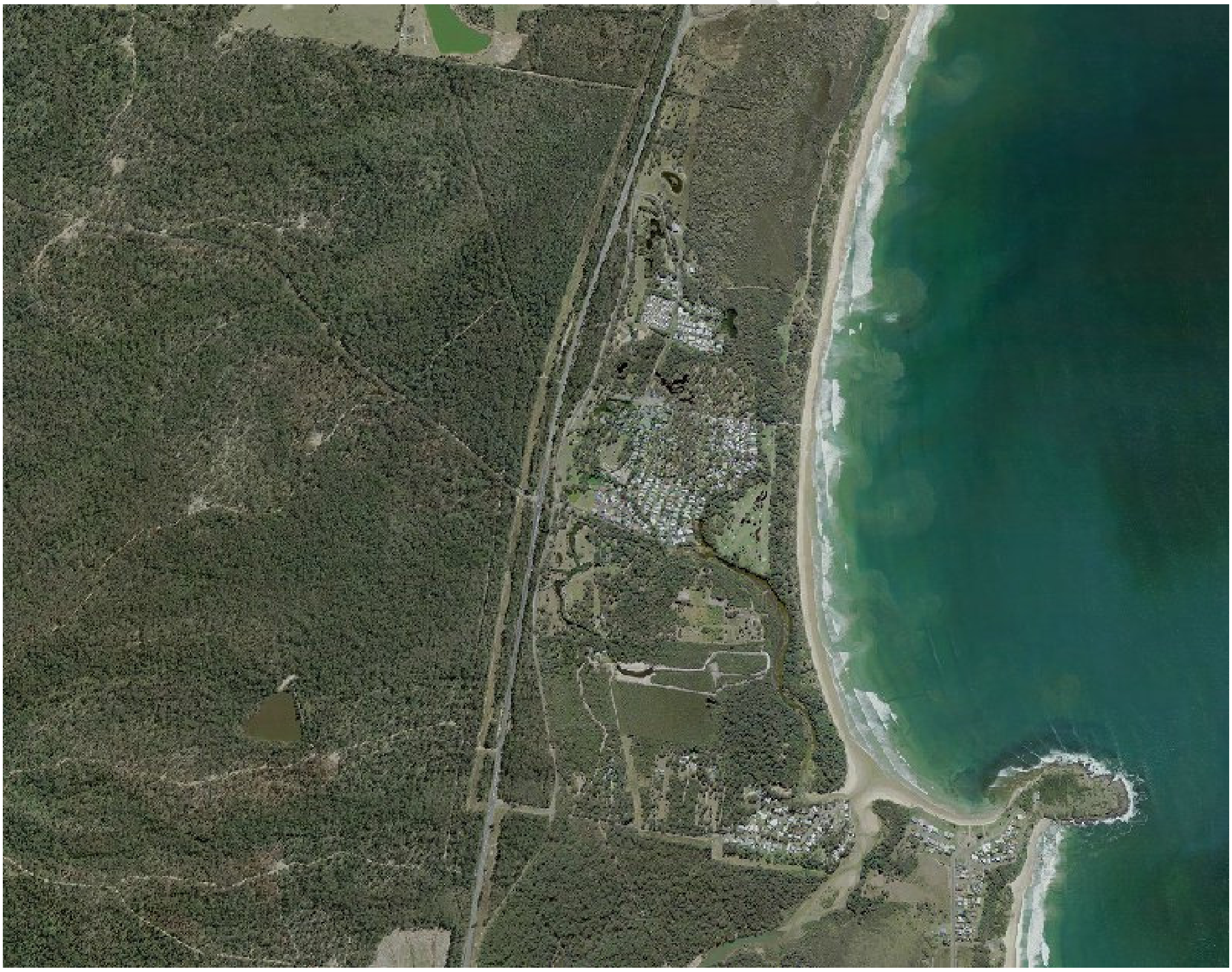
Roads & Maritime Services

Arrawarra Flood Assessment Independent Review

Woolgoolga to Ballina Pacific Highway Upgrade

Draft Report



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INDEPENDENT REVIEW OF ARRAWARRA FLOOD MODELLING WOOLGOOLGA TO BALLINA PACIFIC HIGHWAY UPGRADE

DRAFT

DECEMBER 2013

Project **Independent Review of Arrawarra Flood Modelling Woolgoolga to Ballina Pacific Highway Upgrade**	**Project Number** **113052**
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INDEPENDENT REVIEW OF ARRAWARRA FLOOD MODELLING WOOLGOOLGA TO BALLINA PACIFIC HIGHWAY UPGRADE

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1. INTRODUCTION and BACKGROUND

A joint venture comprising Arup and Parsons Brinckerhoff (APBJV) is undertaking planning and design work for the Woolgoolga to Glenugie section of the Pacific Highway upgrade on the NSW north coast. The section includes the Arrawarra Creek catchment approximately 8 km north of Woolgoolga.

As part of the highway upgrade, for which the proposed alignment is slightly to the west of the current Pacific Highway alignment, it is therefore necessary to determine the flood impacts of the design on existing development in the area. For this purpose, APBJV have developed a RAFTS hydrologic model and TUFLOW hydraulic model of the Arrawarra Creek catchment.

Flooding is a prominent issue for the Arrawarra community, who provided several photos of historical flood events. Based on the available records, seven floods have occurred since 1999 (~14 year period) which have exceeded a level of 2.0 mAHD at the Darlington Park Resort. The highest flood at this location occurred in January 2012, the same event which caused substantial flood damage in the Corindi River catchment further north.

The environmental impact assessment work therefore requires a thorough consideration of flood risk and potential impacts on flood behaviour as a result of the proposed Pacific Highway upgrade works. The flood modelling assessment undertaken by the APBJV is documented in Reference 1.

WMAwater were engaged by RMS to peer review the flood modelling, and to oversee the data collection and community liaison process as an independent observer.

In undertaking the review, WMAwater has implicitly referred to the document *Two Dimensional Modelling in Urban and Rural Floodplains* (Engineers Australia, November 2012 – Reference 2), as a guideline for accepted flood modelling practice in Australia.

1.1. Scope of Review

The scope of work covered in this report is as follows:

- WMAwater's role in community consultation and observing the data collection process;
- Technical review of the development of hydrologic and hydraulic modelling;
- Review of the model validation in relation to observed historical flood behaviour; and
- Assessment of flood impacts resulting from the Pacific Highway Upgrade.

1.2. Catchment Description

Within this catchment, the proposed highway alignment will subtend multiple subcatchments, with four distinct crossings of upper subcatchment areas which differ notably in size and geometry (referred to as CA1 to CA4).

The Arrawarra Creek catchment is roughly bisected by the current Pacific Highway alignment. The majority of development in the catchment, comprising holiday parks and some rural residential, is located in the lower part of the catchment between the highway and the ocean. This developed area of the catchment is relatively low-lying, with ground levels typically below 3.5 mAHD. The upper part of the catchment, to the west of the highway, is primarily within the Wedding Bells State Forest.

1.3. Review of Historical Flood Information

In the course of the data collection phase of the study, WMAwater investigated historical newspaper archives and rainfall records to provide some context about the recent flood events, and to try and identify previous instances of flooding in the Arrawarra and neighbouring Corindi catchment.

A major limitation of the newspaper review was that primary sources of the reports were typically unavailable. Newspaper archiving efforts have been focussed on capital cities and major centres, and as a result there is patchy availability of regional information. In some instances, second-hand reports from distant areas were the only available source.

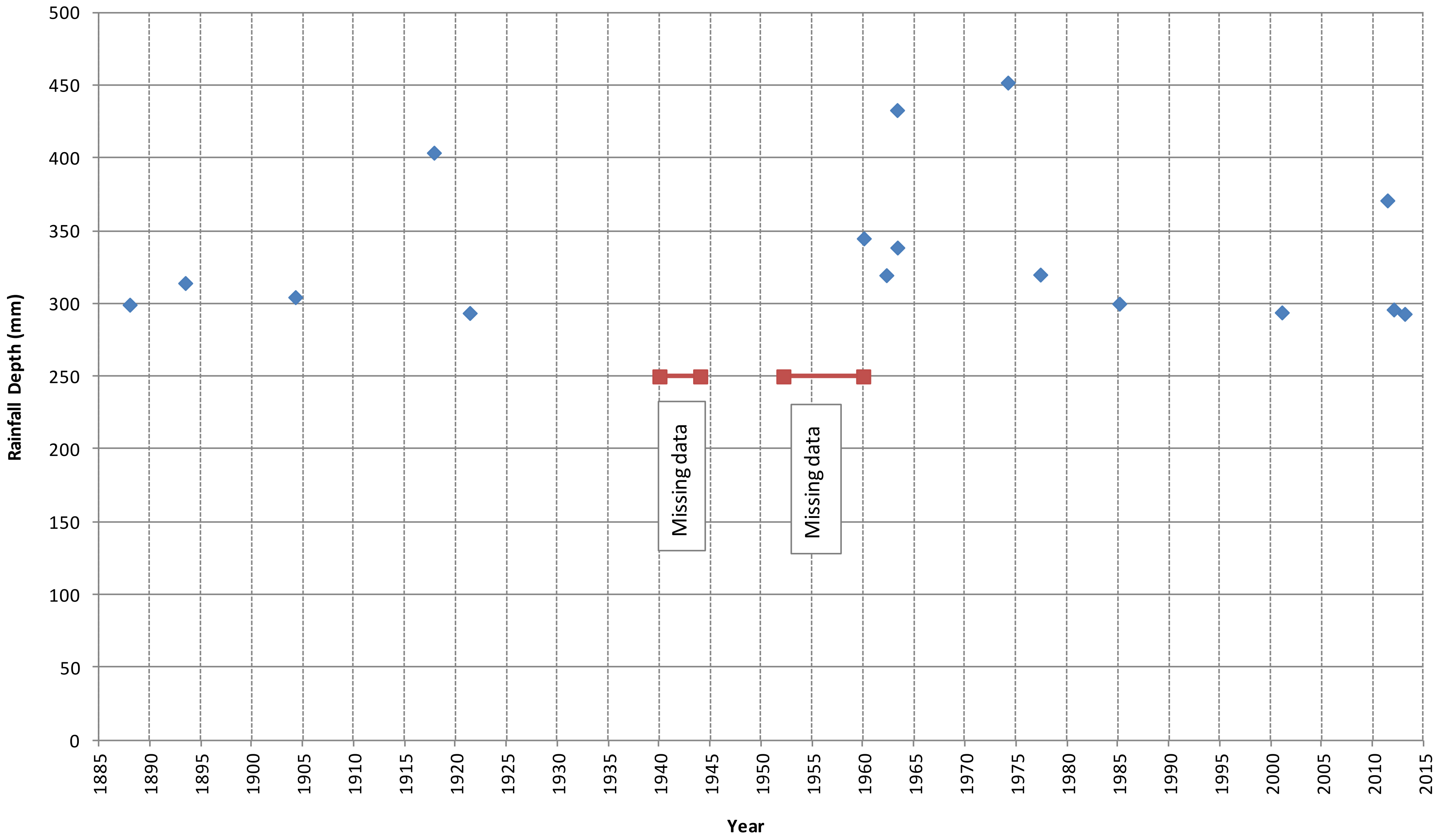
Long term rainfall records can sometimes provide a useful indication of when large floods may have occurred. However rainfall is not the only factor influencing the size of a flood, and other important considerations include whether the catchment was very dry before the rain, whether the rain was highly localised, and whether the rain occurred in a short burst or was spread evenly over a longer period.

The Woolgoolga rainfall gauge is the closest long-term rainfall gauge to Arrawarra. It opened in 1887 and the record is relatively complete. Some periods of a few months are missing, as well as some notable longer periods from 1940 to 1944 and 1952 to 1960.

Diagram 1 (following page) displays major rainfall events from the long-term daily rainfall records at Woolgoolga. The chart displays occasions when more than 290 mm of rain was recorded over a two-day period. The two-day period was selected because major events will often straddle the time when the gauge is read (usually 9am), such as occurred in January 2012.

The historical investigation indicates that January 2012 event was probably among the largest in recent decades, but is not unprecedented in terms of the total depth of rainfall or the height of floodwaters that may have occurred since the 1880s.

Diagram 1: Woolgoolga Rainfall Gauge – Events Exceeding 290 mm over two days.



1.4. Community Consultation

In order to gain a suitable appreciation of the local flood issues and concerns of residents, WMAwater personnel were present and involved at several stages of the community consultation and data collection phase.

Mark Babister met either individually or with groups of landholders to obtain feedback. Two other members of WMAwater staff spent a total of four days with RMS and APBJV personnel during community interviews and data collection exercises for the Corindi and Arrawarra catchments. Approximately 40% of the people visited during this period were from the Arrawarra area.

2. TECHNICAL REVIEW OF FLOOD MODELLING

2.1. Overview

WMAwater completed a preliminary review of hydrologic and hydraulic modelling files provided by the APBJV in July 2013 (Reference 12). The review identified the following points for further investigation and analysis:

- Selection of the critical storm duration for the catchment
- The method used to scale the inflow hydrographs;
- Modelling assumptions for tailwater conditions in the Arrawarra Creek estuary;
- Antecedent condition assumptions; and
- The method of schematisation for culvert 1D/2D connectivity in the TUFLOW model.

Further modelling refinement work was completed by the APBJV as part of the 100% detailed design stage for the works (Reference 1). Final modelling files were not provided to WMAwater, so this review is based on the information presented in the detailed design documentation. The following section presents discussion for each of the issues raised during the preliminary review stage, based on the finalised outcomes presented in the APBJV report.

2.2. Critical Storm Duration

The modelling developed by APBJV uses different storm durations for different inflow locations, depending on the size of the upstream catchment, which is considered an appropriate method for designing the sizes of the highway cross-drainage structures and estimating the flood impacts at these structures. For smaller catchments a duration of 2 hours or 6 hours has been adopted, whereas for larger catchments a 48 hour duration was adopted.

The adopted approach is considered best practice for assessing flood issues relating to sizing cross-drainage for the road embankment design and determining flood impacts. However the approach is less suitable for setting Flood Planning Levels in developed areas of the lower catchment, for which standard practice would be to adopt a consistent storm duration across the catchment. In certain circumstances, this would involve running multiple events as the critical flood behaviour in different parts of the catchment may be driven by similar mechanisms. For example, the peak flow from a catchment may occur during a shorter, more intense storm burst, whereas the peak flood levels in the Arrawarra Creek estuary may be driven more by total runoff volume, which would occur over a longer duration with lower average intensity for the same AEP.

The critical duration methodology is therefore considered appropriate for the project, although it is noted that the 48-hour duration adopted for some catchments is somewhat longer than normally expected to produce the peak flow in catchments of a similar size.

2.3. Hydrologic Modelling Methodology

The peak flows for each sub-catchment were estimated by using a combination of the Probabilistic Rational Method (PRM) and runoff-routing modelling in RAFTS. The values for peak flow obtained using each of these methods were averaged, and then the hydrograph obtained from RAFTS was scaled to produce a peak equivalent to the calculated average. For catchment CA4 the PRM produces a 1% AEP peak flow estimate of 104.9 m^3/s (with a time of concentration of 60 minutes). For the RAFTS modelling, APBJV adopted the 48 hour storm as the critical duration, with a resulting peak flow estimate of 37.1 m^3/s. The average was then calculated as 71.0 m^3/s, and the RAFTS hydrograph was scaled up to match this value at the peak.

It should be noted that the PRM and RAFTS rely on very different underlying approaches to determine the peak flow, and these peak flows are not strictly comparable (particularly for a different duration to the time of concentration). The RAFTS peak flow for a design storm duration of 60 minutes may be similar to the PRM method, although the "time of concentration" is a parameter and does not necessarily correspond to a physical catchment response time. If the model is to be used for a detailed assessment of flood risk in the lower Arrawarra catchment, the method of scaling RAFTS hydrograph to match the PRM peak flow warrants further consideration.

For the design requirements of the project, the hydrologic modelling methodology is considered a reasonable approach.

2.4. Estuarine Flood Modelling

For the purposes of the Pacific Highway Upgrade design and flood impact assessment, the modelling of the Arrawarra Creek estuary and ocean interaction is of sufficient detail. However if the model is to be used for a detailed assessment of flood risk in the developed lower catchment, particularly for smaller more frequent flood events, a more in-depth approach may be warranted. Further discussion on this aspect of the modelling is provided below.

2.4.1. Comments on Entrance Behaviour

Arrawarra Creek is classified by the Office of Environment and Heritage (OEH) as an Intermittently Closed and Open Lake/Lagoon (ICOLL). The condition of the entrance (open or closed) at any given point in time will be dependent on several criteria leading up to that time, including wave climate, catchment rainfall, littoral drift conditions, particle size, and more. The interim entrance management strategy for Arrawarra Creek (Reference 11) identifies the dominant condition for the entrance as being open, based on review of historic aerial photographs. However a 2011 monitoring assessment (Reference 9) identified the dominant condition as closed, possibly because of drought conditions persisting in the region for much of the decade prior to that assessment.

There is a reasonable chance therefore that the entrance may be either open or closed at the commencement of catchment flooding from a major storm event. If the entrance is closed, there is a high likelihood that a major catchment rainfall event will produce sufficient creek water levels to overtop the berm and cause a natural breakout of the entrance. The typical crest level of the berm at the beach is approximately 1.5 mAHD (based on available LiDAR and estimates from Reference 11). Flood events causing levels higher than 1.5 mAHD in Arrawarra Creek can therefore be expected to cause an opening of the entrance if it is closed at the commencement of the event.

2.4.2. Ocean Tailwater Levels

The modelling provided by APBJV assumes a constant ocean tailwater level for the 1% AEP flood event of 2.1 mAHD (with a corresponding initial water level in the lower Arrawarra Creek catchment). As recognised by APBJV in their report, this assumption is somewhat conservative, and likely to result in an over-estimate of peak flood levels in the lower catchment.

NSW government guidelines (Reference 4) specify recommended approaches for setting the tailwater at an ocean water level boundary for flood risk assessment. The guideline provides three approaches to the development of appropriate tailwater levels for open entrances, for consideration in flood risk assessments.

The annual high astronomical tide (due to gravitational effects of celestial bodies) on the NSW coast is around 1.1 mAHD to 1.2 mAHD. Similar levels occur on the NSW north coast. The highest recorded tide at Fort Denison in Sydney Harbour is 1.5 mAHD, which included barometric effects (storm surge) from a low pressure cell, and the 1% AEP level at Fort Denison is 1.45 mAHD. Research has shown that the effects of wave setup in trained, deep entrances are minimal (Hanslow & Nielsen, Reference 5). The Arrawarra Creek outlet is reasonably sheltered by the barrier beach, and the channel is reasonably defined. The combination of the sheltered outlet and defined channel is likely to reduce the influence of wave setup on estuary water levels.

The other aspect of the ocean tailwater condition that may require further attention is whether a fixed or dynamic (tidal) water level is adopted for the downstream model boundary. For a short duration event (up to 6 hours or so) where peak flow from catchment runoff is the primary consideration, a fixed elevated ocean tailwater condition may be appropriate. However, for longer durations (such as a 48 hour event that spans multiple tidal cycles), the runoff volume collecting in the lower catchment and lagoon may be a key consideration. The outflow to the ocean is likely to be significantly higher during the low tide than high tide, even if storm surge and wave setup mechanisms are still occurring. A dynamic ocean level boundary is therefore recommended for modelling longer duration events. It may also be necessary to consider the implications of projected levels of sea level rise.

It is noted that sensitivity assessment undertaken by APBJV, using an alternative tidal boundary level of 0.7 m, indicates that this assumption does not influence the flood impact assessment or the design optimisation process (such as the sizing of Pacific Highway cross drainage culverts), and therefore the adopted assumptions are considered suitable for the intended project purposes.

2.4.3. Bathymetry

The Digital Elevation Model (DEM) for the TUFLOW model appears to be a combination of LiDAR data and detail survey data obtained in the vicinity of the road alignment. The LiDAR dataset is unlikely to provide a good representation of the estuary bathymetry in areas below the normal water level in the creek, or in heavily vegetated parts of the estuary.

Bathymetric survey was collected in August 2005 by the Department of Infrastructure, Planning and Natural Resources as part of the Estuary Management Program. This program is now managed by OEH, and the bathymetry survey data is available for download from the OEH website.

If the model is later adopted for detailed flood risk assessments in the lower Arrawarra floodplain, it is recommended that the bathymetry survey be included in the DEM for the model, to improve the model representation of the creek conveyance.

2.4.4. Antecedent Conditions

The initial tailwater conditions are important in relation to the amount of antecedent volume in the Arrawarra Creek estuary at the commencement of the event. The current modelling assumes a level of 2.1 mAHD to match the ocean tailwater condition for the simulation. However, this level represents a significant volume of flood storage within the lower catchment, and is likely to be conservative in light of the discussion of wave setup and entrance conditions above.

It is noted that sensitivity assessment undertaken by APBJV, using an alternative initial water level of 1.0 mAHD, indicates that this assumption does not influence the flood impact assessment or the design optimisation process (such as the sizing of Pacific Highway cross drainage culverts), and therefore the adopted assumptions are considered suitable for the intended project purposes.

2.5. Suitability for Purpose

This review finds that the revised flood modelling developed by the APBJV is suitable for the intended purposes, that is:

- determining relative impacts on flood behaviour resulting from the proposed work compared to existing catchment conditions; and
- determining road embankment/bridge design levels that satisfy the flood immunity criteria of the project.

However WMAwater agrees with the conclusion presented in the report, that the model is likely to over-estimate design flood levels (i.e. the levels are "conservative"), particularly for more frequent flood events such as the 2 year and 5 year ARI. This is primarily a result of relatively conservative assumptions about coincident ocean tide conditions.

Therefore the modelling in its current form is not recommended for use in setting Flood Planning Levels or detailed assessments of flood risk/flood damages in the developed areas of the lower Arrawarra catchment. Use of the model for these purposes would require:

- more in-depth assessment of coincident ocean flood levels (including components from tides, storm surge, wave setup, etc.);
- dynamic modelling of ocean conditions;
- consideration of the entrance condition (open or closed) during the flood;
- unadjusted scaling of rainfall-runoff hydrographs for model inflows;
- more detailed representation of in-bank conveyance for the estuarine zone; and
- calibration to historical flood behaviour using recorded catchment rainfall data.

3. REVIEW OF FLOOD ASSESSMENT

3.1. Flood Frequency Terminology and Background

This terminology can be somewhat confusing for people unfamiliar with the underlying statistical analysis. The term "*100 year ARI*" essentially indicates the level likely to be exceeded every 100 years ***on average*** over a very long time period. For example over a period of say 2,000 years, we can expect the 100 year ARI flood level to be exceeded within 20 different years in that period. However over relatively short periods, the flood behaviour can depart significantly from these long term averages.

An alternative way of describing this behaviour, which perhaps more clearly acknowledges the random chance associated with flood events, is describe the flood magnitude in terms of probability of occurrence in a given year. For example, an alternative term for the 5 year ARI flood level is *"20% AEP"*, which essentially means there is a 20% chance of a flood exceeding that level each year.

It is not uncommon in Australia to observe periods of a decade where there is no significant flooding, and conversely years where very large floods occur back to back. For example, two of the largest floods on the Macleay River at Kempsey since European settlement occurred within a 12 month period in August 1949 and June 1950. Both floods were estimated to be almost the 100 year ARI level (or perhaps more correctly, a 1% chance of occurring in each year). Maitland experienced four floods in six years between 1949 and 1955 that exceeded the "major" flood level at Belmore Bridge, but only three floods have exceeded this level in almost sixty years since 1956 (Reference 4).

This variability for eastern NSW catchments is known to be correlated to various indicators of global weather circulation patterns, including the El Nino Southern Oscillation Index, the Inter-decadal Pacific Oscillation Index, and others. These indices can persist in a certain condition for periods of several years, resulting in a bias for wetter or drier periods.

3.2. Assessment of Historical Flood Magnitudes

The APBJV compared historical flood levels with the modelled design flood level estimates, and made the following observations with regards to the rarity of recent floods:

- *"The observed flood levels in Table 4-8 are all lower than the 2 year model flood estimate with the event that occurred on 26/1/12 the largest;"*
- *"Based on descriptions from residents and the impacts at the adjacent Corindi Floodplain the event was considered the largest local flood event for some time*;" and
- *"the flood events* [January 2012 and February 2013], *while considered significant by the local residents, were in fact relatively minor events in the context of the Arrawarra floodplain, probably in the 2 to 5 yr ARI range*."

There is evidence to suggest the January 2012 event in particular may have been rarer than the

2 year ARI to 5 year ARI (or 50% AEP to 20% AEP) estimate provided by the APBJV. The review of historical information in Section 1.3 indicates that the 48-hour rainfall, which is assessed as the critical duration for major sub-catchments of Arrawarra creek, was among the heaviest on record for nearby long term gauges. There is potential for significant localised variation in rainfall measurements, however it must also be considered that the relatively conservative tailwater estimates of the APBJV modelling (Section 2.4.2) skew the assessment of more frequent events. For example, the levels quoted in Table 4-8 of Reference 1 are in the range of 2.0 mAHD to 2.75 mAHD, with a ground level of 1.85 mAHD. These levels are quite close to the ocean tailwater level of 2.1 mAHD adopted for the modelling (the ground level is below – but obviously is not frequently inundated by tides). It is therefore considered likely that this tailwater assumption has an influence on this assessment of the rarity of historical floods (although it is not a significant issue for the assessment of the Pacific Highway works).

WMAwater consider it is reasonable to assume that the January 2012 event, and possible the February 2013 event, are among the largest experienced in recent decades within the catchment, based primarily on:

- Strong evidence that in the Corindi River, the January 2012 event was in the order of a 100 year ARI event (Reference 10); and
- The prominence of these events in long term rainfall records at Woolgoolga (see Diagram 1).

3.3. Flood Impact Assessment

The APBJV implemented modelling of two catchment scenarios, representing the following conditions:

Scenario A) Existing catchment conditions (as of August 2013); and

Scenario B) Proposed Pacific Highway Upgrade project conditions, including proposed road embankments, bridges and culverts along the new highway alignment and raising of Eggins Close for improved flood immunity.

The scenarios were modelled by altering the digital terrain model, and adding model components to represent bridges, culverts, etc. The assumed runoff inflows, models parameters such as friction losses, and downstream boundary conditions were unaltered between scenarios. The peak flood levels and flow distributions were then compared to determine the relative impacts of the different works. This methodology is standard practice for flood impact assessment.

3.3.1. Impact of Proposed Pacific Highway Upgrade

The APBJV determined the flood impacts of the proposed W2B project by making comparisons of model results. Peak flood levels for various events under Scenario B were compared to Scenario A to determine the impacts of the project works.

Mapping and tables showing the comparison of these scenarios are presented in Reference 10.

The assessment indicates that the significant flood impacts of the W2B works are generally confined to the upstream side of the new road alignment. Increases of between 0.5 m and 1.5 m are estimated for areas upstream of the upgraded Pacific Highway route, or downstream between the Pacific Highway and the upgraded Eggins Close. The significant adverse impacts do not extend onto the lower developed area of floodplain (Figure 4-4 to 4-6, Reference 1).

While the upstream impacts exceed the standard dictated by the EIS criteria, these areas of exceedance are isolated to forested areas where significant additional flood damages are unlikely.

WMAwater considers that the impact assessment provides a realistic assessment of the likely flood impacts of the project.

4. CONCLUSIONS

4.1. Model Review Outcomes

This review finds that the revised flood modelling developed by the APBJV is suitable for the purposes of design and impact assessment for the Pacific Highway Upgrade project, being generally in accordance with the relevant guidelines specified in Reference 2.

However WMAwater agrees with the conclusion presented in the report, that the model is likely to over-estimate design flood levels (i.e. the levels are “conservative”), particularly for more frequent flood events such as the 2 year and 5 year ARI. This is primarily a result of relatively conservative assumptions about coincident ocean tide conditions.

4.2. Flood Assessment Outcomes

It is considered likely that the conservative tailwater level assumption has an influence on the assessment of the rarity of historical floods presented in Section 4.3.3 of Reference 1.

WMAwater consider it is reasonable to assume that the January 2012 event, and possibly the February 2013 event, are among the largest experienced in recent decades within the catchment (possibly larger than 10 year ARI floods), based primarily on:

- Strong evidence that in the Corindi River, the January 2012 event was in the order of a 100 year ARI event (Reference 10); and
- The prominence of these events in long term rainfall records at Woolgoolga (see Diagram 1).

4.3. Additional Comments

The modelling in its current form is not recommended for use insetting Flood Planning Levels or detailed assessments of flood risk/flood damages in developed areas of the lower Arrawarra catchment. Use of the model for these purposes would require the following refinements:

- more in-depth assessment of coincident ocean flood levels (including components from tides, storm surge, wave setup, etc.);
- dynamic modelling of ocean conditions;
- unadjusted scaling of rainfall-runoff hydrographs for model inflows;
- more detailed representation of in-bank conveyance for the estuarine zone; and
- calibration to historical flood behaviour using recorded catchment rainfall data.

5. REFERENCES

1. APBJV

Woolgoolga to Glenugie – Detailed Design and Documentation
Arrawarra Flood Modelling
Roads and Maritime Services, October 2013.

2. Barton, C. & Babister, M. (Editors)

Australian Rainfall and Runoff – Revision Project 15
Two Dimensional Modelling in Urban and Rural Floodplains
Institution of Engineers Australia, November 2012.

3. Hanslow, D. J., and Nielsen, P.

Wave Setup on Beaches and in River Entrances
Proc. 23rd International Conference on Coastal Engineering
American Society of Civil Engineers, October 1992

4. Keys, C.L.

Making Communities Safer in Times of Flood:
Floodplain Management Authorities of New South Wales, 2008.

5. New South Wales Government

Floodplain Development Manual
April 2005.

6. New South Wales Government

Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments
October 2009.

7. Paterson Consultants Pty Ltd

Pacific Highway Proposed Improvements, Blackadder Creek
Flood Assessment
Roads & Traffic Authority, April 2010.

8. Pilgrim, D.H. (Editor in Chief)

Australian Rainfall and Runoff – A Guide to Flood Estimation
Institution of Engineers, Australia, 1987.

9. Roper T, Creese B, Scanes P, Stephens K, Williams R, Dela-Cruz J, Coade G, Coates B & Fraser M

Assessing the condition of estuaries and coastal lake ecosystems in NSW
Office of Environment and Heritage, 2011.

10. Sinclair Knight Merz

Corindi River Flood Assessment for
Woolgoolga to Ballina Pacific Highway Upgrade
Roads and Maritime Services, December 2013.

11. Umwelt Australia

Interim Entrance Management Strategy – Arrawarra Creek
June 2001.

12. WMAwater

Memorandum – Arrawarra Creek
Preliminary Review of Hydrologic/Hydraulic Modelling
Roads and Maritime Services, July 2013.

Figures

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

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

probable maximum flood event, that is, flood prone land.

floodplain risk management options — The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.

floodplain risk management plan — A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

flood plan (local) — A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.

flood planning area — The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the ■flood liable land• concept in the 1986 Manual.

Flood Planning Levels (FPLs) — FPL•s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the ■standard flood event• in the 1986 manual.

flood proofing — A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.

flood prone land — Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood readiness — Flood readiness is an ability to react within the effective warning time.

flood risk — Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.

existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas — Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: ▪ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or ▪ water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or ▪ major overland flow paths through developed areas outside of defined drainage reserves; and/or

- the potential to affect a number of buildings along the major flow path.

mathematical/computer models — The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach — The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

minor, moderate and major flooding — Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures — Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.

peak discharge — The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF) — The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP) — The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to ■water level•. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.