KEMPSEY HYDRAULIC MODEL

TUFLOW UPDATE

FINAL REPORT



SEPTEMBER 2015

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KEMPSEY HYDRAULIC MODEL- TUFLOW UPDATE

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EXECUTIVE SUMMARY

At the commencement of the Kempsey Floodplain Risk Management Study and Plan it was decided to convert Council's existing flood model to a TUFLOW model. It was considered that TUFLOW would be a more appropriate tool considering its ability to easily model options such as levees. This report documents the updating of the Kempsey flood model to take account of new topographic data and improved modelling techniques. This report is a companion document to the Kempsey Floodplain Risk Management Study (WMAwater, 2015) and should be read in conjunction with this report. The recommended floodplain risk management measures detailed in Kempsey Floodplain Risk Management Study (WMAwater, 2015) were modelled using the hydraulic model described in this report.

The TUFLOW model was calibrated to the 2001 and verified by the 2013 events. The model was found to replicate observed behaviour well.

This report details the investigations, results and findings of the Hydraulic Modelling TUFLOW update Study for the Macleay River at Kempsey. The key elements of which include:

- a summary of available data,
- hydraulic model development,
- calibration and verification of the hydraulic model, and
- definition of the design flood behaviour through the analysis and interpretation of model results.

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

1 INTRODUCTION

The accurate modelling of the flow over the levees is important for modelling the flow through Kempsey. The previous modelling undertaken for the Hydraulic Modelling Study (WMAwater, 2009a) and the draft CBD Options Assessment (WMAwater, 2009b) used SOBEK a 2 dimensional hydraulic model. SOBEK is known to have some minor issues with the modelling of levee overflow.

TUFLOW is widely used in Australia and internationally for assessing flood behaviour and hydraulic hazard. GIS layers are used to modify terrain quickly and easily. Mitigation measures such as levees and roads can be easily modelled. The structure of TUFLOW means it is easier to track changes and options than the method used by SOBEK.

The Pacific Highway upgrade modelling developed a TUFLOW model of the Macleay River based on the SOBEK model. The Pacific highway modelling used TUFLOW as it can easily model changes to roads and culvert structures.

The previous models used photogrammetry and ground survey to define ground levels within the model domain. Detailed Aerial LiDAR Survey (ALS) data is now available for the Kempsey area provide by the Department of Lands.

Given the availability of the RMS TUFLOW model and the ability of TUFLOW to model levees and structures, it was decided at the commencement of the Kempsey Floodplain Risk Management Study and Plan, that the Council model should be updated to TUFLOW. The RMS model provided a sound basis for the model development.

Therefore the RMS TUFLOW model was updated with the ALS terrain data to form the TUFLOW model to be used for the Kempsey Floodplain Risk Management Study and Plan (WMAwater, 2015) assessment of management options. The design flood levels produced by the model are consistent with Council's previously adopted flood levels.

1.1 Study Area

The study area covers the same area as the previous the Kempsey Hydraulic Modelling Report (WMAwater, 2009a). The study area is shown on Figure 1 and Figure 2 The study area includes the township of Kempsey and surrounding floodplain extending downstream to Austral Eden and upstream to Euroka.

2 BACKGROUND

2.1 Catchment Description

The Macleay River catchment covers an area of approximately 11500 km^2; the upper reaches of which are located within the New England Tablelands. The main tributaries including the Apsley, Muddy and Chandler Rivers rise in the Great Dividing Range and flow eastwards across the New England Tableland before falling into rugged gorge country. The Macleay River itself emerges from the gorges some 35 km upstream of Kempsey. Below Kempsey the river meanders through a wide expanse of low lying floodplain which is subject to frequent and persistent flooding.

While the Macleay River is the dominant watercourse on the floodplain, significant tributaries include Christmas, Collombatti and Clybucca Creeks to the north, Belmore River and Kinchela Creek to the south and Parrabel Creek, Five Day Creek and Nulla Nulla Creek upstream of Kempsey. The Macleay River enters the ocean through a trained entrance at South West Rocks which was first breached during the flood of 1893. Previously the river entrance was at Grassy Head. The old channel between Grassy Head and South West Rocks has now become a complex backwater system.

The reach of the Macleay River downstream of Kempsey Traffic Bridge to Seven Oaks forms the first major depositional zone for the estuary. The 2008 geomorphological assessment for the Macleay River at Kempsey (WMAwater, 2008) found, that whilst detailed analysis of waterway area and volumetric and depth comparison suggested gradual trend for net deposition particularly towards Frederickton and further downstream, the amount was not thought to be significant. The assessment found that the potential influence of channel geomorphology is more pronounced for smaller flood events where a significant portion of the flow would be expected to be conveyed within the main channel. By comparison, the impacts of a reduced channel volume in a 1% AEP event were found to be negligible, which is consistent with the different flow distribution likely to occur in an event of this size; flow is not confined to the channel and the overbank and floodplain area convey a significant amount of flow. Although there is a trend for deposition, there is also evidence of scouring in the vicinity of the Kempsey Traffic Bridge following the May 1963 flood (WMAwater, 2008).

2.2 Flood Characteristics

Complex interactions between the river and the floodplain affect the characteristics of flooding. Upstream of Kempsey at Belgrave Falls the river is well defined and floodwaters are mainly constrained to the river channel and a relatively narrow floodplain. Downstream of Aldavilla the floodplain broadens significantly with many connecting waterways further downstream. At Kempsey flow is predominantly confined to a relatively narrow area at the Kempsey Railway Bridge. Immediately downstream of this location a large natural floodway cuts northwards through the CBD where the main river channel at Kempsey Traffic Bridge narrows forcing significant flows through the CBD floodway during large floods (greater than 10% AEP event). Downstream of the Kempsey Traffic Bridge flow begins to spread out across the floodplain into

the East Kempsey Wetland / Pola Creek area towards the southern Frogmore floodplain with an extent of approximately 4 km in the south of Frederickton. Under current conditions inundation of some properties occurs in events smaller than the 10% AEP event. A significant number of properties in Kempsey, Frederickton and the surrounding floodplain area would be inundated in events greater than this with inundation often lasting over 48 hours. The peak 1% AEP flow in the Macleay River at Kempsey is approximately 15,000 m^3/s. At the railway crossing at Kempsey this flow is predominantly confined to a relatively narrow flow area of the main river channel before spilling onto overbank areas and splitting between the floodway and the main channel.

The Levee Gradient Assessment (WMAwater, 2007) noted that different shaped hydrographs, those with the same peak level but different rates of rise and volumes, may change the flood gradient along the levees and subsequently impact the sequence and location of levee overtopping. A close correlation was noted between the rate of water rise and the sequence of levee overtopping and the shape of the hydrograph had a significant impact on the relative sequencing between the Eden Street and First Lane levees. Fast rising floods such as the 1949 flood produce a steeper flood gradient prior to the peak than slow rising floods. Therefore fast rising floods will typically cause the Eden Street levee to overtop first before the First Lane levee. When the rate of rise is lower (typically less than 0.1 m/hr) as smaller broad shape event occurs, the First Lane levee may begin to overtop first. The recent 2013 event gave an opportunity to reassess the consequences of different rates of rise. The critical rate of rise is actually that when flood level are near to the current levee crest heights rather than the rate of rise of the entire rising limb which can be deceptive as the floodplain is filling. When the rate of rise is slower, being less than approximately 0.1 m/hr between 6.7 and 6.9 mAHD at Kempsey Traffic Bridge, the First Lane levee may overtop first. With a faster rate of rise occurring at similar water levels, the Eden Street levee is likely to be the first to overtop.

2.3 Kempsey Levees

Several major levees protect the Kempsey CBD (Photograph 1);

- *Eden Street levee* – earth embankment, runs along the northern side of Eden St between the railway embankment and high ground in the CBD;
- *First Lane levee* – earth embankment, north of First Lane, runs between the railway embankment at Broughton St and high ground just north of Cochrane St;
- *The RSL levee wall* – a concrete wall at the end of Belgrave Street beneath the Kempsey Traffic Bridge, it runs along the river bank opposite the RSL tying into high ground at the northern end and free standing at the southern end;
- *Wide Street/Cooks Lane levee* - protects a small number of houses in West Kempsey, it crosses Wide Street to the west. This levee was constructed as a recommendation on the 1985 Options for Flood Protection Study (Webb McKeown and Associates, 1985).

Photograph 1: Kempsey Levees



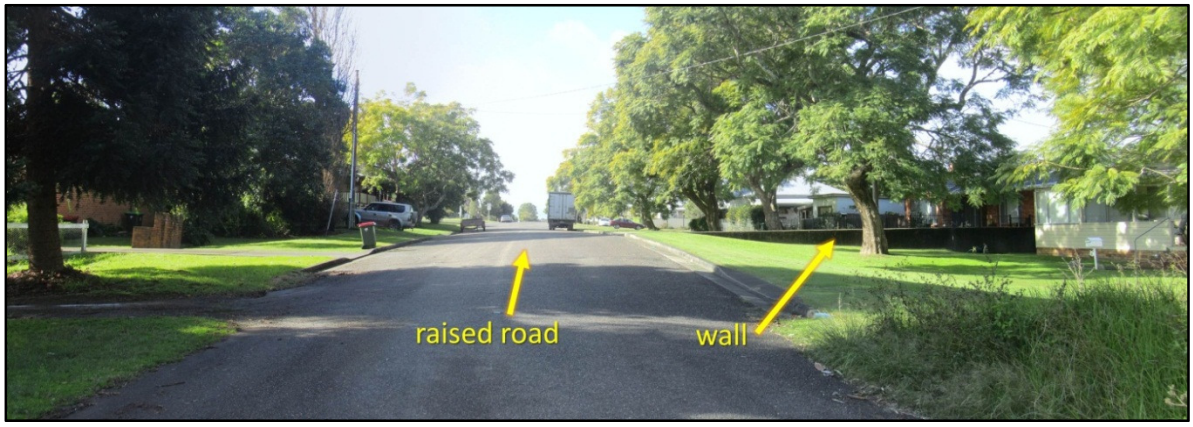
Photograph 1 a) Eden Street levee



Photograph 1 b) RSL levee wall



Photograph 1 c) First Lane levee (from Kemp Street)



Photograph 1 d) Wide Street/Cooks Lane levee (on Wide Street)

2.4 Flood History and Mitigation Works

Kempsey has had several major floods in recent historical times. The 1949 and 1950 floods are considered to be 90-year ARI and 80-year ARI events respectively and caused significant destruction in the town washing away in the order of 50 houses. The 1949 flood in particular cleared a large part of the natural hydraulic floodway through the CBD. These events led to the construction of a series of mitigation works during the 1950s and 1960s including levees, drains and control structures built throughout the floodplain by the Macleay River County Council (subsequently amalgamated into Kempsey Shire Council), drainage unions and private land holders.

An extensive series of levees has been constructed around the town together with a major floodway identified through the middle of the commercial district known as Local Floodway No. 1 (see Figure 2). A government sponsored floodway clearing program followed to clear the residential housing from this floodway. The floodway was the subject of a Commission of Inquiry held in the 1960s which led to a ban on any further development of lands within the floodway.

Currently four main levees protect the Kempsey CBD area; Eden Street, First Lane, the RSL wall and Wide Street/Cooks Lane levee. The Eden Street levee was constructed before the 1930s although has been raised several times since then; to 5.9 mAHD in 1958 and again in 1976 to a design level of 7.5 mAHD (WMAwater, 2007). The First Lane levee was raised in 1976 to a height of 5.9 mAHD (Webb McKeown and Associates, 1997 and Kempsey Shire Council, 2011) as part of a program to increase the level of flood protection at Kempsey. In 1976 a concrete levee was constructed between the Kempsey Traffic Bridge and the RSL (WMAwater, 2007), known as the RSL levee wall. The design height is 7.26 mAHD. The Wide Street/Cooks Lane levee was proposed and subsequently constructed following recommendations in the 1985 Evaluation of Options For Flood Protection report (Webb McKeown and Associates, 1985) and was built to specification at the 1% AEP flood (as per modelled flood level at the time). The levee is actually located on Wide Street and Cooks Lane and comprises a concrete wall. In Cooks Lane the pavement has been raised but during flood events boards are required to be fitted across the road.

The flood mitigation works operate to reduce risk from events smaller than 10% AEP event. In small floods with a recurrence interval of 2 to 3 years, flood gates are closed to contain floodwaters in the major streams and prevent floodwaters spilling onto the floodplain. This minimises the frequency of inundation which is the major cause of agricultural damage and maximises the time available for moving stock during major events. For the Kempsey township the closing of the flood gates has little effect on peak flood levels however can be beneficial for evacuation in adjusting the timing of the peak. The flood gates provide most benefit to Kinchela and Belmore areas which are outside of this study area. In floods between 3 and 10 year recurrence intervals (up to 10% AEP events), flood gates are opened to let floodwaters spill into the floodplain and wetland areas throughout the floodplain. This action helps to reduce flood levels experienced in the Kempsey area and small rural settlements at the expense of agricultural losses. In larger floods (greater than 10% AEP event), the operation of the flood gates does not significantly change flood levels (details on the effect of the flood gates on flood levels are found in the companion report to this document WMAwater, 2015). The Macleay flood

mitigation system is not designed to mitigate floods larger than this and can generally only provide protection in the Lower Macleay up to the “Moderate Flood” level of 5.7 mAHD at the Kempsey Traffic Bridge gauge when general overbank flooding will occur (Kempsey Shire Council, date unknown). During non-flood times the floodgates are left open to allow normal flushing.

As well as works within the Kempsey CBD area, other mitigation works were undertaken between 1949 and 1963 and included levees constructed on the left bank to protect Glenrock-Tennessee area, Christmas Creek levee and headworks and Pola Creek headworks. A training wall between Pola Island to a point downstream of the Kempsey Traffic Bridge was also constructed in the mid-1960s (Kempsey Shire Council, 2011). Between 1963 and 1980 new levees were constructed and natural levees were raised on both banks of the Macleay River from Kempsey to Smithtown.

The majority of these works outside of the town are designed to minimise residential, and agricultural damages during small floods up to the 2.5 year ARI event. The town levee system provides protection up to a 10% AEP event. Generally, the works have fulfilled their design intentions, however some adverse environmental effects including fish kills and black water have caused the community to question the sustainability of the works and their operation policies. Although evidence suggests that major kills have occurred prior to the construction of the works (MHL, 2015). Over time significant settlement in the Macleay River has allowed the floodplain vegetation to change from plants preferring wet conditions to those more tolerable of dry conditions. During a flood, the dry tolerable vegetation becomes covered with flood water which deoxygenates the flood water causing the black water effect. With the advent of flood mitigation in the 1950s the proliferation of dry tolerable plant species expanded on the Lower Macleay exacerbating an existing problem.

2.5 Recent Historical Flood Events

There is a reasonable amount of historical flood information available for both Kempsey and the broader Macleay Valley area. A detailed review and discussion of the available historical information is documented in a number of existing studies (Webb McKeown and Associates, 1989, 1997, 1999, 2004a, 2004b and WMAwater, 2013). In the Hydraulic Modelling Report (WMAwater, 2009a), the May 1980, March 2001, 1963 and 1949 events were used for hydraulic model calibration and verification. The March 2001 event is the first event to overtop the Eden Street and First Lane levees since they were constructed and the largest flood in Macleay valley since 1963.

Since the publication of the Hydraulic Modelling Report in 2009 (WMAwater, 2009a) events of significance have also occurred in May 2009, June 2011 and February 2013.

Due to the nature of the Interdecadal Pacific Oscillation and El-Nino Southern Oscillation the frequency of flooding can be such that a series of events occur in quick succession followed by a period of time where flood events are less frequent. This means that a 5-year ARI event could occur every year for 5 years and then not again for another ten or more years. Likewise two 1% AEP events could occur in successive years, such as occurred in Kempsey with the two

major events of 1949 and 1950 (a 90 year and an 80 year ARI event respectively). Flood events between 2001 and 2013 have been of similar magnitude (5-13 year ARI) and have followed a period of very minor flooding.

Flood water spilling over the levee system at Kempsey does not constitute failure of the levees. An event with an average recurrence interval of between five and seven years will begin to overtop the levees, however no significant damages will occur until approximately a 10% AEP (10-year ARI) flood. Peak flood levels and levee overtopping for recent events is show in below.

Table 1: Historic Flood Events – Peak Levels and Levee Overtopping

Event	Peak Flood Level at Kempsey Traffic Bridge (mAHD)	Levee Overtopped?	
		Eden Street	First Lane
March 2001	7.4	Yes (first)	Yes (second)
May 2009	6.9	No	Yes
June 2011	6.7	No	No
February 2013	7*	No	Yes

*NOTE: 6.94mAHD observed by Council Officer.

While the recent events have resulted in similar peak flood levels, they had different impacts on the CBD and all lead to serious action by the commercial and residential community of Kempsey. Recent flooding in Kempsey has been relativity minor when compared to rare events such as the 1% AEP event. The current levee system offers little mitigation in events of this size.

2.5.1 March 2001

The March 2001 event, approximately a 13-year ARI event, was the first to overtop both the Eden Street and First Lane levees since they were constructed (Webb McKeown and Associates, 2004a). There is some variation in the reported times of levee overtopping at the Eden Street and First Lane levees during this event although data generally suggest the Eden Street levee overtopped first by approximately one or two hours (WMAwater, 2009a). This flood event caused serious flooding and major disruption to the CBD with Belgrave Street and Forth Street becoming impassable for approximately 24 hours. A significant proportion of the total flood damages bill was attributable to inundation of the commercial CBD where some 200 commercial premises were affected although of these, 94 were reported as directly affected (Gissing, 2002). Total direct commercial damage was estimated at $ 2.5 million, averaging $ 28,000 per business (Gissing, 2002). During the event the Kempsey Traffic Bridge Gauge malfunctioned and a manual reading was taken after the peak. From this a peak height of 7.4 mAHD was noted at the Kempsey Traffic Bridge (6.9 m gauge height) at between 21:00 and 22:00 on 10th March (Webb McKeown and Associates, 2004a).



Photograph 2: Kempsey during March 2001 Flood

2.5.2 May 2009

The May 2009 event overtopped First Lane levee at several low points along the levee. The event was smaller than a 10% AEP (10-year ARI) event peaking at 6.9 mAHD on the 24th May 2009. Although water overtopped the levee, the event was small enough not to cause significant damage. There was no flow through the CBD as the Eden Street levee was not overtopped. Council records suggest that backwater reached a level of approximately 3.8 mAHD on the town side.

2.5.3 June 2011

The June 2011 event, was approximately a 20% AEP event (5-year ARI) (WMAwater, 2013b) and did not overtop the levee system however there was some flooding within the CBD (Photograph 3) though Eden Street boat ramp access was breached. Flood levels were reported to have been within 100 mm of the crest of the Eden Street levee peaking at 6.7 mAHD on the 15th June. The Eden Street boat ramp access was breached during the event. An evacuation order was issued for the CBD and over 50 people attended the evacuation centre at Kempsey High School on Broughton and Sea Street West (WMAwater, 2013b). Most evacuated properties were those on Belgrave Street, parts of Smith Street and Clyde Street, although properties on other streets were also evacuated. Following the flood, no residents reported flooding within their main building which in some areas may have been due to effective sandbagging or properties. Flooding was reported in nine secondary buildings however (WMAwater, 2013b). Flood waters did enter the Coles car park.



Photograph 3: Kempsey CBD during June 2011 Flood

Photograph taken approximately 5pm 15/6/2011 (approx. 12 hours before flood peak)

2.5.4 February 2013

This event occurred during this Study and enough data was collected to enable the event to be used in model verification (Section 3.4). The flood peaked on 24th February at just above 7 mAHD at the Kempsey Traffic Bridge gauge (observed height by Council officer was slightly lower at 6.94 mAHD), slightly lower than the March 2001 event. Floodwaters overtopped the First Lane levee and backwater entered the CBD making Belgrave Street impassable. The Eden Street levee was not overtopped although floodwaters were reported to reach 0.05 m from the crest. Floodwaters entered lower part of Eden Street near the Clyde Street intersection via the boat ramp access road. Roads within the CBD were closed as they became impassable (Photograph 4) and the Kempsey Traffic Bridge was open only to emergency vehicle traffic. Evacuation of the CBD was ordered before flood waters overtopped the First Lane levee.

The event is considered to be approximately a 7-year ARI event (WMAwater 2013a) and is not considered to be an extreme event. With only the First Lane levee overtopping, this flood was one of the largest that could occur without major flooding and damages to the CBD. It was notable that during this event there was initially a fast rate of rise until the critical height for levee overtopping (height at the Kempsey Traffic Bridge gauge of between 6.7 mAHD and 6.9 mAHD) when the rate of rise significantly slowed prior to overtopping of the First Lane levee.



Photograph 4: Clyde and Forth Streets in February 2013 Flood

2.6 Previous Studies

Many reports have investigated at flooding in the Macleay Valley. This section considers only the two Council funded reports that immediately preceded this current study.

2.6.1 Kempsey Hydraulic Modelling Study, 2009

The study area for the 2009 Hydraulic Modelling Study (WMAwater, 2009a) included the Kempsey CBD and extends from the Kempsey Railway bridge to Frederickton. The CBD area of Kempsey was represented in detail within the SOBEK model by a 2D grid of 10 m by 10 m cells within a broader grid with 40 m cells. A broader RUBICON (1D) hydraulic model of the Lower Macleay River floodplain, extending from Belgrave Falls to the river entrance was also used as part of this study. The RUBICON model was established previously as part of the Lower Macleay valley Floodplain management Study (Webb McKeown and Associates, 1997). Inflows to this RUBICON model had previously been established in a hydrologic WBNM model of the catchment. The Kempsey Hydraulic Modelling Report (WMAwater, 2009a) details the methodology and outcomes of the hydraulic modelling undertaken to satisfy flood study objectives. Key elements of this report include;

- A summary of available data;
- Description of the hydraulic approach adopted;
- Details of the calibration and verification of the hydraulic models; and
- An analysis and interpretation of model results to quantify the design flood behaviour for the CBD under existing conditions.

The WBNM, RUBICON and SOBEK models were calibrated to the March 2001 flood event and verified against several other historical floods including the 1949, 1963 and 1980 events.

Inflows, boundary conditions and model elements were adapted from this model for the current model.

2.6.2 Draft CBD Options Assessment, 2009

A series of development scenarios for the Kempsey CBD were studied as part of the draft Kempsey CBD Options Assessment (WMAwater, 2009b). This was a preliminary assessment of options for the CBD which would be refined in the Floodplain Risk Management Study (WMAwater, 2015) and was used to provide an indication of which options would be most beneficial. The SOBEK model from the previous Hydraulic Modelling report, was refined to a 5m grid resolution in the CBD to better define building footprints and better resolve localised flow behaviour around features within the CBD area.

To assess potential future land zoning options, four scenarios were established and assessed with the full development under current planning conditions at the time. These options included;

- Option A - A smoothed eastern CBD edge delineated on the basis of mapping of current flow behaviour;
- Option B - A smoothed eastern CBD edge plus development northwards of the Pacific Highway strip;
- Option C - As above plus development of the western CBD adjacent to the floodway; and
- Option D - A trade-off scenario which removes all existing development from the floodway while development of both the eastern and western CBD edges.

The Draft CBD Options Assessment (WMAwater, 2009b) concluded that “in practice, providing options for new development without having an adverse impact on flood risk for existing development, would be difficult as any raised area would generally have some adverse impact. However, significant areas of new development can be created with manageable impacts on peak flood levels.”.

The Draft CBD Options Assessment (WMAwater, 2009b) suggested that the schematisation assumptions made in the SOBEK model would need to be confirmed given the sensitivity of the model to buildings and other flow obstructions. Inflows, boundary conditions and model elements were adapted from this model for the current model.

2.7 Available Data

2.7.1 Topographic Data

Since the Hydraulic Modelling Study (WMAwater, 2009a) and draft CBD Options Assessment (WMAwater, 2009b) were completed, ALS data was flown of the study area. The ALS was flown in 2009.

This data has a considerably improved accuracy compared to the topographic data used in previous studies which was based on orthophotos and ground survey. The 1 m DTM grid data was compared against known survey levels within the Kempsey CBD and found to be suitable for use with 95% of points within 0.15m of the surveyed levels. The OEH guidelines for using LiDAR data, DTMs derived from Aerial Survey Method – Draft Guideline (OEH, in Draft) state that the standard deviation of the ALS should be no greater than 0.15m. Comparison with

ground survey resulted in a standard deviation of 0.084 m for the ALS data set used, which is well within the range acceptable.

Council undertook detailed survey of Eden Street levee, First Lane levee, the RSL wall levee in November 2011. This survey was incorporated into the TUFLOW model geometry.

Detailed hydrosurvey of the Macleay River channel was undertaken in 2003 and used to define the in channel geometry.

2.7.2 Previous Modelling

A TUFLOW model of the Macleay River was produced in 2009 as part of the RMS's Pacific Highway upgrade for the purpose of assessing the impacts of refinements to the Bypass design (WMAwater, 2011). This TUFLOW model used inputs from the 1D RUBICON model originally prepared for the Lower Macleay Floodplain Management Study (Webb McKeown and Associates, 1997) and updated as part of the Kempsey Hydraulic Modelling Study (WMAwater, 2009a). The Kempsey Bypass model was verified against historical events and the RUBICON model as well as a previous SOBEK model established in late 2004 for the Kempsey Bypass Environmental Assessment. This was to ensure that the model reproduced the previously adopted design event modelling.

3 HYDRAULIC MODELLING

The following section details the update to the hydraulic model, calibration and verification of the TUFLOW model and results.

3.1 Conversion from SOBEK to TUFLOW

The accurate modelling of the flow over the levees is important for modelling the flow through Kempsey. The previous modelling was undertaken in SOBEK a 2 dimensional hydraulic model. SOBEK is known to have some minor issues with the modelling of levee overflow. Levees in SOBEK must be modelled as a minimal of three cells wide to ensure the correct overflow.

TUFLOW is widely used in Australia and internationally for assessing flood behaviour and hydraulic hazard. TUFLOW is a finite difference numerical model which is capable of solving the depth averaged shallow water equations in both the one and two dimensional domains. GIS layers are to modify terrain quickly and easily. For example, levees are represented by a line in a GIS layer with elevations in TUFLOW. The structure of TUFLOW means it is easier to track changes and options than the method used by SOBEK. A range of scenarios can be run through the hydraulic model relatively quickly and small changes are easy to implement.

The Pacific Highway upgrade modelling developed a TUFLOW model of the Macleay River based on the SOBEK model. The Pacific highway modelling used TUFLOW as it can easily model changes to roads and culvert structures.

It was decided for this study, given the availability of the RMS TUFLOW model and the ability of TUFLOW to model levees and structures that the Council model should be updated to TUFLOW. The RMS model provided a sound basis for the model development. New ALS data was also available.

The new TUFLOW model extents are shown in Figure 3 and Figure 4. These are slightly larger than the SOBEK model used for the previous CBD assessment (WMAwater, 2009b) but have been established based on locations more appropriate for boundary conditions in TUFLOW modelling and those used in the Kempsey Bypass TUFLOW model (WMAwater, 2011).

3.2 Model Configuration

The model consists of a 2D 10 m grid defining the overbank and channel for the Macleay River and its tributaries. This was considered suitable to provide sufficient detail in the hydraulic results across the whole study area but to also reasonable model run times. While a 5 m cell was used to define the CBD in the Draft CBD Options Assessment (WMAwater, 2009b) with a larger grid to define the floodplain, the different methods used for weir characterisation in TUFLOW allow a larger grid cell size to be used.

The 10m digital terrain model (DTM) was created using the topographic data outlined in Section 2.7. Culverts under roads and bridges were incorporated into the model based on survey.

The model extent and boundaries were located a sufficient distance away from the study area to minimise any influence that the boundary conditions may have on the model results for the area of interest. The TUFLOW model limits were:

- Upstream Boundary: Approximately 6 kms upstream of Kempsey
- Downstream Boundary: 5 kms downstream of Frederickton, and between Austral Eden and Frogmore.

The hydrology from the Hydraulic Modelling Study (WMAwater, 2009a) was adopted for the study. Boundary conditions for the TUFLOW model were extracted from the previous RUBICON model (or from the Kempsey Bypass TUFLOW model where this information had already been converted to the TUFLOW format) for both historical (2001 and 2013 events) and design events (2 Year ARI, 5 Year ARI, 10, 5, 1, 0.5, 0.2 and 0.05 % AEP and Probable Maximum Flood). The upstream inflow boundary was moved a short distance upstream to a location were the flow was more confined.

The Christmas Creek catchment is defined as a storage vs height relationship rather than in 2D to reduce run times. Sensitivity testing showed that this has a negligible effect on flood levels.

As the Kempsey Bypass TUFLOW model had been verified against historic events, the RUBICON model and the SOBEK model (WMAwater, 2011) and the SOBEK model had undergone extensive calibration it was considered appropriate to extract boundary and inflow information from these models.

Details on structures and flows controls were based on data available from previous modelling and detailed field survey. The Kempsey Bypass was included in the TUFLOW model with details of the highway taken from the Kempsey Bypass TUFLOW model.

Where available recent survey was assumed to prevail over assumptions in previous models. The CBD levee crests were updated based on the November 2011 Council survey. WMAwater, 2009b had assumed that the levees were at their design levels rather than the surveyed levels.

Buildings likely to act as flow restrictions were incorporated into the model based on available aerial photography. These features were modelled as impermeable obstructions to floodwaters in particular those buildings present in the current Kempsey Local Floodway No. 1 (see Figure 4)

Manning's 'n' values were originally based on those used in earlier models and refined to provide a good calibration to the 2001 flood event and to reproduce Councils adopted design flood levels. The adopted values are shown as Figure 5 and in Table 2.

3.3 Calibration

As with other models of the study area the March 2001, approximately a 13-year ARI event, event was used for calibration. This event provides a reasonable measure of model performance due to the coverage and quality of the flood data available and the fact that the

March 2001 event was the first event known to overtop both the Eden Street and First Lane levees. While earlier historic events could have been used for calibration there is limited data available and there are a number of terrain changes that have occurred since which require interpretation.

Both the 2009 event (approximately a 10% AEP) and 2011 event (approximately a 5-year ARI) could have been used in calibration, however it was not within the scope of this study to model these events or to derive boundary conditions for these events. As part of WMAwater, 2013 the NSW SES collected flood data on the 2011 event. This event could be used in calibration in a later study. Most recent events are relatively frequent events (5-13yr ARI) and therefore adding additional calibration of events is of limited value particularly when extrapolating to the PMF event. While the 1949 event was a 90 year ARI event there is limited spatial calibration data and rainfall information available. However this event was used for the calibration of models from which this model draws its boundary conditions.

A number of observed peak levels were recorded with varying reliability for the March 2001 event as well as some time varying water level information. The quality of these points and their collection are documented in WMAwater, 2009a.

The hydraulic efficiency of the creeks is represented (in part) within the TUFLOW model by the roughness or friction factor, Manning's "n" value. Manning's "n" is used to describe the influence of the following factors on flow behaviour:

- channel roughness,
- channel sinuosity,
- vegetation and other debris/obstructions in the channel, and
- bed forms and shapes.

As part of the calibration process the Manning's "n" roughness value was adjusted within reasonable limits to best match the recorded flood heights along the creek system. Adopted values were selected based on an assessment of the ground cover types and vegetation density within the floodplain and previous model adopted values. The adopted values used are shown in Figure 5 and Table 2. The model was been calibrated so that the correct volume of water flows over the Eden Street levee and through the CBD floodway.

Table 2: Manning's 'n' Values

Description	Manning's 'n' value
Macleay River Channel	0.025
Floodplain, short growth vegetation, grazing areas	0.04
Floodplain, maintained and low grassed areas	0.03
Overbank / dense vegetation	0.06
Hard surfaces / concrete / bitumen	0.02
Built up areas (where not coded out of model)	0.1

3.3.1 March 2001 Results and discussion

Comparing the results to the available data, the model performance was assessed in terms of peak flood heights, general flow patterns and the relative timing of flooding compared to

observed hydrographs. The modelled flood levels are compared to the corresponding observed levels in Figure 6 and Table 3. As well as a number of observed peak flood levels, a stage hydrograph was available for the Kempsey Traffic Bridge (KTB) gauge which allows calibration of the timing of the event as well as peak levels. The gauge failed during the event but manual readings were taken to complete the stage hydrograph. A comparison of the modelled hydrograph at the Kempsey Traffic Bridge compared to the observed hydrograph can be found on Figure 7 showing that the modelled hydrograph and timings generally match the observed data well.

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Table 3 Peak Flood Levels – Modelled versus Observed – March 2001 Event

Location	Observed (mAHD)	Modelled (mAHD)	Difference (mm)	Comments
J. Farley's Dairy Farm	6.26	6.54	0.28	Reliable. Possibly affected slightly by models downstream boundary.
Collin Paix property	6.59	6.69	0.10	Reliable. Good calibration.
Smith St / First Lane Shell Roadhouse	6.60	6.67	0.07	Unsure on reliability. Good calibration.
Auto Electrics Building, 129 Smith Street	6.60	6.67	0.07	Unsure on reliability. Good calibration
Presbyterian Church	6.82	6.74	-0.08	Unreliable. Fair calibration.
Stanley Street East	3.66	4.02	0.36	Unreliable. Fair calibration.
Sea Street	6.19	6.65	0.46	Unreliable observation.
Gladstone Street railway underpass	6.34	6.67	0.33	Reliable. Possibly localised flood level observed.
JE Lawfords, Cnr 52 Dangar Street/Kemp St	6.55	6.68	0.13	Unsure on reliability. Fair calibration.
Assistance Patrol Building Gamacks Lane / Tozer Street	6.44	6.67	0.23	Unsure on reliability. Fair calibration.
Macleay Pumps, Cnr Smith St & Stuart St	6.66	6.68	0.02	Unsure on reliability. Good calibration.
Clyde Street Mall	6.55	6.68	0.13	Reliable. Good calibration.
Belgrave Street	6.56	6.69	0.13	Reliable. Good calibration.
Mavin Petrol Station Belgrave St Nr Sydney St	6.59	6.69	0.10	Reliable. Good calibration.
RSL car park area	7.40	7.33	-0.07	Reliable. Good calibration.
Cnr Belgrave & Smith St, Traffic Bridge	7.29	7.25	-0.04	Reliable. Good calibration
Macleay Treated Timbers yard, Nr Holman St & Belgrave St	6.39	6.69	0.30	Unsure on reliability. Lower than other observed levels in floodway.
Cavanagh's Bus Depot	8.18	8.10	-0.08	Reliable. Good calibration.
Pierpoints Gravel Yard, Cnr Elbow St & River St	8.23	8.42	0.19	Unsure on reliability. Fair calibration.
End of Cooks Lane	8.46	8.64	0.18	Reliable. Observed level recorded

				prior to peak. Therefore higher modelled flood level is justified.
Queen Street gully	7.65	-	-	Flood level from local flows, not modelled.
PO Donnells, Euroka Road	8.20	8.77	0.57	Unsure on reliability. The SOBEK model was also high here with a difference of 0.57 m.
Cattle Grid off Wrights Lane	5.20	5.09	-0.11	Unreliable. Good calibration.
Driveway off Wrights Lane	4.45	5.04	0.60	Unsure of reliability. Poor calibration.
Yabsleys Lane	4.13	5.15	1.02	Reliable. Poor calibration.

Generally, the model calibrated reasonably well to observed peak flood levels with most modelled points being within 0.15 m of the observed levels. There is a slight tendency for the modelled peak flood levels to be slightly higher than the observed.

Although the model reproduces the observed peak flood levels reasonably well, the ability of the model to match observed flood levels varies across the model domain. Overall the data suggests that the flood gradient in the area at the peak through the CBD was relatively flat; a trend that is reproduced by the TUFLOW model. Along Smith Street the observed flood level is consistent between 6.55 and 6.6 mAHD. The model reproduces this well. West of the railway line in a backwater area there are some inconsistencies in observed levels with nearby levels differing by 0.2m. The difference between modelled and observed levels at Macleay Treated Timbers yard, Nr Holman St & Belgrave St could be explained by localised velocity effects. The SOBEK model produced similar levels through the CBD for this event.

3.4 Verification

During the course of the study the February 2013 event occurred causing overtopping of First Lane levee. Data collection following the event was undertaken by RMS and established a number of peak flood levels thought out the study area. RMS funded a study to investigate the behaviour of the 2013 event (WMAwater, 2013a). Daily and pluviograph data was collected throughout the catchment and a grid of total rainfall for the event was developed. Gauge data at the Kempsey Traffic Bridge was also collected.

For the 2013 event the WBNM model was used with observed rainfall data and the resultant inflows then used to inform the RUBICON model from which boundary conditions were extracted for the TUFLOW model. The event was used to verify the TUFLOW model.

More details on data collection, the modelled behaviour in RUBICON compared to the observed behavior and boundary condition development can be found in WMAwater, 2013a.

3.4.1 February 2013

The calibrated model was used to model the 2013 with no changes other than the addition of the Kempsey Bypass which was not built in the calibration event.

The model calibrated well and no additional changes were needed to the model. The modelled

results were compared to the available data, the model performance was assessed in term of peak flood heights, general flow patterns and the relative timing of flooding. The modelled flood levels are compared to the corresponding observed levels in Figure 9 and Table 4. The comparison of the modelled 2013 event hydrograph with the recorded levels at the KTB gauge is shown in Figure 11. As part of the Pacific Highway Upgrade a gauge was put in at Frederickton in 2008. This gauge was therefore in operation in the 2013 event but not the 2001 event. A comparison of the modelled 2013 event hydrograph with recorded levels at the Frederickton gauge is shown in Figure 12.

Table 4: Peak Flood Levels – Modelled versus Observed - February 2013 event

Location	Observed (mAHD)	Modelled (mAHD)	Difference (mm)	Comments
62 L/B Belmore River	7.54	7.68	0.14	Reliable 8/10
River St	7.46	7.65	0.19	Reliable 8/10
Eden Street	7.39	7.31	-0.08	
Kempsey Traffic Bridge	6.94	6.92	-0.02	
First Lane levee	6.32	6.25	-0.07	
Macleay Valley Way, north Kempsey floodplain	6.32	6.24	-0.08	Reliable 9/10
Frederickton levee / Flood gauge	5.83	5.84	0.01	24/02/2013 at 10:23 - Approximate level on frame of the flood gauge
Rowe Property, upstream	5.43	5.51	0.08	
Rowe Property, downstream Ferry Lane	5.4	5.46	0.06	
Jeffery Property 1 - shed	4.78	5.16	0.38	Unreliable
Jeffery Property 2	5.39	5.33	-0.06	
Jeffery Property 3	5.6	5.37	-0.23	
Old Pacific Highway, Bellimbopinni	4.84	4.71	-0.13	Reliable 9/10
Old Pacific Highway, Bellimbopinni	5.09	4.79	-0.30	Reliable 8/10
Old Pacific Highway, Bellimbopinni	4.95	4.98	0.03	Reliable 9/10
Outer Road, Austral Eden	5.45	5.24	-0.21	Reliable
Hutcheson Street, Austral Eden	3.89	4.22	0.33	Reliable 8/10
Inner Road, Austral Eden	4.11	4.21	0.10	no note on reliability but seems reliable
Yabsleys Lane	4.13	4.88	0.75	Unreliable.

NOTE: Data reliability is rating out of 10 is based on survey comments during data collection.

A good calibration to observed data was achieved. Modelled flood levels were generally within +/- 0.2m of the observed flood levels. The point labelled “Jeffery 1” appears inconsistent with the other observed levels in the area. Timing of the observed and modelled peaks at Kempsey is within 5 minutes of each other (Figure 11), though the modelled hydrograph rises a little too quickly.

3.5 Comparison with Previous Models

A comparison 1% AEP design event with previous calibrated models of the area was undertaken to confirm that adopted design flood levels within the study area had not changed significantly. The reason for this is the inclusion of the Kempsey Bypass and the update of the

model to TUFLOW may have resulted in minor changes. As previous models (SOBEK, RUBICON) did not include the Kempsey Bypass, the new TUFLOW model was compared to the TUFLOW model prepared for assessing impacts of refinements to the Kempsey Bypass design (WMAwater, 2011). This model had previously be confirmed to reproduce the same flood behaviour pre Highway Bypass to the SOBEK model. Table 5 below shows a comparison between the two TUFLOW models.

Table 5: Comparison of Model Results with Previous Models – 1% AEP Event

Location	River/ Floodplain	Peak Level (mAHD)				
		Rubicon	RMA-2	SOBEK	TUFLOW	
					Kempsey Bypass model	New TUFLOW model
Railway Bridge	River	10.2		10.15	10.15	10.02
Traffic Bridge	River	8.7		8.7	8.57	8.51
Pola Creek	River	8.2	8.1	8.11	8.07	8.03
Glenrock Drain	River	7.7	7.7	7.86	7.79	7.77
Upstream Frederickton	River	7.1	7.1	6.96	6.96	6.98
Frederickton	River	6.7	6.8	6.64	6.62	6.62
Downstream Frederickton	River	6.5	6.5	6.32	6.38	6.37
East Kempsey Wetland	Floodplain	n/a	6.7	6.64	6.76	6.65
Old Station Road	Floodplain	6.6	6.6	6.6	6.72	6.60
Frogmore	Floodplain	5.9	5.9	5.93	6.11	6.05
South West Rocks Road	Floodplain	5.9	5.9	5.87	6.02	5.96
Upstream Bridge Right Bank	Floodplain	5.9	5.9	5.88	6.02	5.96

The new TUFLOW model has a tendency to be slightly lower than the Kempsey Bypass model. Slight variations in the model are expected due to the newer topographic data used, refinements to model details such as inclusion of more structures (which were not relevant to the Kempsey Bypass model), a greater emphasis placed on getting the flow through Local Floodway No.1 and the adopted Manning's *'n'* values in the CBD model compared to the Kempsey Bypass model.

4 DESIGN FLOOD EVENT MODELLING

4.1 Boundaries and Inflows

The hydrology for the design flood events was established through previous studies (see Section 2.6). Inflows to the TUFLOW model were extracted from the RUBICON model and the WBNM model as part of the Kempsey Hydraulic Modelling Study (WMAwater, 2009a) (see Figure 3). The hydraulic model was run for the 2-year ARI, 5-year ARI, 10%, 5%, 1%, 0.5%, 0.2% AEP and PMF events. For the design events, the Kempsey Bypass was included in the model geometry. Peak inflows used in the hydraulic modelling in are summarised in Table 6.

Table 6: Macleay River Peak Flows

Event	Macleay River Inflow (m^3/s)
2-year AR	3,500
5-year ARI	5,400
10% AEP	7,700
5% AEP	9,900
1% AEP	15,300
0.5% AEP	20,400
0.2% AEP	24,800
PMF	67,500

NOTE: Peak flows are taken at the inflow to the TUFLOW hydraulic model and include out of bank flows.

4.2 Results and Discussion

4.2.1 Peak Flood Levels and Depths

Peak flood levels and depths for the range of design events modelled are shown in Figure 15 to Figure 28. A summary of peak flood levels at key locations is presented in Table 7 (refer to Figure 13 and 11 for locations).

Generally peak flood levels within the CBD area are similar to those which would be observed at the Kempsey Traffic Bridge gauge. Levels are relatively flat across much of the open floodplain area with little variation due to the vast expanse of floodplain available. Flood depths in the 1% AEP could reach between 2 m and 3.5 m on roads in the CBD.

Table 7: Design Event - Peak Flood Levels

ID	Location	Peak Flood Level (mAHD)							
		2-yr ARI	5-yr ARI	10% AEP	5% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
L01	Euroka Creek (Near Bridge)	6.23	7.38	8.57	9.48	11.27	12.64	13.68	19.87
L02	South West Kempsey (Euroka Creek Area)	6.23	7.38	8.53	9.41	11.17	12.52	13.55	19.62
L03	River Street (Between Wide Street and Cooks Lane)	-	-	-	-	9.48	10.88	11.84	16.89
L04.1	Kempsey Rail Bridge	6.13	6.98	7.91	8.63	10.06	11.20	12.12	17.61
L04.2	Kempsey Rail Bridge (Downstream)	6.13	6.98	7.88	8.61	10.01	11.13	12.03	17.52
L05	South Kempsey (Backwater Area)	6.15	7.00	7.86	8.58	9.93	11.00	11.88	17.31
L06	East Kempsey Swamp	4.62	4.80	5.15	5.65	6.65	7.45	8.07	12.49
L07.1	North of Eden St Levee	-	-	6.59	7.23	8.85	9.90	10.49	16.25
L07.2	South of Eden St Levee	6.14	7.03	7.96	8.54	9.58	10.47	11.14	16.45
L08	Corner Austral and Eden Streets	-	-	7.28	7.77	8.81	9.60	10.31	15.48
L09.1	Kemspey Traffic Bridge (Upstream)	5.97	6.64	7.24	7.70	8.55	9.26	9.87	14.15
L09.2	Kempsey Traffic Bridge (Downstream)	5.97	6.64	7.24	7.70	6.65	7.45	8.07	12.49
L10	Belgrave Street	-	-	6.58	7.12	8.32	9.08	9.66	13.99
L11	Corner Forth and Yaelwood Streets	-	-	6.58	7.07	8.13	8.87	9.47	13.88
L12	Forth Street	-	-	6.58	7.09	8.13	8.83	9.36	13.30
L13	Clyde St Mall	-	-	6.58	7.09	8.13	8.84	9.39	13.35
L14	Corner Stuart and Smith Streets	-	-	6.58	7.08	8.09	8.80	9.36	13.32
L15	Mid Floodway (Between Eden St and First Lane levees)	-	-	6.58	7.05	8.02	8.71	9.28	13.51
L16	West Kempsey (Dangar Street Backwater Area)	-	-	6.58	7.05	8.00	8.71	9.29	13.73
L17	First Lane	-	-	6.58	7.05	7.99	8.65	9.21	13.38
L18	South First Lane levee	-	2.86	6.58	7.04	7.99	8.65	9.20	13.37
L19	North First Lane levee	3.99	6.10	6.57	7.01	7.90	8.56	9.09	13.13
L20	West Kempsey (Willow Drain Backwater Area)	3.99	6.10	6.56	7.00	7.86	8.51	9.03	13.02
L21	North Kempsey Floodplain	3.99	6.09	6.55	6.96	7.77	8.40	8.90	12.85
L22	South West Rocks Road	-	4.08	4.76	5.33	6.12	6.69	7.11	11.36

NOTE: Where no value is shown the location is not flooded.

4.2.2 Flow

Figure 14 depicts the flow extraction locations. Downstream of the Kempsey Rail Bridge, in events approaching a 10% AEP water leaves the main channel and travels down a floodway through the Kempsey township. There is no flow in the Local Floodway No. 1 for the 2-year and 5-year ARI events as water is prevented from entering by the levee system. The amount of the flow through the township depends on the magnitude of the event and is summarised in Table 8. The flow split is shown in Figure 14. Significant flow over River Street occurs in events larger than a 1% AEP event.

Table 8: Macleay River Peak Flow Split

Event	Macleay River Inflow (m^3/s)	Main Channel/ Kempsey Traffic Bridge		Floodway		River Street	
		Flow (m^3/s)	% of Total Inflow	Flow (m^3/s)	% of Total Inflow	Flow (m^3/s)	% of Total Inflow
2-year ARI	3,500	3,400	99	0	0	0	0
5-year ARI	5,400	5,300	99	0	0	0	0
10% AEP	7,700	7,500	98	140	2	0	0
5% AEP	9,900	9,200	93	640	7	0	0
1% AEP	15,300	12,900	84	2,400	16	10	0.1
0.5% AEP	20,400	15,900	78	4,000	20	280	1
0.2% AEP	24,800	18,300	74	5,300	22	680	3
PMF	67,500	33,800	50	15,800	23	6,740	10

NOTE: Percentages may not total 100 due to rounding. Total flow for the PMF event is not fully represented in the three tabulated locations as there are additional flow splits upstream into the Willow Drain backwater area and also backflow into the South Kempsey and Pola Creek areas.

4.2.3 Velocities

Mapping of velocities for the range of design events are shown in Figure 29 to Figure 42. The velocities shown in the figures and are the maximum velocities during the event and therefore do not necessarily occur at the peak flood depth. Velocities within Local floodway No 1 and South West Road near Red Hill lane are significant.

4.2.4 Duration of Flooding

The duration of flooding increases with the magnitude of the event. Within Kempsey the inundation time will be significantly longer if the levees are overtopped and the CBD area needs to drain. Floodwaters can therefore remain in the CBD for several days after the levees are first overtopped. The Hydraulic Modelling Report (WMAwater, 2009a) identified that for the 1% AEP event, once flood waters have subsided and are no longer overtopping the First Lane levee it would take approximately 26 hours for the CBD area to drain to a level of 4.5 mAHD. After this point the water level inside the levee reduces at a rate of approximately 1 m per day following the rate of fall being experienced within the Macleay River floodplain immediately downstream of the First Lane levee. It is approximately three days before flood levels within the levee would be expected to reach a level of 2.5 mAHD. Most existing development within the CBD area is

generally located on land above 4.5 mAHD while below a level of 2.5 mAHD flooding is generally confined to the low lying areas adjacent south of First Lane and in and around the Gladstone Street railway underpass. For the floodplain surrounding Kempsey inundation typically lasts 2-3 days.

4.2.5 Rate of Rise of Floodwaters

The Kempsey Levee Sensitivity Assessment (WMAwater, 2007) found that the rate of rise of flood waters affected the hydraulic gradient through Kempsey and therefore the expected sequencing of levee overtopping. Fast rising floods such as the August 1949 flood, can be expected to produce a steeper hydraulic gradient along the main river between the Eden Street and First Lane levees. In this situation, the Eden Street levee is more likely to overtop the prior to the First Lane levee. For smaller, more frequent events which have a relatively flatter and slow rising hydrograph, such as the May 2009 event and more recent February 2013 event, it is possible that the First Lane levee may overtop first. However, it is also possible in these cases that the Eden Street levee could still overtop first although the relative difference in time between Eden Street overtopping compared to First Lane levee overtopping will be less than that likely to be experienced during fast rising floods. Analysis undertaken on the 2013 event showed the critical rate of rise, in determining which levee would first overtop was between 6.7 and 6.9 mAHD at the Kempsey Traffic Bridge (WMAwater, 2013a), rather than the rate of rise over the full rising limb. The hydraulic modelling undertaken for this Study found similar results.

4.3 Sensitivity Testing

The hydraulic model relies on a number of assumed parameters, the values of which are considered to be the most appropriate for the study area. A range of sensitivity analyse are typically undertaken on different key parameters in order to quantify potential variations corresponding to different modelling assumptions.

As the model matched well with the Kempsey Bypass model (see Section 3.4), and the full range of sensitivity testing was outside of the study scope only sensitivity testing on the Manning's 'n' value was undertaken. The model was run for the 1% AEP event with a 20% increase and 20% decrease in the Manning's 'n' values. Results of the sensitivity analysis are provided in Table 9.

The sensitivity analysis showed that the model is sensitive to the assumed roughness values with increases in flood level of up to 0.4 m due to a 20% increase in the roughness value and decreases of up to 0.5 m due to a reduced roughness value. The relative roughness of the channel and overbank determines how much water is conveyed by the channel and the volume that spills over bank. The model is sensitive to global changes to roughness values. Small changes to land use within the study area are unlikely to have large impacts on flood levels. Significant changes to land use on pastures may affect flood levels.

Table 9: Hydraulic Model Sensitivity to changes in Manning's 'n' Values

Location	1% AEP Flood Level (mAHD)	Difference (m)	
		- n 20%	+ n 20%
Upstream Frederickton (river)	6.97	-0.15	0.19
Glenrock Drain (river)	7.77	-0.38	0.33
Pola Creek (river)	8.03	-0.43	0.37
Traffic Bridge (river)	8.48	-0.47	0.43
Railway Bridge (river)	10.01	-0.32	0.36
Old Station Road (floodplain)	6.6	-0.37	0.39
East Kempsey Wetland (floodplain)	6.65	-0.38	0.39

4.4 Climate Change

The 2005 Floodplain Development Manual (NSW State Government, 2005) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change (sea level rise and rainfall increase) on flood behaviour. Rainfall increases could affect the Macleay River, though sea level rise would have no impact at the study area as it is too far upstream from the ocean. In accordance with the Department of Environment, Climate Change and Water (DECCW) – Floodplain Risk Management Guideline 2007 (NSW Gov, 2007), the following climate change scenarios (rainfall by the year 2070) are considered in this climate change assessment:

- **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 Engineers Australia, CSIRO and the Bureau of Meteorology as part of the revision of Australian Rainfall and Runoff will provide better direction on the possible impacts of climate change on rainfall.

A 10% increase in rainfall results in up to a 0.56m increase in flood levels. A 30% increase in rainfall increases flood levels for a 1% AEP event by 1.68m. Table 10 summarises the impact of climate change on the 1% AEP flood levels. Figure 43 to Figure 48 present the climate change peak flood levels and depths.

Table 10: Climate Change Results

Location	1% AEP Flood Level (mAHD)	Change in Flood Level (m)		
		10% Rainfall Increase	20% Rainfall Increase	30% Rainfall Increase
Upstream Frederickton (river)	6.97	0.28	0.53	0.79
Glenrock Drain (river)	7.77	0.32	0.62	0.92
Pola Creek (river)	8.03	0.33	0.66	1

Traffic Bridge (river)	8.48	0.4	0.75	1.13
Railway Bridge (river)	10.01	0.56	1.11	1.68
Old Station Road (floodplain)	6.6	0.41	0.82	1.21
East Kempsey Wetland (floodplain)	6.65	0.41	0.81	1.2

By looking at the change in rainfall probability for different design events and rainfall increases due to climate change the probability of the current design events in a changed climate can be calculated (Table 11). Based on this assessment it is likely that a 10% AEP event will turn into a 6 Year ARI event in a 10% increase in rainfall climate change scenario increasing its likelihood by 1.66. The frequency of flooding for Kempsey would increase significantly. This would mean that the Kempsey floodway would operate in a 6 year ARI event.

Table 11: Change in ARI of an Event in a changed climate

Current Event ARI (Year)	**ARI of Event in a changed climate**		
	10% Rainfall Increase	20% Rainfall Increase	30% Rainfall Increase
10	6	4	3
20	13	9	6
50	30	20	14

5 CONCLUSIONS

A detailed TUFLOW model was developed of the study area focused on the Kempsey CBD and surround area (West Kempsey, East Kempsey, South Kempsey, Frederickton, Red Hill, Frogmore and part of Austral Eden) making best use of available data. The lower floodplain area (Smithtown, Gladstone, Bellimbopinni, Belmore River area, Kinchela, Kinchela Creek area, Jerseyville, Hat Head and South West Rocks) was not included in the study area.

The model was calibrated to the 2001 and verified against the 2013 flood events. The model also produced similar flood behaviour to the previous modelling of the study area. There is minimal change from Council's previously adopted flood levels.

The TUFLOW model has been used to define flood behaviour for a range of design events (2 Year ARI, 5 Year ARI, 10, 5, 1, 0.5, 0.2 and 0.05 % AEP and Probable Maximum Flood). The impact of climate change rainfall increases on flood levels was quantified. The model is considered fit for purpose for assessing options as part of the Kempsey Floodplain Risk management study.

Refinement of this model is likely to be required with the proposed review of the Lower Macleay Flood Risk Management Plan and any redevelopment of the greater Macleay RUBICON model. This would the incorporation of updated survey of the Lower Macleay levees.

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21. Practical Consideration of Climate Change
Floodplain Risk Management Guideline
New South Wales Government, 2007



Figures

FIGURE 1
STUDY AREA

Austral Eden
Pacific Highway
Frederickton
Christmas Creek
Macleay River
Frogmore
Greenhill
Yarravel
Pacific Highway
Glenrock Drain
Old Pola Creek
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Pola Creek
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
East Kempsey
East Kempsey Wetland
South Kempsey
Gills Creek
Boat Harbour Creek

N

Hydraulic Model Extent

0 0.5 1 2 km

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FIGURE 2
STUDY AREA
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Willow Drain Backflow Area
Verges Drain
First Lane Levee
First Lane
Dangar St Backflow Area
Local Floodway No. 1
Hampden Hall
Old Pola
Pola Creek
Tozer Street
River Street
Cochrane Street
Kemp Street
Broughton Street
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
South West Rocks Road
Holman Street
Forth Street
Cooks Lane
Wide Street Cooks Lane Levee
Euroka Creek
Elbow Street
Belgrave Street
Clyde Street
RSL Levee Wall
Rudder Street
Eden St Levee
N
Hydraulic Model Extent
0 0.25 0.5 1 km

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NOTE: Christmas Creek included as a storage area.

FIGURE 3
HYDRAULIC MODEL SETUP

Austral Eden
Downstream H Boundary
H
time
Frederickton
Frederickton Levee
Christmas Creek
Inflow Boundary
Q
time
Greenhill
Macleay River
Frogmore
Yarravel
Glenrock Drain
Old Pola Creek
Pacific Highway
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
East Kempsey
East Kempsey Wetland
South Kempsey
Gills Creek
Boat Harbour Creek
N
Model Extents
Floodgates
Railway Embankment
Creeks and Drains
Inflow Boundaries
Downstream Boundaries
Culverts
Bridges
Local Inflows
Buildings
0 1 2 4 km

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NOTE: Christmas Creek included as a storage area.

FIGURE 4
HYDRAULIC MODEL SETUP
KEMPSEY

West Kempsey
Kempsey
East Kempsey

Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Old Pola
Sea Street
Danger Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Rudder Street
Eden St Levee
East Kempsey Wetland

N

- Model Extents
- Floodgates
- Railway Embankment
- Creeks and Drains
- Inflow Boundaries
- Downstream Boundaries
- Culverts
- Bridges
- Local Inflows
- Buildings

0 0.25 0.5 1 km

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FIGURE 5
MANNINGS 'n' VALUES

Austral
Eden
Frederickton
Christmas Creek
Macleay River
Frogmore
Glenrock Drain
Old Pola Creek
Pacific Highway
Red Hill
Verges Drain
Kempsey
Chapmans Creek
Pola Creek
Euroka Creek
East Kempsey
East Kempsey Wetland
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent
Surface Type (n value)
Floodplain (0.04)
Hard Surfaces (0.02)
Buildings (0.1)
Overbank (0.06)
Macleay River (0.025)

0 1 2 4
km

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FIGURE 6

CALIBRATION - 2001 EVENT
MODELLED VS OBSERVED FLOOD LEVELS

Austral Eden
Frederickton
Greenhill
Yarravel
Frogmore
Red Hill
West Kempsey
Euroka
Aldavilla
East Kempsey
South Kempsey
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
Pacific Highway
First Lane Levee
Verges Drain
Pola Creek
Chapmans Creek
Eureka Creek
RSL Levee Wall
Eden St Levee
East Kempsey Wetland
Gills Creek
Boat Harbour Creek

6.26
6.54
6.59
6.63
6.19
6.65
6.55
6.67
6.6
6.67
6.6
6.67
8.2
8.77
8.46
8.64
6.44
6.67
8.42
8.1
6.39
6.66
6.82
6.74
3.66
4.02
7.4
7.33
5.04
5.2
5.09
4.13
5.15
7.65

N

Model Extent
Observed Peak Flood Levels (mAHD)
Modelled Peak Flood Levels (mAHD)

Peak Flood Level (mAHD)
High : 10
Low : 3.5

0 1 2 4 km

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FIGURE 7

CALIBRATION - 2001 EVENT
MODELLED VS OBSERVED FLOOD LEVELS KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Old Pole
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Rudder Street

6.19
6.65
6.55
6.67
6.34
6.67
6.6
6.67
6.6
6.67
8.2
8.77
6.44
6.67
8.46
8.64
6.39
6.69
6.66
6.68
6.55
6.68
6.59
6.69
6.56
6.69
7.29
7.25
7.33
8.23
8.42
8.18
8.1
6.82
6.74
3.66
4.02
4.44
5.04
5.2
5.09

Model Extent
Observed Peak Flood Levels (mAHD)
Modelled Peak Flood Levels (mAHD)

Peak Flood Level (mAHD)
High : 10
Low : 3.5

N

0 0.25 0.5 1 km

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FIGURE 8

2001 EVENT CALIBRATION
MODELLED VS OBSERVED
KEMPSEY TRAFFIC BRIDGE HYDROGRAPH

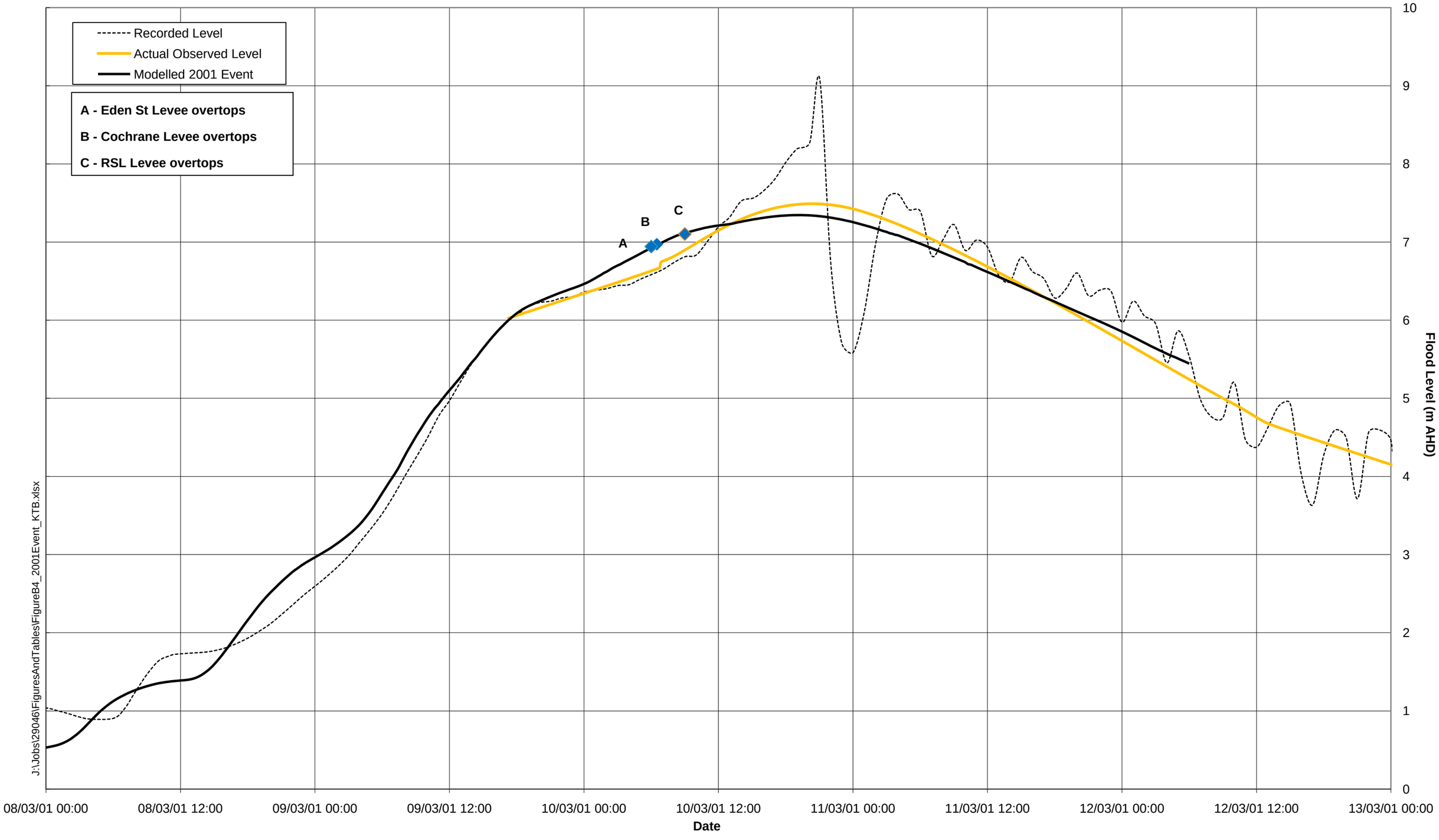


FIGURE 9

CALIBRATION - 2013 EVENT
MODELLED VS OBSERVED FLOOD LEVELS

Austral Eden
Frederickton
Greenhill
Yarravel
Christmas Creek
Macleay River
Pacific Highway
Frogmore
Glenrock Drain
West Kempsey
Verges Drain
Red Hill
Kempsey
First Lane Levee
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Pola Creek
RSL Levee Wall
Eden St Levee
East Kempsey
East Kempsey Wetland
South Kempsey
Gills Creek

4.95
4.98
4.23
4.35
5.09
4.79
3.73
5.45
5.24
4.84
4.71
5.6
5.37
5.33
5.16
3.89
4.22
4.11
4.21
3.34
5.83
5.84
5.4
5.43
5.51
5.46
6.32
6.24
6.32
6.25
6.94
6.92
7.39
7.31
7.54
7.68
4.13
4.88

N

Observed Peak Flood Levels (mAHD)
Modelled Peak Flood Levels (mAHD)
Model Extent

Peak Flood Level (mAHD)
High : 8.5
Low : 4.0

0 1 2 4 km

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FIGURE 10
CALIBRATION - 2013 EVENT
MODELLED VS OBSERVED FLOOD LEVELS
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane
First Lane Levee
6.32
6.25
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
7.46
7.65
Belgrave Street
RSL Levee Wall
Clyde Street
Rudder Street
Eden St Levee
7.39
7.31
6.94
6.92
N
Observed Peak Flood Levels (mAHD)
Modelled Peak Flood Levels (mAHD)
Model Extent
Peak Flood Level (mAHD)
High : 8.5
Low : 4.0
0 0.25 0.5 1 km

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FIGURE 11

2013 EVENT CALIBRATION
MODELLED VS OBSERVED
KEMPSEY TRAFFIC BRIDGE HYDROGRAPH

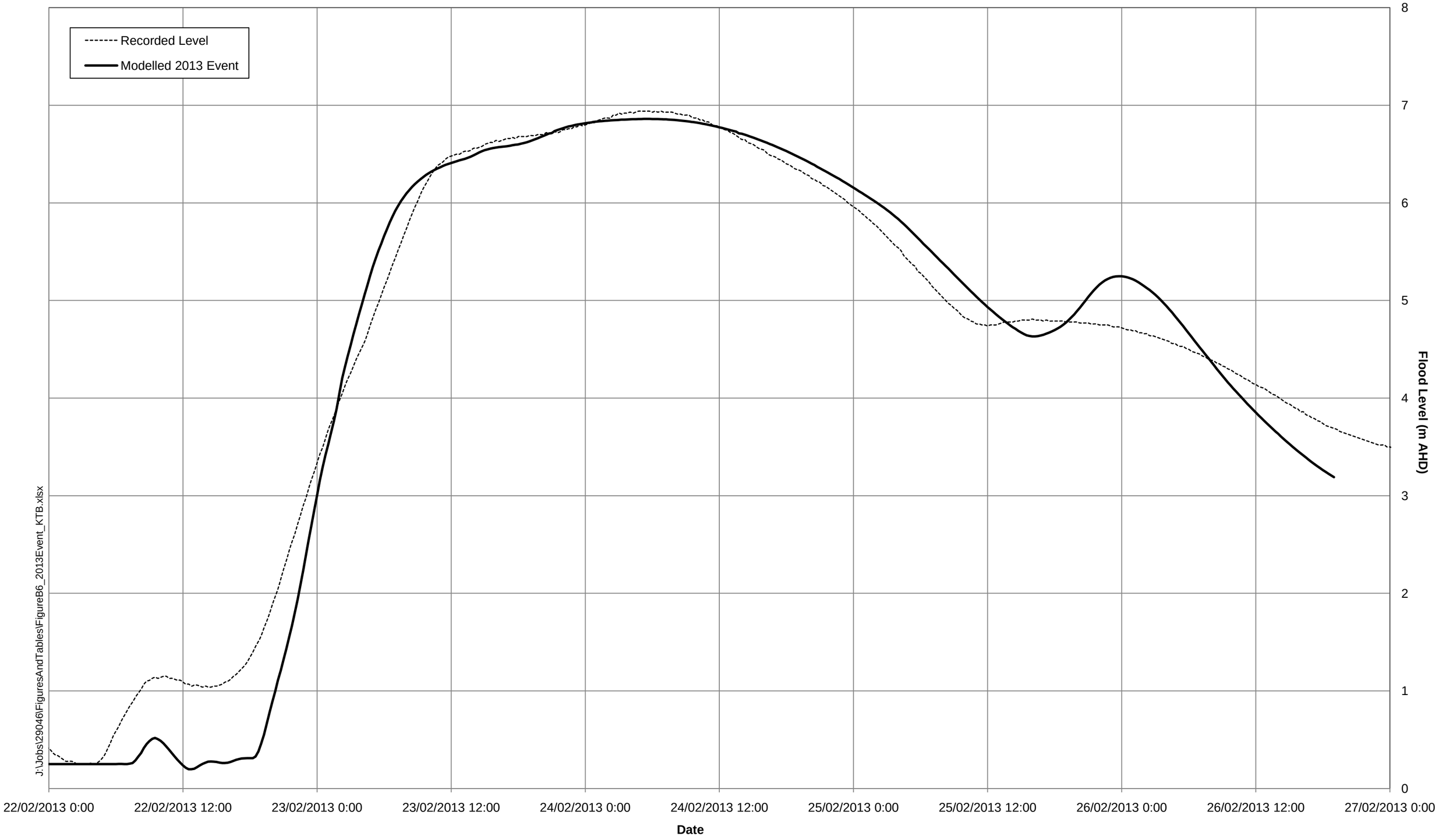
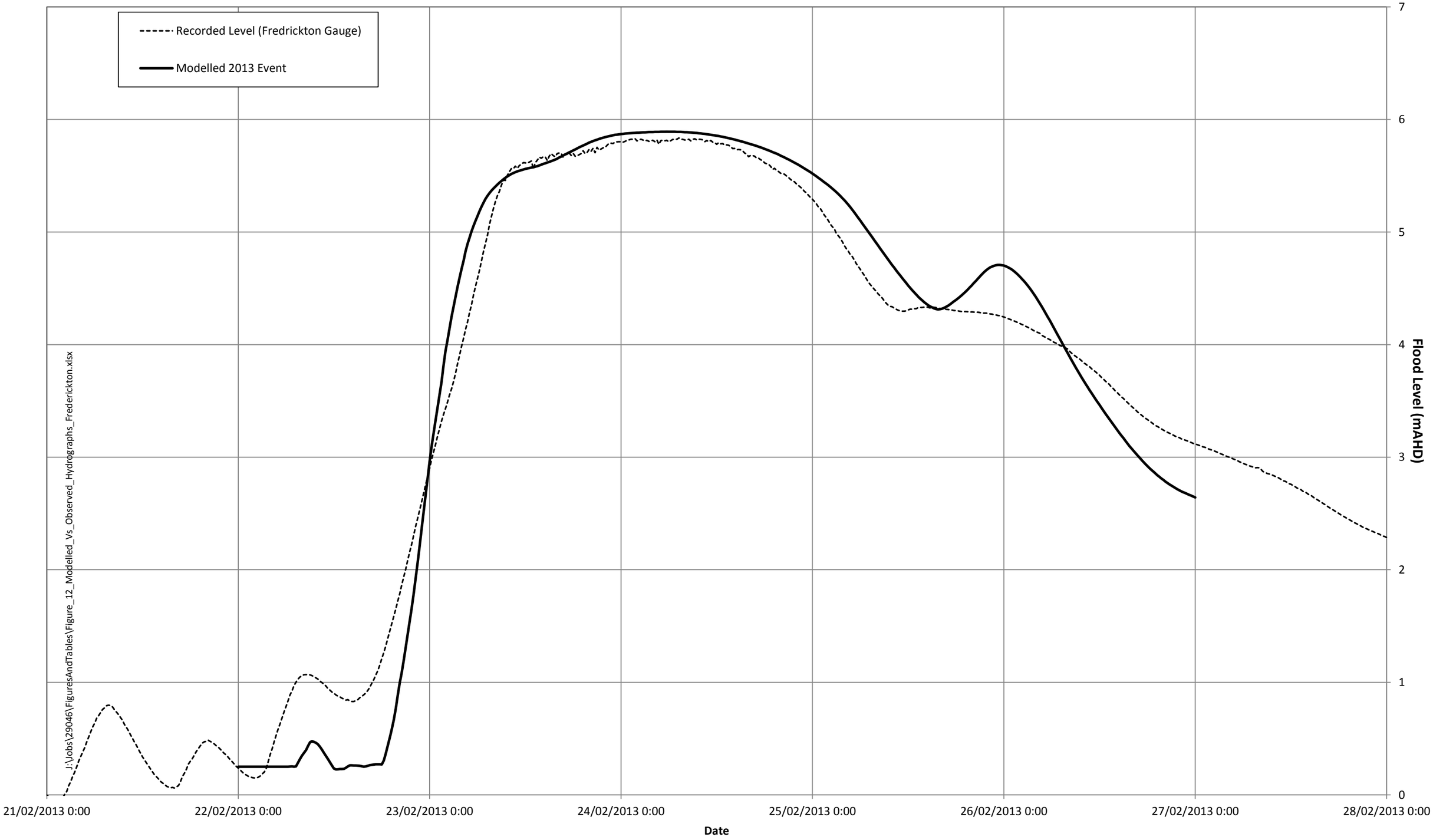


FIGURE 12

2013 EVENT CALIBRATION
MODELLED VS OBSERVED HYDROGRAPHS
FREDERICKTON



NOTE: Reporting locations correspond to tables in report.

FIGURE 13
FLOOD MAPPING LOCATIONS

Austral Eden
Frederickton
Christmas Creek
Upstream Frederickton
Greenhill
Frogmore
L21
L22
Pacific Highway
Yarravel
L20
Glenrock Drain
Old Pola Creek
Macleay River Inflow
L19
Verges Drain
West Kempsey
L18
L17
Pola Creek
Red Hill
Kempsey
L16
L15
Old Station Road
Euroka
L1
Euroka Creek
L3
L11
L12
L14
L10
L13
Traffic Bridge
East Kempsey Swamp
Aldavilla
L2
L7
L8
L9
Railway Bridge
Main Channel Flow
L4
L6
L5
River Street Flow
Flow into Floodway
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent
Reporting Locations
Sensitivity Reporting Locations
Flow Reporting Locations

1% AEP Peak Flood Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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NOTE: Reporting locations correspond to tables in report.

FIGURE 14
FLOOD MAPPING LOCATIONS
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Verges Drain
First Lane
Macleay Valley Way
Pola Creek
Glenrock Drain
Old Pola
South West Rocks Road
Rudder Street
Old Station Road
Euroka Creek
Cooks Lane
Belgrave Street
Clyde Street
Traffic Bridge
Railway Bridge
River Street Flow
Flow into Floodway
Main Channel Flow
L1
L2
L3
L4
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17
L18
L19
L20

Model Extent
Reporting Locations
Sensitivity Reporting Locations
Flow Reporting Locations

1% AEP Peak Flood Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

N

0 0.25 0.5 1 km

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FIGURE 15

PEAK FLOOD DEPTHS AND LEVELS
2-YEAR ARI EVENT

Greenhill
Yarravel
Aldavilla
Euroka
West Kempsey
Kempsey
Frederickton
Austral
Eden
Frogmore
Red Hill
East Kempsey
South Kempsey
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
Pola Creek
Verges Drain
First Lane Levee
Chapmans Creek
Euroka Creek
Wide Street/Gooks Lane Levee
Eden St Levee
RSL Levee Wall
Civils Creek
Boat Harbour Creek
Pacific Highway

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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FIGURE 16
PEAK FLOOD DEPTHS AND LEVELS
2-YEAR ARI EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Pola Creek
Rudder Street
South West Rocks Road
Old F

4 5
4
4
5
5
5
4 5
5
4
5
6

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 0.25 0.5 1 km

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FIGURE 17

PEAK FLOOD DEPTHS AND LEVELS
5-YEAR ARI EVENT

Austral Eden
Frederickton
Greenhill
Yarravel
Frogmore
Pacific Highway
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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FIGURE 18
PEAK FLOOD DEPTHS AND LEVELS
5-YEAR ARI EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Macleay Valley Way
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Pola Creek
South West Rocks Road
Rudder Street

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 0.25 0.5 1 km

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FIGURE 19

PEAK FLOOD DEPTHS AND LEVELS
10% AEP EVENT

Austral Eden
Frederickton
Greenhill
Yarravel
West Kempsey
Kempsey
Euroka
Aldavilla
Red Hill
Frogmore
East Kempsey
South Kempsey
Christmas Creek
Macleay River
Pacific Highway
Glenrock Drain
Old Pola Creek
First Lane Levee
Verges Drain
Pola Creek
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
East Kempsey Wetland
Gills Creek
Boat Harbour Creek
5
6
7
8
9

N

Flood Level (mAHD)
- Major Contours (1m interval)
- Minor Contours (0.5m interval)
- Model Extent

Depth (m)
- 0 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 15
- > 15

0 1 2 4 km

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FIGURE 20

PEAK FLOOD DEPTHS AND LEVELS
10% AEP EVENT
KEMPSEY

West Kempsey

Kempsey

East Kempsey

Tozer Street

River Street

Cochrane Street

Kemp Street

Verges Drain

First Lane Levee

First Lane

Sea Street

Dangar Street

Short Street

Wide Street

Gladstone Street

Macleay Valley Way

Old P

Pola Creek

South West Rocks Road

Euroka Creek

Wide Street/Cooks Lane Levee

Cooks Lane

Belgrave Street

Clyde Street

RSL Levee Wall

Eden St Levee

Rudder Street

9

8

7

6

5

4

N

Flood Level (mAHD)

- Major Contours (1m interval)
- Minor Contours (0.5m interval)
- Model Extent

Depth (m)

- 0 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 15
- > 15

0 0.25 0.5 1 km

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FIGURE 21

PEAK FLOOD DEPTHS AND LEVELS
5% AEP EVENT

Austral Eden
Frederickton
Greenhill
Yarravel
Christmas Creek
Macleay River
Pacific Highway
Frogmore
Glenrock Drain
Old Pola Creek
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Chapmans Creek
Euroka
Kempsey
Pola Creek
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

5
6
7
8
9
10

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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FIGURE 22

PEAK FLOOD DEPTHS AND LEVELS
5% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Old P
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Rudder Street
10
7
6
9
8

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 0.25 0.5 1 km

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FIGURE 23
PEAK FLOOD DEPTHS AND LEVELS
1% AEP EVENT

Austral Eden
Frederickton
Greenhill
Yarravel
Frogmore
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
Pacific Highway
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
East Kempsey
East Kempsey Wetland
South Kempsey
Gills Creek
Boat Harbour Creek

6
1
9
8
12
11
10
7

N

Model Extent
Flood Level (mAHD)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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FIGURE 24
PEAK FLOOD DEPTHS AND LEVELS
1% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Hampden Hall
Verges Drain
First Lane
First Lane Levee
Eden St Levee
Wide Street/Cooks Lane Levee
RSL Levee Wall
Eurokā Creek
Pola Creek
Macleay Valley Way
Tozer Street
River Street
Cochrane Street
Kemp Street
Sea Street
Dangar Street
Short Street
Wide Street
Cooks Lane
Gladstone Street
Belgrave Street
Clyde Street
Rudder Street
South West Rocks Road
12
11
10
9
8
7

N

Model Extent
Flood Level (mAHD)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 0.25 0.5 1 km

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FIGURE 25

PEAK FLOOD DEPTHS AND LEVELS
0.5% AEP EVENT

Austral Eden
Frederickton
Frogmore
Greenhill
Yarravel
West Kempsey
Kempsey
Red Hill
Euroka
Aldavilla
East Kempsey
South Kempsey
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
Pacific Highway
First Lane Levee
Verges Drain
Chapmans Creek
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
Gills Creek
Boat Harbour Creek
6
7
8
9
10
11
12
13
14
15

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure25_Peak_Flood_Depths_and_Levels_05%_AEP_event.mxd

FIGURE 26
PEAK FLOOD DEPTHS AND LEVELS
0.5% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Hampden Hall
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Old Pacific Highway
Pola Creek
South West Rocks Road
Rudder Street
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Eden St Levee
Clyde Street
RSL Levee Wall
13
12
11
10
9
8
6

Model Extent
Flood Level (mAHD)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

N

0 0.25 0.5 1 km

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FIGURE 27

PEAK FLOOD DEPTHS AND LEVELS
PMF EVENT

Austral Eden
Frederickton
Frogmore
Greenhill
Yarravel
Red Hill
Kempsey
Euroka
Aldavilla
East Kempsey
Christmas Creek
Macleay River
Pacific Highway
Old Pola Creek
Glenrock Drain
First Lane Levee
Verges Drain
Chapmans Creek
Euroka Creek
Wide Street
Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
Gills Creek
Boat Harbour Creek

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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FIGURE 28
PEAK FLOOD DEPTHS AND LEVELS
PMF EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Euroka Creek
Verges Drain
First Lane
First Lane Levee
Eden St Levee
Cook St/Cooks Lane Levee
RSL Levee Wall
Hamden Hall
Tozer Street
River Street
Cochrane Street
Kemp Street
Sea Street
Dangar Street
Short Street
Gladstone Street
Wide Street
Cooks Lane
Clyde Street
Macleay Valley Way
Pola Creek
Rudder Street
South West Rocks Road
Old Pacific Highway

Model Extent
Flood Level (mAHD)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

N

0 0.25 0.5 1 km

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FIGURE 29
MAXIMUM FLOOD VELOCITIES
2-YEAR ARI EVENT

Austral Eden
Frederickton
Christmas Creek
Macleay River
Greenhill
Frogmore
Yarravel
Pacific Highway
Glenrock Drain
Old Pola Creek
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Pola Creek
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
RSL Levee Wall
Eden St Levee
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent

Velocity (m/s)

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

0 1 2 4 km

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FIGURE 30
MAXIMUM FLOOD VELOCITIES
2-YEAR ARI EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Gladstone Street
Wide Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Rudder Street

N

Model Extent
Velocity (m/s)
0.00 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00

0 0.25 0.5 1 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure30_Maximum_Flood_Velocities_2yr_ARI_Kempsey.mxd

FIGURE 31
MAXIMUM FLOOD VELOCITIES
5-YEAR ARI EVENT

Austral Eden
Frederickton
Greenhill
Yarravel
Frogmore
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
Pacific Highway
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent

Velocity (m/s)

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

0 1 2 4 km

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FIGURE 32
MAXIMUM FLOOD VELOCITIES
5-YEAR ARI EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Hampden Hall
Old P
Sea Street
Dangar Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Short Street
Wide Street
Gladstone Street
Euroka Creek
Wirle Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Rudder Street
Eden St Levee

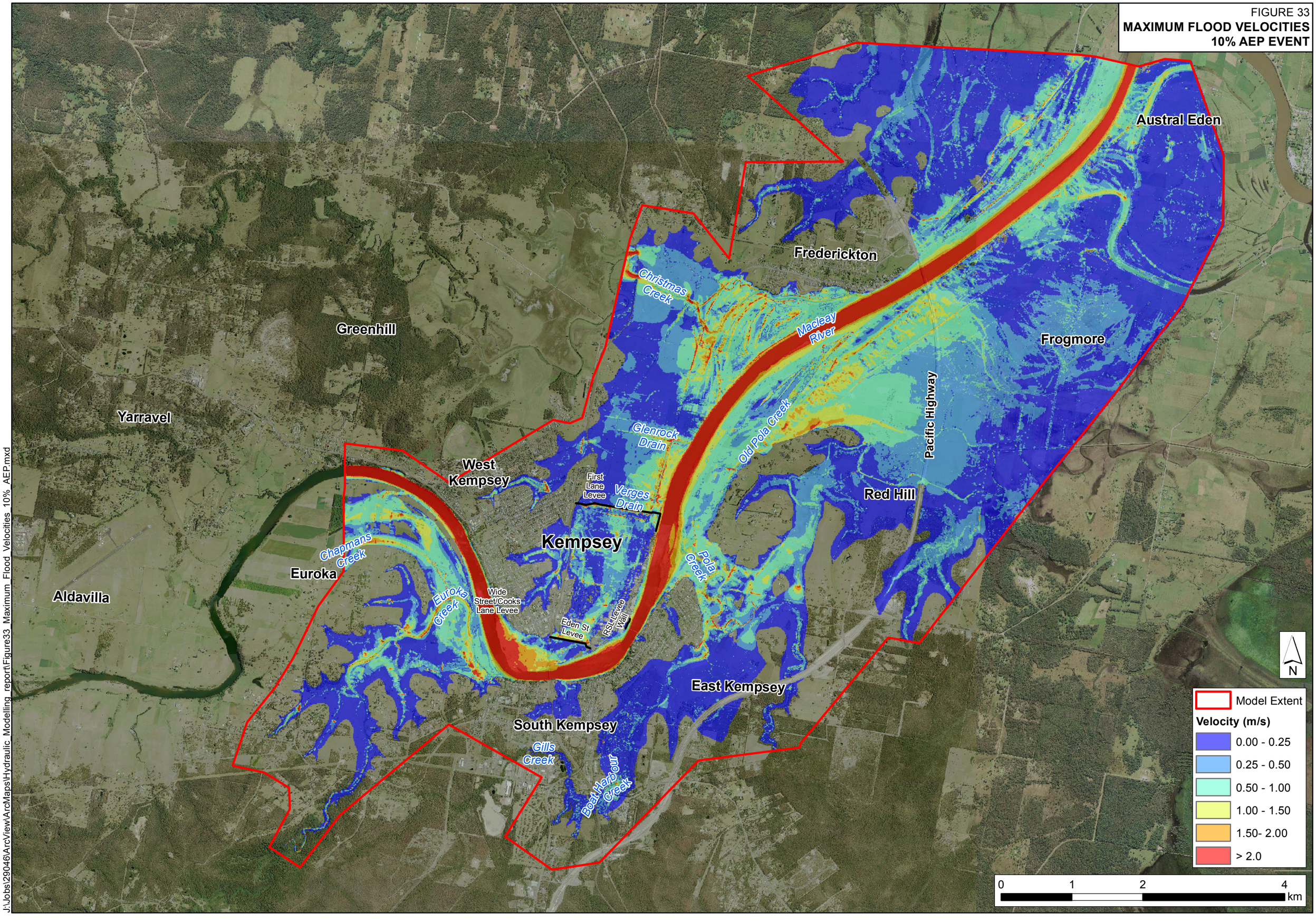
N

Model Extent
Velocity (m/s)
0.00 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00

0 0.25 0.5 1 km

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FIGURE 33
MAXIMUM FLOOD VELOCITIES
10% AEP EVENT



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FIGURE 34
MAXIMUM FLOOD VELOCITIES
10% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Hampden Hall
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Rudder Street

N

Model Extent

Velocity (m/s)

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50- 2.00
- > 2.0

0 0.25 0.5 1 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure34_Maximum_Flood_Velocities_10%_AEP_Kempsey.mxd

FIGURE 35

MAXIMUM FLOOD VELOCITIES
5% AEP EVENT

Austral Eden
Frederickton
Greenhill
Yarravel
Frogmore
Christmas Creek
Macleay River
Glenrock Drain
Old Pola Creek
Pacific Highway
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL Levee Wall
Pola Creek
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent

Velocity (m/s)

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

0 1 2 4 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure35_Maximum_Flood_Velocities_5%_AEP.mxd

FIGURE 36
MAXIMUM FLOOD VELOCITIES
5% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Hampden Hall
Old Pacific Highway
Sea Street
Dangar Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Short Street
Gladstone Street
Wide Street
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Rudder Street
Eden St Levee

N

Model Extent
Velocity (m/s)
0.00 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00

0 0.25 0.5 1 km

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FIGURE 37
MAXIMUM FLOOD VELOCITIES
1% AEP EVENT

Austral Eden
Frederickton
Christmas Creek
Macleay River
Frogmore
Pacific Highway
Greenhill
Yarravel
Glenrock Drain
Old Pola Creek
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Pola Creek
Aldavilla
Euroka Creek
Wide Street/Cooks Lane Levee
Eden St Levee
RSL levee Wall
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent
Velocity (m/s)
0 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00-1.50
1.50 - 2.00
>2.00

0 1 2 4 km

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FIGURE 38
MAXIMUM FLOOD VELOCITIES
1% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Hampden Hall
Old Pacific Highway
Sea Street
Dangar Street
Short Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Wide Street
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Rudder Street
Eden St Levee

N

Model Extent

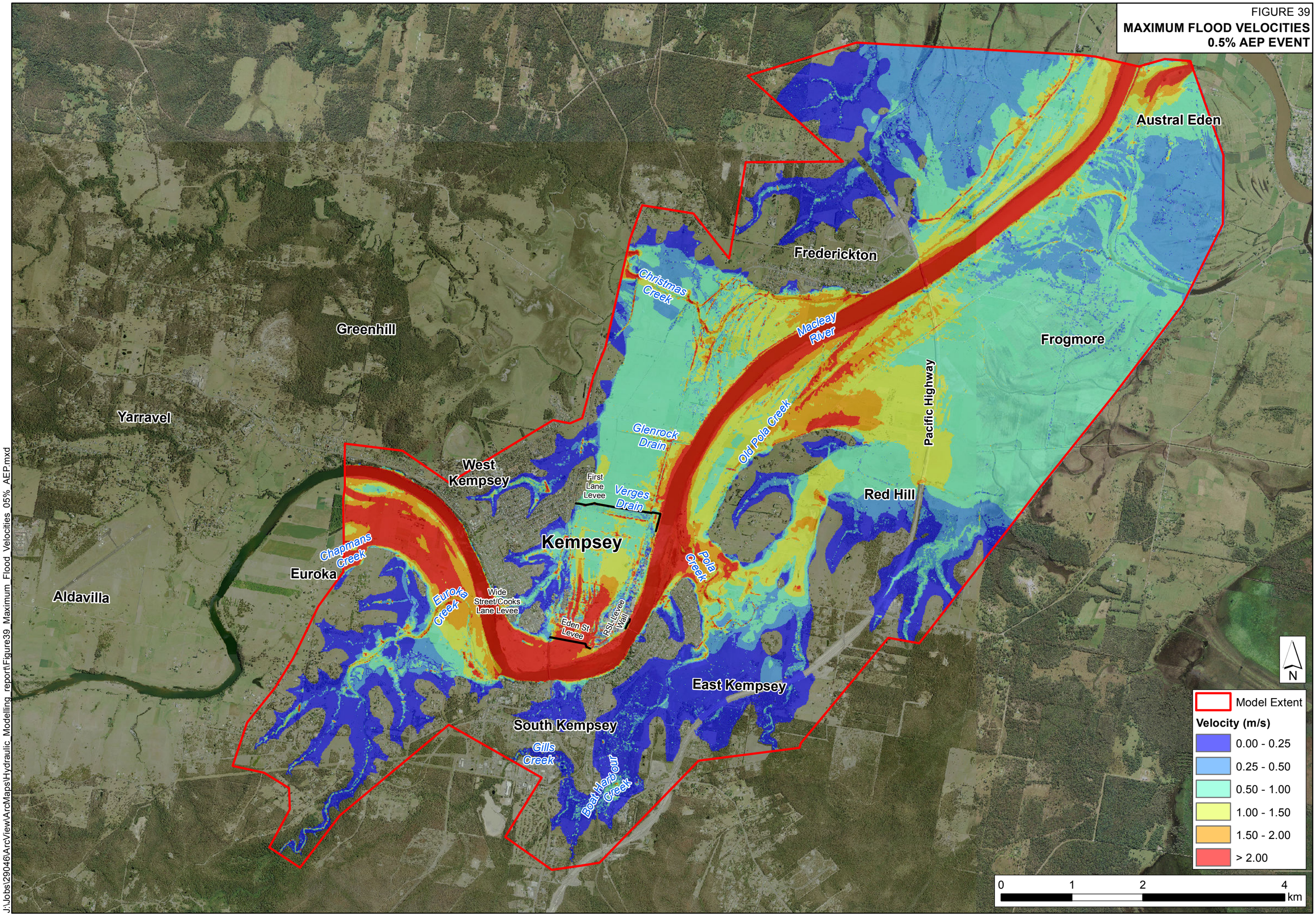
Velocity (m/s)

- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00-1.50
- 1.50 - 2.00
- >2.00

0 0.25 0.5 1 km

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FIGURE 39
MAXIMUM FLOOD VELOCITIES
0.5% AEP EVENT



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FIGURE 40
MAXIMUM FLOOD VELOCITIES
0.5% AEP EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Hamden Hall
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Rudder Street
Eden St Levee

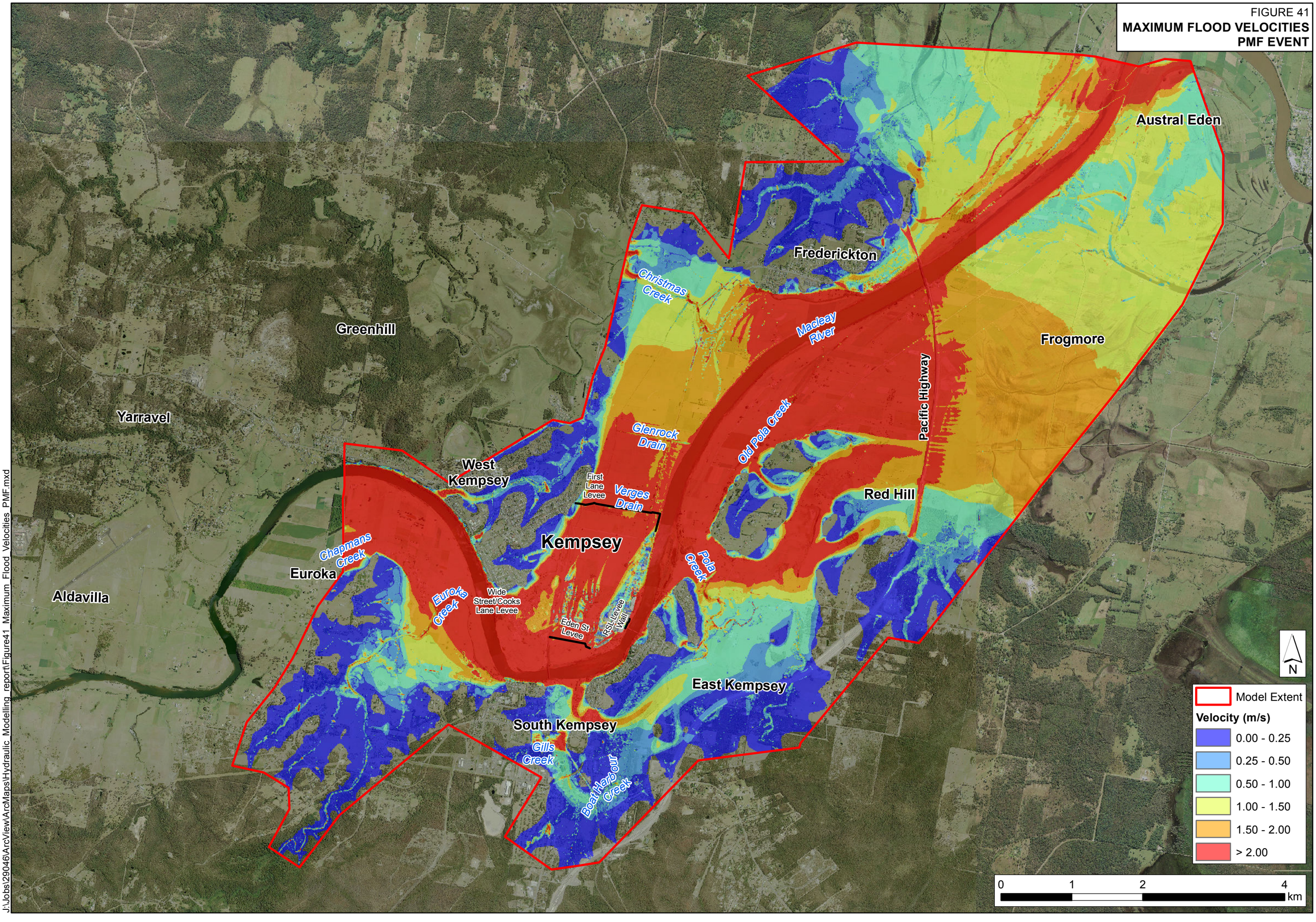
Model Extent
Velocity (m/s)
0.00 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00

N

0 0.25 0.5 1 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure40_Maximum_Flood_Velocities_05%_AEP_Kempsey.mxd

FIGURE 41
MAXIMUM FLOOD VELOCITIES
PMF EVENT



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FIGURE 42
MAXIMUM FLOOD VELOCITIES
PMF EVENT
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Hampden Hall
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
RSL Levee Wall
Clyde Street
Rudder Street
Eden St Levee

N

Model Extent
Velocity (m/s)
0.00 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00

0 0.25 0.5 1 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure42_Maximum_Flood_Velocities_PMF_Kempsey.mxd

FIGURE 43

DESIGN EVENT

PEAK FLOOD DEPTHS AND LEVEL CONTOURS

1% AEP EVENT WITH A 10% RAINFALL INCREASE

Austral Eden

Frederickton

Christmas Creek

Macleay River

Frogmore

Greenhill

Yarravel

Pacific Highway

Glenrock Drain

Old Polla Creek

West Kempsey

First Lane Levee

Verges Drain

Red Hill

Kempsey

Chapmans Creek

Euroka

Aldavilla

Pola Creek

Elliotts Creek

Wide Street/Cooks Lane Levee

Eden St Levee

RSL Levee Wall

East Kempsey

South Kempsey

Gills Creek

Boat Harbour Creek

N

Model Extent

Flood Level (mAHD)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1

1 - 2

2 - 5

5 - 10

10 - 15

> 15

0 1 2 4 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure43_Peak_Flood_Depths_Levels_1%AEP_10%_Rainfall.mxd

FIGURE 44

DESIGN EVENT
PEAK FLOOD DEPTHS AND LEVEL CONTOURS
1% AEP EVENT WITH A 10% RAINFALL INCREASE
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Hampden Hall
Spa Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Rudder Street

Model Extent
Flood Level (mAHD)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

N

0 0.25 0.5 1 km

J:\Jobs\29046\ArcView\ArcMaps\Hydraulic_Modelling_report\Figure44_Peak_Flood_Depths_Levels_1%AEP_10%_Rainfall_Kempsey.mxd

FIGURE 45

DESIGN EVENT
PEAK FLOOD DEPTHS AND LEVEL CONTOURS
1% AEP EVENT WITH A 20% RAINFALL INCREASE

Austral Eden
Frederickton
Greenhill
Yarravel
Frogmore
Christmas Creek
Macleay River
Pacific Highway
Old Pola Creek
Glenrock Drain
West Kempsey
First Lane Levee
Verges Drain
Red Hill
Kempsey
Chapmans Creek
Euroka
Aldavilla
Pola Creek
Eurolia Creek
Wide Street/Cooper Lane Levee
Eden St Levee
RSL Levee Wall
East Kempsey
South Kempsey
Gills Creek
Boat Harbour Creek

N

Model Extent

Flood Level (m)

Major Contours (1m interval)

Minor Contours (0.5m interval)

Depth (m)

0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

0 1 2 4 km

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FIGURE 46

DESIGN EVENT
PEAK FLOOD DEPTHS AND LEVEL CONTOURS
1% AEP EVENT WITH A 20% RAINFALL INCREASE
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Hampden Hall
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Pola Creek
South West Rocks Road
Euroka Creek
Wide Street/Cooks Lane Levee
Cooks Lane
Belgrave Street
RSL Levee Wall
Clyde Street
Eden St Levee
Rudder Street

Model Extent
Flood Level (m)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

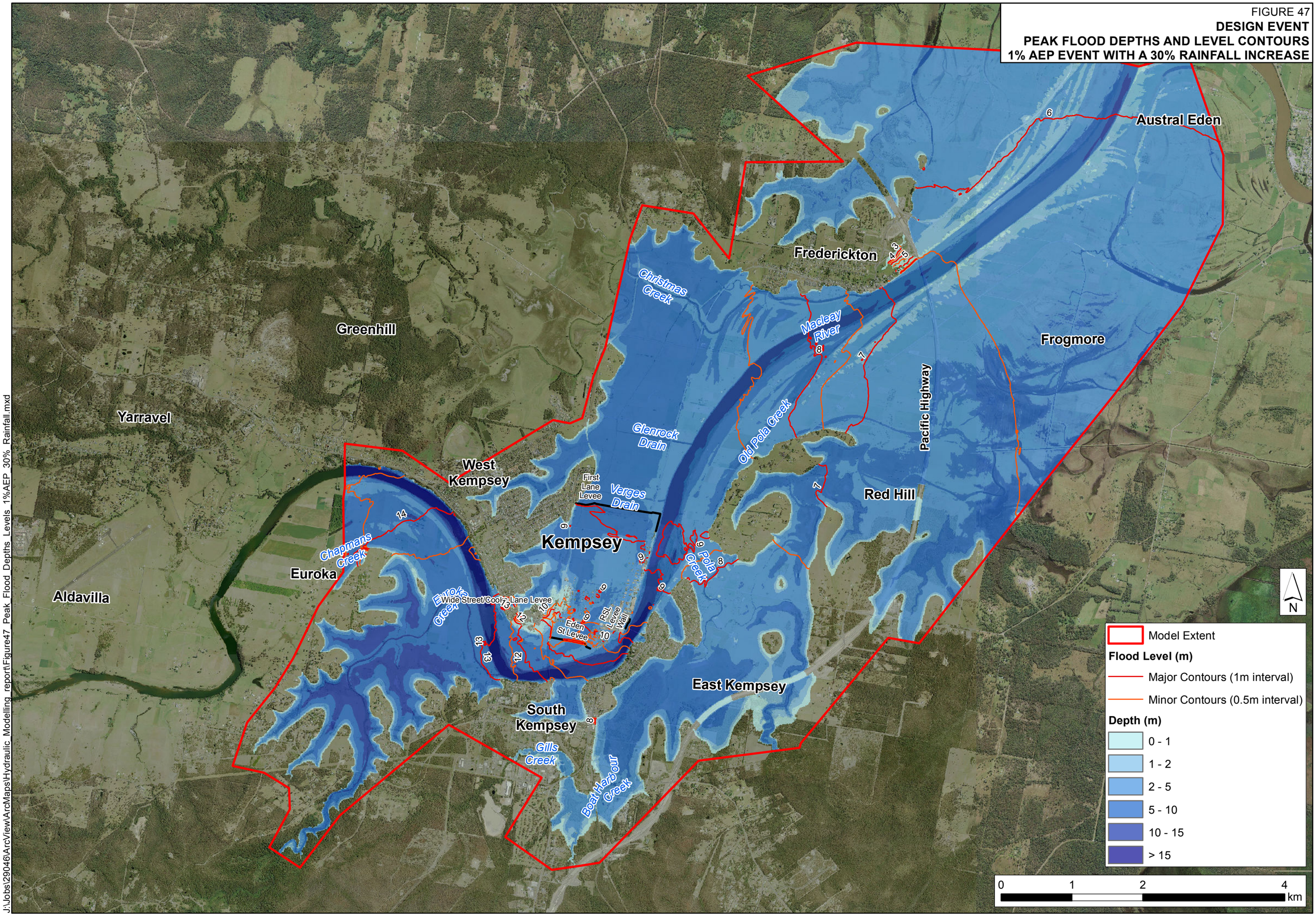
N

0 0.25 0.5 1 km

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FIGURE 47

DESIGN EVENT
PEAK FLOOD DEPTHS AND LEVEL CONTOURS
1% AEP EVENT WITH A 30% RAINFALL INCREASE



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FIGURE 48

DESIGN EVENT
PEAK FLOOD DEPTHS AND LEVEL CONTOURS
1% AEP EVENT WITH A 30% RAINFALL INCREASE
KEMPSEY

West Kempsey
Kempsey
East Kempsey
Tozer Street
River Street
Cochrane Street
Kemp Street
Verges Drain
First Lane Levee
First Lane
Sea Street
Dangar Street
Short Street
Wide Street
Gladstone Street
Macleay Valley Way
Hampden Hall
Pola Creek
South West Rocks Road
Euroka Creek
Cooks Lane
Wide Street/Cooks Lane Levee
Belgrave Street
Clyde Street
RSL Levee Wall
Eden St Levee
Rudder Street
14
13
12
10
9
8

Model Extent
Flood Level (m)
Major Contours (1m interval)
Minor Contours (0.5m interval)
Depth (m)
0 - 1
1 - 2
2 - 5
5 - 10
10 - 15
> 15

N

0 0.25 0.5 1 km

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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 sulphur 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 and 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	The measures that might be feasible for the management of a particular area of

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

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

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

mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the

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

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