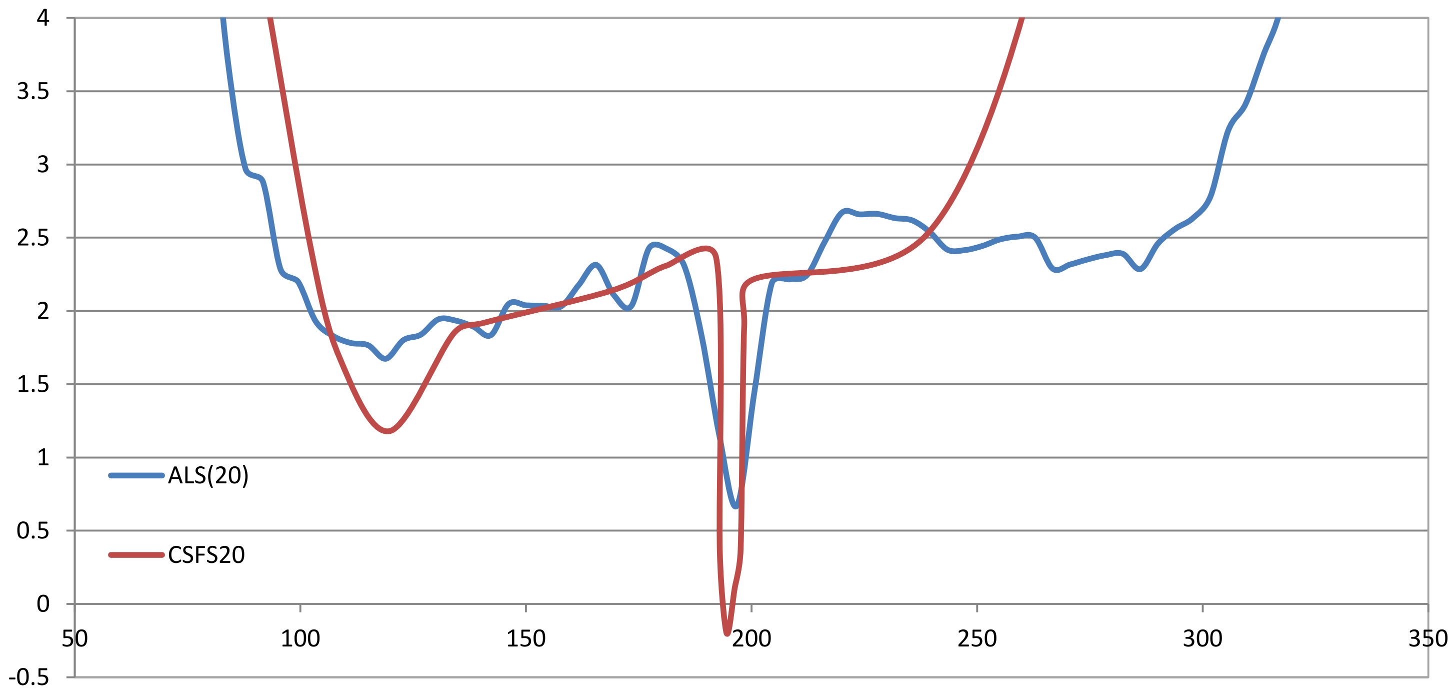


4
3
2
1
0
-1
-2
50
100
150
200
250
300
350
400
450
500
ALS17
CSFS17

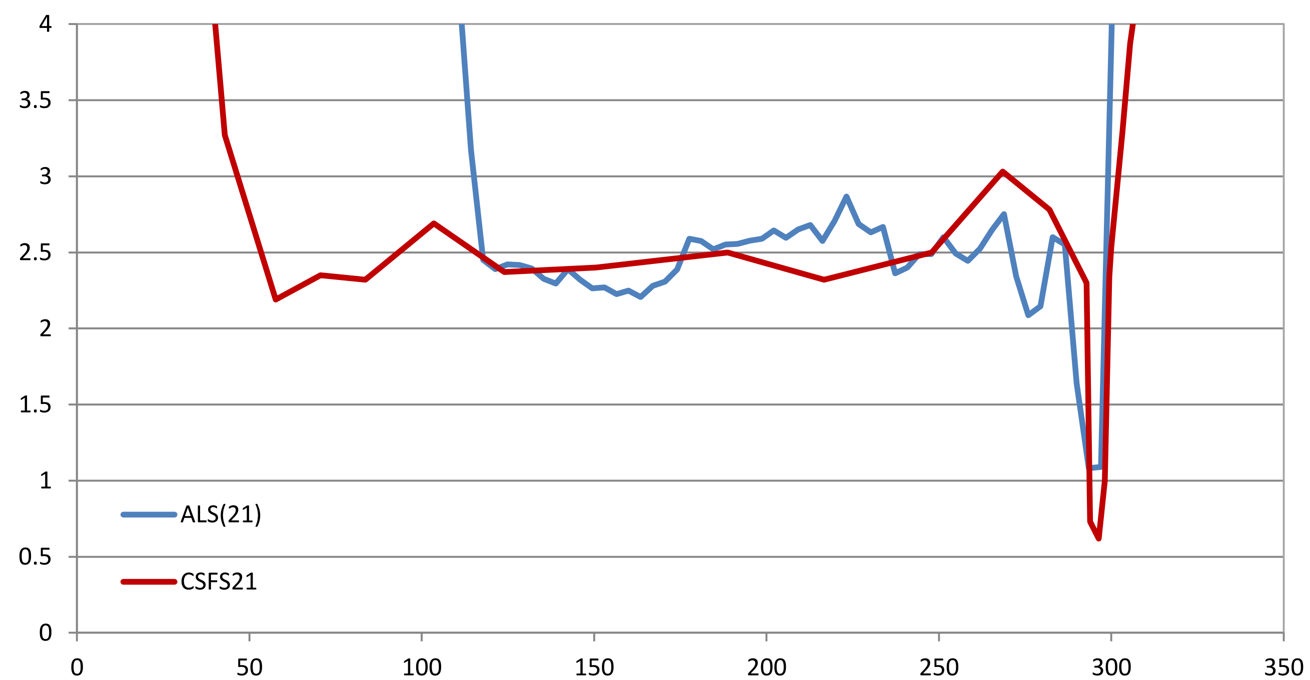


4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
150
250
350
450
ALS(19)
CSFS19

4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
400
ALS(22)
CSFS22



4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
50
100
150
200
250
300
350
ALS(20)
CSFS20



4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
ALS(21)
CSFS21

Appendix F

APPENDIX F: COMPARISON OF DESIGN RESULTS WITH PREVIOUS STUDIES

Table F1 and Figure 16 provide a comparison of the peak design levels taken from the present study and from the modelling approach adopted in Reference 1 (the flood levels were increased to those shown in Reference 1 to reflect construction of the Barralong Road levee).

Table F1: Peak Flood Level in the Erina Creek Review Study Minus Comparable Level from Reference 1 in metres (a positive value indicates that the present study has a higher level than Reference 1 whilst a negative level indicates the present study has a lower level)

Grid Point in Reference 1	Cross-section	PMF	1% AEP	2% AEP	5% AEP
GCSFPMA27	A27	0.33	0.33	0.36	0.39
GCSFPMA26	A26	0.46	0.48	0.51	0.53
GCSFPMA25	A25	0.38	0.41	0.46	0.50
GCSFPMA24	A24	0.32	0.31	0.36	0.42
GCSFPMA23	A23	0.29	0.24	0.30	0.35
GCSFS22	22	0.23	0.09	0.13	0.18
GCSFS21	21	0.19	-0.04	-0.01	0.02
GCSFS20	20	0.26	0.07	0.08	0.11
GCSFS19	19	0.45	0.26	0.27	0.27
GCSFS18	18	0.64	0.39	0.39	0.37
GCSFS17	17	0.84	0.50	0.50	0.47
GCSFS16	16	1.02	0.57	0.56	0.52
GCSFPMA45	A45	1.18	0.62	0.60	0.55
GCSFS15B	15	1.81	0.60	0.57	0.52
GCSFPMA42	A42	1.70	0.56	0.53	0.47
GBRIDGE	A41	0.56	0.22	0.24	0.25
GBRIDGEDS	13	0.05	-0.09	-0.03	0.02
GCSFS13B	A36 (u/s)	0.35	0.14	0.20	0.25
GERINA6US	11	0.43	0.20	0.25	0.28
GBONNALDS	A35	0.37	0.08	0.13	0.13
GCSFS11A	A36 (d/s)	0.45	0.18	0.24	0.27
GCSFS9	9	0.23	0.02	0.10	0.14
GCSFS8	8	0.20	0.04	0.13	0.17
GCSFS7	7	0.17	0.03	0.12	0.15
GCSFS6	6	0.10	0.00	0.08	0.11
GCSFS5	5	0.89	0.08	0.18	0.16
GCSFS4	4	0.60	-0.23	-0.09	-0.08
GCSFS3	3	0.36	-0.29	-0.15	-0.14
GCSFS2	2	0.16	-0.55	-0.41	-0.35
GPUNTBRUS	A32	-0.02	-0.82	-0.66	-0.54

The locations of the sections are shown on the following page as a scan of Figure 5 from Reference

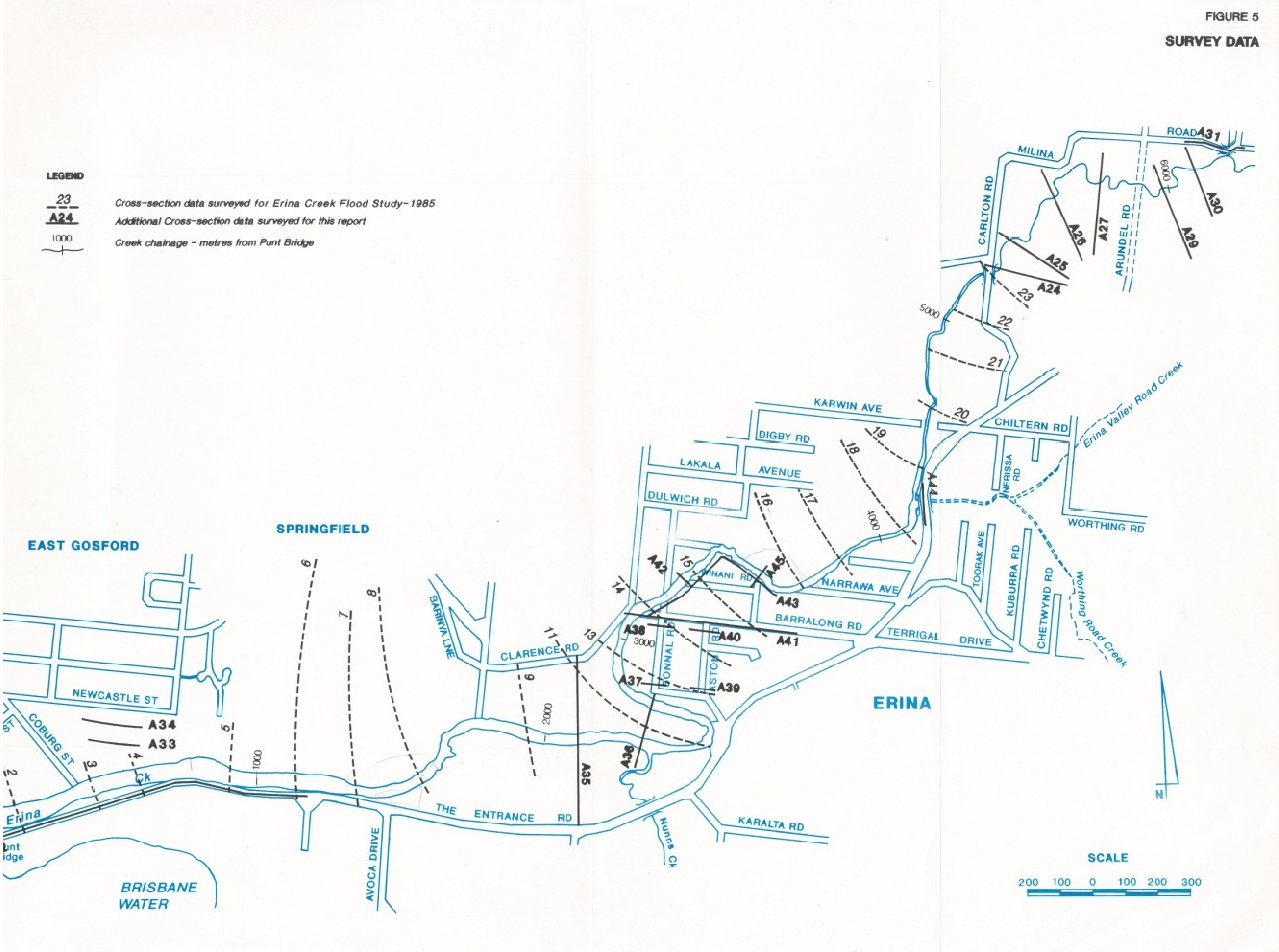


FIGURE 5
SURVEY DATA
LEGEND
23 Cross-section data surveyed for Erina Creek Flood Study-1985
A24 Additional Cross-section data surveyed for this report
1000 Creek chainage - metres from Punt Bridge
EAST GOSFORD
SPRINGFIELD
ERINA
BRISBANE WATER
NEWCASTLE ST
COBURG ST
THE ENTRANCE RD
AVOCA DRIVE
BARINYA LANE
CLARENCE RD
KARWIN AVE
DIGBY RD
LAKALA AVENUE
DULWICH RD
NARRAWA AVE
BARRALONG RD
TERRIGAL DRIVE
KARALTA RD
CHILTERN RD
WORTHING RD
MILINA ROAD
CARLTON RD
ARUNDEL RD
TOORAK AVE
KUBURRA RD
CHETWYND RD
Erina Valley Road Creek
Worthing Road Creek
Nunns Ck
SCALE
200 100 0 100 200 300
N