Cessnock City Council

HUNTER RIVER

REVIEW OF BRANXTON FLOOD LEVELS

FINAL

DECEMBER 2013

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: 9299 2855
Fax: 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

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Client Cessnock City Council	**Client's Representative** Peter Jennings
Authors Rhys Hardwick Jones Richard Dewar	**Prepared by**
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FOREWORD

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

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

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

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

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

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

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

In October 2010 completed the Hunter River (Branxton to Green Rocks) Flood Study for Maitland and Cessnock City Councils. This 2010 Flood Study completed Stage 1 of the above process. This current 2013 study provides an amendment to the 2010 Flood Study within the Cessnock City Council local government area and the results from this present study supersede those from the 2010 study.

1. INTRODUCTION

1.1. Background

The design flood levels currently used at Branxton for development control and planning purposes by Cessnock City Council are based on the Hunter River (Branxton to Green Rocks) Flood Study completed in 2010 by WMAwater (Reference 1). Two TUFLOW models were developed for the study – one from Branxton to Oakhampton, and another from Oakhampton to Green Rocks, with an overlapping section in the vicinity of Oakhampton.

Prior to the undertaking of the 2010 Flood Study, a more localised study was completed at Branxton as part of preliminary design work for the Hunter Expressway crossing of Black Creek at Branxton. This study (Reference 2) estimated 1% AEP flood levels from both Black Creek and Hunter River flood mechanisms, for the purposes of setting the road level.

A discrepancy between the 1% AEP flood levels in these two reports prompted a review by the Design Joint Venture (DJV) contracted to construct the Hunter Expressway, led by Abigroup and also including SMEC and SKM consulting engineers. The review included collection of new information about the level of the February 1955 flood at Branxton, and presented an alternative calibration of the TUFLOW model. Based on this alternative calibration, a 1% AEP flood level was recommended which was between the two previous estimated levels. WMAwater understand that this level was adopted for construction of the expressway.

Cessnock City Council engaged WMAwater to review design flood levels at Branxton in light of the additional work done by the DJV, to determine whether there is justification for adjusting the design levels at Branxton for flood-related development control purposes, and if so, whether adjustments should be made to design levels for the full 2010 Flood Study TUFLOW model extent downstream to Green Rocks.

1.2. Scope of Work

The scope of work for this investigation included the following tasks:

- Review the reports produced by the DJV (Abigroup and SMEC);
- Obtain historical data and model files used as part of the alternative calibration work undertaken by SMEC and include the additional February 1955 flood levels on the relevant figures from the 2010 Flood Study;
- Re-run all calibration events for both the upstream and downstream (relative to Oakhampton) models using the alternative calibration parameters adopted by SMEC;
- Re-run the design events for both upstream and downstream (relative to Oakhampton) models using the alternative calibration parameters from SMEC;
- Compare the results to those from the 2010 Flood Study;
- Assess whether revision of design flood levels to part or all of the study area (Cessnock and Maitland LGA) is appropriate?

2. BACKGROUND

2.1. Study Area

This review is specifically concerned with the estimation of design flood levels at Branxton in the Hunter Valley, but includes consideration of Hunter River flood behaviour from Singleton to Green Rocks / Millers Forest, near Raymond Terrace at the confluence of the Williams River (see Figure 1).

2.2. Lower Hunter Flood Mitigation Scheme

This document makes reference to several features of the Lower Hunter Flood Mitigation Scheme, a system of levees, spillways, floodways, flood gates and other flood control structures primarily constructed after the February 1955 event to mitigate flood risk in and around Maitland. Details of the scheme are available from fact sheets prepared by the Hunter-Central Rivers Catchment Management Authority (Reference 3).

2.3. Historical Flood Behaviour

There is a long history of flood records on the Hunter River since European settlement in the early 19th century. Discussion in this study is limited to those events for which a substantial amount of recorded flood data is available, and which are of sufficient magnitude to make them suitable for calibration of flood models. There are several floods that fall in this category, but the most significant events for calibration of the flood modelling approach are as follows (peak level at Belmore Bridge, Maitland in brackets – dates indicative only):

- 24th to 28th February 1955 (12.1 mAHD);
- 31 January to 4th February 1971 (11.1 mAHD);
- 3rd to 6th March 1977 (10.8 mAHD);
- 8th to 12th June 2007 (10.7 mAHD).

Of particular importance is that these floods have exhibited some inconsistent behaviour along the reach of the Hunter River from Singleton to Morpeth and this is exhibited by comparison of the automatic water level gauge records at Singleton, Greta and Maitland (Figure 1 and Figure 2). Variability is to be expected – no two floods are alike – however the variability in the Hunter River is particularly confounding, and is primarily evident in differences between the 1971, 1977, and 2007 floods, which are the three largest to occur since the historic flood of February 1955. A map of recorded flood marks from the February 1955 and June 2007 events between Branxton and Oakhampton is shown on Figure 2. Unfortunately there are no records for the March 1977 event in this reach (no record at the Greta gauge) and only the Greta gauge record for the February 1971 event.

The relative peak flood heights and travel times for these three events are summarised in Table 1 below. The recorded gauge levels at Singleton, Greta and Maitland are shown in Figure 3 to Figure 5, with the timing of the peaks aligned at Singleton for comparative purposes.

Table 1: Summary of Historical Flood Peaks and Timing

Flood Event	Peak Gauge Level (m)		Peak Gauge Level (mAHD)
	Singleton	Greta (48km d/s of Singleton)	Maitland (35 km d/s of Greta)
February 1971	14.1	12.2	11.1
March 1977	13.4	n/a*	10.8
June 2007	14.0	13.0	10.7
Flood Peak Travel Time from Singleton (hours)			
February 1971	-	15	18
March 1977	-	n/a*	11
June 2007	-	19	28

n/a* Data not available due to gauge failure

The February 1971 and June 2007 floods reached similar heights at Singleton, with the February 1971 event being slightly higher. At Greta, the June 2007 event was significantly higher than the February 1971 flood (a difference of 0.8 m). However, by the time the flood reached Maitland, this behaviour completely reversed, and the June 2007 flood was significantly lower (0.4m) than the February 1971 peak.

The difference of 0.4 m at Belmore Bridge represents a major difference in flow magnitude, as the June 2007 event (10.7 mAHD at Belmore Bridge) was not sufficient to overtop the Bolwarra Spillway, and only resulted in relatively minor overtopping of the Oakhampton spillways (although exacerbated somewhat by the failure of the Oakhampton Road control embankment). In contrast the February 1971 event (11.1 mAHD at Belmore Bridge) overtopped the Bolwarra and Oakhampton Spillways and produced widespread flooding in the Bolwarra flats and Oakhampton Floodway (Photograph 1, following page).

The unexpectedly high June 2007 peak level recorded at Greta prompted a major revision of the Bureau of Meteorology's prediction for the peak flood level at Maitland, as it suggested a flood much larger than February 1971, which would result in major overtopping of the floodways and potentially the ring levee at Maitland, causing isolation of Central Maitland and Lorn and potentially widespread inundation of homes. This revision resulted in a major increase in evacuation activity from Central Maitland.

The March 1977 flood exhibited the reverse behaviour. Like February 1971, it produced a higher flood peak at Belmore Bridge than June 2007, but unlike February 1971 it was significantly lower at Singleton (a difference of 0.6 m). Unfortunately the peak March 1977 level at Greta is not available due to gauge failure, and it is unclear to what extent the March 1977 flood overtopped the major spillways at Maitland, although photographs are available of an embankment failure at Oakhampton Road similar to the one that occurred in June 2007.

Photo 1: Aerial photographs of inundation extent at Maitland in February 1971

In addition to the variability in peak flood levels, the timing of the flood peak between Singleton and Maitland is another key factor to be considered. In June 2007, it took approximately 4 hours longer for the peak to travel from Singleton to Greta, and 10 hours longer (28 hours vs. 18 hours) to travel to Maitland than in February 1971. In contrast, the March 1977 event took just 11 hours to travel from Singleton to Maitland, 17 hours less than in June 2007, even though the peak levels at Belmore Bridge were roughly the same.

The differences in historical flood behaviour are particularly notable when considering the peak water level profiles downstream of Oakhampton (Figure 6). The peculiarity of the June 2007 flood gradient in this reach in comparison to previous events was noted by observers from the Hunter-Central River Catchment Management Authority, State Emergency Services and Department of Environment and Climate Change (refer to Section 3.1.3).

The causes of this variability are highly complex, and cannot be attributed to a single factor.

Aspects that may have contributed include:

- variation in rainfall patterns and the timing of tributary inflows. These contribute to aspects of hydrograph shape such as volume and length, as well as peak flow;
- changes in geomorphology;
- changes in riparian and floodplain vegetation;
- the size of flood and the debris load carried by the flood. Flood behaviour can depend on the elapsed time since the last major flood, and the size of the last flood;
- other land use changes (such as development, construction of levees and dams, etc.).

While the above discussion is somewhat focussed on the observed flooding at Maitland (as this is where the variability is most pronounced), it is relevant for the matter at hand (Branxton flood levels) because a robust assessment of design flood levels from Singleton to Maitland requires this variability to be addressed both in the model calibration and design flood estimation stages of the Flood Study. An assessment that does not recognise this variability may underestimate the role of various flood mechanisms and produce erroneous design flood levels.

2.4. Hunter River Flood Frequency Analysis

Discussion of the design flood level estimates at Branxton requires an understanding of the key assumptions broadly underpinning design flood estimation along the Lower Hunter River. Flood frequency analysis in particular is the primary component of this process. Flood frequency analysis essentially involves statistical interpretation of long records of peak flood level data at individual locations, to determine a corresponding peak flood flow for a given probability (such as the 1% AEP). If conditions at the site have been non-stationary over the period of record (e.g. through changed geomorphology, dam construction upstream, or climate change), the record requires adjustment to be homogeneous.

Annual peak flood height records for a period of more than one hundred years are available at Belmore Bridge in Maitland and at Dunolly Bridge in Singleton. Flood frequency analysis requires the conversion of these flood heights into flow estimates – a process that involves significant uncertainty, and requires measurements of flow velocities by hydrographers during very large floods. These measurements have standard errors of 2% to 20% depending on the measurement conditions (Reference 4). The rating curves (the relationship between water level and discharge) for both Belmore Bridge and Dunolly Bridge are based on fairly limited flow gauging measurements, although the Dunolly Bridge rating curve does include a measurement of the February 1971 flood flow, although only at bank-full conditions for the main channel (i.e. no overbank flow). The uncertainty of flow measurements is exacerbated by the fact that there are significant anabranches/floodways away from the main river channel at these gauge locations. Most flood frequency analyses undertaken at these gauges are anchored to historical estimates of flood flows, particularly the February 1955 peak flow, which is highly uncertain given that as it was a very large event it covered a significant area and not confined to the main channel.

Flood frequency analysis places an emphasis on peak discharge. However numerous other factors are known to contribute to the peak water level for a given flood, including:

- total flood volume, rate of rise and timing (the hydrograph shape, which may involve multiple peaks);
- river channel conditions (including vegetation, dredging and sedimentation);
- timing and magnitude of tributary inflows, which may alter the available river and floodplain storage and/or affect the movement of the flood wave downstream; and
- changes to the rating curve for the rising and falling limbs of the flood (hysteresis), relating to the influence of floodwaters already downstream, which can vary significantly depending on location.

A single-minded focus on the peak flow is not sufficient when seeking to explain the historical variability in flood behaviour. Total volume, duration and other aspects of hydrograph shape and tributary inflow timing must also be considered. There is more than one value for the peak Hunter River flow that produces a 1% AEP peak flood level at Branxton – that is, there are a range of flows that may produce the same peak flood level depending on other characteristics of the flood. One Hunter River flow in a given year might produce the same flood level as a different flow in a different year. The converse is also true – a similar peak flow can produce very different peak flood levels depending on other variables.

The flood frequency approach is site-based and has limitations when attempts are made to extend to long reaches of river (such as between Singleton and Maitland), as the flood frequency process does not contain information about hydrograph shape (volume, rate of rise, duration, twin peaks, etc.). This means that the development of a single design flood hydrograph that can be routed through hydraulic models from Singleton to Maitland (via Branxton) is problematic, and inconsistencies are bound to arise.

The current industry-standard event-based approach to design flood modelling is therefore limited for the estimation of design flood levels at Branxton. This approach is currently the most suitable practical method, but it must be recognised that the uncertainty is particularly pronounced at Branxton, due to its location midway between the available flood frequency sites and the presence of a relatively large tributary (Black Creek).

In the future, stochastic approaches to design flood estimation may provide more certainty about the interactions between the other flood characteristics apart from peak flow as identified above. Even with current techniques, a single-minded focus on peak flow estimates should be avoided, in favour of more comprehensive methodologies that seek to address all aspects of flood behaviour.

3. AVAILABLE DATA

3.1. Previous Studies

A summary of previous studies is provided below, focussing on aspects relevant to the estimation of design flood levels at Branxton, and particularly the model calibration and design flood assumptions adopted in each study.

3.1.1. Singleton Flood Study – BMT WBM (2003)

The Singleton Flood Study (Reference 5) was prepared in accordance with the requirements of the NSW floodplain risk management program. The study included flood frequency analysis at Dunolly Bridge, and development of a two-dimensional model (TUFLOW) with one-dimensional links extending upstream and downstream of the main study area.

The model was calibrated against several historic events, including 1955, 1971 and 1949. Design flood level estimates were obtained for a range of flood events, and the February 1955 event was estimated to be equivalent to a 0.5% AEP flood.

3.1.2. Black Creek Crossing at Branxton - Flood Study – Lyall & Associates (2004)

Lyall & Associates completed a hydraulic modelling assessment of the Hunter River at Branxton to determine design flood levels for the New England Highway crossing of Black Creek (Reference 2). HEC-RAS was used to model a 14 km reach of the Hunter River near the Black Creek confluence, and a 6 km reach of Black Creek upstream of the confluence as far as the New England Highway crossing. The study included flood frequency analysis at Singleton, and estimated design peak discharges in the Hunter River for the 1%, 5%, 10% and 20% AEP flood probabilities. RORB modelling was undertaken to estimate design flows in Black Creek.

The peak flow estimates were used as inflows to the steady state HEC-RAS model. The study determined a peak 1% AEP flood level of 31.3 mAHD at the road crossing of Black Creek (and at Branxton in general).

The February 1955 event was assessed to have a return period rarer than 0.5% AEP (greater than 200 year ARI). Model results were compared with recorded flood levels for the February 1955 flood, but calibration against other events was not undertaken.

3.1.3. Hunter-Central Rivers CMA, SES and DECC (2007):

In the aftermath of the June 2007 flood, a paper was written (Reference 6) by representatives of the Hunter Central Rivers Catchment Management Authority, the State Emergency Services, and the Department of Environment and Climate Change (now Office of Environment and Heritage). The paper documented the operation of the Hunter Valley Flood Mitigation Scheme and the Maitland City Local Flood Plan, and included observations about the flood behaviour.

In particular, the paper made some observations about the differences between the June 2007 event and previous Hunter River flood behaviour:

- *"The flood gradient appears to have been steeper than previously observed or predicted by modelling, resulting in early operation of the Oakhampton spillway. The recent increase in riparian vegetation upstream of Maitland appears to have affected the velocity and gradient.*
- *The amount of flood debris conveyed to Maitland was considerably less than expected for a flood of this size. The increased riparian vegetation cover appears to have retained much debris which would otherwise be washed downstream.*
- *The difference between predicted and actual flood peaks is still being investigated, but is mostly likely due to rainfall timing and patterns – no two floods are alike."*

3.1.4. Hunter River (Branxton to Green Rocks) Flood Study – WMAwater (2010)

Two separate TUFLOW models were established with an overlapping intermediate area at Oakhampton (Reference 1). The models were calibrated to historical flood height data (1955, 1971, 1977 and 2007) where data was available and then used for design flood estimation.

CALIBRATION

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

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

between Branxton and Oakhampton and the available recorded data downstream of Oakhampton. The Manning's "n" assumptions adopted for the February 1971 event were also adopted for the February 1955 event.

It was apparent from a comparison of the recorded flood height data at Singleton, Greta and Maitland (Belmore Bridge), as discussed in Section 2.3, that different channel conveyances had to be adopted to replicate the recorded changes in relative gauge heights at the three locations between 1971 and 2007. The change in conveyance could be due to a change in channel dimensions (erosion and/or sedimentation) or channel friction (represented by the Manning's "n" parameter). There is no conclusive evidence in this regard however a comparison of aerial photographs taken in 1974 and 2009 indicated that there was considerably more vegetative growth along the banks in 2009 than in 1974. This is confirmed (at many locations) by anecdotal evidence from local landowners.

Thus a different set of Manning's "n" values was adopted to simulate the pre June 2007 flood events compared to the June 2007 and design events. The adopted roughness values are shown in the tables below.

Table 2: Adopted Mannings "n" values - upper TUFLOW model

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

Table 3: Adopted Mannings "n" values - lower TUFLOW model

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

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

In light of the results, it is considered likely that there were significant changes to channel conveyance in the Hunter River upstream of Oakhampton between February 1955 and June

2007, as a result of geomorphologic processes and coordinated programs to reinstate riparian vegetation. The topographic data used to build the model was obtained in 2008, and aerial photographs from a similar period were available. It is therefore unsurprising that a more comprehensive match was obtained for modelling of the June 2007 flood. Evidence of changes to riparian vegetation justified the use of slightly different Manning's "n" roughness values between 1955/1971 and 2007, but overall it was considered preferable to determine a consistent set of modelling parameters and assumptions that would provide the best estimate of design flood behaviour under present conditions. A summary of the model calibration results (taken from Reference 1) are provided in Table 4.

Table 4: Calibration Summary – WMAwater 2010 Flood Study

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

The model calibration was poorest for the February 1955 event at the very upstream extent of the models (i.e. at Branxton). The modelled February 1955 flood level at Branxton was 35.5 mAHD, 1.3 m above the recorded level. As discussed above, this relatively poor match for a single event was preferred rather than reduce the quality of the calibration for the majority of the study area and other more recent floods.

DESIGN FLOOD LEVELS

The Hunter River design inflows to the Upper TUFLOW model were determined iteratively, in conjunction with determination of the tributary inflows, so that after running the design event through the Upper TUFLOW model the resulting peak flow at Oakhampton matched the adopted peak flow from flood frequency analysis. The flood frequency analysis was undertaken using a modelled rating curve relationship between flows at Oakhampton and water levels at Belmore Bridge. The shape of the design flood hydrograph was adopted as the shape of the February 1955 flood event. This Hunter River flow at Oakhampton (near the downstream limit) in the Upper TUFLOW model was then used as the inflow to the Lower TUFLOW model.

The estimated 1% AEP flood level at Branxton from the WMAwater (2010) study was 34.8 mAHD. This level is higher than the (newly) accepted February 1955 flood level of 34.2 mAHD, which is reflective of the calibration results at Branxton being too high.

3.1.5. Review of Hunter River Design Flood Levels near Black Creek, Branxton – BMT WBM April 2011

The difference in estimated 1% AEP peak flood levels between the LACE 2004 study (31.3 mAHD) and the WMAwater 2010 study (34.8 mAHD), prompted the then RTA to request a third-party review, which was undertaken by BMT WBM (Reference 7).

The review provides a good summary of the differences between the calibration and design flood modelling approaches, and the limitations in relation to determining Branxton design flood levels. The review noted the importance of the constriction point in the Hunter River floodplain approximately 1 km downstream of the Black Creek confluence, and its effect on the localised flood gradient. The review also highlighted the importance of the hysteresis effect, whereby the February 1955 peak flood level at Branxton was assessed to be some 0.5 m above the flood level at the time of peak flow (from WMAwater 2010). This effect is not accounted for using the steady state modelling approach adopted in LACE 2004.

The review recommended a localised adjustment to the February 1955 calibration profile for both studies, and calculated an adjustment to the 1% AEP flood levels based on various factors.

The review calculated an increase of 2 m for the 1% AEP LACE 2004 study, and a reduction of 1.8 m for the WMAwater 2010 study, and recommended that a revised 1% AEP flood level of “the order of 33.0 mAHD – 33.5 mAHD” be adopted. The review also noted that given the uncertainties relating to design flood level estimation at this location, it may be prudent to adopt the February 1955 peak flood level of 34.2 mAHD for flood planning and development control purposes.

3.1.6. Review of Design Flood Levels at New England Highway Crossing of Black Creek (Draft Only for Discussion) – Lyall & Associates, April 2011

In response to the review by BMT WBM, Lyall & Associates revised the modelling work undertaken in their 2004 study (Reference 8). The 1% AEP peak flood flow was increased and a freeboard was included, to give a revised 1% AEP flood level of 32.3 mAHD for design purposes of the New England Highway crossing at Black Creek. Hydraulic roughness values were not altered from the original 2004 assessment.

The revision maintained a steady state modelling approach, and did not address issues relating to unsteady flood behaviour such as floodplain storage and hysteresis effects. The revision also did not address the peculiar behaviour of the June 2007 flood, which produced 5% to 2% AEP flooding between Singleton, Branxton and Greta, but less then 10% AEP flooding at Maitland.

3.1.7. Review of Hunter River Flood Modelling – Zone 4 – SMEC, April 2011

Following the third-party review by BMT WBM and response by Lyall & Associates, SMEC on behalf of the Hunter Expressway Design Joint Venture (DJV) undertook a localised re-calibration of the TUFLOW model developed by WMAwater for the 2010 Flood Study (Reference 9). The localised re-calibration focussed on improving the match with the February 1955 level at Branxton of 34.2 mAHD, which was selected after a rigorous review of available historical flood marks and accounts from residents.

The DJV presented two alternative calibration scenarios, based on revised Mannings “n” roughness values, and also alternative inflow hydrographs for the June 2007 event. The model was re-run for the February 1955 and June 2007 events, as well as the 1% AEP design flood. The revised parameters are summarised in Table 5 below.

Table 5: Alternative Calibration Mannings "n" values (SMEC, 2011)

Description	“Calibration 2”	“Calibration 4”
River Bed	0.022	0.022
River Banks	0.04	0.04
General Floodplain	0.03	0.025

A comparison of the calibration results with those from WMAwater (2010) is provided in Section 4.2. On the basis of the localised re-calibration, the DJV recommended that the “Calibration 2” parameters should be adopted, giving a 1% AEP design peak flood level of 33.5 mAHD at Branxton. There was no recommendation for freeboard above this level, and it is not clear whether an additional freeboard was adopted for the crossing.

It was noted in the DJV report that the methodology did not “take into account all considerations that would normally be undertaken for a full Flood Study… carried out in accordance with the requirements of the NSW Floodplain Development Manual.” Some considerations that were not addressed included comparisons with recorded flood behaviour downstream of Oakhampton (including Maitland, where significant amounts of data are available), validation against the February 1971 flood, or discussion of the inconsistent flood behaviour in June 2007 compared with earlier floods. It was recommended that the work should be reviewed by relevant stakeholders to ascertain consensus or otherwise with the findings.

3.1.8. Singleton Floodplain Risk Management Study (Public Exhibition Draft) – Paterson Consultants, September 2011

The Floodplain Risk Management Study assesses the extent of flood risk, and measures that can be undertaken to mitigate or manage flood risk at Singleton. Reference 10, undertaken by Paterson Consultants and on public exhibition at the time of writing, included a flood frequency assessment and validation of the hydraulic model developed for the Singleton Flood Study (BMT WBM, 2003) against the June 2007 flood event.

The study makes several recommendations relating to updating the Singleton Flood Study hydraulic model, including the following tasks:

- obtain ALS data over the whole floodplain to confirm and extend adequate ground level data for two dimensional flood modelling;
- extend the TUFLOW model downstream to the confluence of the Hunter River and Glendon Brook;
- extend the TUFLOW model upstream to Maison Dieu and utilize the ALS data to resolve the topography of the Hunter River break-out across the Putty Road;
- re-calibrate and verify the extended TUFLOW model to:
    - reproduce the historical gaugings at Dunolly Bridge; and
    - achieve the best fit against the 1955, 1971 and 2007 flood level data.

3.2. Additional Historical Flood Data

SMEC undertook a detailed review of available flood marks from the February 1955 event at Branxton (Reference 9). Some additional flood marks were also obtained for the June 2007 event. On the basis of this review it was recommended that a level of 34.2 mAHD be adopted as the peak February 1955 flood level at Branxton.

The level of 34.2 mAHD agrees with a map of the flood inundation extent prepared by the Water Resources Commission and currently held by OEH (Reference 11). This map is reproduced in Figure 17. WMAwater therefore agrees with the assessment that the best estimate of the peak February 1955 level is 34.2 mAHD at Branxton.

The new higher reliability flood marks were added to the map of flood marks (Figure 2) and the historical flood profile (Figure 7) included in the WMAwater 2010 Flood Study.

An updated database of flood levels for the February 1955 event is provided in Appendix B.

4. HYDRAULIC MODELLING REVIEW

4.1. 2007 Hunter River Flow Hydrograph

The WMAwater (2010) and SMEC (2011) studies used different inflow hydrographs to the TUFLOW model upstream of Branxton, for the June 2007 event. The SMEC inflow (peak 6,000 m^3/s) was obtained from the outflow from the Singleton Flood Study model developed by BMT WBM (2003). BMT WBM (2011) and SMEC (2011) were critical of the use of a different hydrograph by WMAwater in the Flood Study (with a maximum peak of 3,000 m^3/s, and two other prior inflow peaks reaching 2,000 m^3/s). More recently, Paterson Consultants used the Singleton Flood Study model to obtain a different hydrograph again, as part of the Draft Singleton Floodplain Risk Management Study (September 2011), with a total flow peak of 4,500 m^3/s, and a peak in the Hunter River of 3,300 m^3/s. The BMT WBM and Paterson Consultants hydrographs did not account for the inflows from Black Creek and Glendon Brook between Singleton and Branxton.

It is noted that the approach used by WMAwater to develop the June 2007 inflow hydrograph was essentially the same as that used by BMT WBM and by Paterson Consultants. That is, the hydrograph was iterated to produce a match to observed water levels at a particular gauge or gauges. The BMT WBM hydrograph was obtained by matching the gauged water levels at Dunolly Bridge. The WMAwater hydrograph was developed to match gauged water levels at Greta, Oakhampton, Bolwarra, Belmore Bridge, McKimms Corner, Morpeth and Green Rocks in the Hunter River, and Wallis Creek and Louth Park on the floodplain. In each case the Mannings “n” values used were constrained by the requirement to match the rating curve at the relevant gauge underpinning the flood frequency analysis (i.e. Dunolly Bridge at Singleton and Belmore Bridge at Maitland).

The differences essentially arise from the different ranking of the June 2007 flood at different locations. At Singleton, BMT WBM (2011) assessed the June 2007 flood as a 5% AEP event. However the same analysis at Maitland indicates the June 2007 flood was equivalent to approximately a 10% AEP event. The AEP of the flood at Branxton is not necessarily a simple interpolation of these two findings, due to the influence of tributaries such as Black Creek and Glendon Brook, which were significant for the June 2007 flood.

As noted by Paterson Consultants (September 2011), “*the nature of the floodplain at Singleton is such that it is relatively easy to match the recorded levels at Dunolly for a variety of hydrographs*.” This is also true at other locations, and highlights that the peak flow is not the only factor contributing to the modelled flood levels at a given point. The rating curves at the Dunolly Bridge and Belmore Bridge gauges have too much uncertainty (when overbank flow occurs) to say with confidence what the actual peak discharges were for the historic floods.

In summary, the estimated peak discharges for the TUFLOW inflow hydrographs form only part of the calibration process. The peak values are affected by the shape and volume of the hydrograph, the adopted Mannings “n” roughness values, and the assumed interactions with other tributary inflows. A good fit to recorded flood levels can be obtained by multiple combinations of each of these factors, and peak discharges in the Hunter River for large floods cannot be determined with significantly more certainty than the other contributing factors.

4.2. Comparison of Calibration Results

The model files used for the alternative calibration were obtained from SMEC, which included the following scenarios:

- February 1955 “Calibration 2” and “Calibration 4”;
- June 2007 “Calibration 2” and “Calibration 4”;
- 1% AEP “Calibration 2” and “Calibration 4”;

Each of the above scenarios was run for the upstream model (Branxton to Oakhampton) only by SMEC. WMAwater extracted the outflows from the upstream model results and used them as inflows to the downstream model (Oakhampton to Green Rocks), consistent with the approach used in the Flood Study (WMAwater, 2010). The results were compared with historical data to determine the alternative calibration performance downstream of Oakhampton. The February 1971 event was also run for both upstream and downstream models which was not undertaken by SMEC.

Only the results from the “Calibration 2” set of calibration parameters were assessed, as this was the alternative calibration consistent with the adopted 1% AEP flood level in the DJV report (SMEC/Abigroup 2011). Additionally, the 0.025 value adopted for the floodplain under the “Calibration 4” parameter set is considered unreasonably low for these areas. “Calibration 2” is hereafter referred to as the SMEC calibration. Note that parameters such as Mannings “n” roughness were not changed for the downstream model (i.e. the WMAwater values were used), in order to maintain consistency with the established rating curve at Belmore Bridge.

A qualitative assessment of the match between modelled and recorded flood behaviour is given for each scenario in Table 6 (also indicates the chart or map on which the qualitative assessment was based).

The main differences in the calibration results are the match obtained for the June 2007 and February 1955 events. For February 1955, the WMAwater calibration gave a relatively poor match to the longitudinal profile of peak flood heights (Figure 7), particularly at Branxton, where the peak flood level was overestimated by 1.3 m. The SMEC calibration shows a closer match, with a slight overestimation of 0.3 m. Further downstream, the differences reduce, and from Melville Ford to Oakhampton the WMAwater and SMEC peak February 1955 profiles are very similar. In the downstream model, both sets of results show a reasonable match with recorded flood level data for February 1955 (Figure 15a and Figure 15b).

Table 6: Comparison of Calibration Results

Flood Event	Recorded Data	WMAwater 2010 Calibration Match	DJV 2011 "Calibration 2" Match
June 2007	Branxton-Oakhampton Profile (Figure 7)	Excellent	Poor
	Oakhampton-Green Rocks Profile (Figure 8)	Good	Not as good
	Branxton Extent (Figure 9)	Good	Fair
	Greta Hydrograph (Figure 10)	Excellent	Fair
	Oakhampton-Green Rocks Hydrographs (Figure 11)	Excellent	Very Poor
	Wallis Creek Hydrographs (Figure 12)	Good	Very Poor
February 1971	Greta Hydrograph (Figure 13)	Fair	Fair
	Maitland Hydrographs (Figure 14)	Good	Slightly improved
February 1955	Branxton-Oakhampton Profile (Figure 7)	Poor	Good
	Maitland Hydrographs (Figure 15)	Good	Fair

For June 2007, in the upstream model extent the WMAwater calibration gave a good match to the longitudinal profile of peak flood heights (Figure 7), the flood extent at Branxton (Figure 9), and the time-varying water level information at Greta (Figure 10). In comparison, the SMEC calibration gave a relatively poor match to these data, with the peak flood level over-estimated at Greta by 1.0 m and occurring approximately 4 hours too early. The longitudinal peak flood level profile is typically above recorded levels by 1.0 m to 1.5 m, and the extent at Branxton is slightly overestimated relative to the WMAwater calibration.

For the downstream model for June 2007, the WMAwater results show an excellent match to several water level recorders located on the Hunter River between Oakhampton and Green Rocks (Figure 11a), and on the Wallis and Fishery Creek floodplain near South Maitland (Figure 12a). The SMEC results show a very poor match (Figure 11a), primarily as a result of the higher inflow used by SMEC for the 2007 event (approximately 5,000 m^3/s at Oakhampton compared with 2,700 m^3/s for the WMAwater calibration). The model results using the SMEC calibration indicate major overtopping of the Oakhampton and Bolwarra spillways, which did not occur in the actual event. Sensitivity testing indicated that even a very low channel roughness (n=0.02) still produced major overtopping of these spillways using the SMEC flows. In addition to a significant over-estimation of flood levels (by 0.6 m at Belmore Bridge), the SMEC model calibration results in the flood peak arriving at Belmore Bridge approximately 10 hours before the observed peak (Figure 11b).

The difference in travel time of the flood peak between Singleton, Greta and Maitland is a strong indication that the alternative SMEC roughness parameters are too low for the June 2007 event, although they are probably appropriate for the earlier floods. This result supports the argument that changes to riparian and floodplain vegetation and possibly channel geometry over the last thirty to forty years justify a change in Mannings "n" roughness values for present day conditions relative to the 1950s and 1970s, as adopted in the WMAwater Flood Study (2010).

In summary the alternative SMEC roughness parameters give an improved match for the February 1955 event at Branxton. A similar match for February 1955 is obtained at other locations further downstream, and for the February 1971 event. A significantly poorer match is observed for the June 2007 event.

The mixed results discussed above raise a question of which set of calibration parameters should be adopted for determining design flood levels.

4.3. Discussion

It is clear that floodplain conditions have changed significantly since 1955. Historical flood behaviour between Singleton and Maitland has been highly variable, suggesting that floodplain conditions may have changed significantly in the period since 1955. Aerial photographic evidence supports the argument particularly that riparian vegetation conditions have changed, with vegetation being substantially thicker in 2007 than in 1971. The vegetation conditions in 1955 are not well documented. There is also evidence that the February 1955 flood had a major effect on river geomorphology, with deposition of large amount of sediment (sand and silt) eroded from the upper catchment, and changes to the river alignment downstream of Maitland. The extent of these changes near Branxton is not well understood.

The model calibration process cannot ignore these changes and must account for them to some degree. We are faced with the dilemma that a single set of calibration parameters will not produce an excellent match at all locations. The results suggest there are significant limitations with the estimation of a single flow hydrograph as a model input for long reaches of the Hunter River, as uncertainties in the hydrograph shape and peak and the inflows from tributaries are compounded as the flow moves downstream. It is therefore justifiable to adopt a different calibration for different locations.

The February 1955 is the major flood of record at Branxton and for most of the Hunter River, and therefore must be accorded significant weight in model calibration and planning decisions. However a substantial period of time has passed since that flood, and considerable changes to the Hunter River and the floodplain have occurred in the intervening 50 years. The June 2007 event is the most recent significant flood, and the flood for which the most data (quality and quantity) are available. The June 2007 flood also occurred at a similar time that topographic data used to develop the model were obtained. The June 2007 flood must therefore also be given significant weight when considering the model calibration.

The 2007 experience suggests that flood levels in the reach from Branxton to Oakhampton are likely to be higher now than they would have been for the same inflow hydrograph in the 1970s and possibly the 1950s. However, the June 2007 flood was much smaller than February 1955, which is somewhat problematic as the flood magnitude of interest (the 1% AEP) is closer to the February 1955 magnitude, and it is hard to tell whether larger floods would be similarly affected by the changes to the floodplain. Would the February 1955 flood hydrograph cause higher levels if it occurred today as a result of altered geomorphology and riparian/floodplain vegetation conditions between Singleton and Maitland? It is not possible to say with certainty. The WMAwater 2010 Flood Study model suggests so, as illustrated by the relatively high calibration of the February 1955 event at Branxton despite very good calibration to other Hunter River flood data.

5. IMPLICATIONS FOR FLOOD PLANNING LEVELS

5.1. Design Flood Levels

Given the uncertainties at Branxton, it is reasonable to place an emphasis on the February 1955 flood, as the major flood of record, for setting localised Flood Planning Levels for floodplain risk management planning and development control. The alternative calibration ("Calibration 2") undertaken by the Hunter River Expressway DJV (SMEC, 2011) is therefore considered more appropriate for setting design flood levels at Branxton, and other areas of the Hunter River floodplain within the Cessnock City Council LGA, as this calibration gives a better match with the recorded February 1955 flood behaviour. The 1% AEP peak flood level at Branxton using the alternative calibration is 33.5 mAHD, and the modelled February 1955 flood level is 34.5 mAHD.

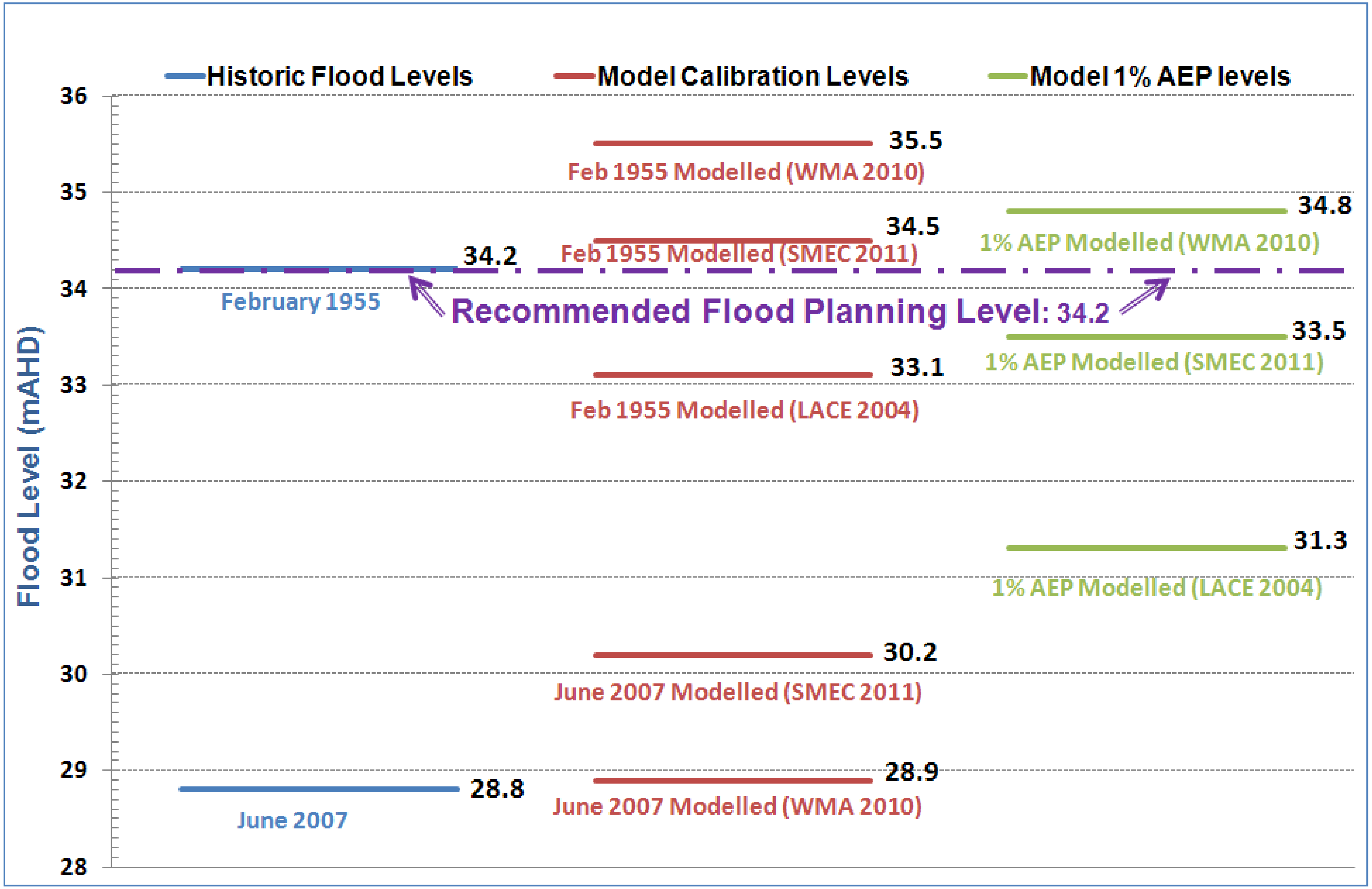
For the remainder of the model study area (within the Maitland LGA as far downstream as Green Rocks), it is reasonable to rely on a calibration process that provides a balanced match to the full range of historical flood data, and which addresses the observed variability and changes in flood behaviour over time. It is therefore considered more appropriate to rely on the more rigorous calibration methodology adopted for the Flood Study (WMAwater, 2010) for estimating design flood levels in the Maitland City Council LGA.

The LGA boundary between Cessnock and Maitland City Councils provides an appropriate boundary to implement the discontinuity between the two sets of flood levels. This will result in different design flood levels (and different Flood Planning Levels) on either bank of the Hunter River between the Lambs Creek confluence and Greta, with each bank under the jurisdiction of a different Council. However the floodplain in this area is sparsely populated and the existing rural properties in the area are typically above the 1% AEP flood level. Adopting an administrative boundary at this location between different sets of design flood levels is therefore unlikely to cause significant difficulties.

The revised 1% AEP flood level profile is shown on Figure 16. Selected profiles from the various model calibration events are shown for comparative purposes.

A graphical summary of various key flood levels, including historic flood levels and modelled levels from various sources, is provided on the following page.

Diagram 1: Schematic of Key Flood Level Estimates at Branxton



5.2. Freeboard

It is necessary to determine an appropriate level of freeboard above the 1% AEP flood level for determining Flood Planning Levels, particularly for residential property. Freeboard is required to account for:

- uncertainties in the design flood level estimates;
- differences in water level across the floodplain resulting from local factors;
- increases in water level resulting from wave action (whether wind-induced or as a result of vehicles and boats moving through floodwaters);
- effects of climate change; and
- the cumulative effect of infill development.

At Branxton, the most significant of these factors are the uncertainties in design flood level estimates, wave action, and possibly climate change. This flood level review has particularly highlighted the uncertainties surrounding design flood level estimation, primarily as a result of the estimates being based on at-site flood frequency analysis from Singleton and Maitland. Both of these sites are a significant distance away and have uncertain rating curves for overbank flow.

Historical flood levels at Branxton also exhibit a relatively wide range, with the estimated February 1955 peak level being almost 5 m higher than the June 2007 flood level, compared to a 0.4 m difference at Dunolly Bridge (Singleton) and a 1.4 m difference at Belmore Bridge (Maitland). In light of this large range and relative uncertainty, it is reasonable to adopt a higher freeboard than the 0.5 m typically used for residential development (Floodplain Development Manual, 2005).

There are unlikely to be significant localised gradients in flood levels, due to backwater flooding from the Hunter River being the dominant flood mechanism. Flows in Black Creek or Anvil Creek are likely to have a flood gradient, but the flood levels will generally be lower than the Hunter River flood level for an equivalent flood probability, particularly for major floods (e.g. the 1% AEP). Cumulative infill development is unlikely to cause major changes to flood levels due to the relatively large amount of rural floodplain storage around Branxton.

It is therefore recommended that a 0.7 m freeboard be adopted (on top of the 1% AEP food level) for setting interim Flood Planning Levels for residential development at Branxton. This level of freeboard gives a Flood Planning Level of 34.2 mAHD (33.5 mAHD + 0.7 m), which is equivalent to the February 1955 major flood of record.

Re-evaluation of the interim Flood Planning Levels should be undertaken as part of a Floodplain Risk Management Study for Branxton, including consideration of appropriate Flood Planning Levels for commercial development (possibly based on smaller floods than the 1% AEP event). The Floodplain Risk Management Study should be the process by which the definitive Flood Planning Levels for the area are set.

5.3. Huntlee Urban Release Area

The Huntlee Urban Release Area is located south of Branxton on the opposite side of the Hunter Expressway. The major urban release zone, with an area of 17.3 km^2, is planned to eventually support a population of approximately 30,000. The Huntlee site straddles the border of the Singleton and Cessnock Local Government Areas.

Black Creek runs alongside and through the Huntlee site, bisecting the western part of the site within the Singleton LGA, and forming the north-western boundary of the site until the Main North Railway Line crossing. The Huntlee site is therefore affected by backwater flooding from the Hunter River in Black Creek.

LiDAR aerial survey data were available for the Branxton area as part of the 2010 Flood Study (Reference 1). However aerial survey for the Huntlee site was not available at the time, and mapping of this area could not previously be completed. Cessnock City Council provided additional LiDAR survey covering the Huntlee area to WMAwater in June 2013. Mapping of various flood level extents has therefore been undertaken as part of this review report to identify the Flood Planning Area extent within the Huntlee site using the recommended Flood Planning Level.

Figure 18 and Figure 19 show ground level contours for the Branxton and Huntlee areas using available LiDAR information. Figure 20 and Figure 21 show the extent of inundation from Hunter River backwater at various flood levels, including the recommended interim Flood Planning Level of 34.2 mAHD.

It can be observed on Figure 20 and Figure 21 that an increase of flood level from 33.5 mAHD to 34.8 mAHD (the difference between the SMEC and WMAwater modelling estimates) generally results in only a slight change to inundation extent.

6. CONCLUSIONS

On the basis of this review, it is recommended that:

1. The alternative “Calibration 2” model parameters (SMEC, 2011) should be adopted for setting Hunter River design flood levels within the Cessnock City LGA (see Figure 16). The adjusted 1% AEP design flood level at Branxton is 33.5 mAHD. This recommendation is consistent with the findings of the review by BMT WBM (Reference 7).
2. The design flood levels for Maitland LGA should not be adjusted, and should remain as determined in the Hunter River Flood Study (WMAwater, 2010).
3. Flood Planning Levels for development should be determined as part of a Floodplain Risk Management Study at Branxton including consideration of appropriate Flood Planning Levels for commercial development (possibly based on smaller floods than the 1% AEP event or a merits-based approach).
4. Until the Floodplain Risk Management Study at Branxton is undertaken, a freeboard of 0.7 m above the 1% AEP flood level should be adopted for residential development at Branxton, giving an **Interim Flood Planning Level** equivalent to the recorded February 1955 peak flood level of **34.2 mAHD**.
5. Following the next major flood on the Hunter River it is imperative that extensive flood data is collected as soon after the event as possible. A re-evaluation of the TUFLOW model calibration should then be undertaken.

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10. Paterson Consultants

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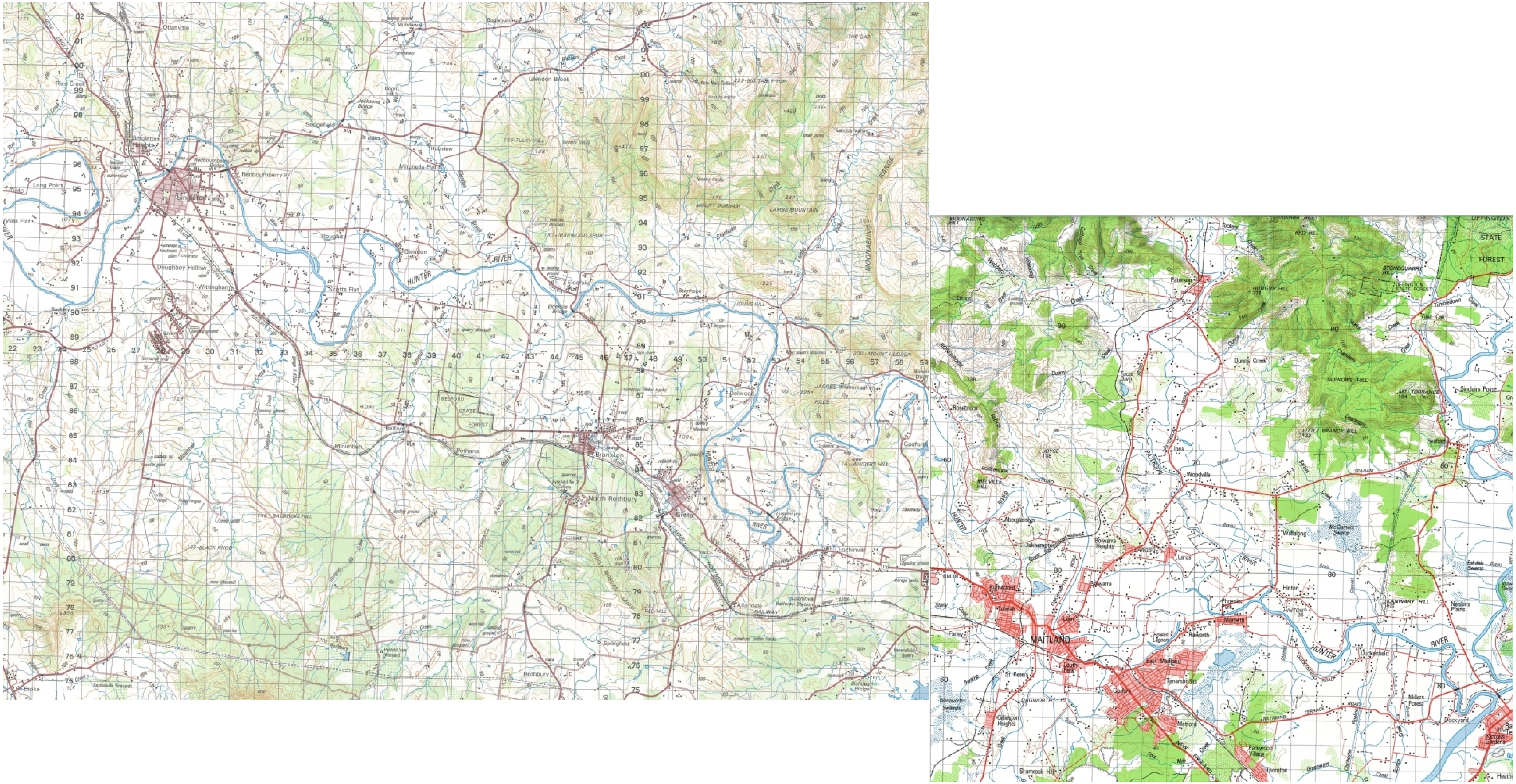
11. Water Resources Commission

Town of Branxton – Inundation Map of the February 1955 Flood
OEH Reference D10086/Branxton/FF16039812

Figures

FIGURE 1

STUDY AREA



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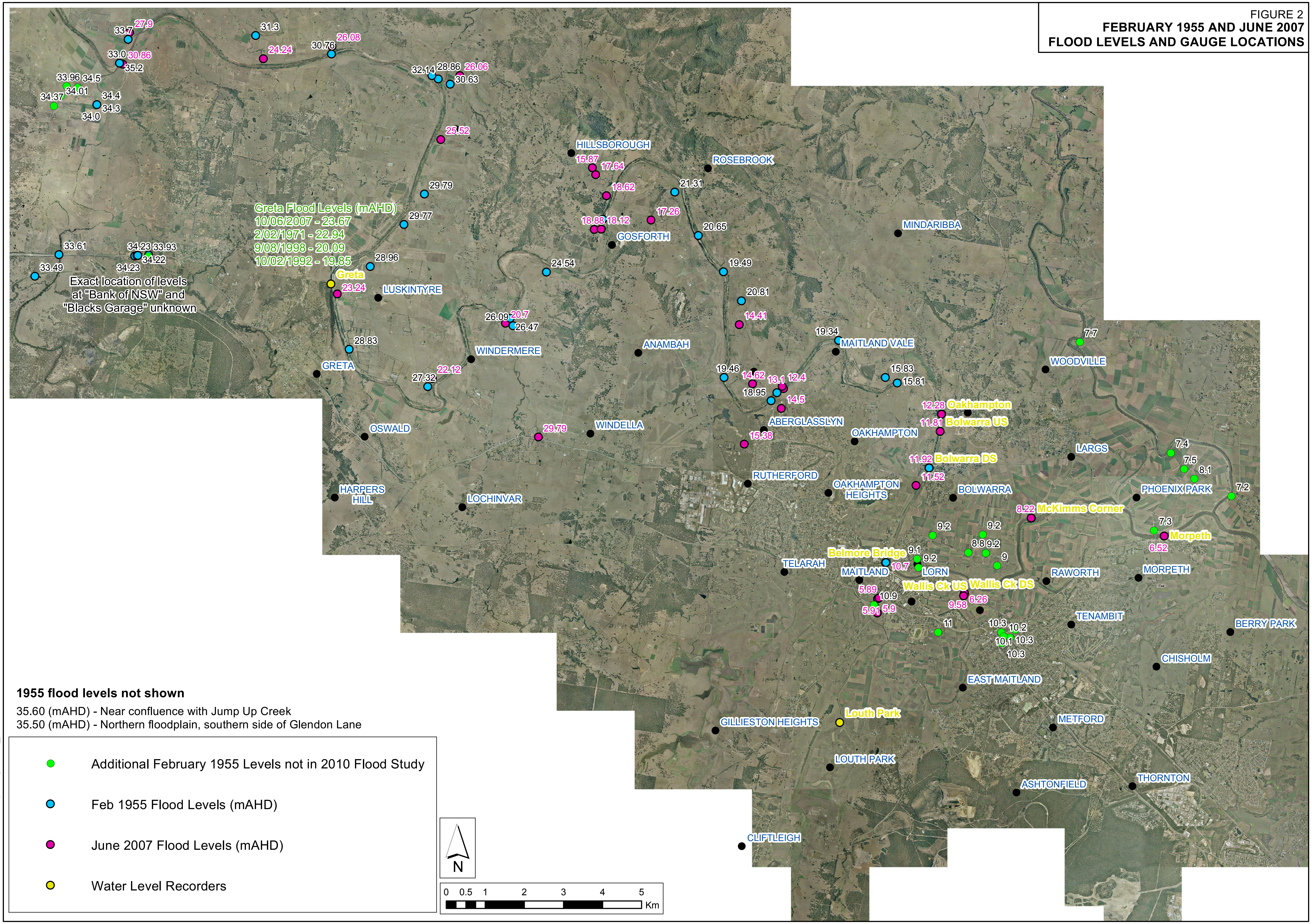

FIGURE 2
FEBRUARY 1955 AND JUNE 2007 FLOOD LEVELS AND GAUGE LOCATIONS

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FIGURE 3

STAGE HYDROGRAPHS AT SINGLETON WITH PEAKS ALIGNED

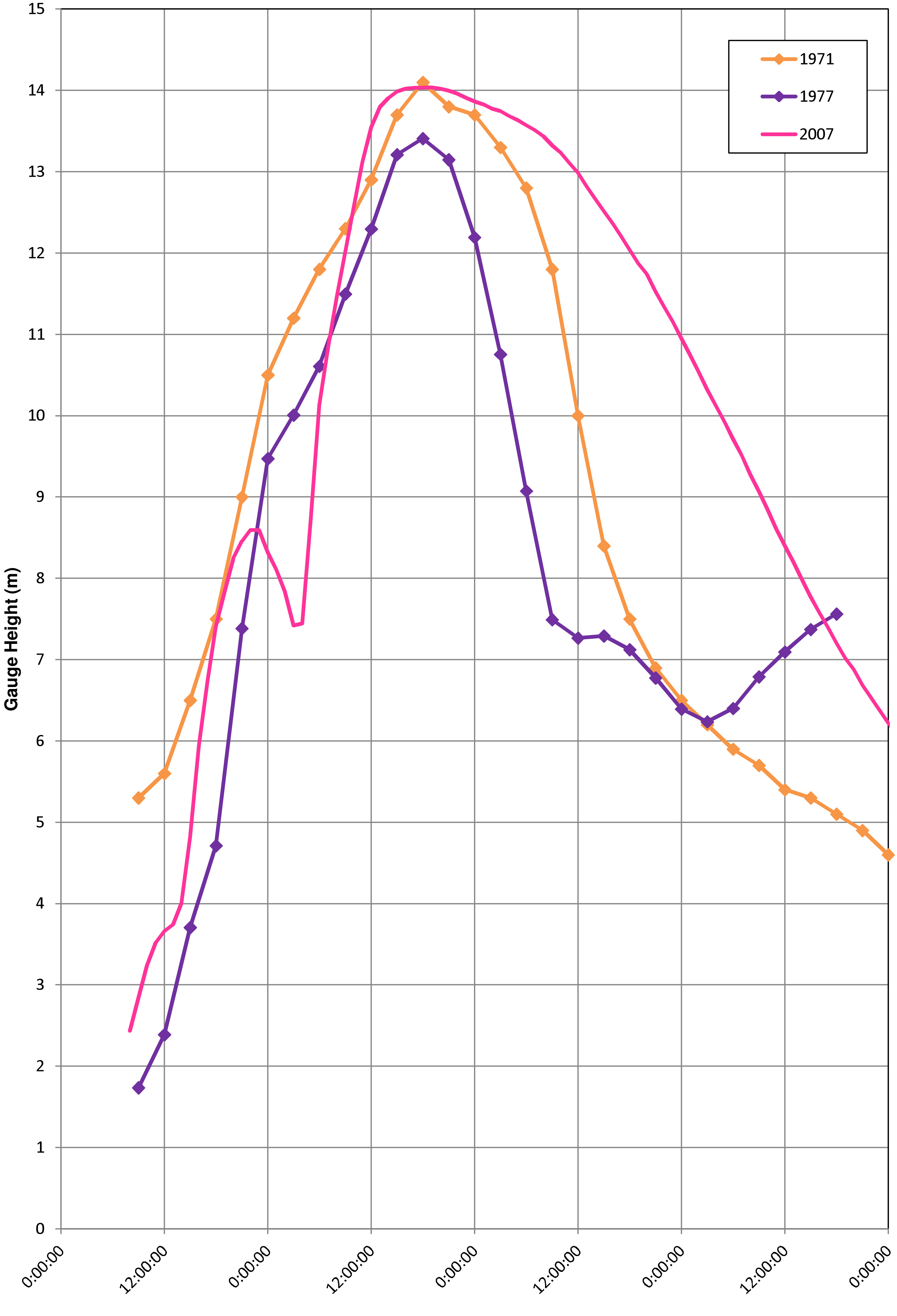


FIGURE 4
STAGE HYDROGRAPHS AT GRETA

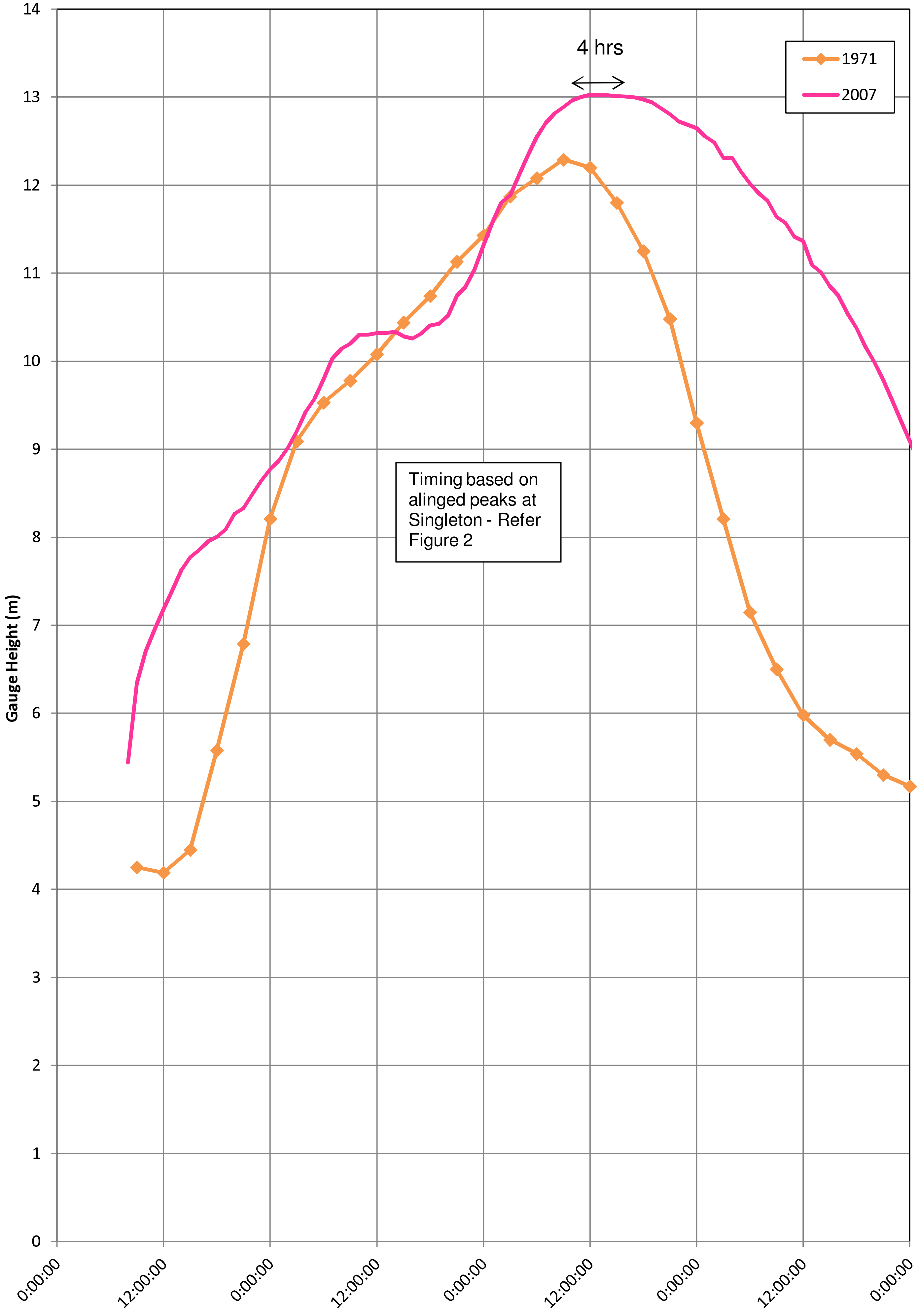


FIGURE 5
STAGE HYDROGRAPHS AT MAITLAND

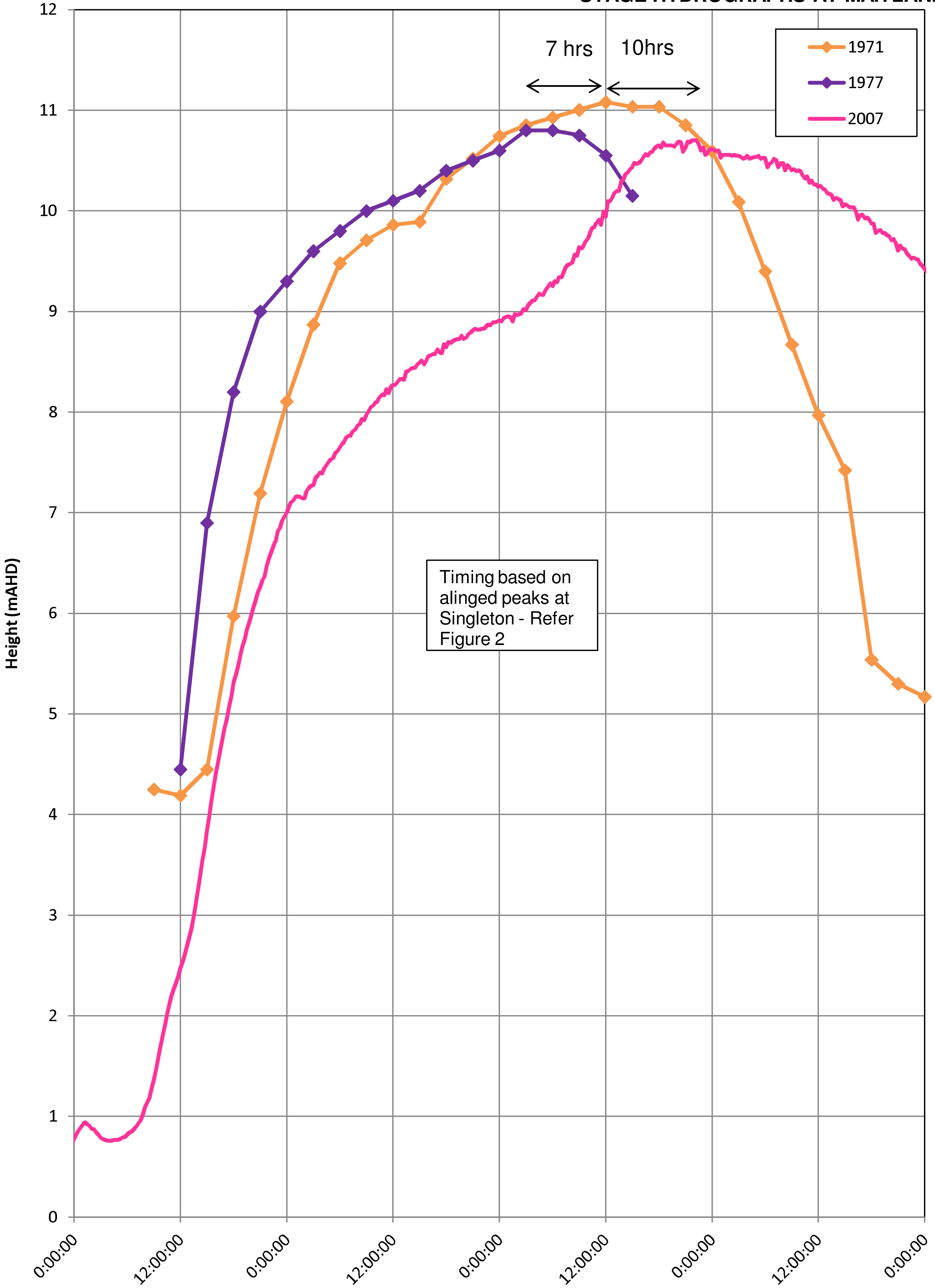
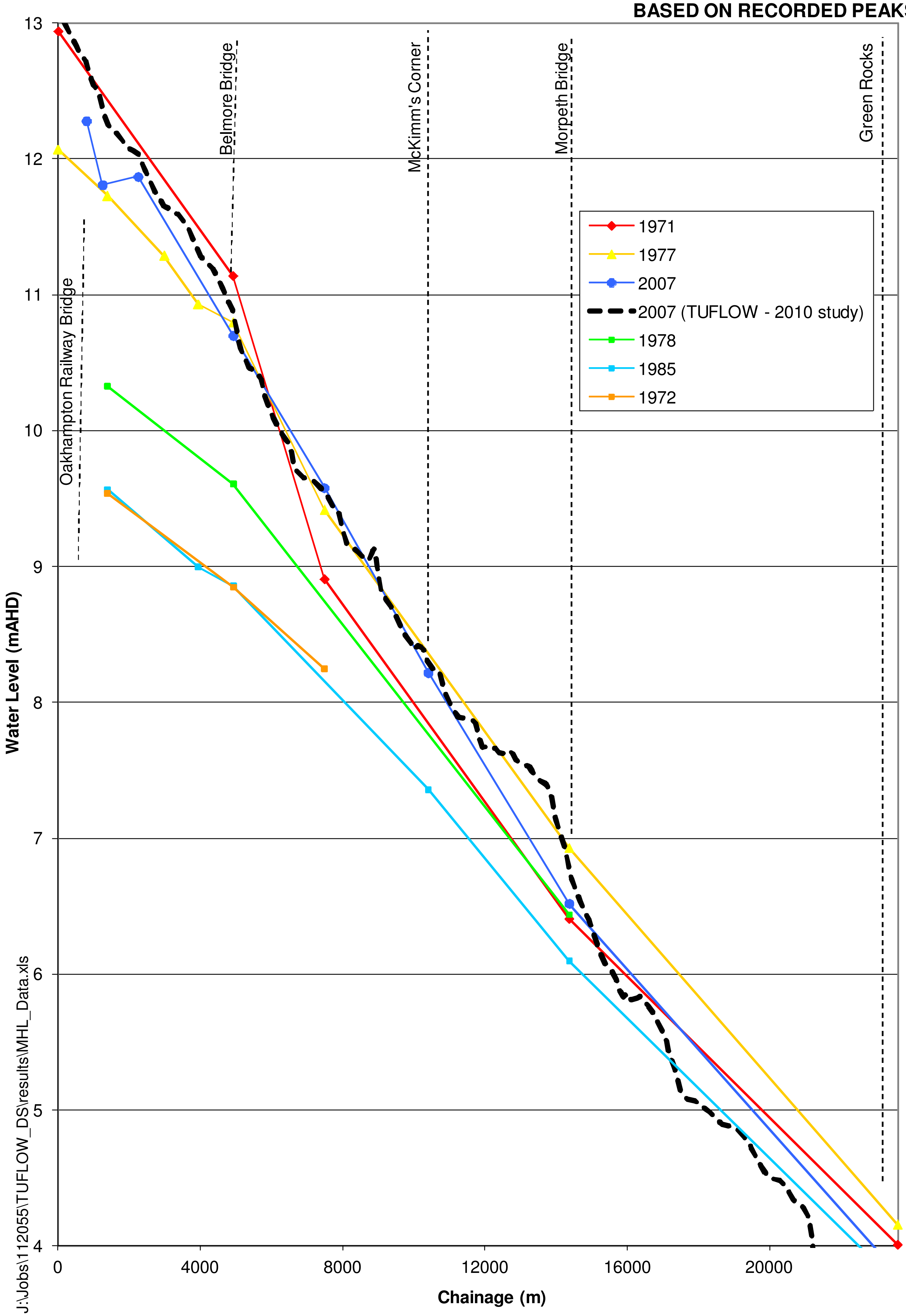


FIGURE 6

HISTORICAL PEAK FLOOD LEVEL PROFILES BASED ON RECORDED PEAKS



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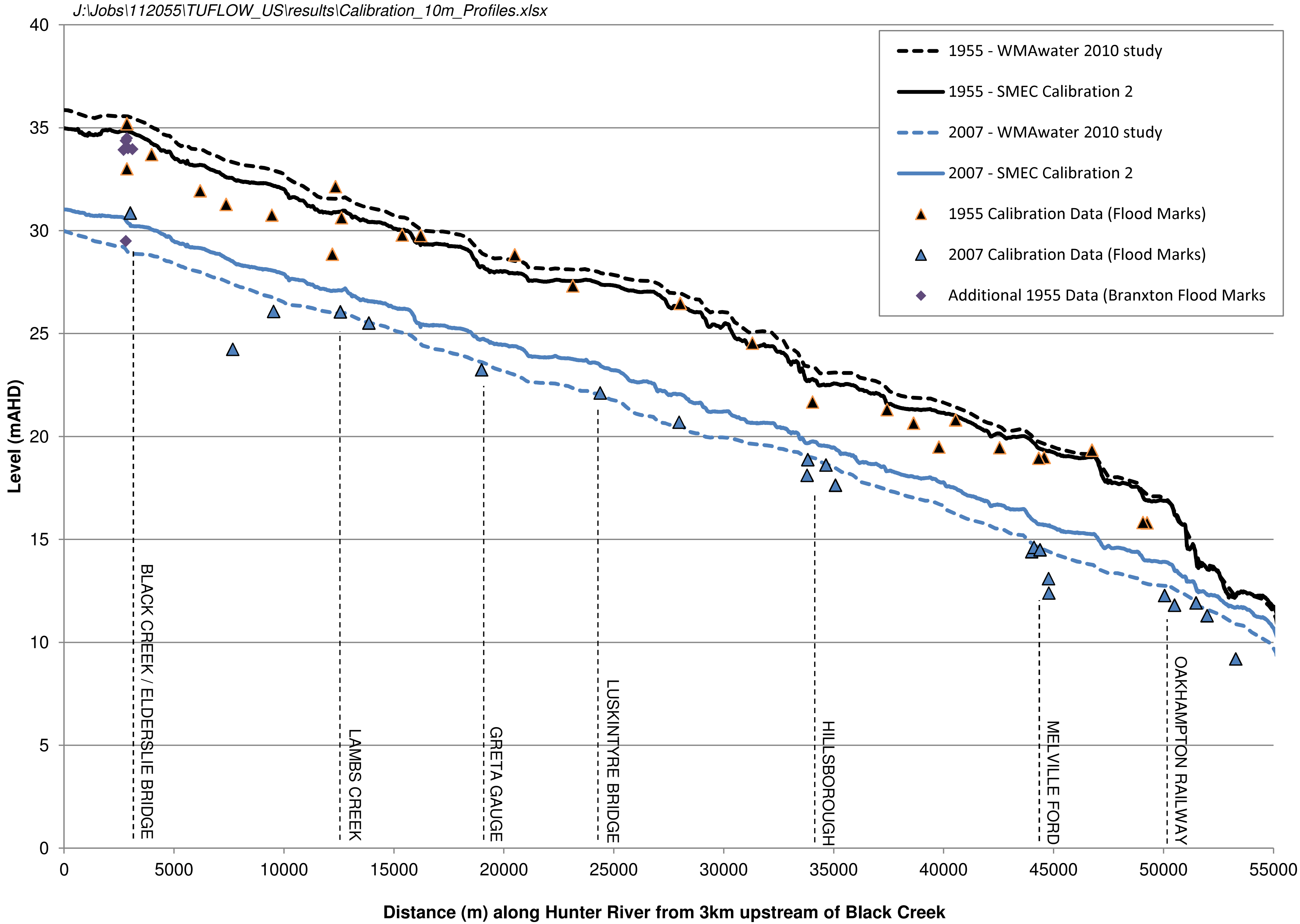

FIGURE 7
HISTORICAL PEAK LEVEL PROFILE CALIBRATION
UPSTREAM OF OAKHAMPTON

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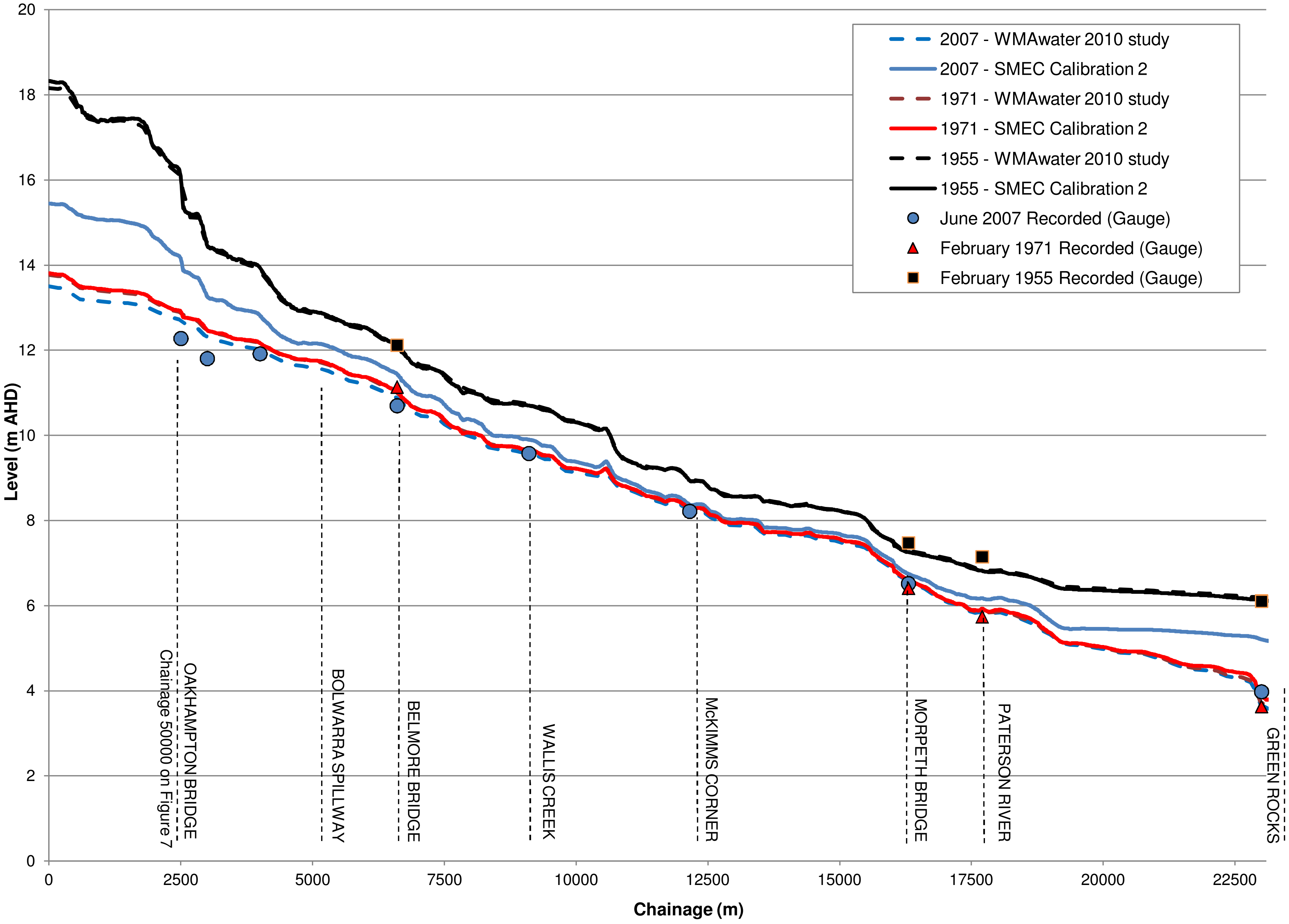
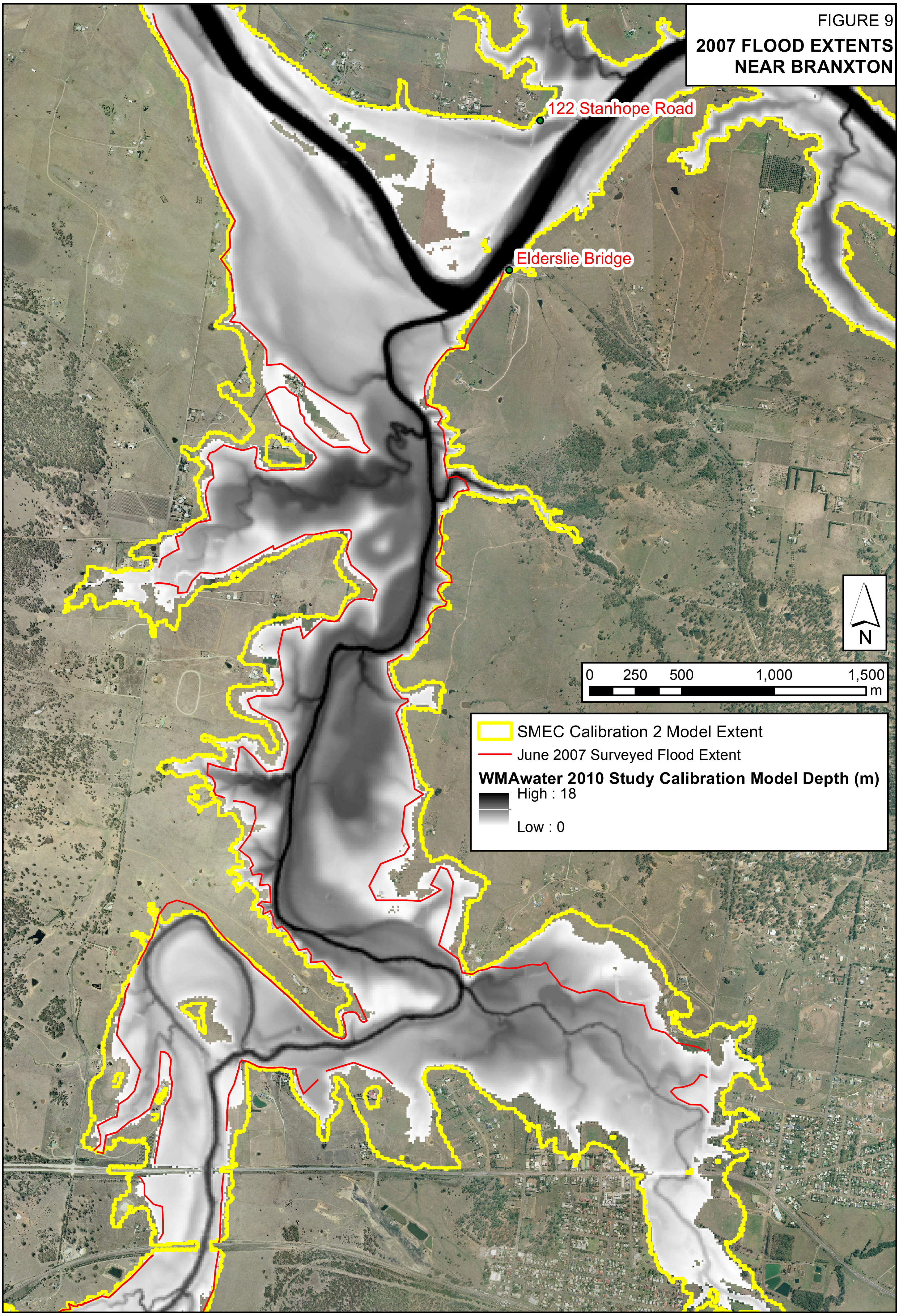


FIGURE 8
HISTORICAL PEAK LEVEL PROFILE CALIBRATION DOWNSTREAM OF OAKHAMPTON



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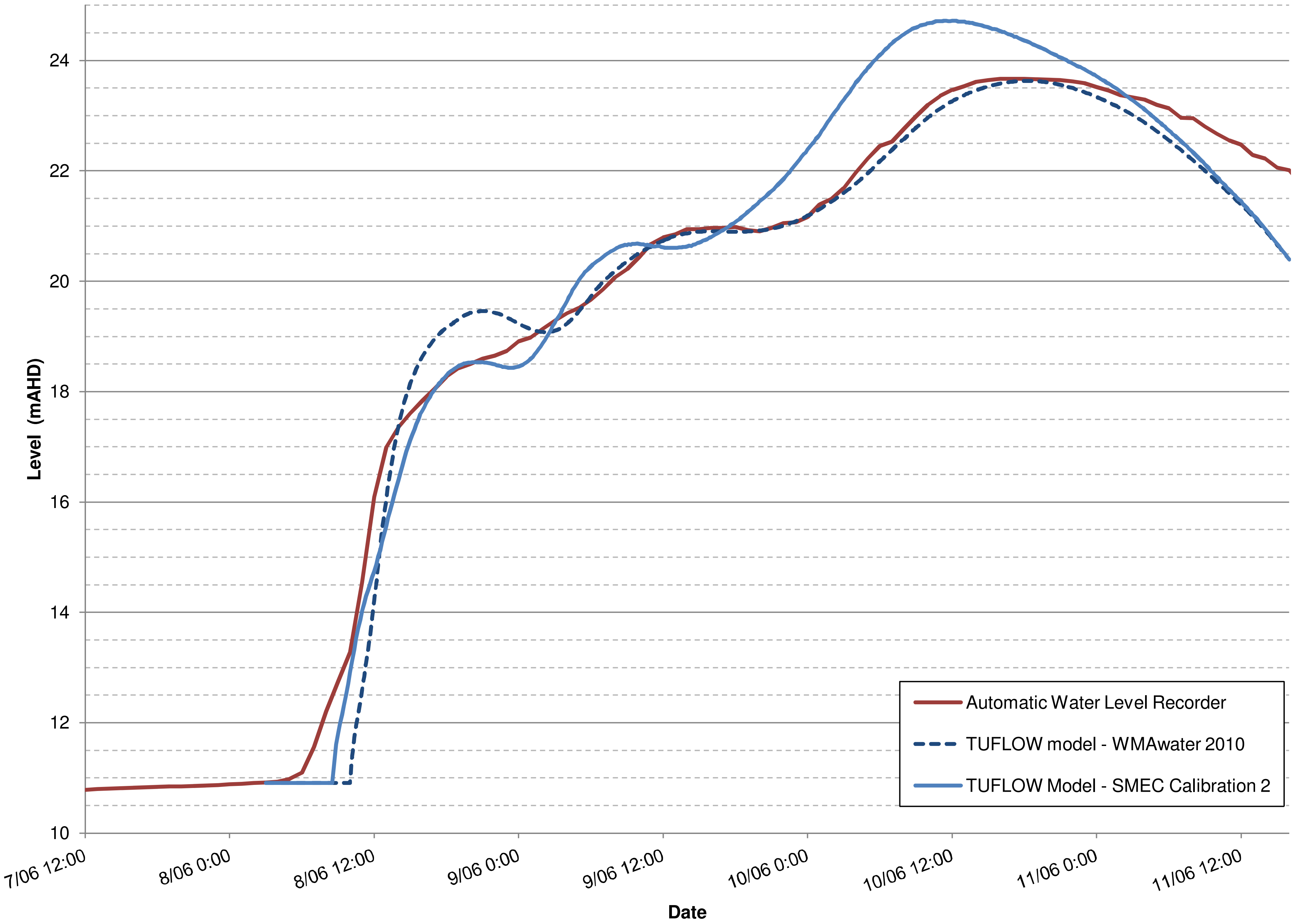

FIGURE 10
STAGE HYDROGRAPHS
JUNE 2007 EVENT
GRETA GAUGE

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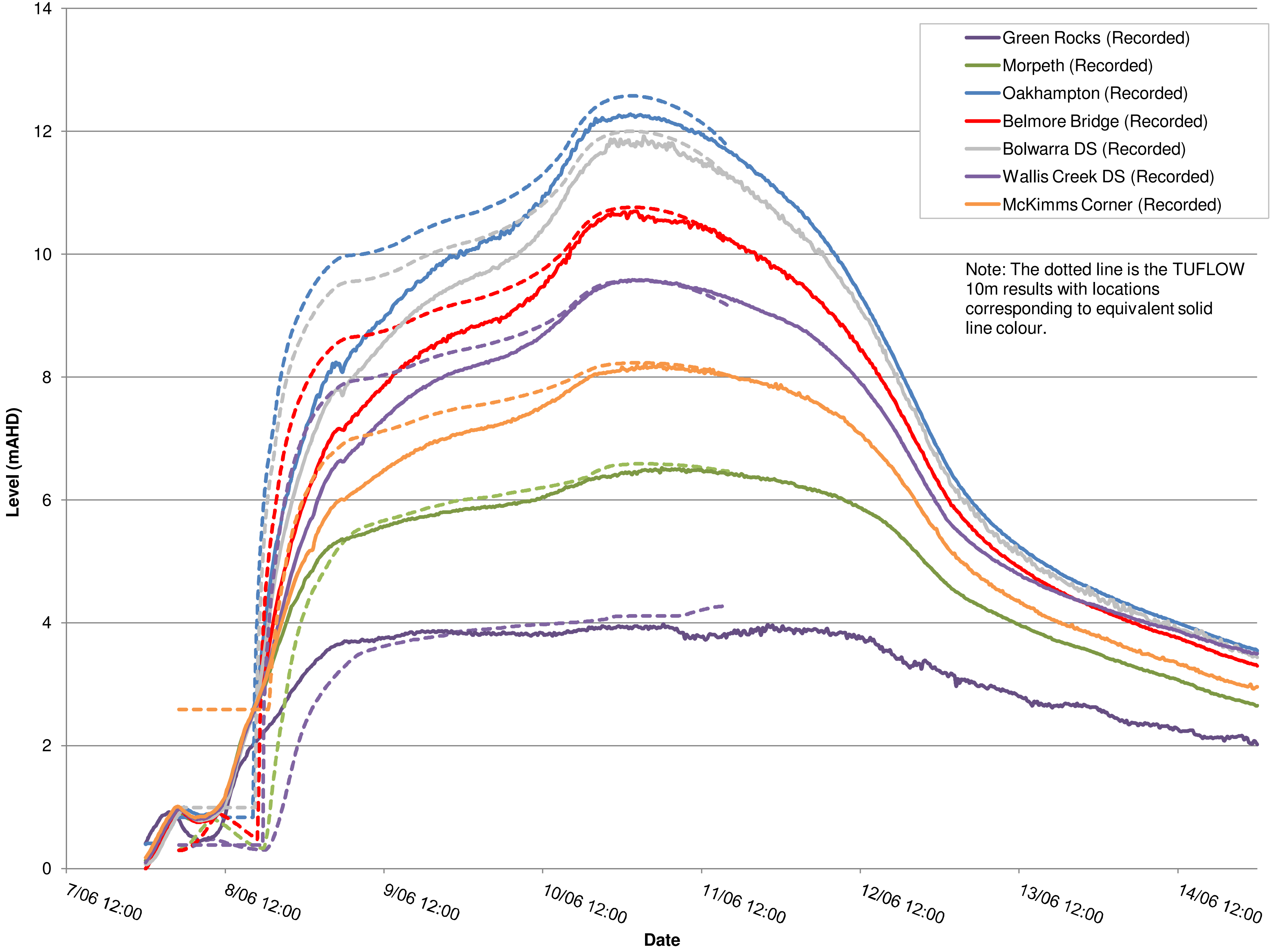

FIGURE 11a
HUNTER RIVER STAGE HYDROGRAPHS DOWNSTREAM OF OAKHAMPTON
WMAwater Calibration - JUNE 2007

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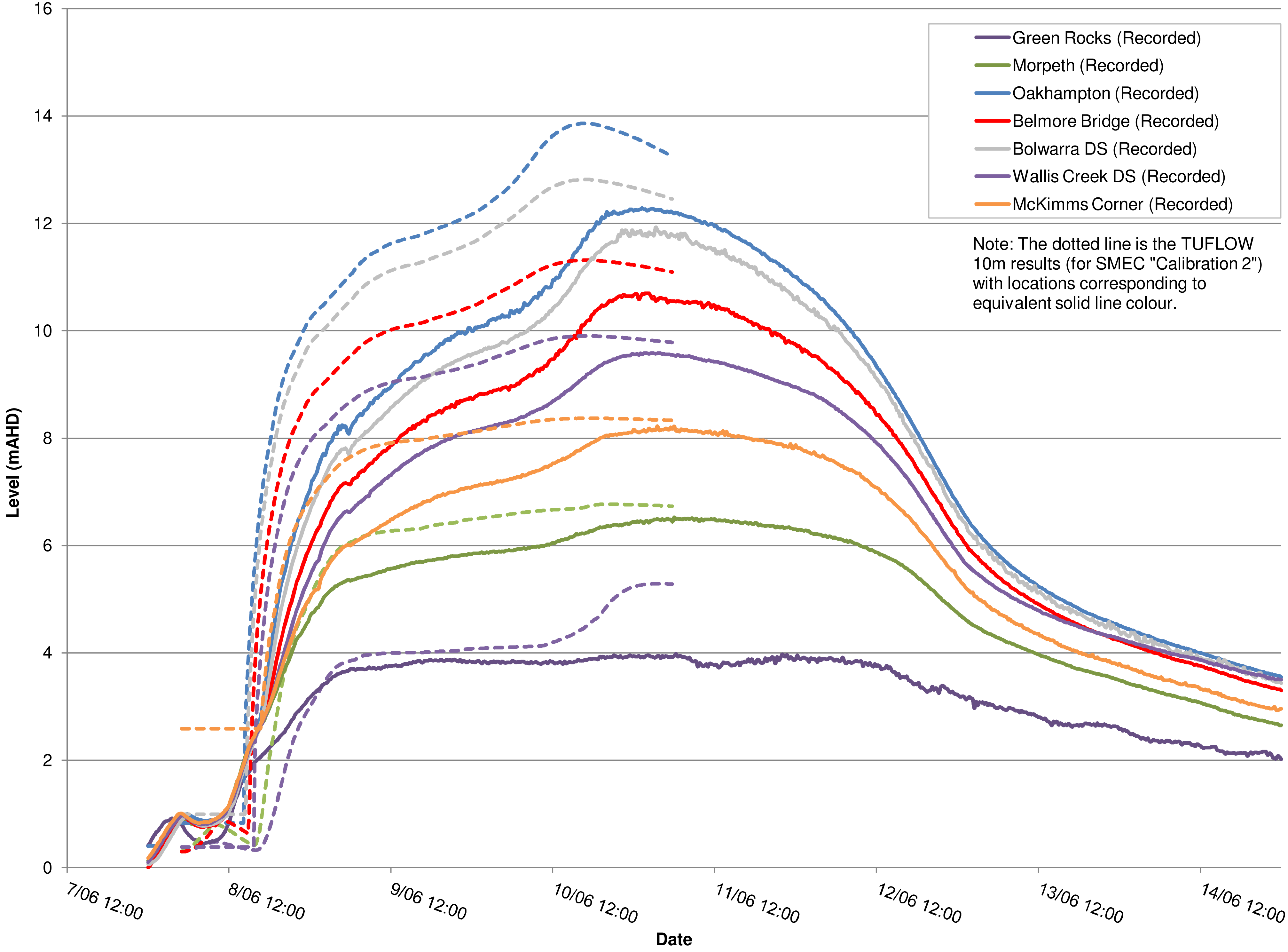

FIGURE 11b
HUNTER RIVER STAGE HYDROGRAPHS DOWNSTREAM OF OAKHAMPTON
SMEC Calibration 2 - JUNE 2007

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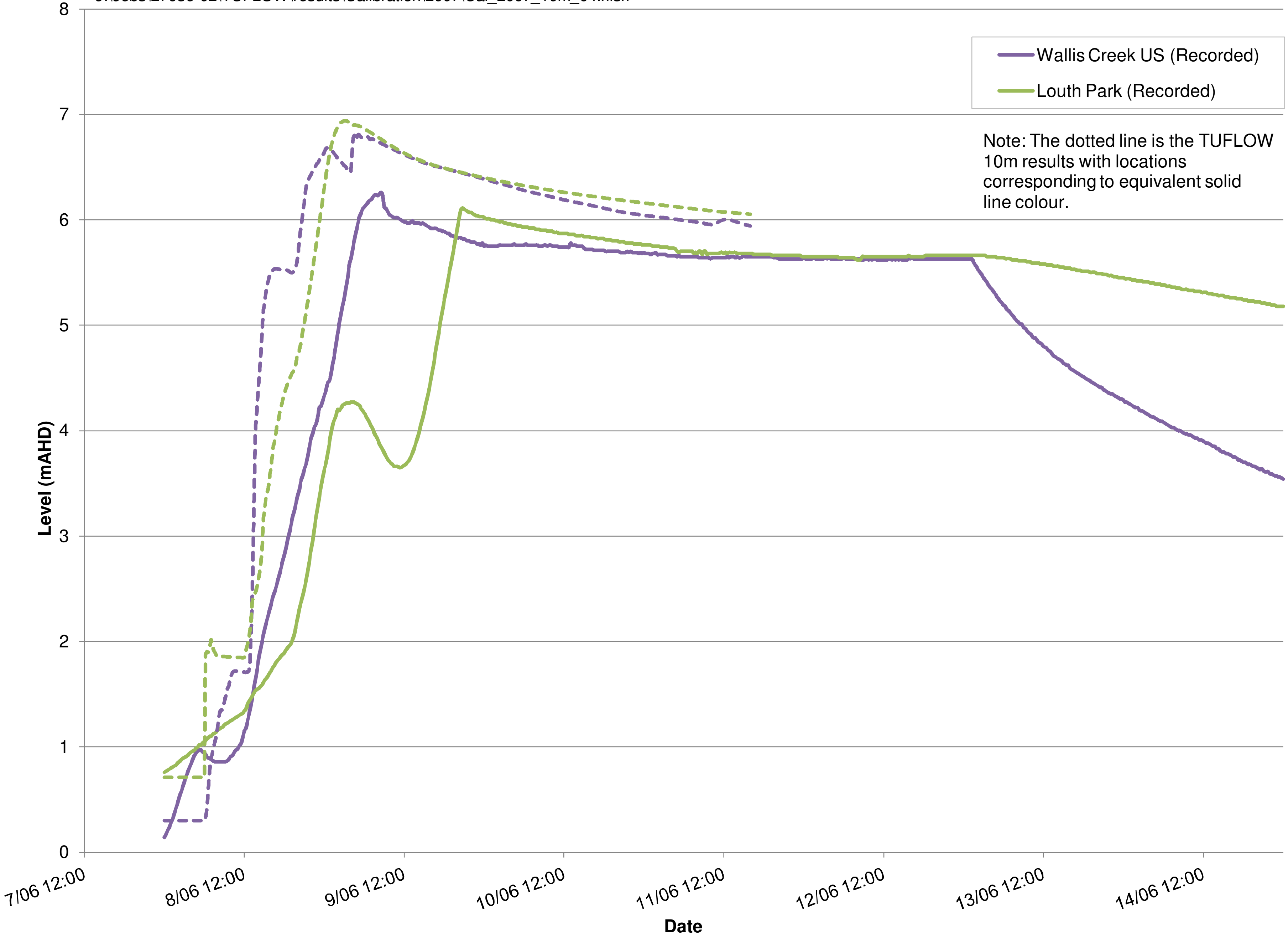


FIGURE 12a
FLOODPLAIN STAGE HYDROGRAPHS DOWNSTREAM OF OAKHAMPTON
WMAwater Calibration - JUNE 2007

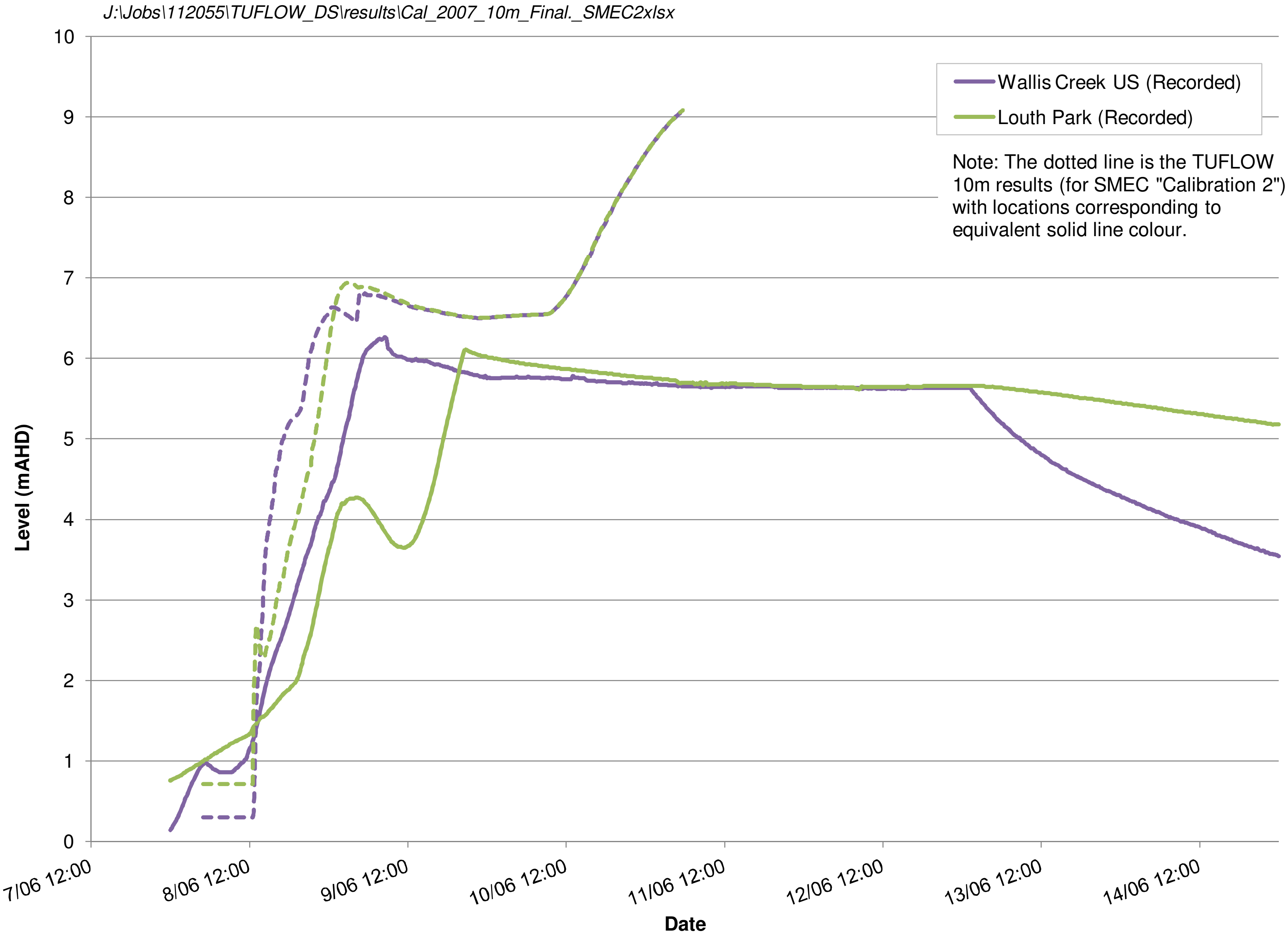


FIGURE 12b

FLOODPLAIN STAGE HYDROGRAPHS DOWNSTREAM OF OAKHAMPTON
SMEC Calibration 2 - JUNE 2007

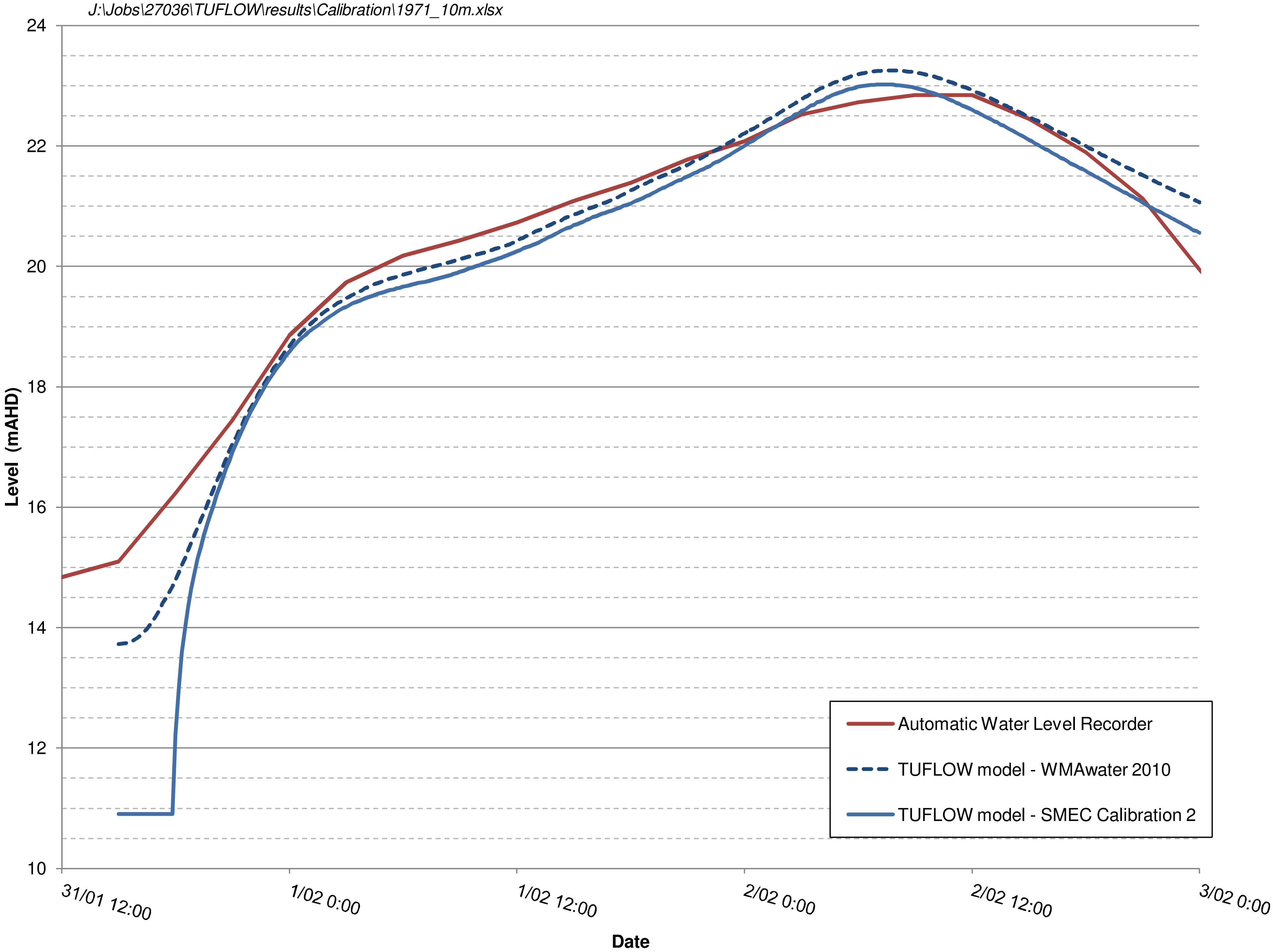


FIGURE 13
STAGE HYDROGRAPHS
FEBRUARY 1971 EVENT
GRETA GAUGE

FIGURE 14a
HUNTER RIVER STAGE HYDROGRAPHS DOWNSTREAM OF OAKHAMPTON
WMAwater Calibration - FEBRUARY 1971

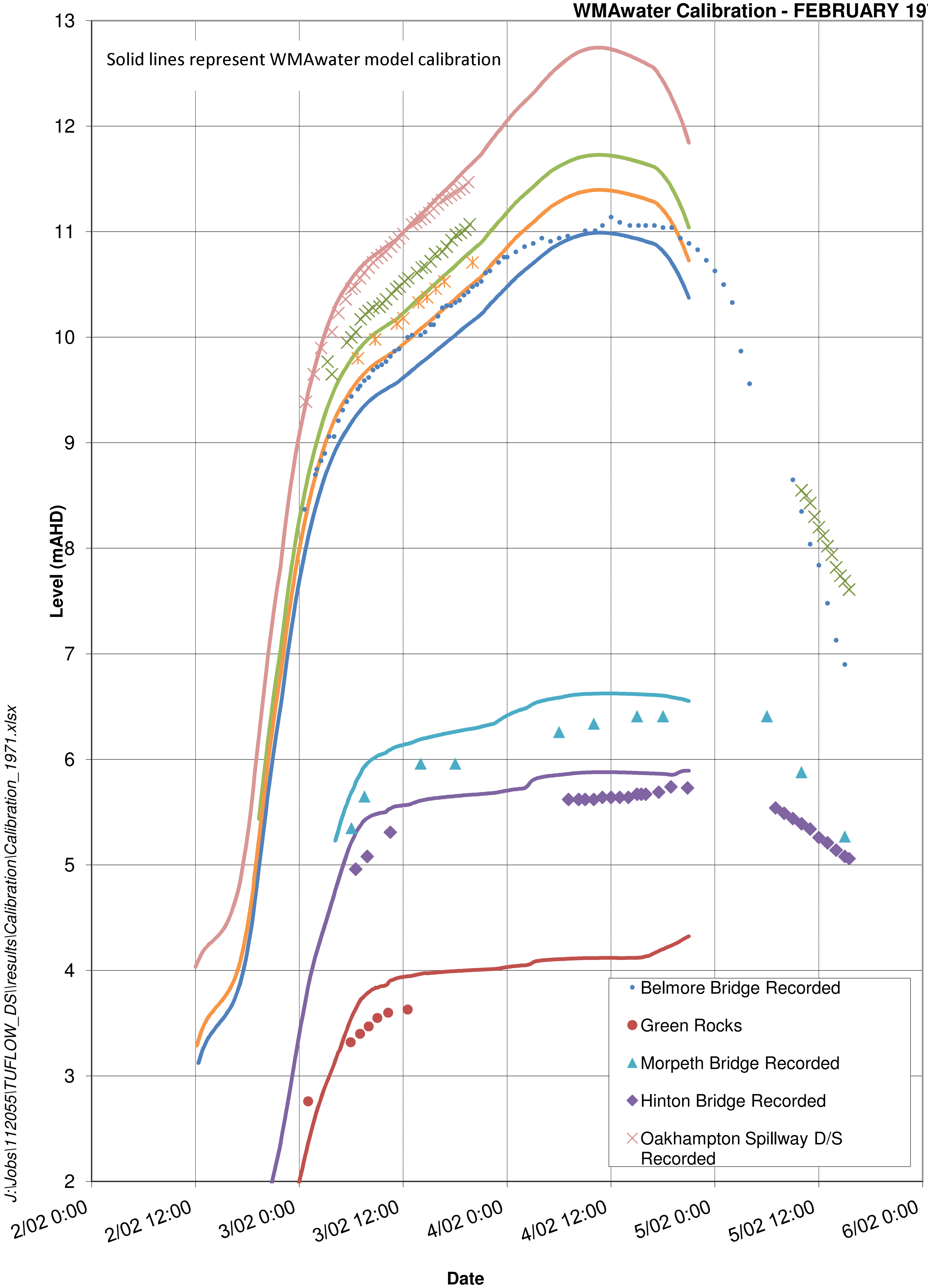


FIGURE 14b
HUNTER RIVER STAGE HYDROGRAPHS
DOWNSTREAM OF OAKHAMPTON
SMEC Calibration 2 - FEBRUARY 1971

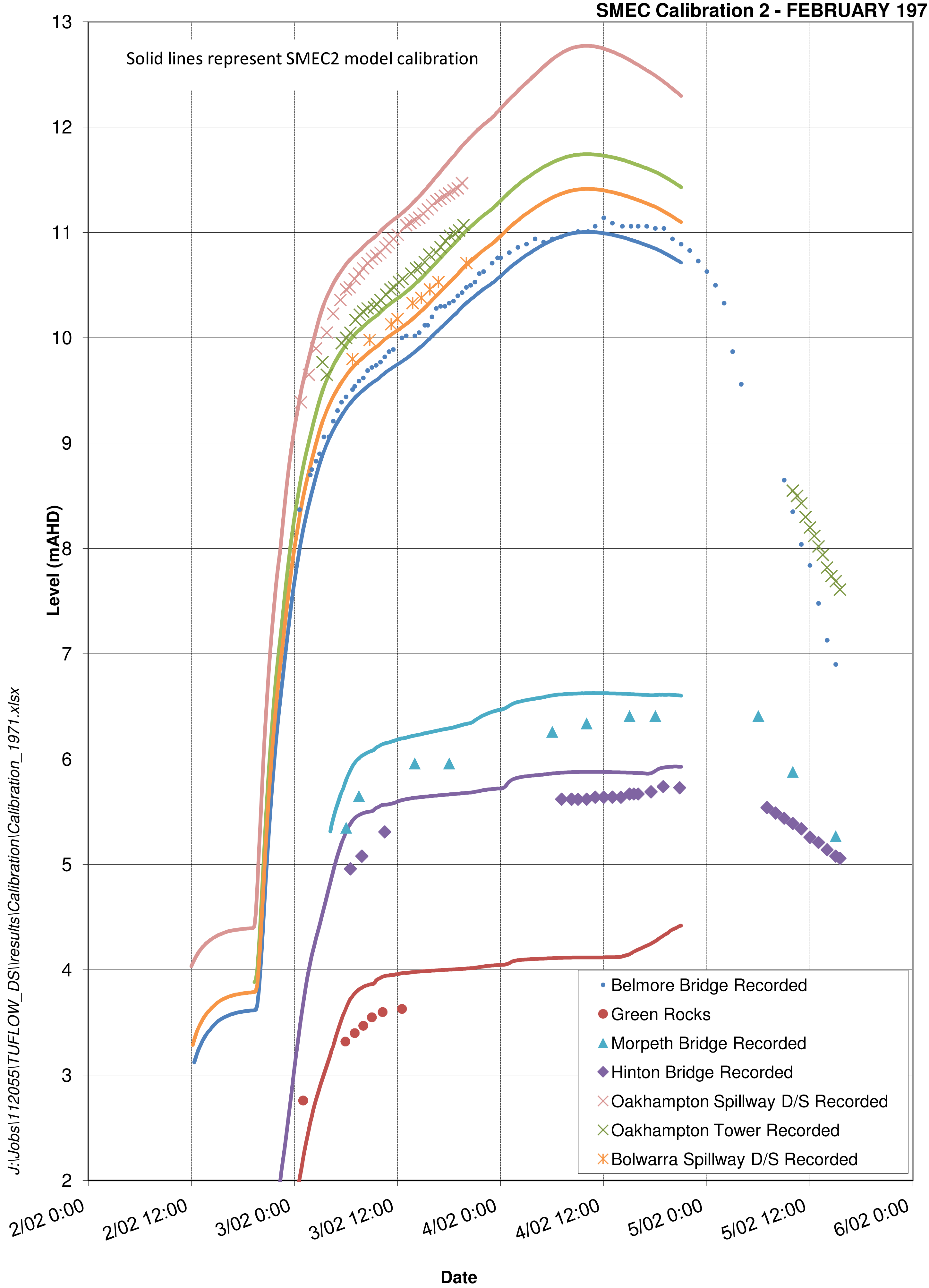


FIGURE 15a
HUNTER RIVER STAGE HYDROGRAPHS
DOWNSTREAM OF OAKHAMPTON
WMAwater Calibration - FEBRUARY 1955

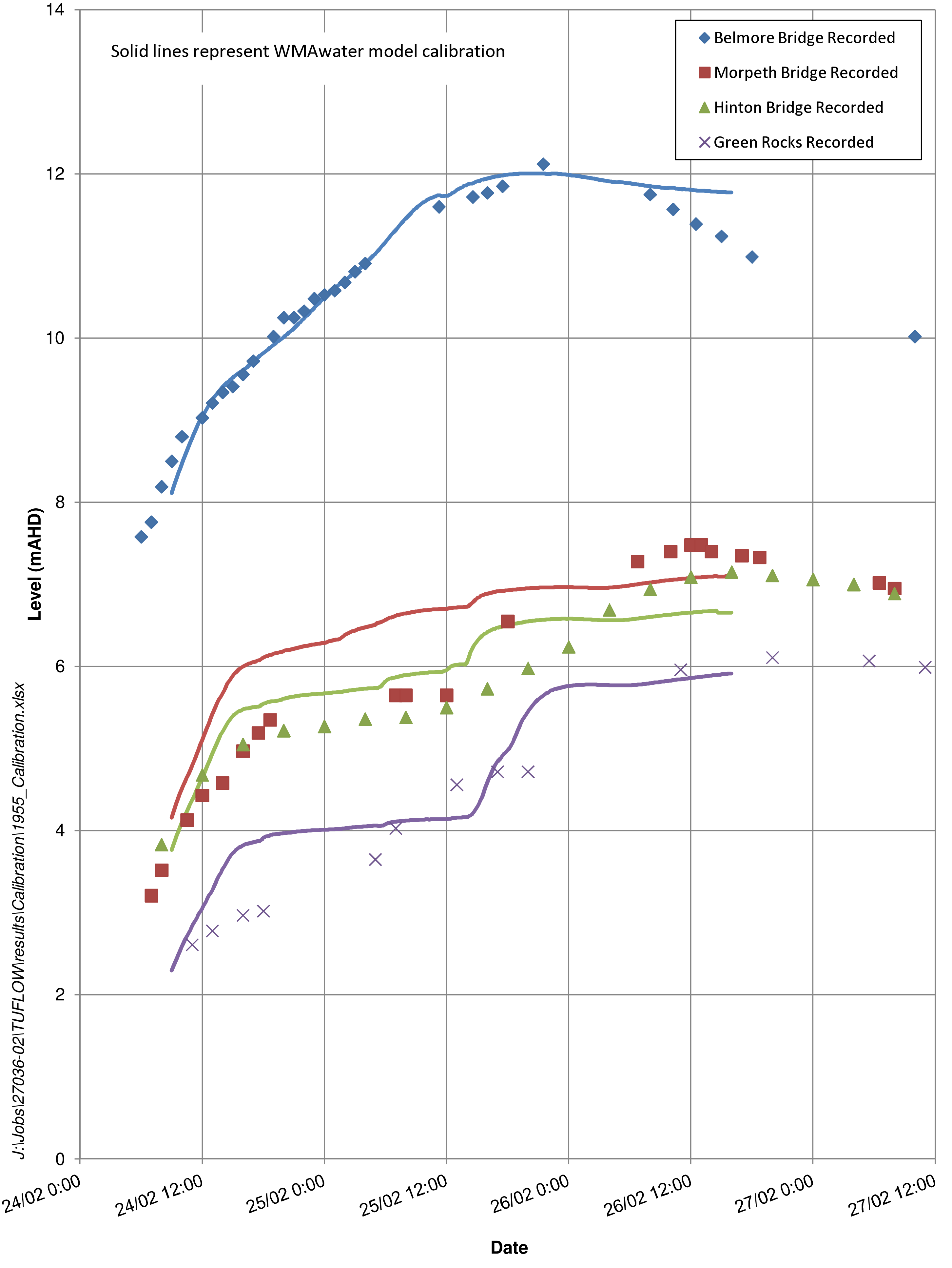
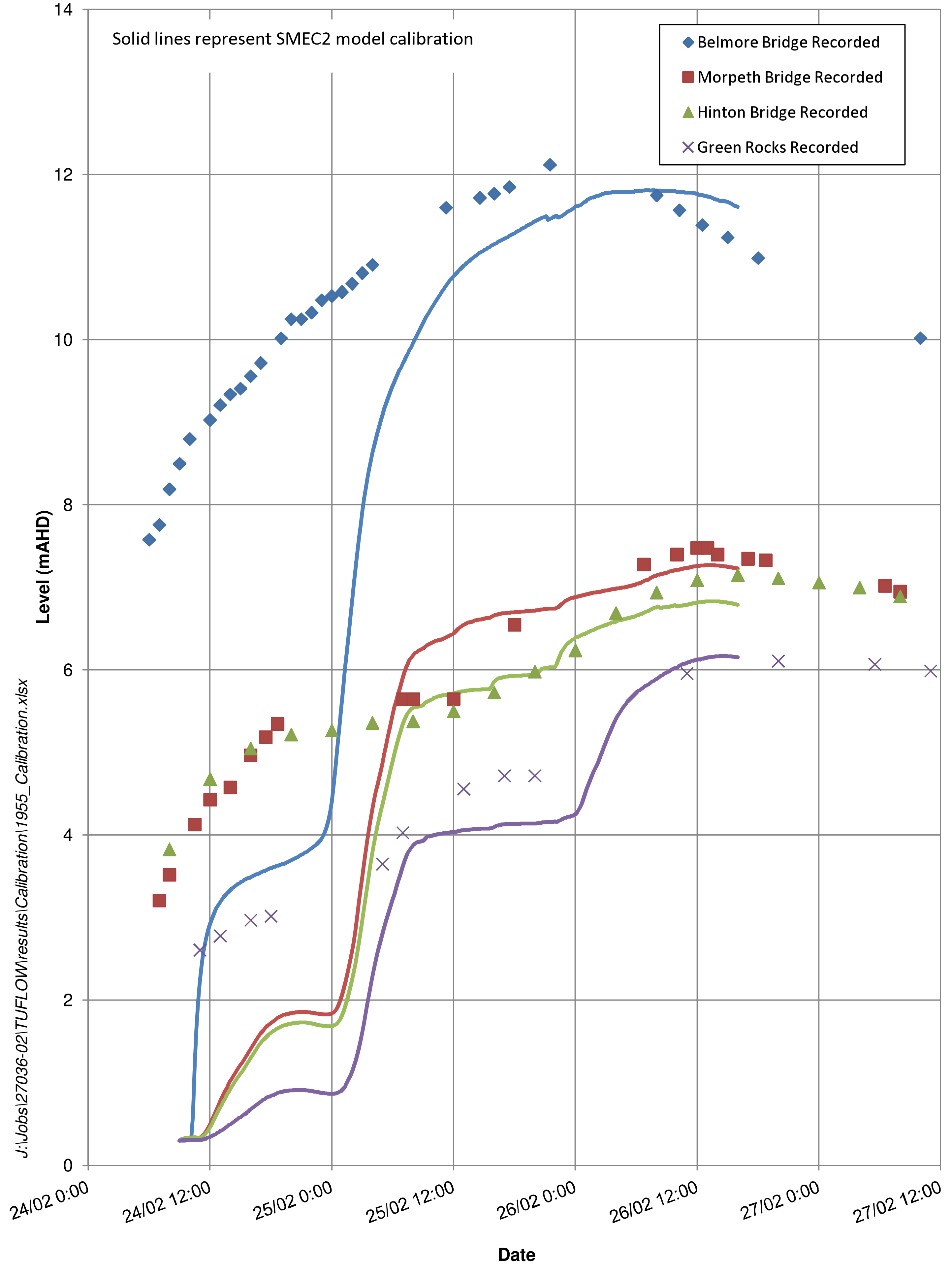


FIGURE 15b
HUNTER RIVER STAGE HYDROGRAPHS DOWNSTREAM OF OAKHAMPTON SMEC Calibration 2 - FEBRUARY 1955



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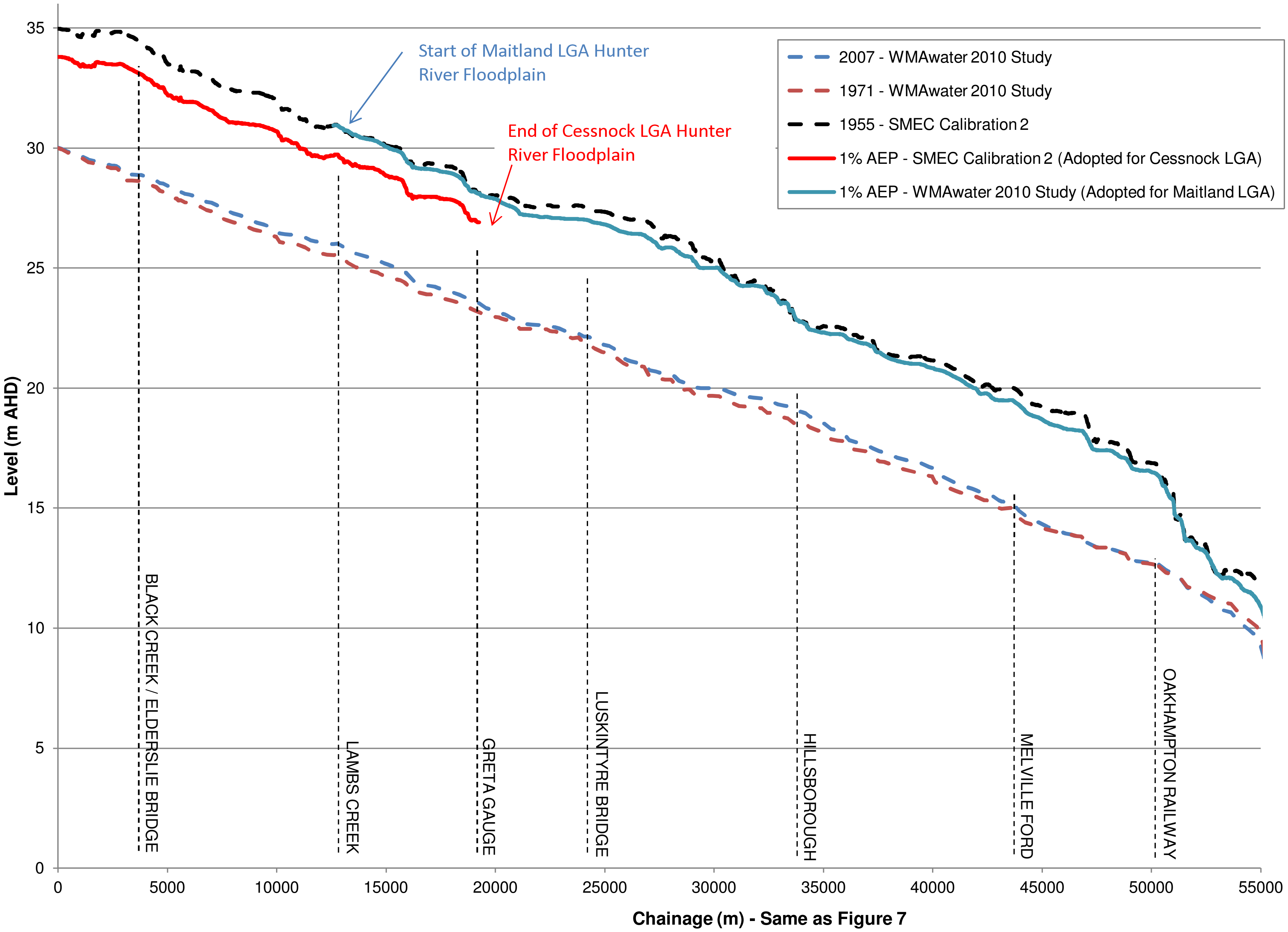

FIGURE 16
REVISED 1% AEP DESIGN PEAK LEVEL PROFILE UPSTREAM OF OAKHAMPTON

FIGURE 17

WATER RESOURCES COMMISSION
1955 FLOOD EXTENT PLAN

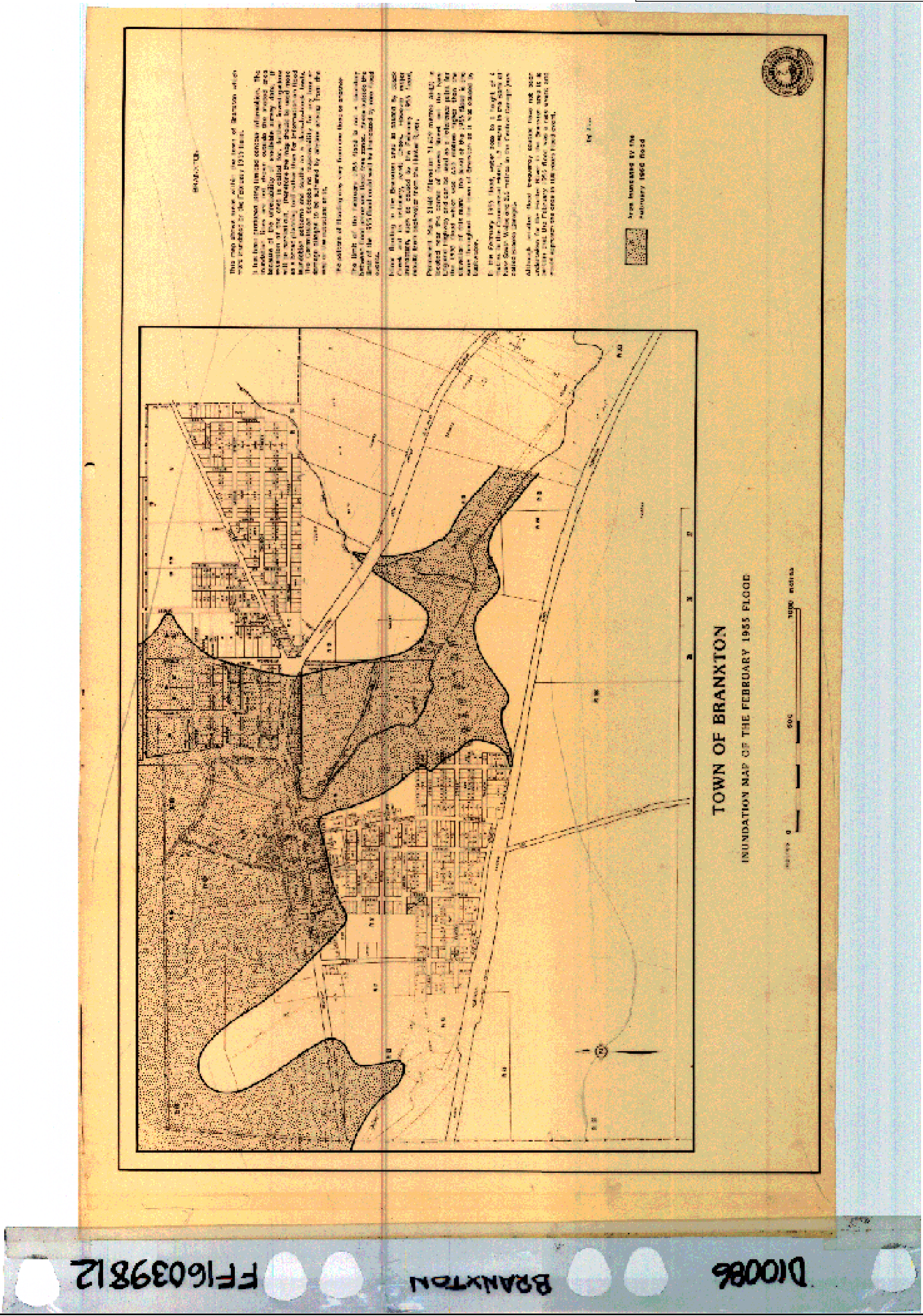

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FIGURE 18

BRANXTON

GROUND LEVEL CONTOURS

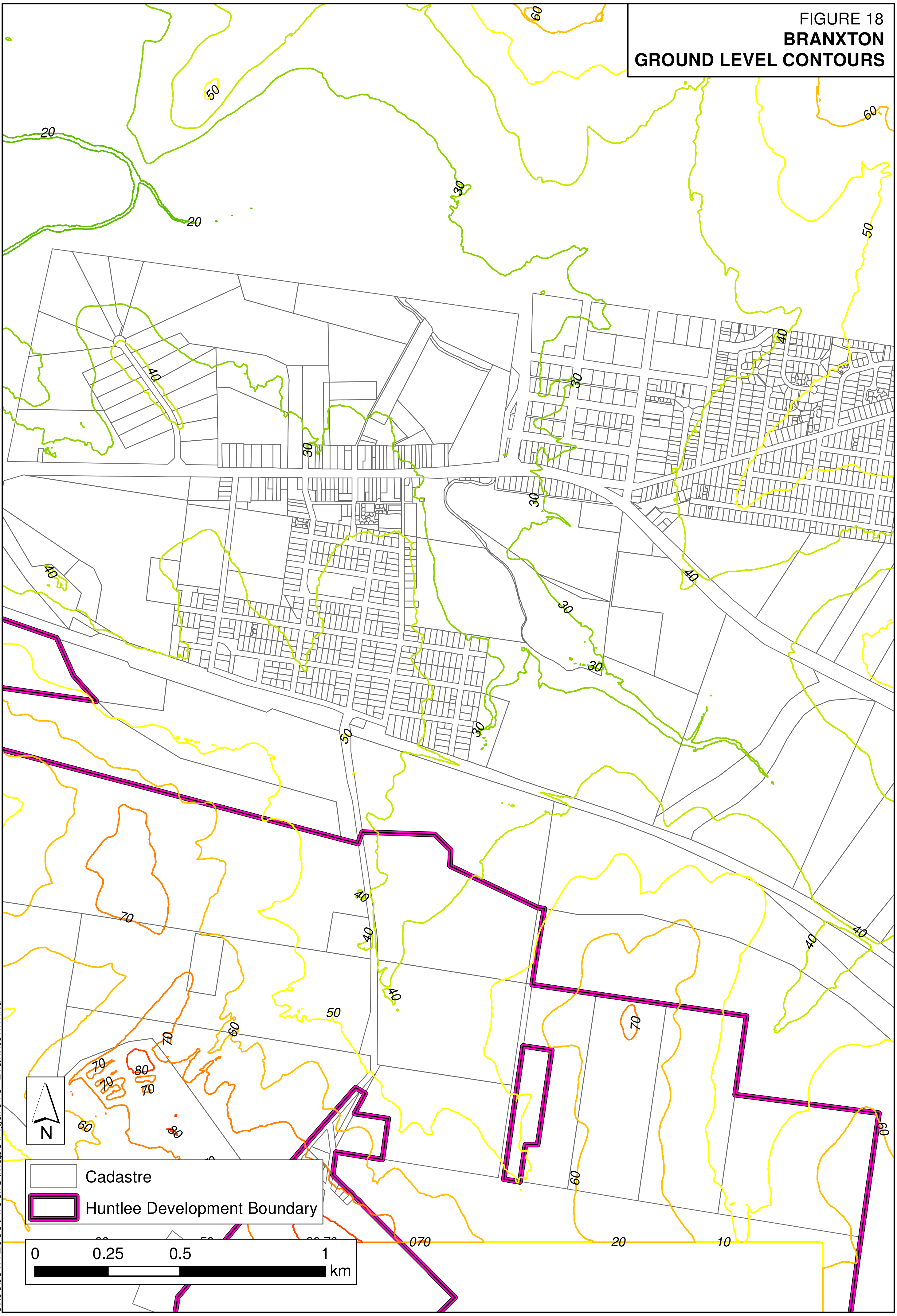
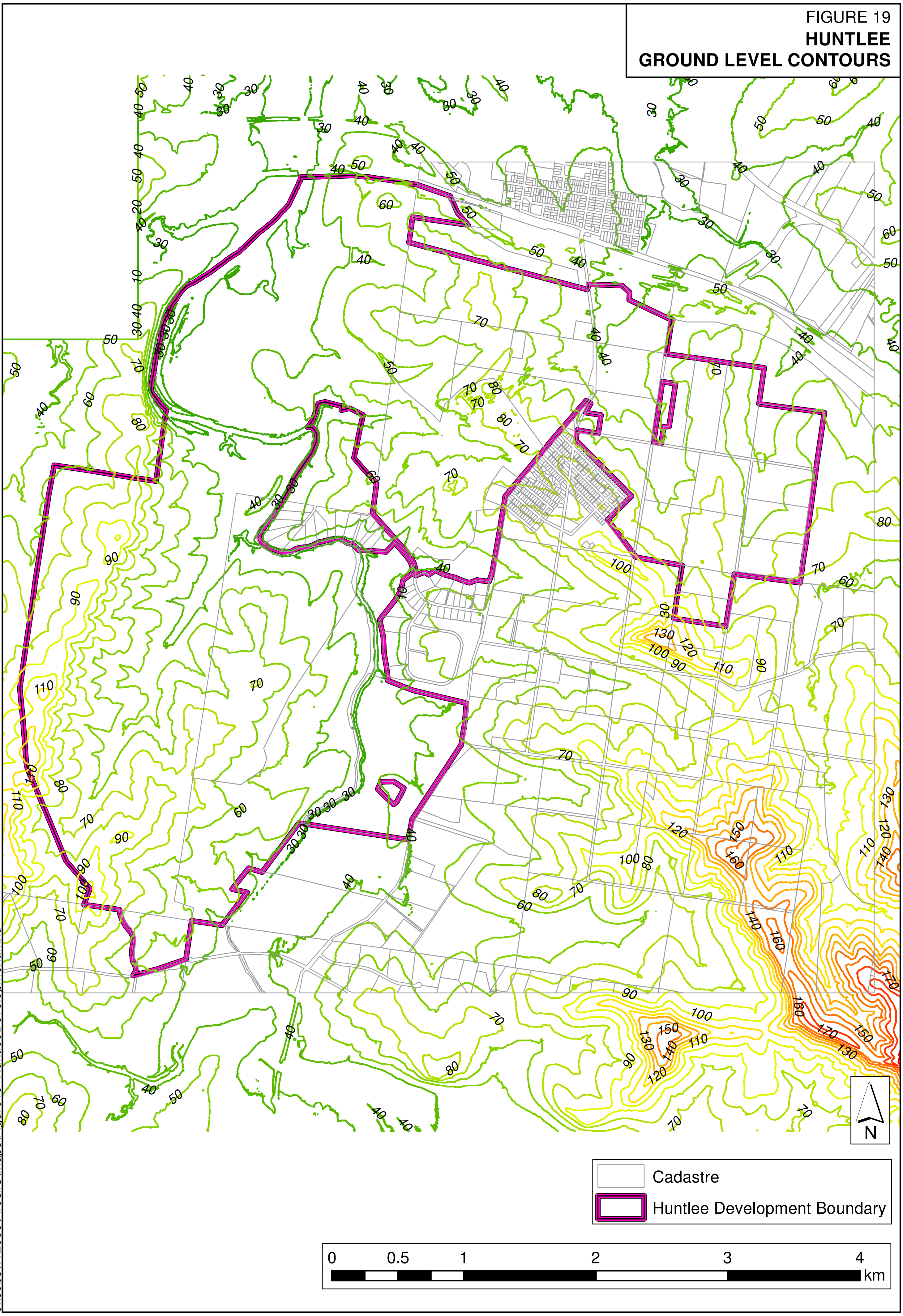


FIGURE 19
HUNTLEE
GROUND LEVEL CONTOURS



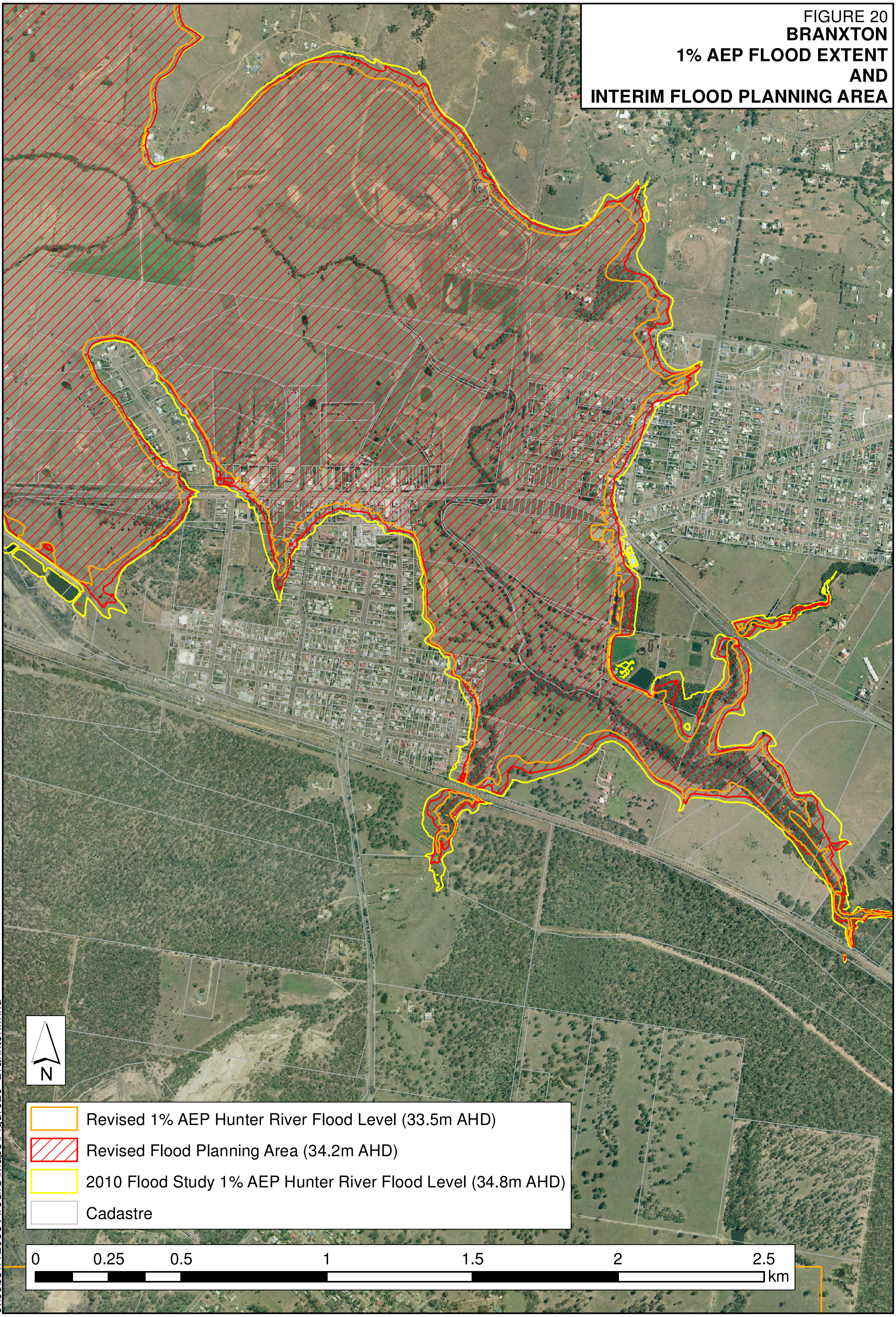


FIGURE 20
BRANXTON
1% AEP FLOOD EXTENT
AND
INTERIM FLOOD PLANNING AREA

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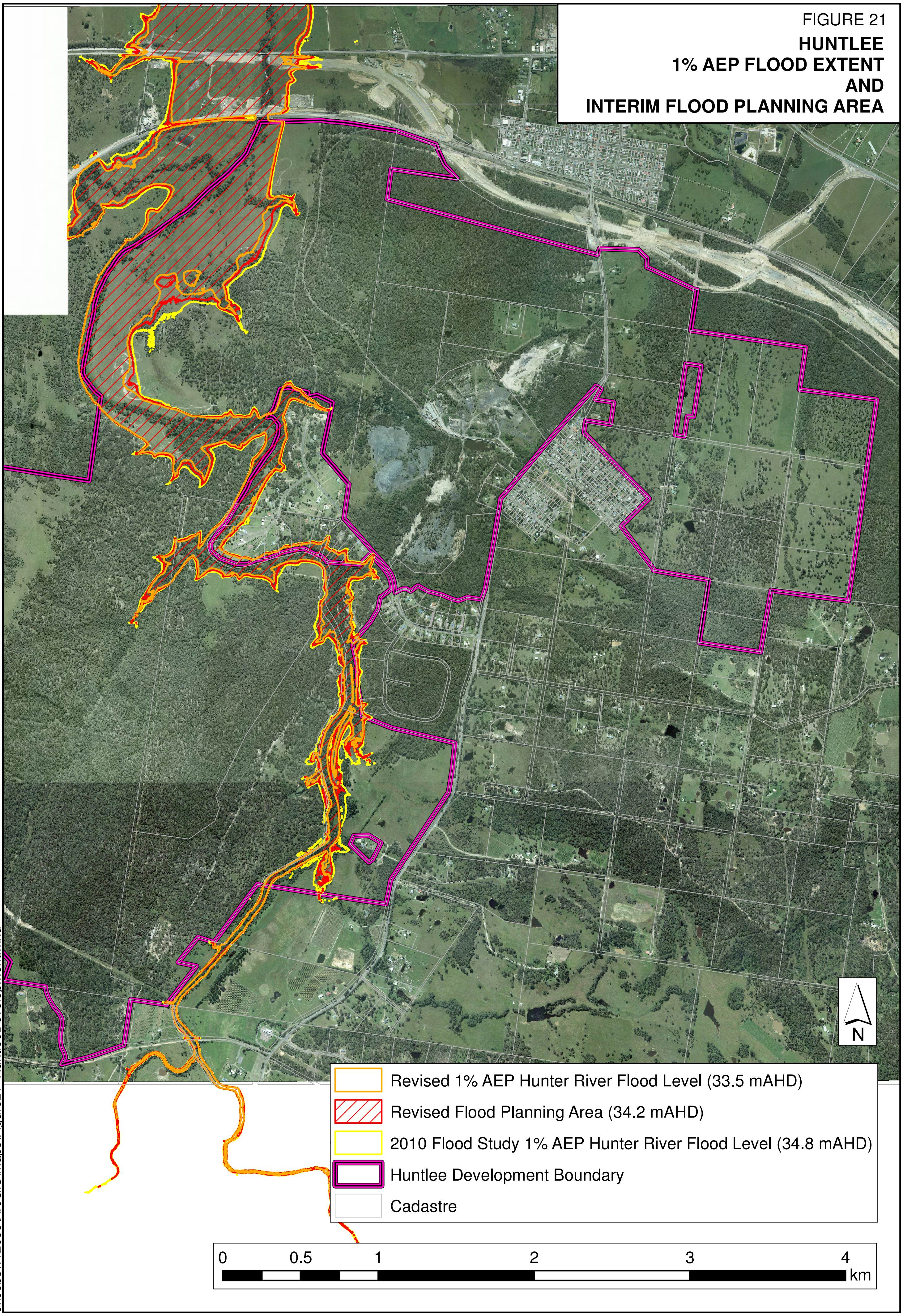
FIGURE 21

HUNTLEE
1% AEP FLOOD EXTENT
AND
INTERIM FLOOD PLANNING AREA



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Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

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

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

	the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.

hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
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	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable,

(PMF)	snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to "water level". Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.

Appendix B

APPENDIX B: DATABASE OF FEBRUARY 1955 FLOOD MARKS

WMAwater 2010	SMEC Update	Location	Comments	Source	Report	Estimated MGA94 Easting (m)	Estimated MGA94 Northing (m)
35.6		Hunter River	Near confluence with Jump Up Creek	DECC	WMA	340823.02	6392078.69
35.5		Hunter River	Northern floodplain, southern side of Glendon Lane	DECC	WMA	339625.28	6392172.69
35.2		Hunter River	U/S Elderslie Bridge	RTA	WMA	344813.29	6390575.57
34.63		Commercial Hotel		RTA	WMA	345559.74	6385664.3
	34.5	Mrs.Browns house, Standen Drive (Mark # 6)	Top of roof gable		SMEC Zone 4	343732.44	6389960.25
34.4		Black Creek	Western floodplain near Standen Drive 1 km U/S confl with Hunter River	RTA	WMA	344234.02	6389514.13
	34.371	Neil Standen's House, at floor level (Mark #10)			SMECZone 4	343129.95	6389484.92
34.3		Black Creek	Western floodplain near Standen Drive 1 km U/S confl with Hunter River	RTA	WMA	344234.02	6389514.13
34.23		Branxton cnr N-E Hwy and Bowen Street	Flood level was 2.55 m above PM 214414	DECC	WMA	345208.5	6385638.1
34.23		Blacks Garage	Exact location unknown	RTA	WMA	345282.6	6385653.28
34.22		Bank of NSW	Exact location unknown	RTA	WMA	345263.87	6385652.47
	34.005	Neil Standen's House, at window sills (Mark #9)	Exact location unknown		SMECZone 4	343311.66	6389745.22
34		Black Creek	Western floodplain near Standen Drive 1 km u/s confluence with Hunter River	DECC	WMA	344234.07	6389514.14
	33.964	Jim's "Front House" (Mark #11)	Location shown in SMEC report		SMECZone 4	343456.85	6389993.43
33.7		Hunter River	Northern floodplain near intersection Elderslie/Stanhope Road	RTA	WMA	345037.42	6391184.03
	33.931	Royal federal Hotel (Mark #1)	cnr N-E Hwy and Cessnock road		SMECZone 4	345547.79	6385640.93
33.61		N-E Hwy Bridge over Black Creek	Level taken from 1958 Bridge Design Drawing	RTA	WMA	343264.72	6385671.93
33.49		Black Creek	Western floodplain at Homestead 1 km U/S N-E Highway Bridge	DECC	WMA	342646.09	6385118.66
33.467		Hunter River	U/S Elderslie Bridge (north west corner of bridge)	DECC	WMA	344813.42	6390575.58
32.14		Hunter River	Near corner of Luskintyre and Stanhope Road	DECC	WMA	352973.96	6390173.07
31.3		Hunter River	Flood level northern floodplain near Stanhope Bridge	DECC	WMA	348300.67	6391280.9
30.76		Hunter River	Near Stanhope Road	DECC	WMA	350243.26	6390806.98
30.63		Hunter River	Near corner of Luskintyre and Stanhope Road	DECC	WMA	353278.72	6390038.97
29.79		Hunter River	East bank near end of Dalwood Road	DECC	WMA	352620.43	6387222.94
29.77		Hunter River	Source unknown	DECC	WMA	352096.23	6386442.74
28.96		Hunter River	Source unknown	DECC	WMA	351230.7	6385369.96
28.86		Hunter River	Near corner of Luskintyre and Stanhope Road	DECC	WMA	352815.48	6390258.4
28.83		Hunter River	Source unknown	DECC	WMA	350694.31	6383248.79
27.32		Hunter River	Source unknown	DECC	WMA	352705.76	6382297.93
26.47		Hunter River	Source unknown	DECC	WMA	354814.74	6384041.19
26.09		342 Windemere Road	Flood level taken at house floor	Maitland Council	WMA	354887.15	6383855.59
24.54		Hunter River	Source unknown	DECC	WMA	355741.23	6385223.67
21.68		Hunter River	Source unknown	DECC	WMA	357191.91	6386576.83
21.31		Hunter River	Source unknown	DECC	WMA	359032.69	6387271.7

WMAwater 2010	SMEC Update	Location	Comments	Source	Report	Estimated MGA94 Easting (m)	Estimated MGA94 Northing (m)
20.81		Hunter River	Source unknown	DECC	WMA	360739.38	6384492.24
20.65		Hunter River	Source unknown	DECC	WMA	359630.03	6386162.35
19.49		Hunter River	Source unknown	DECC	WMA	360276.14	6385235.87
19.46		Hunter River	Source unknown	DECC	WMA	360288.33	6382529.55
19.34		Hunter River	Source unknown	DECC	WMA	363226.27	6383480.42
18.99		Hunter River	Source unknown	DECC	WMA	361641.49	6382139.45
18.95		Hunter River	Source unknown	DECC	WMA	361495.2	6381932.21
15.83		Hunter River	Source unknown	DECC	WMA	364420.95	6382529.55
15.81		Hunter River	Source unknown	DECC	WMA	364725.71	6382383.26
13		Hunter River	Source unknown	DECC	WMA	365542.48	6380213.33
12.1		Hunter River	Source unknown	DECC	WMA	364433.14	6377787.4
10.9		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	364125.83	6376710.33
9.2		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	365622.35	6378491.91
9.1		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	365230.4	6377886.17
9.2		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	365266.04	6377672.39
11		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	365768.89	6376013.01
9.2		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	366904.65	6378514.76
8.8		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	366536.29	6378054.31
9.2		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	366981.39	6378038.96
9		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	367273	6377716.65
10.3		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	367380.44	6376013.01
10.3		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	367395.79	6375736.74
10.1		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	367733.45	6376074.4
10.3		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	367610.66	6375874.88
10.2		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	367441.83	6375905.57
7.3		Hunter River floodplain	Figure 3	Oct98 Flood Study	WMA	371294.22	6378622.19
7.7,7.7,7.5		Paterson River	Figure 3	Oct98 Flood Study	WMA	369391.05	6383441.51
7.4		Paterson River	Figure 3	Oct98 Flood Study	WMA	371723.97	6380602.11
7.5		Paterson River floodplain	Figure 3	Oct98 Flood Study	WMA	372061.63	6380187.71
8.1		Paterson River floodplain	Figure 3	Oct98 Flood Study	WMA	372322.54	6379942.13
7.2		Paterson River	Figure 3	Oct98 Flood Study	WMA	373274.13	6379497.04