Woolgoolga to Glenugie
Detailed Design and
Documentation

Arrawarra Flood Modelling

DRAFT

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Roads and Maritime Services

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Glossary

AHD	Australian Height Datum
APBJV	Arup Parsons Brinckerhoff Joint Venture
ARI	Average Recurrence Interval
AEP	Annual Exceedence Probability
AR&R	Australian Rainfall & Runoff
AS	Australian Standard
AUSTROADS	The Association of Australian and New Zealand Road Transport and Traffic Authorities
BOM	Bureau of Meteorology
CD	Cross Drainage
DEM	Digital Elevation Model
FHWA	Federal Highway Association
GPT	Gross Pollutant Trap
IFD	Intensity Frequency Duration
IV	Independent Verifier
LD	Longitudinal drainage
Overtop	Flood level above deck/highway level
QRT	Quantile Regression Technique
PDSB	W2G Project Development Services Brief
PRM	Probabilistic Rational Method
RMS	Roads and Maritime Services
S2W	Sapphire to Woolgoolga Project
SID	Safety by Design
Surcharge	Flood level above soffit level of structure but below lowest deck/highway level
WAE	Works as Executed
W2G	Woolgoolga to Glenugie
WQ	Water Quality
WSUD	Water Sensitive Urban Design

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1. Introduction

1.1 Project background

The proposed upgrade of the Pacific Highway between Woolgoolga and Glenugie is part of the Pacific Highway Upgrade Program. This program is a joint commitment by the NSW and Federal Governments to provide a continuous dual carriageway on the Pacific Highway between Hexham (near Newcastle) and the Queensland border.

The proposed upgrade extends over approximately 31 km from the Sapphire to Woolgoolga Pacific Highway Upgrade (S2W – approximately 32 km north of Coffs Harbour) to the Glenugie Upgrade Alliance (GUA) project (approximately 64 km north of Coffs Harbour). Section 1 of the overall project extends from the southern tie-in north of Arrawarra interchange to chainage 16,200 m within the existing 3.4 km Halfway Creek upgrade.

The Arup Parsons Brinckerhoff Joint Venture (APBJV) has been established for the purpose of preparing the detailed design and documentation for the construction of this upgrade. This report describes the 100% hydrology and flooding assessment for the Arrawarra Floodplain located within Section 1 (chainage 0 to 2,000) of Woolgoolga to Glenugie Pacific Highway Upgrade.

1.2 Scope of this report

This document reports the flow estimates and associated hydraulic design of the structures crossing the following watercourse:

- Arrawarra floodplain (CH00 –CH2000)

Arrawarra floodplain refers to an area east (downstream) of the existing Pacific Highway extending approximately from Mulloway Drive in the south to Tasman St in the north. For purposes of the W2G project the Arrawarra floodplain assessment is based on the northern arm of Arrawarra Creek and the associated floodplain located between Arrawarra Beach Road and Tasman St.

Other major and minor watercourses are discussed in the relevant hydrology and flooding and cross drainage design reports (W2G-G-DR-RP-0002; W2G-1-DR-RP-0002 - Section 1; and W2G-2-DR-RP-0002 - Section 2) with the methodology/analysis as described in the Drainage Design Criteria Report (W2G-G-DR-RP-0001).

This report has been prepared to summarise the analysis undertaken to inform the 100% detailed design phase of the design process, but does not take into account any further highway amendments to upgrade the highway to an ultimate design (i.e. 3 lane configuration).

The 100% detailed design phase represents the completion of the design, co-ordination, communication, review; and verification process. With regards to the Arrawarra Flood Modelling this includes confirmation of the proposed highway and Eggins Drive flood immunities (road levels), sizing of the cross drainage infrastructure and confirmation of the impacts such as changes to flood extents, levels, velocities and durations resulting from these elements. This report is one of the final inputs to the 100% detailed design drawings which will be ultimately ‘Issued for Construction” by RMS as part of the Tender process.

1.3 Assessment criteria

1.3.1 Pacific Highway Upgrade Design Guidelines

The Pacific Highway Upgrade Design Guidelines, Roads and Maritime Services (2012) require that the following performances be achieved by the proposed W2G Pacific Highway Upgrade:

- Model and assess impacts of the 1 in 100 year ARI and PMF flooding events;
- Provide 1 in 100 year ARI flood immunity on the carriageway;
- Assess the structural adequacy of the project bridge structures; and
- Minimise flood impacts to properties outside the project boundary in the 1 in 100 year ARI event.

1.3.2 Woolgoolga to Ballina Environmental Impact Statement

The EIS that has been prepared to support the proposed upgrade of the Pacific Highway between Woolgoolga and Ballina (see Section 2.1) outlines a number of flood management objectives. A summary of these objectives are provided below:

- Roadway flood immunity is defined for this project as the edge of pavement being at or above the designated flood level. Therefore, all lanes would be free from flood inundation in the designated flood event.
- The minimum level of flood immunity for M class roadways for this project is 20 year ARI and the target immunity, if feasible, is 100 year ARI. All M class roads of the project, apart from those crossing the Richmond and Clarence river floodplains, would have 100 year ARI flood immunity.
- Flood level impact objectives:
  - *Houses, commercial premises and urban areas*: Less than 50 millimetres increase in flood height for any assessed flood event (less than and equal to the 100 year ARI event).
  - *Cane farm land*: Less than 50 millimetres increase in flood height for any assessed flood event (less than and equal to 100 year ARI event).
  - *Grazing area, forested lands, other rural areas*: Generally less than an increase of 250 millimetres, with localised increases of up to 400 millimetres for short duration / local catchment flooding acceptable over small areas (nominally less than five hectares) up to the 100 year ARI event.
  - It should be noted that for purposes of the Arrawarra floodplain assessment, afflux has been limited to as close to zero as feasible based on RMS specific guidance for this area. This guidance is based on reducing the impacts of the highway upgrade on the large number of permanent/temporary residencies/sites located within or near the floodplain.

- Flood inundation duration impact objectives:
  - *Houses, commercial premises and urban areas*: No more than five per cent increase in the flood duration.
  - *Cane farm land*: No more than five per cent increase in the flood duration.
  - *Grazing area, forested lands, other rural areas*: No more than ten per cent increase in the flood duration.
- Flood velocity and direction impact objectives:
  - *Houses, commercial premises and urban areas*: Velocity-depth products to remain in the zone of low hazard for children (i.e. less than 0.4 metres squared per second based on Australian Rainfall and Runoff, Project 10, 2011) where the velocity-depth products are currently low hazard. This objective is justified in terms of maintaining safe flooding conditions during flood events.
  - *Cane farm land*: Velocities to remain below one metre per second where currently below this figure based on erosion on bare soils. An increase of not more than 20 per cent where existing velocity is above one metre per second. This objective is justified in terms of minimising the erosion of soil on cane farms based on accepted velocity limits for erosion.
  - *Grazing area, forested lands, other rural areas*: Velocities to remain below one metre per second where currently below this figure. An increase of not more than 20 per cent where existing velocity is above one metre per second. This objective is justified in terms of minimising the erosion of soil on agricultural lands based on accepted velocity limits for erosion.
  - No changes to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.
- Floodwater rate of rise and warning time:
  - *Houses, commercial premises and urban areas*: Rates of floodwater rise and warning times should be similar to those of the base case.
  - *Cane farm land*: no consideration.
  - *Grazing area, forested lands, other rural areas*: Rates of floodwater rise and warning times should be similar to those of the base case.
- Flood evacuation and flood access:
  - *Houses, commercial premises and urban areas*: Time available to evacuate should be similar to that for the base case. Evacuation routes should not be impassable due to flood water inundation for any longer or any sooner than the base case.
  - *Cane farm land*: no consideration.
  - *Grazing area, forested lands, other rural areas*: Time available to move stock to higher ground should be similar to that for the base case. Stock access to higher ground should not be impeded by the project or the flood impacts attributable to the project.

1.3.3 Coffs Harbour City Council

Consultation has been undertaken with Coffs Harbour City Council (CHCC) to determine the availability of existing flood information, to discuss the floodplain modelling approach and to agree a suitable level of immunity for the Eggins Drive upgrade. CHCC have requested a 100 year level of immunity for Eggins Drive in order to provide a similar access outcome to the current situation in this floodplain.

1.4 Departures from standard

1.4.1 Flood impact

Clause 2.1.6.3 of the Description of Services requires that the Project Works and the Temporary Works will have no material adverse impacts on the performance of any existing surface water. The effects of the Project Works and the Temporary Works must be predicted and the extent to which the existing surface water conditions may be acceptably affected (Acceptable Effects) must be determined.

The Acceptable Effects are outlined in the EIS criteria (see Section 1.3), and the locations shown in Table 1-1 do not comply with this criteria.

Table 1-1 Predicted flood impact departures from standard

Location	Chainage	Departure	Justification/Mitigation
Arrawarra Floodplain	0 to 2,000	Flood level increase up to maximum 1.53 m. Individual properties below are located within the floodplain.	See Note 1
Properties impacted:	Lot88 on DP1146153	+0.59m	See Note 1
	Lot103/ /DP752853 -Upstream of Highway	+0.61 m	See Note 1
	Lot103/ /DP752853 - Downstream of Highway	+1.53 m	See Note 1
	Lot101/ /DP752853 - Upstream of Highway	+0.45 m	See Note 1
	Lot101/ /DP752853 - Downstream of Highway	+1.51 m	See Note 1
	Lot100/ /DP752853 - Upstream of Highway	+0.91m	See Note 1
	Lot100/ /DP752853 - Downstream of Highway	+0.96m	See Note 1
	Lot83/ /DP752820	+0.79m	See Note 1
	Property - Lot4/ /DP806515	+0.61m	See Note 1

Note 1 – The impacted area is forested land and contains no habitable buildings. The raising of Eggins Drive to provide a 100yr level of immunity for public access and a target of nil to low afflux impacts on the downstream habitable properties/caravan parks result in unavoidable afflux increases upstream of the highway upgrade. On balance the 100% design provides the most cost effective and least impact solution. Details of the flood extents are provided in this report.

2. Review of available information

2.1 Existing studies

A number of studies were reviewed as part of a data gathering and understanding exercise for the proposed highway upgrade; however these studies do not provide any flood information for the Arrawarra Floodplain. These are documented in the general Hydrology & Flooding Report, covering the other major watercourses (W2G-G-DR-RP-0002).

The Woolgoolga to Ballina Upgrade, Working Paper – Hydrology and Flooding (Woolgoolga to Ballina (W2B) Planning Alliance, November 2012) prepared to support the EIS did not identify any significant flood risks for the Arrawarra Floodplain and the subsequent assessment including this report have been undertaken as part of the detailed design development.

One previous study has been undertaken for the Arrawarra area, and this is summarised below.

A. Flood Study on Lot 350 DP 703698 from Coffs Harbour Council, GHD, July 1995.

The report documents a flood study undertaken to assess flooding at Lot 350 DP 703698. The key preliminary findings are shown in Table 2-1.

Table 2-1 Key hydrological and hydraulic components of Lot 350 DP 703698 flood study

Watercourse	Catchment Area (km^2)	Hydrological Modelling Approach	100 year ARI Peak Flow (m^3/s)	Hydraulic Modelling Approach	100 year ARI Peak Level (mAHD)	Tidal Boundary Level (mAHD)
Arrawarra Creek and Tributaries	18.47*	WBNM	262	1D – Mike 11	3.35	2.50

** = Total catchment for Arrawarra Creek at ocean outlet including tributaries*

This study reported the 48 hour duration event to be the critical storm for all locations to the east of the Pacific Highway. As part of this study a number of varying duration events were tested in the model with a conclusion that the 24 hour event produced the highest peak flow and worse case 100 year flood level.

In addition the downstream boundary was tested using a constant (2.50m AHD) tide level and a varying natural tide level (varies approx. 2.50 – 0 m AHD with 2 highs and two lows in a 24 hour period). The resulting 100 year flood levels varied by only 90mm indicating that flooding was no particularly sensitive to the tidal boundary condition.

B. Modification Environmental Assessment: Arrawarra Rest Area, NSW Roads and Traffic Authority, Aurecon, April 2011.

The report documents the hydrology and water assessment undertaken for the rest area and Arrawarra Creek. A summary of the flood analysis is provided, however no reporting locations correlate with those used in this study.

2.2 Historic Flooding

Historic flooding has been observed at a number of locations including the Arrawarra Floodplain along the Pacific Highway within the W2G project alignment. These are documented in the general Hydrology & Flooding Report, covering the other major watercourses (W2G-G-DR-RP-0002).

As part of the public consultation process information on historical flooding in the Arrawarra Floodplain has been provided by the community and includes flood level observations, photographs and rainfall information. A summary of the historical information is provided in Table 2-2. A discussion on the use of this information in validating the 100% flood modelling is provided in Section 4.3.3 with a copy of the information and photos specifically used provided in Appendix C.

Table 2-2 Historic flooding information – Arrawarra Floodplain

Date	Location	Description	Source
2011, 2012, 2013	9 Quail Cl	Various Flood Photos	Owner
1997, 1998, 2001, 2007, 2011, 2012, 2013	Darlington Park	Various Flood Photos & rainfall records	Caravan Park Manager
2011,2012	Various residential locations	Flood level observations surveyed by RMS surveyor	Various local residents

2.3 Topographic and geometric information

2.3.1 Ground data

A Digital Terrain Model (DTM), constructed from ALS data, was available for the Arrawarra floodplain. This data has a typical vertical accuracy of +/- 150 mm and a typical horizontal accuracy of +/- 550 mm. The grid resolution of the data is 5m.

A DTM of 10 m grid resolution was also available for the entire project area. This was not used for any hydraulic analysis however it was used to inform catchment derivation and parameterisation.

2.3.2 Hydraulic Structures

A combination of detailed topographic survey and as-constructed drawings were used to provide level and geometric information at existing key hydraulic structures.

3. Hydrology

3.1 Hydrological modelling methods

The design flows in the watercourses have been assessed using three hydrological assessment methods as follows:

XP-RAFTS hydrologic modelling

The XP-RAFTS hydrologic model was chosen to estimate design hydrographs as it is capable of representing a range of physical characteristics that influence runoff behaviour such as rainfall patterns, catchment shape, catchment slope, drainage features, channel and floodplain storage, and variations in catchment land use. The XP-RAFTS model converts rainfall to runoff by applying rainfall losses to both the impervious and pervious catchments within the model to produce excess rainfall hyetographs. The resulting runoff is then routed down the catchment to produce a total flow estimate at the location of interest.

The layout and full details of adopted model parameters for the XP-RAFTS models developed for the watercourses are included in Appendix B.

Probabilistic Rational Method (PRM)

The probabilistic Rational Method is recommended in AR&R (1997) for use in eastern New South Wales. It is based on data from 308 gauged catchments and is applicable to catchments up to 250 km^2 in area.

The PRM is used to estimate a peak flow of selected ARI from an average rainfall intensity of the same ARI. As such, it has been used within this assessment as an alternative flow estimation methodology.

Quantile Regression Technique (QRT)

This technique estimates the design flood peak discharge directly using catchment characteristics data by multiple regression analysis. Data from 56 catchments[1] has been combined to produce QRT equations for differing ARI flood events for eastern NSW.

AR&R Project 5 (Nov. 2009) has found that the QRT outperforms the PRM for NSW. Based on this guidance, the QRT has generally been afforded greater weighting within design hydrological considerations than the PRM and has been used within this assessment as an alternative flow estimation methodology.

[1] It should be noted that no catchments under 10 km^2 were included within the contributing dataset.

3.2 Hydrological input data

3.2.1 Catchment descriptions

All catchments within this assessment are predominantly rural with either pastoral or forested land use. The Arrawarra floodplain catchments slope from west to east through privately owned land. Two private surface water reservoirs are located within the catchment, each collecting and storing water sourced from different ends of the catchment.

Due to the location on the eastern flanks of a localised coast range, each catchment has steep upper sub-catchments. At the location of the proposed Pacific Highway Upgrade the Arrawarra floodplain watercourse gradients are relatively gentle. Catchment extent plans are provided as Figure 3-1 and Figure 3-2.

Relevant summary catchment descriptors, derived from ALS data, are provided in Table 3-1.

Table 3-1 Summary catchment descriptors

Watercourse	Catchment Area (km2)	Max. Elevation (mAHD)	Min. Elevation (mAHD)	Average Catchment Slope (%)	Average Watercourse Slope (%)
Arrawarra 1 (CD-0044)	0.68	97.2	4.9	4	1.5
Arrawarra 1a (CD-0002 SR)	0.04	10.6	3.8	3.3	2.3
Arrawarra 2 (CD0032)	1.58	93.8	2.4	3.6	2.1
Arrawarra 3 (CD0073	0.2	20.7	3.7	2.9	1.6
Arrawarra 4 (CD0140) to (CDFC0200)	3.63	91.2	2.9	2	1.4

3.2.2 Hydrological parameters

The following hydrologic parameters have been used in the XP-RAFTS and PRM/QRT methodologies. Detailed parameters for each sub-catchment are provided in Appendix B.

Rainfall Data

IFD data

Intensity Frequency Duration (IFD) data was taken from the Bureau of Meteorology website for each of the catchment centroids. An output table displaying this data for a range of ARI events and storm durations is provided in Appendix B.

Areal Reduction Factor

Due to the relatively small size of the catchments, no Areal Reduction Factor (ARF) has been applied. This is a conservative approach as it assumes that the design storm will be applied across the entire catchment. Given the relatively small catchment sizes and longer critical storm durations of the catchments being assessed, this parameter has been set to 1 as a conservative measure.

Temporal distribution

The study area is located within Zone 1 of the AR&R temporal rainfall zones.

Rainfall Losses

XP-RAFTS

An initial and continuing loss model was adopted for this study based on a combination of regional values recommended in AR&R (1997) and site-specific considerations. For this reason, the initial loss value has been assigned to reflect the predominance of forest over much of the catchments. Such land cover will produce higher losses at the start of a storm event due to the greater capacity to intercept rainfall.

Loss parameters may vary subject to the intensity of the rainfall event and the preceding weather conditions. Based on experience and ARR guidance, lower loss values are assigned to the higher ARI storm events and reflect the increased likelihood of the preceding conditions being wetter. The pervious and impervious loss parameters are provided in Table 3-2.

Table 3-2 Rainfall losses

ARI (YR)	Surface type	Initial loss (mm)	Continuing loss (mm/hr)
1 - 100	Rural	15	2.5
2000	Rural	5	2.5
PMF	Rural	5	2

PRM/QRT

No rainfall losses are used in this method.

Catchment characteristics

XP-RAFTS - Baseline

The fraction impervious values for the various land uses and the adopted fraction impervious and Manning's coefficients are presented in Table 3-3. The vectored slope for each sub-catchment has been calculated using the DTM data.

Table 3-3 Fraction impervious and Manning's coefficients

Catchment type	Percentage of impervious	Manning's 'n'
Dense Woodland/Bush	5 %	0.100
Open Woodland/Bush	5 %	0.060
Low density vegetation, rural open space	5 %	0.040

PRM/QRT - Baseline

Each catchment has been assumed to be 100% pervious within the PRM calculations. Runoff coefficients were adopted from AR&R with 0.8 adopted for the coastal lowlands (Chainage -50 to Chainage 8,000).

XP-RAFTS/PRM/QRT – Proposed Case

The LEP for Coffs Harbour City Council has been reviewed and there is no significant development planned within any of the catchments affected by the proposed highway upgrade. Therefore the baseline hydrology has not been altered for the post development case. Sensitivity checks have been carried out for flow variation in Section 5.

Time of concentration and catchment lag

XP-RAFTS

The Arrawarra floodplain catchments are each at the upstream end of their respective sub-catchments and so routing lag times are not required.

PRM/QRT

The time of concentration has been generated using the methods specified in AR&R.

3.2.3 Large to extreme events

No specific 2000 year ARI or PMF hydrology has been calculated for the Arrawarra floodplain as there are no bridge structures located within the floodplain. An extreme event of similar magnitude to a PMF event has been estimated using a local hydrological scaling factor based on the adjacent Corindi catchment hydrology to provide an a event of extreme magnitude for sensitivity checking purposes.

Analysis of the Corindi catchment hydrology illustrates that the PMF event is in the order of 3.8 times larger than the estimated 100 year ARI event. As the catchment is similar to the Arrawarra catchment, this factor was applied to the Arrawarra catchment hydrology to provide an estimate of an extreme event for sensitivity testing in the design process.

3.3 Hydrological modelling results

For all watercourses the design (or critical) storm duration adopted is the one producing the largest peak discharge at the location of interest. Critical duration peak flow results for the differing hydrological methods are provided in Table 3-4.

Table 3-4 Comparison of 100 yr ARI peak flow estimates

Catchment	XP-RAFTS (m3/s)	XP-RAFTS – Critical Duration (hrs)	PRM (m3/s)	PRM (m3/s) (% difference to XP-RAFTS)
Arrawarra 1 (CD-0044)	9.0	6	24.4	171%
Arrawarra 1a (CD-0002 SR)	0.7	2	2.3	229%
Arrawarra 2 (CD0032)	18.8	48	50.0	166%
Arrawarra 3 (CD0073	2.8	2	8.9	218%
Arrawarra 4 (CD0140) to (CDFC0200)	37.1	48	104.9	183%

As expected for cases of small (<10 km^2), flat catchments as are present in the Arrawarra region, the PRM estimate provides a conservative picture when compared to the XP-RAFTS estimates.

3.4 Adopted hydrology

3.4.1 Discussion

Table 3-4 highlights the degree of variability in 100 year ARI event peak flow estimates using differing hydrological methods. No suitable rainfall, stream flow or flood level data is available for these watercourses. Therefore, it was not possible to undertake any calibration or validation of hydrological estimates. In such circumstances it is necessary to adopt a peak flow estimate based on relevant guidance, hydrological experience and engineering judgement.

The XP-RAFTS analysis undertaken as part of this assessment is considered to use the most appropriate hydrological parameters based on catchment knowledge and engineering judgement. The derivation of sub-catchments have been specifically delineated on the basis of slope and land use to represent an accurate picture of the catchment's hydrological response.

The QRT method has been specifically developed for eastern NSW and is based on the most up-to-date guidance. However, no catchments under 10 km^2 were included in the dataset for development of the QRT method and therefore it is not recommended for use on catchments smaller than this value. The PRM is considered the more appropriate method for application on catchments smaller than 10 km^2.

3.4.2 Arrawarra floodplain

The catchment size of each of these watercourses is less than 10 km^2 and therefore the QRT method has not been considered. Comparison of the XP-RAFTS and PRM peak flow reveals a degree of variability, by differing percentages. To reflect the strengths of each method, whilst still applying a degree of conservatism, a hybrid approach has been adopted by the APBJV in consultation with RMS. Peak flows for each ARI event will therefore reflect an average of the XP-RAFTS and PRM results. The hydrograph shape will use the XP-RAFTS results.

3.4.3 Adopted hydrology results

Table 3-5 displays the adopted peak flow results at each watercourse for a range of ARI events.

Table 3-5 Adopted peak flow results

Catchment	Critical Duration (hrs)	Peak Flow (m^3/s)					
	100 yr ARI	2yr	10yr	20yr	50yr	100yr	PMF*
Arrawarra 1 (CD-0044)	6	5.2	9.2	11.2	14.1	16.7	63.46
Arrawarra 1a (CD-0002 SR)	2	0.5	0.8	1	1.3	1.5	5.7
Arrawarra 2 (CD0032)	48	10.7	19	23.4	29.1	34.4	130.72
Arrawarra 3 (CD0073)	2	1.9	3.2	4	5	5.9	22.42
Arrawarra 4 (CD0140) to (CDFC0200)	48	21.3	38.6	47.7	59.7	71	269.8

**Estimate of PMF event flow based on local catchment scaling factor of 3.8*

It should be noted that the Arrawarra Floodplain has a constricted outlet to the ocean and as a result, longer duration storm event (volumetric) are likely to produce the larger flood levels in the floodplain. This flooding mechanism is further discussed in Section 4.0. In the case of the Arrawarra floodplain the 48 hour event produces both the peak flow event and volumetric flood level event.

A shorter duration check using a 6 hour duration peak flow event (approx. 20% lower peak flow than 48 hour) has been undertaken and is further discussed in Section 5.3.

4. Hydraulic modelling

4.1 Hydraulic modelling methods

The method of hydraulic assessment applied to a particular watercourse is influenced by a number of factors including the nature and topography of the catchment in question, the output data required and the availability and quality of existing hydraulic analysis. The following hydraulic approaches have been adopted for the watercourses in this assessment.

The Arrawarra floodplain consists of four relatively small catchments ranging from 20ha to 360ha in size which flow in a west to east direction. These catchments are dissected by the existing Pacific Highway then again by Eggins Drive before discharging into the Pacific Ocean approximately 1km further downstream.

The width and flat nature of the floodplain coupled with a lack of well-defined channels in each of the catchment flow paths means a Tuflow model is best suited to assess hydraulic impacts and inform design.

For purposes of assessing the impact of the proposed design, the modelling adopted relies upon a comparative approach. That is the existing and post road construction flood levels, extents, velocities and durations are compared. The model utilised has been constructed using available ground data, structures information and best judgement engineering parameters. No comprehensive or detailed validation has been undertaken or is possible given the catchment is ungauged (rainfall and flow) and no detailed flood and rainfall information is available. The modelling undertaken is considered suitable for the assessment of impacts from the proposed road and the setting of the road flood immunity however the modelling should not be considered as a fully detailed flood study as defined in the NSW Floodplain Development Manual 2005.

4.2 Modelling set-up and assumptions

4.2.1 Arrawarra floodplain model

2D Domain

The 2D model domain generated for simulation in Tuflow is based on a 5 m² square grid. This grid size was decided on upon based on the narrow flow passages and small features that required representation in the model.

The extent of the 2D domain was defined by digitising an area that included:

- All potential flow paths within the greater Arrawarra floodplain area, including creeks and drainage lines;
- All design features of the proposed highway and service road alignment;
- The existing highway, service road and associated cross-drainage;
- Suitable inflow locations between 200m and 500m upstream of the area of interest to ensure flow patterns are able to stabilise.

1D Network

Culvert structures have been represented using the 1D domain in this model.

Upstream Boundary Locations

There are eight (8) inflow locations representing local catchments. These have been determined based on a review of the DTM data to identify appropriate inflow points. Five (5) of the inflow points are located at the upper reaches of the available DTM data extremities for each catchment, spanning the width of the relevant catchment. Three (3) inflow locations are located at the flat lower extents of the Arrawarra catchment with local flow distributed across the entire catchment allowing accurate representations of flow in these flat areas.

Downstream Boundaries

The downstream boundary condition has been defined as a constant high tide tail water level of 2.1mAHD. This level represents a 20yr ARI tide level and was advised as a suitable downstream boundary condition for a 100 year ARI flood event by Coffs Harbour City Council. Although conservative this is consistent with other flood studies undertaken by Council.

The proposed combined event probability is well in excess of the immunity requirement for the highway upgrade (100 year ARI) and sensitivity checking of alternate tide level combinations with a 100 year ARI flood event were undertaken. This is further discussed in detail within Section 5.5

The outcome of these tide sensitivity checks demonstrated that the flood levels in the Arrawarra floodplain for the peak flood events were not particularly sensitive to the tidal boundary condition and a constant high tide tail water level of 2.1mAHD was adopted for simplicity.

Roughness

Manning's n values for homogeneous surfaces (e.g. grass, dense trees, highways) have been determined via site inspection and a review of aerial photography. The roughness values adopted are based on hydraulic references (e.g. Chow, 1959). The values adopted within this model are shown in Table 4-1.

Table 4-1 Arrawarra floodplain ESTRY-Tuflow model roughness values

Surface Type	Manning's 'n'
Bush land	0.100
Channel central bed	0.025
Channel banks	0.075
Roads (dirt)	0.035
Roads (sealed)	0.020
Urban rural	0.080
Culvert barrels (smooth concrete)	0.013
Low density vegetation	0.035

Structures

Existing structures

The model created to simulate flooding in the existing case Arrawarra floodplain represents four major flow path areas incorporating 14 separate culvert structures. Of these structures 9 convey flow under the existing Pacific Highway, while the remaining culverts pass flow under the Eggins Drive link road and Arrawarra Beach Road. The key dimensions and levels of the existing structures are provided in Table 4-2 and their location shown on Figure 4-1

Table 4-2 Existing Arrawarra floodplain culverts

Hydraulic * Structure	Chainage	Structure dimensions (m)	Length (m)	Road** Shoulder Upstream (mAHD)
CD-0044	-440	5 / 2.2 x 0.9 RCBC	70	9.56
CD-0044 SR	-440	4 / 0.75 Ø RCP	11.15	5.58
CD-0002 SR	-20	3 / .045 Ø RCP	10.27	3.63
CD0033	330	9 / 2.4 x 0.9 RCBC	17.23	4.42
CD0033 SR	330	2 / 0.75 Ø RCP	12.63	2.9
CD0072	720	3 / 1.8 x 0.9 RCBC	18.36	6.22
CD0080 SR	800	3 / 0.45 Ø RCP	21.26	3.68
CD0140	1,400	3 / 2.4 x 1.2 RCBC	18.66	4.23
CD0150	1,500	3 / 0.45 Ø RCP	17	2.6
CD0157 SR	1,570	3 / 0.45 Ø RCP	15	2.83
CD0165	1,650	3 / 2.4 x 1.2 RCBC	14.9	4.01
CD0182	1,820	3 / 2.4 x 1.2 RCBC	14.95	4.08
CD0195	1,950	3 / 2.4 x 1.2 RCBC	14.95	4.09
CD0206	2,060	6 / 1.5 x 0.9 RCBC	17.3	4.09

** SR denotes side road (service or local)*

*** Road refers to the Pacific Highway Upgrade or Eggins Drive as appropriate.*

Proposed structures (100% design stage)

The proposed highway and Eggins Drive upgrade results in a significant number of the existing structures being made redundant. Table 4-3 summarises the new culvert arrangements and their location is provided in Figure 4-1. It should be noted that a large culvert arrangement (CD-0044) constructed for the S2W project will require partial infilling as part of the W2G post development flood mitigation/management.

The design makes provision for a 100 year ARI standard of flood immunity for the Pacific Highway Upgrade and Eggins Drive across the Arrawarra Floodplain.

Table 4-3 Proposed 100% design Arrawarra floodplain structures

Hydraulic * Structure	Chainage	Structure dimensions	Length (m)	Road** Shoulder Upstream (mAHD)	Road** Shoulder Downstream (mAHD)	Comment
CD-0044	-440	3 / 2.2 x 0.9 RCBC	70	10.00	9.63	Reduced capacity
CD-0044 SR	-440	1 / 1.2 Ø RCP	22.05	7.49	7.50	New
CD-0002 SR	-20	1 / .045 Ø RCP	17.15	5.37	5.00	New
CD0032	320	5 / 2.4 x 0.9 RCBC	39.52	4.84	4.83	New
CD0032 SR	320	3 / 3.0 x 1.2 RCBC	19.76	4.43	4.05	New
CD0073	730	1 / 1.5 Ø RCP	44.1	6.37	6.37	New
CD0080 SR	800	4 / 0.6 Ø RCP	24.5	4.91	4.46	New
CD0085 SR	850	3 / 1.2 Ø RCP	14.7	7.58	7.56	New
CD0140	1,400	2 / 1.2 Ø RCP	51.45	6.90	6.97	New
CD0158 SR	1,580	8 / 2.7 x 0.9 RCBC	19.76	3.89	3.86	New
CD0166	1,660	3 / 1.05 Ø RCP	44.1	4.93	5.84	New
CD0182 SR	1,820	3 / 2.4 x 1.2 RCBC	14.95	4.24	4.13	Retained
CD0195 SR	1,950	3 / 2.4 x 1.2 RCBC	14.95	4.18	4.16	Retained
CDFC0200	2,000	3 / 3.0 x 3.0 RCBC	54.34	6.94	7.87	New
CD0206 SR	2,060	6 / 1.5 x 0.9 RCBC	17.3	4.10	4.35	Retained

** SR denotes side road (service or local)*

*** Road refers to the Pacific Highway Upgrade or Eggins Drive as appropriate.*

4.3 Hydraulic modelling results

4.3.1 Existing case

100 year ARI event

Results for the 100 year ARI and other return interval events are provided in Table 4-4. The existing predicted 100yr ARI flood extents, depths and levels are shown in Figure 4-2.

The existing Pacific Highway has a 100 year ARI flood immunity within the study area. However Eggins Drive is shown to overtop at a number of locations in areas downstream of the existing Pacific Highway culverts. A maximum overtopping depth of 1.17m occurs in the vicinity of CD0150 SR. Eggins Drive has also been predicted to overtop at multiple locations for lesser flood events (2yr ARI).

The flood extents and depths indicate significant flooding of existing properties and large parts of the caravan parks. Flood depths vary subject to topography but depths exceeding 0.5m occur over a large number of properties/sites. Flood velocities in the flood plain after they break out from the local creek/channel system are relatively low. The duration of flood impacts in the flood plain varies subject to topography however a large portion of the properties and Caravan Parks are affected for a period exceeding 36 hours in the 100 year ARI event.

4.3.2 Proposed case (with upgrade)

Design storm flood event results

A comparison between existing and proposed case results for a range of design events including the 100 year ARI are provided in Table 4-4 and are shown for the 100 year ARI, 50 year ARI and 2 Year ARI events in Figure 4-3 through Figure 4-6 respectively. The proposed highway upgrade and Eggins Drive have been designed with a 100 year level of immunity and no overtopping occurs in the 100yr ARI event.

Table 4-4 Arrawarra floodplain proposed case flood level results for 2 – 100 year ARI events

Structure*	ARI	Upstream			Downstream			Proposed Case Freeboard to Road** Upstream (m)	Proposed Case Freeboard to Road ** Downstream (m)
		Existing water level	Proposed water level	Water level change	Existing water level	Proposed water level	Water level change		
CD-0044	100	8.39	9.00	0.608	7.28	7.54	0.262	0.999	2.093
	50	8.28	8.77	0.491	7.24	7.48	0.240	1.230	2.159
	20	8.14	8.51	0.365	7.19	7.36	0.180	1.491	2.269
	10	8.03	8.34	0.306	7.14	7.21	0.063	1.664	2.429
	5	7.94	8.20	0.263	7.11	7.14	0.032	1.800	2.497
	2	7.79	8.01	0.215	7.05	7.07	0.017	1.994	2.569
CD-0044 SR	100	6.00	7.50	1.499	5.49	5.41	-0.079	0.010	1.989
	50	5.98	7.44	1.451	5.47	5.41	-0.064	0.070	1.993
	20	5.96	7.32	1.358	5.45	5.40	-0.045	0.122	1.998
	10	5.94	7.11	1.176	5.43	5.39	-0.034	0.326	2.009
	5	5.92	7.01	1.091	5.41	5.38	-0.021	0.431	2.016
	2	5.88	6.74	0.857	5.37	5.37	-0.006	0.704	2.033
CD-0002 SR	100	3.82	5.25	1.426	3.66	3.56	-0.098	0.120	1.435
	50	3.82	5.09	1.278	3.62	3.56	-0.063	0.278	1.439
	20	3.80	4.89	1.088	3.63	3.56	-0.077	0.480	1.443
	10	3.79	4.54	0.745	3.64	3.56	-0.083	0.832	1.439
	5	3.79	4.41	0.622	3.63	3.56	-0.073	0.959	1.443
	2	3.77	4.09	0.318	3.60	3.54	-0.052	1.281	1.457
CD0032	100	4.11	4.57	0.455	3.47	3.82	0.358	0.271	1.009
	50	3.96	4.32	0.360	3.41	3.69	0.282	0.519	1.137
	20	3.79	4.00	0.208	3.34	3.51	0.161	0.841	1.327
	10	3.68	3.70	0.026	3.30	3.36	0.067	1.133	1.470
	5	3.60	3.52	-0.080	3.25	3.26	0.008	1.321	1.571
	2	3.48	3.17	-0.312	3.19	3.06	-0.126	1.669	1.772

Structure*	ARI	Upstream			Downstream			Proposed Case Freeboard to Road** Upstream (m)	Proposed Case Freeboard to Road ** Downstream (m)
		Existing water level	Proposed water level	Water level change	Existing water level	Proposed water level	Water level change		
CD0032 SR	100	3.43	3.80	0.371	3.42	3.43	0.009	0.635	0.623
	50	3.36	3.66	0.301	3.27	3.29	0.012	0.768	0.767
	20	3.29	3.46	0.172	3.08	3.09	0.010	0.968	0.966
	10	3.25	3.31	0.066	2.96	2.95	-0.003	1.120	1.100
	5	3.21	3.20	-0.006	2.90	2.90	0.002	1.230	1.156
	2	3.15	2.97	-0.176	2.78	2.79	0.009	1.461	1.262
CD0073	100	4.52	5.47	0.946	4.28	4.80	0.517	0.903	1.571
	50	4.43	5.28	0.849	4.25	4.71	0.459	1.086	1.656
	20	4.35	5.13	0.782	4.22	4.58	0.355	1.235	1.791
	10	4.29	4.93	0.642	4.20	4.47	0.275	1.436	1.898
	5	4.25	4.77	0.522	4.17	4.43	0.253	1.599	1.943
	2	4.20	4.58	0.380	4.14	4.37	0.225	1.791	2.001
CD0080 SR	100	3.81	4.77	0.960	3.42	3.43	0.006	0.141	1.029
	50	3.78	4.67	0.888	3.27	3.29	0.011	0.238	1.172
	20	3.69	4.50	0.809	3.08	3.08	0.006	0.412	1.376
	10	3.56	4.25	0.687	2.94	2.93	-0.011	0.665	1.525
	5	3.43	3.98	0.550	2.87	2.86	-0.007	0.926	1.596
	2	3.27	3.62	0.345	2.66	2.66	0.000	1.293	1.802
CD0085 SR	100	7.07	7.33	0.259	6.59	6.76	0.173	0.247	0.802
	50	7.05	7.29	0.236	6.57	6.73	0.157	0.286	0.834
	20	7.04	7.24	0.207	6.55	6.69	0.141	0.332	0.868
	10	7.02	7.22	0.197	6.54	6.66	0.126	0.358	0.897
	5	7.01	7.20	0.191	6.53	6.64	0.114	0.378	0.920
	2	6.99	7.18	0.188	6.51	6.61	0.099	0.398	0.950
CD0140	100	3.86	4.66	0.797	3.56	3.67	0.112	2.240	3.303
	50	3.71	4.49	0.788	3.46	3.60	0.132	2.405	3.374
	20	3.54	4.25	0.715	3.34	3.48	0.138	2.643	3.493
	10	3.38	3.99	0.607	3.20	3.41	0.205	2.907	3.562
	5	3.31	3.90	0.595	3.12	3.39	0.270	2.996	3.578
	2	3.12	3.43	0.306	2.92	3.22	0.299	3.468	3.755

Structure*	ARI	Upstream			Downstream			Proposed Case Freeboard to Road** Upstream (m)	Proposed Case Freeboard to Road ** Downstream (m)
		Existing water level	Proposed water level	Water level change	Existing water level	Proposed water level	Water level change		
CD0158 SR	100	3.56	3.67	0.119	3.56	3.55	-0.001	0.212	0.302
	50	3.47	3.59	0.127	3.47	3.48	0.010	0.293	0.380
	20	3.34	3.47	0.124	3.34	3.34	0.003	0.420	0.512
	10	3.20	3.31	0.108	3.20	3.20	0.005	0.579	0.652
	5	3.12	3.21	0.082	3.12	3.13	0.007	0.680	0.726
	2	2.90	2.95	0.050	2.90	2.91	0.006	0.933	0.948
CD0166	100	3.92	4.66	0.732	3.57	3.66	0.089	0.277	2.179
	50	3.79	4.49	0.699	3.48	3.58	0.097	0.441	2.256
	20	3.65	4.26	0.605	3.36	3.45	0.091	0.678	2.385
	10	3.55	4.00	0.453	3.24	3.29	0.059	0.934	2.541
	5	3.47	3.92	0.451	3.21	3.24	0.036	1.011	2.593
	2	3.36	3.64	0.284	3.14	3.10	-0.044	1.294	2.738
CD0182 SR	100	3.93	3.67	-0.255	3.57	3.56	-0.004	0.562	0.563
	50	3.80	3.53	-0.265	3.48	3.48	0.002	0.705	0.648
	20	3.64	3.38	-0.263	3.35	3.35	-0.004	0.860	0.774
	10	3.52	3.28	-0.239	3.29	3.21	-0.078	0.953	0.912
	5	3.43	3.24	-0.189	3.25	3.16	-0.087	0.993	0.961
	2	3.29	3.13	-0.160	3.17	3.08	-0.090	1.103	1.043
CD0195 SR	100	3.99	3.89	-0.098	3.57	3.57	0.001	0.283	0.593
	50	3.88	3.80	-0.080	3.48	3.49	0.008	0.374	0.676
	20	3.76	3.69	-0.064	3.37	3.37	0.003	0.482	0.793
	10	3.65	3.62	-0.036	3.32	3.31	-0.012	0.556	0.851
	5	3.57	3.56	-0.002	3.30	3.30	-0.002	0.610	0.866
	2	3.42	3.44	0.018	3.24	3.25	0.007	0.734	0.912
CDFC0200	100	4.06	4.61	0.548	4.04	3.99	-0.044	2.324	3.881
	50	3.97	4.46	0.490	3.93	3.91	-0.018	2.477	3.958
	20	3.86	4.27	0.411	3.82	3.82	0.005	2.660	4.047
	10	3.78	4.16	0.372	3.73	3.76	0.035	2.779	4.107
	5	3.72	4.07	0.346	3.66	3.72	0.065	2.870	4.149
	2	3.63	3.90	0.272	3.55	3.63	0.082	3.036	4.241

Structure*	ARI	Upstream			Downstream			Proposed Case Freeboard to Road** Upstream (m)	Proposed Case Freeboard to Road ** Downstream (m)
		Existing water level	Proposed water level	Water level change	Existing water level	Proposed water level	Water level change		
CD0206 SR	100	4.02	3.94	-0.080	3.59	3.59	-0.001	0.164	0.754
	50	3.92	3.86	-0.059	3.55	3.52	-0.027	0.247	0.822
	20	3.80	3.76	-0.041	3.51	3.48	-0.023	0.343	0.860
	10	3.71	3.70	-0.015	3.47	3.46	-0.015	0.407	0.886
	5	3.64	3.65	0.017	3.44	3.44	-0.003	0.449	0.904
	2	3.53	3.56	0.033	3.44	3.40	-0.040	0.541	0.944

** SR denotes side road (service or local)*

*** Road refers to the Pacific Highway Upgrade or Eggins Drive as appropriate.*

The flood modelling generally indicates that flood impacts downstream of Eggins Drive are limited with a maximum increase of 13mm occurring in a 50yr ARI event. These impacts would be compliant with the W2B EIS afflux criteria. However moderate to significant flood increases are predicted to occur upstream of the proposed highway upgrade with a maximum increase of 1.53m in a 100 year ARI event. These impacts exceed the W2B EIS afflux criteria. A summary of the properties where impacts exceed the W2B EIS criteria are provided in Table 4-5.

Table 4-5 100 year ARI property flood level impacts caused by project works

Location	Existing Case Flood Level (mAHD)	Proposed Case Peak Flood Level (mAHD)	Flood Level Change (m)	Property type
Property - Lot88 on DP1146153	8.42	9.01	0.591	Forest
Property - Lot103/ /DP752853	8.39	9.00	0.608	Forest
Property - Lot103/ /DP752853	5.97	7.50	1.534	Forest
Property - Lot101/ /DP752853	4.12	4.57	0.450	Forest
Property - Lot101/ /DP752853	3.74	5.25	1.507	Forest
Property - Lot100/ /DP752853	4.56	5.47	0.907	Forest
Property - Lot100/ /DP752853	3.81	4.77	0.960	Forest
Property - Lot83/ /DP752820	3.87	4.66	0.788	Forest
Property - Lot4/ /DP806515	4.05	4.66	0.613	Forest

The results in Table 4-5 demonstrate that moderate to significant flood level increase impacts occur on land that is currently forested with no buildings. No further mitigation is proposed for properties impacted by flood increases. Consultation with the affected property owners will be undertaken by RMS as part of the ongoing community consultation for the Arrawarra Floodplain.

Selected property afflux comparison

As part of the local detailed survey undertaken for the project, five representative locations within the caravan parks were surveyed so that flood level impacts could be tabulated at these specific locations. These are provided in Table 4-6 below and also represented by spot levels on the baseline and post development flood map figures.

Table 4-6 100 year ARI selected property afflux comparison

Location and Lot	Property Threshold Level (mAHD)	2 year ARI			100 year ARI		
		Existing Case Depth (m)	Proposed Case Depth (m)	Water Level Change (m)	Existing Case Depth (m)	Proposed Case Depth (m)	Water Level Change (m)
A- 350/ /DP703698	2.9	0.102	0.105	0.003	0.756	0.754	-0.002
B - 34/ /DP600591	3.23	0.000	0.000	0.000	0.617	0.615	-0.002
C- 351/ /DP703698	3.16	0.000	0.000	0.000	0.278	0.277	-0.001
D - 351/ DP703698	3.27	0.399	0.390	-0.009	1.163	1.170	0.007
E - 351/ /DP703698	3.22	0.820	0.811	-0.009	1.583	1.589	0.006

The flood modelling indicates that flood impacts at the surveyed locations are minor. These impacts would be compliant with the W2B EIS afflux criteria.

Rare/extreme flood event results

An assessment of an extreme event has been undertaken. Table 4-7 summarises the post development flood levels, while Figure 4-7 shows the flood depths, levels and extents. Both the Pacific Highway Upgrade and Eggins Drive carriageways are predicted to overtop during this event.

Table 4-7 Arrawarra floodplain proposed case flood level results for PMF event

Structure*	ARI	Proposed water level (mAHD)		Proposed Case Freeboard to Road** Upstream (m)	Proposed Case Freeboard to Road** Downstream (m)
		Upstream	Downstream		
CD-0044	PMF	9.99	7.81	0.01	1.82
CD-0044 SR	PMF	7.66	5.53	-0.22	1.87
CD-0002 SR	PMF	5.51	4.88	-0.14	0.12
CD0032	PMF	5.72	5.48	-0.88	-0.64
CD0032 SR	PMF	5.35	4.91	-0.91	-0.85
CD0073	PMF	6.59	5.00	-0.22	1.37
CD0080 SR	PMF	4.97	4.89	-0.06	-0.43
CD0085 SR	PMF	7.91	6.99	-0.34	0.58
CD0140	PMF	6.67	4.94	0.23	2.04
CD0158 SR	PMF	4.92	4.94	-1.03	-1.08
CD0166	PMF	6.66	4.95	-1.73	0.89
CD0182 SR	PMF	4.94	4.94	-0.70	-0.82
CD0195 SR	PMF	4.94	4.94	-0.77	-0.78
CDFC0200	PMF	6.65	4.95	0.28	2.92
CD0206 SR	PMF	4.94	4.94	-0.84	-0.60

** SR denotes side road (service or local)*

*** Road refers to the Pacific Highway Upgrade or Eggins Drive as appropriate.*

4.3.3 Historical flood data – validation

Information provided by the local community is outlined in Section 2.2. The data supplied can be broken down into three key areas, namely; flood observations, rainfall data and flooding photos.

Flood Observations

Local residents have identified flood marks and levels based on their observations of the 2012 and 2013 flood events. An RMS surveyor has attended the properties and surveyed the observed levels. A total of 12 properties have provided flood level information for this report. A summary of the flood level observations and a comparison to the modelled 100yr and 2yr ARI design flood levels is provided in Table 4-8.

Rainfall Data

Daily rainfall records collected by a local resident at the Darlington Park Resort are available for the period 1997 – 2013. This information has been collected from a daily read gauge maintained by the local resident. Rainfall totals for the observed flood events are provided in Table 4-8 The APBJV has not checked these observations against BOM records for nearby gauges to confirm validity. The recent draft report prepared for the Corindi Floodplain (Corrindi River Flood Assessment for Woolgoolga to Ballina Pacific Highway Upgrade – Draft Report, NSW Roads and Traffic Authority, SKM, November 2013) has predicted rainfall data for the 2012 and 2013 flood events in the Corindi Floodplain catchment using rainfall radar data and rainfall gauges. This rainfall has not been specifically used in this study and may be suitable for the Arrawarra catchment however a design event of a similar duration and intensity has been utilised in the validation.

Flood Photos

A series of photos have been provided by the local community. The largest number of photos has been provided for the Darlington Park Resort and cover flood events in 1997, 1998, 2001, 2007, 2011, 2012, 2013. RMS has undertaken a ground level survey at the property where these observations have occurred with levels varying between 1.8 to 2.12m AHD. The habitable portion of these properties is typically elevated 1.0 m above these levels. A series of the supplied photos have been used to estimate a flood level for the provided flood events. A garden shed located within the Darlington Park Resort provides a consistent reference point for the various flood events. The garden shed has a surveyed level of 1.85m AHD. A copy of these photographs is provided in Appendix C.

Data Assessment and Discussion

Table 4-8 summarises the observed flood levels and depths at the individual residential properties and compares them to the design 2yr and 100yr ARI modelled baseline (existing) flood levels and depths. The table contains the highway 100yr and 2 yr design event of 48 hours and the 100yr 6 hour event which is of a similar duration to the events observed in the 2012 and 2013 flooding events.

Table 4-8 Comparison of observed to modelled flood levels at various residencies

Property ID	Address	Description	Observed Depth (m)[1]	Observed Level (m AHD)	2yr ARI (Baseline) Depth (m)	100yr ARI (Baseline) Depth (m)	2yr ARI (Baseline) Level (m AHD)	100yr ARI (Baseline) Level (m AHD)	100yr ARI (Baseline) Depth (m)	100yr ARI (Baseline) Level (m AHD)
					48 Hour Duration			6 Hour Duration		
301a	3 Arrawarra Beach Road	2012 OR 2013 (MOST LIKELY 2013) DEBRIS FLOOD HEIGHT/EXTENT IN FRONT YARD	0.08	4.55	0.23	0.33	4.70	4.79	0.32	4.79
301b	3 Arrawarra Beach Road	2012 OR 2013 (MOST LIKELY 2013) DEBRIS FLOOD HEIGHT/EXTENT IN FRONT YARD	0.09	4.52	0.19	0.31	4.62	4.74	0.31	4.74
301c	3 Arrawarra Beach Road	2012 OR 2013 (MOST LIKELY 2013) DEBRIS FLOOD HEIGHT/EXTENT IN FRONT YARD	0.10	4.45	0.23	0.34	4.58	4.69	0.34	4.69
301d	3 Arrawarra Beach Road	2012 FLOOD HEIGHT @ FRONT STEP.	0.22	4.38	0.05	0.18	4.21	4.34	0.18	4.34
302a	1 Arrawarra Beach Road	2013 FLOOD HEIGHT AT REAR OF HOUSE.	0.31	3.12	0.51	0.61	3.33	3.43	0.55	3.37
302b	1 Arrawarra Beach Road	2013 FLOOD HEIGHT ON BRIDGE	0.78	3.48	0.37	0.72	3.07	3.43	0.49	3.20
307	20 Arrawarra Beach Road	2013 FLOOD HEIGHT/EXTENT @ PAVERS AT REAR GARAGE.	0.00	3.79	OME*	0.16*	OME*	3.95*	OME*	OME*
308	3 Ellem Close	FRONT DOOR FLOOD LEVEL	0.10	3.88	OME*	0.1*	OME*	3.88*	0.05	3.87
313	134 Eggins Drive	2013 FLOOD HEIGHT AT REAR STEPS.	0.31	2.67	0.30	1.06	2.65	3.42	0.63	2.98
314a	134 Eggins Drive	2013 FLOOD HEIGHT AT FRONT STEPS.	0.43	2.56	0.53	1.29	2.66	3.42	0.85	2.98
314b	134 Eggins Drive	2013 FLOOD HEIGHT AT REAR STEPS.	0.77	2.95	0.48	1.24	2.66	3.42	0.81	2.98
314c	134 Eggins Drive	2013 FLOOD HEIGHT ON LIGHT POLE	0.39	2.71	0.34	1.10	2.65	3.42	0.66	2.98
314d	134 Eggins Drive	2013 FLOOD HEIGHT ON LIGHT POLE	0.67	2.70	0.63	1.39	2.66	3.42	0.96	2.98
317a	100 Eggins Drive	2012 FLOOD HEIGHT/EXTENT IN YARD.	-0.15	2.36	0.15	0.91	2.66	3.42	0.47	2.99
317b	100 Eggins Drive	2012 FLOOD HEIGHT/EXTENT ON BRIDGE DECK	0.40	1.90	1.16	0.91	2.66	3.42	1.48	2.98

Property ID	Address	Description	Observed Depth (m)[1]	Observed Level (m AHD)	2yr ARI (Baseline) Depth (m)	100yr ARI (Baseline) Depth (m)	2yr ARI (Baseline) Level (m AHD)	100yr ARI (Baseline) Level (m AHD)	100yr ARI (Baseline) Depth (m)	100yr ARI (Baseline) Level (m AHD)
					48 Hour Duration			6 Hour Duration		
318	74 Eggins Drive	2012 FLOOD HEIGHT/EXTENT AT EDGE OF DAM/DRIVEWAY.	-0.96	1.64	0.17	0.82	2.77	3.42	0.47	3.07
322	6 Ellem Close	2012 EXTENT - SIDE OF OPEN DRAIN.	-0.39	2.63	0.28	0.58	3.31	3.61	0.58	3.60
323	10 Ellem Close	2012 EXTENT - SIDE OF OPEN DRAIN.	0.15	3.18	0.32	0.73	3.36	3.76	0.73	3.76
324a	210 Eggins Drive	2012 TENNIS COURT FLOOD LEVEL	0.02	3.08	-**	0.50	-**	3.55	0.20	3.26
324b	210 Eggins Drive	2012 FENCE FLOOD LEVEL	0.55	3.00	0.44	1.10	2.90	3.55	0.80	3.26
324c	210 Eggins Drive	2012 FRONT PATH FLOOD LEVEL (ON PATH - EXTENT)	0.03	3.04	-**	0.54	-**	3.55	0.25	3.25
324d	210 Eggins Drive	2012 CAMP KITCHEN FLOOD LEVEL (ON PATH - EXTENT)	0.12	3.12	-**	0.56	-**	3.55	0.26	3.26
325	45 Arrawarra Beach Road	2012 HEADWALL FLOOD LEVEL/EXTENT (DRAIN FULL).	0.21	3.81	OME*	0.1	OME*	3.7	OME*	OME*
331a	8 Arrawarra Road	2012 FLOOD LEVEL @ HEADWALL OUT THE FRONT OF PROPERTY.	0.17	3.95	OME*	0.20	OME*	3.97	0.20	3.94
331b	8 Arrawarra Road	2012 FLOOD LEVEL/EXTENT IN FRONT OF GARAGE. 2013 FLOODS WERE A SIMILAR SCENARIO AS 2012, JUST NOT AS MUCH WATER.	0.14	3.91	OME*	0.20	OME*	3.96	OME*	OME*
333	47 Arrawarra Road	2012 FLOOD LEVEL AT HOUSE.	0.62	4.22	OME*	0.20	OME*	3.80	OME*	OME*

Legend *XXX – Level within 150mm* *XXX – Level within 300mm* *XXX – Level greater than 300mm* *XXX – Data not used - Inconsistent with surrounding flood level observations.*
Level comparison is between the observed flood levels/depth and the baseline (existing) design model flood level/depth predictions.

[1] - Observed flood depth estimated from observed flood level (as surveyed) and ground model. Ground level has not been surveyed at the observed flood level location. Negative (-0.15) depths would indicate an anomalous depth or survey level

** - Interpolated flood level and depth only for location outside Arrawarra Creek north arm model extents*

OME - Flood level estimation not possible due to location outside Arrawarra Creek north arm model extents*

*-** - No flooding predicted for this event at this location.*

Table 4-9 summarises the estimate water depth, flood level and rainfall total at the Darlington Park Resort location.

Table 4-9 Estimated Flood Depths and Levels at Darlington Park Resort

Year	Depth estimate** (m)	Ground Level (m)	Flood Level (m AHD)	48 Hour Rainfall***(mm)
1997	Unable to determine	1.85	Unable to determine	Unable to determine
1999	0.15	1.85	2.0	Unable to determine
2001	0.30	1.85	2.15	191 (174, 17)
2007	0.40	1.85	2.25	Unable to determine
2011	0.45	1.85	2.30	303 (104,199)
2012	0.75	1.85	2.60	247 (73,174)
2012*	0.45	2.30	2.75	247 (73,174)
2013	0.65	1.85	2.50	236 (38,198)

* - *Relates to Eggins Drive location directly outside Darlington Park Resort (see Photos I & J Appendix C)*

** - *Depths estimated at Garden Shed within Darlington Park Resort (see Photos Appendix C).*

***- *Rainfall depths estimated from Darlington Park Resort daily rainfall records. Daily totals in brackets.*

Table 4-10 summarises the flood levels and rainfall depths from the 100% design model at the Darlington Park Resort location.

Table 4-10 Darlington Park Resort Flood Levels and Rainfall Depths - 100% Design

ARI	Darlington Park Resort – Flood Level (m AHD)*	Eggins Drive– Flood Level (m AHD)**	Design Hyetograph Total Rainfall Depth (mm)***
2	2.64	2.90	202 (85)
50	3.25	3.45	446 (159)
100	3.44	3.55	505 (191)

* - *Relates to Garden Shed within Darlington Park Resort (see Photos Appendix C)*

** - *Relates to Eggins Drive location directly outside Darlington Park Resort (see Photos I & J Appendix C)*

***- *2 day rainfall total depths taken from project derived design Intensity Frequency Duration curves. 9 hour duration rainfall totals in brackets.*

It should be noted that the recent draft report prepared for the Corindi Floodplain (Corrindi River Flood Assessment for Woolgoolga to Ballina Pacific Highway Upgrade – Draft Report, NSW Roads and Traffic Authority, SKM, November 2013) has undertaken a detailed flood and rainfall validation process using rainfall radar data, rainfall gauges and flood observations for the 2012 and 2013 flood events in the Corindi Floodplain catchment. The assessment concludes that the flood events occurring were a result of approximate 100yr ARI rainfall depths that occurred in a period of 4 to 9 hours. The review of flood results for the Arrawarra Floodplain should consider the peak flood level predictions for the 48 hour duration event as well a shorter duration event. A 100yr 6 hour duration event is included in Section 5.1 Sensitivity Analysis and is suitable for this purpose.

The observed flood levels in Table 4-8 and Table 4-9 provide a reasonable match. Overall 78% of the observed flood levels are within 300mm of the modelled flood levels while 30% are within 150mm. There is generally a good correlation between the 100yr ARI model and observed flood levels in the lower reaches of Arrawarra Creek (Arrawarra Beach Road area). It is considered that this downstream area is less sensitive to the duration of the rainfall event and that various duration 100yr flood events are likely to produce similar 100yr flood levels as a result of the channel geometry and bed level.

However flood level observations in the middle floodplain area (Eggins Drive and Arrawarra Road areas) are generally lower than the modelled levels. It should be noted that the flood level observations for the middle floodplain area however, fit reasonably well against the flood photos and flood level observations at the garden shed in the Darlington Park Resort. This would indicate a good reliability in flood level observations at this location and the potential that the flood model may be over estimating flood levels in this area.

A review of the resident supplied two day rainfall totals for the observed flood events against the design two day rainfall totals would indicate a return period of between the 2 to 5 yr ARI for a 48 hour event. However embedded within the two days totals are significant daily events that could represent significantly higher return periods in the order of between the 20-100yr ARI for shorter duration events. These are likely to be consistent with the findings of the Corrindi River Flood Assessment for Woolgoolga to Ballina Pacific Highway Upgrade – Draft Report. However given the lack of a time series for the local gauging information the actual duration of the vents occurring at Arrawarra cannot be confirmed.

Conclusion

The 100% design model would be considered to provide flood levels estimates that provide a reasonable fit to the flood level observation provided by the local residents. The design model may be considered to produce moderately conservative flood levels in the middle floodplain area, however no ‘order of magnitude’ differences are present. It should be noted that the difference between the100yr and 2yr ARI flood levels downstream of Eggins Drive are generally in the range of 300-600mm. This demonstrates that flood levels are not particularly sensitive to rainfall intensities but to total rainfall depths.

For purposes of setting the highway upgrade and Eggins Drive levels to achieve the 100yr ARI immunity, the model would be considered suitable albeit moderately conservative. For purposes of the afflux assessment, the 100% model provides a suitable comparative base. The current 100% design model, upon review of the flood validation data, is considered to provide satisfactory flood level estimates and has therefore been adopted with no further calibration.

The information supplied by the Darlington Park Resort and other residents would be considered of use in the future, should a full flood study be undertaken for the area. This flood study would serve a different purpose to that undertaken for this project (ie to set 100 year ARI flood levels for development purposes).

4.3.4 Climate change assessment

4.3.4.1 Allowance and assessment criteria

An allowance of 15% has been added to the peak 100 year ARI flows in order to provide an indication of the potential impact of climate change on the hydraulic performance of each structure. The guidance document (http://www.environment.nsw.gov.au/resources/climatechange/ccscenarionsw.pdf) provides climate change scenarios for the NSW North Coast region. It advises a +5% to +20% increase in peak rainfall to 2050, and a >+9% increase in run-off to 2030. Given the anticipated 100 year design life of the proposed highway it is considered appropriate to assess a +15% increase in peak flows.

This is also consistent with the value adopted for the adjoining Glenugie Upgrade project. Further information is provided in the Drainage Design Criteria Report (W2G-G-DR-RP-001).

The criteria for assessment is that the proposed Pacific Highway Upgrade road level is not overtopped during the 100 year ARI however reporting of the potential impact on the highway and Eggins Drive road flood immunity as a result of climate change allowance have been documented.

4.3.4.2 Results

The results from the climate change allowance assessment are provided in Section 5.2.

4.4 Culvert scour

Scour protection requirements at cross-drainage culverts are documented in the relevant Section 1 cross-drainage report (W2G-1-DR-RP-0002).

5. Sensitivity analysis

5.1 General

Although the chosen parameters are considered to represent most accurately the existing hydrologic and hydraulic conditions, sensitivity analysis is undertaken to gauge the potential consequences should key assumptions change or have to be changed. The sensitivity analysis also demonstrates that the model behaves as theoretically expected.

5.2 Inflows – Climate Change

The hydrological analysis is un-calibrated and therefore retains a degree of uncertainty within the estimates. There is also the potential that future development and/or land use changes within the catchment may alter the magnitude or timing of peak flows. For this reason an assessment has been made of the impact on peak flood levels by increasing the peak 100 year ARI flow by + 15% (see Table 5-1). This assessment dually functions as the climate change impact assessment discussed in Section 4.3.3.

The results in Table 5-1 show that, in general, the predicted peak flood levels are not particularly sensitive to variation in the peak inflow. The Pacific Highway upgrade or Eggins Drive would not be overtopped at any location however a shallow depth intrusion to the trafficable lane is predicted adjacent culvert CD-0044SR on Eggins Drive. This depth would not be expected to affect the trafficability of the road.

Table 5-1 Sensitivity of peak 100 year ARI flood levels to peak inflow variation

Structure*	Upstream Peak Flood Level (mAHD)			Downstream Peak Flood Level (mAHD)			Proposed Case Freeboard to Road** Upstream (m)	Proposed Case Freeboard to Road** Downstream (m)
	Proposed Case	15% Peak Flow	Water level change	Proposed Case	15% Peak Flow	Water level change		
CD-0044	9.00	9.23	0.228	7.54	7.59	0.051	0.771	2.043
CD-0044 SR	7.50	7.55	0.051	5.41	5.41	0.002	-0.113	1.987
CD-0002 SR	5.25	5.36	0.115	3.56	3.60	0.033	0.005	1.403
CD0032	4.57	4.79	0.226	3.82	4.11	0.284	0.045	0.725
CD0032 SR	3.80	4.09	0.296	3.43	3.57	0.139	0.338	0.485
CD0073	5.47	5.70	0.230	4.80	4.92	0.118	0.673	1.453
CD0080 SR	4.77	4.90	0.128	3.43	3.57	0.139	0.013	0.890
CD0085 SR	7.33	7.36	0.029	6.76	6.78	0.026	0.217	0.777
CD0140	4.66	4.84	0.181	3.67	3.75	0.083	2.059	3.220
CD0158 SR	3.67	3.76	0.081	3.55	3.64	0.090	0.130	0.212
CD0166	4.66	4.84	0.181	3.66	3.74	0.087	0.096	2.092
CD0182 SR	3.67	3.82	0.151	3.56	3.65	0.089	0.411	0.474
CD0195 SR	3.89	4.00	0.104	3.58	3.66	0.081	0.179	0.501
CDFC0200	4.61	4.79	0.178	3.99	4.08	0.087	2.146	3.793
CD0206 SR	3.94	4.03	0.096	3.59	3.67	0.083	0.068	0.671

** S* SR denotes side road (service or local)*

*** Road refers to the Pacific Highway Upgrade or Eggins Drive as appropriate.*

5.3 Inflows – Short Duration Event

The peak flood levels have been predicted to occur for a 48 hour duration event. However a number of the smaller upstream catchments have local peak durations of 6 hours. The 100 year ARI six hour duration event has been run in the model to determine any local differences. Table 5-1 summarises the model results.

Table 5-2 Peak 100 year ARI flood levels for 6 hour duration event

Structure*	Upstream Peak Flood Level (mAHD)			Downstream Peak Flood Level (mAHD)		
	Proposed Case	6 Hr Duration Peak Flow	Water level change	Proposed Case	6 Hr Duration Peak Flow	Water level change
CD-0044	9.00	8.79	-0.21	7.54	7.39	-0.15
CD-0044 SR	7.50	7.34	-0.16	5.41	5.40	-0.01
CD-0002 SR	5.25	4.83	-0.42	3.56	3.59	+0.03
CD0032	4.57	4.49	-0.08	3.82	3.88	-0.06
CD0032 SR	3.80	3.88	+0.08	3.43	3.07	-0.36
CD0073	5.47	5.28	-0.19	4.80	4.55	-0.25
CD0080 SR	4.77	4.45	-0.32	3.43	2.99	-0.44
CD0085 SR	7.33	7.33	-0.00	6.76	6.76	-0.00
CD0140	4.66	4.60	-0.06	3.67	3.49	-0.18
CD0158 SR	3.67	3.39	-0.28	3.55	3.26	-0.28
CD0166	4.66	4.60	-0.06	3.66	3.38	-0.28
CD0182 SR	3.67	3.53	-0.14	3.56	3.31	-0.25
CD0195 SR	3.89	3.86	-0.03	3.58	3.38	-0.20
CDFC0200	4.61	4.56	-0.05	3.99	3.97	-0.02
CD0206 SR	3.94	3.91	-0.03	3.59	3.54	-0.05

** S* SR denotes side road (service or local)*

*** Road refers to the Pacific Highway Upgrade or Eggins Drive as appropriate.*

The results demonstrate that typically the 48 hour duration rainfall event produces the largest 100yr ARI peak flood levels, however at two locations the local event produces a moderately higher peak flow.

The 30mm difference downstream of CD0002SR has no impact on the100 year flood immunity of the highway upgrade or Eggins Drive with freeboard exceeding 1.4m. The afflux impact is negligible as the existing flood level at this location is 3.66m AHD.

The 80mm difference upstream of CD0032SR has no impact on the100 year flood immunity of the highway upgrade or Eggins Drive with freeboard exceeding 300mm. The impact is constrained to the area between the two roads which is within the RMS project boundary.

5.4 Roughness

A roughness sensitivity check has not been undertaken for the Arrawarra Floodplain. The mechanism for the peak flooding event assessed is related to the volume of water entering the floodplain and leaving via the narrow outlet channel. The flooding is therefore sensitive to volume rather than the peak flow of the local catchment hydrographs. Flood level predictions for the design events would therefore not be sensitive to roughness.

5.5 Downstream boundary

As outlined in Section 4.2 the flood and tidal event combination selected for the design would be considered conservative. To test this, a sensitivity check using a typical high tide of 0.7m AHD with the 100 year ARI design event was undertaken. Coincidentally this is also similar to the typical level of the sandbar that blocks the creek exit when the outlet is closed. Additionally a check on the initial water level in the floodplain was undertaken by reducing the starting water level from 2.1m AHD to 1.0m AHD. The starting water level is used to assist in model stability and fills areas of topography with water below this level.

The peak flood level result comparison is provided in Table 5-3. The results show only minor differences (10mm) in peak flood levels irrespective of the starting tide level or floodplain water level. This occurs because the outlet channel for the Arrawarra Floodplain acts as a control (constraint) on water leaving the floodplain due to the narrow local topography and channel bed level. This control is established upstream of the channel outlet as demonstrated in Figure 5-1 below. Therefore for purposes of the design events selected, the starting tide level is not critical. This is consistent with the observations made in a previous study (see Section 2.1A)

In a similar fashion the volume of water present within the model with either a 2.1m or 1.0m AHD starting level is minor (10mm) and does not have any significant impact on the flood level predictions for the design events.

The impacts of climate change on the downstream boundary have also been considered. Increase of up to 0.9m to peak tide events are predicted over the next 100 years. The proposed Highway and Eggins Drive is elevated well above a conservative assumed king tide level of 2.1m (1.2m AHD + 0.9m climate change) and would not be subject to inundation. The current 20yr tide is currently predicted to be 2.1m AHD and 3.0m AHD assuming a 0.9m increase. This is extremely conservative as components of this peak tide estimate (wave height, storm surge) are likely to have a significantly reduced impact at the highway. In any event the proposed Highway and Eggins Drive are located above this level and would not be subject to inundation.

Table 5-3 Sensitivity of peak 100year ARI flood levels to downstream boundary variation

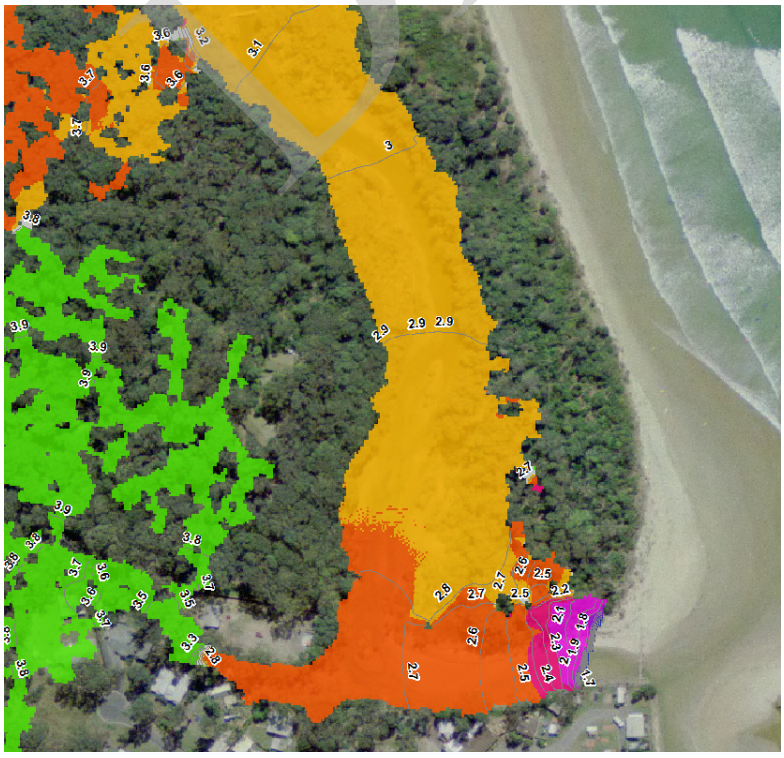
Structure*	Upstream Peak Flood Level (mAHD)			Downstream Peak Flood Level (mAHD)		
	Proposed Case**	Tidal Boundary Reduced***	Initial Water Level Reduced****	Proposed Case**	Tidal Boundary Reduced***	Initial Water Level Reduced****
CD-0044	9.00	9.00	9.00	7.54	7.54	7.54
CD-0044 SR	7.50	7.50	7.50	5.41	5.41	5.41
CD-0002 SR	5.25	5.25	5.25	3.56	3.56	3.56
CD0032	4.57	4.55	4.56	3.82	3.81	3.82
CD0032 SR	3.80	3.78	3.79	3.43	3.42	3.42
CD0073	5.47	5.46	5.46	4.80	4.80	4.80
CD0080 SR	4.77	4.77	4.77	3.43	3.42	3.42
CD0085 SR	7.33	7.32	7.33	6.76	6.76	6.76
CD0140	4.66	4.65	4.65	3.67	3.67	3.67
CD0158 SR	3.67	3.66	3.67	3.55	3.55	3.55
CD0166	4.66	4.65	4.65	3.66	3.65	3.66
CD0182 SR	3.67	3.66	3.67	3.56	3.56	3.56
CD0195 SR	3.89	3.89	3.89	3.57	3.56	3.57
CDFC0200	4.61	4.61	4.61	3.99	3.99	3.99
CD0206 SR	3.94	3.94	3.94	3.59	3.58	3.59

** SR denotes side road (service or local)*

*** The proposed case incorporates a 2.1m AHD starting water level and tidal boundary condition.*

**** This case incorporates a 1.0m AHD starting water level and 0.7m AHD tidal boundary condition.*

***** This case incorporates a 1.0m AHD starting water level and 2.1m AHD tidal boundary condition.*



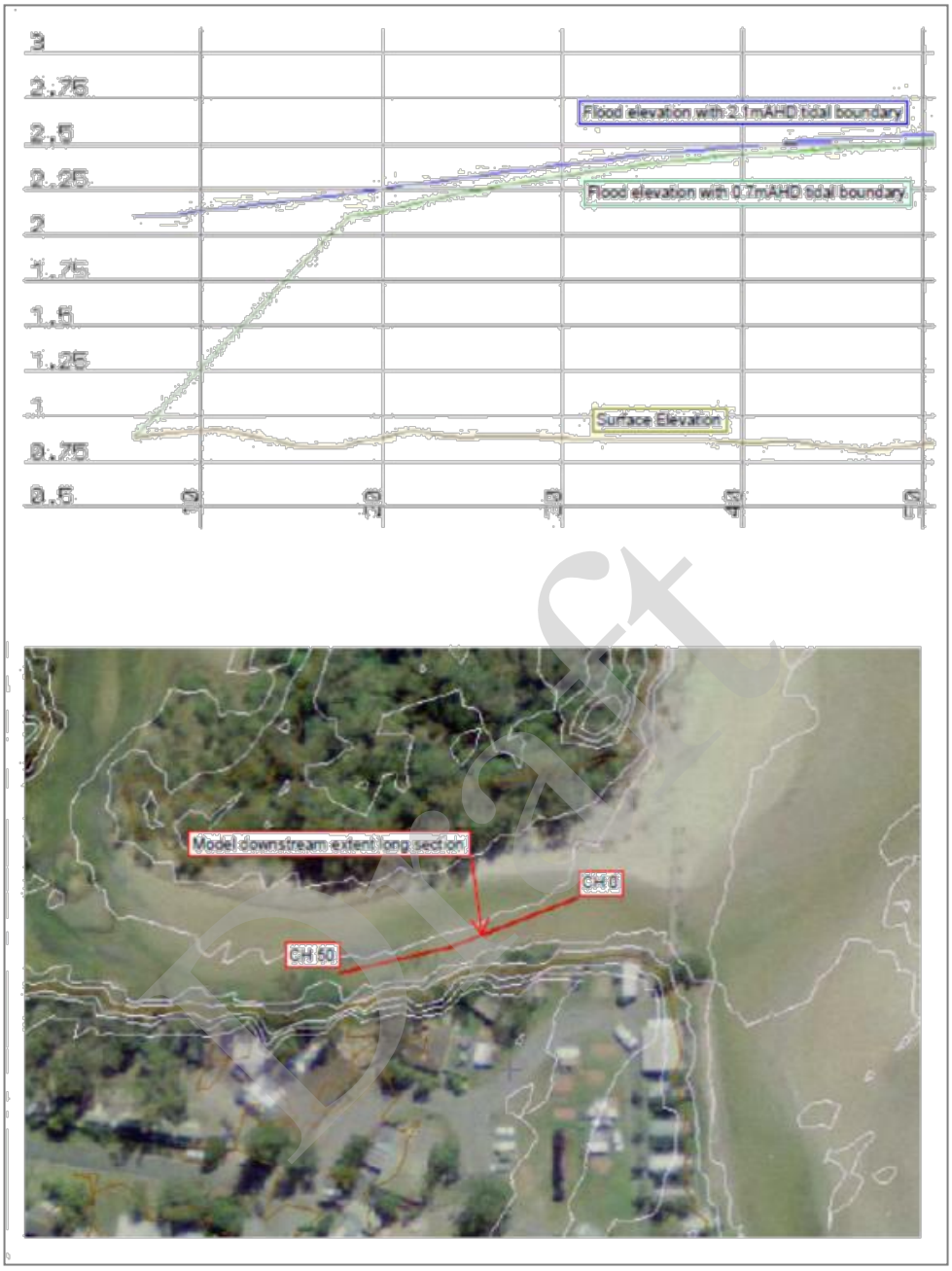


Figure 5-1 Upstream Channel Outlet Control

6. Conclusions and recommendations

6.1 Conclusion

The proposed highway upgrade and Eggins Drive have a 100 year ARI level of flood immunity.

The floodplain area located downstream of Eggins Drive is subject to minor flood level increases up to a maximum of 13mm. These impacts are compliant with the afflux criteria provided in the W2B EIS.

There is however a number of properties located upstream of the Pacific Highway Upgrade that are adversely impacted by a flood level changes in excess of the EIS criteria. These impacted areas are forested land and contain no habitable buildings.No further flood mitigation is proposed.

6.2 Recommendation

Consultation with the affected landowners should be undertaken as part of the ongoing Arrawarra Floodplain community consultation process.

7. References

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