Transport
Roads & Maritime Services

INDEPENDENT REVIEW OF FLOOD MODELLING

Pacific Highway, Woolgoolga to Ballina upgrade

Final report

JULY 2012

ROADS & MARITIME SERVICES

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

FINAL REPORT

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FINAL REPORT

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Project Woolgoolga To Ballina Pacific Highway Upgrade – Independent Review Of Flood Modelling	**Project Number** 111052
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Date 4 July 2012	**Verified by**

Revision	Description	Date
2	Final Report	July 2012
1	Draft Report	May 2012

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

TABLE OF CONTENTS

PAGE

EXECUTIVE SUMMARY v

1. INTRODUCTION 1

1.1. Background 1

1.2. Scope of Independent Review 1

1.3. Supplied Information 2

1.4. Limitations 3

2. BACKGROUND OF MODELS 5

2.1. Overview 5

2.2. Purposes of the Models 5

2.3. Design Criteria 5

2.4. Modelled Scenarios 6

2.5. History of the Models 6

3. REVIEW OF MODELS 8

3.1. Summary of Key Findings 8

3.2. Detailed Findings 10

3.2.1. Corindi River 10

3.2.2. Halfway Creek 15

3.2.3. Pheasant Creek 18

3.2.4. Coldstream River 23

3.2.5. Pillar Valley Creek 27

3.2.6. Chaffin Creek 32

3.2.7. Champions Creek 36

3.2.8. Clarence River 41

3.2.9. Mororo Creek 50

3.2.10. Tabbimoble Creek 52

3.2.11. Tabbimoble Floodway 1 54

3.2.12. Oaky Creek 56

3.2.13. Richmond River 58

3.2.14. Ballina Bypass 64

4. FURTHER DISCUSSIONS 69

4.1. Comparison against Previous Assessments 69

4.2. Feasibility of Drainage Structures 72

4.3. Community Engagement 73

5. CONCLUSIONS AND RECOMMENDATIONS 76

5.1. Summary 76

5.2. Recommendations 76

6. REFERENCES 77

LIST OF APPENDICES

Appendix A: Glossary
Appendix B: Summary of Models
Appendix C: Drainage Structures/Waterway Crossings Inventory

LIST OF TABLES

Table 1: Summary of models adopted in the flood assessment (from south to north)................ vi
Table 2: Models used in previous assessment (adopted from Reference 2).............................. 7

LIST OF FIGURES

Figure 1: Sub-catchments delineation for the Corindi River floodplain
Figure 2: DEM generated for the Corindi River model
Figure 3: Impacts above 250 mm upstream of the proposed highway embankment for the 100 year ARI event
Figure 4: DEM generated for the Halfway Creek model
Figure 5: Sub-catchments delineation for the Pheasant Creek floodplain
Figure 6: Omission of proposed works (Chainage 39400 – 40000) from the model
Figure 7: Sub-catchments delineation for the Coldstream River floodplain
Figure 8: Impacts above 250 mm upstream of the proposed highway embankment for the 100 year ARI event
Figure 9: Sub-catchments delineation for the Pillar Valley Creek floodplain
Figure 10: Plot of mass balance error for the Pillar Valley Creek model
Figure 11: Sub-catchments delineation for the Chaffin Creek floodplain and nearby creeks
Figure 12: Sub-catchments delineation for the Champions Creek floodplain and nearby creek
Figure 13: Changes to peak flood level on the floodplain after implementing the corrections
Figure 14: Changes to volume of water entering/exiting the model after implementing the corrections
Figure 15: Sub-catchments delineation for the Clarence River floodplain/Shark Creek basin
Figure 16: Plot of mass balance error for the Clarence River model
Figure 17: Abnormalities found in the Zpts check layer
Figure 18: Excessive lowering of Zpts for culvert inlets/outlets
Figure 19: Inflow boundary condition for the Esk River and extent of hydraulic model boundary
Figure 20: Missing 2D-2D connection for the refined Shark Ck basin domain
Figure 21: Impacts of up to 100 mm at Chatsworth/Harwood Island for the 20 year ARI event
Figure 22: WBNM sub-catchments delineation for the Richmond River floodplain near Wardell
Figure 23: Plot of mass balance error for the Richmond River model
Figure 24: Available flood storage behind hydraulic model boundary
Figure 25: Schematisation of the Richmond River bridge
Figure 26: Wrong attribute for 1D bridge/channel
Figure 27: Flow hydrographs sampled from downstream of the confluence of Broadwater and Richmond River
Figure 28: Schematisation error for Emigrant Creek
Figure 29: Impacts above 60 mm for the 20 year ARI event
Figure 30: Representation of the proposed road embankment for the highway upgrade in SOBEK
Figure 31: SOBEK model results for the Richmond River floodplain near Woodburn/Tuckombil Canal
Figure 32: Works proposed as part of the Pacific Highway Upgrade at Chatsworth/Harwood Island (adopted from Reference 2)

EXECUTIVE SUMMARY

WMAwater have been engaged by Roads and Maritime Services (formerly Roads and Traffic Authority) to conduct an independent assessment of the flood modelling undertaken by SKM for the proposed upgrade of the Pacific Highway from Woolgoolga to Ballina. This independent review, which included specific community engagement and consultation, was conducted as part of a commitment made to the local community and landholders as well as due to a change in modelling methodology from the previous four smaller section assessments to the refined concept assessment. The review process is independent of the Environmental Assessment.

This document presents detailed findings from a review of the hydrologic and hydraulic models developed/adopted for the flooding investigations, with particular focus on the implementation and modelling of the major cross drainage structures and waterway crossings for the proposed highway upgrade. These structures pose significant influence on the associated flood impacts of the proposed works which serve as a major concern for the local community as raised during the flood focus group meetings. The outcomes of the development of the concept design must meet the flood immunity objectives established.

The review found several aspects of the modelling approach and schematisation which require further work or need to be addressed in order to facilitate a more reliable assessment of the flood issues for the proposed works. Issues pertaining to the individual models are discussed in detail in Section 3.2 while a summary of key findings applicable to all models is outlined in Section 3.1 and briefly described as follows:

(1) The energy losses introduced by bridges and other major drainage structures that constrict flows have not been validated or benchmarked against alternative calculation methods or model such as HEC-RAS, which is necessary for the correct estimation of the potential afflux generated upstream of such structures;
(2) The impact of blockages on the performance of the highway cross drainage structures has not been considered even though the presence of vegetation growth (cane farms etc.) on both sides of the highway corridor increases the risk of blockage for these culverts. The sensitivity of the model results to the blockage assumption should be examined; and
(3) The review of sub-catchment delineation identified a few locations where flows from upstream catchment areas have been allocated downstream of a significant control feature such as the raised highway embankment. This occurred generally during the initial period of the simulation runs. The sub-catchment delineation should be revised where necessary for locations where the hydraulic model is used to size the cross drainage structures.

An overview of the 14 hydrologic/hydraulic models adopted for the flood assessment is presented as Table 1, including other minor findings not covered by the previous points.

Table 1: Summary of models adopted in the flood assessment (from south to north)

Watercourse (Models)	General Comments	Findings Requiring Attention
All Watercourses/Models	• Modelling approach appropriate • Developed models suitable for purpose subject to minor corrections where applicable	This Phase (1) Need to validate form losses of critical structures against alternative methods (2) To consider impact of blockages on drainage structure performance (3) To revise sub-catchment delineation where necessary for post development scenarios
Corindi River (XP-RAFTS + TUFLOW)	• Proposed drainage structures/waterway crossings implemented properly	This Phase • Afflux >250mm found at small areas outside of project boundary though no assets affected, larger waterway crossings not justified Prior to Detailed Design • Model terrain could be extended for modelling extreme events, i.e. PMF
Halfway Creek (XP-RAFTS + TUFLOW)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	This Phase • Local catchment runoff excluded though contribution to flow is minimal Prior to Detailed Design • Model terrain could be extended for modelling extreme events, i.e. PMF
Pheasant Creek (WBNM + TUFLOW)	• Afflux criteria met	This Phase • Proposed works (Ch 39400-40000) for unnamed creek floodplain north of Pheasant Ck not included in the model • Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary • Omission of form losses for major waterway structures proposed

Watercourse (Models)	General Comments	Findings Requiring Attention
Coldstream River (WBNM + TUFLOW)	• Proposed drainage structures/waterway crossings implemented properly	This Phase • Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary • Afflux >250mm found at small areas outside of project boundary though no assets affected, larger waterway crossings not justified • Omission of form losses for major waterway structures proposed
Pillar Valley Creek (WBNM + TUFLOW)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	This Phase • Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary • Omission of form losses for major waterway structures proposed
Chaffin Creek (WBNM + TUFLOW)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	This Phase • Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary • Omission of form losses for major waterway structures proposed
Champions Creek (WBNM + TUFLOW)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	This Phase • Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary • Omission of form losses for major waterway structures proposed
Clarence River (Cordery-Webb, UH, FFA + TUFLOW)	• Model calibration and validation performed • Proposed drainage structures/waterway crossings implemented properly	This Phase • Hydraulic model running at moderately high Courant numbers • A few abnormalities found in the model 2D elevations (Zpts) • Missing a 2D-2D connection for linking model domains • Afflux up to 100mm found at isolated locations, may have been addressed by later design changes

Watercourse (Models)	General Comments	Findings Requiring Attention
		Prior to Detailed Design • Hydrosurvey data used to develop the model terrain could be updated • Cross-sections for Serpentine Channel not based on actual surveyed data
Mororo Creek (XP-RAFTS + MIKE-FLOOD)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	• Nil
Tabbimoble Creek (XP-RAFTS + MIKE-FLOOD)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	• Nil
Tabbimoble Floodway 1 (XP-RAFTS + MIKE-FLOOD)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	• Nil
Oaky Creek (XP-RAFTS + MIKE-FLOOD)	• Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	• Nil
Richmond River south (WBNM + TUFLOW)	• Model calibration and validation performed • Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	This Phase • Form loss adopted for proposed bridge structures relatively low and needs to be validated • Specification error for bridge/channel along Rocky Mouth Ck
Richmond River north (XP-RAFTS, FFA + TUFLOW)	• Model calibration and validation performed • Proposed drainage structures/waterway crossings implemented properly • Afflux criteria met	This Phase • Hydraulic model run time could be extended further • Schematisation error for waterway upstream of Emigrant Ck

Despite concerns raised by the community, optimisation or refinements made to the concept design of the waterway crossings since the previous assessments appear to be warranted owing to the significant revision of the hydraulic model and the availability of new calibration and terrain data. This is reinforced by the fact that deficiencies were found in the models developed for the previous assessments and the recent models were refined to address some of these shortcomings.

Overall it is WMAwater's conclusion that the flood modelling undertaken by SKM for the proposed Pacific Highway upgrade only requires minor revision, with a list of recommendations resulting from this review provided in Section 5.2. It is likely that there will be minimal changes to the estimated design flood levels particularly in the vicinity of the proposed highway corridor for the assessed flood events. Based on the findings of this review and the outcomes of the community engagement process, WMAwater is confident that the Alliance is in a position to deliver the flood assessment working paper for the coming review.

1. INTRODUCTION

WMAwater have been engaged by Roads and Maritime Services (formerly Roads and Traffic Authority) to conduct an independent assessment of the flood modelling undertaken by SKM for the proposed upgrade of the Pacific Highway from Woolgoolga to Ballina.

1.1. Background

To date, the Woolgoolga to Ballina (W2B) section of the Pacific Highway upgrade is in the planning stages. The concept design was developed by the Woolgoolga to Ballina Planning Alliance (Alliance) consisting of the Roads and Maritime Services (RMS), Sinclair Knight Merz (SKM) and Aurecon. Previously the project has been assessed as four separate projects (i.e. Woolgoolga to Wells Crossing, Wells Crossing to Iluka Road, Iluka Road to Woodburn, and Woodburn to Ballina) and since then it has been combined into a refined concept design for the entire section. Planning approval is currently being sought by the Alliance as part of an Environmental Assessment. As part of the refined concept design a number of specialist reports have been prepared, including a technical paper on hydrology and flooding. This paper also includes further hydrologic and hydraulic assessment of the highway upgrade, outlining updates to existing modelling and establishment of new models for previously omitted sections.

The refined concept design has been on public exhibition and submissions related to flooding in particular have been received. Two flood focus groups have been established by RMS (for Clarence River and Richmond River), which allowed the Alliance to meet with representatives from the local community and landholders to discuss the management of potential impacts of the proposed highway upgrade on local floodwater levels. Commitment has been made to the community to undertake an independent peer review of the revised modelling, which included specific community engagement and consultation. This review is independent of the Environmental Assessment process.

The need for independent community engagement has also arisen from a change in modelling methodology from the four smaller section assessments to the refined concept assessment. Up to 17 separate models were previously established using different modelling platforms (including SOBEK, TUFLOW, MIKE-FLOOD and HEC-RAS); since then this has been refined using the two modelling platforms: TUFLOW and MIKE-FLOOD.

1.2. Scope of Independent Review

The scope of the review covers the review of the overall modelling undertaken by SKM with respect to approach and results, as well as items related to community engagement in relation to the flood impacts and feedback received on the project.

The review focused on the TUFLOW and MIKE-FLOOD models developed and used by SKM to conduct the hydrologic and flooding assessment of the proposed highway upgrade. An overview of the model extents is provided in Figure A1. The model setup was examined in terms of general model structure, model schematisation, boundary conditions, roughness, hydraulic structures and model run parameters. Results presented in previous assessments (which involved the use of SOBEK to model the Richmond River) were also used to compare with those based on the updated model, particularly where significant changes were introduced to the model as part of the revised design leading to changes in the results. Where relevant, the ability of the models to replicate historical flood events was also examined. The review then specifically focused on the results of the modelling and the associated impacts of the works on the community, including any changes in the refined concept (such as a reduction in the required waterway area) that may impact on the community. The whole process was guided by the criteria established in the flood impact objectives defined as part of the refined concept technical paper on hydrology and flooding.

An additional aspect of the review was to engage the local community through participation in the flood focus group meetings as well as further meetings with affected landholders with significant concerns. These tasks were undertaken as directed by the RMS. The progress and outcomes of the review process were discussed during further meetings with the RMS.

1.3. Supplied Information

WMAwater has principally relied on the following materials in the completion of this review:

- *Previous Reports Pertaining to the Study*
  - **Woolgoolga to Ballina Concept Plan and Early Works Working Paper 2**, November 2010 (Reference 2);
  - **Woodburn to Ballina Preferred Route/Concept Design Hydrology/Hydraulics Report**, October 2007 (Reference 3);
  - **Richmond River Flood Mapping Study Final Report**, March 2010 (Reference 4); and
  - **Lower Clarence River Flood Study Review Final Report**, March 2004 (Reference 5).

- *Concept Design of Highway Upgrade*
  - **RTA Concept Plan for Class M Dual Carriageway Woolgoolga to Ballina**, May 2011 (Reference 6).

- *Model Files and Results (further details in Appendix B)*
  1. **Ballina Bypass** – hydrologic/hydrodynamic model (TUFLOW), dated 2010;
  2. **Richmond River** – hydrodynamic models (TUFLOW and SOBEK), dated 2010 and 2006 respectively;
  3. **Oaky Creek** – hydrodynamic model (MIKE-FLOOD), dated 2008;
  4. **Tabbimoble Floodway** – hydrodynamic model (MIKE-FLOOD), dated 2008;
  5. **Tabbimoble Creek** – hydrodynamic model (MIKE-FLOOD), dated 2008;
  6. **Mororo Creek** – hydrodynamic model (MIKE-FLOOD), dated 2008;
  7. **Clarence River** – hydrodynamic model (TUFLOW), dated 2010;
  8. **Champions Creek** – hydrologic (WBNM) and hydrodynamic model (TUFLOW),

dated 2005 and 2010 respectively;

9. **Chaffin Creek** – hydrologic (WBNM) and hydrodynamic model (TUFLOW), dated 2005 and 2010 respectively;
10. **Pillar Valley Creek** – hydrologic (WBNM) and hydrodynamic model (TUFLOW), dated 2005 and 2010 respectively;
11. **Coldstream River** – hydrologic (WBNM) and hydrodynamic model (TUFLOW), dated 2005 and 2010 respectively;
12. **Pheasant Creek** – hydrologic (WBNM) and hydrodynamic model (TUFLOW), dated 2005 and 2010 respectively;
13. **Halfway Creek** – hydrodynamic model (TUFLOW), dated 2010; and
14. **Corindi River** – hydrodynamic model (TUFLOW), dated 2011.

Also provided with the model files are the Digital Elevation Models (DEMs) and geo-referenced aerial photography of the different catchments, cadastre and various GIS datasets relating to current land use, water bodies and local roads.

1.4. Limitations

Whilst it was endeavoured to provide a review as comprehensive as possible, there are limitations associated with the outcomes presented in this report. Firstly, some of the models used in the assessment have undergone development over a significant period of time and certain files, particularly the hydrologic models, which were used to inform inflows into the hydraulic models, were not readily accessible. Hence, where the development of the hydrology could not be reviewed and the reliability of the model outputs ascertained, it was assumed that the inflow hydrographs routed through the hydraulic models were appropriate and reliable.

In preparing this report, WMAwater has relied upon, and presumed accurate, information (or absence thereof) provided by the Alliance and other sources. Except as otherwise stated in the report, WMAwater has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, then it is possible that our observations and conclusions as expressed in this report may change.

WMAwater have not re-run the hydraulic models, and it was assumed that the results grids correspond to the definitions in the control files provided for the model runs.

It is not within the scope of this assessment to review all cross drainage structures and waterway crossings (both major and minor) proposed for the highway upgrade since the sizing of the minor structures for local runoff or crossings for minor tributaries was carried out presumably using alternative methods or models in addition to the ones reviewed herein.

The independent review process was conducted concurrently with the refinement of the proposed highway upgrade drainage design. As such, some of the findings outlined in this report might have already been addressed as improvements were being made to the models and the Environmental Assessment being finalised by SKM. These subsequent changes were made by SKM in response to the community feedback from the flood focus group meetings as well as the preliminary findings reported by WMAwater.

2. BACKGROUND OF MODELS

2.1. Overview

A major focus of this review has been on the implementation and modelling of the cross drainage structures and major waterway crossings which have significant influence on the associated flood impacts of the proposed works. The flood models used for the assessment must therefore be deemed fit for purpose and the outcomes of the development of the concept design must meet the flood immunity objectives established. This is discussed in the following sections.

2.2. Purposes of the Models

The models developed/adopted as part of the hydrologic and flooding investigations were used to inform the development of the highway upgrade concept design and the environmental assessment of the concept plan and the early works. Existing flood behaviour of the various catchments which the highway corridor passes through was assessed through the use of these computer flood models. A total of 14 different hydraulic flood models were used in the assessment, with hydrological models used to inform catchment inflows. Peak flood levels and other parameters defining flood behaviour (i.e. depths, velocities, flows) were ascertained for the relevant parts of the rivers, creeks and floodplains in the study area. The defined flood behaviour then formed the basis of the concept design and impact assessment process. The impacts of the project, taking into consideration the required design objectives and waterway structures, were assessed using the same flood models as those used to define the existing flooding behaviour.

2.3. Design Criteria

The aim of the highway upgrade design is to provide 1 in 20 year minimum flood immunity across the major floodplains (i.e. Clarence River and Richmond River floodplains) and 1 in 100 year minimum flood immunity across the remaining areas. It should be noted that the level of the existing highway across the floodplains in the study area is generally well below the proposed immunity levels (Reference 2). If a section of the highway is affected by both major riverine flooding (e.g. Richmond/Clarence River) as well as flooding from local catchments (e.g. a tributary creek of these larger rivers), then the level has to be above the 20 year ARI river flood levels or above the 100 year ARI local catchment flood levels, whichever is higher. In addition, all bridges proposed as part of the highway upgrade concept design would have the soffit (underside of bridge structure) at least 300 mm above the 100 year ARI flood level.

This review then proceeded to investigate whether the sizing of the cross drainage structures and design of the major waterway crossings produced impacts that meet the following objectives, as outlined in Reference 2:

- Minimise potential changes to the hydrological regime of the river floodplains;

- Minimise potential changes to flood levels and velocities on smaller river and creek systems;
- Minimise potential increased impacts on properties, dwellings and existing road infrastructure;
- Minimise potential impact on existing drainage systems and smaller, more frequent flood events;
- Houses and urban areas: less than 50 mm increase in flood height for any assessed flood event (less than 100 year ARI event);
- Cane land: less than 50 mm increase in flood height for any assessed flood event (less than a 100 year ARI event) and no more than five per cent increase in the flood duration; and
- Other agricultural lands: generally less than 250 mm increase in flood height for any assessed flood event (less than a 100 year ARI event).

The last criterion (afflux < 250 mm for rural lands) was found to be applicable generally for lands with no inhabitants as farm houses or sheds are largely absent from the vicinity of the proposed development corridor.

2.4. Modelled Scenarios

Three modelling scenarios were carried out by SKM, corresponding to the different stages of the highway upgrade including:

- Existing – pre-development conditions;
- Early Works (EW) – early construction of road embankments; and
- Pacific Highway Upgrade (PHU) – post-development conditions.

The potential impacts on flooding behaviour for the various stages of construction were assessed using the same flood models used in defining the existing flood behaviour. The EW scenario was modelled for the Clarence River and Richmond River catchments only.

The effect of climate change on the flood immunity of the concept design has also been assessed, whereby a sea level rise of 0.6 m and a rainfall intensity increase of 10% were assumed to represent a scenario for the half-way point of the 100 year design life of the project's main infrastructure in 2070.

2.5. History of the Models

The major watercourses crossed by the project have been assessed as part of previous flood assessments. These were mostly carried out as part of the route selection and preferred route assessments of the previous development projects for sections of the Pacific Highway upgrade within this project. Further, several models used in the assessment of the proposed highway upgrade have been adopted by local Councils (i.e. Richmond Valley Council and Richmond River County Council) as part of their floodplain management programme, and therefore have been subjected to rigorous review in the past.

A number of different flood modelling programs have been used to simulate flood behaviour on the watercourses crossed in these previous projects. The hydrological and hydraulic models for each watercourse are presented in Table 2.

Table 2: Models used in previous assessment (adopted from Reference 2)

Watercourse	Hydrological Model	Hydraulic Model
Corindi River (including Blackadder Creek and Cassons Creek)	XP-RAFTS	TUFLOW[1]
Halfway Creek	XP-RAFTS	HEC-RAS[2]
Pheasant Creek	WBNM[5]	TUFLOW[1]
Coldstream River	WBNM[5]	TUFLOW[1]
Pillar Valley Creek	WBNM[5]	TUFLOW[1]
Chaffin Creek	WBNM[5]	TUFLOW[1]
Champions Creek	WBNM[5]	TUFLOW[1]
Clarence River (and floodplain areas, Shark Creek and Chatsworth/Harwood Islands)	Cordery-Webb and FFA[6]	TUFLOW[1] (multiple 2D domains)
Mororo Creek	XP-RAFTS	MIKE-FLOOD[3]
Tabbimoble Creek	XP-RAFTS	MIKE-FLOOD[3]
Tabbimoble Floodway 1	XP-RAFTS	MIKE-FLOOD[3]
Oaky Creek	XP-RAFTS	MIKE-FLOOD[3]
Richmond River south (including Tuckombil Canal and MacDonalds Creek)	WBNM[5]	SOBEK[4]
Richmond River and its surrounding tributaries	XP-RAFTS	MIKE-11
Richmond River south (including Tuckombil Canal and MacDonalds Creek)	XP-RAFTS	TUFLOW[1]
Richmond River north (Ballina - including Duck Creek and Emigrant Creek)	XP-RAFTS and FFA[6]	TUFLOW[1] (multiple 2D domains)

[1, 3] 2D/1D dynamically linked model
[2] 1D model
[4] 2D model
[5] Watershed Boundary Network Model
[6] Flood Frequency Analysis

As mentioned previously, the different hydraulic models have subsequently been refined to two modelling platforms: TUFLOW and MIKE-FLOOD, for the purposes of this project.

3. REVIEW OF MODELS

3.1. Summary of Key Findings

This section outlines key findings stemming from the review process, with particular focus on the implementation and modelling of the cross drainage structures and major waterway crossings for the proposed highway upgrade. These structures have significant influence on the associated flood impacts of the proposed works which serve as a major concern for the local community, as raised during the flood focus group meetings. Due to the extensive review already conducted in the past, as well as calibration performed for some of the adopted models (i.e. Clarence River and Richmond River models), the hydrologic modelling and hydraulic model calibration have not been reviewed in detail.

WMAwater consider that there are several aspects of the modelling approach and schematisation which require further work or need to be addressed in order to facilitate a more reliable assessment of the flood issues for the proposed works:

(1) To validate the flows and energy losses introduced by bridges and other major drainage structures that constrict flows using alternative calculation methods or model such as HEC-RAS;
(2) To consider the impact of blockages on the performance of the highway cross drainage structures; and
(3) To review sub-catchment delineation at locations where the raised highway embankment serves as a control feature that attenuates flows, resulting in upstream afflux.

These general comments apply to all the models adopted or developed for the assessment carried out herein.

For point (1), the head loss across key structures should be reviewed and benchmarked against other methods (eg. using HEC-RAS or Hydraulics of Bridge Waterways). The TUFLOW user manual (Reference 7) states that:

"*It is strongly recommended that the losses through a structure be validated through:*
- *Calibration to recorded information (if available).*
- *Cross-checked using desktop calculations based on theory and/or standard publications (eg. Hydraulics of Bridge Waterways, US FHA 1973).*
- *Cross-checked with results using other hydraulic software.*"

This is carried out to ensure that the form losses of key structures are adequately represented and modelled so as not to underestimate the potential afflux generated upstream.

For point (2), the presence of vegetation growth (cane farms etc.) on both sides of the highway corridor increases the risk of blockage at the culvert entrances/exits and allowance should therefore be made to include a blockage factor which could vary with the size of the drainage structure. Currently there is no consensus regarding the design approach that should be adopted, though preliminary guidance could be obtained from *Project 11: Blockage of Hydraulic Structures* which is a support project of the current revision of the Australian Rainfall and Runoff. The sensitivity of the predicted flood afflux to blockages of such structures should also be examined, focusing in particular on structures that convey high velocity flows and with steep gradient.

In regards to point (3), for any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model. The review of sub-catchment delineation identified a few locations where flows from catchment areas upstream of the proposed highway upgrade corridor have been allocated downstream of the control (e.g. around Wardell in the Richmond River model and the Shark Ck catchment in the Clarence River model). This occurred generally during the initial period of the simulation runs when the model 2D cells were mostly dry. For locations where the hydraulic model is used to size the cross drainage structures (usually not the case for minor culverts which were designed, using alternative methods or models like DRAINS, to convey runoff primarily from local catchments), it is advisable that the flow application location should be carefully considered and the sub-catchment delineation should be revised where necessary in order to provide a more accurate estimate of flood levels and extents both up and downstream of these structures.

Other minor schematisation errors have also been identified and are discussed further in Section 3.2 of this report.

The implications of these schematisation errors are expected to be relatively minor in regards to the 100 year ARI flood levels (or 20 year ARI flood levels for the Clarence River and Richmond River catchments) and impact assessment. These errors do, however, severely limit the models' ability to resolve events of differing magnitude, particularly rarer events such as the PMF.

It is recommended that the issues identified herein be corrected and model results be regenerated. Ideally minor schematisation errors should be corrected too, however, it is noted that these would have minimal impacts on modelled flood behaviour around the proposed highway upgrade corridor for the 20 year Clarence/Richmond River flood events or 100 year flood events in the other catchments.

3.2. Detailed Findings

The following sections discuss detailed findings derived from the review of the individual models and cover both the hydrologic (if available) and hydraulic modelling of the various catchments which the highway corridor passes through (from south to north). An overview of all the models is provided in Appendix B. All items outlined within the scope of the review (refer to Section 1.2) have been examined thoroughly and only findings that are of significance to the project are presented herein.

3.2.1. Corindi River

3.2.1.1. Model Development and Approach Undertaken

Flood modelling of the Corindi River catchment was carried out using a XP-RAFTS hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2007). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 2.8 km by 3 km, with a 2D grid resolution of 5 m. The model covers most of the Corindi River floodplain including the minor tributaries: Cassons Creek and Blackadder Creek. Major drainage structures such as box culverts were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 1 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.1.2. Review of Hydrologic Model

WMAwater were unable to review the XP-RAFTS model for this catchment as it was not provided. Nevertheless, delineation of the sub-catchments for the hydrologic modelling can be examined using the DEM generated by TUFLOW. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the highway located west of the existing Pacific Highway, where upstream flows will be impeded by this control feature before reaching the downstream floodplains. With the current sub-catchment delineation, flow is allocated downstream of the embankment at the start of the simulation run when the model 2D cells were mostly dry, as shown in Figure 1. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

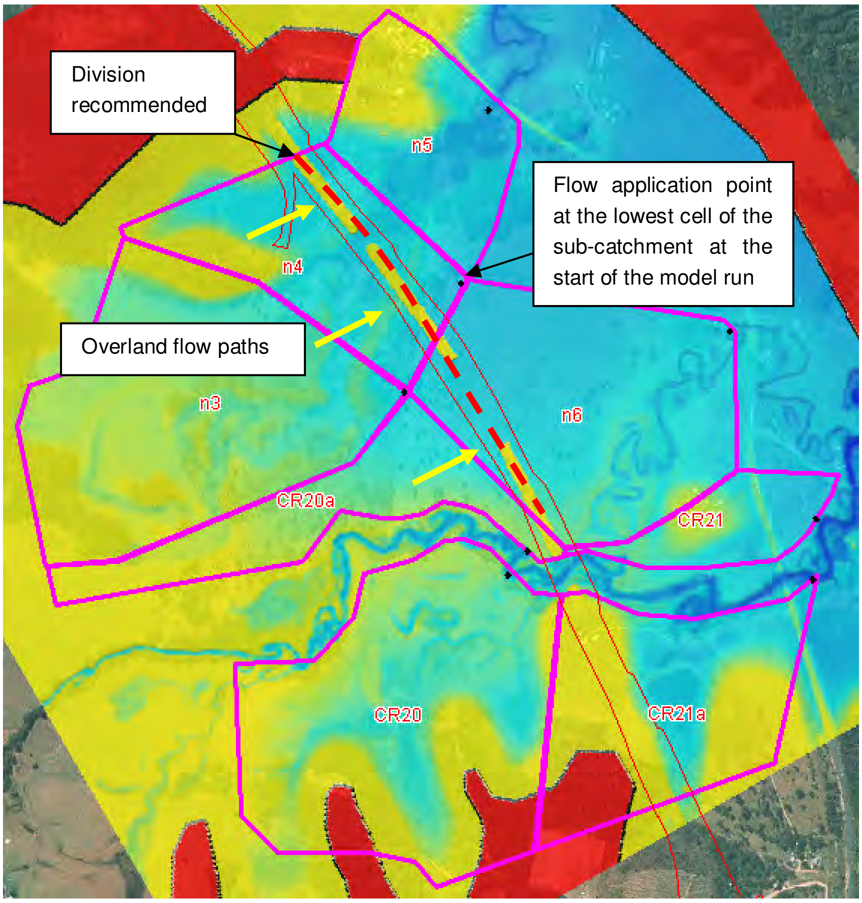

Figure 1: Sub-catchments delineation for the Corindi River floodplain

3.2.1.3. Review of Hydraulic Model

General Model Setup

A 2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 5 m grid was used for the model domain and with a time step of 1 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance, since Corindi River and its tributaries were modelled in 2D, but it is postulated that the available ALS or contour survey data might have dictated the resolution of the grid used.

The intention was to provide 100 year ARI flood immunity for the Pacific Highway Upgrade for this floodplain, hence model runs were carried out for the 100 year ARI flood events. The storm duration used was the 6 hour flood event, which was found to be critical for this catchment.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of* *mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was about 1.5% which is acceptable.

Boundary Conditions

Boundary conditions including inflows from the hydrologic model and downstream tailwater levels were implemented properly in the model, though WMAwater were not able to ascertain whether both inputs were appropriately defined. The 1D/2D connections for the various drainage structures have also been properly implemented and the hydraulic model boundary was accurately demarcated.

Digital Elevation Model

"Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level. However, it is important to note that the DEM developed for the model may not be applicable when modelling extreme events like the PMF, as the DEM was extended to just outside of the 100 year ARI flood extent, as illustrated in Figure 2.

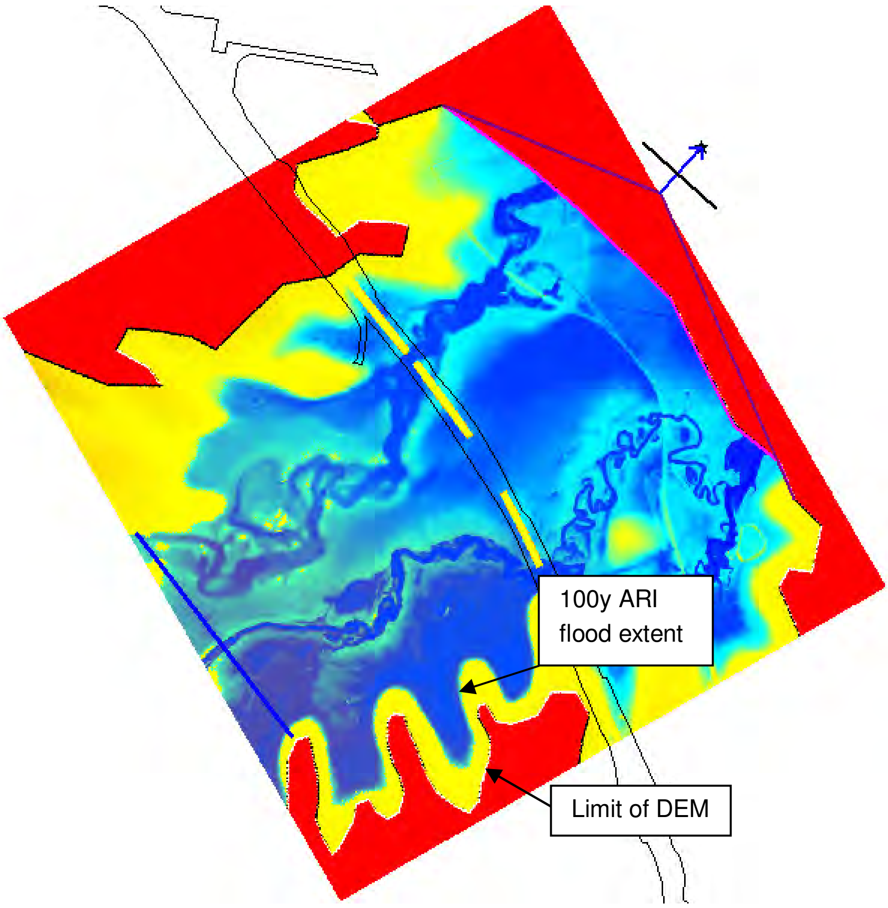

Figure 2: DEM generated for the Corindi River model

Structures Implementation

For the implementation of waterway structures like bridges, layered flow constrictions were applied to the relevant 2D cells to account for form losses introduced by the bridge piers. As discussed in Section 3.1, it is vital that an alternative method or model be used to validate the flow constriction attributes or form losses adopted for key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled, so as not to underestimate the potential afflux caused upstream.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have largely been implemented in the model, though with minor variations. The changes introduced include the provision of extra, as well as larger, box culverts and construction of a 55 m bridge over Cassons Creek, which led to improvements in the afflux upstream of the proposed road embankment. Further details of included drainage structures in the modelling are provided in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. However, there was no change to the roughness for the Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable, as the highway remains dry over the duration of the simulation run.

Impact Assessment

When examining the flood impacts caused by the proposed works within the Corindi River floodplain, afflux above 250 mm was found upstream of the proposed highway embankment based on the 100 year ARI results grids provided to WMAwater, as illustrated in Figure 3. This was reported in Reference 2. It was further remarked that "*To reduce flood impacts on agricultural land to 250 mm, substantially larger bridges would be required. The additional cost of these bridges is considered to outweigh the disbenefits of the impacts.*" WMAwater consider this to be a valid argument and recommend that the issue be relayed to the local community and various stakeholders in order to achieve a resolution to the problem.

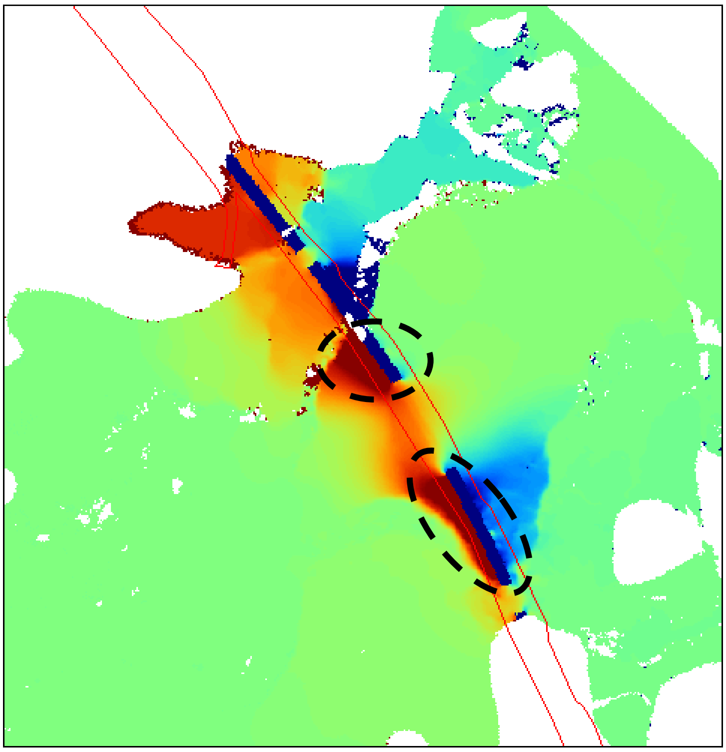

Figure 3: Impacts above 250 mm upstream of the proposed highway embankment for the 100 year ARI event

3.2.2. Halfway Creek

3.2.2.1. Model Development and Approach Undertaken

Flood modelling of the Halfway Creek catchment was carried out using a XP-RAFTS hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2007). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 2.4 km by 1 km, with a 2D grid resolution of 2 m. Major drainage structures such as box culverts were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 2 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.2.2. Review of Hydrologic Model

WMAwater were unable to review the XP-RAFTS model for this catchment as it was not provided. It was also found that the local catchment runoff was not modelled, thus assuming that flooding in this area is predominantly due to river flow. This assumption is reasonable as the local catchment area is less than 10% of the total catchment contributing to that point. Nevertheless, WMAwater still recommend that local catchment flows be included to provide a more accurate assessment of the flood impacts of the proposed works.

3.2.2.3. Review of Hydraulic Model

<u>General Model Setup</u>
A 2D hydrodynamic model was established using TUFLOW with 1 m contour data used to develop the 2 m DEM adopted for the model domain. With a time step of 1 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance but 2 m is perfectly acceptable considering the resolution of the survey data available. The 100 year ARI event was modelled to ensure that the section of the Pacific Highway in this catchment would have a 100 year ARI flood immunity.

<u>Mass Balance</u>
Mass balance check was carried out referring to the TUFLOW-generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was almost 0% which is more than acceptable.

Boundary Conditions

Boundary conditions including inflows from the hydrologic model and downstream tailwater levels were implemented properly in the model, though WMAwater were not able to ascertain whether both inputs were appropriately defined. The 1D/2D connections for the drainage structures have also been properly implemented and the hydraulic model boundary was accurately demarcated.

Digital Elevation Model

"Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level. However, it is important to note that the DEM developed for the model may not be applicable when modelling extreme events like the PMF, as the DEM was extended to just outside of the 100 year ARI flood extent, as illustrated in Figure 4.

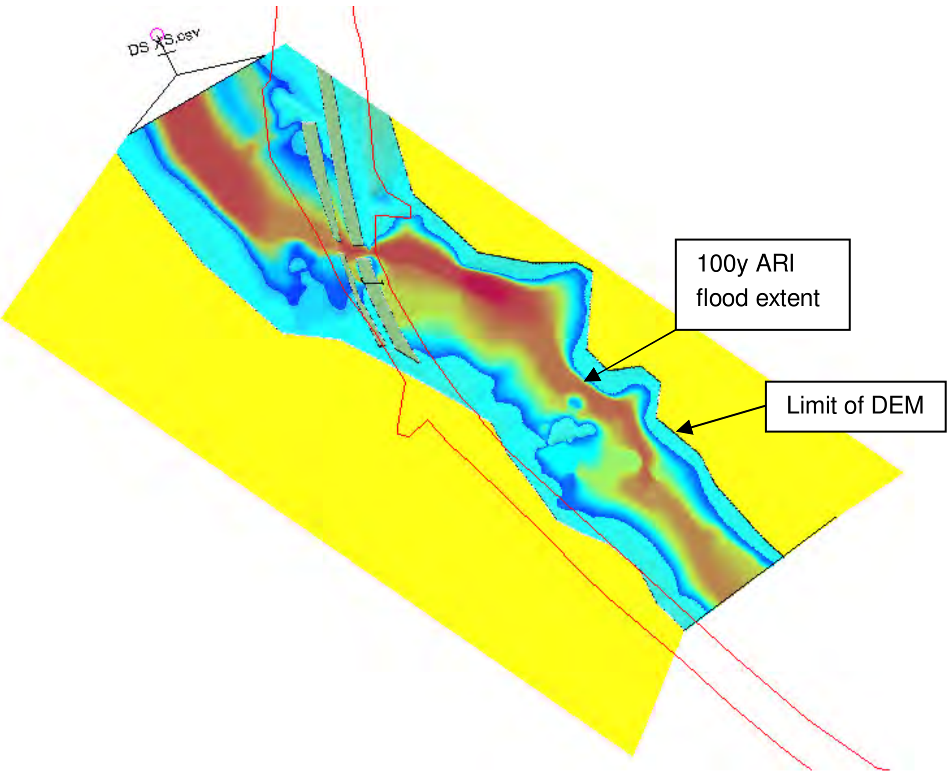

Figure 4: DEM generated for the Halfway Creek model

Structures Implementation

For the implementation of waterway structures like bridges, flow constrictions were applied to the relevant 2D cells to account for form losses introduced by the bridge piers. As discussed in Section 3.1, it is vital that an alternative method or model be used to validate the flow constriction attributes or form losses adopted for key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled so as not to underestimate the potential afflux caused upstream.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been implemented in the model albeit with slight augmentation. Further details of included drainage structures in the modelling are provided in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (the implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. However, there was no change to the roughness for the Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable, as the highway remains dry over the duration of the simulation run.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.3. Pheasant Creek

3.2.3.1. Model Development and Approach Undertaken

Flood modelling of the Pheasant Creek catchment was carried out using a WBNM hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2008). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 13.9 km by 7.7 km, with a 2D grid resolution of 10 m. The model extent covers both the Pheasant Creek and Picaninny Creek catchments as well as an unnamed creek situated further north. The downstream section of this model overlaps with the Clarence River model extent and all rivers/creeks and their tributaries flow into the Clarence River floodplain. Major drainage structures such as box culverts were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 3 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.3.2. Review of Hydrologic Model

WBNM was used to estimate the runoff hydrographs primarily for the catchments upstream of the proposed highway embankment and the flows were subsequently inputted into the TUFLOW hydraulic model. The initial/continuing loss model adopted for the hydrologic model deviates slightly from standard industry practice or that recommended by Australian Rainfall and Runoff (Reference 1) in that no initial loss was specified while 2 mm/hr was used for the continuing loss. Though this approach is slightly conservative, the values were well within reasonable range. All surfaces were assumed to be pervious. The reason for selecting these values was not known to WMAwater. In contrast, runoff for catchments downstream of the highway embankment was modelled using TUFLOW's Rainfall (RF) option, whereby instead of flow hydrographs, rainfall hyetographs were specified and then applied to the hydraulic model. However, it was found that this has not been implemented correctly, therefore resulting in errors in the inflows. This is further discussed in Section 3.2.3.3.

Delineation of the sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the highway where water flowing down from the range will be impeded by this control feature before reaching the downstream floodplains. With the current sub-catchment delineation, flow is allocated downstream of the embankment at the start of the simulation run when the model 2D cells were mostly dry, as shown in Figure 5. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

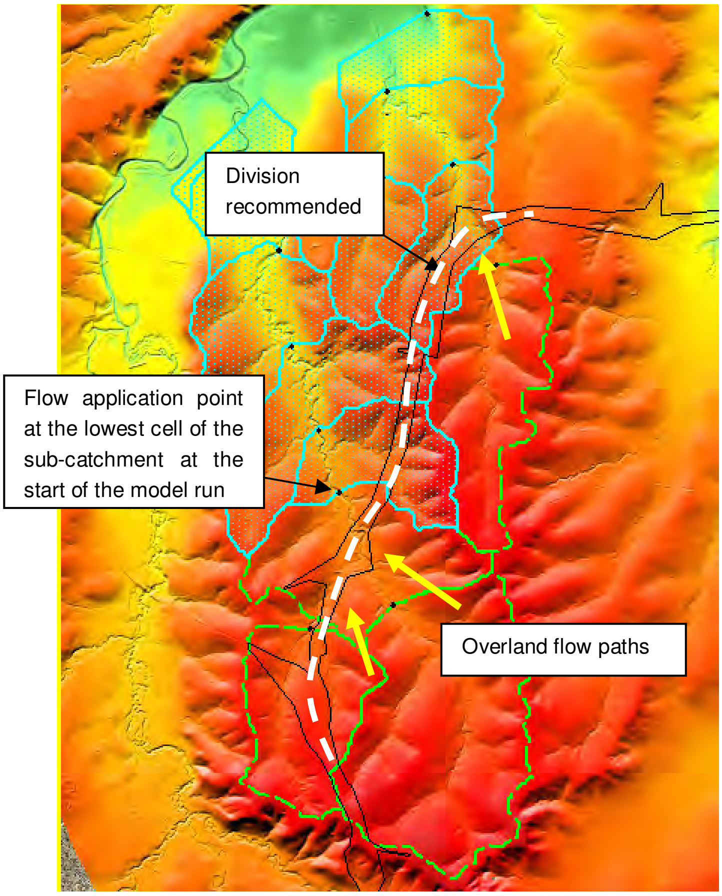

Figure 5: Sub-catchments delineation for the Pheasant Creek floodplain

Generally the recommended parameter values (Reference 8) have been adopted for the WBNM model. The peak flows from the model were further verified against other flow estimation methods and their sensitivity to the adopted lag parameters has also been investigated. A rain gauge factor was also applied to account for spatial variations in the total rainfall across the catchment.

3.2.3.3. Review of Hydraulic Model

General Model Setup

A 2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 10 m grid was used for the model domain and with a time step of 5 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance since Pheasant Creek and its tributaries were modelled in 2D but it is postulated that the available ALS or topographic survey data might have dictated the resolution of the grid used.

The intention was to provide 100 year ARI flood immunity for the Pacific Highway Upgrade for this floodplain, hence model runs were carried out for the 100 year ARI flood events. The storm duration used was the 2 hour flood event, which was found to be critical for this catchment.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was almost 0% which is more than acceptable.

Boundary Conditions

Boundary conditions implemented in the model include inflows from the hydrologic model and downstream tailwater levels derived from the Clarence River model. 2 event scenarios were modelled for the design flood events: 100 year ARI local flooding + 5 year ARI Clarence River flooding and 100 year ARI local flooding + 100 year ARI Clarence River flooding, though the former was adopted as it represented a more realistic scenario.

As mentioned previously, WMAwater identified errors in the implementation of TUFLOW's Rainfall (RF) option that enables the application of rainfall hyetographs instead of runoff hydrographs as inflows into the hydraulic model. Firstly, the "RF" option was omitted from the "Read MI SA" command line meaning that the rainfall time series data were read as flow hydrographs instead of rainfall hyetographs as intended. Secondly, the TUFLOW user manual (Reference 7) states that "The rainfall time-series data must be in mm versus hours" and "Initial and continuing losses are entered as attributes to the 2d_sa layer". WMAwater found that both have not been carried out, as the rainfall time-series data were specified in mm/hr versus minutes and losses were not specified in the corresponding 2d_sa layer. In addition, the contributing catchment area has to be specified in km^2 and a rain gauge factor should be included as one of the additional attributes for the "RF" option. The implication of these errors is further discussed in Section 3.2.7.2, and it is shown that the consequences on the impact assessment results are minimal.

The 1D/2D connections for the various drainage structures have been properly implemented and the hydraulic model boundary was accurately demarcated.

Digital Elevation Model

The DEM developed for this catchment was of a finer resolution (based on a 5 m DEM) than the broader DEM developed for the Clarence River model. "Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment/levee crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level. However, WMAwater found that the proposed works for the stretch of highway from Ch 39,400 to Ch 40,000 (located on the unnamed creek floodplain north of Pheasant Creek) were omitted or not modelled. The reason for this omission could not be ascertained and WMAwater recommend that the proposed works be included (if not already done so) as part of the flood impact assessment, as the upstream catchments contributing to the afflux caused by construction of the new road embankment may be substantial.

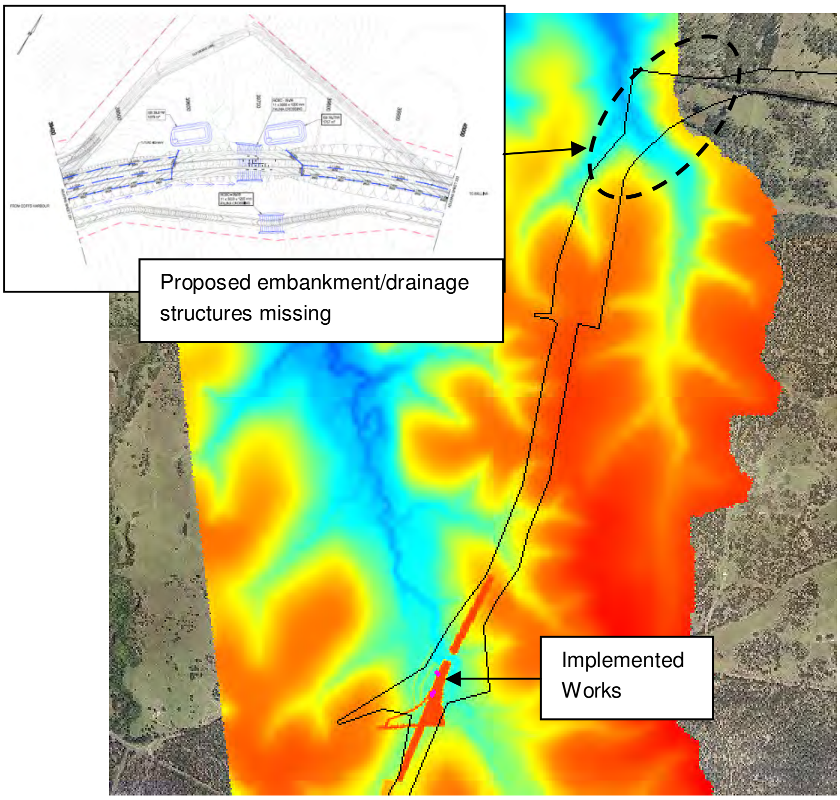

Figure 6: Omission of proposed works (Chainage 39400 – 40000) from the model

Structures Implementation

For this model, waterway crossings like bridges were modelled as gaps in between the abutments/road embankments, with no consideration of potential form losses caused by the bridge piers. As such, this may result in underestimation of potential afflux caused upstream. WMAwater recommend that the flow constriction methods available in TUFLOW be employed and an alternative method or model be used to validate the flow constriction attributes or form losses adopted for these key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have largely been implemented in the model with the exception of the proposed works for the stretch of highway from Ch 39,400 to Ch 40,000 (located on the unnamed creek floodplain north of Pheasant Creek) as discussed previously. Further details of included drainage structures in the modelling are provided in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (the implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. However, there was no change to the roughness for the Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable as the highway remains dry over the duration of the simulation run.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria. The higher impacts resulting from the creek diversion is not unreasonable as the peak flood depth of the diverted creek is comparable to that at its present location.

3.2.4. Coldstream River

3.2.4.1. Model Development and Approach Undertaken

Flood modelling of the Coldstream River catchment was carried out using a WBNM hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2008). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 5.9 km by 10.5 km, with a 2D grid resolution of 10 m. The model extent covers the Coldstream River floodplain and its tributaries. The downstream section of this model overlaps with the Clarence River model extent and all rivers/creeks and their tributaries flow into the Clarence River floodplain. The modelling approach undertaken is considered appropriate and as per standard practice. Section 3 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.4.2. Review of Hydrologic Model

WBNM was used to estimate the runoff hydrographs primarily for the catchments upstream of the proposed highway embankment and the flows were subsequently inputted into the TUFLOW hydraulic model. The initial/continuing loss model adopted for the hydrologic model deviates slightly from standard industry practice or that recommended by Australian Rainfall and Runoff (Reference 1) in that no initial loss was specified while 2 mm/hr was used for the continuing loss. Though this approach is slightly conservative, the values were well within reasonable range. All surfaces were assumed to be pervious. The reason behind selecting these values was not known to WMAwater. In contrast, runoff for catchments downstream of the highway embankment was modelled using TUFLOW's Rainfall (RF) option, whereby instead of flow hydrographs, rainfall hyetographs were specified and then applied to the hydraulic model. However, it was found that this has not been implemented correctly, therefore resulting in errors in the inflows. This is further discussed in Section 3.2.4.3.

Delineation of the sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the highway where water flowing down from the range will be impeded by this control feature before reaching the downstream floodplains. With the current sub-catchment delineation, flow is allocated downstream of the embankment at the start of the simulation run when the model 2D cells were mostly dry, as shown in Figure 7. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

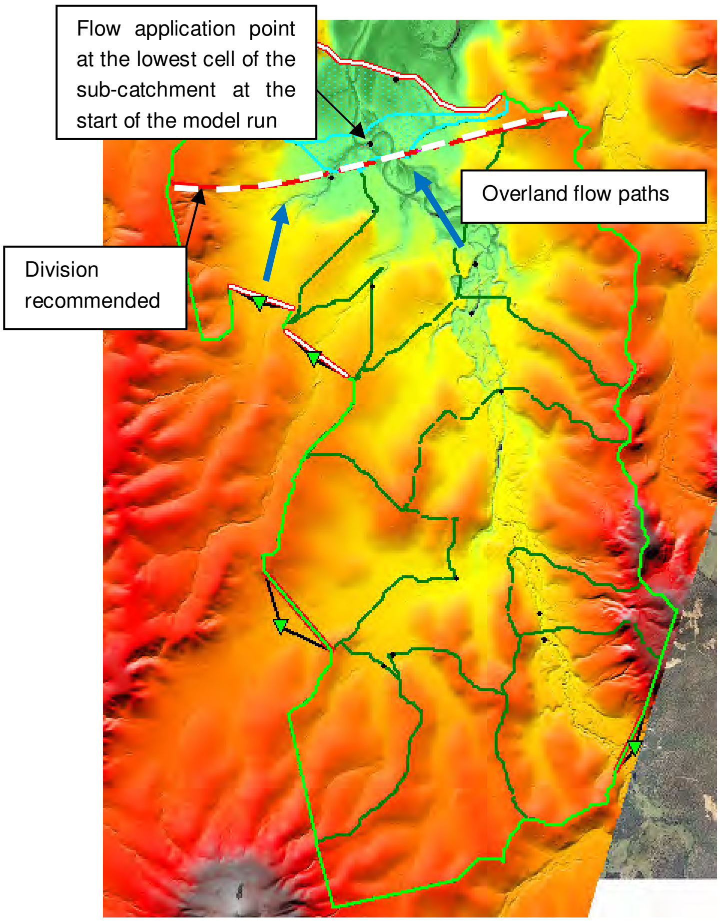

Figure 7: Sub-catchments delineation for the Coldstream River floodplain

Generally the recommended parameter values (Reference 8) have been adopted for the WBNM model. The peak flows from the model were further verified against other flow estimation methods and their sensitivity to the adopted lag parameters has also been investigated. A rain gauge factor was also applied to account for spatial variations in the total rainfall across the catchment.

3.2.4.3. Review of Hydraulic Model

<u>General Model Setup</u>

A 2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 10 m grid was used for the model domain and with a time step of 5 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance since Coldstream River and its tributaries were modelled in 2D but it is postulated that the available ALS or topographic survey data might have dictated the resolution of the grid used.

The intention was to provide 100 year ARI flood immunity for the Pacific Highway Upgrade for this floodplain hence model runs were carried out for the 100 year ARI flood events. The storm duration used was the 9 hour flood event which was found to be critical for this catchment.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was almost 0% which is more than acceptable.

Boundary Conditions

Boundary conditions implemented in the model include inflows from the hydrologic model and downstream tailwater levels derived from the Clarence River model. 2 event scenarios were modelled for the design flood events: 100 year ARI local flooding + 5 year ARI Clarence River flooding and 100 year ARI local flooding + 100 year ARI Clarence River flooding, though the former was adopted as it represented a more realistic scenario.

As mentioned previously, WMAwater identified errors in the implementation of TUFLOW's Rainfall (RF) option that enables the application of rainfall hyetographs instead of runoff hydrographs as inflows into the hydraulic model. Firstly, the "RF" option was omitted from the "Read MI SA" command line meaning that the rainfall time series data were read as flow hydrographs instead of rainfall hyetographs as intended. Secondly, the TUFLOW user manual (Reference 7) states that "The rainfall time-series data must be in mm versus hours" and "Initial and continuing losses are entered as attributes to the 2d_sa layer". WMAwater found that both have not been carried out as the rainfall time-series data were specified in mm/hr versus minutes and losses were not specified in the corresponding 2d_sa layer. In addition, the contributing catchment area has to be specified in km^2 and a rain gauge factor should be included as one of the additional attributes for the "RF" option. The implication of these errors is further discussed in Section 3.2.7.2 though it is shown that the consequences on the impact assessment results are minimal.

Digital Elevation Model

The DEM developed for this catchment was of a finer resolution (based on a 5 m DEM) than the broader DEM developed for the Clarence River model. "Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment crest levels. Some were also used to improve on model instabilities though this is not unreasonable. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

Structures Implementation

For this model, waterway crossings like bridges were modelled as gaps in between the abutments/road embankments with no consideration of potential form losses caused by the bridge piers. As such, this may result in underestimation of potential afflux caused upstream. WMAwater recommend that the flow constriction methods available in TUFLOW be employed and an alternative method or model be used to validate the flow constriction attributes or form losses adopted for these key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled.

There is no culvert or other drainage structures proposed for this catchment according to the RTA concept design plan (Reference 6).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain and major watercourses are reasonable. However, there was no change to the roughness for the Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable as the highway remains dry over the duration of the simulation run.

Impact Assessment

When examining the flood impacts caused by the proposed works within the Coldstream River floodplain, afflux above 250 mm was found upstream of the proposed highway embankment based on the 100 year ARI results grids provided to WMAwater, as illustrated in Figure 8. This was reported in Reference 2. However, there is no mention as to whether it is feasible to extend the proposed bridge span or to introduce additional drainage structures to address the issue. WMAwater recommend that further work be carried out if the impact objectives are indeed not met.

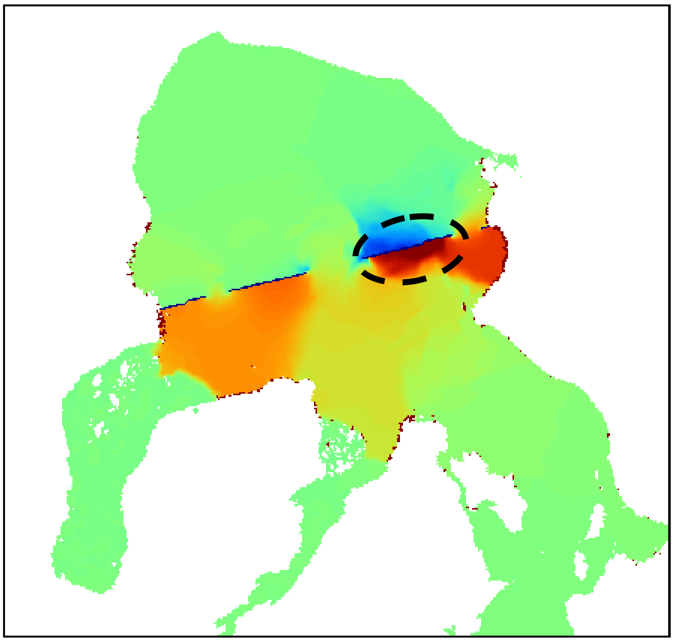

Figure 8: Impacts above 250 mm upstream of the proposed highway embankment for the 100 year ARI event

3.2.5. Pillar Valley Creek

3.2.5.1. Model Development and Approach Undertaken

Flood modelling of the Pillar Valley Creek catchment was carried out using a WBNM hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2008). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 7.4 km by 5.8 km, with a 2D grid resolution of 10 m. The model extent covers the Pillar Valley Creek floodplain and its tributaries. The downstream section of this model overlaps with the Clarence River model extent and all rivers/creeks and their tributaries flow into the Clarence River floodplain. Major drainage structures such as box culverts were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 3 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.5.2. Review of Hydrologic Model

WBNM was used to estimate the runoff hydrographs primarily for the catchments upstream of the proposed highway embankment and the flows were subsequently inputted into the TUFLOW hydraulic model. The initial/continuing loss model adopted for the hydrologic model deviates slightly from standard industry practice or that recommended by Australian Rainfall and Runoff (Reference 1) in that no initial loss was specified while 2 mm/hr was used for the continuing loss. Though this approach is slightly conservative, the values were well within reasonable range. All surfaces were assumed to be pervious. The reason behind selecting these values was not known to WMAwater. In contrast, runoff for catchments downstream of the highway embankment was modelled using TUFLOW's Rainfall (RF) option whereby instead of flow hydrographs, rainfall hyetographs were specified and then applied to the hydraulic model. However, it was found that this has not been implemented correctly, therefore resulting in errors in the inflows. This is further discussed in Section 3.2.5.3.

Delineation of the sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the highway where water flowing down from the range will be impeded by this control feature before reaching the downstream floodplains. With the current sub-catchment delineation, flow is allocated downstream of the embankment at the start of the simulation run when the model 2D cells were mostly dry, as shown in Figure 9. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

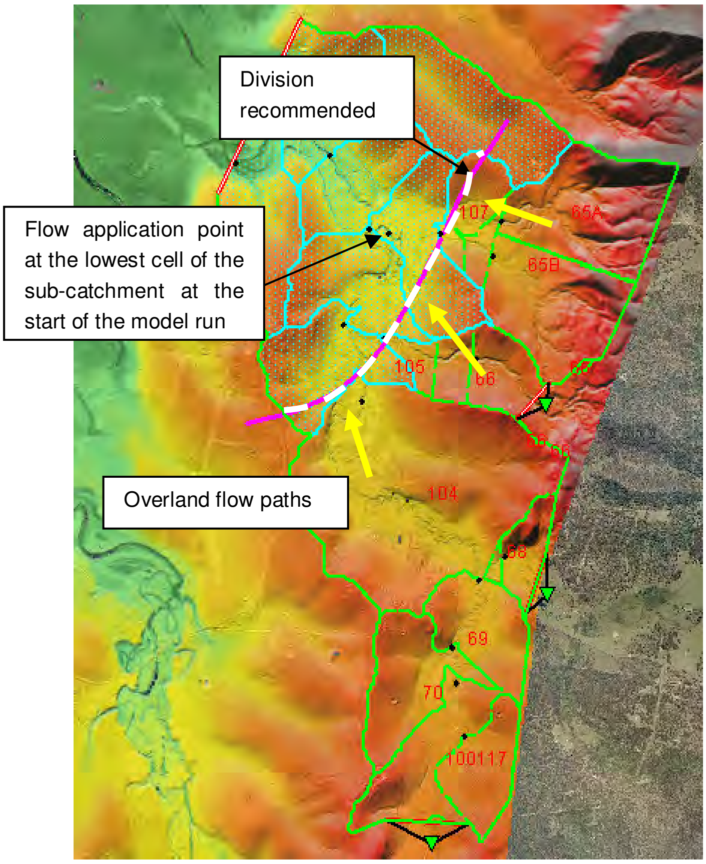

Figure 9: Sub-catchments delineation for the Pillar Valley Creek floodplain

Generally the recommended parameter values (Reference 8) have been adopted for the WBNM model. The peak flows from the model were further verified against other flow estimation methods and their sensitivity to the adopted lag parameters has also been investigated. A rain gauge factor was also applied to account for spatial variations in the total rainfall across the catchment.

3.2.5.3. Review of Hydraulic Model

General Model Setup

A 2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 10 m grid was used for the model domain and with a time step of 5 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance since Pillar Valley Creek and its tributaries were modelled in 2D but it is postulated that the available ALS or topographic survey data might have dictated the resolution of the grid used.

The intention was to provide 100 year ARI flood immunity for the Pacific Highway Upgrade for this floodplain hence model runs were carried out for the 100 year ARI flood events. The storm duration used was the 2 hour flood event which was found to be critical for this catchment.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" Referring to Figure 10, high mass balance errors were encountered at the commencement of the simulation. These are quite common for the model initialisation period as dry cells become wet, and the errors dropped to within the ±1% threshold once significant flows started to enter into the model. In contrast, the manual calculations revealed that the mass balance error was about 0.7%, which is acceptable. It can also be highlighted that there is negligible difference in the mass errors between the different scenario runs.

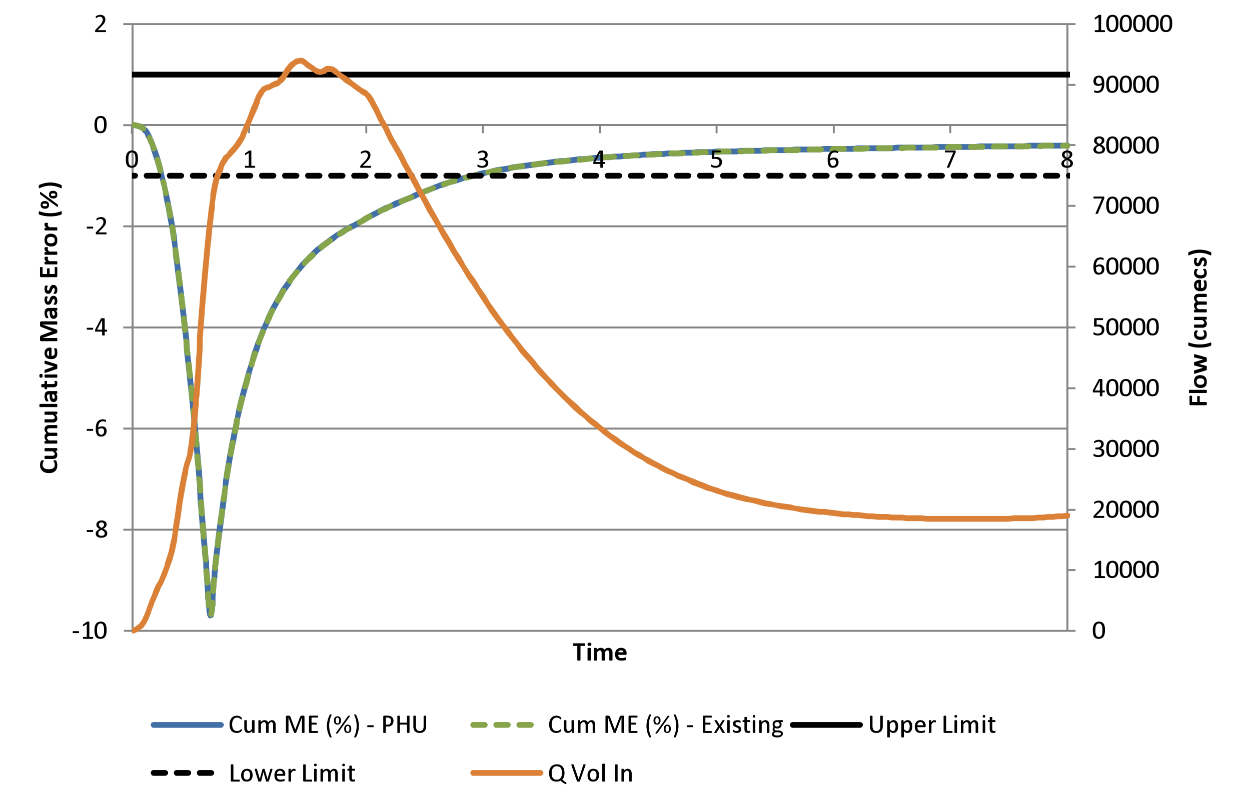

Figure 10: Plot of mass balance error for the Pillar Valley Creek model

Boundary Conditions

Boundary conditions implemented in the model include inflows from the hydrologic model and downstream tailwater levels derived from the Clarence River model. 2 event scenarios were modelled for the design flood events: 100 year ARI local flooding + 5 year ARI Clarence River flooding and 100 year ARI local flooding + 100 year ARI Clarence River flooding, though the former was adopted as it represented a more realistic scenario.

As mentioned previously, WMAwater identified errors in the implementation of TUFLOW's Rainfall (RF) option that enables the application of rainfall hyetographs instead of runoff hydrographs as inflows into the hydraulic model. Firstly, the "RF" option was omitted from the "Read MI SA" command line meaning that the rainfall time series data were read as flow hydrographs instead of rainfall hyetographs as intended. Secondly, the TUFLOW user manual (Reference 7) states that "The rainfall time-series data must be in mm versus hours" and "Initial and continuing losses are entered as attributes to the 2d_sa layer". WMAwater found that both have not been carried out as the rainfall time-series data were specified in mm/hr versus minutes and losses were not specified in the corresponding 2d_sa layer. In addition, the contributing catchment area has to be specified in km^2 and a rain gauge factor should be included as one of the additional attributes for the "RF" option. The implication of these errors is further discussed in Section 3.2.7.2 though it is shown that the consequences on the impact assessment results are minimal.

The 1D/2D connections for the various drainage structures have been properly implemented and the hydraulic model boundary was accurately demarcated.

<u>Digital Elevation Model</u>
The DEM developed for this catchment was of a finer resolution (based on a 5 m DEM) than the broader DEM developed for the Clarence River model. "Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment/levee crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

<u>Structures Implementation</u>
For this model, waterway crossings like bridges were modelled as gaps in between the abutments/road embankments with no consideration of potential form losses caused by the bridge piers. As such, this may result in underestimation of potential afflux caused upstream. WMAwater recommend that the flow constriction methods available in TUFLOW be employed and an alternative method or model be used to validate the flow constriction attributes or form losses adopted for these key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been implemented in the model. Further details of included drainage structures in the modelling are provided in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

<u>Roughness</u>
The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. However, there was no change to the roughness for the

Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable as the highway remains dry over the duration of the simulation run.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.6. Chaffin Creek

3.2.6.1. Model Development and Approach Undertaken

Flood modelling of the Chaffin Creek catchment was carried out using a WBNM hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2008). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 8.5 km by 9.6 km, with a 2D grid resolution of 10 m. The model extent covers the Chaffin Creek floodplain and its tributaries as well as several unnamed creeks situated nearby. The downstream section of this model overlaps with the Clarence River model extent and all rivers/creeks and their tributaries flow into the Clarence River floodplain. Major drainage structures such as box culverts were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 3 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.6.2. Review of Hydrologic Model

WBNM was used to estimate the runoff hydrographs primarily for the catchments upstream of the proposed highway embankment and the flows were subsequently inputted into the TUFLOW hydraulic model. The initial/continuing loss model adopted for the hydrologic model deviates slightly from standard industry practice or that recommended by Australian Rainfall and Runoff (Reference 1) in that no initial loss was specified while 2 mm/hr was used for the continuing loss. Though this approach is slightly conservative, the values were well within reasonable range. All surfaces were assumed to be pervious. The reason behind selecting these values was not known to WMAwater. In contrast, runoff for catchments downstream of the highway embankment was modelled using TUFLOW's Rainfall (RF) option whereby instead of flow hydrographs, rainfall hyetographs were specified and then applied to the hydraulic model. However, it was found that this has not been implemented correctly, therefore resulting in errors in the inflows. This is further discussed in Section 3.2.6.3.

Delineation of the sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the highway where water flowing down from the range will be impeded by this control feature before reaching the downstream floodplains. With the current sub-catchment delineation, flow is allocated downstream of the embankment at the start of the simulation run when the model 2D cells were mostly dry, as shown in Figure 11. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

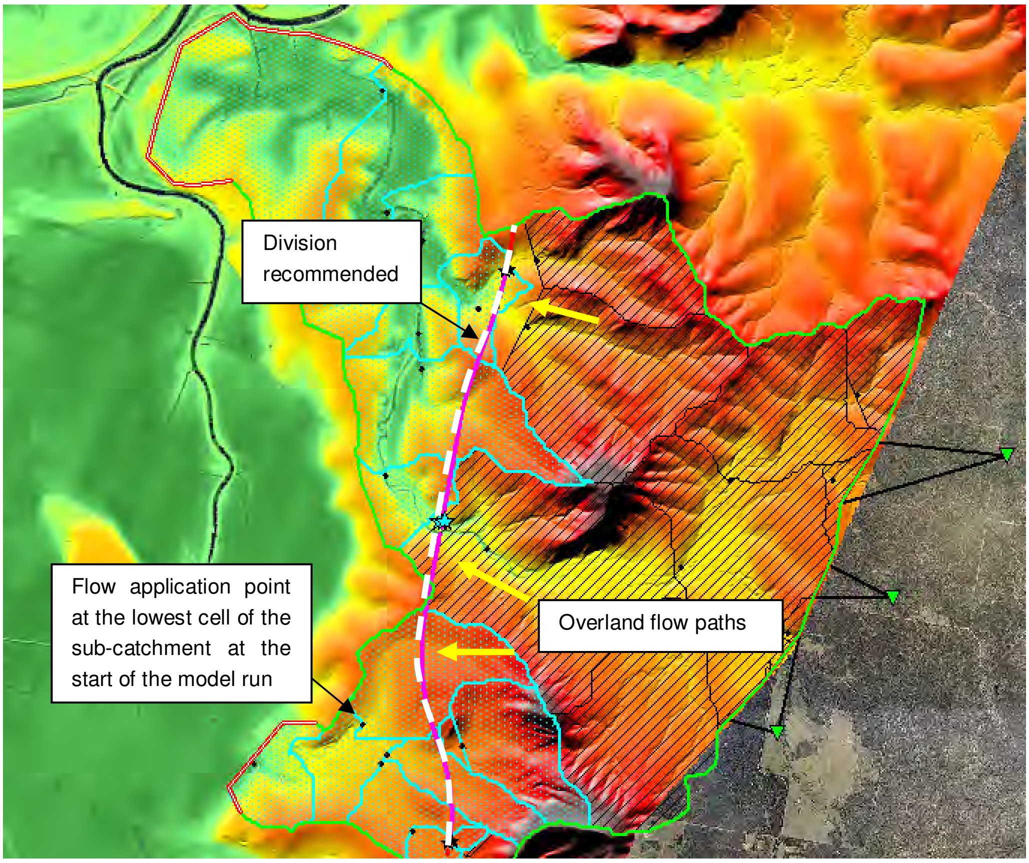

Figure 11: Sub-catchments delineation for the Chaffin Creek floodplain and nearby creeks

Generally the recommended parameter values (Reference 8) have been adopted for the WBNM model. The peak flows from the model were further verified against other flow estimation methods and their sensitivity to the adopted lag parameters has also been investigated. A rain gauge factor was also applied to account for spatial variations in the total rainfall across the catchment.

3.2.6.3. Review of Hydraulic Model

<u>General Model Setup</u>

A 2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 10 m grid was used for the model domain and with a time step of 5 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance since Chaffin Creek, its tributaries and several of the nearby unnamed creeks were modelled in 2D but it is postulated that the available ALS or topographic survey data might have dictated the resolution of the grid used.

The intention was to provide 100 year ARI flood immunity for the Pacific Highway Upgrade for this floodplain hence model runs were carried out for the 100 year ARI flood events. The storm duration used was the 2 hour flood event which was found to be critical for this catchment.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was about 0.1% which is more than acceptable.

Boundary Conditions

Boundary conditions implemented in the model include inflows from the hydrologic model and downstream tailwater levels derived from the Clarence River model. 2 event scenarios were modelled for the design flood events: 100 year ARI local flooding + 5 year ARI Clarence River flooding and 100 year ARI local flooding + 100 year ARI Clarence River flooding, though the former was adopted as it represented a more realistic scenario.

As mentioned previously, WMAwater identified errors in the implementation of TUFLOW's Rainfall (RF) option that enables the application of rainfall hyetographs instead of runoff hydrographs as inflows into the hydraulic model. Firstly, the "RF" option was omitted from the "Read MI SA" command line meaning that the rainfall time series data were read as flow hydrographs instead of rainfall hyetographs as intended. Secondly, the TUFLOW user manual (Reference 7) states that "The rainfall time-series data must be in mm versus hours" and "Initial and continuing losses are entered as attributes to the 2d_sa layer". WMAwater found that both have not been carried out as the rainfall time-series data were specified in mm/hr versus minutes and losses were not specified in the corresponding 2d_sa layer. In addition, the contributing catchment area has to be specified in km^2 and a rain gauge factor should be included as one of the additional attributes for the "RF" option. The implication of these errors is further discussed in Section 3.2.7.2 though it is shown that the consequences on the impact assessment results are minimal.

The 1D/2D connections for the various drainage structures have been properly implemented and the hydraulic model boundary was accurately demarcated.

Digital Elevation Model

The DEM developed for this catchment was of a finer resolution (based on a 5 m DEM) than the broader DEM developed for the Clarence River model. "Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

Structures Implementation

For this model, waterway crossings like bridges were modelled as gaps in between the abutments/road embankments with no consideration of potential form losses caused by the bridge piers. As such, this may result in underestimation of potential afflux caused upstream. WMAwater recommend that the flow constriction methods available in TUFLOW be employed and an alternative method or model be used to validate the flow constriction attributes or form losses adopted for these key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been implemented in the model. Further details of included drainage structures in the modelling are provided in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. However, there was no change to the roughness for the Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable as the highway remains dry over the duration of the simulation run.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.7. Champions Creek

3.2.7.1. Model Development and Approach Undertaken

Flood modelling of the Champions Creek catchment was carried out using a WBNM hydrological model and a TUFLOW (2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (RTA, 2008). The hydrological model was used to estimate the inflows hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 6.5 km by 9 km, with a 2D grid resolution of 10 m. The model extent covers the Champions Creek floodplain and an unnamed creek situated north. The downstream section of this model overlaps with the Clarence River model extent and all rivers/creeks and their tributaries flow into the Clarence River floodplain. The modelling approach undertaken is considered appropriate and as per standard practice. Section 3 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.7.2. Review of Hydrologic Model

WBNM was used to estimate the runoff hydrographs primarily for the catchments upstream of the proposed highway embankment and the flows were subsequently inputted into the TUFLOW hydraulic model. The initial/continuing loss model adopted for the hydrologic model deviates slightly from standard industry practice or that recommended by Australian Rainfall and Runoff (Reference 1) in that no initial loss was specified while 2 mm/hr was used for the continuing loss. Though this approach is slightly conservative, the values were well within reasonable range. All surfaces were assumed to be pervious. The reason behind selecting these values was not known to WMAwater. In contrast, runoff for catchments downstream of the highway embankment was modelled using TUFLOW's Rainfall (RF) option whereby instead of flow hydrographs, rainfall hyetographs were specified and then applied to the hydraulic model. However, it was found that this has not been implemented correctly, therefore resulting in errors in the inflows. This is further discussed in Section 3.2.7.3.

Delineation of the sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the highway where water flowing down from the range will be impeded by this control feature before reaching the downstream floodplains. With the current sub-catchment delineation, flow is allocated downstream of the embankment at the start of the simulation run when the model 2D cells were mostly dry, as shown in Figure 12. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

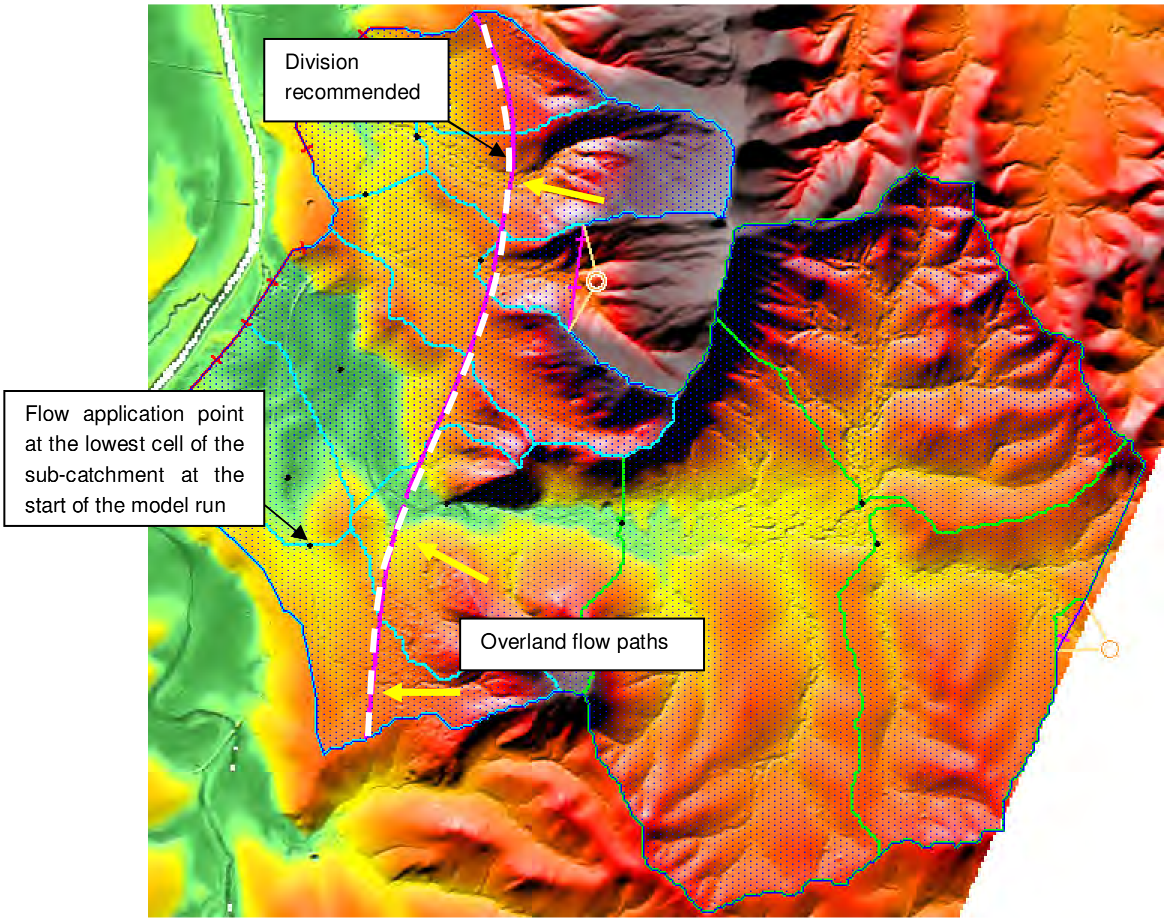

Figure 12: Sub-catchments delineation for the Champions Creek floodplain and nearby creek

Generally the recommended parameter values (Reference 8) have been adopted for the WBNM model. The peak flows from the model were further verified against other flow estimation methods and their sensitivity to the adopted lag parameters has also been investigated. A rain gauge factor was also applied to account for spatial variations in the total rainfall across the catchment.

3.2.7.3. Review of Hydraulic Model

General Model Setup

A 2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 10 m grid was used for the model domain and with a time step of 5 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance since Champions Creek and the nearby unnamed creek were modelled in 2D but it is postulated that the available ALS or topographic survey data might have dictated the resolution of the grid used.

The intention was to provide 100 year ARI flood immunity for the Pacific Highway Upgrade for this floodplain hence model runs were carried out for the 100 year ARI flood events. The storm duration used was the 2 hour flood event which was found to be critical for this catchment.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was about 0.1% which is more than acceptable.

Boundary Conditions

Boundary conditions implemented in the model include inflows from the hydrologic model and downstream tailwater levels derived from the Clarence River model. 2 event scenarios were modelled for the design flood events: 100 year ARI local flooding + 5 year ARI Clarence River flooding and 100 year ARI local flooding + 100 year ARI Clarence River flooding, though the former was adopted as it represented a more realistic scenario.

As mentioned previously, WMAwater identified errors in the implementation of TUFLOW's Rainfall (RF) option that enables the application of rainfall hyetographs instead of runoff hydrographs as inflows into the hydraulic model. Firstly, the "RF" option was omitted from the "Read MI SA" command line meaning that the rainfall time series data were read as flow hydrographs instead of rainfall hyetographs as intended. Secondly, the TUFLOW user manual (Reference 7) states that "The rainfall time-series data must be in mm versus hours" and "Initial and continuing losses are entered as attributes to the 2d_sa layer". WMAwater found that both have not been carried out as the rainfall time-series data were specified in mm/hr versus minutes and losses were not specified in the corresponding 2d_sa layer. In addition, the contributing catchment area has to be specified in km^2 and a rain gauge factor should be included as one of the additional attributes for the "RF" option. The implication of these errors on the impact assessment results nevertheless is minimal as the affected sub-catchments are mostly located downstream of the proposed embankment and as such any changes to the peak flood level (with the corrections implemented) is confined to the downstream area, as can be seen from Figure 13. Having re-run the model with the corrections in place, WMAwater also observe a more realistic inflow/outflow hydrograph as shown in Figure 14 whereby the downstream sub-catchments modelled using TUFLOW's RF option are contributing to the flow peak earlier on as opposed to the later stages of the modelled flood event.

Figure 13: Changes to peak flood level on the floodplain after implementing the corrections

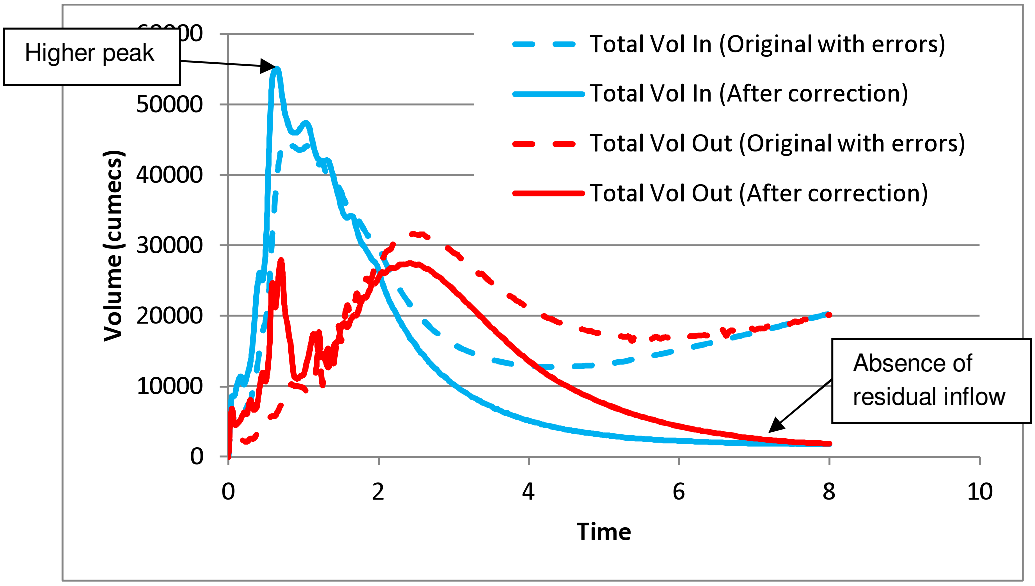

Figure 14: Changes to volume of water entering/exiting the model after implementing the corrections

Digital Elevation Model

The DEM developed for this catchment was of a finer resolution (based on a 5 m DEM) than the broader DEM developed for the Clarence River model. "Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels as well as road/embankment crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

Structures Implementation

For this model, waterway crossings like bridges were modelled as gaps in between the abutments/road embankments with no consideration of potential form losses caused by the bridge piers. As such, this may result in underestimation of potential afflux caused upstream. WMAwater recommend that the flow constriction methods available in TUFLOW be employed and an alternative method or model be used to validate the flow constriction attributes or form losses adopted for these key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled.

There is no culvert or other drainage structures proposed for this catchment according to the RTA concept design plan (Reference 6).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain and major watercourses are generally reasonable though for the existing roads, 0.08 was adopted which is unusually high and inconsistent with the value adopted for a similar surface for the neighbouring catchment models (i.e. 0.03). Also, there was no change to the roughness for the Pacific Highway upgrade corridor to reflect the surface change. This is not unreasonable as the highway remains dry over the duration of the simulation run.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.8. Clarence River

3.2.8.1. Model Development and Approach Undertaken

The Clarence River TUFLOW model was developed by WBM for the Clarence River County Council between 2000 and 2004 (Reference 5) as part of a revision of the 1988 Flood Study conducted by the Public Works Department. The approach undertaken involved the use of several hydrological models (i.e. FFA, Cordery-Webb and Unit-Hydrograph approach) that were used to estimate the inflow hydrographs for application to the hydraulic model. The 2D flood model was further refined for the Pacific Highway Upgrade study whereby critical areas on the floodplain such as the Shark Creek basin and Chatsworth and Harwood Islands were represented using a finer model grid for the purposes of the impact assessment.

The TUFLOW model domain covers an area of approximately 59 km by 29 km, with a 2D grid resolution of 60 m. The critical areas, i.e. Shark Creek basin and Chatsworth/Harwood Islands, were modelled in refined domains of 20 m grid resolution “nested” in the main model domain for detailed analysis. With the exception of Shark Creek and Serpentine Channel (which were represented as 1D elements), all the rivers/creeks and their tributaries were modelled in the 2D grid. This approach is considered appropriate as flows are largely distributed across the floodplains for this particular catchment and the major watercourses were adequately represented in the 60 m 2D domain.

The model covers the lower Clarence River floodplain including a number of towns such as Grafton, Ulmarra, Maclean and Yamba. Three sections of the project (section 3 to 5) were assessed using the Clarence River model.

The refined model was calibrated to flows and flood levels recorded during the floods of May 1980, May 1996 and March 2001 (Reference 2).

3.2.8.2. Review of Hydrologic Model

The hydrologic inflows used as inputs to the flood model were derived using a combination of the following methods/models:

- Inflows from the Clarence River upstream of Mountain View developed using flood frequency analysis;
- Inflows for the tributaries downstream of Mountain View developed using the Cordery-Webb model; and
- Inflows for the catchment floodplain areas determined using the simplified Unit-Hydrograph approach.

WMAwater were unable to review these models as they were not provided, though their development has been discussed in detail in Reference 5. It was reported that 30 mm initial loss and 2 mm/hr continuing loss were adopted for the hydrologic models. Even though the initial loss value is inconsistent with those adopted for the other catchments, the adopted losses are in-line with those recommended by Australian Rainfall and Runoff (Reference 1).

Delineation of the floodplain sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the Pacific Highway located on the Shark Creek basin, where water flowing down from the range will be impeded by this control feature before reaching the Clarence River, as shown in Figure 15. With the current sub-catchment delineation, flow is allocated downstream of the embankment directly into the river at the start of the simulation run when the rest of the model 2D cells were mostly dry. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

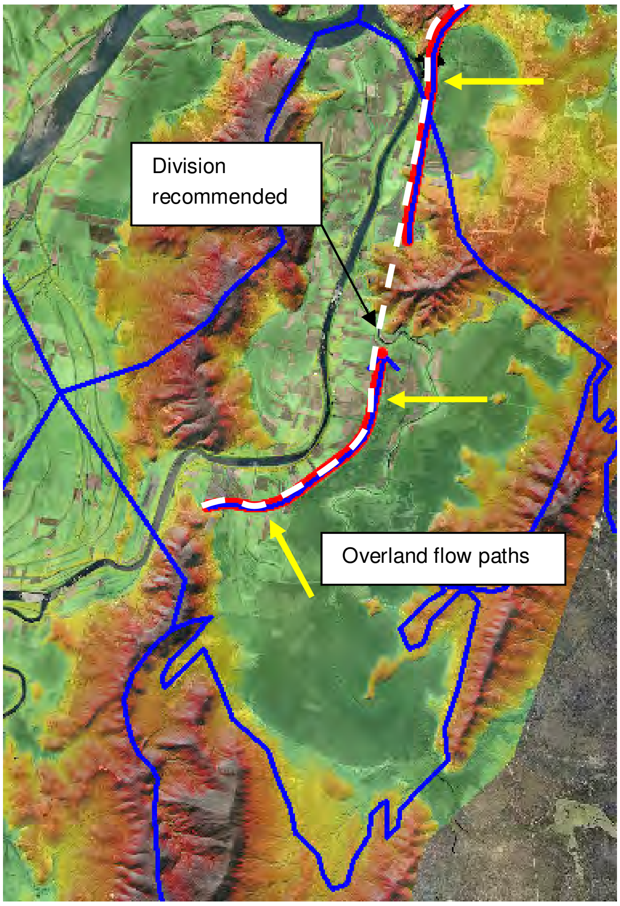

Figure 15: Sub-catchments delineation for the Clarence River floodplain/Shark Creek basin

3.2.8.3. Review of Hydraulic Model

General Model Setup

A 2D hydrodynamic model was established using TUFLOW, with the watercourses located in the critical areas, i.e. Shark Creek and Serpentine Channel, represented as 1D elements. As mentioned previously, a 60 m grid was used for the main model domain with a time step of 18 s used for this domain. However, it is recommended that a smaller time step be used as the model was operating at moderately high Courant Numbers (>5). Another advised check which could be performed is to rerun the model with a lower time step to ensure that no measurable change in results is observed. In contrast, a finer grid resolution would have provided better representation of in-bank creek conveyance since most creeks/tributaries were modelled in 2D and some were represented only by 1 cell. Nevertheless, the implication of a marginally reduced in-bank conveyance is expected to be minimal since a large amount of conveyance would be expected to be in the overbank for the modelled flood events. This underestimation would be conservative for design applications and hence is not of concern. The adopted grid size, however, does limit the applicability of the model for use in simulation of the more frequent events.

The minimum level of flood immunity for the Pacific Highway Upgrade is 20 year ARI for the Clarence River floodplain hence model runs were carried out for the 20 year as well as 100 year ARI flood events. The critical storm duration adopted for the study was not reported but the design floods were simulated such that the storm tide peak coincides with the peak of the rainfall on the tributary catchments and the floodplain (Reference 5).

Only one downstream tailwater boundary condition was utilised, which was placed at the Clarence River ocean outlet near Yamba. Here, the design flood ocean levels were adopted from the 1988 Lower Clarence River Flood Study (PWD, 1988).

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" Referring to Figure 16, high mass balance errors were encountered at the commencement of the simulation. These are quite common for the model initialisation period as dry cells become wet and the errors dropped to within the ±1% threshold once significant flows started to enter into the model. In contrast, the manual calculations revealed that the mass balance error was about -0.7% which is acceptable. It can also be highlighted that there is negligible difference in the mass errors between the different scenario runs.

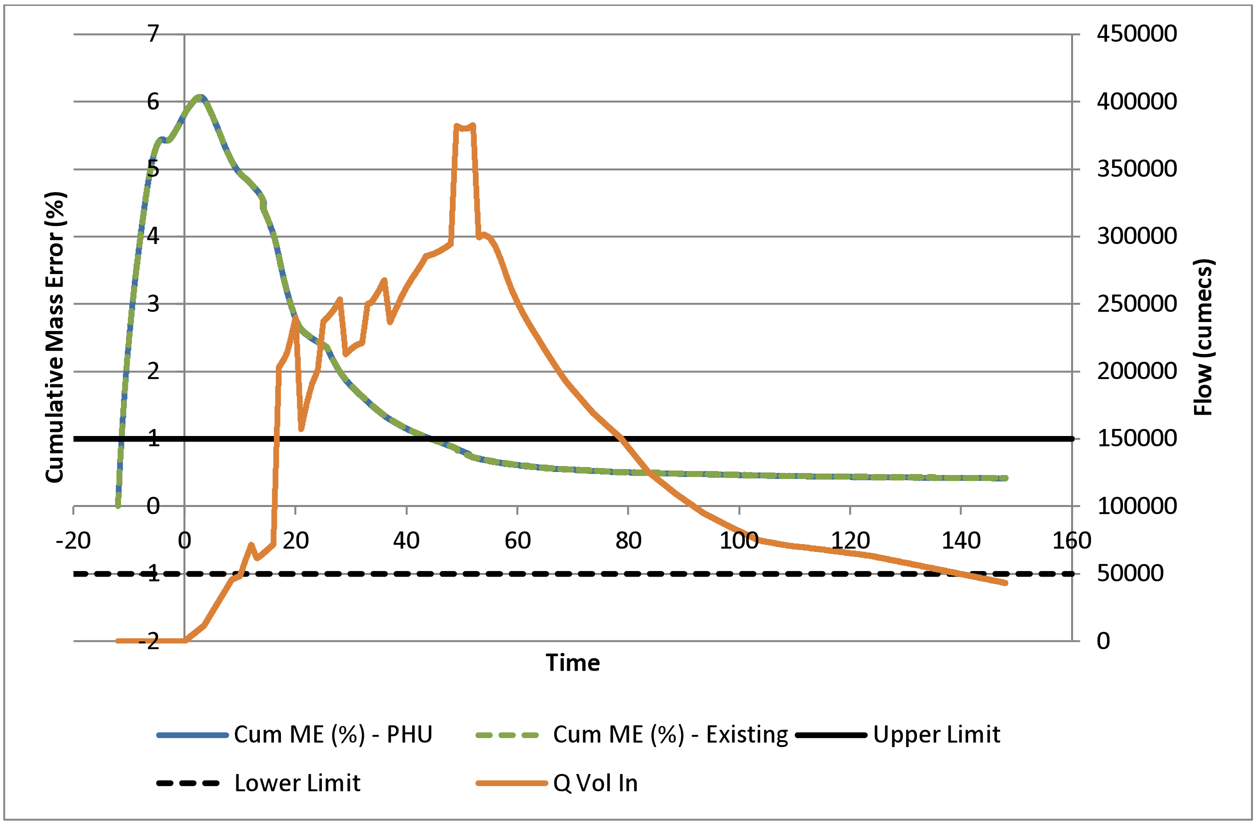

Figure 16: Plot of mass balance error for the Clarence River model

Digital Elevation Model

The Digital Elevation Model (DEM) developed for the 2D hydraulic modelling was largely based on ground contour survey carried out between 1958 and 1960 as well as more recent aerial survey carried out by the RTA for this project. The hydrographic survey data of the Clarence River, which were used to define the depth and physical characteristics of the river, are dated 1963, 1978 and 1979, as reported in Reference 5. This is of concern as the geometry of the Clarence River would have been subjected to changes over the years with the occurrence of floods as well as implementation of various mitigation measures along the floodplain. WMAwater recommends that up-to-date hydrosurvey data be used in the flood assessment for the subsequent detailed design stage, which are available from the Office of Environment and Heritage website (http://www.environment.nsw.gov.au/estuaries/stats/ClarenceRiver.htm). The model results should then be revised accordingly based on the new data available.

"Terrain modifiers" have been used in this model to ensure adequate representation of topographic features of gullies/creek in-bank levels and levee/road/embankment crest levels. Some were also used to improve on model instabilities, though this is not unreasonable. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 20 year ARI peak flood level but allowing overtopping for the 100 year ARI flood event. Examination of the final 2D elevations (known as Zpts in TUFLOW) used by the model, however, revealed a few abnormalities that might be intentionally/unintentionally created which could have caused the instabilities in this model. One example of this is shown in Figure 17 (Zpt = -9,999). Another example is shown in Figure 18 whereby the 2D SX cell that facilitated the transition of flow from the 2D domain into the 1D reach (or vice versa) was lowered excessively through the use of a "Z" flag. The TUFLOW manual states that "It is not recommended to use the Z flag without first checking that the reason for the discrepancy in elevations between 1D and 2D domains is appropriate." Thus, a thorough review of the final topography used in the model is warranted.

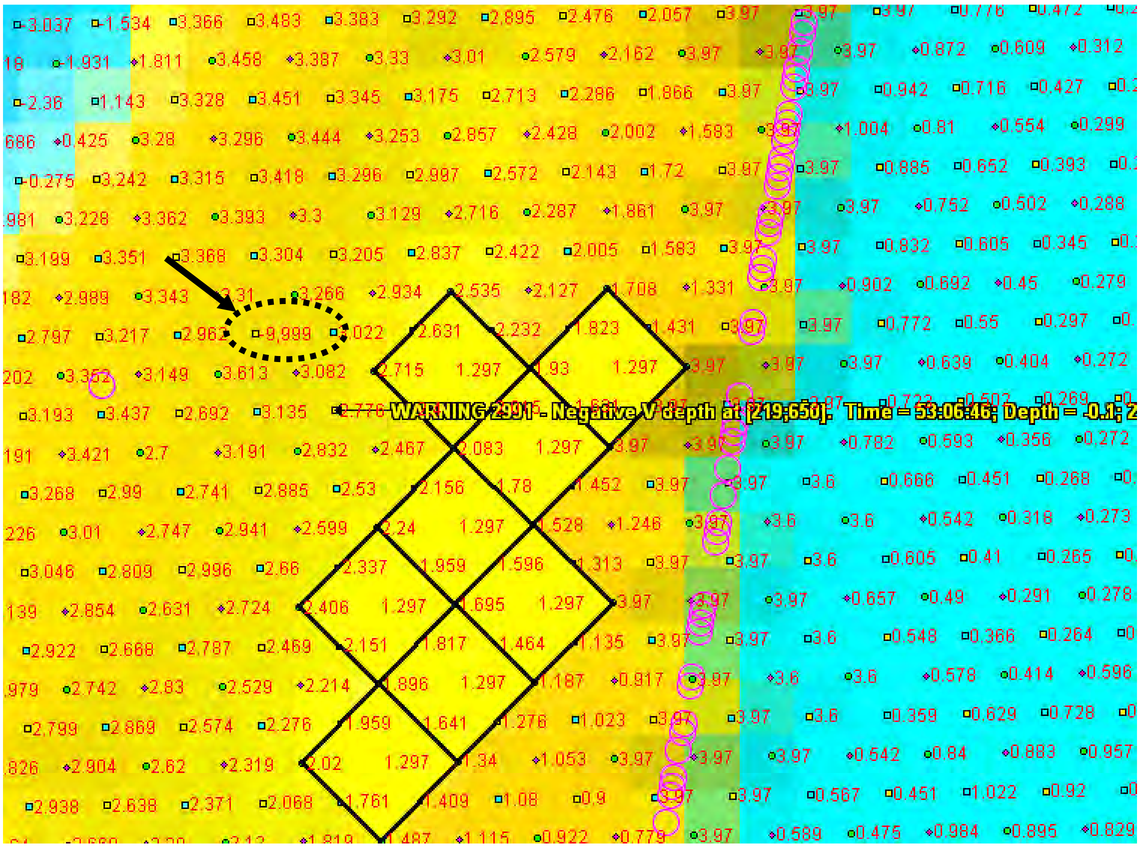

Figure 17: Abnormalities found in the Zpts check layer

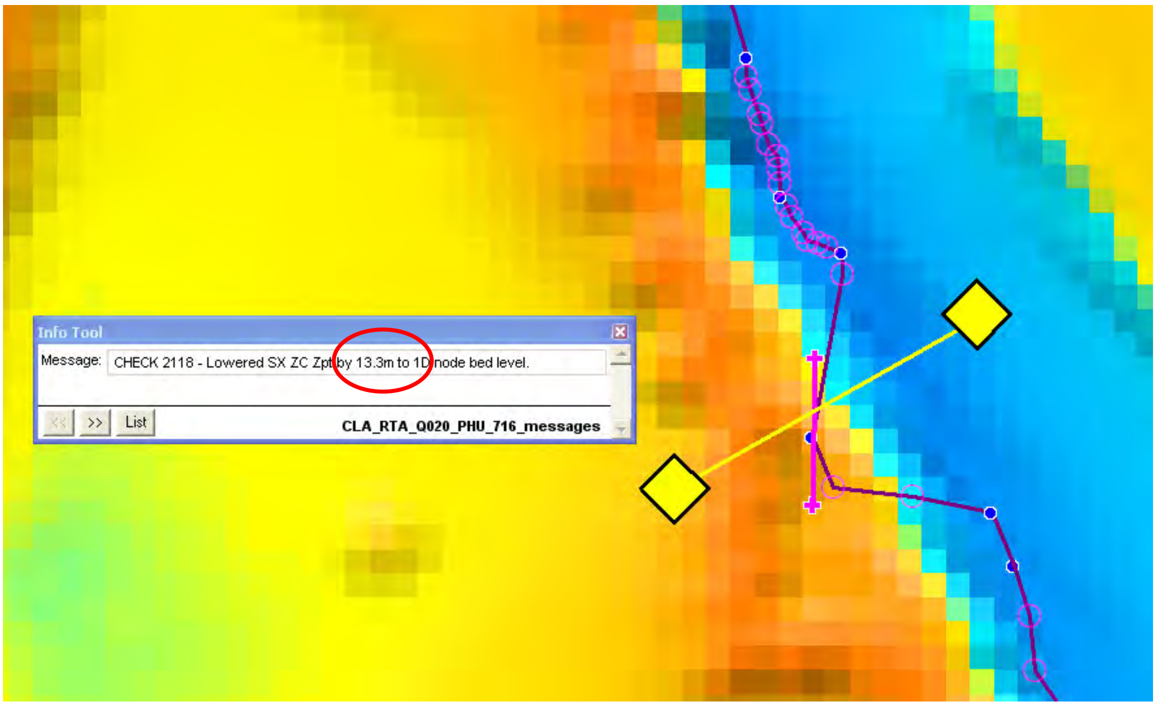

Figure 18: Excessive lowering of Zpts for culvert inlets/outlets

Boundary Conditions

The inflow boundary conditions for the Clarence River and its tributaries have been implemented properly, though the ones for Broadwater Creek and Esk River could be relocated further upstream. The premise of this is that the current boundary where the inflows transition from the 1D node into the 2D domain is located along the existing flow paths within the floodplain and the hydraulic model boundary acted as an "imaginary" wall that prevented water from filling the remaining flood storage available in the floodplain (refer to Figure 19) or retained more water in the model instead of allowing them to discharge freely out of the model. Relocating the boundary further upstream, for example, may result in a slight reduction of the predicted peak flood level, but the implication of this oversight is minor when compared to the total floodplain storage available in this particular model. For the boundary close to the ocean, it is also recommended that the hydraulic model boundary be relocated and placed along the shoreline, as well as implementing a tailwater boundary condition similar to that of the Clarence River ocean outlet.

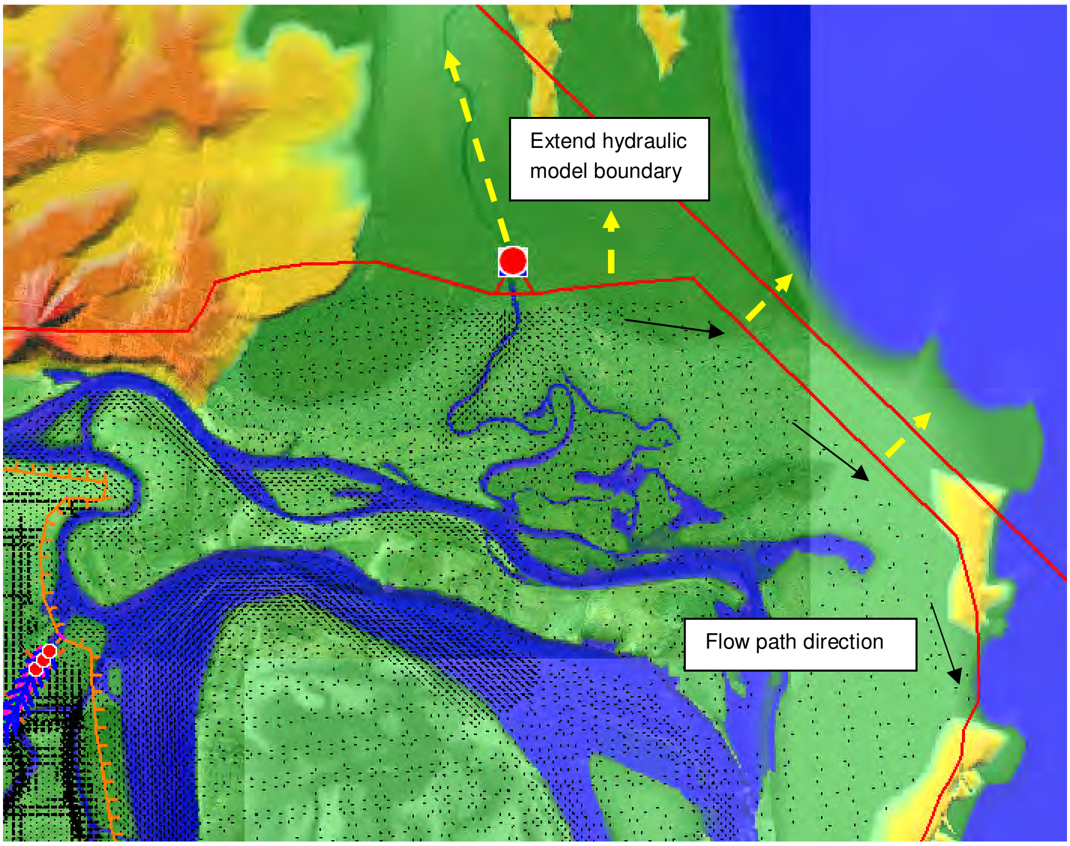

Figure 19: Inflow boundary condition for the Esk River and extent of hydraulic model boundary

The linking or "stitching" of the multiple 2D domains has been implemented correctly with the exception of the southern boundary of the refined model domain of the Shark Creek basin. It was determined that the 2D-2D link polyline necessary for the transfer of the momentum of flows is missing at this location (refer to Figure 20). Consequently, flows coming down from the upstream catchments were prevented from entering the refined domain by this "imaginary wall" and instead took a detour through Shark Creek to enter into the lower floodplains. Upon closer examination, there exists a levee close to the boundary with a maximum elevation of 2.06 mAHD, thus the modelled flood behaviour replicates to some extent what is actually taking place in existing conditions. However, the 20 year ARI peak flood level for this location was determined to be around 3.75 mAHD and therefore overtopping of the levee occurs for the larger events and the current setup would not have modelled this phenomenon. Fortunately, the peak flood levels predicted on both sides of the "wall" are the same, even though the flow paths have been altered from their actual behaviour. The implication of this is that the momentum and timing of the flows through this part of the floodplain will be incorrect. This can be fixed by adding the 2D-2D link, preferably located along the existing levee.

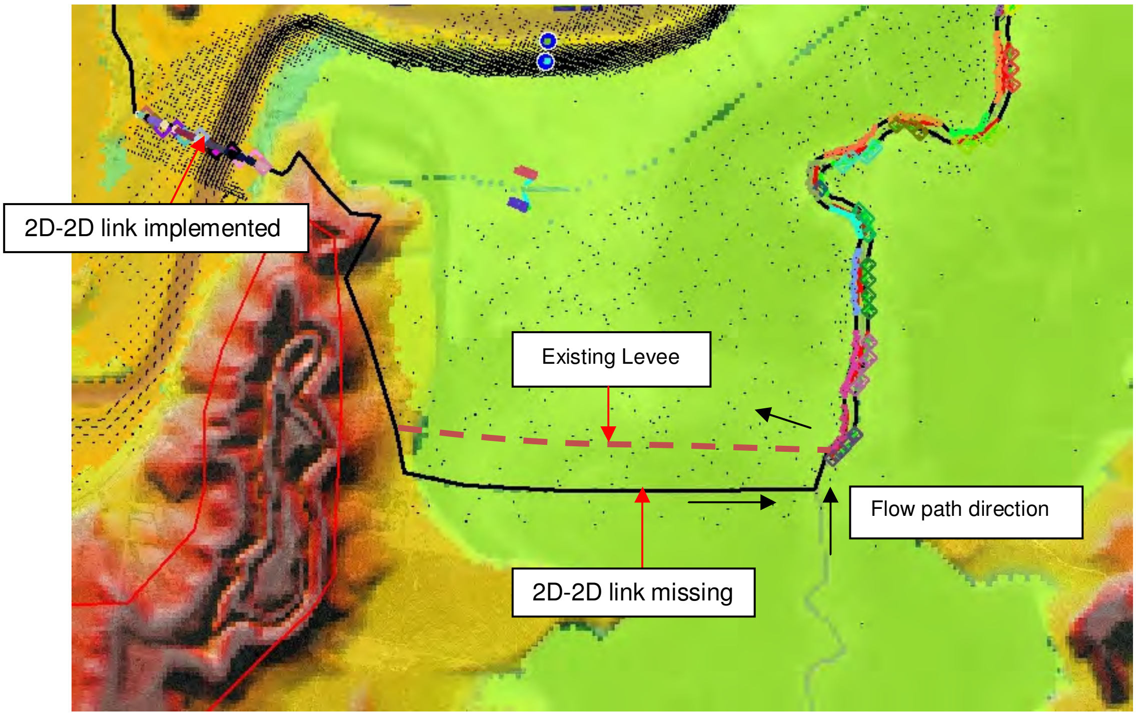

Figure 20: Missing 2D-2D connection for the refined Shark Ck basin domain

Modelling Waterways

It is of concern that arbitrary cross sections were adopted for Serpentine Channel (at a depth of 2 m albeit with varying widths) instead of actual surveyed data. The implication of this is that flow conveyance was not correctly quantified for the channel, though this may not be critical as the primary mode of flooding on Chatsworth/Harwood Island for the larger floods is inundation resulting from the overtopping of the Clarence River bank. WMAwater recommend that survey be undertaken to ascertain the channel cross section if existing survey data are not available, so as to facilitate a more accurate assessment of the flood behaviour occurring in this vicinity.

Structures Implementation

For the implementation of waterway structures, flow constrictions were applied to the relevant 2D cells whereas if a 1D channel/creek was present, a nominal loss was specified for that reach where the bridge crosses, which is common practice. As discussed in Section 3.1, it is vital that an alternative method or model be used to validate the flow constriction attributes or form losses adopted for key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled so as not to underestimate the potential afflux caused upstream.

The approach undertaken in modelling the proposed bridges would also be an issue if the peak flood level is high enough to overtop the bridge deck, which may be the case for the PMF event. For such flow conditions, additional form losses must be included to account for the resistance introduced by the bridge deck. Alternatively, the use of a weir element to represent the overflow across the bridge or the layered flow constriction method available in newer versions of TUFLOW could be employed.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have largely been implemented in the model though several were excluded from the model particularly for the highway stretch from Shark Creek basin to Clarence River bridge. The reason for this was not mentioned in the report (Reference 2) though it is postulated that the additional box culverts were not required as the afflux criteria has already been met for this location. Further details are provided in the structures inventory included in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the various 2D model domains and major watercourses are reasonable. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway and viaducts.

Impact Assessment

When examining the flood impacts caused by the proposed works within the Clarence River floodplain, afflux of up to 100 mm was found at the Chatsworth/Harwood Island floodplain based on the 20 year ARI results grids provided to WMAwater, as illustrated in Figure 21. This finding does not concur with Figure 3.18 as shown in Reference 2. WMAwater are not able to determine whether the same results were used for reporting but recommend further work be carried out if the impact objectives are indeed not met.

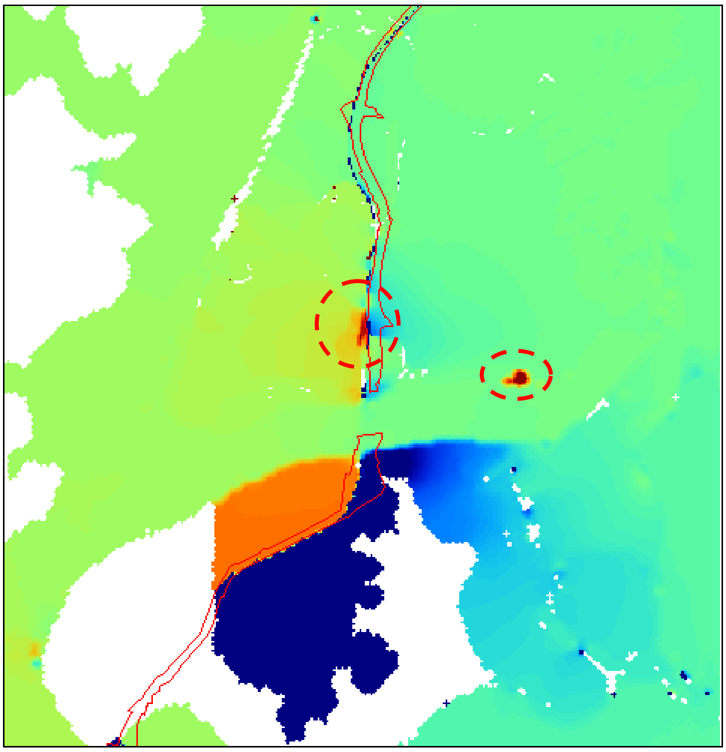

Figure 21: Impacts of up to 100 mm at Chatsworth/Harwood Island for the 20 year ARI event

3.2.9. Mororo Creek

3.2.9.1. Model Development and Approach Undertaken

Flood modelling of the Mororo Creek catchment was carried out using a XP-RAFTS hydrological model and a MIKE-FLOOD (1D/2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (Connell Wagner, 2009). The hydrological model was used to estimate the inflow hydrographs for application to the hydraulic model.

The MIKE-FLOOD model domain covers an area of approximately 3.1 km by 4.1 km, with a 2D grid resolution of 5 m. Culverts/weirs were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Sections 5 and 6 of the project were assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.9.2. Review of Hydrologic Model

WMAwater were unable to review the XP-RAFTS model for this catchment as it was not provided.

3.2.9.3. Review of Hydraulic Model

General Model Setup

A 2D hydrodynamic model was established using MIKE-FLOOD with a 1 m ALS used to develop the 5 m DEM adopted for the model domain. A time step of 1 s was used and the 20 year and 100 year ARI events were modelled to ensure that the section of the Pacific Highway in this catchment would have a 100 year ARI flood immunity. 2D elements of the model were defined in the MIKE21 model file while the MIKE11 model file provided the definition for the 1D drainage structures.

Boundary Conditions

Boundary conditions including inflows from the hydrologic model and downstream tailwater levels were implemented properly in the model, though WMAwater were not able to ascertain whether both inputs were appropriately defined.

Digital Elevation Model

The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

Structures Implementation

WMAwater have examined the implementation of the drainage structures and found that they were properly schematised using the appropriate connections to link the 1D and 2D elements. Reasonable losses were specified for the culverts and weirs were used to model culvert overflows. The drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been properly implemented in the model. Nevertheless, the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.10. Tabbimoble Creek

3.2.10.1. Model Development and Approach Undertaken

Flood modelling of the Tabbimoble Creek catchment was carried out using a XP-RAFTS hydrological model and a MIKE-FLOOD (1D/2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (Connell Wagner, 2009). The hydrological model was used to estimate the inflow hydrographs for application to the hydraulic model.

The MIKE-FLOOD model domain covers an area of approximately 4.7 km by 5.8 km, with a 2D grid resolution of 5 m. Culverts/weirs were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 6 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.10.2. Review of Hydrologic Model

WMAwater were unable to review the XP-RAFTS model for this catchment as it was not provided.

3.2.10.3. Review of Hydraulic Model

General Model Setup
A 2D hydrodynamic model was established using MIKE-FLOOD with a 1 m ALS used to develop the 5 m DEM adopted for the model domain. A time step of 1 s was used and the 100 year ARI event was modelled to ensure that the section of the Pacific Highway in this catchment would have a 100 year ARI flood immunity. 2D elements of the model were defined in the MIKE21 model file while the MIKE11 model file provided the definition for the 1D drainage structures.

Boundary Conditions
Boundary conditions including inflows from the hydrologic model and downstream tailwater levels were implemented properly in the model though WMAwater were not able to ascertain whether both inputs were appropriately defined.

Digital Elevation Model
The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

Structures Implementation
WMAwater have examined the implementation of the drainage structures and found that they were properly schematised using the appropriate connections to link the 1D and 2D elements. Reasonable losses were specified for the culverts and weirs were used to model culvert overflows. The drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been properly implemented in the model though some

were combined to form a large culvert structure. The impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1). Waterway crossings like bridges on the other hand were modelled by introducing piers, which accounted for the resistance posed by the constriction introduced by the structure.

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.11. Tabbimoble Floodway 1

3.2.11.1. Model Development and Approach Undertaken

Flood modelling of the Tabbimoble Floodway 1 catchment was carried out using a XP-RAFTS hydrological model and a MIKE-FLOOD (1D/2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (Connell Wagner, 2009). The hydrological model was used to estimate the inflow hydrographs for application to the hydraulic model.

The MIKE-FLOOD model domain covers an area of approximately 4.1 km by 3.1 km, with a 2D grid resolution of 5 m. Culverts/weirs were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 7 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.11.2. Review of Hydrologic Model

WMAwater were unable to review the XP-RAFTS model for this catchment as it was not provided.

3.2.11.3. Review of Hydraulic Model

<u>General Model Setup</u>
A 2D hydrodynamic model was established using MIKE-FLOOD with a 1 m ALS used to develop the 5 m DEM adopted for the model domain. A time step of 1 s was used and the 100 year ARI event was modelled to ensure that the section of the Pacific Highway in this catchment would have a 100 year ARI flood immunity. 2D elements of the model were defined in the MIKE21 model file while the MIKE11 model file provided the definition for the 1D drainage structures.

<u>Boundary Conditions</u>
Boundary conditions including inflows from the hydrologic model and downstream tailwater levels were implemented properly in the model though WMAwater were not able to ascertain whether both inputs were appropriately defined.

<u>Digital Elevation Model</u>
The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

<u>Structures Implementation</u>
WMAwater have examined the implementation of the drainage structures and found that they were properly schematised using the appropriate connections to link the 1D and 2D elements. Reasonable losses were specified for the culverts and weirs were used to model culvert overflows. The drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been properly implemented in the model though with

variation to their sizes. The impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1). Waterway crossings like bridges on the other hand were modelled by introducing piers which accounted for the resistance posed by the constriction introduced by the structure.

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway.

Impact Assessment

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.12. Oaky Creek

3.2.12.1.Model Development and Approach Undertaken

Flood modelling of the Oaky Creek catchment was carried out using a XP-RAFTS hydrological model and a MIKE-FLOOD (1D/2D) hydraulic model. These models were developed for the RTA as part of previous flood assessments for the Pacific Highway upgrade concept design (Connell Wagner, 2009). The hydrological model was used to estimate the inflow hydrographs for application to the hydraulic model.

The MIKE-FLOOD model domain covers an area of approximately 4.4 km by 4 km, with a 2D grid resolution of 5 m. Culverts/weirs were represented as 1D elements in the hydraulic model. The modelling approach undertaken is considered appropriate and as per standard practice. Section 7 of the project was assessed using this model. The flood model is not calibrated to historical flood events due to lack of flood records in the catchment.

3.2.12.2.Review of Hydrologic Model

WMAwater were unable to review the XP-RAFTS model for this catchment as it was not provided.

3.2.12.3.Review of Hydraulic Model

<u>General Model Setup</u>
A 2D hydrodynamic model was established using MIKE-FLOOD with a 1 m ALS used to develop the 5 m DEM adopted for the model domain. A time step of 1 s was used and the 100 year ARI event was modelled to ensure that the section of the Pacific Highway in this catchment would have a 100 year ARI flood immunity. 2D elements of the model were defined in the MIKE21 model file while the MIKE11 model file provided the definition for the 1D drainage structures.

<u>Boundary Conditions</u>
Boundary conditions including inflows from the hydrologic model and downstream tailwater levels were implemented properly in the model though WMAwater were not able to ascertain whether both inputs were appropriately defined.

<u>Digital Elevation Model</u>
The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 100 year ARI peak flood level.

<u>Structures Implementation</u>
WMAwater have examined the implementation of the drainage structures and found that they were properly schematised using the appropriate connections to link the 1D and 2D elements. Reasonable losses were specified for the culverts and weirs were used to model culvert overflows. The drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been properly implemented in the model. Nevertheless,

the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for the 2D model domain, major watercourses and 1D drainage structures are reasonable. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway.

Impact Assessment

Flood impacts of more than 250 mm were predicted for the proposed works when considering that local catchment flooding is the dominant mechanism. WMAwater agree with the comment in Reference 2 that "*the peak 100 year ARI flood levels in this area are dominated by long duration Richmond River flood events*", and as such the project would not result in significant changes to the dominant flood levels in this area. Nevertheless, WMAwater recommend that this should be verified using the Richmond River model preferably by including this section of the highway upgrade in the model domain.

3.2.13. Richmond River

3.2.13.1. Model Development and Approach Undertaken

The Richmond River TUFLOW model was developed by BMT WBM as part of the Richmond River Flood Mapping Study (Reference 4) using up-to-date terrain data (ALS) over most of the Richmond River floodplain. The approach undertaken involved hydrological modelling using WBNM (Watershed Network Bounded Model) and hydraulic modelling using a dynamically linked 1D/2D TUFLOW model. The hydrological model was used to estimate the inflow hydrographs for application to the hydraulic model.

The TUFLOW model domain covers an area of approximately 56 km by 44 km, with a 2D grid resolution of 60 m. The adoption of a 1D/2D hydraulic model approach was practical given the size of the study area. Many of the significant watercourses have dimensions of the same order of magnitude as the grid resolution (or less), which means they would not be adequately represented in the 60 m 2D domain. Numerous rivers/creeks and their tributaries have accordingly been modelled in 1D integrated with the 2D grid. Given the computational limitations and consideration of the study area size, this modelling approach is considered appropriate.

The model covers most of the Richmond River floodplain including the three main drainage basins: the Richmond River, Wilsons River and Bungawalbin Creek, and terminates at the ocean outlet at Ballina. The Ballina Bypass model results, however, were given preference in the flood impact assessment for the lower parts of the Richmond River floodplain (Broadwater to Ballina). Three sections of the project (section 8 to 10) were assessed using the Richmond River model.

Extensive calibration of the model has been carried out by BMT WBM and this TUFLOW model was therefore preferred over the old 2D SOBEK model developed as part of the previous route selection phase. This was reported in Reference 4. The calibration/verification exercise was performed using over 250 flood marks gathered for the February 1958, March 1974, January 2008 and May 2009 flood events. As such, this flood model is deemed suitable for the assessment herein.

3.2.13.2. Review of Hydrologic Model

WBNM was used to estimate the runoff hydrographs for the entire Richmond River catchment (approximately 6,850 km^2) which were subsequently inputted into the TUFLOW hydraulic model. The initial/continuing loss model adopted for the hydrologic model is consistent with standard industry practice and the adopted losses are in-line with those recommended by Australian Rainfall and Runoff (Reference 1): 20 mm for initial loss and 2 mm/hr for continuing loss, assuming all surfaces are pervious. Delineation of the sub-catchments for the hydrologic modelling was examined using the DTM provided. The outlets of these sub-catchments define the location of inflow hydrograph boundary conditions for the hydraulic model. For any significant control feature (such as a culvert or bridge at a major road or road embankment) a sub-catchment should only include contributing areas upstream of the control, such that the flow attenuation caused by the control can be estimated in the hydraulic model.

The review of sub-catchment delineation identified locations where flows from catchment areas upstream of a major control have been allocated downstream of the control, in particular for the post-development modelling scenario. One such control is the road embankment that will be constructed as part of the new alignment of the Pacific Highway located west of Wardell, where water flowing down from the range will be impeded by this control feature before reaching the Richmond River. With the current sub-catchment delineation, flow is allocated downstream of the embankment directly into the river at the start of the simulation run when the rest of the model 2D cells were mostly dry, as shown in Figure 22. This outcome is true for the duration of the simulation run as long as wet cells are absent from upstream of the controls. Consequently, this arrangement may underestimate the extent of flood inundation upstream of the controls though WMAwater have not ascertained to what extent the results may vary.

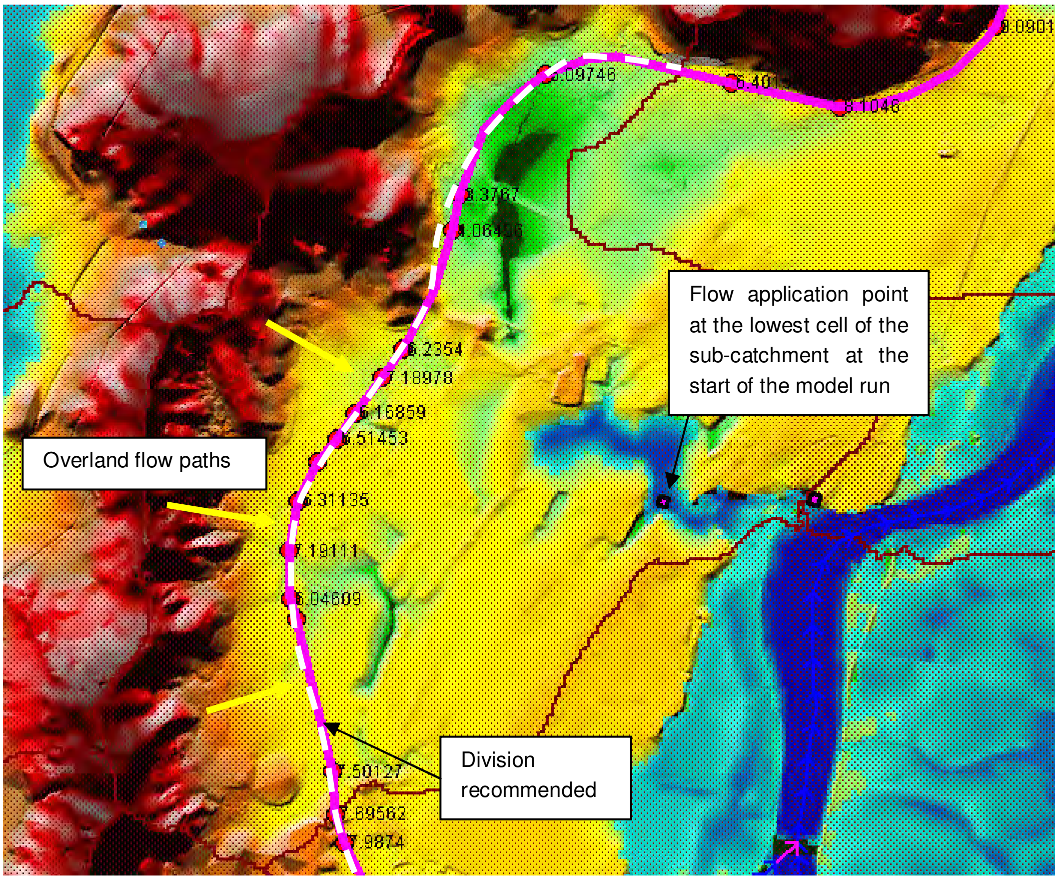

Figure 22: WBNM sub-catchments delineation for the Richmond River floodplain near Wardell

As the Richmond River catchment size is substantial, an areal reduction factor has been applied in accordance to the AR&R (Reference 1). Generally the recommended parameter values (Reference 8) have been adopted for the WBNM model with the exception of the lag parameters which were adjusted to match local catchment conditions using recorded streamflow data (Reference 4).

3.2.13.3. Review of Hydraulic Model

General Model Setup

A 1D/2D hydrodynamic model was established using TUFLOW. As mentioned previously, a 60 m grid was used for the model domain and with a time step of 10 s used for the 2D domain, the Courant stability criterion was met. A finer resolution would have provided better representation of in-bank creek conveyance in which a few minor tributaries were modelled in 2D and some were represented only by 1 cell. Nonetheless this has to be balanced with the model run times (slightly more than 24 hours with the current setup).

The intention was to provide 20 year ARI flood immunity for the Pacific Highway Upgrade for the Richmond River floodplain, hence model runs were carried out for the 20 year as well as 100 year ARI flood events. The storm durations used were the 48 hour and the 72 hour flood events though the latter was found to be critical for the lower floodplains where the proposed works are located on.

Mass Balance

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold as shown in Figure 23. The manual calculations, on the other hand, revealed that the mass balance error was almost 0% which is more than acceptable.

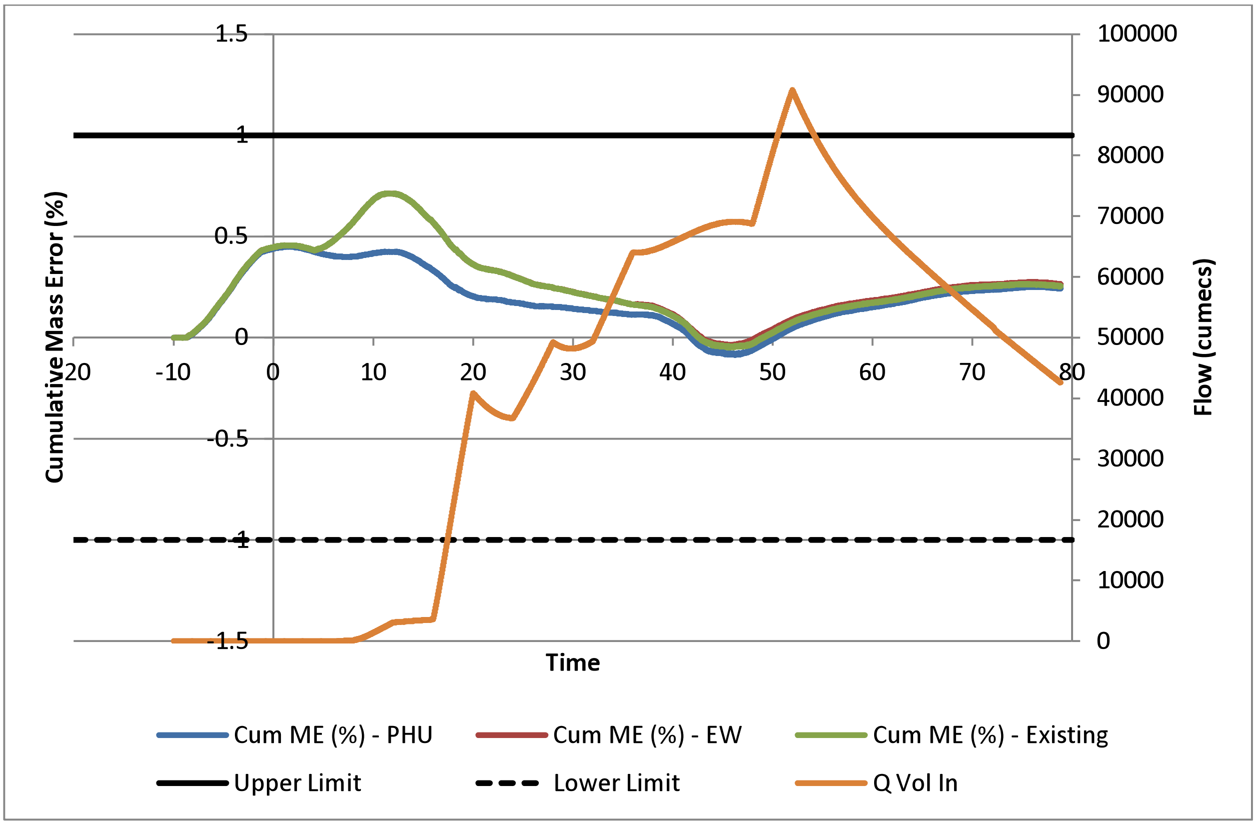

Figure 23: Plot of mass balance error for the Richmond River model

Boundary Conditions

In addition to inflows from the hydrologic model, two downstream tailwater boundary conditions were utilised, one placed at the Richmond River ocean outlet while the other was placed at the Evans River outlet. Both were properly implemented with the time to peak of the design storm matching that of the tidal boundary.

In examining the hydraulic model boundary, it was found that for several locations the boundary acted as an "imaginary" wall that prevented water from filling the remaining flood storage available in the floodplain (refer to Figure 24) or retained more water in the model instead of allowing them discharge freely out of the model. Relocating the boundary to the top of the ridge for example may result in a slight reduction of the predicted peak flood level but the implication of this oversight is minor when compared to the total floodplain storage available in this particular model.

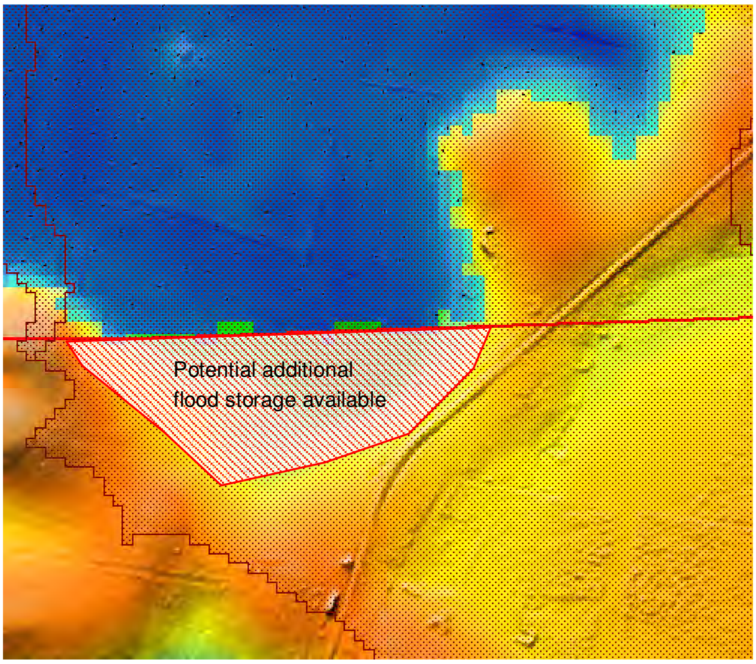

Figure 24: Available flood storage behind hydraulic model boundary

Digital Elevation Model

"Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels and road/embankment crest levels. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 20 year ARI peak flood level but allowing overtopping for the 100 year ARI flood event.

Structures Implementation

For existing bridge structures two parallel 1D network elements were implemented which is common practice:

- A culvert or bridge cross-section to represent the flow path underneath the bridge deck; and

- A weir element to represent the overflow across the bridge/road.

The major waterway structures proposed as part of the highway upgrade are the bridges crossing the Richmond River and Tuckombil Canal. For these structures, a nominal form loss was incorporated in the 1D river section as shown in Figure 25 which has not been validated against an alternative method or model. The validation process is vital in ensuring that the losses of such structures are adequately represented and modelled so as not to underestimate the potential afflux caused upstream, as discussed in Section 3.1. Currently, a form loss of 0.06 was specified for the Richmond River bridge whereas 0.08 was adopted for the bridge crossing Tuckombil Canal. Preliminary test runs carried out by WMAwater indicate that a 5 mm increase of peak flood level can be expected when the form loss is increased from 0.06 to 0.1 for the Richmond River bridge. Further, constriction introduced by the bridge piers to be constructed on the adjacent river overbank area has not been accounted for in the model.

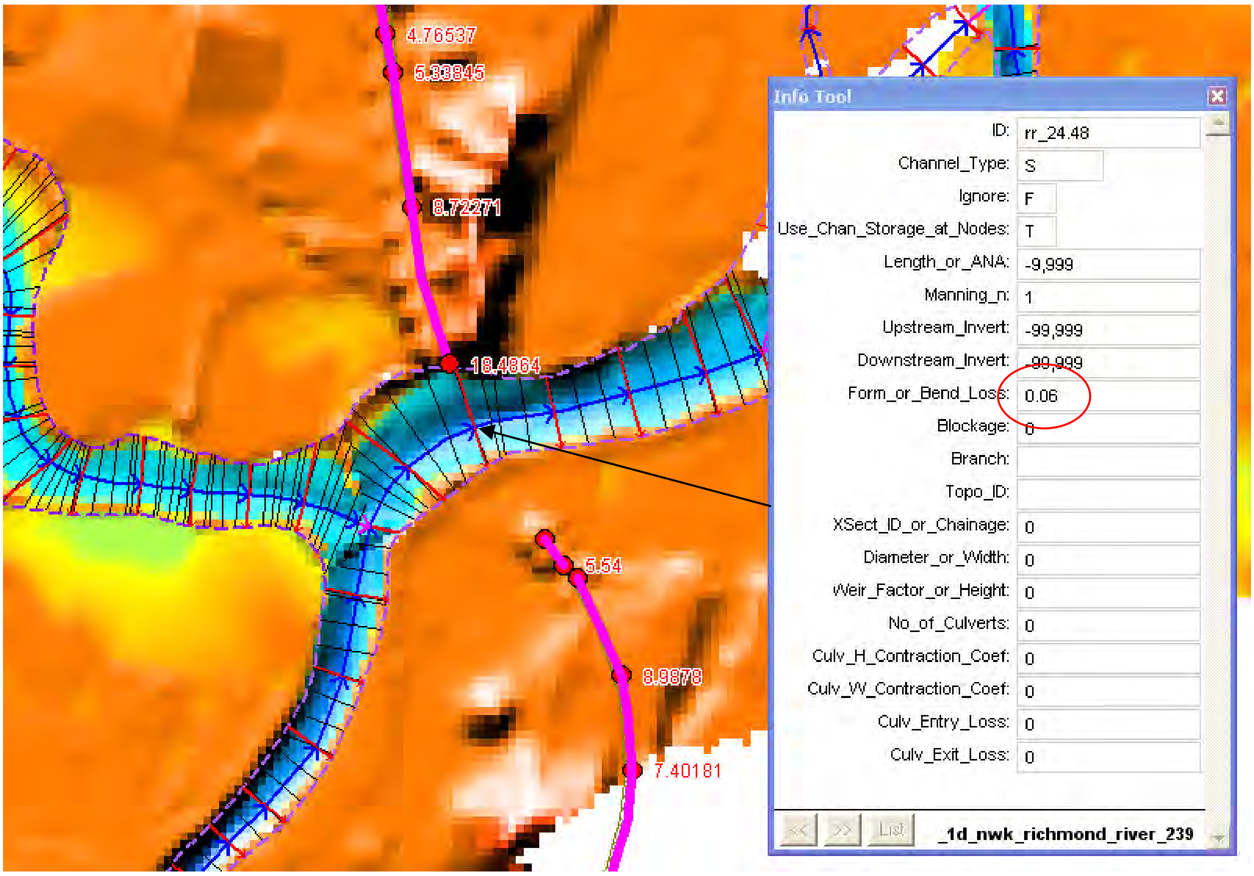

Figure 25: Schematisation of the Richmond River bridge

The approach undertaken in modelling the proposed bridges would also be an issue if the peak flood level is high enough to overtop the bridge deck, which may be the case for the PMF event. For such flow conditions, additional form losses must be included to account for the resistance introduced by the bridge deck. Alternatively, the use of a weir element (as per modelling the existing bridges) or the layered flow constriction method available in newer versions of TUFLOW could be employed. Nevertheless, the bridges proposed in the concept design would have the soffit (underside of bridge structure) at least 300 mm above the 100 year ARI flood level.

WMAwater also identified specification errors in relation to the attributes for one of the 1D bridge/channel located along Rocky Mouth Ck. The implication of adopting “S” (open channel) for the “Channel_Type” attribute instead of “B” (bridge) for this particular 1D section is that a Manning’s “n” value of 1 was used by TUFLOW that significantly attenuates flows for this section of the open creek, as can be seen in Figure 26. The Manning’s “n” attribute is ignored if the “B” attribute is specified instead.

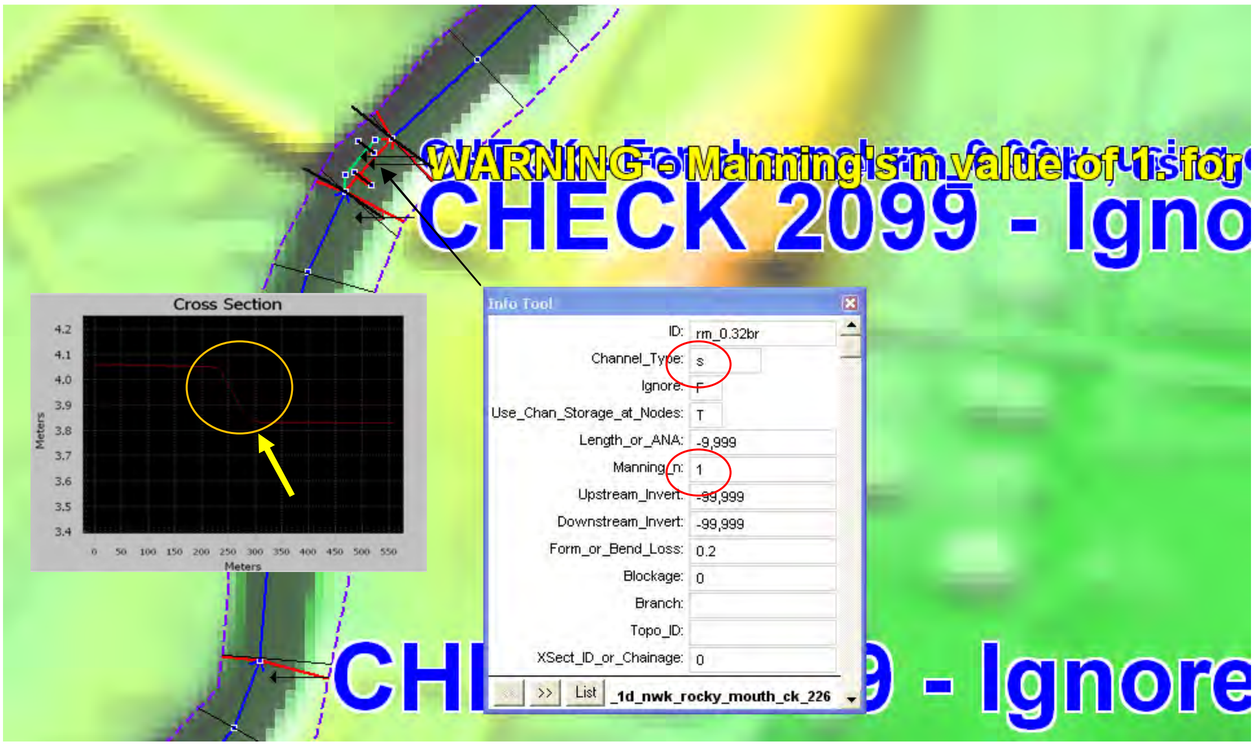

Figure 26: Wrong attribute for 1D bridge/channel

The drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have been properly implemented in the model. Nevertheless, the impact of blockages on the performance of these structures was not investigated (the implication of this is discussed in Section 3.1).

<u>Roughness</u>

The Manning’s “n” roughness values adopted for both the 1D and 2D model domains are generally reasonable, though for a few of the smaller watercourses including Rocky Mouth Creek, Sandy Creek and Deep Creek, 0.07 was used to define the creek in-bank roughness. It is postulated that the use of this higher Manning’s “n” value usually reserved for creeks with significant vegetation is warranted, since the model was calibrated to replicate actual site conditions. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway and viaducts.

<u>Impact Assessment</u>

The flood impacts are found to be reasonable and satisfy the established afflux criteria.

3.2.14. Ballina Bypass

3.2.14.1. Model Development and Approach Undertaken

The Ballina Bypass TUFLOW model was developed by BMT WBM as part of the Ballina Bypass Pacific Highway upgrade project and the Ballina Flood Study Update, covering the lower Richmond River floodplain from Broadwater to the ocean outlet at Ballina. The lower sections of Chilcotts Creek, Maguires Creek, Duck Creek, Emigrant Creek and North Creek were also included in the model. XP-RAFTS was used in the hydrological modelling of the various creek inflows while local catchment hydrology was determined using TUFLOW's direct rainfall approach. The TUFLOW hydraulic model comprised of a 2D model nested within a broader 1D model which extends south to Broadwater.

The TUFLOW model domain covers an area of approximately 14 km by 20 km, with a 2D grid resolution of 40 m. The critical areas of the Bypass were modelled in refined domains of 10 m grid resolution "nested" in the main model domain for detailed analysis. The major watercourses were modelled in 2D while the smaller rivers/creeks such as Emigrant Creek and its tributaries were modelled as 1D elements integrated with the 2D grid. This approach is considered appropriate as the major watercourses were adequately represented in the 40 m 2D domain while the minor watercourses, which have dimensions of the same order of magnitude as the grid resolution (or less), were represented using 1D elements.

Two sections of the project (sections 10 and 11) were assessed using this model and the results obtained supersede those of the Richmond River model as presented in Section 3.2.13.

The old tidal hydraulic model (which formed the basis of the later 2D flood model) developed for the 1996 Ballina Floodplain Management Study was calibrated to extensive tidal level and discharge recordings taken in November 1994 (BMT WBM, 1996). In the Ballina Flood Study Update, which included an upgrade of the model to two dimensions, extensive calibration of this refined model has been carried out by BMT WBM against historical flood events for which adequate rainfall and flood level records exist. These floods were those that occurred in March 1974, February 1976 and June 2005. As such, this flood model is deemed suitable for the assessment herein.

3.2.14.2. Review of Hydrologic Model

The XP-RAFTS hydrologic model was used to determine the catchment runoff from the Maguires Creek, Emigrant Creek, North Creek and other minor creek catchments. The runoff hydrographs were subsequently inputted into the TUFLOW hydraulic model. WMAwater were unable to review the parameter values adopted for this model as the model was not provided.

On the other hand, the local catchment hydrology was modelled using TUFLOW's Rainfall (RF) option whereby instead of flow hydrographs, rainfall hyetographs with losses were specified and then applied to the hydraulic model. The initial/continuing loss model adopted is consistent with standard industry practice and the adopted losses are in-line with those recommended by Australian Rainfall and Runoff (Reference 1): 25 mm for initial loss and 2.5 mm/hr for continuing loss, assuming all surfaces are pervious. Delineation of the floodplain sub-catchments for the hydrologic modelling was examined and found to be satisfactory.

As the catchment size for the model is substantial, an areal reduction factor has been applied in accordance to the AR&R (Reference 1). A rain gauge factor was also applied to account for spatial variations in the total rainfall across the catchment.

3.2.14.3. Review of Hydraulic Model

<u>General Model Setup</u>

A 1D/2D hydrodynamic model was established using TUFLOW, with the minor watercourses not adequately represented in the 2D grid modelled as 1D elements. As mentioned previously, a 40 m grid was used for the main model domain and with a time step of 10 s used for the 2D domain, the Courant stability criterion was met. Similarly the criterion was met for the refined 10 m domain with a time step of 5 s used. A finer resolution would have provided better representation of in-bank creek conveyance particularly for the major watercourses. Nonetheless this has to be balanced with the model run times (slightly more than 12 hours with the current setup).

Inspection of the flow hydrograph for the Richmond River (sampled from downstream of the confluence of Broadwater and Richmond River) revealed that the model may have been terminated prematurely soon after the river reaching its peak water level, as shown in Figure 27. WMAwater recommend that the model run time be extended to ensure that the peak of the river is modelled in entirety as it influences the peak flood level predicted for the downstream side of the Pacific Highway.

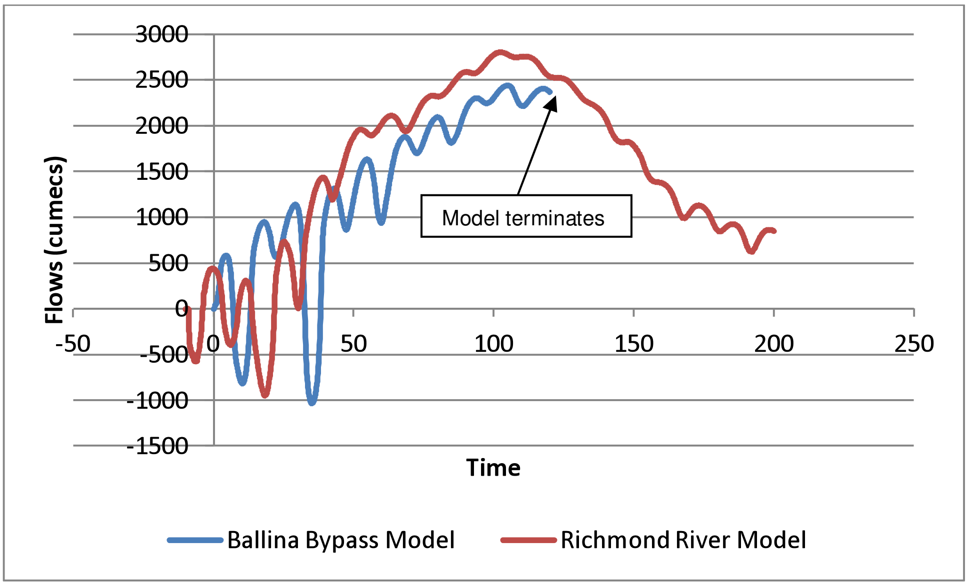

Figure 27: Flow hydrographs sampled from downstream of the confluence of Broadwater and Richmond River

The intention was to provide 20 year ARI flood immunity for the Pacific Highway Upgrade for the Richmond River floodplain hence model runs were carried out for the 20 year as well as 100 year ARI flood events. Two storm durations have been modelled, the 12 hour and the 72 hour events. The former event is the critical flood event for local catchment flooding whereas the latter is critical for flooding in the Richmond River. An envelope of the results was generated and used in the impact assessment of the proposed works.

<u>Mass Balance</u>

Mass balance check was carried out both manually and also referring to TUFLOW generated mass balance check. The TUFLOW user manual (Reference 7) states that "*the calculation of mass errors is in itself an estimation and has errors associated with the calculation process. It is also recommended that conventional mass balance checks be carried out as a matter of course to cross-check.*" With the automated check, the errors were found to be within the ±1% threshold. The manual calculations, on the other hand, revealed that the mass balance error was about 0.1% which is acceptable.

<u>Boundary Conditions</u>

Similar to the Clarence River model, one downstream tailwater boundary condition was placed at the river mouth with the time to peak of the design storm matched that of the tidal boundary. WMAwater were unable to determine whether the rated boundaries (water levels vs. time) placed upstream of Broadwater and Richmond River were properly developed as part of the previous floodplain management study in which calibration of the model was carried out. Nevertheless, the 1D/2D boundary conditions have been properly implemented in the model including the linking/"stitching" of the multiple 2D domains.

<u>Digital Elevation Model</u>

The hydrographic survey for the lower Richmond River obtained as part of the Ballina Flood Study Update was incorporated into the broader DEM developed for the Richmond River model (Reference 4). The combined grid was then used to define the DEM for this hydraulic model.

"Terrain modifiers" have been used to ensure adequate representation of topographic features of gullies/creek in-bank levels and road/embankment crest levels. Some were also used to improve on model instabilities though this is not unreasonable. The raised embankment of the proposed highway upgrade was properly implemented at a level that is above the 20 year ARI peak flood level but allowing overtopping for the 100 year ARI flood event. The final design of the Ballina Bypass project was also incorporated into the model so that an assessment of the cumulative impacts of both projects could be carried out for the lower Richmond River floodplain.

<u>Modelling Waterways</u>

WMAwater identified that the cross section "*EC0001.csv*" was incorrectly snapped to the downstream node of Channel "*487*" (located at the upstream reaches of Emigrant Creek). There are two implications for this error, both of which are shown in Figure 28. Firstly, as Manning's "n" roughness values were defined in this particular cross section, the Mannings_n attribute in the 1d_nwk layer becomes a multiplier and the resulting roughness value for this channel becomes $0.1 \times 0.07 = 0.007$, which is applicable only to excessively smooth surfaces. Secondly, referring to the figure inset, this cross section (with a width of 54 m) was also incorrectly assigned to the red 1d_nwk polyline which represented the flow path along the adjacent floodplain. The original floodplain cross section with a width of up to 350 m was overwritten, hence this led to an underestimation of the floodplain storage available for this section of the creek.

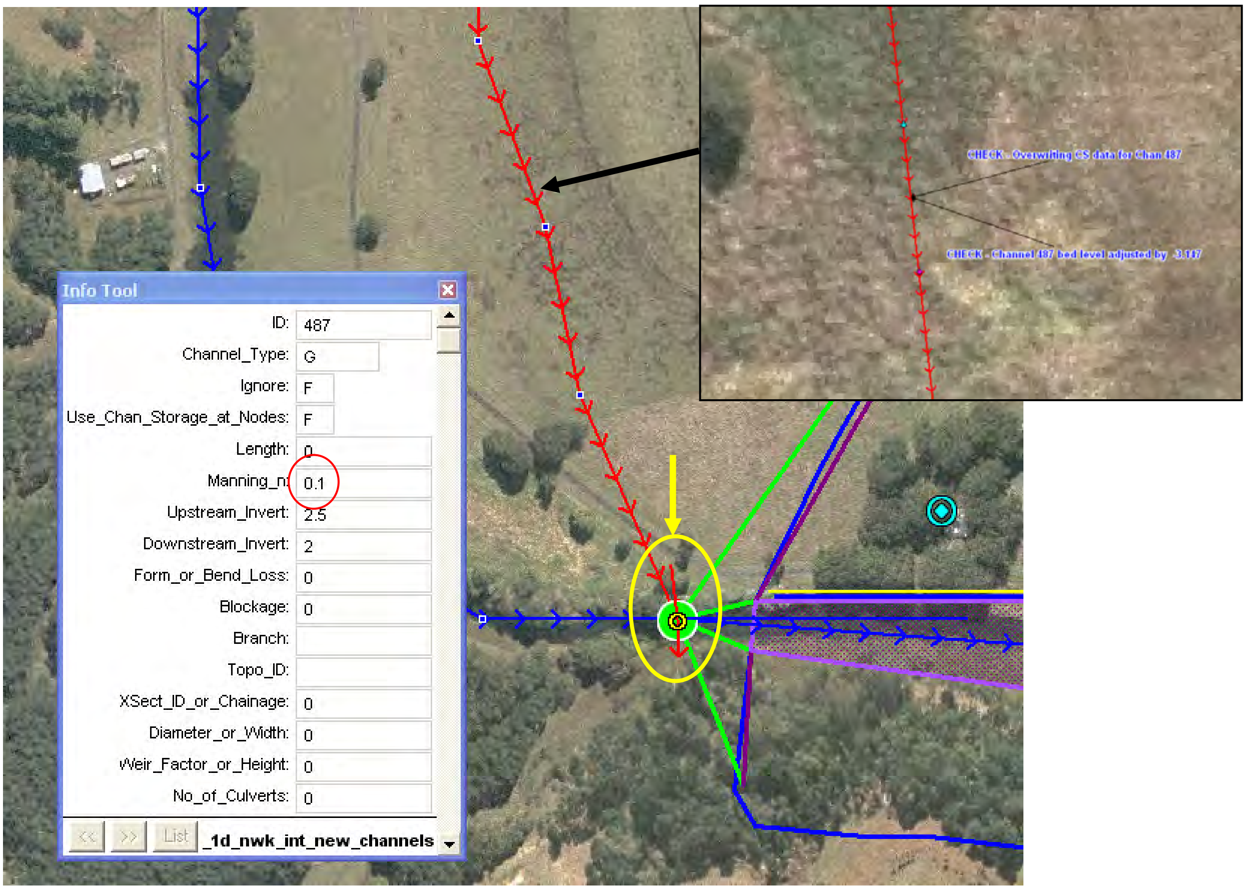

Figure 28: Schematisation error for Emigrant Creek

<u>Structures Implementation</u>

For the implementation of waterway structures, flow constrictions were applied to the relevant 2D cells whereas if a 1D channel/creek was present, a nominal loss was specified for that reach where the bridge crosses, which is common practice. As discussed in Section 3.1, it is vital that an alternative method or model be used to validate the flow constriction attributes or form losses adopted for key waterway structures in order to ensure that the losses of such structures are adequately represented and modelled so as not to underestimate the potential afflux caused upstream.

The approach undertaken in modelling the proposed bridges would also be an issue if the peak flood level is high enough to overtop the bridge deck, which may be the case for the PMF event. For such flow conditions, additional form losses must be included to account for the resistance introduced by the bridge deck. Alternatively, the use of a weir element to represent the overflow across the bridge or the layered flow constriction method available in newer versions of

TUFLOW could be employed.

Drainage structures as defined in the RTA concept design plan (Reference 6) for the proposed highway upgrade have largely been implemented in the model though several were excluded from the model for the highway stretch approaching the Duck Creek bridge (from south). The reason for this omission was not mentioned in the report (Reference 2) though it is postulated that the additional box culverts were not required as the afflux criteria has already been met for this location. Further details of included drainage structures in the modelling are provided in Appendix C. Also, the impact of blockages on the performance of these structures was not investigated (implication of this is discussed in Section 3.1).

Roughness

The Manning's "n" roughness values adopted for both the 1D and 2D model domains are generally reasonable, though for the smaller watercourses including Emigrant Ck, Duck Ck and North Ck, 0.07 was used to define the creek in-bank roughness. It is postulated that the use of this higher Manning's "n" value usually reserved for creeks with significant vegetation is warranted since the model was calibrated to replicate actual site conditions. Different roughness values were also introduced for the Pacific Highway upgrade corridor to reflect the surface change due to the construction of the highway.

Impact Assessment

When examining the flood impacts caused by the proposed works within the lower Richmond River floodplain, afflux of more than 60 mm was exhibited on the east side of the Pacific Highway based on the 20 year ARI results grids provided to WMAwater, as illustrated in Figure 29. This impact, however, was found within the project boundary (demarcated by the red polylines in the figure) and hence is not of concern.

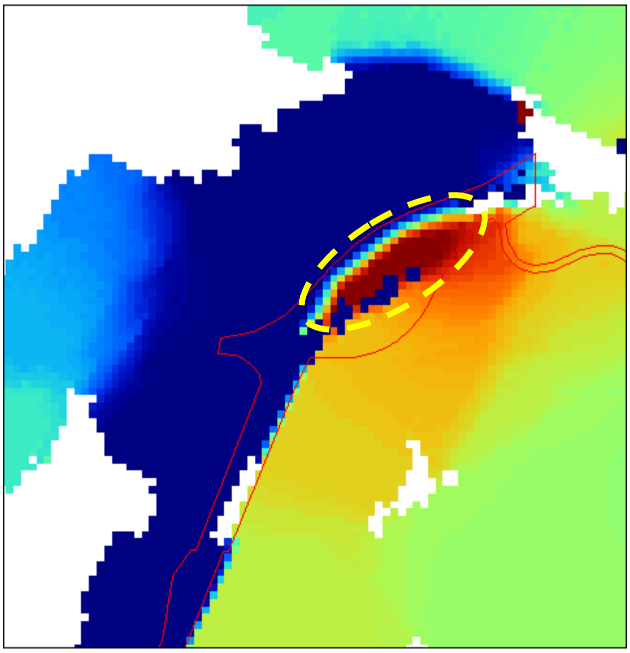

Figure 29: Impacts above 60 mm for the 20 year ARI event

4. FURTHER DISCUSSIONS

4.1. Comparison against Previous Assessments

As part of the scope of this review, WMAwater have considered the modelling and results presented in previous assessments and compared them against those currently adopted by SKM. Of particular interest are the modelling outcomes of the Richmond River catchment whereby significant refinements were made to the concept designs of the waterway crossings and drainage structures compared to those proposed in the previous development stage of the project. The hydraulic modelling for the previous assessment of the Pacific Highway Upgrade from Woodburn to Ballina (within the Richmond River catchment) was undertaken using SOBEK by Brown Consulting.

The differences in the assessment outcomes can be explained as follows:

<u>TUFLOW vs. SOBEK</u>
For the previous study, an integrated 1D/2D hydraulic model – SOBEK was developed that covered the lower Richmond River floodplain from just upstream of Coraki to the river mouth at Ballina. For the current assessment, a new 1D/2D hydraulic model – TUFLOW was developed using new and more accurate terrain data (ALS) and the model was extended to cover most of the Richmond River floodplain. Though inherent differences exist between the two hydrodynamic models, both are more than capable of solving the shallow water equations, which include a mathematical description of the physical processes thought to control the movement of flood waves in two spatial dimensions. Literature which discusses and differentiates their performance and predictive capability in flood modelling is available (i.e. Reference 10), hence this is not discussed further herein. For the assessments, a 60 m model grid size was adopted for both hydraulic models.

<u>Model Calibration</u>
While the SOBEK model was calibrated to the 1974 and 1976 flood events (of which only two flood records were used for the 1974 flood and one for the 1976 flood), the TUFLOW model was calibrated more extensively with the available flood records from recent events (i.e. 2008 and 2009 flood events). The latter model was also verified using data from the 1958 and 1974 flood events, thus providing confidence in the reliability of the model predictions. In total over 250 recorded flood levels for four flood events were used in the calibration/verification of the TUFLOW hydraulic model. As such, this model has also been adopted by Richmond Valley Council as the basis for development control across the Richmond River floodplain.

<u>Model Schematisation</u>
In addition to the new ALS data available for the development of the DEM used in the TUFLOW model, which provides a better definition of the overland flow paths, several refinements/improvements were introduced, such as implementation of bridge losses and incorporation of sub-grid-scale features like minor drains and road embankments that were not adequately represented in the SOBEK model. It was found that no provision was made to model the proposed waterway crossings in the SOBEK model (other than providing a gap in

between the abutments), i.e. potential losses due to bridge decks/piers not accounted for and no deviation in the Manning's "n" roughness implemented for the bridge section. WMAwater also consider that the representation of the proposed highway embankment in the DEM of the SOBEK model as depicted in Figure 30 resulted in poor representation of the embankment overtopping/weir flows that would occur for larger events like the 100 year ARI event. It is generally recommended that 2-3 cells be raised to adequately model weir flow over an embankment instead of only 1 cell, which was the approach used in the previous assessment.

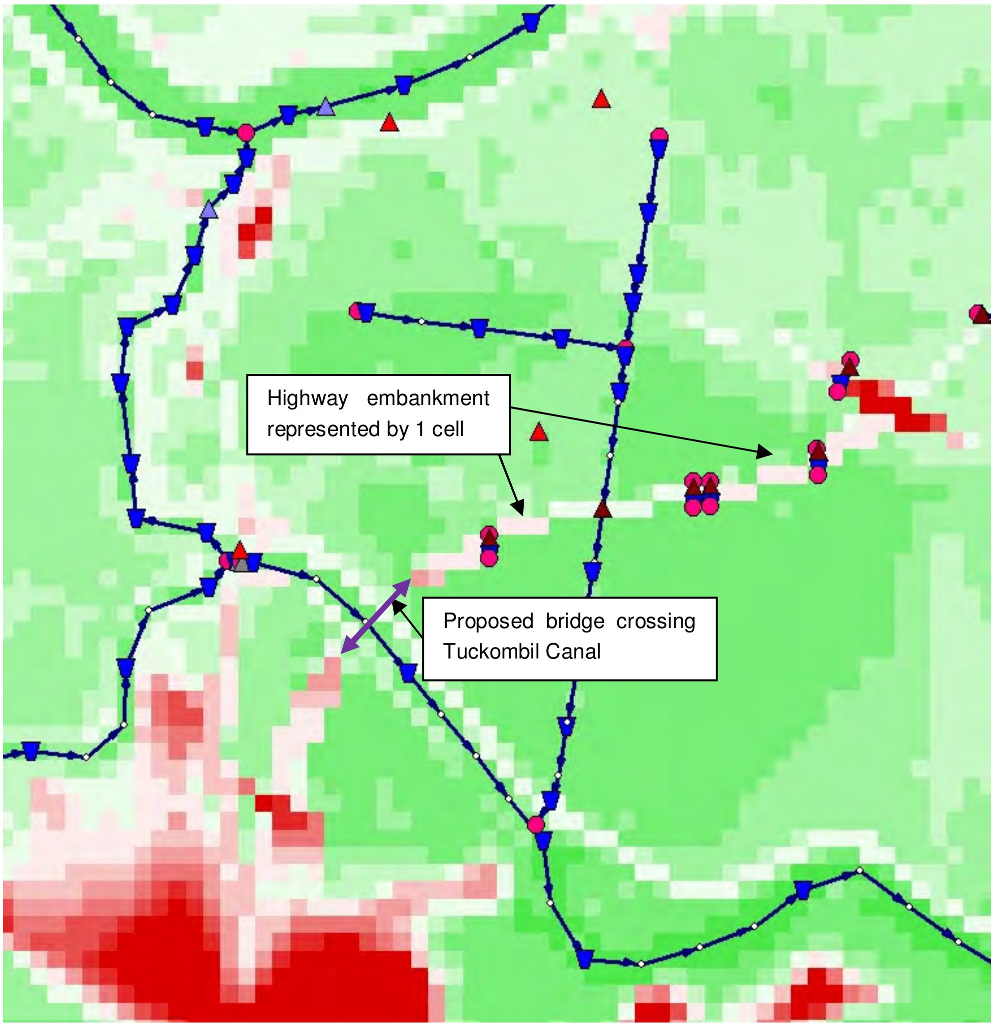

Figure 30: Representation of the proposed road embankment for the highway upgrade in SOBEK

Concept Plan Design

Since the previous study was carried out by Brown Consulting prior to 2007, the concept plan of the proposed works has undergone numerous iterations and the TUFLOW model developed for the impact assessment was subjected to rigorous review as part of the Richmond River Flood Mapping Study initiated by the Richmond River County Council (RRCC) and Richmond Valley Council (RVC). The revision and optimisation of the concept plan design have resulted in the shortening of the bridge over the Tuckombil Canal as well as the viaduct crossing the Woodburn Drain. Minor changes were also made to the other cross drainage structures located along the proposed highway corridor (details of which can be found in Reference 2). The latest design iteration has resulted in impacts that are less than 50 mm for the assessed flood events, thus satisfying the flood impact objectives imposed for the project even with the reduced openings.

WMAwater postulate that reducing the bridge span over the southern floodplains of Tuckombil Canal in the SOBEK model would have minimal impact on the afflux in the floodplain as the model predicted that this floodplain (bounded by the existing Pacific Highway and Tuckombil Canal, indicated by the yellow arrow in Figure 31) will be filled by backwater from downstream of the Canal/proposed highway embankment. This was replaced by 2 box culverts in the TUFLOW model which serve largely to accommodate the backwater flow and to utilise the available storage at the location.

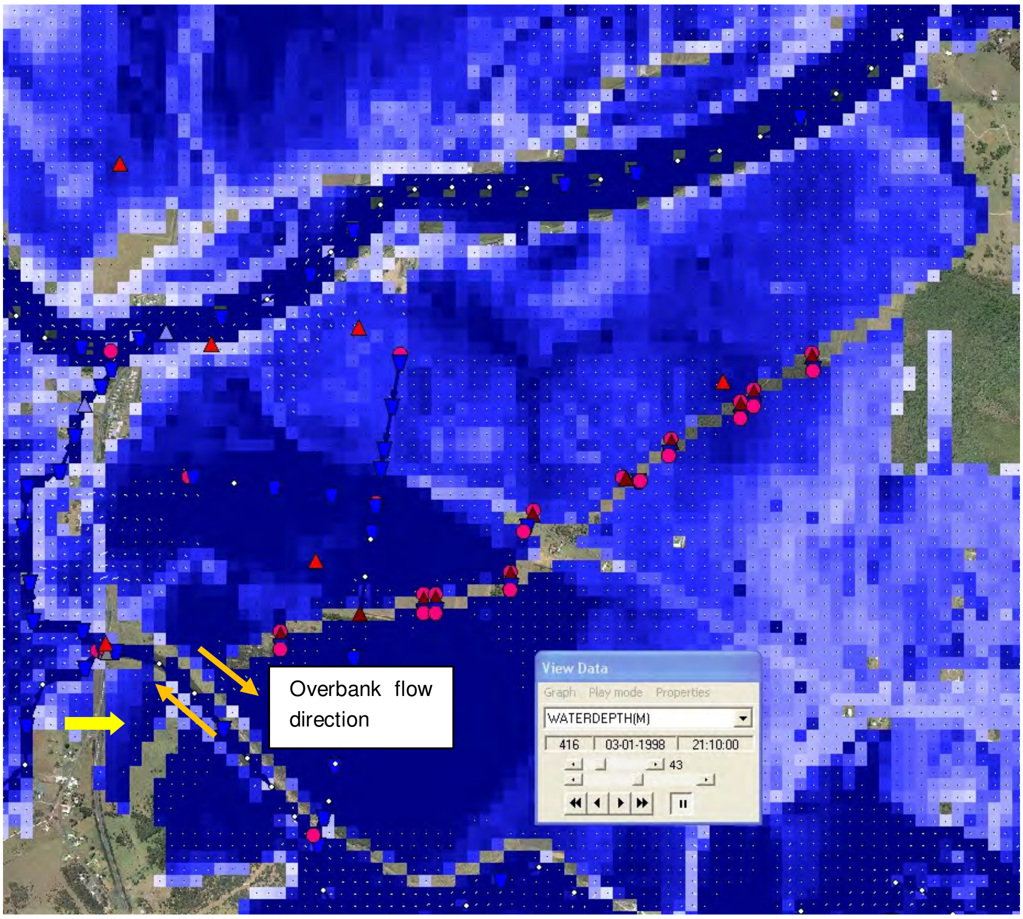

Figure 31: SOBEK model results for the Richmond River floodplain near Woodburn/Tuckombil Canal

<u>Summary</u>

Overall, it is WMAwater's conclusion that the design changes of the waterway crossings are warranted with the significant refinement of the hydraulic model and the availability of new calibration and terrain data. Deficiencies found in the SOBEK model developed as part of the previous assessment further reinforce the need for a better model that is capable of representing the key features of the proposed works and provide more reliable predictions of the flood behaviour. Many of these deficiencies have been addressed in the more recent TUFLOW model.

4.2. Feasibility of Drainage Structures

Besides sizing the drainage structures to meet the impact objectives established for the floodplain, it is of WMAwater's view that adequate consideration should also be given to the feasibility of constructing and maintaining such structures on site and whether alternative structures would be more appropriate. A case in point is the cross drainage structures proposed for the Pacific Highway stretch from Harwood to Chatsworth, located within the Clarence River catchment. The dimensions of these structures are indicated in Figure 32. The majority of the box culverts proposed are of the nominal standard sizes with the exception of the 3.0 m × 0.45 m box culverts (circled in red) which come in sets of >30. This design would pose significant maintenance and construction issues and it is worth investigating alternative options like constructing multiple plank bridges, opting for deeper/larger culvert cross sections and raising the road, for example, across those sections of the highway upgrade. The ease of construction and carrying out structure maintenance are certainly important factors that should be regarded during the design stages of the proposed works. Proper maintenance of the drainage structures will allow the structures to achieve their intended objectives in terms of meeting the flood criteria. It is also important to note that bridge structures are more efficient drainage structures than culverts and opting for these structures may significantly alter the afflux on either side of the embankment.

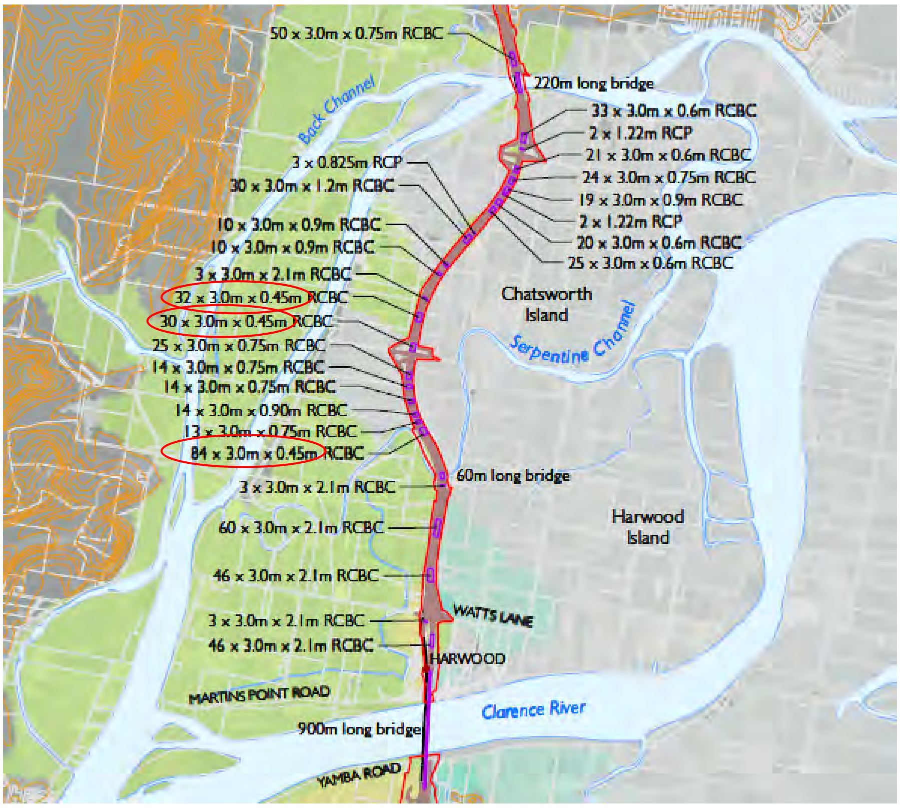

Figure 32: Works proposed as part of the Pacific Highway Upgrade at Chatsworth/Harwood Island (adopted from Reference 2)

4.3. Community Engagement

As part of the community engagement process, WMAwater were present in the Flood Focus Group meetings at Wardell and Harwood. The focus groups address the importance of investigating the flood impact reduction measures while the highway upgrade is being designed to ensure properties and the environment in the floodplains are protected when the proposed works are built. In reviewing the flood modelling for the proposed upgrade, WMAwater considered the key issues/concerns raised by the local community and landholders during the meetings and this is discussed further herein.

<u>Concerns raised by the Richmond River/Wardell FFG</u>

1. Sizing of the proposed bridges and culverts for the highway section crossing Tuckombil Canal/Evans River floodplain.
   - Since the previous assessment, the sizing of the drainage structures has been optimised using the refined hydraulic models while ensuring the established flood impact objectives are met.
   - The latest TUFLOW hydraulic model adopted for the Richmond River floodplain has been calibrated and validated using several historical flood events, thus providing a certain degree of confidence in the predicted results when conducting the design event modelling. This is discussed in Section 3.2.13.1.
   - Deficiencies were found in the SOBEK hydraulic model used in previous assessments as reported in Section 4.1, thus results obtained from this model were not reliable.
   - The rate of flood level rise and the flood inundation duration will not change significantly, as documented in Reference 2.

2. Provision of culverts to provide drainage for catchments upstream of the proposed highway embankment near Lumleys Lane.
   - The drainage structures for this part of the catchment have not been specifically modelled in either the Richmond River model or the Ballina Bypass model. It is understood that these culverts have been designed using alternative methods or models like DRAINS to convey flows from upstream local catchments, with consideration of the potential afflux generated up and downstream of the embankment.

3. Provision of drainage structures at Wardell Interchange and for Saltwater Creek/Randles Creek.
   - Similar to the previous point, the drainage structures for this part of the catchment have not been specifically modelled in either the Richmond River model or the Ballina Bypass model but designed using alternative methods or models.

4. Maintenance of drainage structures, management of debris in particular waste from the cane farms as well as blockage of rope safety fences.
   - Consideration of blockages of the drainage structures is one major aspect highlighted by WMAwater (as discussed in Section 3.1) and the sensitivity of the peak flood levels to the blockages of such structures warrants further investigation. Providing an allowance for a blockage factor, depending on the size of the drainage structures, would address

this concern.

- The maintenance of these structures is the responsibility of RMS and would ensure that the structures achieve the objectives in terms of flood criteria.

5. Concerns regarding the flood modelling, such as the scenarios adopted and meeting the afflux criteria.
   - The modelling approach adopted and the design scenarios considered are deemed appropriate and sufficient for the assessment herein.
   - Development of the proposed highway concept design to meet the afflux criteria is the major objective of the assessment and has been examined in detail throughout the course of this review.

6. Access/egress during flood events for residents, SES etc.
   - The primary aim of the flood modelling exercise conducted is to minimise changes to existing flood behaviour, hence changes to flood evacuation routes/access should be minimal.
   - Upgrading the highway to achieve higher flood immunity will ensure that flood access is substantially improved compared to existing conditions.

7. Assessment of sea level rise and rainfall intensity increase due to climate change.
   - Modelling of the major river floodplains has incorporated climate change scenarios including sea level rise and rainfall intensity increase, and their impacts on the flood immunity of the proposed highway upgrade have been examined as part of the flood assessment.

Concerns raised by the Clarence River/Harwood FFG

1. Changes to flooding behaviour in the Shark Creek Basin due to the proposed works.
   - Both mainstream flooding (due to Clarence River) and local catchment flooding have been modelled in all scenarios.
   - Any changes to the flood behaviour resulting from the proposed works will be examined and reported as part of the Environmental Assessment, though the flood impacts have been found to be acceptable and within the afflux criteria.
   - Bridges and culverts on the Shark Creek floodplain have been sized to allow water backflow into/exit from the Basin during different times of the flood event.

2. Impacts to the cane drainage network in the Shark Creek Basin.
   - Culverts to connect the cane drains located on both sides of the road embankment were implemented in the Clarence River model, hence the existing drainage pathways are still maintained.
   - Other cross drainage structures were omitted from the model as the actual design of these structures is still underway. Nevertheless, it is endeavoured to preserve the connectivity of the cane drains as well as other microsystems located on the proposed highway route.

3. Sizing of the proposed bridges and culverts for the highway section crossing Coldstream River.
    - Flood impacts determined for the current concept design have not met the afflux criteria thus extension of the proposed bridge structures or inclusion of additional drainage structure may be needed if the costs could be justified, as discussed in Section 3.2.4.3.

4. Potential increases to peak flood levels in Maclean with the increase risk of overtopping of the levee.
    - Flood immunity of Maclean levee will be marginally reduced, with overtopping of the levee predicted to occur in a 1 in 35 year flood once the proposed works are in placed compared to 1 in 36 year flood for existing conditions. The annual risk of overtopping increases by just 0.1%.

5. Maintenance of drainage structures, management of debris in particular waste from the cane farms.
    - Consideration of blockages of the drainage structures is one major aspect highlighted by WMAwater (as discussed in Section 3.1) and the sensitivity of the peak flood levels to the blockages of such structures warrants further investigation. Providing an allowance for a blockage factor, depending on the size of the drainage structures, would address this concern.
    - The maintenance of these structures is the responsibility of RMS and would ensure that the structures achieve the objectives in terms of flood criteria.

6. Flood assessment of frequent, smaller flood events.
    - For the Clarence River catchment, the assessment has been carried out for the 1 in 20 year flood to determine the appropriate height of the road embankment while the 1 in 100 year flood was used to determine the effects of large flood and define flood-liable land.
    - Smaller flood events should result in smaller impacts for the catchment.

7. Concerns regarding the flood modelling such as the data used.
    - The modelling approach adopted, the design scenarios considered and the input data used are deemed appropriate and sufficient for the assessment herein. The model has used best available data and once better data become available in the future, these should be incorporated into the model.
    - As discussed in Section 3.2.8.3, the hydrosurvey data may require an update to reflect changes in the geometry of the river over the years.

8. Access/egress during flood events for residents, SES etc.
    - The primary aim of the flood modelling exercise conducted is to minimize changes to existing flood behaviour, hence changes to flood evacuation routes/access should be minimal.
    - Upgrading the highway to achieve higher flood immunity will ensure that flood access is substantially improved compared to existing conditions.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

The independent review conducted herein has been comprehensive but not necessarily exhaustive, with the focus primarily on the implementation and modelling of the cross drainage structures and major waterway crossings which have significant influence on the associated flood impacts of the proposed works. All models have been critically reviewed and several issues pertaining to the modelling approach undertaken were identified, most of which have minor implications to the final model results but need to be addressed at the project detailed design stage. Discussions of these issues are provided in Section 3.

Despite concerns raised by the community, optimisation or refinements made to the concept design of the waterway crossings since the previous assessments appear to be warranted owing to the significant revision of the hydraulic model and the availability of new calibration and terrain data. This is reinforced by the fact that deficiencies were found in the models developed for the previous assessments and the recent models were refined to address some of these shortcomings.

Overall, it is WMAwater's conclusion that the flood modelling undertaken by SKM for the proposed upgrade of the Pacific Highway from Woolgoolga to Ballina only requires minor revision, with the recommendations outlined in the following section. It is likely that there will be minimal changes to the estimated design flood levels, particularly in the vicinity of the proposed highway corridor for the assessed flood events. Based on the findings of this review and the outcomes of the community engagement process, WMAwater is confident that the Alliance is in a position to deliver the flood assessment working paper for the coming review.

5.2. Recommendations

The actions identified below are required to provide a more reliable assessment of the flood issues for the proposed works and to ensure that the impact objectives are adequately met:

- To validate the flows and energy losses introduced by bridges and other major drainage structures that constrict flows using alternative method/model such as HEC-RAS;
- To consider the impact of blockages on the performance of the highway cross drainage structures;
- To review sub-catchment delineation at locations where the raised highway embankment serves as a control feature that attenuates flows resulting in upstream afflux; and
- To correct minor schematisation errors and to regenerate model results.

For the subsequent detailed design and construction stages, WMAwater recommend that the DEM for the hydraulic models be further refined or multiple refined model domains be established for critical areas like the proposed highway upgrade development corridor, so as to facilitate detailed analysis of the flows and velocities in the vicinity and to provide more accurate assessment of the resulting afflux.

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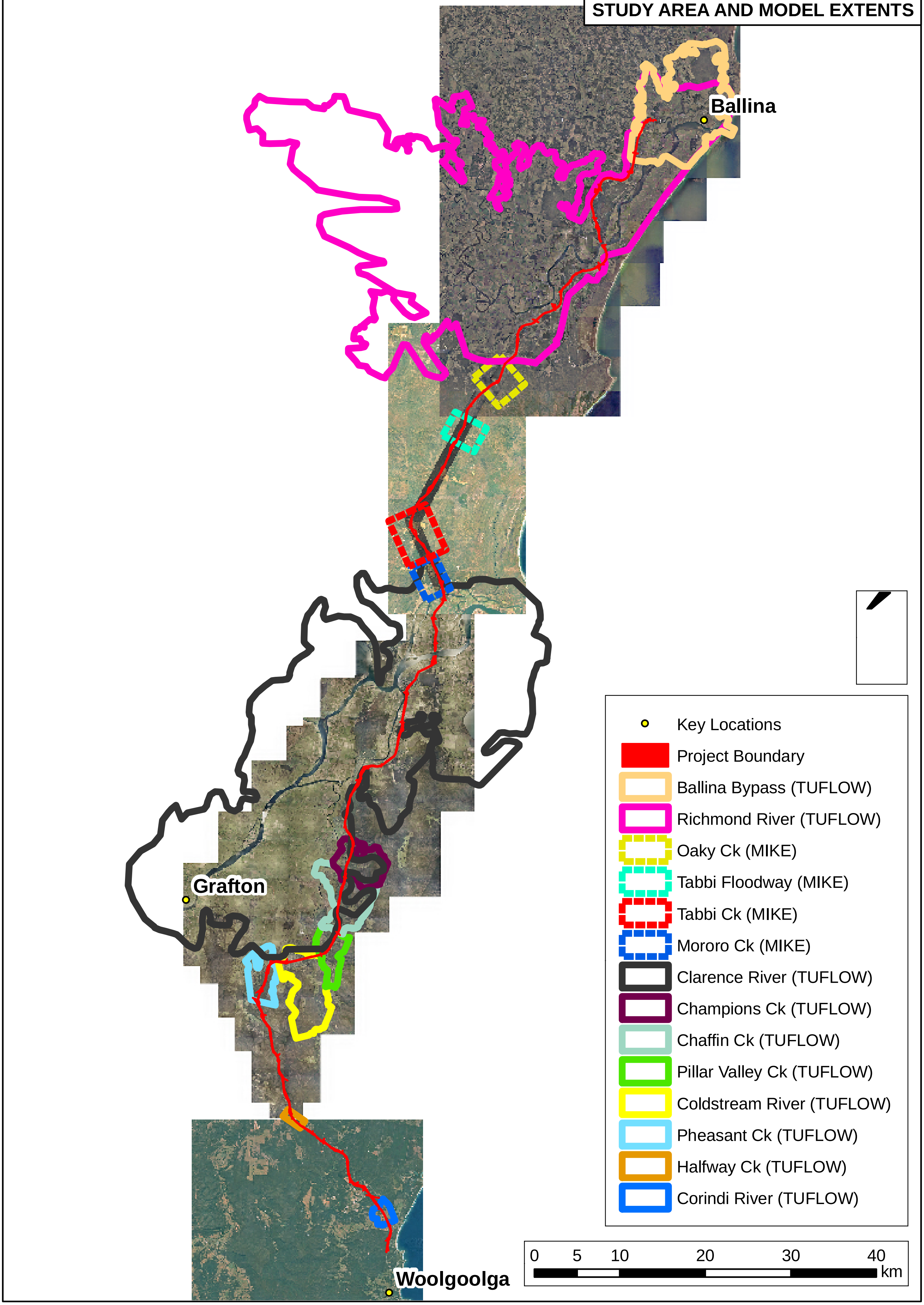
Figures

FIGURE A1

STUDY AREA AND MODEL EXTENTS



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Appendix A

Glossary

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils — Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.

Annual Exceedance Probability (AEP) — The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).

Australian Height Datum (AHD) — A common national surface level datum approximately corresponding to mean sea level.

Average Annual Damage (AAD) — Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.

Average Recurrence Interval (ARI) — The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.

caravan and moveable home parks — Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.

catchment — The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.

consent authority — The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.

development — Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).

infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.

new development: refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas The remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and 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)	FPLs are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood

storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.

freeboard Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.

habitable room **in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.

in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.

hazard A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.

hydraulics Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

- major overland flow paths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

mathematical/computer models

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

merit approach

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

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

minor, moderate and major flooding

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

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

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

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

modification measures

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

peak discharge

The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF)

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

Probable Maximum Precipitation (PMP)

The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends

	(World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to water level. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Summary of Models

Appendix B

Catchment/Model Name	Ballina Bypass (Northmost)	Richmond River	Oaky Creek	Tabbimoble Floodway 1	Tabbimoble Creek	Mororo Creek
Model Extent	Lower Richmond River floodplains (Broadwater to Ballina)	Upper and lower Richmond River floodplains (Upper: Woodburn to Broadwater; Lower: Broadwater to Ballina - superseded by Ballina Bypass model)	Oaky Creek denoted 'North' or 'NTH'	Tabbimoble Floodway denoted 'TF1'	Tabbimoble Creek denoted 'TabVK'	Mororo Creek denoted 'South' or 'STH'
Model Origin/Progression	XP-RAFTS, ESTRY - tidal hydraulic model - Broadwater to Ocean (WBM 1996) 2D TUFLOW model developed by WBM for Ballina Bypass Project nested within 1D model of local creeks and channel extending from Broadwater to ocean (WBM 2002-2009) - adopted by SKM	XP-RAFTS + MIKE-11 (WBM 1999) - not used by SKM Inflows from WBM (1999) + SOBEK (RTA 2007) - developed by Brown - calibrated to 1974, 1976 events - not used by SKM TUFLOW developed by WBM (2010) for Richmond Valley Council and Richmond River County Council - calibrated to 2009, 2008 event, verified by 1974, 1958 events - adopted by SKM	XP-RAFTS and MIKE FLOOD developed by RTA as part of Iluka Road to Woodburn Pacific Hwy upgrade (Connell Wagner, 2009) - adopted by SKM			
Models Provided for Review	TUFLOW - SKM (current) - version 2007-07-BF XP-RAFTS not provided old models N/A	TUFLOW - SKM (current) - version 2009-07-AF-iSP WBNM output files provided old SOBEK model provided	MIKE FLOOD XP-RAFTS not provided	MIKE FLOOD XP-RAFTS not provided	MIKE FLOOD XP-RAFTS not provided	MIKE FLOOD XP-RAFTS not provided
Pacific Hwy Section Covered	10 to 11, Ballina Bypass	8 to 11	7	7	6	5, 6
DEM/Raw ALS Data Used	2.5m	5m 1m for Tuckombil Canal/Evans Head area superseding base DEM	1m	1m	1m	1m
Adopted Hydrological Model Design Loss Model Sub-Catchments	TUFLOW RF (Local), XP-RAFTS and FFA (U/S) 25mm IL, 2.5mm/hr CL 80 Local (B - 6; A - 74) + 6 Cross Boundary Flows	WBNM 20mm IL, 2mm/hr CL 84 Local (Upper - 1; Lower Richmond - 47; Bungawalbin - 4; Mid Richmond - 29; Wilsons - 3) + 19 Cross Boundary Flows	XP-RAFTS unknown 9 Local + 4 Cross Boundary Flows	XP-RAFTS unknown 9 Local + 3 Cross Boundary Flows	XP-RAFTS unknown 21 Local + 2 Cross Boundary Flows	XP-RAFTS unknown 12 Local
Adopted Hydraulic Model	TUFLOW (extent overlaps with Richmond River model)	TUFLOW	MIKE FLOOD	MIKE FLOOD	MIKE FLOOD	MIKE FLOOD
Grid	A: 40m; B: 10m (Bypass)	60m	5m	5m	5m	5m
Domain	Multiple 2D Domains: A (14320m x 19520m); B (5120m x 6200m)	56310m x 44400m	4400m x 4000m	4050m x 3090m	4700m x 5800m	3100m x 4100m
Time Step for Design Runs	2D: A: 10s (Main Domain); B: 5s (Bypass); 1D: 1s	2D: 10s; 1D: 2s	2D: 1s; 1D: 1s	2D: 1s; 1D: 1s	2D: 1s; 1D: 1s	2D: 1s; 1D: 1s
Setup/Build	1D/2D, nested domain for Ballina Bypass	1D/2D	2D and 1D for drainage structures	2D and 1D for drainage structures	2D and 1D for drainage structures	2D and 1D for drainage structures
Manning's 'n'	defined and reasonable	defined and reasonable	defined and reasonable	defined and reasonable	defined and reasonable	defined and reasonable
Calibration Events	unknown	1954, 1974, 2008, 2009 (calibration results N/A)	no calibration events	no calibration events	no calibration events	no calibration events
Design Events	20y, 100y	20y, 50y, 100y (not run: 500y, PMF)	100y	100y	100y	20y, 100y
Design Storm Duration	72hr (critical for Richmond), 12hr (critical for local)	48hr (only for 20y), 72hr (ALL events - probably critical for lower floodplains/Hwy)	120, 180, 270min	270, 360, 540min	360min	60, 90, 120, 180min
Climate Change Assessment	yes (sea level rise)	yes (rainfall, sea level rise)	unknown	unknown	unknown	unknown
Model Log File provided	yes, but not complete	no	no	no	no	no
Model Build	yes	yes	yes	yes	yes	yes
Check Files	1D - yes, 2D - yes	1D - yes, 2D - yes	N/A	N/A	N/A	N/A
Results Files	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - Yes except for 'existing' results	1D - yes, 2D - yes	1D - yes, 2D - yes

Catchment/Model Name	Clarence River	Coldstream River LCM5	LCM4	LCM3	LCM2	LCM1
Model Extent	Clarence River (floodplain areas include Shark Creek, Chatsworth/Harwood Islands)	5 Local Catchment Models (LCM1, LCM2, LCM3, LCM4, LCM5) - all flow into the Clarence River floodplain Champions Ck and nearby creeks	Chaffin Ck and nearby creeks	Pillar Valley Ck	Coldstream River	Pheasant Ck
Model Origin/Progression	TUFLOW model developed for Clarence River County Council by WBM (2004) Model further refined for the Hwy upgrade studies - adopted by SKM	WBNM, TUFLOW developed for the RTA in previous flood assessments for the Wells Crossing to Iluka Road Pacific Hwy upgrade concept design (RTA 2008) - adopted by SKM				
Models Provided for Review	TUFLOW - SKM (current) - version 2007-07-DB no hydrologic model provided old WBM TUFLOW model provided	TUFLOW - SKM (current) WBNM model and output files provided old RTA TUFLOW models provided	TUFLOW - SKM (current) WBNM model and output files provided old RTA TUFLOW models provided	TUFLOW - SKM (current) WBNM model and output files provided old RTA TUFLOW models provided	TUFLOW - SKM (current) WBNM model and output files provided old RTA TUFLOW models provided	TUFLOW - SKM (current) WBNM model and output files provided old RTA TUFLOW models provided
Pacific Hwy Section Covered	3 to 5	3	3	3	3	3
DEM/Raw ALS Data Used	25m used in original calibration	Model log mentioned 5m DEM used but where gaps exist the 20m DEM or older DEM was used instead				
<u>Adopted Hydrological Model</u> Design Loss Model Sub-Catchments	Cordery-Webb, Unit-Hydrograph and FFA 30mm IL, 2mm/hr CL (WBM, 2004) 8 Local + 8 Cross Boundary Flows	WBNM 0mm IL, 2mm/hr CL 12 Local + 2 Cross Boundary Flows	WBNM 0mm IL, 2mm/hr CL 24 Local + 5 Cross Boundary Flows	WBNM 0mm IL, 2mm/hr CL 19 Local + 4 Cross Boundary Flows	WBNM 0mm IL, 2mm/hr CL 13 Local + 5 Cross Boundary Flows	WBNM 0mm IL, 2mm/hr CL 13 Local
<u>Adopted Hydraulic Model</u>	TUFLOW	TUFLOW (extent overlaps with Clarence model)	TUFLOW (extent overlaps with Clarence model)	TUFLOW (extent overlaps with Clarence model)	TUFLOW (extent overlaps with Clarence model)	TUFLOW (extent overlaps with Clarence model)
Grid	Clarence River: 60m; Shark Creek + Chatsworth Island: 20m	10m	10m	10m	10m	10m
Domain	Multiple 2D Domains: Clarence River (58700m x 28800m); Shark Creek (6000m x 7800m); Chatsworth Island (7600m x 7600m)	6500m x 9000m	8480m x 9600m	7390m x 5770m	5940m x 10540m	13870m x 7700m
Time Step for Design Runs	2D: Main Domain: 20s; Clarence River: 18s; Shark Creek + Chatsworth Island: 6s; 1D: 3s	2D/1D: 5s	2D/1D: 5s	2D/1D: 5s	2D/1D: 5s	2D/1D: 5s
Setup/Build	2D, with refinements in critical areas, i.e. <u>Chatsworth and Harwood Islands, Shark Creek Basin</u> using 20m x 20m grid; <u>Serpentine Channel and Shark Creek</u> using 1D elements	2D and 1D for drainage structures	2D and 1D for drainage structures	2D and 1D for drainage structures	2D and 1D for drainage structures	2D and 1D for drainage structures
Manning's 'n'	defined and reasonable	defined and reasonable	defined and reasonable	defined and reasonable	defined and reasonable	defined and reasonable
Calibration Events Design Events Design Storm Duration	1980, 1996, 2001 (calibration for refined model, results N/A) 20y, 50y, 100y 160hr - ALL events (240hr for later runs)	no calibration events 5y (old runs), 20y (old runs), 100y 2hr, old runs - 3hr	no calibration events 5y (old runs), 20y (old runs), 100y 2hr, old runs - 3hr	no calibration events 5y (old runs), 20y (old runs), 100y 2hr, old runs - 1hr, 3hr, 9 hr	no calibration events 5y (old runs), 20y (old runs), 100y 9hr, old runs - 2hr	no calibration events 5y (old runs), 20y (old runs), 100y 2hr, old runs - 9hr
Climate Change Assessment	yes (rainfall, sea level rise for 20y event)	yes (rainfall, discharge)	yes (rainfall, discharge)	yes (rainfall, discharge)	yes (rainfall, discharge)	yes (rainfall, discharge)
Model Log File provided	yes, complete	yes, complete (for all LCMs)				
Model Build	yes	yes	yes	yes	yes	yes
Check Files	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes
Results Files	1D - yes (20y only), 2D - yes (20y only)	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes	1D - yes, 2D - yes

Catchment/Model Name	**Halfway Ck**	**Corindi River (Southmost)**
Model Extent	Halfway Creek	Corindi River (includes Blackadder Ck and Cassons Ck)
Model Origin/Progression	XP-RAFTS developed for RTA as part of previous flood assessments of proposed upgrade (RTA 2007) TUFLOW developed for current assessment - adopted by SKM	XP-RAFTS, TUFLOW developed for RTA as part of previous flood assessment undertaken for Woolgoolga to Wells Crossing Pacific Hwy concept design (RTA 2007) - adopted and redone by SKM with improvements (previously built by GHD)
Models Provided for Review	TUFLOW - SKM (current) XP-RAFTS not provided old HEC-RAS? N/A	TUFLOW - SKM (current) XP-RAFTS output files provided old GHD TUFLOW models provided
Pacific Hwy Section Covered	2	1
DEM/Raw ALS Data Used	2m grid based on 1m contour	unknown
Adopted Hydrological Model	XP-RAFTS?	XP-RAFTS
Design Loss Model	unknown	unknown
Sub-Catchments	1 Upstream Inflow	8 Local + 1 Upstream Inflow
Adopted Hydraulic Model	TUFLOW	TUFLOW
Grid	2m	5m
Domain	2400m x 1000m	2800m x 3000m
Time Step for Design Runs	2D: 0.5s; 1D: 0.1s	2D: 1s; 1D: 0.5s
Setup/Build	2D (one 1D culvert)	2D (with 1D elements)
Manning's 'n'	default value at 0.04 (slightly high) otherwise fine	defined and reasonable
Calibration Events	no calibration events	no calibration events
Design Events	100y only	100y (not run: 2000y, PMF)
Design Storm Duration	not known, <4hr	6h, existing runs - 4.5hr, 9hr, 12hr, more durations for old runs
Climate Change Assessment	unknown	unknown
Model Log File provided	no	no
Model Build	yes	yes
Check Files	1D - yes, 2D - yes	1D - yes, 2D - yes
Results Files	1D - yes, 2D - yes	1D - yes, 2D - yes

Drainage Structures/Waterway Crossings Inventory

Appendix C

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
0		Start of Section One			
320	9x2400x900	Box Culvert			* not modelled
1660	3x2500x1200	Box Culvert			* not modelled
1860	2400x1200	Box Culvert			* not modelled
1980	2500x1200	Box Culvert			* not modelled
2100	3x3000x2400	Box Culvert			* not modelled
2820	3000x2700	Box Culvert/Fauna Crossing			* not modelled
3160	2x900	RCP			* not modelled
3547.75	90500	6 span (15000 each)	2m approx.	Report	* modelled as 85m bridge - Corindi River bridge (Corindi model)
3880	5x2700x1200	Box Culvert		Report	* modelled 6x2700x1200 instead (Corindi model)
3999.75	300500	20 span (15000 each)	2-3m	Report	* modelled as 290m bridge (Corindi model)
4360	6x2700x1200	Box Culvert		Report	* modelled 3x2700x1200 instead (Corindi model)
4710	8x2700x1200	Box Culvert		Report	* modelled as 55m bridge, 2x3000x900, 5x3000x900, 5x3000x900 box culverts instead (Corindi model)
5660	2400x1200	Box Culvert (Corrindi Access Track)			* not modelled
5660	2x2400x900	Box Culvert (main rd)			* not modelled
6131.20	76600	4 span (16000-22000-22000-16000)	7m		* not modelled
6220	3000x900	Box Culvert (Corrindi Access Track)			* not modelled
6650	2x2400x1500	Box Culvert			* not modelled
6700	3000x900	Box Culvert (Corrindi Access Track)			* not modelled
6780	3000x3000	Box Culvert/Fauna Crossing			* not modelled
8480	2x1200x900	Box Culvert			* not modelled
8510	3000x3000	Box Culvert/Fauna Crossing			* not modelled
8580	2x900x600	Box Culvert			* not modelled
8700	2x900x600	Box Culvert			* not modelled
8920	2x900x600	Box Culvert			* not modelled
8974.80	31500	3 span (8000-15000-8000)	6-2m		* not modelled
9560	1x750	RCP			* not modelled
10080	3000x2400	Box Culvert/Fauna Crossing			* not modelled
10100	3000x2400	Box Culvert/Fauna Crossing			* not modelled
10340	2x2100x900	Box Culvert			* not modelled
10750	2x3000x3000	Box Culvert/Fauna Crossing			* not modelled
11500	3x600	RCP			* not modelled
11770	2x600	RCP			* not modelled
11780	3000x3000	Box Culvert/Fauna Crossing			* not modelled
11890	1x600	RCP			* not modelled
12320	3000x3000	Box Culvert/Fauna Crossing			* not modelled
12880	3000x3000	Box Culvert/Fauna Crossing			* not modelled
13310	2x3000x3000	Box Culvert/Fauna Crossing			* not modelled
13840	3000x3000	Box Culvert/Fauna Crossing			* not modelled
14050	2x1350	RCP/Fauna Crossing			* not modelled
14180	1x750	RCP			* not modelled
14290	2x600	RCP			* not modelled
14600		End of Section One			
17000		Start of Section Two			
17710	1x600	RCP (Lemon Tree Rd?)			* not modelled
17720	1x600	RCP (main rd)			* not modelled
18090	3x1200x1800	Box Culvert (main rd)			* not modelled
18100	3x2400x900	Box Culvert (Lemon Tree Rd?)			* not modelled
18780	3x2400x900	Box Culvert			* not modelled
19180	3000x2400	Box Culvert/Fauna Crossing			* not modelled
19670	2x3000x2400	Box Culvert/Fauna Crossing			* not modelled
19880	2x450	RCP			* not modelled
20070	2x450	RCP			* not modelled
20650	4x3000x2400	Box Culvert/Fauna Crossing			* modelled slightly larger box culverts (Halfway Ck model)
20710.75	60500 NB, 45500 SB	4 span NB (15000 each) 3 span SB (15000 each)	2m approx.		* modelled as twin 30-35m bridges - Halfway Ck bridges (Halfway Ck model)
20880	3000x2400	Box Culvert/Fauna Crossing			* not modelled
21290	3000x3000	Box Culvert/Fauna Crossing			* not modelled
22369.75	60500	4 span (15000 each)	2m approx.		* not modelled
22810	1x1500	RCP			* not modelled
23130	3000x1800	Box Culvert/Fauna Crossing			* not modelled
23740	3000x1800	Box Culvert/Fauna Crossing			* not modelled
24570	3000x1800	Box Culvert/Fauna Crossing			* not modelled
24650	3000x1800	Box Culvert/Fauna Crossing			* not modelled
25530	2x750	RCP			* not modelled
25960	1x600	RCP			* not modelled
26390	1x900	RCP			* not modelled

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
27420	3600x2400	Box Culvert/Fauna Crossing			* not modelled
29360	TBA	Fauna Crossing - Glenugie Extension			* not modelled
29840	TBA	Fauna Crossing - Glenugie Extension			* not modelled
30180	TBA	Fauna Crossing - Glenugie Extension			* not modelled
30800	TBA	Fauna Crossing - Glenugie Extension			* not modelled
31600		End of Section Two			
33800		Start of Section Three			
35200	2x2400x2400	Box Culvert/Fauna Crossing			* not modelled
36050	6x2400x1800	Box Culvert/Fauna Crossing		?Report	* modelled (LCM1 model)
36394.75	75500	4 span (15000 each)	2m approx.	Report	* modelled as 55m bridge - Pheasant Ck bridge (LCM1 model)
37100	2x1200	RCP			* not modelled
37320	2x2400x2400	Box Culvert/Fauna Crossing			* not modelled
37600	1x750	RCP			* not modelled
37810	4x600	RCP			* not modelled
38070	2x600	RCP			* not modelled
38520	2x600	RCP			* not modelled
38530	2x600	RCP (on west side-rd?)			* not modelled
39080	2x900	RCP			* not modelled
39110	2x900	RCP (on west side-rd?)			* not modelled
39660	11x3000x1200	Box Culvert/Fauna Crossing			* not modelled
39690	11x3000x1200	Box Culvert/Fauna Crossing (on east side - rd?)			* not modelled
40200	4x750	RCP			* not modelled
41600	2x900	RCP			* not modelled
42594.75	135500	9 span (15000 each)	2m approx.	Report	* modelled as 120m bridge - Coldstream River trib bridge (LCM2 model)
43174.75	315500	21 span (15000 each)	4-5m	Report	* modelled as 300m bridge - Coldstream River bridge (LCM2 model)
43959.75	180500	12 span (15000 each)	4m approx.	Report	* modelled as 160m bridge - unnamed creek bridge (LCM2 model)
46127.20	100600	4 span (25000)	4m approx.	Report	* modelled as 80m bridge - Pillar Valley Ck anabranch bridge (LCM3 model)
46397.20	100600	4 span (25000)	4m approx.	Report	* modelled as 90m bridge - Pillar Valley Ck bridge (LCM3 model)
46735.00				MISSING	* modelled as 50m bridge - Pillar Valley Ck trib 1 bridge (LCM3 model)
47070	4x3000x1500	Box Culvert		Report	* modelled (LCM3 model)
47714.75	75500	5 span (15000 each)		Report	* modelled as 60m bridge - Pillar Valley Ck trib 3 bridge (LCM3 model)
47880	3x1200x1200	Box Culvert	4m	Report	* modelled (LCM3 model)
48800	3x900	RCP			* not modelled
48815.33	35500	3 span (10000-15000-10000)	4.6m min		* not modelled
49318.00	120000	8 span (15000 each)	3.5-4m	Report	* modelled as 80m bridge - unnamed creek bridge (LCM4 model)
49500	6x3600x1500	Box Culvert/Fauna Crossing		Report	* modelled (LCM4 model)
50150	2x1200	RCP			* not modelled
50352.13	45000	3 span (15000 each)	5m	Report	* modelled as 25m bridge - unnamed creek bridge (LCM4 model)
50880	3x600	RCP			* not modelled
51480	2400x3600	Box Culvert/Fauna Crossing			* not modelled
52492.00	75000	3 span (25000 each)	5m	Report	* modelled as 60m bridge - Chaffin Ck bridge (LCM4 model)
52650	6x3600x2100	Box Culvert/Fauna Crossing		Report	* modelled (LCM4 model)
53760	3600x3600	Box Culvert/Fauna Crossing			* not modelled
54760.00	90000	6 span (15000 each)	4m	Report	* modelled as 60m bridge - unnamed creek bridge (LCM4 model)
55120	6x1500x1500	Box Culvert/Fauna Crossing		Report	* modelled (LCM4 model)
56951.10	31500	3 span (8000-15000-8000)	5.3m min		* not modelled
57081.00	88000	4 span (22000 each)	2-3m	Report	* modelled as 60m bridge - Champions Ck bridge (LCM5 model)
58270	2x3000x900	Box Culvert			* not modelled
58693.39	75500	5 span (15000 each)	5.3m min	Report	* modelled as 50m bridge - unnamed creek bridge (LCM5 model)
59330	3600x3600	Box Culvert/Fauna Crossing			* not modelled
60150	2400x1200	Box Culvert			* not modelled
60860	3600x3600	Box Culvert/Fauna Crossing			* not modelled
61098.90	35500	3 span (10000-15000-10000)	5.3m min		* not modelled
61860	3x2100x900	Box Culvert			* not modelled
61960	1x900	RCP			* not modelled
62280	4x3000x1800	Box Culvert			* not modelled
62870	2x2400x900	Box Culvert			* not modelled
63660	4x600	RCP			* not modelled
63980	2x675	RCP			* not modelled
64240	3000x1800	Box Culvert/Fauna Crossing			* not modelled
64550	3600x3600	Box Culvert/Fauna Crossing			* not modelled
65540	3x900	RCP/Fauna Crossing			* not modelled
66080	2x900	RCP			* not modelled
66240	3000x3600	Box Culvert/Fauna Crossing			* not modelled
66270	2100x750	Box Culvert/Fauna Crossing			* not modelled

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
66550	2100x750	Box Culvert			* not modelled
67208.71	35500	3 span (10000-15000-10000)	5.3m min		* not modelled
67220	3x900	RCP			* not modelled
67431.00	31500	3 span (8000-15000-8000)	5.3m min		* not modelled
67440	2x1200	RCP - 3 sets going through intersection			* not modelled
68060	2x900	RCP			* not modelled
68120	2x750	RCP			* not modelled
68480	4x600	RCP			* not modelled
68730	4x600	RCP (East side rd)			* not modelled
68740	4x600	RCP			* not modelled
68800		End of Section Three			
68800		Start of Section Four			
69020	4x600	RCP			* not modelled
70508.85	18500	1 span (18000)	2.5m	Alt route?	* modelled 3x3000x3000 instead (Clarence model)
71110	2x3300x1800	Box Culvert			* not modelled
71730	3x1800x1800	Box Culvert			* not modelled
72640	3x1800x900	Box Culvert			* not modelled
73060	3600x1800	Box Culvert			* not modelled
73300	1x1200	RCP			* not modelled
73477.57	15500	1 span (15000)	2.5m	Alt route?	* modelled 2x3000x3000 instead (Clarence model)
73880	2x2400x900	Box Culvert		Alt route?	* not modelled
74808.70	448600	14 span (32000 each)	4m approx.	Alt route?	* Shark Ck bridge - modelled
75610	3600x2400	Box Culvert			* not modelled
76640	2400x1500	Box Culvert			* not modelled
77320	2x2400x2100	Box Culvert (Main rd only)			* modelled (Clarence model)
77350	3x3000x2400	Box Culvert (Main rd and Mcintyres ln)		Alt route?	* not modelled
77880	3600x1800	Box Culvert			* not modelled
78020	3600x1800	Box Culvert			* not modelled
78510	5x3000x1200	Box Culvert		Alt route?	* modelled 5x3000x2100 instead (Clarence model)
78920	2x2400x900	Box Culvert			* not modelled
79020	10x3000x1200	Box Culvert		Alt route?	* modelled (Clarence model)
79130	2400x900	Box Culvert			* not modelled
79720	2x2400x900	Box Culvert			* not modelled
79980	4x3000x2400	Box Culvert			* modelled 4x1500x2400 instead with floodgates (Clarence model)
80207.95	15500	1 span (15000)	??	Alt route?	* not modelled
80390	1x900	RCP			* not modelled
80610	8x2400x1200	4 sets of Box Culverts going through intersection		Alt route?	* modelled (Clarence model)
81030	2x600	RCP			* not modelled
81270	3600x3600	Box Culvert/Pedestrian Access			* not modelled
81500	1x900	RCP			* not modelled
81620	1x600	RCP			* not modelled
81830	1x750	RCP			* not modelled
82000		End of Section Four			
82000		Start of Section Five			
82110	1x750	RCP			* not modelled
82170	2x600	RCP			* not modelled
82460	2x600	RCP			* not modelled
82590	2x600	RCP			* not modelled
82710	2x600	RCP			* not modelled
82790	1x600	RCP			* not modelled
82940	1600x1200	Box Culvert/Fauna Crossing			* not modelled
83200	2x1200x600	Box Culvert			* not modelled
85050	3x3000x900	Box Culvert			* not modelled
85180	2x3000x900	Box Culvert			* modelled 17x3000x1800 instead (Clarence model)
85490	1x900	RCP			* not modelled
85986.945	1323170	33 span (8x29500, 10x43725, 2x43850, 6x43150, 1x37800, 5x45700, 1x35950)		?Report picture	* Clarence River Main Arm bridge - modelled
87520	46x3600x2100	Box Culvert		?Report picture	* modelled as BC in 2d_fc spanning 7 cells with 3m width
87780	3x3000x2100	Box Culvert (West side only)		?Report picture	* modelled (Clarence model)
88250	46x3000x2100	Box Culvert		?Report picture	* modelled as BC in 2d_fc spanning 7 cells with 3m width
88750	60x3000x2100	Box Culvert		?Report picture	* modelled as BC in 2d_fc spanning 9 cells with 3m width
89310	3x3000x2100	Box Culvert		?Report picture	* modelled 6x3000x1200 instead (Clarence model)
89386.75	77500	7 span (11000 each)	2.5m	?Report picture	* Serpentine Ck bridge - modelled
89910	84x3000x450	Box Culvert		?Report picture	* modelled as 14x3000x900, 13x3000x750, 28x3000x450 instead (Clarence model)
90280	14x3000x750	Box Culvert		?Report picture	* modelled (Clarence model)
90440	14x3000x750	Box Culvert		?Report picture	* modelled (Clarence model)

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
90540	25x3000x750	Box Culvert		?Report picture	* modelled (Clarence model)
90850	30x3000x450	Box Culvert		?Report picture	* modelled (Clarence model)
91190	32x3000x450	Box Culvert		?Report picture	* modelled (Clarence model)
91440	3x3000x2100	Box Culvert		?Report picture	* modelled 3x3000x1200 instead (Clarence model)
91730	10x3000x900	Box Culvert		?Report picture	* modelled (Clarence model)
91870	10x3000x900	Box Culvert		?Report picture	* modelled (Clarence model)
92210	30x3000x1200	Box Culvert		?Report picture	* modelled (Clarence model)
92350	3x825	RCP		?Report picture	* modelled (Clarence model)
92640	25x3000x600	Box Culvert		?Report picture	* modelled (Clarence model)
92750	20x3000x600	Box Culvert		?Report picture	* modelled (Clarence model)
92880	2x1200	RCP		?Report picture	* modelled (Clarence model)
92910	19x3000x900	Box Culvert		?Report picture	* modelled (Clarence model)
93020	24x3000x750	Box Culvert		?Report picture	* modelled (Clarence model)
93160	21x3000x600	Box Culvert		?Report picture	* modelled (Clarence model)
93320	33x3000x600	Box Culvert		?Report picture	* modelled (Clarence model)
93490	33x3000x600	Box Culvert			* modelled 2x1200 instead (Clarence model)
94036.79	216600	8 span (27000 each)	2.5m	?Report picture	* Clarence River North Arm bridge near Chatsworth - modelled
94890	4x600	RCP			* not modelled
95210	4x750	RCP			* not modelled
95410	6x3000x600	Box Culvert	4 sets over intersection		* not modelled
95790	3000x600	Box Culvert			* not modelled
96030	2x1500x600	Box Culvert		?Report	* modelled (Mororo/South model)
96170	1x750	RCP			* not modelled
96260	6x1500x600	Box Culvert		Report	* modelled (Mororo/South model)
96400		End of Section Five			
96400		Start of Section Six			
96730	2x1800x800	Box Culvert		Report	* modelled (Mororo/South model)
97030	2x2000x1500	Box Culvert		Report	* modelled (Mororo/South model)
98080	1x600	RCP			* 4 culverts modelled as one large box culvert (Tab Ck model)
99150	2x2000x1500	Box Culvert		Report	* 4 culverts modelled as one large box culvert (Tab Ck model)
99270	2x2000x1500	Box Culvert			* 4 culverts modelled as one large box culvert (Tab Ck model)
100460	2x750	RCP			* 4 culverts modelled as one large box culvert (Tab Ck model)
100700	2400x1800	Box Culvert/Fauna Crossing			* not modelled
101594.80	132000	12 span (11000 each)	2m approx.	?Report picture	* gap between road embankments
102906.35	88000	8 span (11000 each)	2m approx.	?Report picture	* gap between road embankments
103830	4x1200	RCP		?Report	* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
103840	4x1200x1200	Box Culvert		Report	* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
103980	3x1200	RCP		Report	* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104020	3x1200x1200	Box Culvert		Report	* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104310	1x450	RCP			* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104480	1x450	RCP			* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104550	2x750	RCP		Report	* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104570	2x525	RCP			* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104650	3x1050	RCP		Report	* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
104940	2x750	RCP			* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
105160	2x1050	RCP			* 11 culverts modelled as 4 large box culverts (total area is equal) (Tab Ck model)
105570	2x1050	RCP			* not modelled
106220	6x1650	RCP			* not modelled
106370	6x1650	RCP			* not modelled
106680	??	"Retain Existing"			* not modelled
108150	6x1050	RCP			* not modelled
108230	1x600	RCP			* not modelled
110200		End of Section Six			
111300		Start of Section Seven			
111810	1200x450	Box Culvert			* not modelled
113350	4x600	RCP			* not modelled
113360	4x600	RCP			* not modelled
113380	4x600	RCP			* not modelled
113390	4x600	RCP			* not modelled
113970	20x600	RCP			* not modelled
114880	4x900	RCP		Report	* labelled '3/900RCP' (and not 4) and much larger XS area in MIKE11 (and is rectangular) (Tab Floodway model)
115320.57	88000	8 span (11000 each)	2m approx.		* gap between road embankments
115530	1x900	RCP		Report	* modelled but with larger XS area in MIKE11 (and is rectangular) (Tab Floodway model)
115950	??	Picture on Map			* not modelled explicitly (possibly as part of the other culverts) (Tab Floodway model)
116290	??	Picture on Map			* not modelled explicitly (possibly as part of the other culverts) (Tab Floodway model)

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
116610	1x600	RCP			* not modelled
116840	2x900	RCP			* not modelled
117120	2x900	RCP			* not modelled
117420	1x600	RCP			* not modelled
117990	1x900	RCP			* not modelled
118530	2x1200x900	Box Culvert			* not modelled
118880	??	Fauna Crossing			* not modelled
119860	1x600	RCP			* not modelled
120300	??	"Retain Existing"			* not modelled
120740	1500x900	Box Culvert			* not modelled
121640	2x1500x600	Box Culvert		?Report picture	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
121860	2x1500x600	Box Culvert		Report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
122200	3x1500x600	Box Culvert		Report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
122320	3x2700	RCP/Fauna Crossing		?Report - these are only put down as additional in the report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
122610	3x2400	RCP/Fauna Crossing		?Report - these are only put down as additional in the report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
123640	6x2400	RCP		?Report - these are only put down as additional in the report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
124110	1x600	RCP 2 sets on NB and SB		Report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
124570	4x1800	RCP 2 sets on NB and SB		Report	* modelled but with larger XS area in the MIKE11 model (Oaky Ck/North model)
125550	1x600	RCP			* not modelled
126400		End of Section Seven			
126400		Start of Section Eight			
126770	1x600	RCP			* not modelled
127310	1x600	RCP			* not modelled
130050	2x3000x1500	Box Culvert		?Report picture	* modelled
130160.97	150500	6 span (25000 each)	3m	?Report picture	* Tuckombil Canal - modelled
130520	2x3600x1800	Box Culvert		?Report picture	* modelled
130790	2x3600x1500	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
131119.97	75500	3 span (25000 each)	2m approx.	Report text	* modelled
132020	3x3600x900	Box Culvert	Provide Rip Rap apron d50=300mm	?Report picture	* modelled
132090	2x3600x900	Box Culvert/Fauna Crossing			* not modelled
132580	1x675	RCP	Provide Rip Rap apron d50=300mm		* not modelled
133090	20x3300x1200	Box Culvert	Provide Rip Rap apron d50=300mm	Report text	* modelled but only 19
133190	1x675	RCP			* not modelled
133640	1x675	RCP	Provide Rip Rap apron d50=300mm		* not modelled
134740	1800x1200	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
135220	750x400	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
135340	750x450	Box Culvert		?Report picture	* modelled
135560	2400x750	Box Culvert	Provide Rip Rap apron d50=300mm	?Report picture	* not modelled
135640	2400x750	Box Culvert			* modelled
136470	900x600	Box Culvert	Provide Rip Rap apron d50=300mm	?Report picture	* not modelled
136540	900x600	Box Culvert			* modelled
136716.97	18500	1 span (18000)	2m approx.	?Report picture	* MacDonalds Creek Bridge - modelled
137430	2100x450	Box Culvert 2 sets at intersection	Provide Rip Rap apron d50=300mm		* not modelled
137600		End of Section Eight			
137600		Start of Section Nine			
138240	1x900	RCP			* not modelled
140870	2400x2700	Box Culvert	Provide Rip Rap apron d50=300mm	?Report picture	* modelled
141230	3x2100x1200	Box Culvert	Provide Rip Rap apron d50=300mm	?Report picture	* modelled
141940	3x1500x1500	Box Culvert	Provide Rip Rap apron d50=300mm	?Report picture	* modelled
142340	1500x900	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
142700	?????	INTERSECTION???			* not modelled
143490	3600x600	Box Culvert (Main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
143490	2100x450	Box Culvert (Broadwater rd only)			* not modelled
143560	1x375	RCP (Broadwater rd only)			* not modelled
143620	1x450	RCP (Broadwater rd only)			* not modelled
143740	600x450	Box Culvert (Broadwater rd only)			* not modelled
143840	3600x1200	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
144340	1800x450	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
144810	2x3300x600	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
145000		End of Section Nine			
145146.97	75500	5 span (15000 each)	1.5-2m	Report text + picture	* gap between road embankments
145338.83	789300	11 span (40000-50000-50000-50000-50000-50000-70000-115000-115000-115000-70000)	5-15m	Report text + picture	* Richmond River Bridge - modelled
145400		Start of Section Ten			
146490	3000x3000	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
146740	3000x900	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
147340	2x3000x900	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
148290	3000x600	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
148440	1500x600	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
148740	3300x900	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
148850	1200x900	Box Culvert (Old Bagotville rd only)			* not modelled
149020	1x825	Box Culvert (Montis rd only)			* not modelled
149272.22	18000	1 span (17500)	1.8m min		* not modelled
150090	3x3600x1500	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
150640	2400x1500	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
150680	3x3600x600	Box Culvert (West side rd only)			* not modelled
150740	5x3600x1600	Box Culvert/Fauna Crossing			* not modelled
150820	4x3600x600	Box Culvert (West side rd only)			* not modelled
151290	1x600	RCP 2 sets	Provide Rip Rap apron d50=300mm		* not modelled
151630	1x600	RCP 2 sets	Provide Rip Rap apron d50=300mm		* not modelled
151790	1x600	RCP (West side rd only)			* not modelled
151810	3x3000x600	Box Culvert (main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
151830	2x3000x600	Box Culvert (west side rd only)			* not modelled
151978.97	18000	1 span (17500)	1.8m min		* not modelled
151980	4x3600x900	Box Culvert (west side rd only)			* not modelled
152260	1x600	RCP 2 sets both west rd and main rd	Provide Rip Rap apron d50=300mm		* not modelled
152420	1x750	RCP (West side rd only)			* not modelled
152570	900x450	Box Culvert (west side rd only)			* not modelled
152610	1x450	RCP (West side rd only)			* not modelled
152710	2700x900	Box Culvert (west side rd only)			* not modelled
152810	3x2700x900	Box Culvert 2 sets both west rd and main rd	Provide Rip Rap apron d50=300mm		* not modelled
153110	2x1500x450	Box Culvert (west side rd only)			* not modelled
153110	2x3300x600	Box Culvert (main rd only)			* not modelled
153210	1x600	RCP 2 sets both west rd and main rd	Provide Rip Rap apron d50=300mm		* not modelled
153530	1050x450	RCP (West side rd only)			* not modelled
153620	2x3300x900	Box Culvert (west side rd only)			* not modelled
153630	3x3000x1800	Box Culvert/Fauna Crossing (main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
153730	3x3000x900	Box Culvert (west side rd only)			* not modelled
153750	3x3000x1800	Box Culvert/Fauna Crossing (main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
153880	1x600	RCP (West side rd only)			* not modelled
153920	1x675	RCP (main rd only)			* not modelled
153960	1x600	RCP (West side rd only)			* not modelled
154100	3x3000x900	Box Culvert (west side rd only)	Provide Rip Rap apron d50=300mm		* not modelled
154100	5x3600x1800	Box Culvert/Fauna Crossing (main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
154160	3000x600	Box Culvert (west side rd only)			* not modelled
154420	1500x450	Box Culvert (west side rd only)			* not modelled
154570	ϕ675	Box Culvert? (main rd only)			* not modelled
154580	1500x450	Box Culvert (west side rd only)			* not modelled
154770	4200x600	Box Culvert (east side rd only)	Provide Rip Rap apron d50=300mm		* not modelled
154780	3000x600	Box Culvert (main rd only)			* not modelled
154790	2x1800x450	Box Culvert (west side rd only)			* not modelled
155190	2x1500x450	Box Culvert (west side rd only)			* not modelled
155190	2700x600	Box Culvert (main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
155440	2x2400x450	Box Culvert (west side rd only)			* not modelled
155455.07	15500	1 span (15000)	3.6m min		* not modelled
155940	2x3600x600	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
156310	4x3300x1200	Box Culvert	Provide Rip Rap apron d50=300mm		* not modelled
156980	2x1800x1200	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
157160	2x1800x1200	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
157320	2400x1800	Box Culvert/Fauna Crossing	Provide Rip Rap apron d50=300mm		* not modelled
157440	1500x900	Box Culvert 3 sets along intersection	Provide Rip Rap apron d50=300mm		* not modelled
157590	3000x900	Box Culvert (west side rd only)			* not modelled
157660	3x2100x1800	Box Culvert/Fauna Crossing (west side rd only)			* not modelled
157670	2x3600x1800	Box Culvert/Fauna Crossing (main rd only)	Provide Rip Rap apron d50=300mm		* not modelled
157824.82	18300	1 span (17500)	3m		* not modelled
158600		End of Section Ten			
158600		Start of Section Eleven			
159040	7x3600x1200	Box Culvert/Fauna Crossing (main rd only)			* not modelled
159040	4x3000x900	Box Culvert/Fauna Crossing (east side rd only)	Provide Rip Rap apron d50=300mm		* not modelled
162730	3x3000x1500	Box Culvert	Provide Rip Rap apron d50=300mm	Report text	* modelled 3x3000x1200 (Ballina model only)
163040	5x1050	RCP	Provide Rip Rap apron d50=300mm	Report text	* modelled (Richmond model and unidirection in Ballina model)

Chainage (m)	Culvert No. & Dimensions / Bridge Deck Length (mm)	Type / Bridge Span	Approx. Clearance / Details	Source	Comments
163440	11x1200x900	Box Culvert	Provide Rip Rap apron d50=300mm		* modelled (Richmond model only)
164040	11x2700x900	Box Culvert	Provide Rip Rap apron d50=300mm		* modelled (Richmond model only)
164050	15x3000x1500	Box Culvert	Provide Rip Rap apron d50=300mm	Report text - slightly diff chainage	* modelled (Ballina model and 7x2100x900 in Richmond model)
921.36 (MCSW)	108000	6 span (18000 each)	2m approx.		* gap between road embankments (Richmond & Ballina model) - Duck Creek
164321.00	180000	10 span (18000 each)	2-3m		* gap between road embankments (Richmond & Ballina model) - Duck Creek
1252.42 (MCSW)	153530	3 span (39500-70000-39500)	5m	?Report picture	* gap between road embankments (Richmond & Ballina model) - Emigrant Creek
605.015 (MCSW)	153530	3 span (39500-70000-39500)	5m		* gap between road embankments (Richmond & Ballina model) - Emigrant Creek
165600		End of Section Eleven			