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Ballina Flood Study Update

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Title :	Ballina Flood Study Update
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Synopsis :	This report contains a technical description of work, including calibration, completed on the Ballina Flood Study Update.

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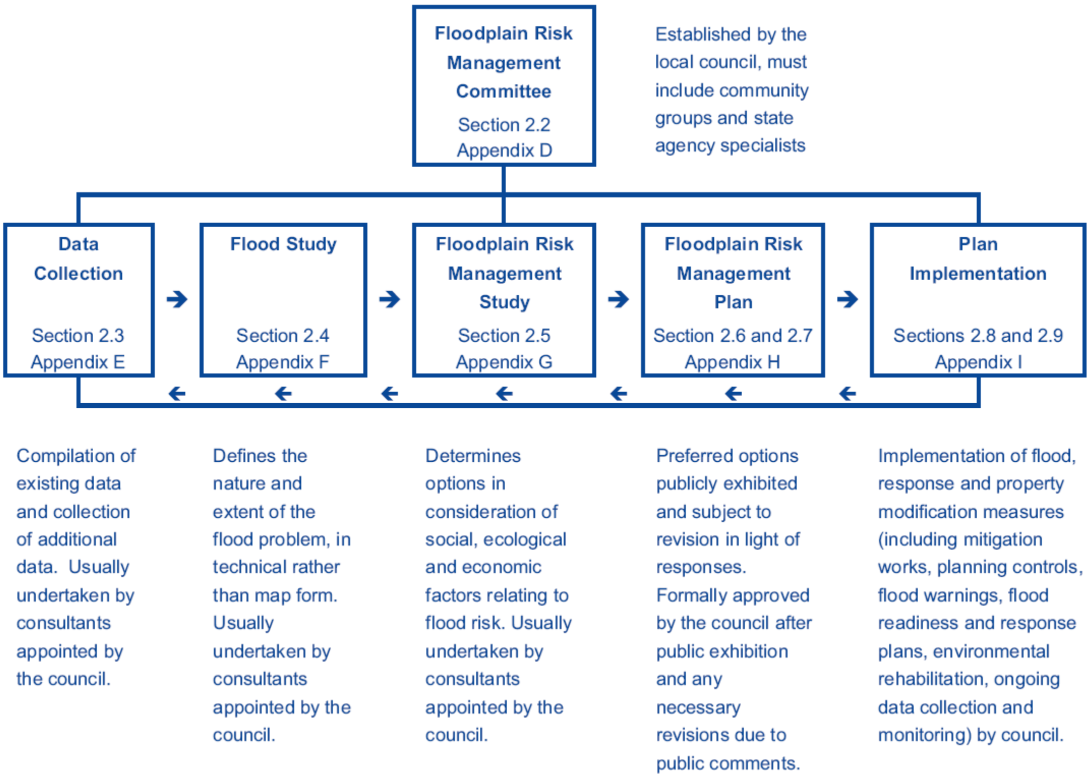
FOREWORD

The NSW Government's Flood Prone Land Policy is published in the 'Floodplain Management Manual: The Management of Flood Liable Land' (the Manual) of the then (2005) NSW Department of Infrastructure, Planning and Natural Resources. This policy acts to ensure that flood prone land is not the subject of uncontrolled development inconsistent with its exposure to flooding.

Financial and technical support is provided by the State Government's Department of Environment and Climate Change (DECC) to local councils, in whom rests primary responsibility for floodplain risk management.

Much of the lower floodplain of the Richmond River and hence Ballina Shire itself is flood prone. The risk to future development areas on this flood prone land within the Shire can be managed by adopting appropriate development controls, minimum fill levels for lots and minimum floor levels for buildings. Floodplain risk managers also need to look at existing risk (current development on flood prone land) and at residual risk from rare flood events.

Ballina Shire Council has a commitment to produce the Ballina Floodplain Risk Management Study and Plan. The following figure, reproduced from the Manual, shows this study, being solely updates to Data Collection and Flood Study, as the first two steps in the floodplain risk management process.



The Manual defines a Flood Study as a comprehensive technical investigation of flood behaviour. A Flood Study defines the nature of flood risk by providing information on the extent, level and velocity of floodwaters and on the distribution of flood flows across various sections of the floodplain for the full range of flood events up to and including the Probable Maximum Flood (PMF).

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GLOSSARY

Afflux	The change in flooding characteristics (level, depth, velocity, etc) caused by the inclusion of embankments or other constrictions in relation to the existing case (sometimes referred to as flood impact).
Australia Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
bathymetry	The topography and elevations of areas under water (eg. river beds).
cadastre	The property boundaries, including to road reserves, of a region.
catchment	The catchment at a particular point is the area of land that drains to that point.
design floor level	The minimum (lowest) floor level specified for a building.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year or 1% probability flood). The design flood may comprise two or more single source dominated floods.
development	Existing or proposed works, which may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in terms of volume over time. It is not the velocity of flow that is a measure of how fast the water is moving rather than how much is moving. Discharge and flow are interchangeable.
digital elevation model (DEM)	A three-dimensional model of the ground surface.
effective warning time	The available time that a community has from receiving a flood warning to when the flood reaches them.
flood	Above average river or creek flows that overtop banks and inundate floodplains.
flood awareness	An appreciation of the likely threats and consequences of flooding and an understanding of any flood warning and evacuation procedures. Communities with a high degree of flood awareness respond to flood warnings promptly and efficiently, greatly reducing the potential for damage and loss of life and limb. Communities with a low degree of flood awareness may not fully appreciate the importance of flood warnings and flood preparedness and consequently suffer greater personal and economic losses.
flood behaviour	The pattern / characteristics / nature of a flood.
flood frequency analysis	An analysis of historical flood records to determine estimates of design flood flows.
flood fringe	Land which may be affected by flooding but is not designated as a floodway or flood storage.
flood hazard	The potential threat to property or persons due to flooding.

flooding	The State Emergency Service uses the following definitions in flood warnings: **Minor flooding**: causes inconvenience such as closing of minor roads and the submergence of low level bridges. **Moderate flooding**: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic bridges may be covered. **Major flooding**: extensive rural areas are flooded with properties, villages and towns isolated and/or appreciable urban areas are flooded.
flood level	The height or elevation of flood waters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
flood liable land / floodplain	Land inundated as a result of the probable maximum flood (PMF).
flood proofing	Measures taken to improve or modify the design, construction and alteration of buildings to minimise or eliminate flood damages and threats to life and limb.
floodplain management	The coordinated management of activities that occur on flood liable land.
flood source	The source of the flood waters. In this study the Richmond River and the local creeks are different sources of flood waters.
floodplain management standard	A set of conditions and policies that define the benchmark from which floodplain management options are compared and assessed.
flood planning level	The flood selected for planning and floodplain management activities. The flood may be an historical or design flood. It should be based on an understanding of the flood behaviour and the associated flood hazard. It should also take into account social, economic and ecological considerations.
flood storages	Floodplain areas that are important for the temporary storage of flood waters during a flood.
floodways	Those areas of the floodplain where a significant discharge of water occurs during floods. (NSW Floodplain Development Manual, 2005)
freeboard	A factor of safety usually expressed as a height above the flood standard. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
high hazard	Danger to life and limb; evacuation difficult; potential for structural damage, high social disruption and economic losses.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.

hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
low hazard	Flood depths and velocities are sufficiently low that people and their possessions can be evacuated.
management plan	A clear and concise document, normally containing diagrams and maps, describing a series of actions which will allow an area to be managed in a coordinated manner to achieve defined objectives.
peak flood level, flow or velocity	The maximum flood level, flow or velocity occurring during a flood event.
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
topography	A description of the elevations of natural and artificial features.
triangular irregular network (TIN)	A mass of interconnected triangles used to model three-dimensional surfaces such as the ground (see DEM) and the surface of a flood.
velocity	The speed at which the flood waters are moving. Typically, modelled velocities in a river or creek are quoted as the depth and width averaged velocity, ie. the average velocity across the whole river or creek section.

LIST OF ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
ADCP	acoustic doppler current meter
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ALS	airborne laser scanning
ARI	Average Recurrence Interval
BOM	Bureau of Meteorology
BSC	Ballina Shire Council
cm	centimetre
CRG	Community Reference Group
cumecs	cubic metres per second
DCP	development control plan
DECC	NSW Department of Environment and Climate Change
DEM	Digital Elevation Model
DNR	NSW Department of Natural Resources
DTM	Digital Terrain Model
F2	2 year ARI short duration geographical factor for obtaining 6 minute duration intensities
F50	50 year ARI short duration geographical factor for obtaining 6 minute duration intensities
GIS	geographic information systems
HAT	highest astronomical tide
hr	hour
IEAust	The Institution of Engineers Australia
km	kilometre
LAT	lowest astronomical tide
LWOST	low water of spring tide
m	metre

m^3/s	cubic metres per second
mAHD	Elevation in metres relative to the Australian Height Datum
MHL	Manly Hydraulics Laboratory, NSW Department of Commerce
MHWN	mean high water neap
MHWS	mean high water spring
MLWN	mean low water neap
MLWS	mean low water spring
mm	millimetre
NSW	New South Wales
PMF	Probable Maximum Flood
P.O.	post office
RCBC	reinforced concrete box culverts
RCP	reinforced concrete pipe
RP	Real Property
RTA	NSW Roads and Traffic Authority

SUMMARY

INTRODUCTION AND BACKGROUND

As part of local and state government's commitment to improving the flood risk management of the Richmond River floodplain in the Ballina Shire, BMT WBM Pty Ltd was commissioned by Ballina Shire Council (Council) and the NSW Department of Environment and Climate Change (DECC) to update the 1997 Ballina Floodplain Management Study.

The purpose of the 1997 study was to provide advice to Council for the effective management of the floodplain with respect to flooding issues, and in particular, to the future development of flood prone areas of Ballina. During the 1997 study, a computer model of the floodplain was developed to assist in meeting the following objectives:

- improve the understanding of the complex flooding characteristics of the catchment;
- assess the impacts that anticipated development would have on flooding;
- determine absolute flood levels across the floodplain for a range of storm events;
- identify floodways and mitigation measures; and
- determine minimum fill levels for development on the floodplain.

The purpose of this Ballina Flood Study Update is to upgrade the computer model, taking advantage of recent technological advances to provide a 'state of the art' model of the floodplain. In turn, this model will be used to review the policies and management strategies associated with the floodplain and assess the impacts that future development and public infrastructure works will have on flooding. This 'Base Case' model will then be continually updated to assist future strategic planning and rezoning decisions across the floodplain.

The Ballina Flood Study Update is the first stage of Council's progression with the NSW State Governments 'Floodplain Risk Management Process'. Refer to the Foreword for the flowchart.

FLOOD STUDY UPDATE PROCESS

Key elements of the Ballina Flood Study Update process are summarised below:

- Community consultation;
- Data acquisition and review;
- Model development and calibration;
- Existing catchment design event modelling; and
- Future development and mitigation modelling.

COMMUNITY CONSULTATION

A Community Reference Group (CRG) consisting of local land owners and other key stakeholders was established at the start of the project. Throughout the course of the Flood Study Update, five meetings were held with the CRG to discuss the progress of the study and refine future objectives. The input provided by members of the CRG was considered and further investigated where there was a potential reduction in flood risk.

DATA ACQUISITION AND REVIEW

During the early stages of the Ballina Flood Study Update, a questionnaire was circulated amongst the community as part of the data acquisition process. The questionnaire enabled residents to share their knowledge of past floods. Typically, maximum flood levels and flow patterns were of key benefit, as were photographs and recollections of experiences. A database of historical flood data was then developed including relevant flood levels that were surveyed by Council during the process.

In addition to the above, rainfall and flood levels have been added to the previous information used during the 1997 study. These data were subsequently used for calibration of the June 2005 flood event.

MODEL DEVELOPMENT

The computer model developed for the 1997 study was based upon a network of one-dimensional (1D) elements representing the channels and floodplains of the Richmond River and local creeks downstream of Broadwater. The 1D computer model was considered appropriate given the technology and software available at that time.

Since 1997, advances in computer technology (both software and hardware) have enabled more detailed two-dimensional (2D) flood modelling to be undertaken. The 2D modelling enables complex flow patterns to be represented incorporating the varying terrain and land uses that characterise the floodplain. Two-dimensional modelling is ideally suited to the lower Richmond River and associated creeks where complex flow patterns exist.

HISTORICAL EVENT MODELLING FOR MODEL CALIBRATION AND VERIFICATION

Once the computer model had been developed, the model was calibrated and verified to actual flood events. Calibration is an important aspect of modelling that provides a degree of confidence in the model results.

For the calibration and verification process, three historical flood events were selected; March 1974, February 1976 and June 2005. Records of rainfall and ocean levels were collected and applied to the model for each of the three storm events. The results of the simulated flood were then compared to information recorded during the actual flood event. Such information included stream gauges, surveyed water levels and debris lines, photographs and videos, and local descriptions of flood behaviour. Where necessary, the model parameters were adjusted to ensure a good representation of actual catchment flooding.

SOURCES OF FLOODING

Flooding in Ballina has been identified to originate from three different sources:

- Flooding of the Richmond River;
- Local catchment flooding caused by rainfall centred on Maguires Creek, Emigrant Creek and North Creek; and
- Flooding due to elevated ocean levels, or storm surge.

Richmond River flooding tends to be dominant across the Richmond River floodplain to Ballina Island, across the lower Emigrant Creek floodplain and across the North Creek catchment. Local catchment flooding is the dominant source of flooding in upper Emigrant and Maguires Creeks, whilst the area covering Ballina Island to the ocean experiences worst flooding from elevated ocean levels.

Refer to Figure S-1 for the existing floodplain source dominance.

DESIGN EVENT MODELLING

Design events are theoretical flood events that are considered to have a likely chance of occurring during a certain period of time. For example, a 100 year Average Recurrence Interval (ARI) flood is an event which is likely to happen once during a 100 year period. The 100 year flood is larger than any of the modelled historical flood events of 1974, 1976 and 2005, and any recorded flood events in Ballina including the 1954 event.

Each design event comprises the three sources of flooding discussed above. For each average recurrence interval event, the maximum flood levels from each of the three source events were extracted. This provided a maximum envelope of peak flood levels across the model area.

Since the 1997 study, additional records of peak flood levels at the Broadwater Richmond River Gauge have become available. Using flood level records from almost 90 years, the statistical analysis (i.e. a flood frequency analysis) from the 1997 study was reviewed and updated. This ensured that the most up-to-date design flood flows were being applied to the model boundary at Broadwater.

FLOOD PLANNING

Flood planning refers to the design criteria applied to all future developments and infrastructure projects. Criteria discussed here are the required flood immunity and the maximum allowable increase in flood level resulting from the works.

The NSW Roads and Traffic Authority has set the 100 year ARI flood event as the desirable flood immunity for the Ballina Bypass between Cumbalum and Ross Lane to the north. Between the Bruxner Highway intersection and Cumbalum, the highway will have 20 year ARI flood immunity. These are largely controlled by the topography of the area

Ballina Shire Council roads, such as the Ballina Western Arterial and North Creek Road are to have 20 year ARI flood immunity.

Council has adopted a flood impact standard ensuring an increase of no more than 50mm in flood level during the 100 year ARI event. The maximum increase is derived from a comparison with 2005 floodplain conditions.

CLIMATE CHANGE

Climate change is expected to cause sea levels to rise. Therefore, an extensive literature review was undertaken for the Ballina Flood Study Update to determine the expected magnitude of increase. Following discussions with Council and DECC, the content of the Third Assessment Report by the Intergovernmental Panel on Climate Change (IPCC (2001)) was considered the most appropriate scientific judgement. A 50 year planning horizon was adopted resulting in a mean sea level increase equal to 200mm. This value has been applied to all design storm events modelled. This value is consistent with the Fourth Assessment Report by the IPCC released in November 2007.

No allowance has been made for potential changes in rainfall intensity or increases in storm surge magnitude.

FUTURE DEVELOPMENT AND FLOOD MITIGATION MODELLING (BASE CASE MODELLING)

For the future development flooding assessment, design event modelling was undertaken for the 5, 20, 50, 100 and 500 year ARI storms and the Probable Maximum Flood (PMF). Using the existing floodplain as the comparative case, modelling was undertaken to determine flooding impacts of future development in the catchment. All currently approved or rezoned urban development was represented in the model in addition to proposed public infrastructure works. These are:

- RTA Ballina bypass;
- BSC western arterial;
- North Creek revetment wall (airport);
- Upgrade to the Ballina sewerage treatment works;
- Ballina waste management centre;
- Commercial development on Smith Drive;
- Residential development at West Ballina;
- Southern Cross industrial development;
- Residential development at North Ballina;
- Residential development at Ballina Heights; and
- Residential development at Lennox Head.

Strategies were then developed through discussions with Council, DECC and the community reference group for the mitigation of flood impacts of the developments. Mitigation measures include flood relief culverts, floodways and other management measures. During the process, various mitigation strategies were investigated and discarded, whilst others were recommended for further investigation. Refer to Figure S-2 for locations of future development and associated mitigation strategies.

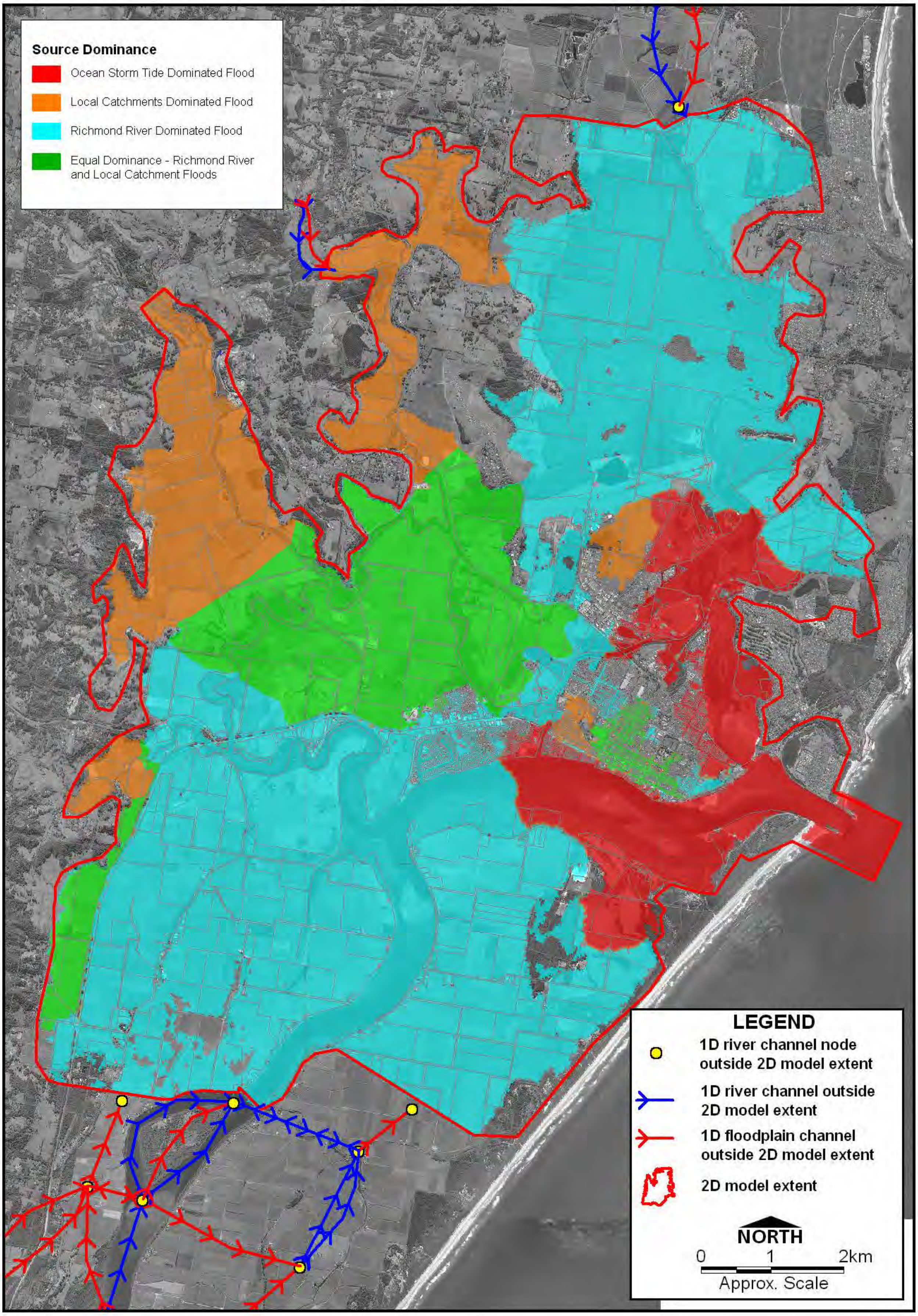
Working to the design objectives, the combination of the developed case and associated mitigation strategy formulated the 'Base Case' flood model. The base case model will then be used for future strategic planning and rezoning assessments within the floodplain. The existing policy, ensuring no greater than 50mm cumulative impact for any development, is proposed to be continued.

Refer to Figure S-3 for the 100 year ARI Base Case peak flood levels.

RECOMMENDED AMENDMENTS TO COUNCIL POLICY

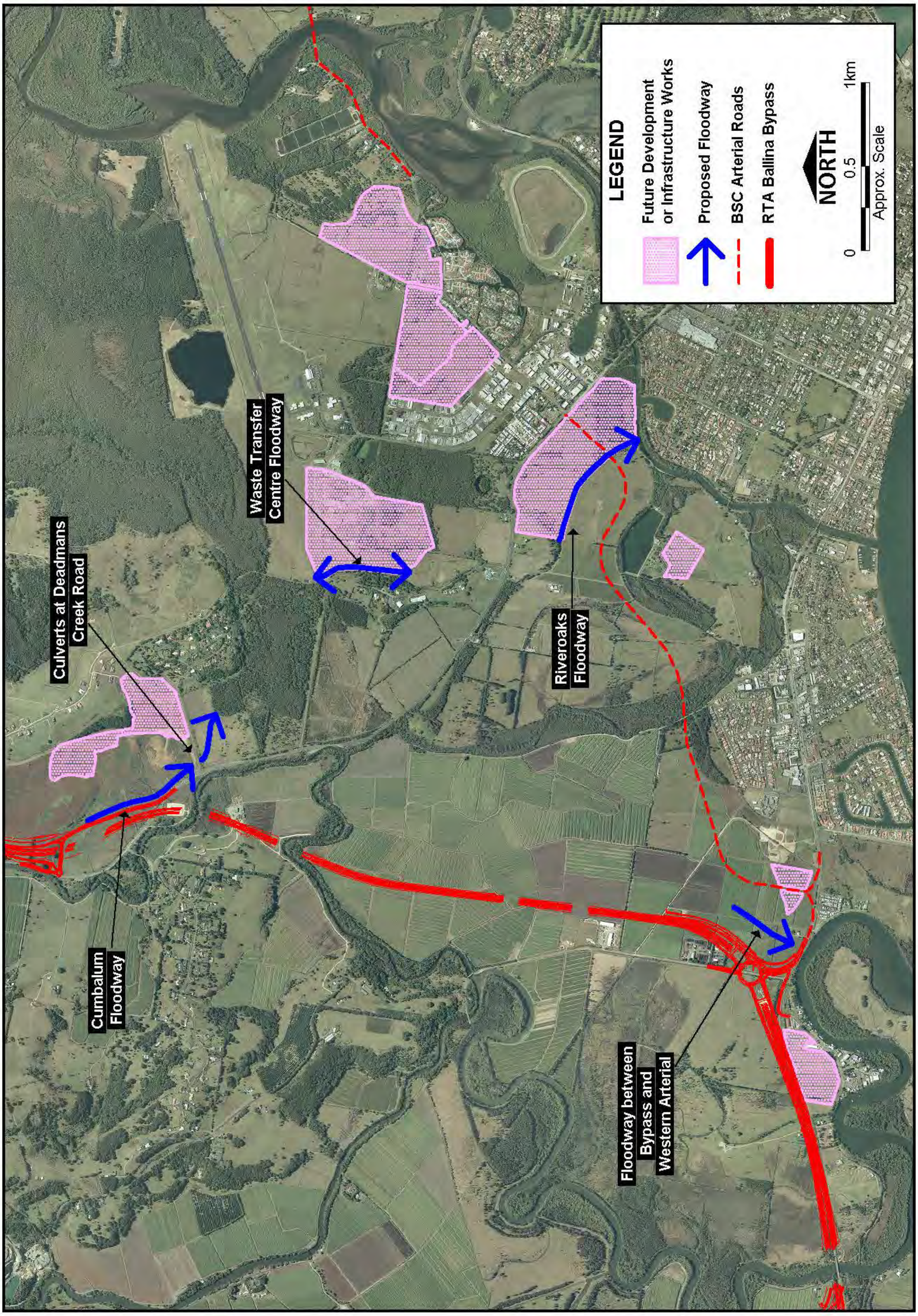
A review of Council's minimum fill levels has been undertaken using the revised flood levels across the catchment. In March 2008, Council adopted the revised Policy Statement No. 11: Flood Levels. The Policy Statement includes the following amendments:

- minimum fill levels determined from both the 1997 and 2007 flood modelling; and
- minimum freeboard policy changed to 500mm for residential development, to be consistent with the recommendations of the NSW Floodplain Development Manual (2005).



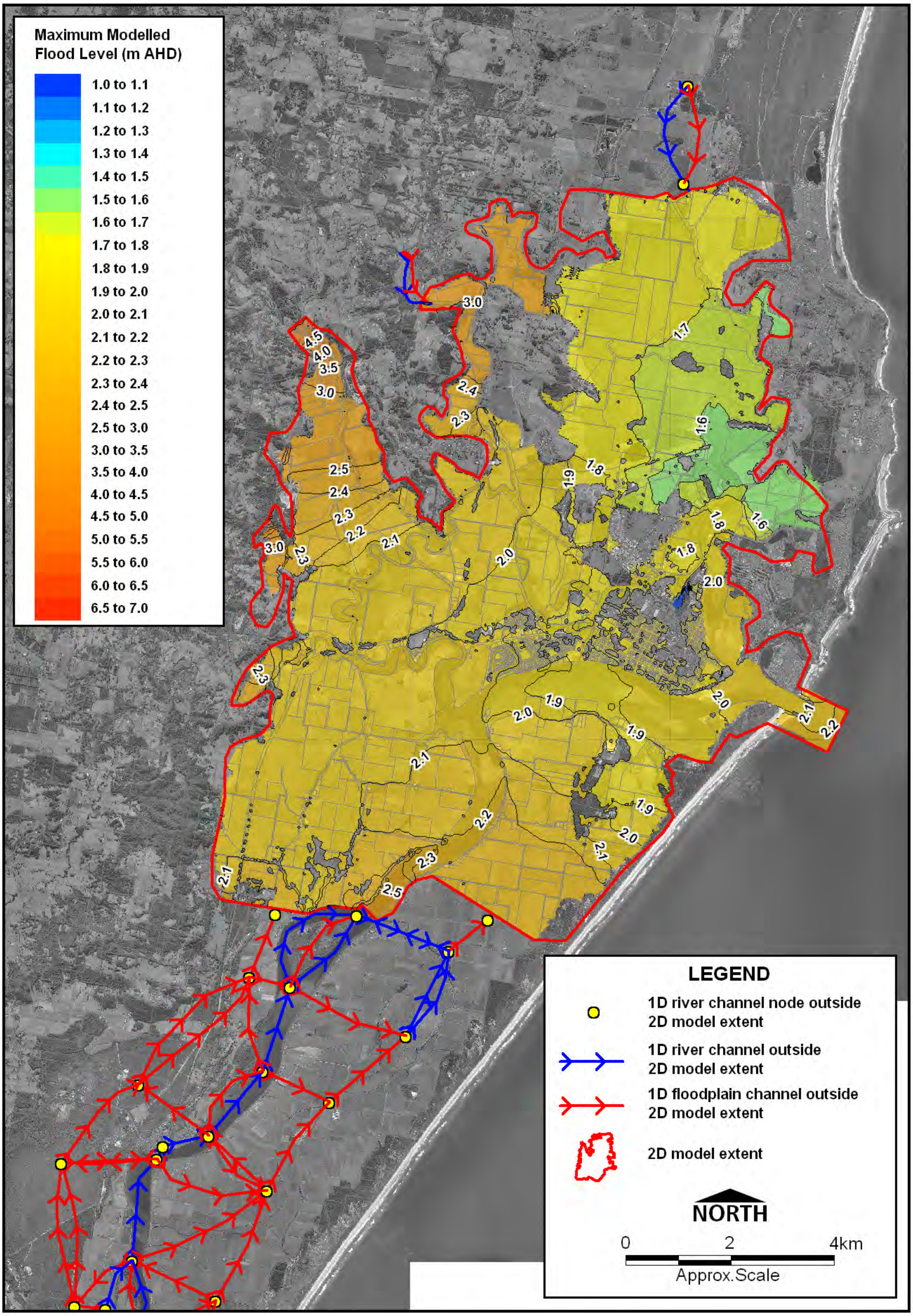
Existing Floodplain Source Dominance of Peak Flood Level - 100 Year ARI

Figure S-1



Future Development, Infrastructure Works and Mitigation Measures

Figure S-2



Base Case Peak Flood Levels (mAHD) - 100 Year ARI

Figure S-3

1 INTRODUCTION

1.1 General

The Ballina Floodplain Management Study of 1997 (the previous study) was based on one-dimensional hydraulic modelling of the Richmond River and local catchments. In order to progress the preparation of a Floodplain Risk Management Study and Plan for Ballina, Ballina Shire Council (Council) expressed the need to embark on more advanced two-dimensional (2D) hydraulic modelling and geographic information systems (GIS) based flood mapping. This study is to update these two components of the previous study. Inherent in the modelling update is updated data collection.

Figure 1-1 shows the relationship between the lower Richmond River floodplain and the project study area.

For this Flood Study Update, a 2D flood model of the Richmond River in Ballina has been developed for Council by BMT WBM Pty Ltd (BMT WBM). The flood model defines existing flood behaviour and provides a means for assessing floodplain management measures. The flood model comprises a hydrologic model and a hydraulic model. The hydrologic model was developed in the previous study. The hydraulic model has been updated to a coupled 2D/1D model and uses a combination of data from the previous study and recent bathymetric and floodplain survey.

The hydrologic and hydraulic models were calibrated and verified using historical flood events to demonstrate the validity of the models. To calibrate the models, it was first necessary to obtain information such as flood heights, flooding patterns and velocities during historical flood events. Historical events used in the calibration process are the March 1974, February 1976 and the smaller June 2005 flood events.

1.2 Why Revisit the Flood Study?

1.2.1 Technological Advances in Modelling

The first and foremost reason for this update is technological advances in modelling. At the time of the original floodplain management study, 2D modelling was in early stages of development and dominated by finite element software, which in their earliest form were problematic at the changing wet-dry boundary typical of most floodplains. The use of one-dimensional (1D) models in a quasi-2D network fashion was the standard adopted by most floodplain authorities of the time.

Once limited to coastal hydraulics, 2D modelling of free-surface flows is today used for a broad range of investigations, from the ocean to the floodplain. Coupled with the advances in modelling are the advances in computing power. Development in computer hardware technology (i.e. computational speed) is a key factor influencing the expansion of 2D model use.

Application of 2D modelling techniques using hydrodynamic codes has been common practice in some countries (e.g. Australia) in recent years especially to characterise flooding in rural and broad floodplain environments.

Many of the limitations of the 1D approach are eliminated when a 2D modelling approach is adopted. Using a 2D model precludes the need to spend significant time developing model geometry, and defining flow paths and flow splits. All of these can be taken directly from the specified topography. Two-dimensional modeling enables:

- conservation of momentum parallel and transverse to the main flow;
- resolution of complex flow patterns;
- more realistic representation of sheet flow;
- flow velocity and water depth to be calculated throughout the modelling domain to input to safety/risk assessments; and
- ease of geo-referencing model results, such that little interpretation is required.

Currently, most 2D packages include additional 1D/2D capability and nested grids which make them more flexible for urban systems and large scale applications which require selected fine scale detail (i.e flood impact assessment of individual allotments).

1.2.2 Additional Data Collection

More than ten years have elapsed since the data collection phase of the previous study. During that time, significant data collection (rainfall, streamflow, ocean levels, floodplain spot heights) has occurred, all of which adds to the knowledge database of floodplain behaviour.

Coupled with data collection by local authorities, as part of this study, the community were requested to complete questionnaires entitled '*Ballina Flood Study Update: Can You Help?*' which brought to light significant new floodplain spot heights and eye-witness observations on the presence or absence of flooding. These were valuable in establishing a reliable model structure.

A summary of the data collection is included as Appendix A. A copy of the questionnaire is included as Appendix B.

1.2.3 Changed Standards and Best Practice

During the intervening years since the previous study, the NSW Government's Floodplain Development Manual has been updated twice. In addition, DECC's Draft Floodplain Risk Management Guideline No 5 (Ocean Boundary Conditions) (2004) was published. One of the most significant changes of these documents is recognition of the potential implications of climate change on flooding behaviour. Climate change is expected to affect flood behavior as sea levels rise and the pattern of flood producing storms potentially intensify. The potential impacts need to be considered.

1.2.4 Improved Flood Mapping

With the improved topography inherent in 2D flood modelling, flood mapping becomes a much more accurate and simpler exercise, with a flood surface being generated in the model in geo-referenced coordinates. There is increased confidence in flooding results due to lower interpretation required during flood mapping. Animations can be created from the simulations to dynamically map the movement of water.

This information will then enable Council to undertake more informed decision making and emergency response planning.

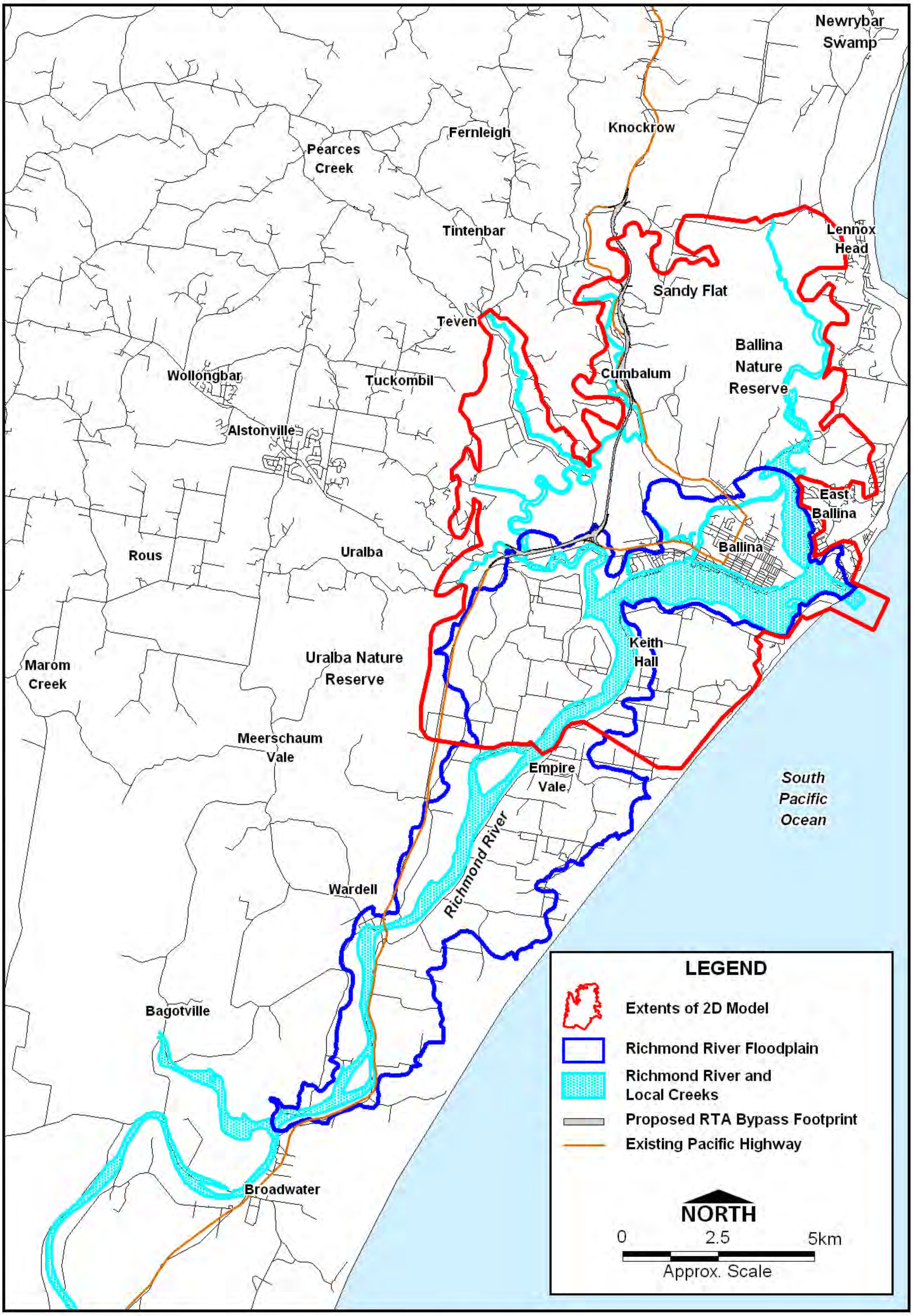
1.2.5 Ease of Model Refinement

The final reason for revisiting the flood study is the ease with which a 2D model can be refined for local investigations (e.g. flood impact assessments). A local replacement of the model ground elevations can be used to simulate floodplain filling scenarios or inclusion of floodways. 1D structure elements can be altered to investigate the extent and size of impacts of bridge/culvert blockage or their augmentation.

1.3 Purpose of This Report

This report is a technical document designed to describe the development and simulation of the flood model and present the simulation results as GIS-based flood mapping. A range of calibration and design events under existing floodplain characteristics and approved future conditions will be considered.

This study will form the basis for the preparation of a Floodplain Risk Management Study and Plan for Ballina.



Location of Study Area on Lower Richmond River

Figure 1-1

2 BACKGROUND

2.1 Parties Involved

The Ballina Flood Study Update has involved Council's Civil Committee and Community Reference Group which comprised the following representatives:

- Elected members of Council;
- Council staff from engineering, planning and environmental disciplines;
- representatives of the local community (local flood affected landholders (residential and business), the Chamber of Commerce);
- representatives of development consultants;
- an officer from the DECC; and
- local and divisional representatives from the SES.

BMT WBM is an independent consultant appointed by Council to undertake the flood study update.

2.2 Floodplain Management

2.2.1 Previous Studies

Investigation of flooding on the lower Richmond River floodplain commenced with Richmond River County Council's 'Flood Mitigation Strategy' in 1974. The 'Ballina Floodplain Management Study' (WBM, 1997) addresses flooding issues along the Richmond River downstream from the town of Broadwater. The 1997 study also lists the raft of regional and development specific flooding reports available to 1995. Further documents published by WBM in July 1999 are entitled 'Summary of Flood Assessments around Ballina 1997-1999' and 'Ballina Floodplain Management Study – Additional Scenario Analyses'.

Of these, the 1997 Floodplain Management Study was the definitive study as adopted by Council and used to derive Minimum Fill Levels within the Shire, primarily focusing on areas downstream of Pimlico Island. For the balance of the Shire to the south, the local 'Wardell & Cabbage Tree Island Flood Study' was prepared by Patterson Britton and Partners in October 2004 and is currently being extended by the same consultant to a Floodplain Risk Management Study and Plan.

2.2.2 Ballina Floodplain Management Study

The previous Ballina Floodplain Management Study defined existing flood behaviour, established baseline floodplain management details and documented the findings of flood impact investigations of development proposals within Ballina township environs. It is the existing flood behaviour, and the model that simulated this, that is revisited in this study.

The model for the previous study was developed using the ESTRY software and a combination of topographic data, including:

- bed profiles obtained from ADCP measurements undertaken by Manly Hydraulics Laboratory (MHL) in November 1994;
- cross-sections of the Richmond River obtained by the NSW Public Works Department in 1980;
- cross-sections of Fishery Creek and North Creek Canal, which were gathered by Ballina Shire Council specifically for the study;
- contour information of ground above high water mark provided by the Department of Natural Resources and as seen on 1:25,000 topographic maps, 1:50,000 topographic maps and 1:4,000 orthophoto maps;
- a variety of plans extracted from Ballina Shire Council office (road, bridge, subdivision and other development plans);
- NSW Roads and Traffic Authority's (RTA) road design plans;
- drainage plans from Richmond River County Council (via Ballina Shire Council); and
- comprehensive field surveys carried out by Ballina Shire Council specifically for the study to supplement the information on plans at major controls (i.e. levees and roads).

The data as a collective provided an adequate level of detail for model development at that time in the main areas of interest of Ballina and its north and west surrounds. In areas of no data, floodplain ground levels were estimated based on vegetation, land use and neighbouring floodplains. The level of detail would be inadequate for any 2D modelling exercise.

The tidal (in-bank) component was calibrated to water levels and discharges collected by MHL over a tidal cycle in November 1994. Calibration was achieved by adopting a Manning's *n* roughness value of 0.022 for all sections of the channel.

A fully one-dimensional flood model was developed to cover the channel and floodplain of the lower Richmond River. It was calibrated to measurements recorded during major flooding that occurred in March 1974, February 1976 and June 1983.

This model was then used to predict envelopes of peak flood levels and flows for design floods representing the 100, 50, 20 and 10 year average recurrence interval (ARI) flood scenarios. A Probable Maximum Flood (PMF or extreme flood) was also formulated in a similar manner to the design floods.

2.2.3 Outcomes of Previous Study

Council adopted and reissued 'Policy Statement No. 11 – Flood Levels' in December 1998, forming part of Council's DCP. Minimum fill levels are based on the assessed 100 year ARI flood levels, applying to urban developments and rural dwellings. 'Map 1' of the Policy Statement is a contour plan showing minimum fill levels for the floodplain. The following detail has been extracted from the Policy Statement:

Ballina Township:	Minimum Fill Height	R.L. 1.8 mAHD
	Minimum Floor Level	R.L. 2.1 mAHD
Remaining Flood Prone Areas:	Minimum Fill Height	100 year ARI flood level
	Minimum Floor Level	300mm above the 100 year ARI flood level

2.3 Catchment Description

This study includes consideration of the plateau catchments and flooding behaviour of Emigrant Creek, Maguires Creek, North Creek and the lower Richmond River. These catchments are dominated by rolling topography and hills with slopes ranging from 5% to 30%. The model also includes three minor tributaries of Emigrant Creek; Sandy Flat Creek, Chilcotts Creek and Duck Creek.

The majority of the catchment areas have been cleared for agricultural purposes or for development on the lower floodplain.

Catchment delineations are shown in Figure 2-1. Refer also to Figure 2-2 for locality.

The catchment consists of a series of elevated ridges that run along the coastal escarpment at the boundary of the Alstonville Plateau and the Richmond River and North Creek floodplains. Low lying landscape features include the Ballina Nature Reserve to the east of the plateau.

'Local catchment' flooding is defined as flooding caused by runoff from creeks in the study area and excludes Richmond River flooding.

2.3.1 Emigrant Creek

Emigrant Creek has a long narrow catchment of southerly orientation. The catchment area to the bridge at Tintenbar is 28 km^2. Within this catchment is Emigrant Creek Dam, which has a full supply volume of 819ML and contributes to Ballina's water supply. Testing of the hydrologic model and of different dam levels showed the dam does not have a major influence on the calculated flood hydrographs at Ballina. The dam was assumed full for all flood events.

2.3.2 Maguires Creek

Maguires Creek has a catchment area of 48 km^2 to the bridge at Teven. The creek originates on the Alstonville Plateau, before flowing north east through the town of Alstonville continuing in a north-easterly direction for over 10 km stream distance before turning south east and passing through Teven village before joining Emigrant Creek at the dual bridges on Teven Road. The only major tributary of Maguires Creek is Houghlahans Creek.

2.3.3 North Creek

The hills surrounding Newrybar swamp drainage basin, drain via a series of gullies. Under natural conditions, these gullies would have merged onto flat, peaty areas that form the Newrybar swamp. The very flat slopes in the central areas inhibited natural drainage, which was further exacerbated by the high tides and the heavily timbered areas in the lower catchment. Siltation of the floodplain downstream of Ross Lane may also be restricting the passage of floodwater. Intense rainfalls can occur over the catchment and if runoff coincides with high tide conditions, long inundation and slow drainage is inevitable.

A network of floodgates exists in the vicinity of Ross Lane, immediately downstream of two main flood mitigation drains. The tidal limit for North Creek extends approximately 4km upstream from Ross Lane. The western edge of the catchment is steep, with falls of up to 100m over 500m where the topography drops from the ridge of the Main Coast Range to the Newrybar plain. The remainder of the catchment is generally very flat, in the range 0 mAHD to 10 mAHD, with much of the area in the order of 1 mAHD to 3 mAHD.

The continuous clearing and development of the upper and middle reaches of the catchment has modified the runoff behaviour of the catchments. It is likely that runoff is presently faster (i.e. the catchments are more responsive) and in greater volumes than that which occurred prior to land clearing.

2.3.4 Deadmans Creek

Deadmans Creek has its source in the vicinity of Ross Lane. The creek flows south through the swampland of the Ballina Nature Reserve, joins Roberts Creek, then flows east where it discharges into North Creek, which later flows into the Richmond River at Ballina.

2.3.5 Sandy Flat Creek

Sandy Flat Creek (formerly Palmers Creek, circa 1970) flows south-west and is a tidally influenced tributary of Emigrant Creek, with its point of confluence approximately 1 km south-east of Tintenbar on the study area boundary. The existing Pacific Highway crosses Sandy Flat Creek just upstream of the point of confluence with Emigrant Creek. During large flood events, when the Richmond River is in flood and Emigrant Creek is backwater affected, floodwaters from Emigrant Creek breakout across the Pacific Highway and Sandy Flat to flow into North Creek to the east. Much of the Sandy Flat appears to act as a flood storage area. Levels need to build up to a significant depth to overtop the Sandy Flat Road ridge to the east.

2.3.6 Richmond River

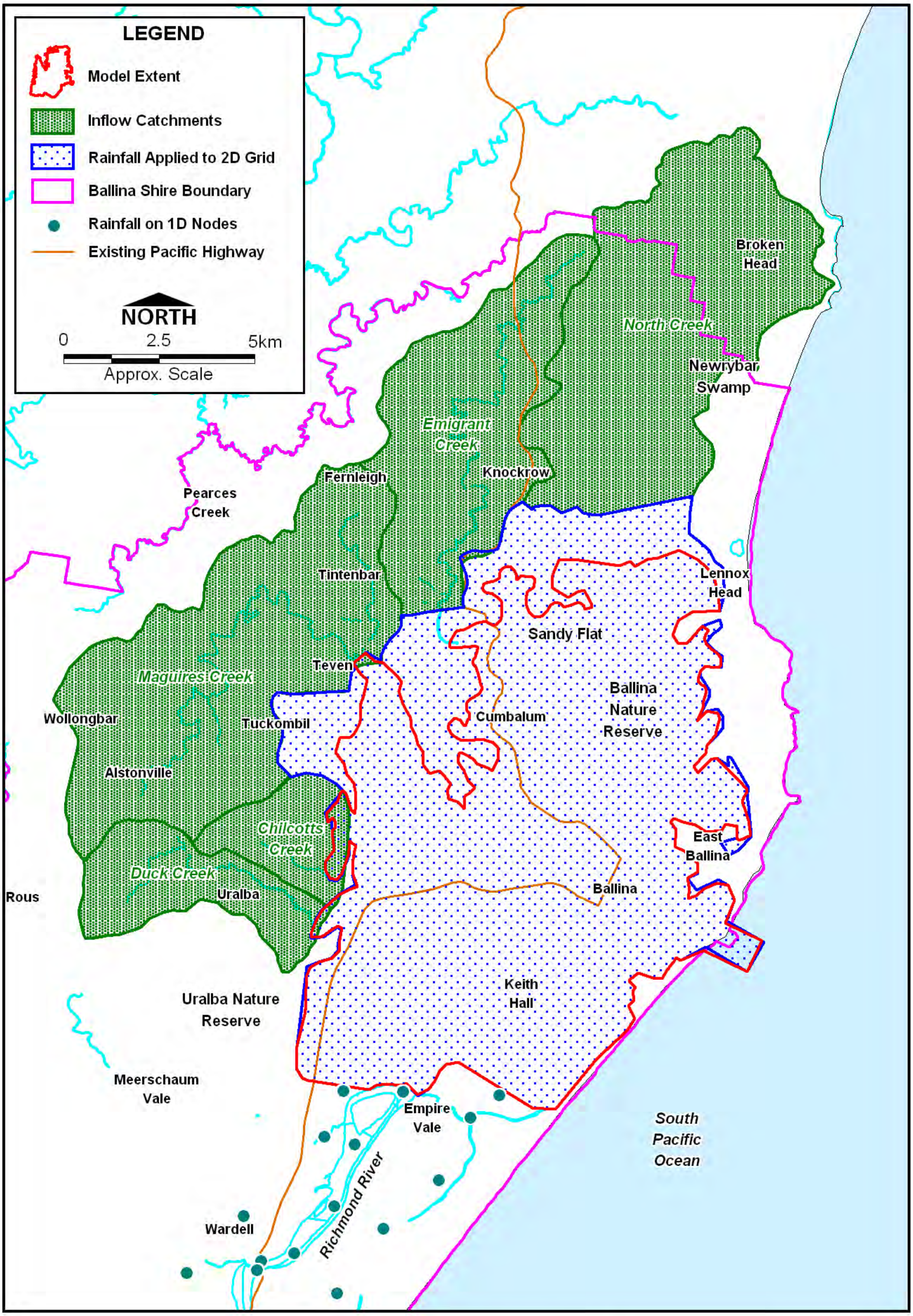
The Richmond River catchment covers an area of approximately 6,900 km^2 and is one of the largest river systems in northern New South Wales (NSW). Ballina lies near the Richmond River mouth. The upstream reach extends from Kyogle to Casino. The 'middle' section of the river includes the rural towns of Coraki, Woodburn and Broadwater.

2.4 Data Collection

The database of information collected for this study includes:

- topographic information (derived from orthorectified aerial photography);
- structure waterway openings;
- historical rainfall;
- historical ocean tide levels;
- historical Richmond River levels;
- historical stream gauge records in the creek system;
- floodplain peak water spot heights during several historical events; and
- physical characteristics of the floodplain as they have varied over time.

Some of this information has been retained from the previous Ballina Floodplain Management Study. Other information has been purposely collected as part of this updating study. Details are provided in Appendix A.



Catchment Delineation **Figure 2-1**

Local Area and Extents of 2D Model **Figure 2-2**

3 STUDY METHODOLOGY

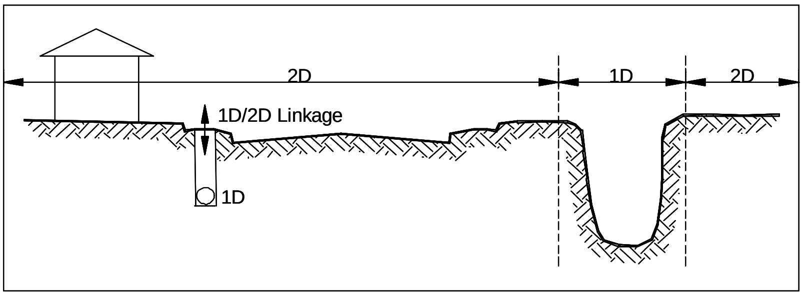
The Ballina Flood Study Update is a key step in producing an effective and accurate Floodplain Risk Management Study and Plan. In order to achieve this goal, Council has identified the need to develop a detailed 2D hydraulic model and associated GIS based flood mapping of Ballina.

BMT WBM have used the 1D/2D coupled capability of TUFLOW for the detailed hydraulic model.

3.1 Rationale for Adopted 2D / 1D Approach

The study area contains flood-prone areas with the following features:

- Significant lengths of creeks and canals where no bathymetry data exists and that would be adequately represented using a 1D hydrodynamic solution.
- Potential for significant areas to be filled, thereby possibly requiring flood mitigation works to offset the impacts (as previously identified in the Ballina Floodplain Management Study and subsequent scenarios studies).
- A number of road, disused rail and farm levee embankments that would influence the propagation of flood waters.



- Hydraulic structures (eg. culverts, bridges) that are best represented using the appropriate 1D structure equations.
- A trained river entrance with an offshore bar that would influence the intrusion of a storm surge.

Given the above characteristics, a 2D modelling approach is highly desirable for representing the floodplains and the river entrance (where bathymetry data exists). However, to correctly model the creeks, canals and smaller hydraulic structures, a 1D solution is preferred.

TUFLOW enables Council to fully utilise the existing calibrated ESTRY 1D model to define major waterways throughout the study area whilst focusing the detailed 2D modelling on areas of key interest in and around Ballina. This preserves Council's considerable investment to-date in the ESTRY model, and greater continuity on any changes to Council's flood planning controls.

3.2 Adopted Methodology

The methodology employed in this study is summarised as follows:

- Data required for the hydrologic and hydraulic modelling development and calibration including digital photogrammetric survey for the production of a Digital Elevation Model (DEM) was collected, reviewed and placed in a suitable format. This process is detailed in Appendix A.

- The hydrologic model (for the June 2005 calibration event only) and the hydraulic model were then developed. Topography, structures, land uses (impervious area) and initial roughness values were input. Details on the model development are detailed in Section 4.
- Separate models were developed for the calibration events. Historical changes to the topography and/or structures were integrated into the relevant model. The floods of March 1974 and February 1976 were used to calibrate the models as per the previous study. June 2005 was also added as a calibration event. Details of the calibration are provided in Section 5. For the March 1974 event, continuous gauge records and recorded flood levels were available. Recorded flood levels were available for the February 1976 flood event. However, stream gauge records were not available. As there are no changes to topography between the 1974 and the 1976 events, the 1976 flood event was simulated in parallel with the 1974 event to ensure changes made to one model could adequately reproduce recorded flood levels for both events. The June 2005 event was used as third calibration event and was the final model to be simulated. A hydrologic model was developed for this event, as it had not been simulated in earlier studies. Simulation results for each of these historical event simulations are presented throughout Section 5 using tables and figures.
- Once the calibration was accepted by Council and DECC, the model was used to simulate design flood events. The design flood set-up is described in Section 6. The hydrology of the previous study was extended to include flood probabilities not previously studied (5 year ARI and 500 year ARI).
- Results for 100 year ARI and 20 year ARI design flood events under existing floodplain conditions (present day topographical and land use conditions) are presented in Section 7.
- With input from Council on future infrastructure and approved development, the full range of design events under base case floodplain conditions were prepared and modelled as presented in Section 8. These cases will form the basis of future floodplain management planning.

4 MODEL DEVELOPMENT

As stated previously, the flood model consists of a hydrologic model and a 2D/1D hydraulic model. This section details the set-up of these two models for existing floodplain conditions.

4.1 Hydrologic Model

The hydrologic model determines the runoff resulting from a particular rainfall event. The hydrologic model covers the entire Richmond River catchment downstream of Broadwater. The primary outputs from the hydrologic model are hydrographs at varying locations along the waterways to describe the quantity, rate and timing of stream flow that results from rainfall events. These hydrographs then become a key input into the hydraulic model.

It was determined that the hydrology of the previous study was adequate to define the inputs to the updated 2D hydraulic model. Hence, a hydrologic model was only prepared for events not previously studied. This includes the new calibration event, June 2005, plus the 5 year ARI and 500 year ARI design floods.

For the upstream boundary on the Richmond River at Broadwater, the flood frequency analysis of the 1997 study has been updated. Refer to Appendix D.

4.1.1 Previous Model Selection and Development

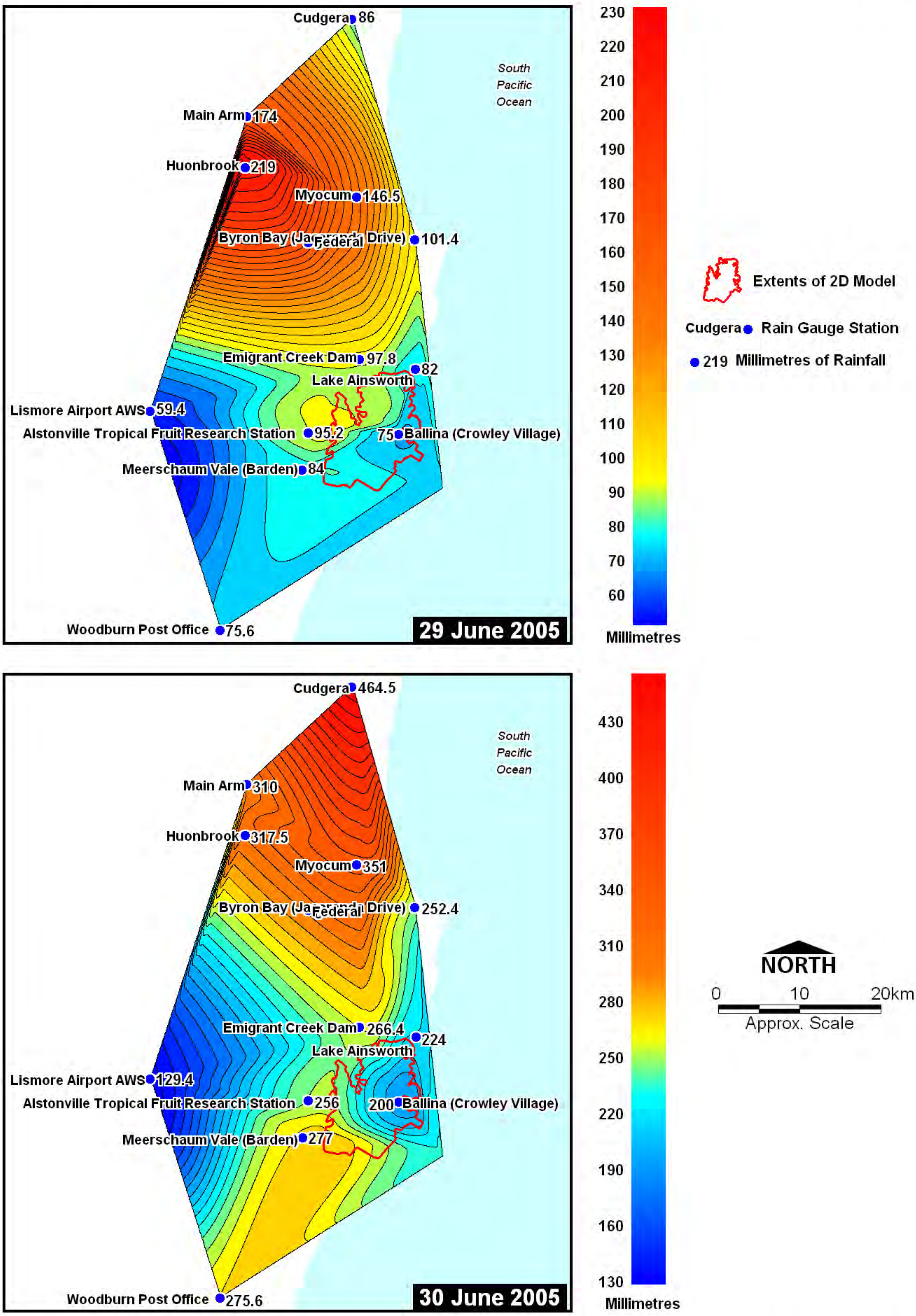
The XP-RAFTS program was used to develop the hydrology in the previous study. Catchment boundaries, sub-catchment areas and slopes were derived from 1:25,000 topographic maps of the catchment.

Local catchment flooding was determined using hydrologic models for the catchments discharging into the Lower Richmond River; Maguires Creek, Emigrant Creek, North Creek, and other minor creeks.

Suitable streamflow data for calibration of the hydrologic model was available at one location along Maguires Creek. This station has recorded data from 1973 to 1993 but was considered to be based on an extended rating curve of questionable accuracy. Based on calibration of the Maguires Creek catchment to March 1974, February 1976 and June 1983 events, similar catchment coefficients were applied to the other catchments in the study area. For each calibration event, spatial pattern (or areal rainfall distribution) was determined from total event rainfalls at the two continuous stations (Federal P.O. and Alstonville Tropical Fruit Research Station) plus daily stations at Byron Bay, Ballina (Crowley Village), and Wardell. Rainfalls at Broadwater Sugar Mill and Bangalow Motel were only used for the 1974 distribution as these stations closed in December 1975.

4.1.2 Hydrology in This Study

For the June 2005 calibration event, temporal patterns and rainfall totals were applied at Alstonville and Lake Ainsworth. Areal rainfall distribution for daily rainfall totals were derived from the rainfall data of the 13 gauging stations discussed in Appendix A as shown on Figure 4-1.



Areal Rainfall Distribution - 29 and 30 June 2005 Figure 4-1

The non-linearity exponent of –0.35 and Manning's n of 0.05 of the previous study has been applied to the June 2005 catchment modelling.

As there is no streamflow data currently recorded for any of the local catchment streams, it is not possible to undertake hydrologic calibration for this event. Instead, design rainfall losses derived in the previous study have been applied to each of the catchment models (i.e 25mm initial loss and 2.5 mm/hr continuing loss) and the resulting flow hydrographs have been combined with direct rainfall onto the floodplain at the same loss rates to produce hydraulic model results. These have then been compared with historical values at calibration points and rainfall losses revisited where calibration is not achieved.

For the 5 and 500 year ARI design floods, intensity-frequency-duration (IFD) data at Alstonville is used as per BOM's review in the previous study. Although not utilised in the model, IFD for Lake Ainsworth has been reviewed, being derived from Australian Rainfall and Runoff procedures, and hence is lower generally than that for Alstonville.

Areal reduction factors and rainfall temporal patterns for these two design floods have been taken directly from the previous study.

4.2 Hydraulic Model

The hydraulic model simulates the movement of floodwaters through waterway reaches, storage elements, and hydraulic structures. The hydraulic model calculates flood levels and flow patterns, also modelling the complex effects of backwater, roughness, overtopping of embankments, waterway confluences, bridge constrictions and other hydraulic structure behaviour across the study area.

4.2.1 2D Model Domain

This model has a 2D component that extends from Ross Lane in the north to Pimlico-Riverbank Road, Empire Vale in the south, up Emigrant Creek to Rocky Gully at Tintenbar, and up Maguires Creek to the bridges at Teven (corner Tintenbar Road and Houghlahans Creek Road). The total area of the 2D domain exceeds 115 km^2.

The coastal streams north of the river of East Ballina, Skenners Head and Lennox Head (including Lake Ainsworth) are not included in the model.

On the Richmond River, the 2D model extends from Pimlico Island to the ocean, just beyond the ends of the training walls. The lower reaches of Emigrant Creek (downstream of the Pacific Highway at Duck Creek) and North Creek (downstream of Prospect Bridge) are also characterised in 2D.

The model comprises two 2D domains as follows:

- A 10m square grid for the Emigrant Creek floodplain upstream of Maguires Creek including Sandy Flat Creek; and
- 40m square grid for the remainder of the study area.

The extent and layout of the 2D model is shown in Figure 4-2. The purpose for the multi-domain approach is to ensure sufficient representation of the topographical features in Emigrant Creek, including the Ballina Bypass.

Each square grid element contains information on ground levels, surface resistance to flow (Manning's n value) and initial water level.

4.2.2 1D Network Upstream of 2D Domain

The balance area of the Richmond River and floodplain to the south of Pimlico Island retains the 1D components from the previous Ballina Floodplain Management Study (i.e. from Pimlico to Broadwater and Bagotville Barrage on Tuckean Broadwater). Similarly, North Creek upstream of Ross Lane to 'Boronia Park' and Emigrant Creek north to the bridge on Tintenbar Road also utilise the previous 1D network.

An exception to the 1D network extent is the 2005 calibration event, for which there was no recorded data on the river at Broadwater and, hence, the 1D domain had to be shortened to Wardell. This is discussed further in Section 5.4.3.

The 2005 calibration model and design floods model use new bathymetry for cross-sections in-bank and original ESTRY model floodplain cross-sections outside the 2D model domain out-of-bank. The 1974 and 1976 calibration models use channel and floodplain sections as in the original ESTRY model.

No mapping has been produced for these networks upstream of the 2D domain. The *Wardell to Cabbage Tree Island Flood Study* covers the section of the Richmond modelled in 1D in this study.

4.2.3 1D/2D Network Within 2D Domain

Parts of the model that are characterised by 1D flood behaviour and, hence, have been modelled in 1D include the in-bank sections of:

- Emigrant Creek upstream of the Pacific Highway bridge;
- Maguires Creek upstream of the confluence with Emigrant Creek;
- Duck Creek and Chilcotts Creek to their confluence with Emigrant Creek;
- North Creek upstream of Prospect Bridge;
- The Canal for its full extent; and
- Fishery Creek from opposite Horizon Drive to its confluence with the Richmond River.

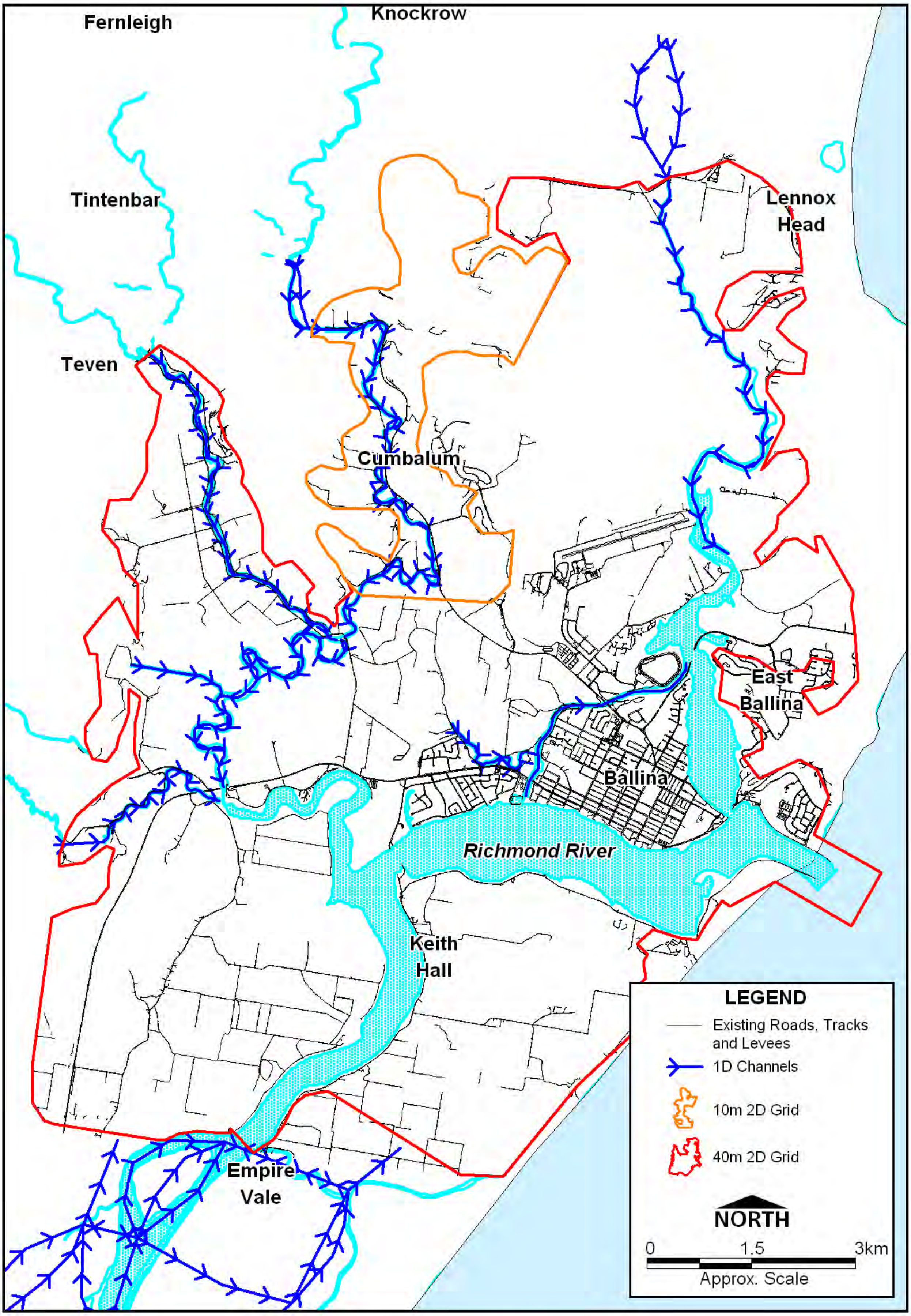
Cross-sections for each of these channels have been extracted from the original ESTRY model. Out of bank flows are modelled in the 2D domain of the model with flow transfer possible to/from each grid cell adjacent the creek section.

Mapping within these in-bank sections is achieved by interpolated flood levels between channel nodes.

4.3 Sensitivity Testing

As part of the calibration process sensitivity analyses have been carried out to test the relative effect of changing key model parameters. Model parameters that have been tested include:

- Floodplain Roughness (Manning's n)
- Creek/River/Waterway Roughness (Manning's n)
- Variation of hydrologic model parameters.



Model Layout Figure 4-2

5 CALIBRATION MODELLING

5.1 Calibration and Verification Process

Flood model calibration was carried out to three flood events: March 1974; February 1976 and June 2005. These three events represent a range of magnitudes and sources of flooding. The March 1974 and February 1976 events were previously used for calibration of the ESTRY model in the 1997 Ballina Floodplain Management Study.

The maps in this section show simulations of flooding that occurred in Ballina in 1974, 1976 and 2005 and are for calibration purposes only. These maps do not indicate the full extent of flood prone land and cannot be used to infer that any particular property is flood free.

Reasons for differences between recorded flood marks and the computer model's predictions include:

- The rainfall that occurred during the flood is recorded at more than one location within the catchment. Away from these locations, the rainfall applied to the model is an interpolation or extrapolation of these recordings, introducing uncertainty in the modelling.
- Flood marks vary in reliability from a watermark on a wall (good indicator of the flood peak) to a vague memory (poor indicator). The marks, which are shown as circles on the calibration figures later in this section, have been graded and colour coded according to their reliability as follows:
  - Red for Grade 1 (most reliable);
  - Green for Grade 2 (less reliable); and
  - Blue for Grade 3 (least reliable and discounted).

  The numbers next to the circles are:
  - the point ID (in pink); and
  - the difference in metres between the model's prediction and the flood mark (in blue).

  More information on each point is shown in the relevant table. As a general rule, the model predictions are ideally within 0.2 metres of the Grade 1 marks. For other marks, the model is ideally at or above the mark, as these marks are not necessarily representative of the flood peak, but an indicator that the flood was at least that high. The model is above the mark if it has a black triangle pointing upwards in the middle of the circle (positive number), and is below if the triangle points down (negative number).
- The hydraulic model does not include the underground pipe drainage system. This is because the additional work involved to include all the pipes in the study area would not necessarily yield any real improvement in the accuracy of the model when simulating major floods. Consequently, some areas are modelled as having no underground drainage and may show considerable extents of quite shallow inundation that may not have occurred.
- The ground level data over the floodplain is from photogrammetry (a technique that uses aerial photography to determine the level of the ground surface). The vertical accuracy of the photogrammetric ground levels on clearly visible surfaces is no more than 0.1 metres higher or lower than the true ground level. In some areas, such as under vegetation and other

obstructions, the accuracy can be considerably less. This uncertainty affects the extent of flooding predicted, particularly where wide shallow inundation is displayed.

- Any debris build-up and partial blockage of bridges, culverts and pipes, which may be the cause of more extensive flooding, were not included in the computer model simulation.
- The computer models themselves have uncertainties, as no computer model can be a perfect representation of reality. The hydraulic model presented in this report simulates flooding down to a resolution of 40 metres. Therefore, fine-scale obstructions to floodwaters such as fences, walls, small buildings, etc are only roughly represented, and any localised flood effects (e.g. water surcharging against a wall) are not depicted.

5.2 March 1974 Flood Event

5.2.1 Description

Model runs commence 09th March 1974 at 0:00. The highest predicted tide, of 0.91m AHD, was on 7th March at 07:25, hence, prior to commencement of model simulation. Richmond River levels did not peak until after 12:00 on 13th March. Spring tides were still being experienced at this time.

5.2.2 Recorded data

The data used is as per the previous 1997 Ballina Floodplain Management Study, which includes:

- Rainfall at Alstonville and Federal;
- Recorded river levels at Broadwater;
- Stream gauges on Emigrant and Maguires Ck; and
- Original floodplain points including those determined during this study.

5.2.3 Model set up

The tidal boundary was originally derived from tidal predictions for Coffs Harbour. An additional 300mm surge was added to the 1974 tidal boundary, to account for reports of elevated ocean levels along the coastline due to the cyclonic depression. The upstream boundary is based on recorded levels at Broadwater.

5.2.4 Changes to the Floodplain to Represent 1974 Topography and Land Use

The following changes were made from the present day model to represent conditions in 1974:

- Pacific Highway to the west of Ballina was lowered, generally by 300mm;
- Fill for subdivisions to the west of Ballina was removed (ground levels lowered to 0.5m-0.8m AHD);
- The Richmond River bed at the ocean outfall was lowered by 2m;
- RTA pad at Cumbalum removed (ground lowered to 0.7m AHD); and
- Cumbalum Heights and Deadmans Creek Road lowered to previous levels.

5.2.5 Replication of Recorded Levels

Table 5-1 presents the modelling results comparison for this event. Figures 5-1, 5-2 and 5-3 illustrate the recorded versus modelled flood levels for Emigrant Creek, Maguires Creek and the Richmond River respectively. Peak flood levels and depths are presented in Figures 5-4 and 5-5 respectively.

Table 5-1 Replication of Recorded Levels – March 1974 Calibration Event

Location ID	Property Owner and Address	Description	Recorded Level (m AHD)	Peak modelled level (m AHD)	Difference: Modelled level - Recorded level	Comments	Reliability Grading	Model prediction
1	Amy Fraser 24 Riverview Av West Ballina	Top of 2nd brick from garage floor level	1.75	1.44	-0.31	Possible inaccuracy due to uncertain ground levels during development of West Ballina	2	Below recorded level
2	Keith Gallaway 60 Riverside Dr West Ballina	Ground Level in back yard beside path	1.40	1.32	-0.08	Possible inaccuracy due to uncertain ground levels during development of West Ballina	2	Below recorded level
3	Gus Donaghy 117 Crane St Ballina Island	25 mm below existing floor level	1.93	1.99	0.06		1	Above recorded level
4	Grace Mitchell 65 Grant St Ballina Island	25 mm below landing at front door	1.87	2.01	0.14		1	Above recorded level
5	Jim Walsh 234 River Dr Empire Vale	Top of lounge room wall vent beside tap on north side of garage	2.16	2.15	-0.01		1	Below recorded level
6	John Felsch 971 River Dr Keith Hall	35 in yard on north side of house	1.57	1.47	-0.10		1	Below recorded level
7	Kevin Simpson 14 Uralba Rd Uralba	Mark on wall stud in garage	1.87	1.86	-0.01		1	Below recorded level
8	As per Council Orthophoto Maps		1.47	1.44	-0.03		1	Below recorded level

General notes:
Reliability Grading: 1 = Most reliable, recorded at peak of flood. 2 = Less reliable, may not have been recorded at peak of flood. 3 = Not reliable

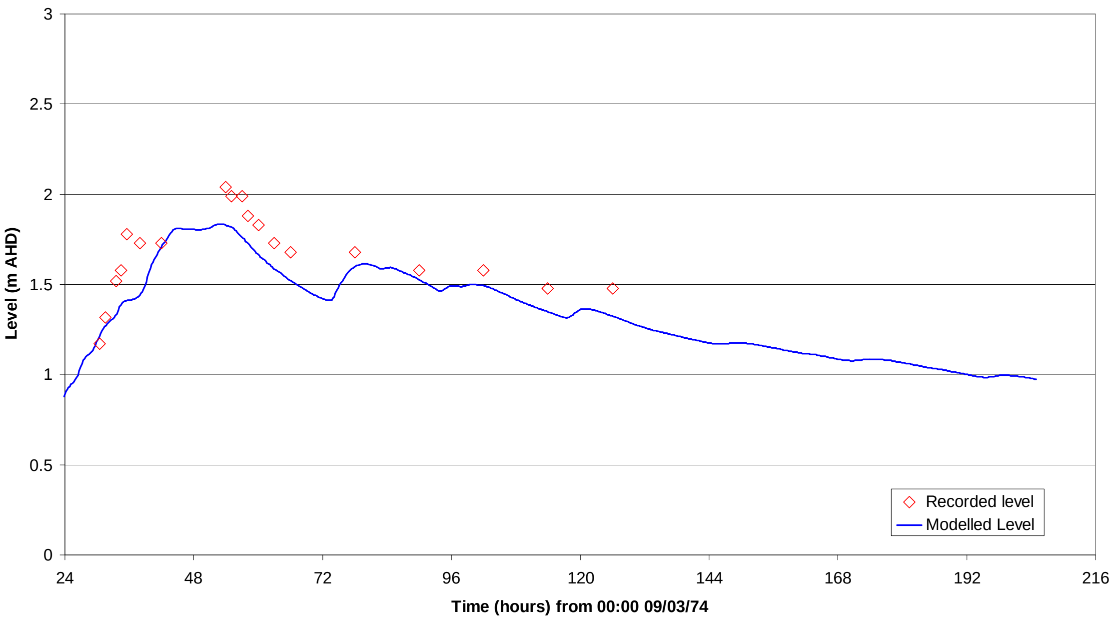


Figure 5-1 Calibration at Emigrant Creek Stream Gauge– March 1974 Event

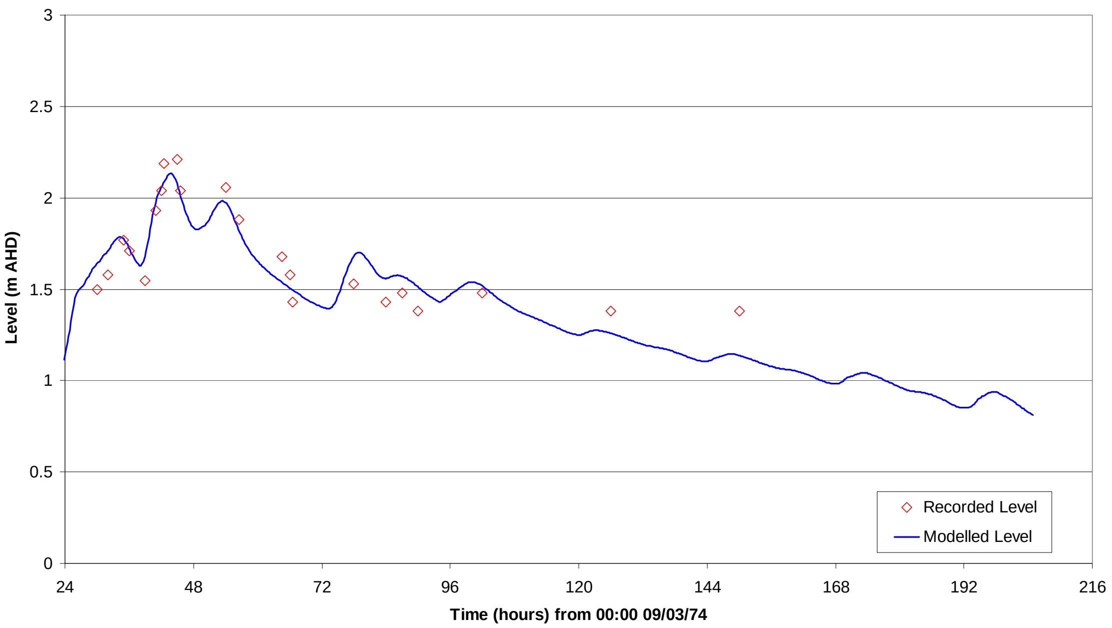


Figure 5-2 Calibration at Maguires Creek Stream Gauge– March 1974 Event

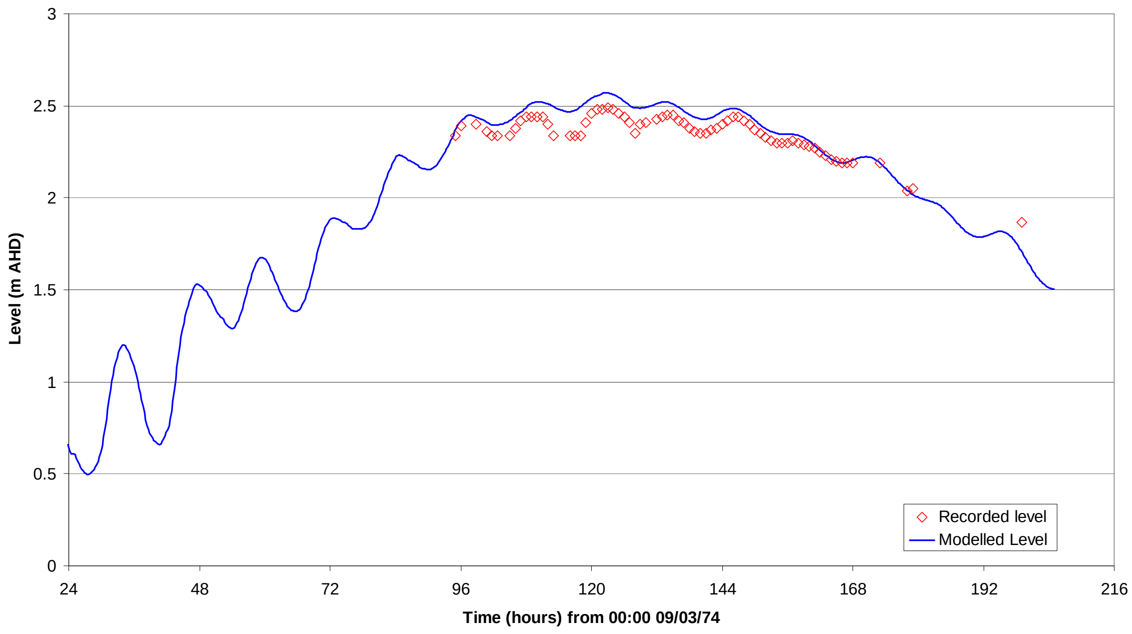
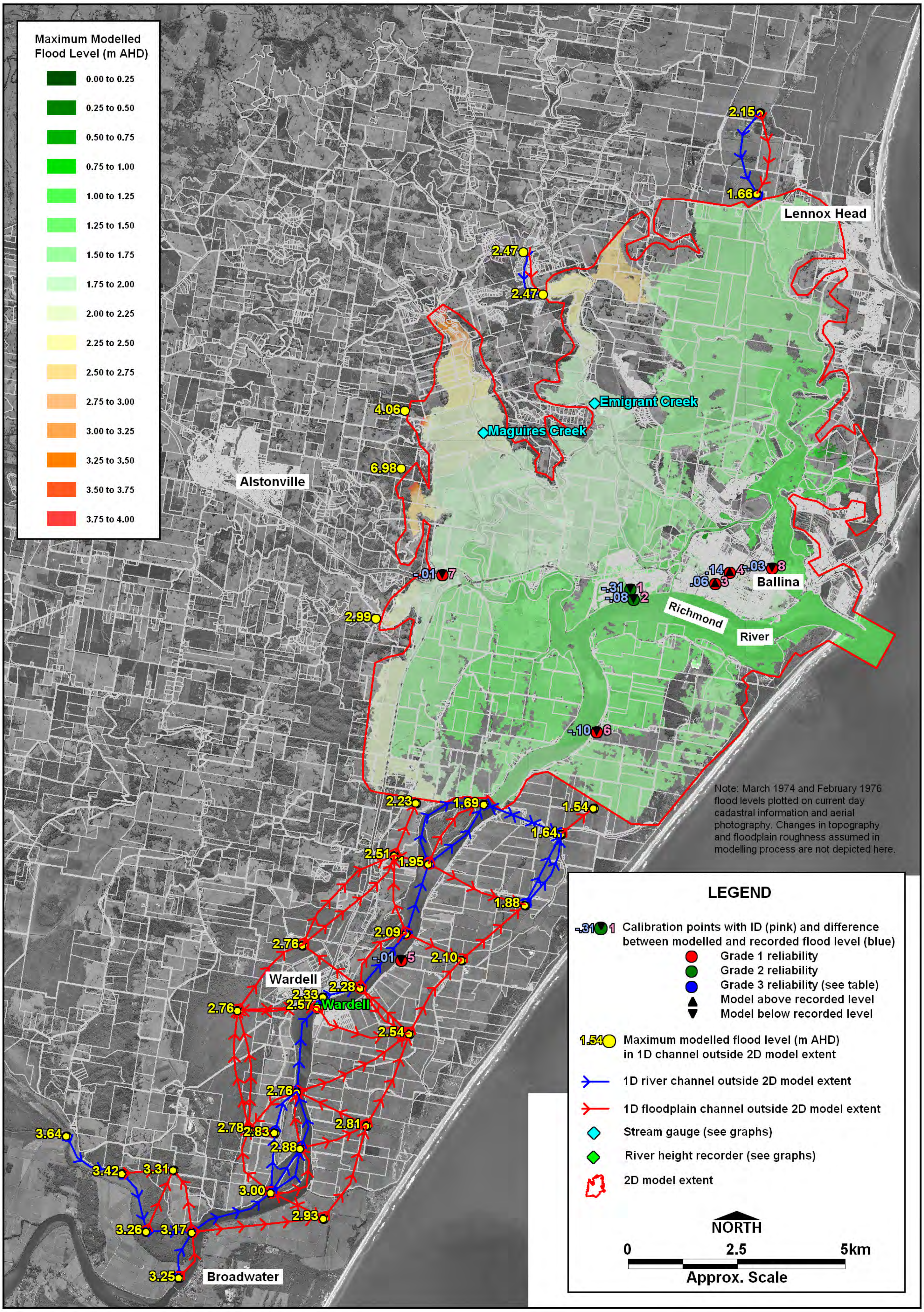
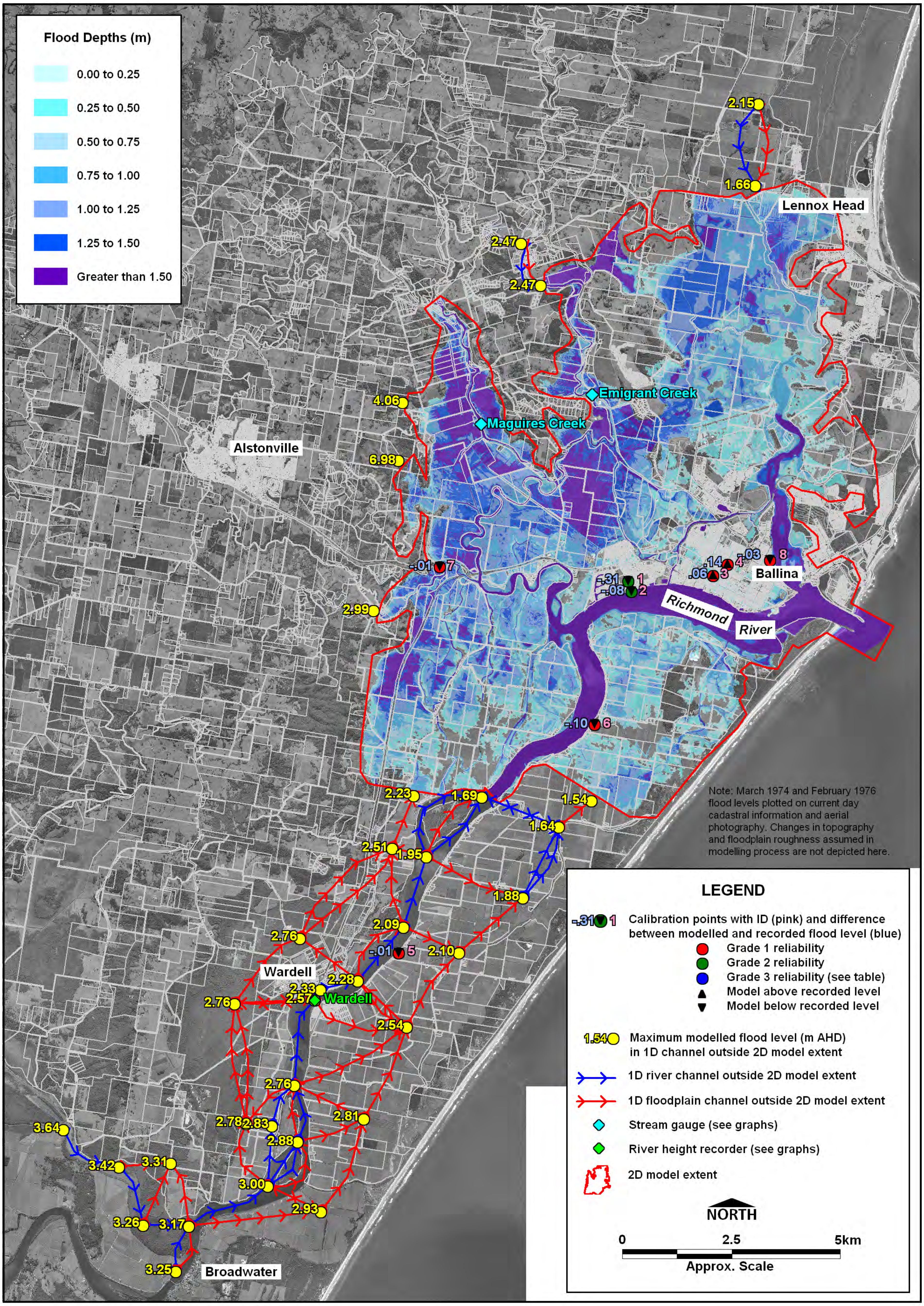


Figure 5-3 Calibration at Wardell, Richmond River Height Recorder– March 1974 Event



March 1974 Calibration Results-Flood Levels (mAHD) Figure 5-4



March 1974 Calibration Results-Flood Depths (m)

Figure 5-5

In addition to the hard evidence of the previous records, Council provided BMT WBM with a series of aerial photos taken during the 1974 flood. Model inundation at the date and time the photos were taken agree well with what can be deduced from those photos. Figure 5-6 shows the comparison.

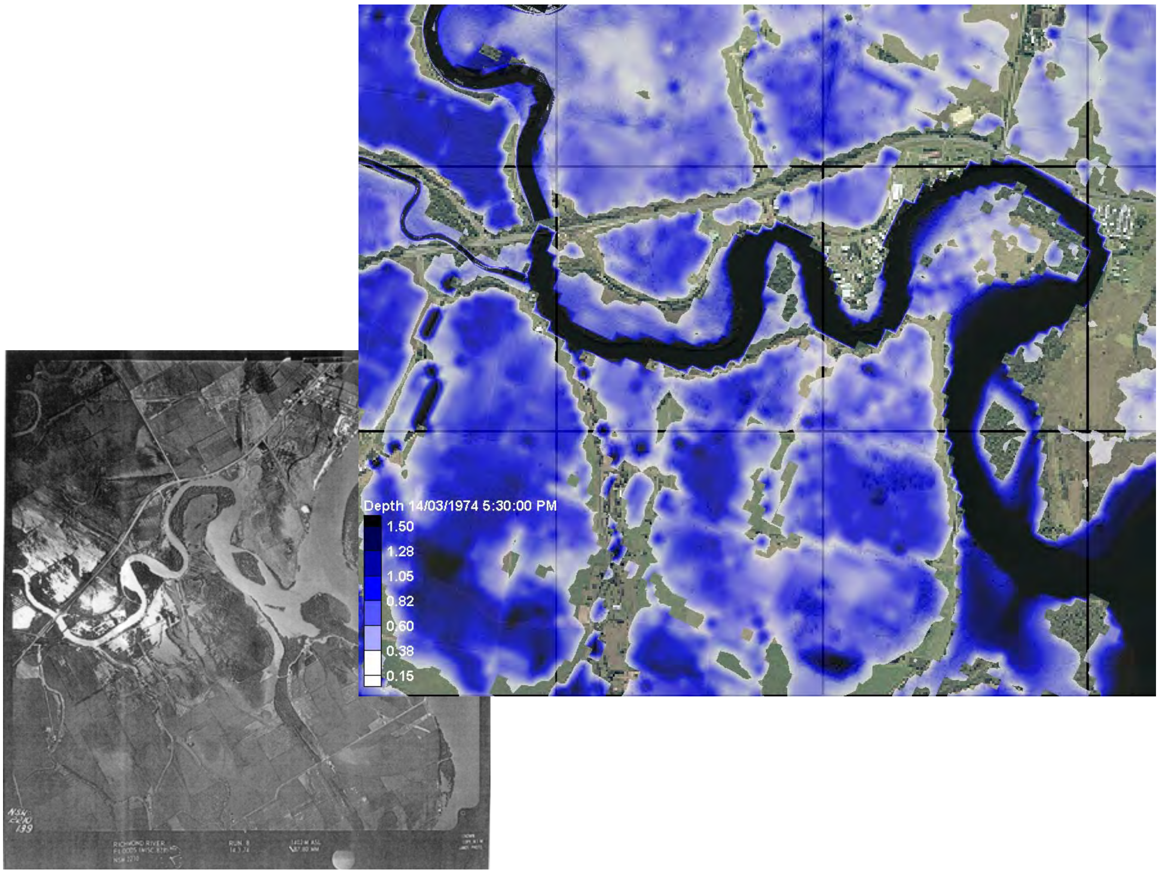


Figure 5-6 Comparison of Model Results with Inundation shown on Aerial Photography

5.2.6 Conclusions on 1974 Event Calibration

Of the eight available flood data points, six have been classified as being most reliable (i.e. Grade 1). The modelled peak flood levels for these six points are all within 150mm of the recorded peak flood levels.

The comparison between the modelled and recorded flood levels at the Emigrant and Maguires Creek stream gauges also showed a good match. Modelled flood levels at the Emigrant Creek stream gauge were generally between zero and 200mm lower than the recorded levels. Modelled flood levels at the Maguires Creek stream gauge were generally within 200mm of the recoded levels with an even distribution between higher and lower predictions compared to the recorded levels.

To conclude, given the limited calibration data available, a reasonable calibration has been achieved for this flood event.

5.3 February 1976 Flood Event

5.3.1 Description

Model runs commence 27th February 1976 at 01:00 EST (02:00 daylight savings time). The highest predicted tide, of 0.93m AHD, was earlier in the month on 16th February at 09:35. Richmond River levels did not peak until the morning of 29th February. Only neap tides were being experienced at this time with maximum predictions during model simulation of 0.78 mAHD.

5.3.2 Recorded data

Again, the data used is as per the previous 1997 Ballina Floodplain Management Study, which includes:

- Rainfall at Alstonville and Federal;
- Recorded river levels at Broadwater;
- Floodplain points; and
- Aerial photographs.

5.3.3 Changes to the Floodplain to Represent 1976 Topography and Land Use

These as are per the changes for the 1974 calibration event, but with minor changes at West Ballina to account for progress in development.

5.3.4 Replication of Recorded Levels

Council received verbal advice in September 2006 and May 2007 that four houses on Smith Drive did not flood above floor level in the 1970's. Table 5-2 shows the model is consistent with the verbal reports. The locations of the four properties are shown on Figure 5-7.

Table 5-2 Calibration at Residences on Smith Drive

Residence	Ground Level	Floor Level	1974 Flood Level	1976 Flood Level	1974 Difference
1 Smith Drive	1.10	1.8	1.35	1.17	0.5
40 Smith Drive	0.87	2.3	1.43	1.38	0.9
83 Smith Drive	1.19	2.1	1.46	1.43	0.6
87 Smith Drive	1.52	1.7	1.46	1.43	0.2

Notes: 1. All ground levels sourced from photogrammetry
2. All levels in m AHD
3. Floor levels supplied by Council surveyors
4. Flood levels are the modelled peaks taken at the main residence shown on the aerial photography

The modelling results comparison for this event are presented in Table 5-3. Peak flood levels and depths are presented in Figures 5-8 and 5-9 respectively.

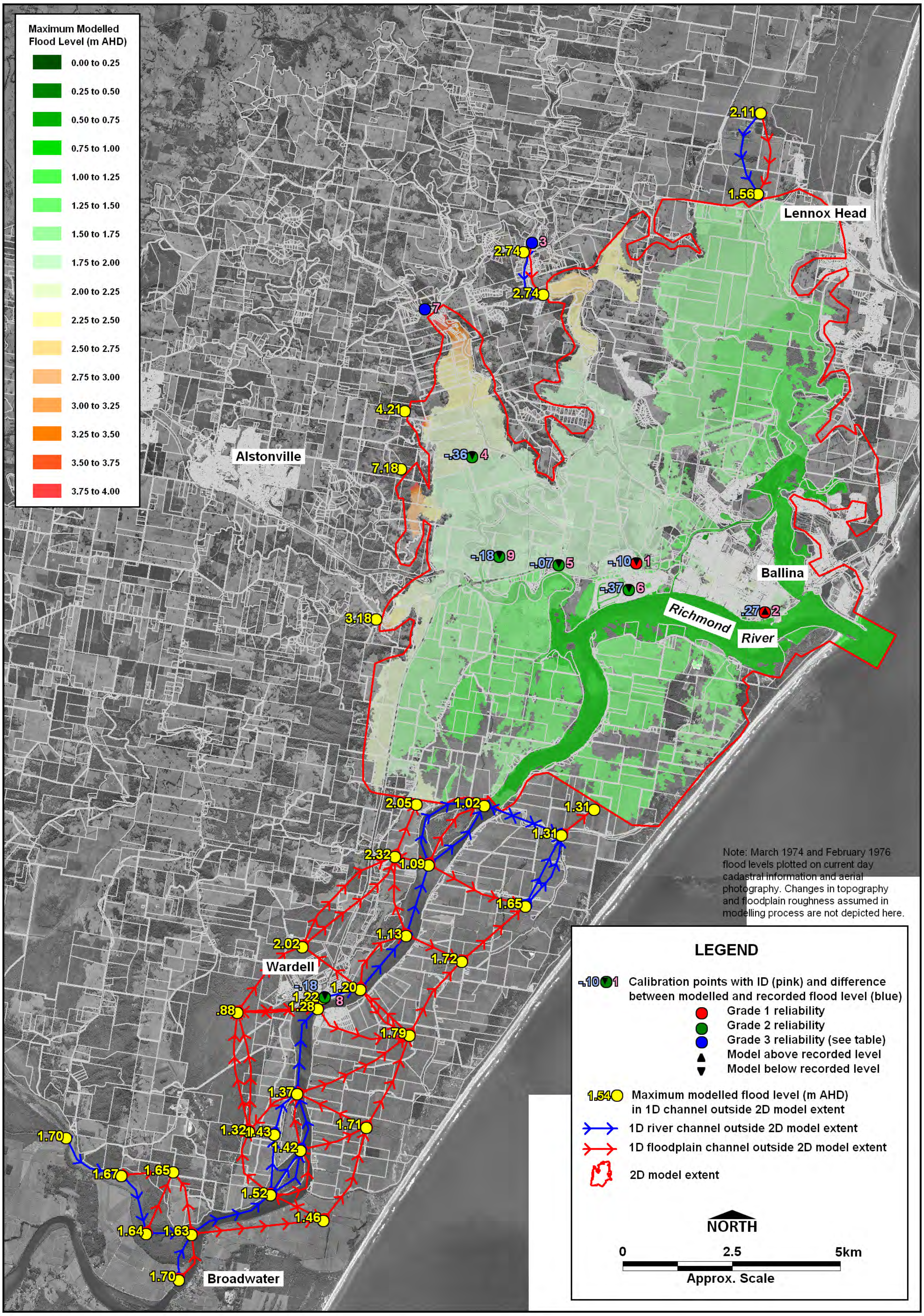
Smith Drive Property Locations **Figure 5-7**

Table 5-3 Replication of Recorded Levels— February 1976 Calibration Event

Location ID	Description	Recorded Level (m AHD)	Peak modelled level (m AHD)	Difference: Modelled level - Recorded level	Comments	Reliability Grading	Model prediction
1	Floor Level at front door of Lot 2, Barlows Road, West Ballina (Russ Ronan)	1.85	1.76	-0.10		1	Below recorded level
2	Bottom of weatherboard of 1/10 Owen St, Ballina Island (Burnice Kentwell)	1.73	1.99	0.27		1	Above recorded level
3	Old School	3.90			Discounted as outside extent of study survey	3	
4	As per Council Orthophoto Maps	2.40	2.04	-0.36		2	Below recorded level
5	As per Council Orthophoto Maps	1.85	1.78	-0.07		2	Below recorded level
6	As per Council Orthophoto Maps	1.64	1.27	-0.37		2	Below recorded level
7	As per Council Orthophoto Maps	3.86			Discounted as outside extent of study survey	3	
8	As per Council Orthophoto Maps	1.40	1.22	-0.18		2	Below recorded level
9	As per Council Orthophoto Maps	1.95	1.77	-0.18		2	Below recorded level

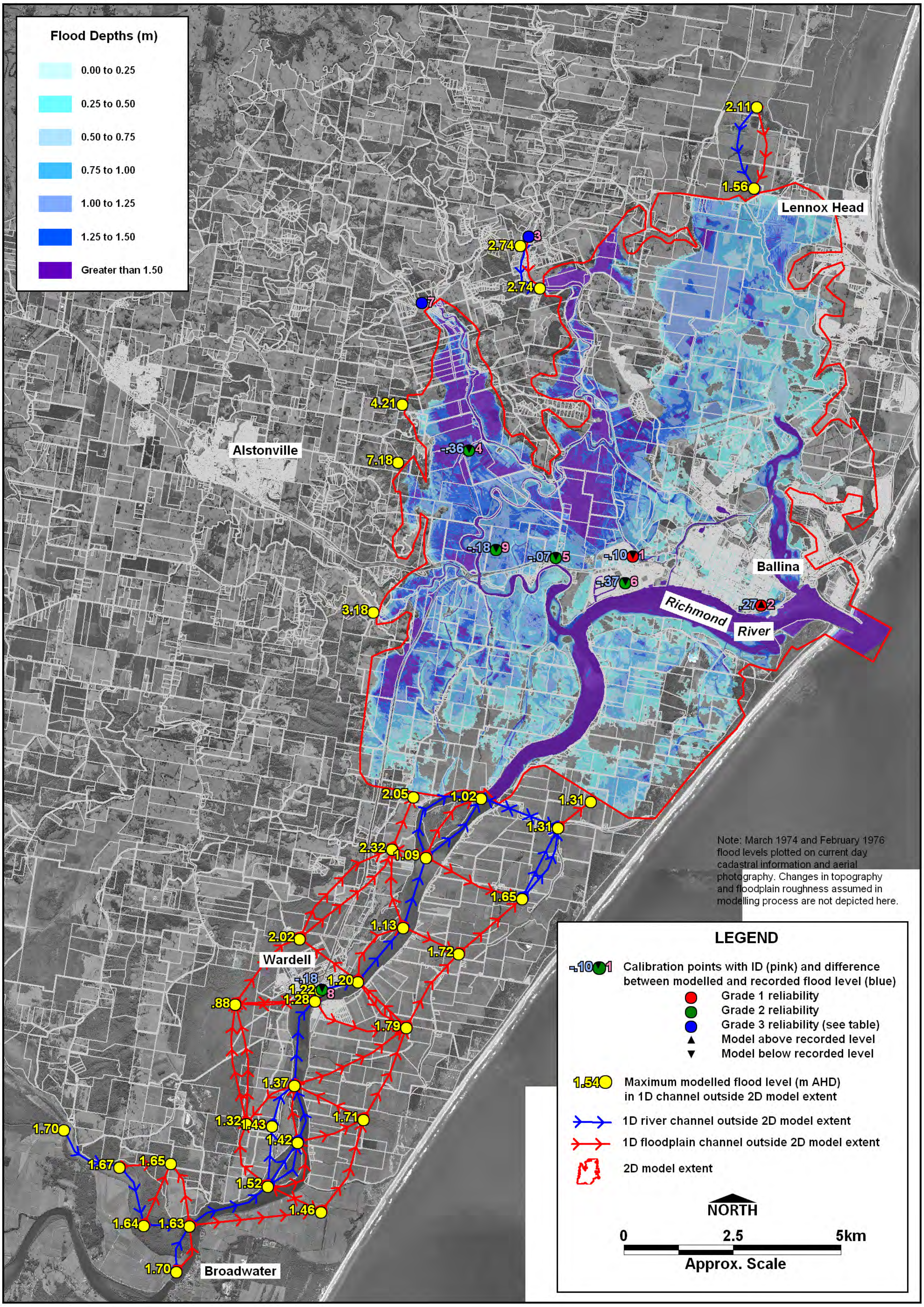
General Notes: It is possible that the datum used in surveying recorded flood levels of the points from Council Orthophoto maps is different to the survey datum used today. This may explain why the model predictions at points 4 to 9 are all below the recorded flood levels

Reliability Grading: 1 = Most reliable, recorded at peak of flood. 2 = Less reliable, may not have been recorded at peak of flood. 3 = Not reliable



February 1976 Calibration Results-Flood Levels (mAHD)

Figure 5-8



February 1976 Calibration Results-Flood Depths (m)

Figure 5-9

5.3.5 Conclusions on 1976 Event Calibration

Similar to the 1974 event, and largely due to thirty years having elapsed since the event, only limited calibration data has been made available for this event. Unlike the 1974 event, only two flood data points have been classified as being most reliable (i.e. Grade 1). Due to the limited flood data points for this event, more emphasis has been placed upon the use of Council orthophoto maps for the determination of peak flood levels.

The two flood data points are within 100mm and 270mm of the modelled peak flood level. Five points were used from the orthophoto maps. Predicted flood levels are all within 70mm and 370mm lower than the recorded equivalent. There is some uncertainty regarding the datum having been used between the surveyed data points and the datum used in the flood modelling. This may explain why all modelled flood levels are below the recorded levels.

Stream gauges on Emigrant and Maguires Creeks were not available for this event.

To conclude, and similar to the 1974 event calibration, given the limited data available, a reasonable calibration has been achieved for this event.

5.4 2005 Flood Event

5.4.1 Description

In late June 2005, a slow-moving upper low in Western NSW was coupled with a strong high feeding moist NE winds into a deep trough on the East Coast. These conditions caused a significant rainfall event in SE QLD and NE NSW. Heavy showers started across the region on 27th June 2005. By the afternoon of 29th June, heavy rainfall was occurring across the Northern Rivers and the SE QLD coast, continuing until the morning of 30th June when rainfall began to ease. Over the 48 hour period until 09:00 on 30th June, falls of up to 500mm had been recorded in the Wilsons River catchment upstream in the Richmond Valley.

Woodburn P.O. recorded a daily rainfall total of 276mm, although only minor flooding was experienced at Woodburn. Alstonville Tropical Research Centre had its highest recorded daily rainfall of 256mm. On 30th June, the Pacific Highway was closed 3km north of Ballina.

Model runs commence 28th June 2005 at 12:30. The highest predicted tide did not occur until the flood had receded in early July. Richmond River levels at Wardell did not peak until the evening of 1st July.

5.4.2 Recorded Data

5.4.2.1 Richmond River

The Broadwater Gauge station at the Sugar Mill no longer records continuous hydrographs of river levels and now only records annual maximum levels. As the flood did not reach ‘minor flood’ level at the new SES Broadwater Gauge further upstream (beyond the bridge), no record of flood level was kept here. The flood level was recorded at Wardell throughout this event and in the absence of recorded levels at Broadwater, this data was used as the upstream boundary for the flood model for this calibration event. The recorded flood level at Wardell, as provided by Manly Hydraulics Laboratory (MHL), is shown in Figure A-8 in Appendix A. The peak flood level at Wardell was 1.13m AHD which was recorded between 18:30 and 19:30 on 1st July 2005.

Flood level hydrographs were also recorded on the Richmond River at Missingham Bridge and at Burns Point Ferry and are shown in Figures A-6 and A-7 respectively. This data was used for calibration of the model at these locations. The Burns Point data was obtained from Manly Hydraulics Laboratory and was used with a 0.78m datum shift surveyed by Council. The Missingham Bridge data (the Ballina backup gauge) was also obtained from MHL and was used with a 1.02m datum shift surveyed by Council. The recorded data at Missingham Bridge shows heavy noise around the high tides that may have been caused by wave interference at this gauge.

Ocean levels

Ballina tide gauge recorded levels to LWOST datum throughout the June 2005 event, which are shown in Figure A-5 in Appendix A. These were used as the downstream boundary for the flood model for this calibration event. Note that this figure is produced assuming that LWOST is ≈0.80m below AHD (i.e. LWOST is equivalent to MLWS).

Rainfall

Figure 4-1 shows the spatial distribution of the daily rainfall totals for 30th June 2005. This shows that the highest recorded rainfall totals were to the north of Ballina and the local catchments. Within the study area the recorded daily rainfall was greater on the higher parts of the catchment at the Alstonville Tropical Fruit Research Station and the Emigrant Creek Dam with lower daily totals recorded at the coastal gauges of Lake Ainsworth and Crowley Village (Ballina).

Figure 5-10 shows the hourly rainfall data recorded at Alstonville for eight days from 00:00 on 25th June. The most intense rain during this event fell between 06:00 on 28th June and 12:00 on 30th June. The peak recorded hourly rainfall was 30.25mm at 21:00 on 29th June.

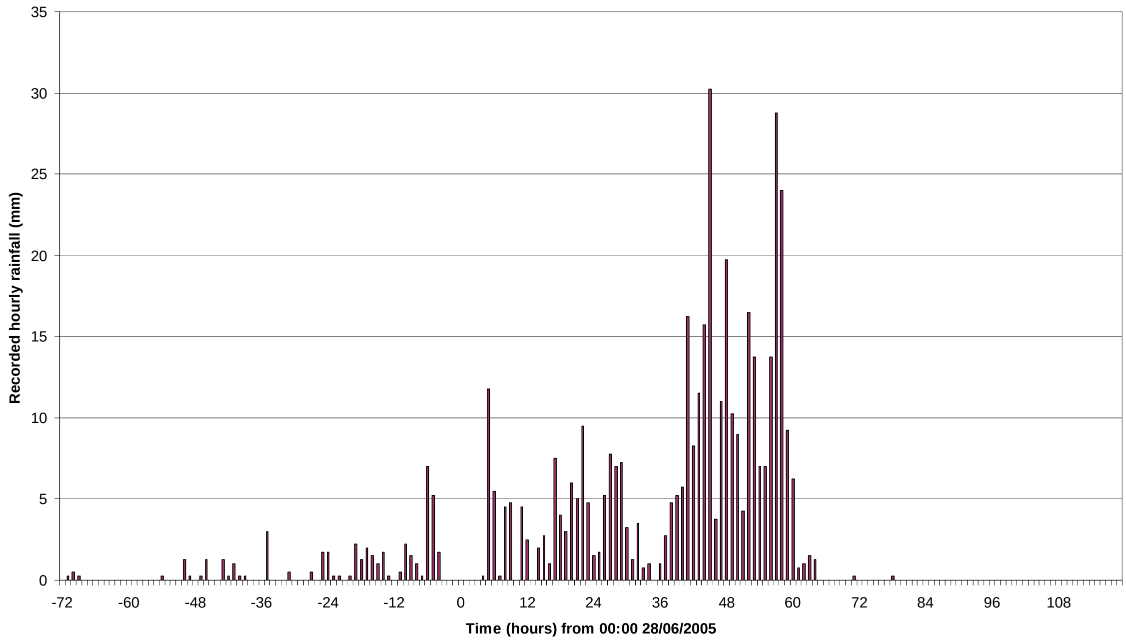


Figure 5-10 Recorded Alstonville Rainfall – June 2005 Calibration Event

Figure 5-11 shows the fifteen minute recorded rainfall data at Lake Ainsworth for four days from 28th June. The most intense rainfall recorded at this gauge fell between 12:00 on 29th June and 12:00 on 30th June. The highest recorded fifteen minute total was 23mm at 06:45 on 30th June.

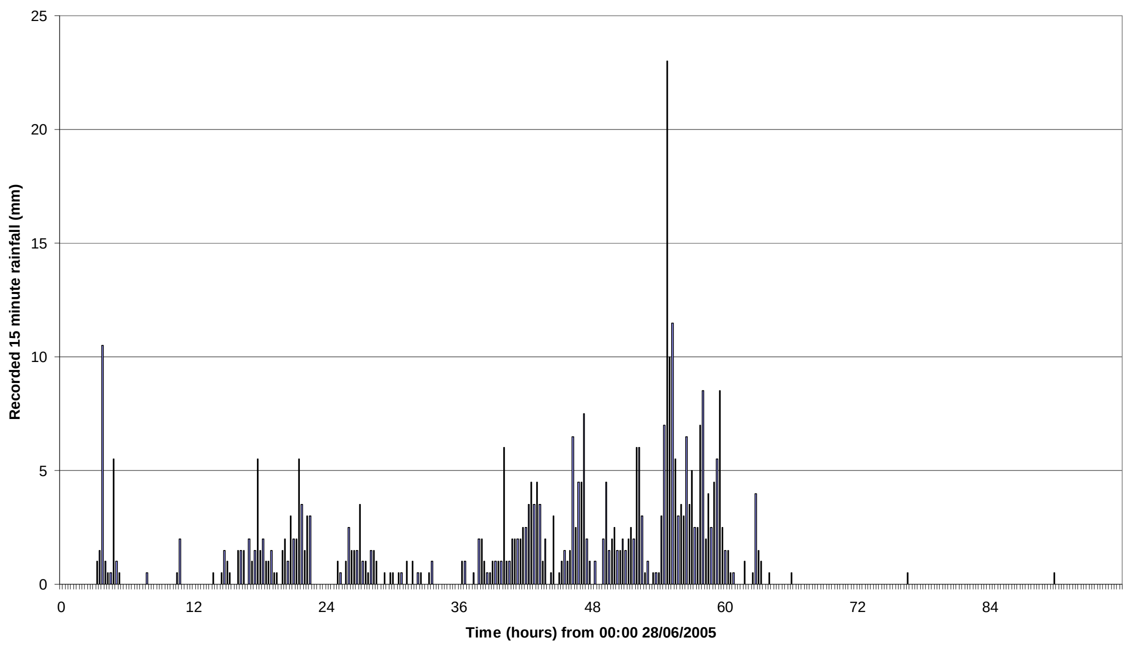


Figure 5-11 Recorded Lake Ainsworth Rainfall – June 2005 Calibration Event

Floodplain levels

There are sixteen points with recorded flood levels for the June 2005 flood event which were located as part of the 2005 community flood survey process. The recorded flood levels have been reported mostly from debris lines and photographic evidence. The locations of these sixteen floodplain points are shown on Figure 5-14 and Figure B-11 in Appendix B. Council collected level information for these points where appropriate. Further verification of the model was undertaken using photographs, media reports and anecdotal evidence.

5.4.3 Model set up

The upstream extent of the flood model on the Richmond River was moved downstream from Broadwater to Wardell because there was no recorded level data at Broadwater for this event. The recorded flood levels at Wardell were used to form the upstream boundary of the 1D model on the Richmond River.

At the downstream end of the model the boundary was moved in from the ocean to the location of the Ballina tide gauge shown on Figure 5-14 and Figure A-11 where levels were recorded for this event.

The topography used for the 2005 calibration event was developed from the photogrammetry data collected for this study in late 2004 and the surveyed bathymetry captured in September 2004 under DECC's Estuary Program (Refer Appendix A). This data was believed to fully represent the topographical situation in June 2005 and no adjustments were undertaken.

The Manning's n roughness values used in this scenario are shown in Table 5-5. The same roughness values were used in all three calibration events.

5.4.4 Replication of Recorded Levels

Table 5-4 presents the modelling results comparison for this event. Figures 5-12 and 5-13 illustrate the recorded versus modelled flood levels for the stream gauges at Missingham Bridge and Burns Point respectively. Peak flood levels and depths are presented in Figures 5-14 and 5-15 respectively.

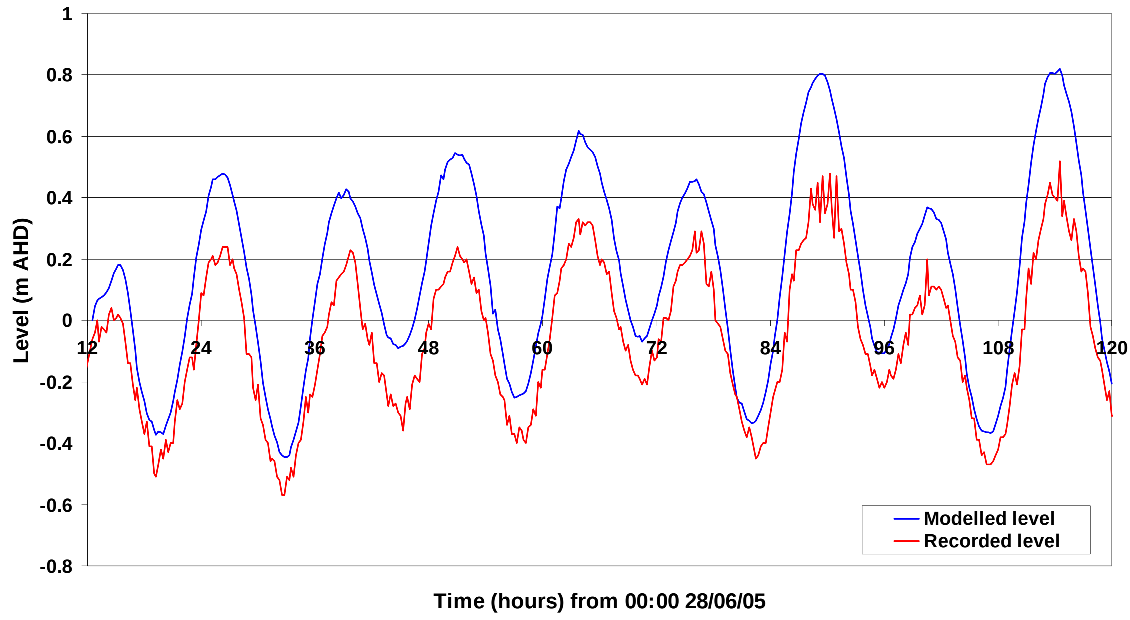


Figure 5-12 June 2005 calibration: Stream Gauge at Missingham Bridge

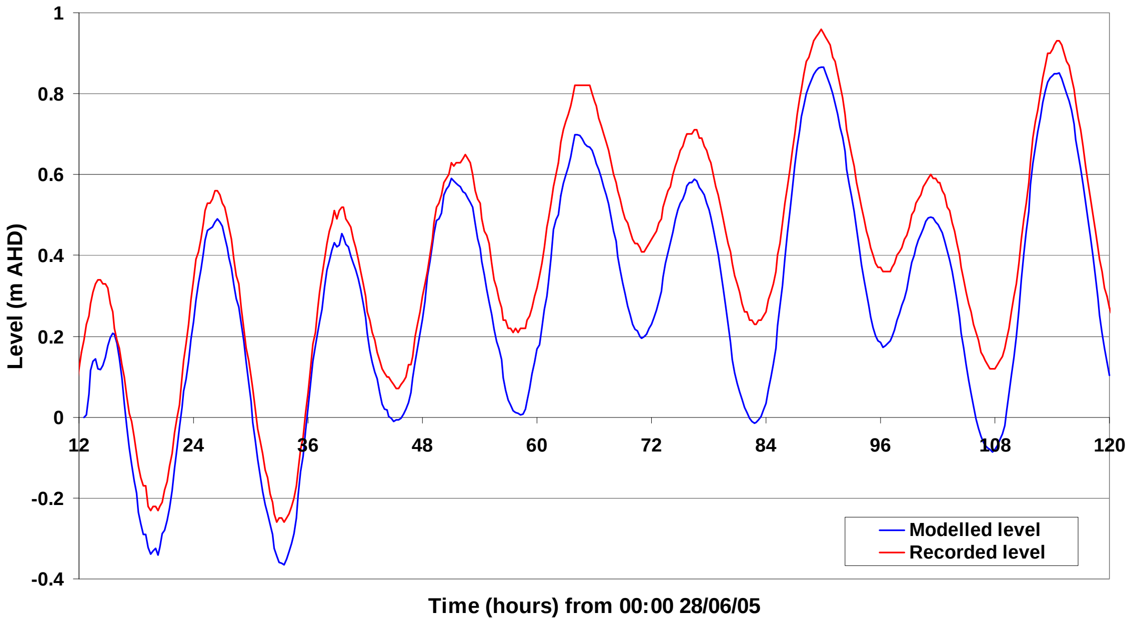


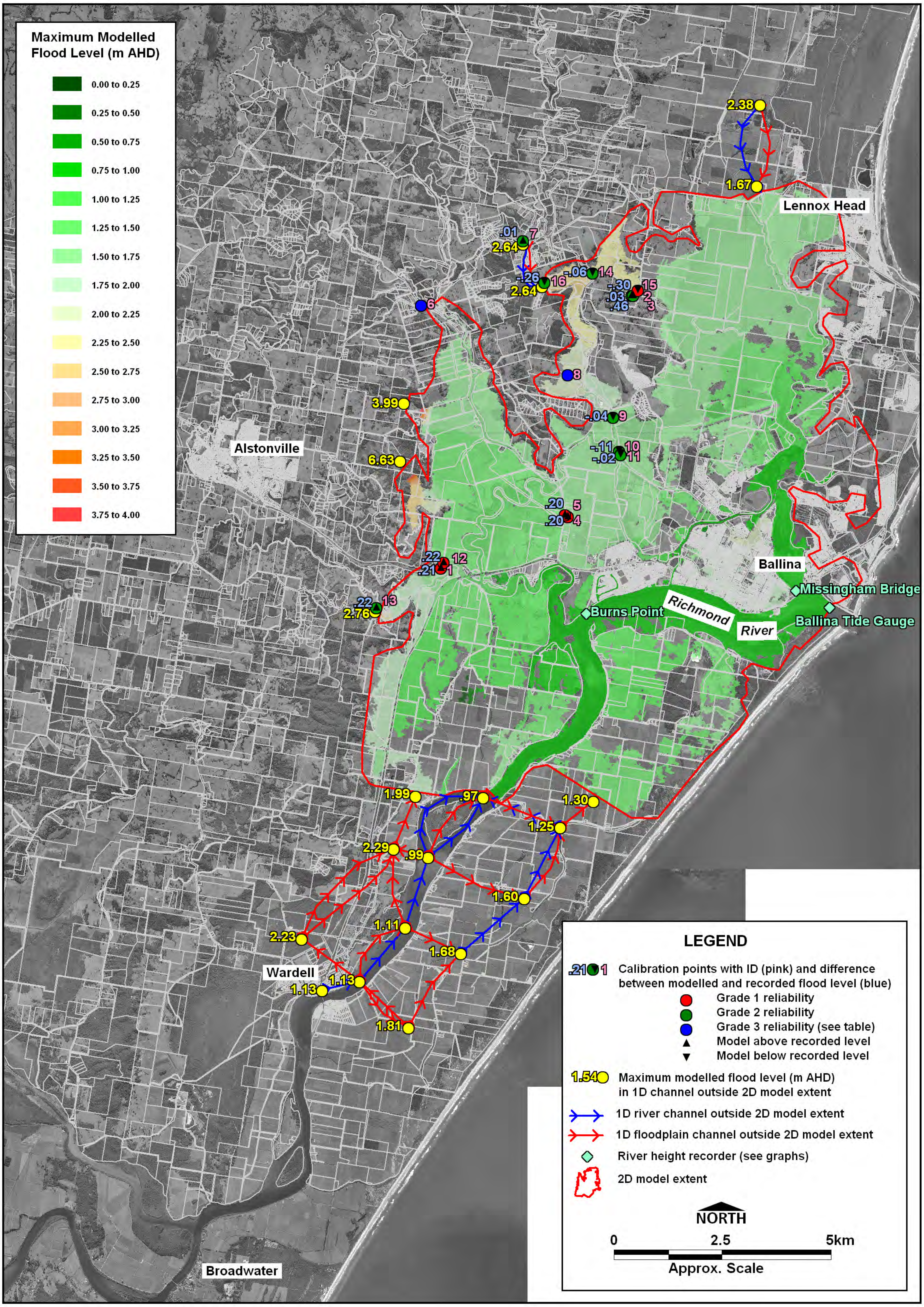
Figure 5-13 June 2005 calibration: Stream Gauge at Burns Point

Table 5-4 Calibration Results - June 2005 Calibration Event

ID	Description	Recorded Level (m AHD)	Peak modelled level (m AHD)	Difference: Modelled level - Recorded level	Comments	Reliability Grading	Model prediction
1	14 Uralba Road. Recorded level on fibreglass tank outside - top of middle rung (Kevin Simpson)	1.48	1.69	0.21		1	Above recorded level
2	Water level on Sandy Flat Road (1.25km east of Pacific Highway). Estimated from photo	2.39	2.42	0.03		2	Above recorded level
3	Water level on Sandy Flat Road (1.35km east of Pacific Highway). Estimated from photo	1.97	2.42	0.46		2	Above recorded level
4	B&B Timbers. Water mark on door and counter of office	1.30	1.50	0.20		1	Above recorded level
5	B&B Timbers. Level at front gate	1.30	1.50	0.20		1	Above recorded level
6	Teven Road Flood Level. Road closed Thursday AM (30/06/05)	4.84			Discounted as outside extent of study survey	3	
7	Fernleigh Road closed Thursday AM (30/06/05). Recorded level not peak of flood	2.63	2.64	0.01	On the edge of model extent	2	Above recorded level
8	Peak flood level at Anderson's (Cumbalum Road) from surveyed levels and photos	2.70			Discounted due to survey inaccuracy	3	
9	Pacific Highway at Cumbalum. (Photos available)	1.69	1.65	-0.04		2	Below recorded level
10	Pacific Highway south of Cumbalum. (Photos available)	1.70	1.59	-0.11		2	Below recorded level
11	Pacific Highway south of Cumbalum. (Photos available)	1.60	1.58	-0.02		2	Below recorded level
12	Peak level of water across Bruxner Highway. Road closed Thursday PM (30/06/05)	1.30	1.52	0.22		1	Above recorded level
13	Debris level at Uralba Road south of Bruxner Highway	2.54	2.76	0.22	On the edge of model extent	2	Above recorded level
14	Debris line at intersection of Pacific Highway and Sandy Flat Road	2.67	2.61	-0.06		2	Below recorded level

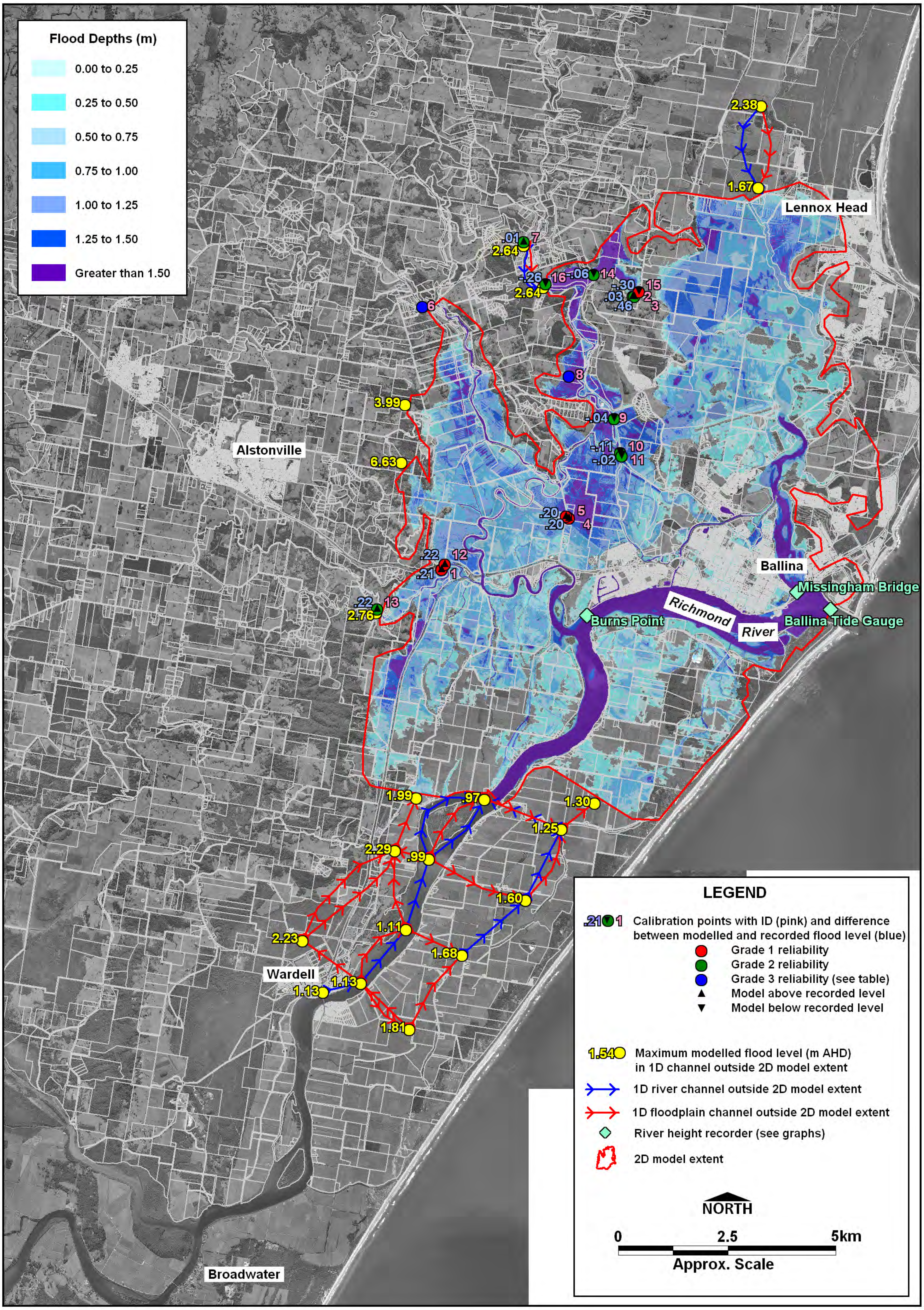
ID	Description	Recorded Level (m AHD)	Peak modelled level (m AHD)	Difference: Modelled level - Recorded level	Comments	Reliability Grading	Model prediction
15	Flood level in Barlow's shed	2.72	2.42	-0.30		1	Below recorded level
16	Flood level at Hayter's property	2.90	2.64	-0.26		2	Below recorded level

General notes:
Reliability Grading: 1 = Most reliable, recorded at peak of flood. 2 = Less reliable, may not have been recorded at peak of flood. 3 = Not reliable



June 2005 Calibration Results-Flood Levels (mAHD)

Figure 5-14



June 2005 Calibration Results-Flood Depths (m)

Figure 5-15

The RTA provided BMT WBM with a series of photos taken during the June 2005 flood. Model inundation at the date and time the photos were taken agree well with what can be deduced from those photos. Refer to Figures 5-16 and 5-17.

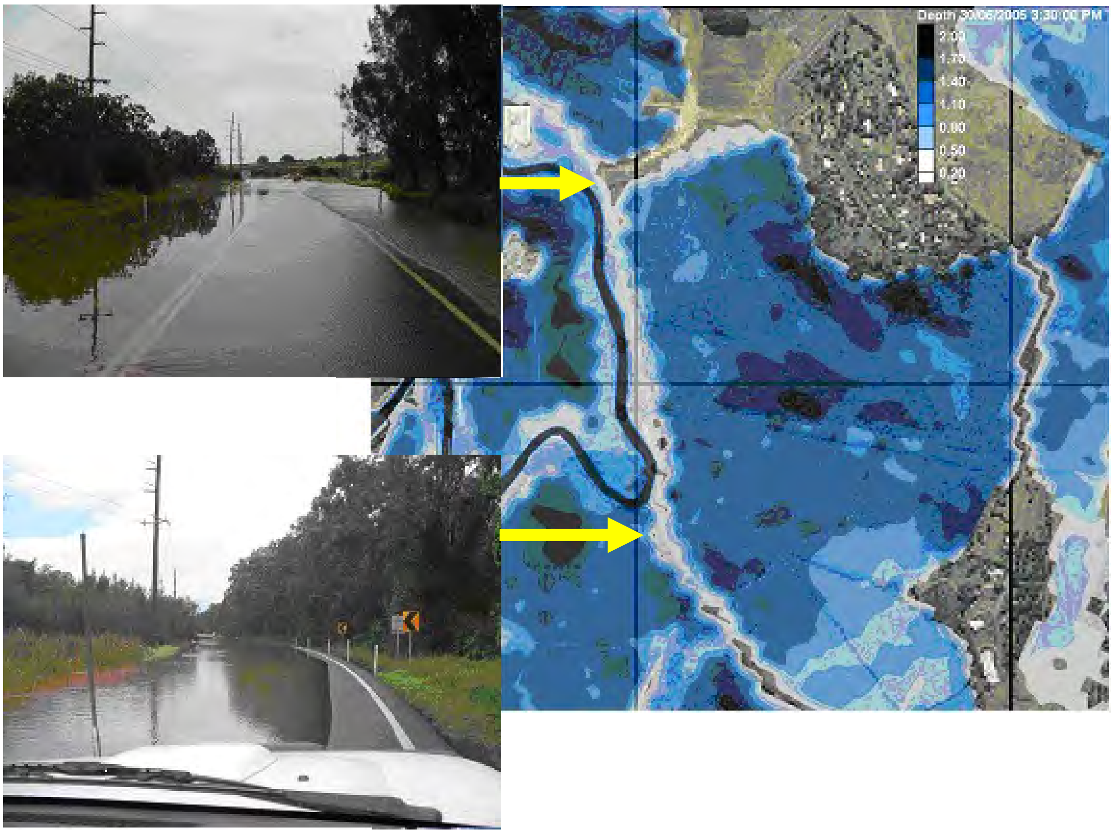


Figure 5-16 Comparison of Model Results with Inundation shown on Photography on Pacific Highway adjacent Emigrant Creek

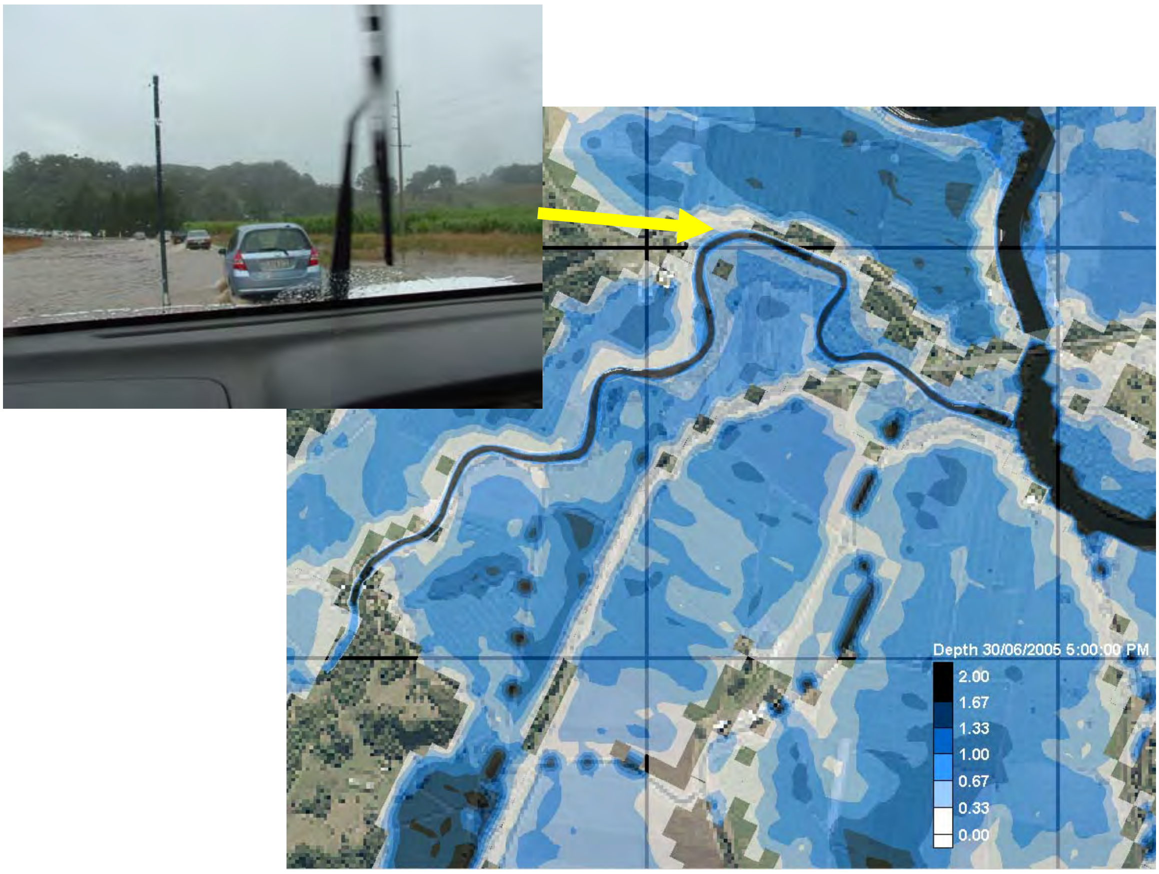


Figure 5-17 Comparison of Model Results with Inundation shown on Photography on Bruxner Highway adjacent Pacific Highway Intersection

Discussions were held with Mr Bob Boyes of B&B Timbers on Teven Road as part of investigations for the RTA's Ballina bypass project. Mr Boyes noted that the flood peaked at 21:00 on 30th June 2006.

Whilst the calibration run showed peak flood levels between 14:00 and 16:00 on the same day, the model indicates no discernible differences in flood levels between these three times. Mr Boyes provided photos of debris marks in the office and commented that the flood reached 'waist height' at the front fence. He noted at this time that water was flowing, unusually, from east to west.

Figure 5-18 shows good agreement with this evidence. Modelled peaks were only 0.2m above the recorded value in the office surveyed by Council. In addition, the calibration run shows water initially building up out the front of his property, as per his comments about initially moving the timber to the back of the property, before floodwaters arrived from the east. Peak depths in the sag on the bend of Teven Road were modelled at 0.75m.

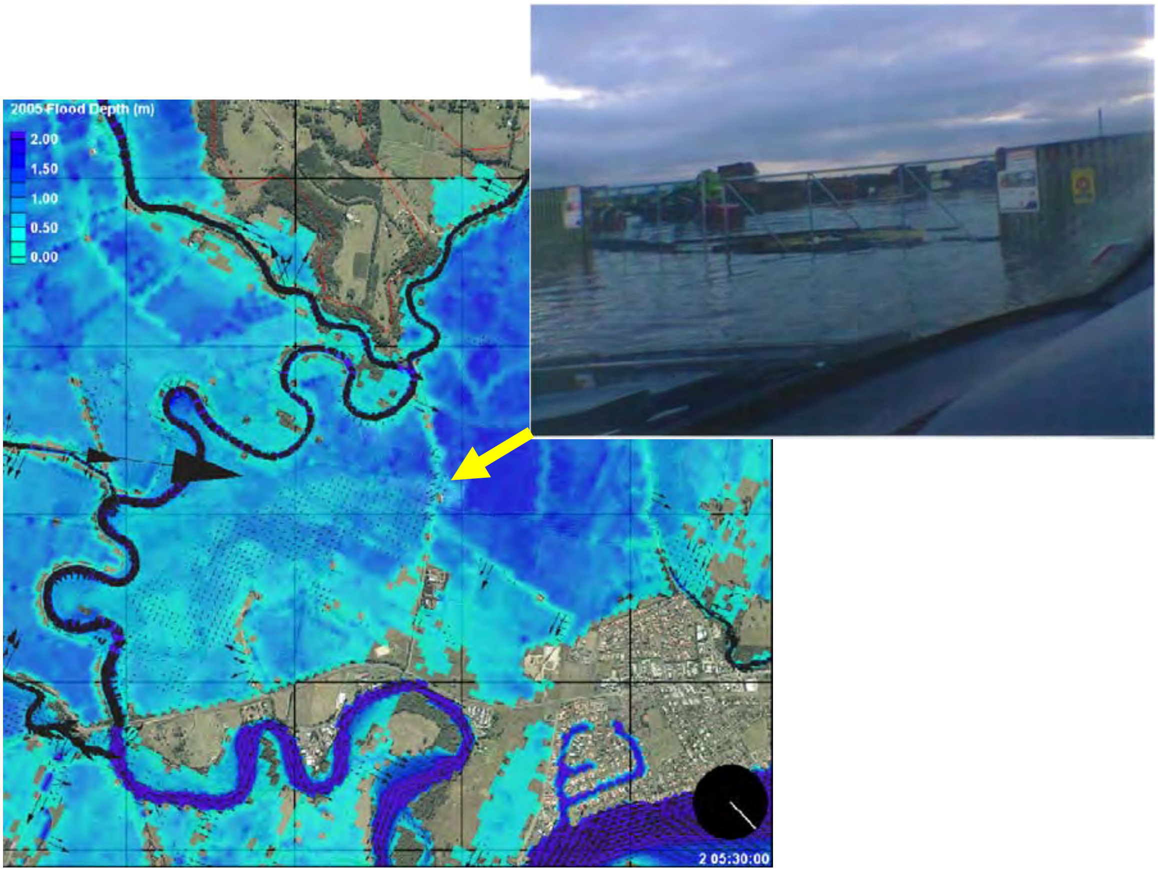


Figure 5-18 Comparison of Model Results with Inundation shown on Photography on Teven Road adjacent B&B Timbers

5.4.5 Conclusions on 2005 Event Calibration

More data has been made available for this flood event than the two previous 1970's events. For this event, 16 flood data points were surveyed; five were classified most reliable (i.e. Grade 1), nine less reliable (i.e. Grade 2) and two were discounted.

The five most reliable recorded data points are within 300mm of the modelled results. Eight of the nine less reliable data points are within 260mm of the modelled peak flood levels, with the ninth being modelled as 460mm higher than the recorded equivalent. It should be noted that this point was estimated from a photograph.

At the Missingham bridge stream gauge, the modelled flood levels are consistently 100mm to 200mm higher than the recorded levels. At the Burns Point stream gauge, the opposite trend is present, with the modelled flood levels being consistently between 100mm and 200mm lower than the recorded levels.

Although, more data is available for this event than the 1970's events, there is still less than adequate data to undertake a more thorough calibration. Given the limited dataset, a reasonable calibration has been achieved.

5.5 Calibration Results

The flood model has been calibrated to three historical flood events, all achieving a reasonable calibration. The key variable determined during the calibration process is the surface roughness.

Manning's *n* values for floodplain regions vary depending on the vegetation type and the stage of growth of the vegetation, particularly for crops such as sugar cane. The Manning's n values listed in Table 5-5 were adopted. These agree well with calibration results from the 1997 Ballina Floodplain Management Plan, also presented in the same table.

Table 5-5 Manning's 'n' Values

Vegetation Type	TUFLOW Model	ESTRY Model
Township Areas	1.000 for buildings 0.025 for roads	0.040
Lightly Vegetated Fields	0.050	0.060
Mature Sugar Cane	0.150	0.150
Dense Swamp Vegetation	0.150	0.200
Bed of Creeks & River	0.022	0.022
Lightly Vegetated Creek	0.070	0.028-0.100
Maintained Grass	0.035	-

6 DESIGN EVENT MODELLING

6.1 Introduction

To enable the hydraulic model to be used as a decision support tool for catchment management, design event modelling has been undertaken. The objectives of the design event modelling include:

- To assess the potential impacts of climate change;
- To assess the flooding behaviour of the catchment resulting from a variety of storm events;
- To determine minimum fill levels across the floodplain;
- To assess the impacts of future development on the catchment; and
- To devise strategies for the mitigation of impacts caused by future development.

6.2 Model Parameters

The following model parameters have been adopted following the calibration process.

Manning's n values adopted are the same as those for the 2005 calibration event as presented in Table 5-5. Land use on the catchment remains unchanged from the 2005 calibration event modelling.

Rainfall losses of 25mm initial loss and 2.5mm/hr continuing loss have been applied both directly on the floodplain and to hydrological model local catchment inflows on the hydraulic model boundary. Losses remain unchanged from the previous floodplain management study.

6.3 Design Floods

Six design flood events have been modelled as part of the Ballina Flood Study Update. The six events are the 5, 20, 50, 100 and 500 year ARI flood events and the probable maximum flood (PMF). Only the 20 and 100 year ARI flood events have been mapped for the existing catchment conditions. All flood events have been used for the base case modelling described in Section 8.

The 100 year ARI flood is a hypothetical flood or combination of floods that represents the worst case scenario likely to occur once every 100 years on average (that is, the flood or combination of floods likely to have a 1% chance of occurring in any one year).

The probable maximum flood is a hypothetical flood or combination of floods that represents an extreme scenario and is only used for special purposes where a high factor of safety is recommended, or in consideration of floodplain planning (e.g. evacuation and isolation of communities).

6.3.1 Sources of Flooding

The three main sources of flooding in Ballina are:

- Richmond River flooding;
- Local catchment flooding (in Emigrant, Maguires and North Creeks); and
- Flooding from ocean storm tides.

These three sources are represented in the flood model by:

- Stage (flood level) versus time relationships at Broadwater and the Bagotville Barrage which form a boundary at the upstream extent of the model on the Richmond River;
- Flow versus time relationships representing local catchment runoff into the upstream extents of the model on Emigrant, Maguires, North and other creeks. Rainfall is also applied onto the floodplains in the model; and
- Level versus time relationships representing the ocean level at the downstream extent of the model.

The design flood modelling undertaken for this study accounts for all three sources of flooding. This is further described in Section 6.3.5.

6.3.2 Richmond River Flooding

The Richmond River is modelled in this flood study update between Broadwater and the ocean at the river entrance. The design flood levels used as the upstream boundary for this study have been derived from a flood frequency analysis of recorded flood levels at Broadwater Sugar Mill.

A flood frequency analysis of recorded levels at Broadwater was undertaken for the 1997 Ballina Floodplain Management Study based on a 73 year record of historical peak levels from 1917. During the period since 1989 there have been no flood events at the Broadwater gauge which reached the threshold at which the SES record level data. Despite there having been no further recorded levels at Broadwater the flood frequency analysis has been revised for this study using an extended record period of 89 years.

As part of the revision process, the recent ALS data was used to redefine the cross section used for the rating analysis. As a result, the rating curve was revised. Appendix D presents the flood frequency analysis and re-rating of the gauge.

The design flows were converted into peak flood levels at Broadwater using the stage-discharge rating curve derived in this analysis. These levels were then compared to the peak levels used in the previous Floodplain Management Study. Refer to Table D-5 in Appendix D. Whilst the design flows resulting from the flood frequency analysis have decreased compared to the previous study there is little difference in the peak levels at Broadwater. This is due to the amended rating curve. The peak levels to be used at Broadwater for the design events in this flood study were based on the revised flood frequency analysis discussed in this report.

The temporal distribution (shape) of the upstream boundary at Broadwater is unchanged from the 1997 Floodplain Management Study. During that study, an analysis of four historical floods which exceeded the approximate 10 year ARI peak flood level was undertaken. The shape of the hydrographs were compared and showed a distinct pattern. The pattern was selected and the peak flood levels from the flood frequency analysis applied to derive an appropriate stage hydrograph for each design event.

6.3.3 Local Catchment Flooding

Boundaries for local catchment flooding are represented in two ways. Inflows at the upstream modelled extents of Maguires, Emigrant, North and other creeks are modelled as flow-time boundaries using relationships derived from results of the hydrological modelling. Further downstream, there are additional inflows to the hydraulic model representing rainfall on the floodplain.

The boundaries for local catchment flooding for the 20, 50 and 100 year ARI and PMF flood events are unchanged from the 1997 Ballina Floodplain Management Study and are the result of hydrological model undertaken for that study. The 5 year and 500 year ARI design floods were not included in the 1997 Ballina Floodplain Management Study and local catchment boundaries for these events have been derived for this study. The design rainfall for the 500 year ARI event was extrapolated from the design rainfalls for other ARI events from the 1997 Ballina Floodplain Management Study. The same temporal pattern was applied to the 500 year ARI rainfall as for the 100 year ARI rainfall. The event was simulated in the calibrated RAFTS hydrological model to provide local catchment inflows for this event.

6.3.4 Ocean Levels

The astronomical tide for Ballina is semi-diurnal with typical water level fluctuations as shown in Table 6-1; the Maritime Safety (Queensland) published tidal plane for the Breakwater Entrance of Richmond River at Ballina. All values in the table assume MSL is at Australian Height Datum[1].

Table 6-1 Tidal Plane (mAHD) at Ballina

HAT	1.11
MHWS	0.61
MHWN	0.31
MLWN	-0.29
MLWS	-0.59
LAT	-0.79

[1] The actual AHD difference to MSL datum is not published in any tide tables. Ballina Shire Council's surveyor undertook 8 separate measurements of AHD to MSL difference over 3 days in March 2006 with a recorded difference of 0.05m +/- 0.1m. The presence of a strong southerly swell during measurement added to the uncertainty. Low tide recorded by this gauge experiences an offset and phase lag because of site limitations (Ref: MHL, 1994). Thus discounting measurements taken at LW the recorded difference was 0.005m +/- 0.01m. Hence the assumption of equality, which is only approximately true for the majority of standard and secondary ports with tides published nationally, is valid.

A study of elevated ocean water levels (i.e. from cyclones and east-coast tropical lows) was carried out for the Richmond River entrance (Lawson & Treloar, 1994). The study considered the probability of elevated ocean water levels due to low pressure systems and wave forces.

Extended investigations of that study in 1995 produced a set of water level hydrographs over the duration of a flood event for various probabilities of recurrence. These hydrographs were used in the hydraulic model to simulate the effects on flooding in the Richmond River floodplain of elevated and varying ocean water levels. The storm tide peak was timed to coincide with the local rainfall peak and was set to occur approximately three days before the flood peak at Broadwater.

Tide and storm surge curves were adopted from the 1997 Ballina Floodplain Management Study. For the 500 year ARI storm surge, values were extrapolated from the existing dataset.

An extensive literature review was undertaken for this study to determine the expected magnitude of increase in sea levels. Following discussions with Council and DECC, the content of the Third Assessment Report by the Intergovernmental Panel on Climate Change (IPCC (2001)) was considered the most appropriate scientific judgement. A 50 year planning horizon was adopted resulting in a mean sea level rise equal to 200mm. This value has been applied to all design storm events modelled. Refer to Appendix C for a summary of the literature review and Table C-4 for details of the adopted sea level rise.

No allowance has been made for potential changes in rainfall intensity or increases in storm surge magnitude.

6.3.5 Combining Sources of Flooding

In the 1997 Ballina Floodplain Management Study, flooding of the lower Richmond River region was determined to originate from three major sources:

- Richmond River flood: overtopping of the Richmond River caused by rainfall over the Richmond River catchment;
- Local catchment flood: localised rainfall swelling local creeks and floodplains such as Maguires, Emigrant and North Creeks, which are located north and west of Ballina; and
- Ocean storm tide: elevated ocean levels caused by low depressions (barometric setup), strong onshore winds (wind setup) and storm wave conditions (wave setup). The peak ocean elevated levels were determined to be 1.7, 1.8 and 2.0 for the 10, 20 and 100 year average recurrence events respectively (BFMS, 1997). Anticipated sea level rise due to climate change was not considered in the ocean levels for the 1997 Ballina Floodplain Management Study.

Flooding could potentially occur from any combination of these sources. However, a manageable combination of events was assumed for the purposes of that study.

It is prudent to review whether some refinement of the flood combinations (of river, local and ocean) of the previous study should be considered.

The 2004 draft Department of Natural Resources Floodplain Risk Management Guideline No 5 (Ocean Boundary Conditions), published since the previous study, defines that a catchment draining to the ocean should be modelled in two ways. The two resulting flood profiles should then be combined to form an envelope of the upper limit of each profile. The guideline defines these two profiles, for a 100 year ARI flood, as:

1 Simulate a 100 year ARI flood with a normal tide; and

2 Simulate a small flood (i.e. a 5 year ARI flood) with a 100 year elevated ocean level.

In October 2006, Council was consulted on whether to apply the design floods of the guidelines or to adopt the methods used during the 1997 Ballina Floodplain Management Study. The outcomes of the consultation were presented to the Civil Committee and the Community Reference Group on 31st October 2006. In conclusion, it was agreed that the same combinations be used in accordance with the 1997 Ballina Floodplain Management Study.

Table 6-2 below shows the sixteen model scenarios that were undertaken to develop the flood envelopes for the six design events in this study.

The scenarios are grouped such that:

Scenario A = Richmond River dominated flood;

Scenario B = Local catchments dominated flood;

Scenario C = Ocean storm tide dominated flood; and

Scenarios D, E, F & G = Combination flood events.

DNR's Floodplain Risk Management Guideline No 5 (Ocean Boundary Conditions) recommends that river and local catchment flood modelling coincides with a neap tidal cycle and ocean storm surge modelling coincides with 'a small flood (i.e. 5 year ARI)'. The 10 year event[2] as the non-dominant source adopted from the previous Ballina Floodplain Management Study is more conservative and has been carried through to this study.

This guideline also calls for the use of a state-wide tailwater curve with a peak of 2.6 mAHD representing a 100 year storm surge with some conservativeness for the influence of climate change, in the absence of site specific or alternate analysis reviewed by DNR. The previous Ballina Floodplain Management Study adopted a 2.0 mAHD 100 year storm surge based on site specific analysis conducted by Lawson and Treloar (Ballina Ocean Level Study, 1994) with no allowance for mean sea level rise.

As discussed in the previous section, a 200mm allowance for sea level rise has been globally added to the storm tide levels produced during the 1994 Ballina Ocean Level Study.

[2] The difference between a neap high and the peak of a 10 year ARI ocean storm surge tide is approximately 1.4m at Ballina.

Table 6-2 Ballina Flood Study Design Event Scenarios

	Scenario	Richmond River Level	Local catchment storm	Ocean boundary
100y ARI	A	100y	100y 72h	10y surge + climate change allowance
	B	10y	100y 12h	10y surge + climate change allowance
	C	10y	10y 12h	100y surge + climate change allowance
50y ARI	A	50y	50y 72h	10y surge + climate change allowance
	B	10y	50y 12h	10y surge + climate change allowance
	C	10y	10y 12h	50y surge + climate change allowance
20y ARI	A	20y	20y 72h	10y surge + climate change allowance
	B	10y	20y 12h	10y surge + climate change allowance
	C	10y	10y 12h	20y surge + climate change allowance
5y ARI	D	5y	5y 12h	5y surge + climate change allowance
500y ARI	A	500y	500y 72h	10y surge + climate change allowance
	B	100y	500y 12h	10y surge + climate change allowance
	C	100y	100y 12h	500y surge + climate change allowance
PMF	E	10,000y	PMP[1] (centred on Maguires Ck catchment)	500y surge + climate change allowance
	F	10,000y	PMP[1] (centred on Emigrant Ck catchment)	500y surge + climate change allowance
	G	10,000y	PMP[1] (centred on North Ck catchment)	500y surge + climate change allowance

Notes: 1. PMP = Probable Maximum Precipitation is the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year.

6.4 Discussion of Historical Events

Members of the Community Reference Group were interested to ascertain the probability of recent historical events in order to put the design event magnitude into perspective. Discussion is divided into event components of:

- Ocean level
- River flows
- Local flows
- Rainfall

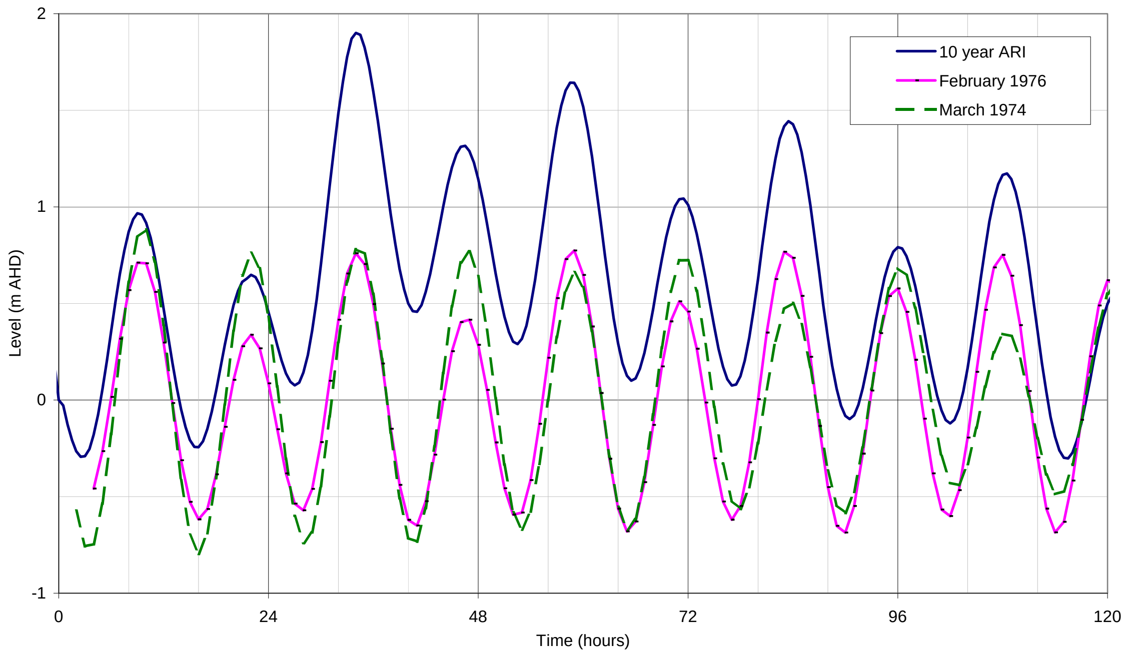
The magnitude of historical events considered include March 1974, February 1976, June 1983, July 1985 and June 2005. Other recorded values are included where they provide further insight. Tables are sorted in order of magnitude from lowest record.

6.4.1 Ocean Level

Table 6-3 compares the historical flood peak levels at the ocean outlet of the Richmond River with elevated storm surge design levels from Lawson & Treloar's investigations. None of the historical floods had downstream tailwater levels in the vicinity of the 10 year ARI storm tide. Figure 6-1 shows the magnitude of the 10 year ARI design ocean storm surge compared to the 1974 and 1976 calibration event prevailing tides.

Table 6-3 Stage (mAHD) from Ocean Storm Surge Frequency Relationship at Ballina

Event	Recorded[3]	Richmond River Ocean Level Plots (L&T, 1995)
July 1985	ND	
February 1976	0.64	
June 1983	0.74	
June 2005	0.79	
March 1974	0.94	
10 year ARI		1.7
100 year ARI		2.0



Source: K:\B15219.k.wjs_ballina\tuflow\boundaries\design event boundaries.xls

Figure 6-1 Comparison of Design Event and Calibration Event Ocean Levels

[3] Only in June 2005 was Ballina Tide Gauge operational. Levels in other years have been interpolated from recordings at Tweed Heads and Coffs Harbour

6.4.2 River Flooding

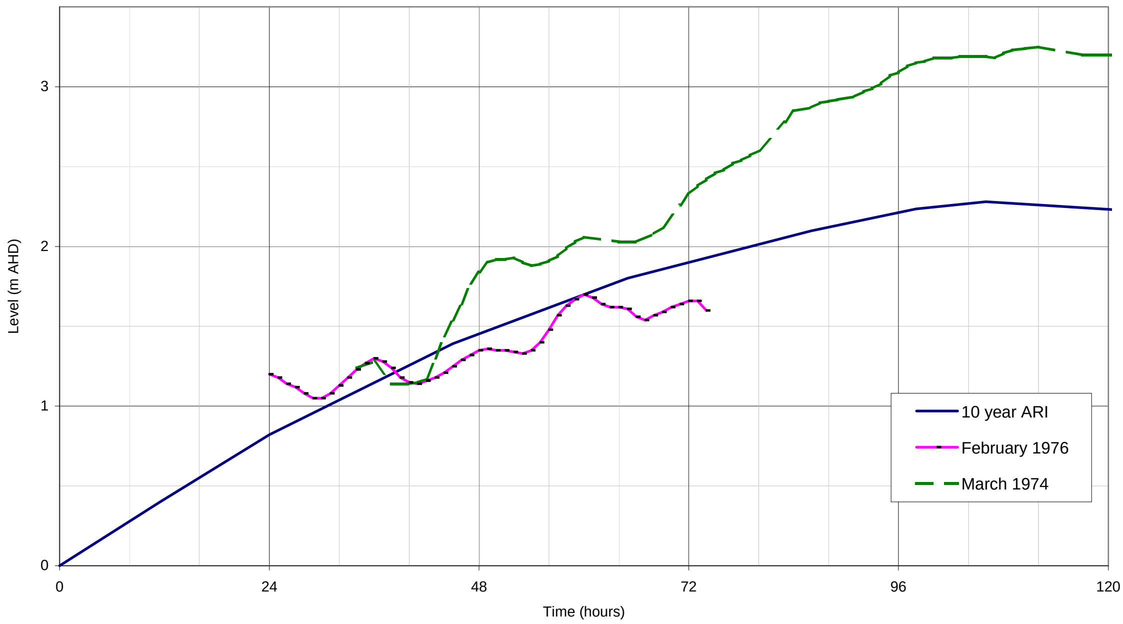
The Lower Richmond River Flood Study (PWD, 1987) published partial duration series from 1917 to 1983 of stage (water level to a local datum) in the Richmond River at Broadwater. The series was partial because only records above a designated threshold level were kept. From this, the frequency of various historical storm peaks was determined and is presented in Table 6-4.

Table 6-4 Stage (mAHD) from Partial Duration Series Frequency Relationship for the Richmond at Broadwater

Event	Recorded	Lower Richmond River Flood Study 1917-1983 (PWD, 1987)	Ballina Flood Study Update 1917-2005
July 1985	Below threshold		
June 2005	Below threshold		
June 1983	1.54 (Minor)		
February 1976	1.69 (Moderate)		
5 year ARI		approx 1.6	1.80
June 1967	2.09 (Moderate)		
April 1988	2.40 (Moderate)		
10 year ARI			2.15
July 1962	2.58 (Major)		
20 year ARI		3.14	2.57
March 1974	3.25 (Major)		
50 year ARI			3.27
June 1948	3.29 (Major)		
February 1954	3.72 (Major)		
100 year ARI		3.84	3.92

The updated frequency relationships at Broadwater, based on the partial records to 2005, are also presented in Table 6-4. From this it can be seen that March 1974 calibration event was approximately a 50 year ARI event in the Richmond River at Broadwater. February 1976 was only a moderate flood in the Richmond River and in June 2005, river levels did not rise sufficiently for any record to be taken.

Figure 6-2 shows the available 1974 and 1976 recorded level hydrographs with the 10 year ARI design hydrograph.



Source: K:\B15467.k.wjs_Ballina_Bypass\Tuflow\boundaries\Design Event Boundaries.xls

Figure 6-2 Comparison of Design Event and Calibration Event Richmond River Levels at Broadwater

6.4.3 Local Flooding

Two level gauging stations previously existed within this study area. Their details are:

1 Teven Creek (Gauging Station 203436), records from 16th January 1972 to 15th March 1974; and

2 Emigrant Creek at Cumbalum (Gauging Station 203442), records from 10th March 1970 to 11th May 1980.

Whist both gauges were operational during the March 1974 calibration event, there is insufficient record of local creek flood levels or flows to undertake frequency analysis. Hence no comment on the magnitude of local catchment flows can be made.

6.4.4 Rainfall

Alstonville Tropical Fruit Research Station (Rainfall Station 203415) has continuous rainfall records since 1st February 1921. In 1987, the Public Works Department (PWD) calculated intensity-frequency-duration (IFD) data for that station based on data available to 1983 and the 'strong rainfall gradient' method of the 1977 edition of Australian Rainfall and Runoff.

Since that time there have been several storm events with greater than the predicted 100 year ARI intensity from that study. This prompted the Bureau of Meteorology (BOM) to revise and re-publish the IFD for this location. Their republication is discussed in the 1997 Ballina Floodplain Management Study. A continuous rainfall record from 1969 to 1995 was used.

This resulted in the February 1976 rainfall event, previously thought to be greater than a 100 year ARI storm, being now considered to have had a probability between 20 and 50 years ARI. The March

1974 storm had a probability of less than 20 years ARI and the June 2005 storm had a probability of less than 5 years ARI.

The revision to the Alstonville IFD has resulted in it being one of the highest rainfall locations in Australia. Table 6-5 compares historical and design event rainfall.

Table 6-5 Rainfall (mm) at Alstonville Tropical Fruit Research Station (Maximum 12 hr total)

Event	Recorded[4]	Lower Richmond River Flood Study 1917-1983 (PWD, 1987)[5]	Ballina Floodplain Management Study 1969-1995 (WBM, 1997)
June 1983	ND		
July 1985	ND (197.0 24h total)		
June 2005	165		
5 year ARI			220.8
February 1981	229.6		
February 1995	271.5		
March 1974	278.2		
March 1977	281.4		
20 year ARI		258 (316)	328.8
February 1976	361.1		
50 year ARI			412.8
100 year ARI		336 (432)	481.2

6.4.5 Conclusions

The recent historical events are in all aspects (rainfall, river levels and downstream tides) more frequent than the 50 and 100 year ARI design events used in this study (with the exception of the upstream river levels in March 1974).

Given the various flooding mechanisms within the study area (i.e. rainfall, river levels and downstream tides), it is important not to use the historical events as a basis for comparison for the design events. Flooding behaviour resulting from the different design events is likely to be significantly different than the historical flood events.

[4] ND = no data

[5] Values shown in parenthesis are the equivalent value for Federal rainfall station

7 MODELLING OF THE EXISTING FLOODPLAIN

7.1 Overview

This section presents the hydraulic model results for 2005 topographical and land use conditions.

It should be noted that the existing pre-loading berm parallel to Deadmans Creek Road (for the proposed Cumbalum Way) has been removed from the model for a length of approximately 210 metres. The Cumbalum Way development consent levels have been used, and will be no higher than the existing Pacific Highway at the western end of Deadmans Creek Road (i.e. approximately 1.4m AHD).

Only the 20 and 100 year ARI results are presented for the existing floodplain conditions.

7.2 Design Event Flood Mapping

GIS mapping for the 20 year ARI flood event has been undertaken for the peak flood level and depth envelopes. These are presented in Figure 7-1 and Figure 7-2 respectively.

GIS mapping for the 100 year ARI flood event has been undertaken for the peak flood level and depth envelopes. These are presented in Figure 7-3 and Figure 7-4 respectively.

In addition, flood hazard is mapped in Figure 7-5. Areas of High and Low Hazard Category as defined in the NSW Floodplain Management Manual are shown.

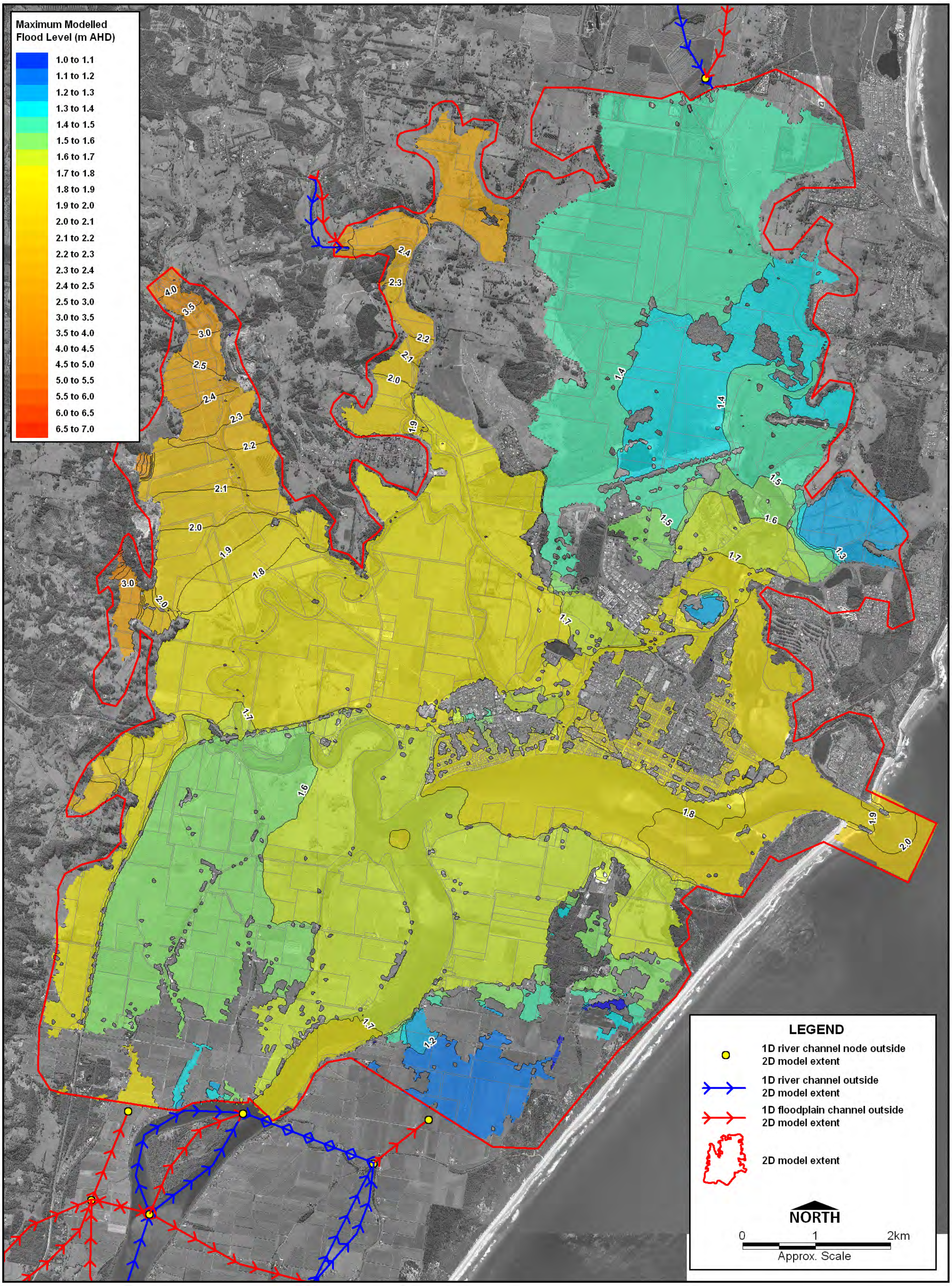
7.3 Source Dominance

Source dominance is categorised as:

- Ocean Storm Tide Dominated Flood;
- Local Catchments Dominated Flood;
- Richmond River Dominated Flood; or
- Equal Dominance - Richmond River and Local Catchment Floods.

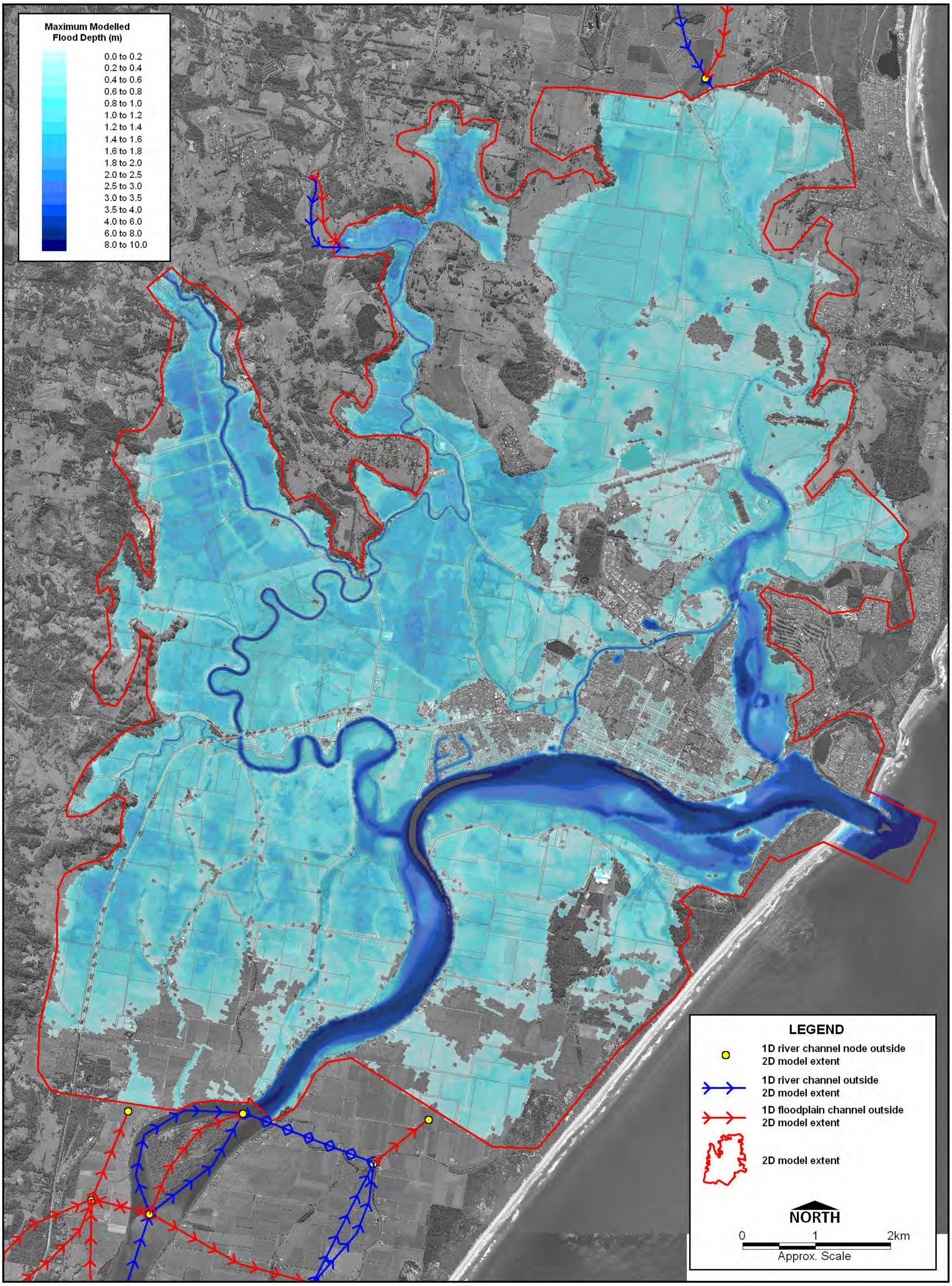
Refer to Figure 7-6 for source dominance mapping.

Logically, the tidal dominance extends up the Richmond River and North Creek from the ocean boundary. Local catchment dominance is confined to Emigrant and Maguires Creek floodplains upstream of their confluence and Ballina township. A large area of equal dominance between local catchment and Richmond River flooding is centred on Emigrant Creek and loosely bounded in the south and east by the existing Pacific Highway. The area of equal dominance is based upon less than 20mm difference between the local catchment and Richmond River dominated floods. The balance of the area is dominated by Richmond River flooding.

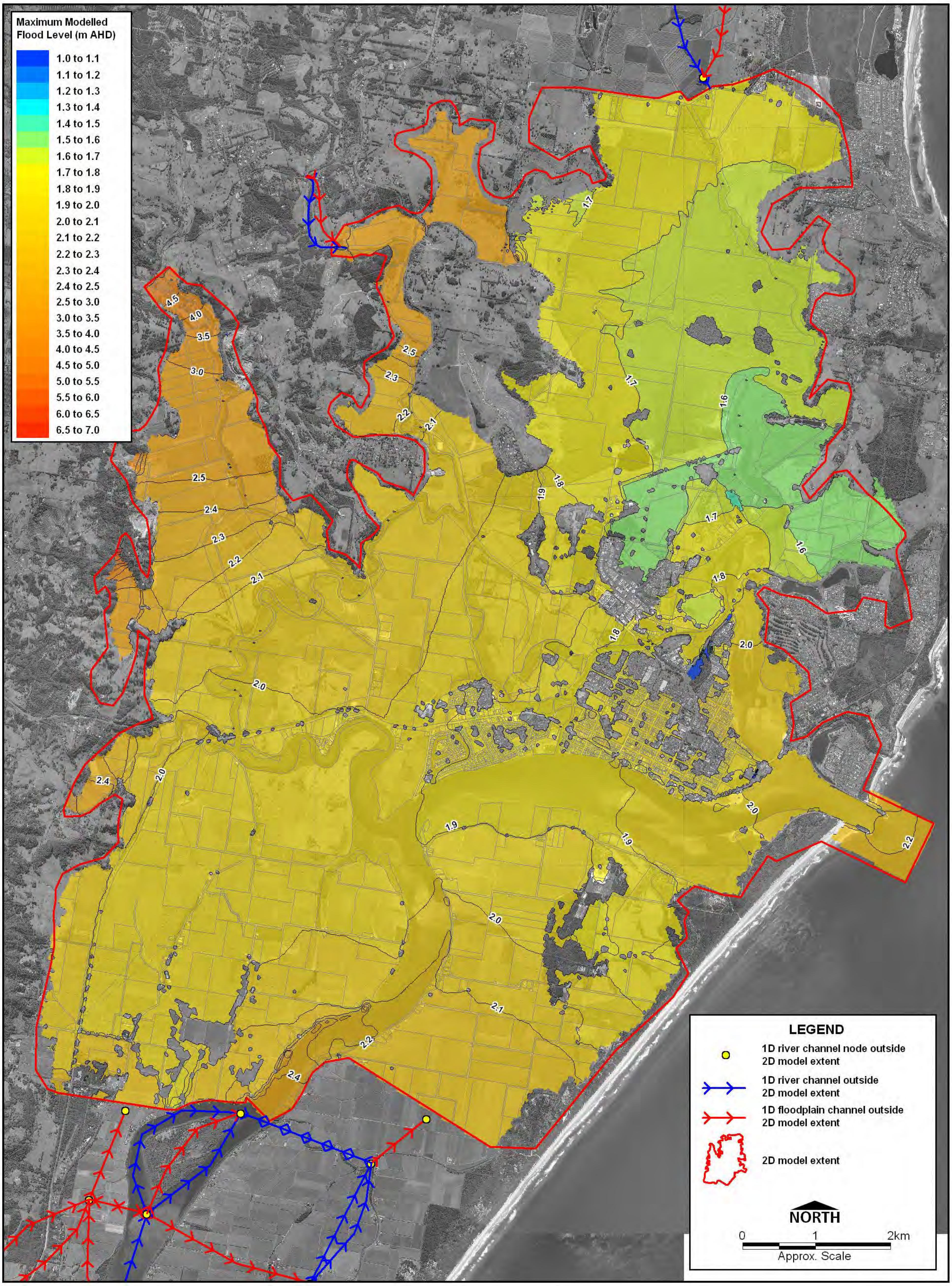


Existing Floodplain Peak Flood Level (mAHD) - 20 Year ARI

Figure 7-1

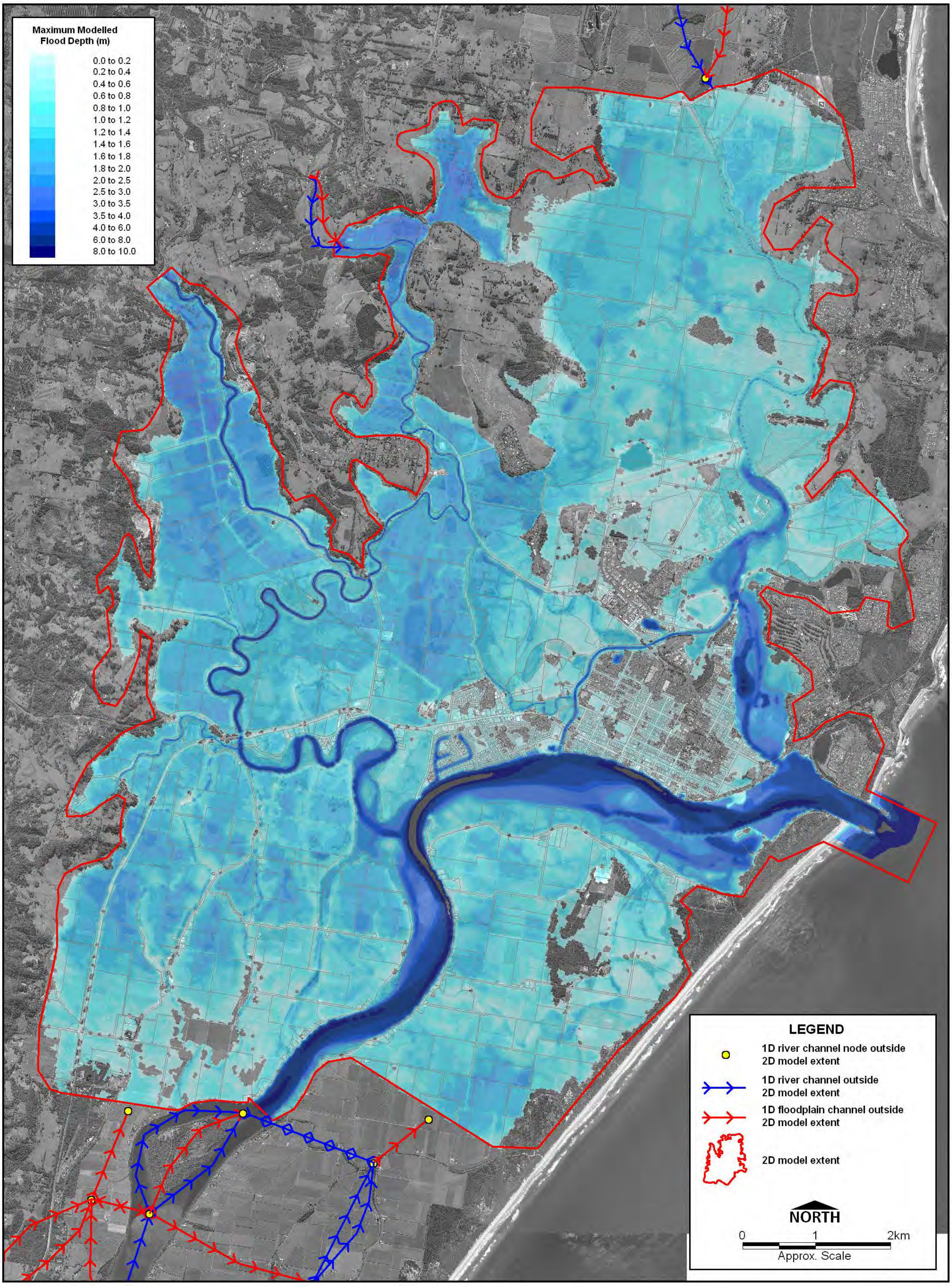


Existing Floodplain Peak Flood Depth (m) - 20 Year ARI **Figure 7-2**



Existing Floodplain Peak Flood Level (mAHD) - 100 Year ARI

Figure 7-3



Existing Floodplain Peak Flood Depth (m) - 100 Year ARI

Figure 7-4

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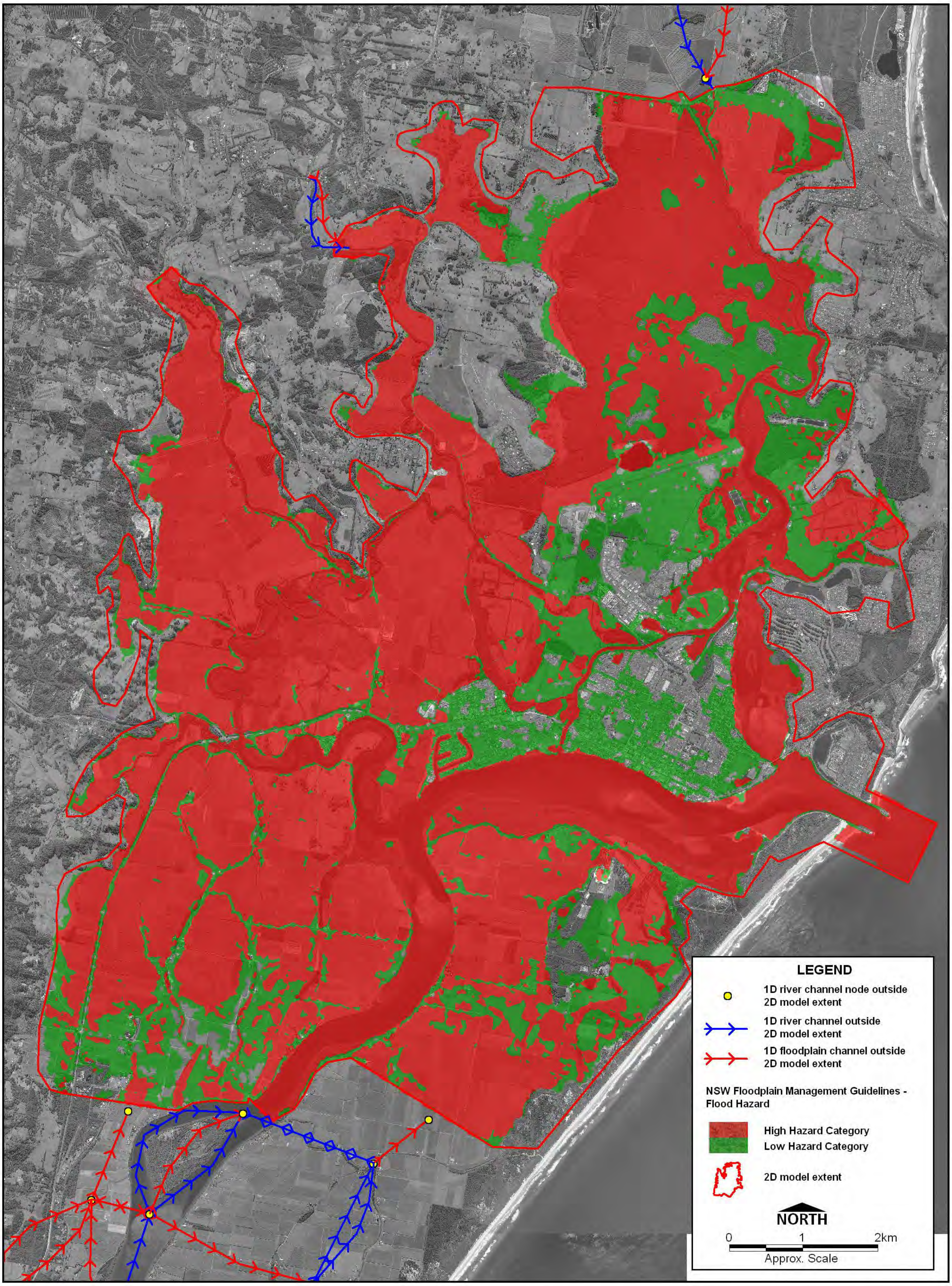
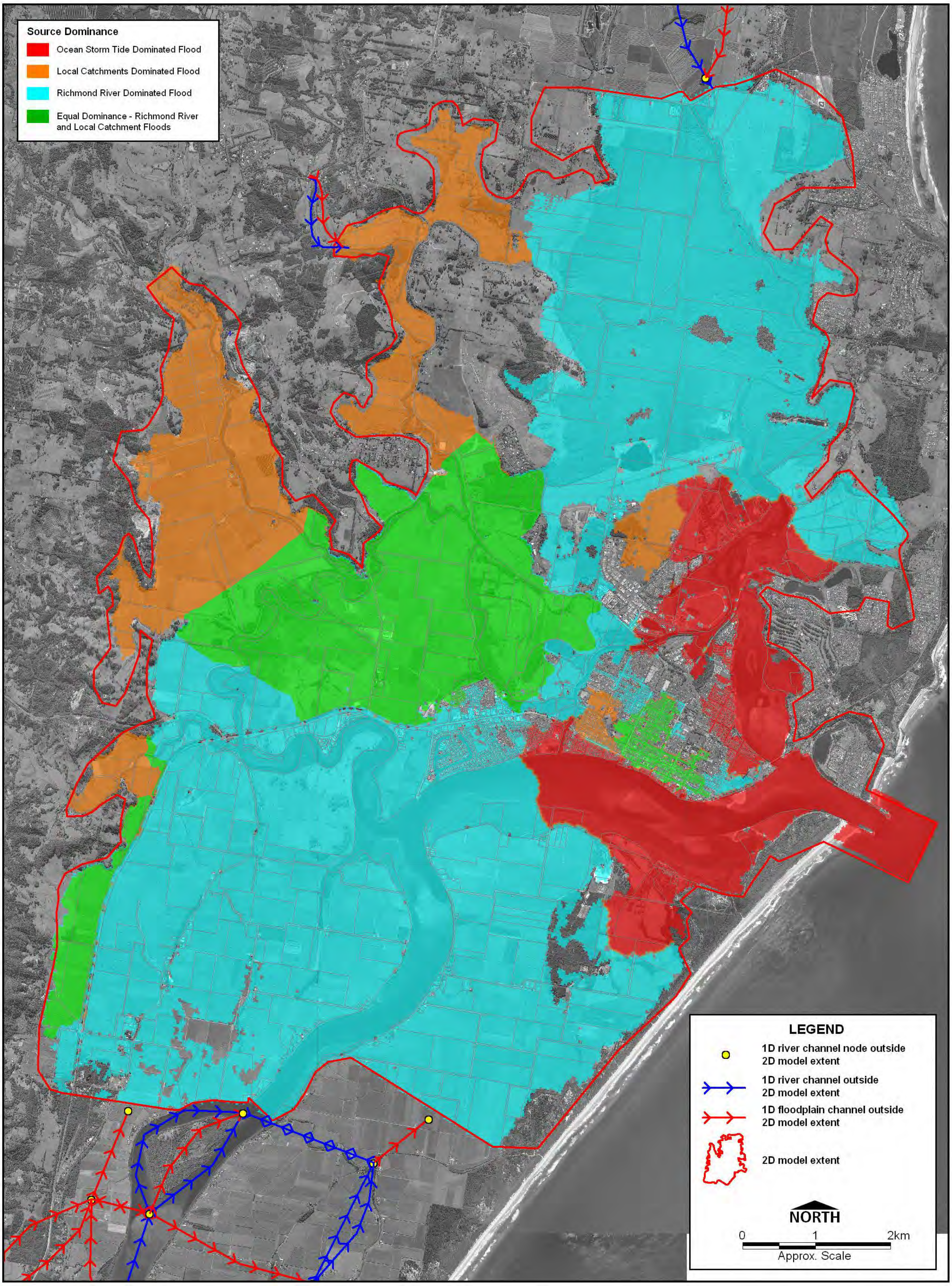


Existing Floodplain Peak Flood Hazard - 100 Year ARI

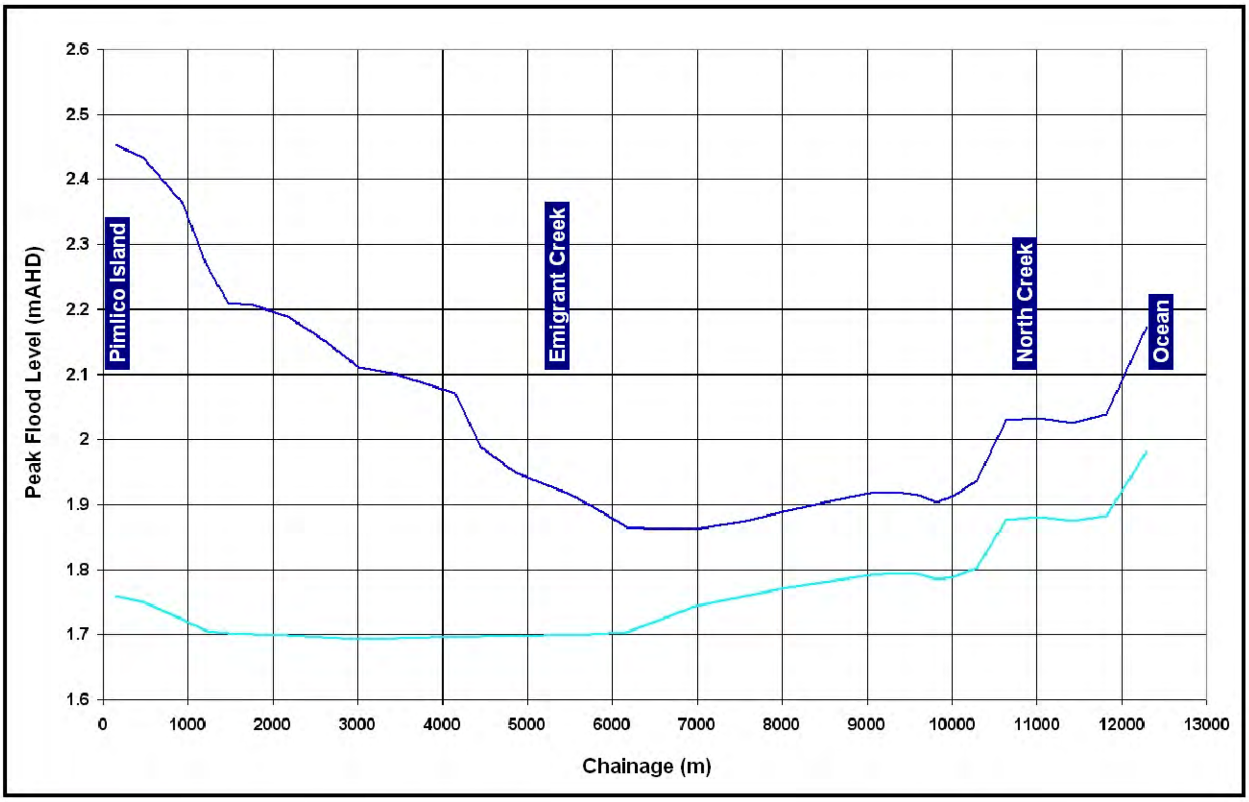
Figure 7-5



Existing Floodplain Source Dominance of Peak Flood Level - 100 Year ARI **Figure 7-6**

7.4 Long Section Profiles

Long section profiles for the Richmond River, Emigrant Creek, Maguires Creek and North Creek are presented in Figures 7-7, 7-8, 7-9 and 7-10. The 20 and 100 year ARI peak flood levels are presented for the combined source dominance.



100 year ARI existing peak flood level

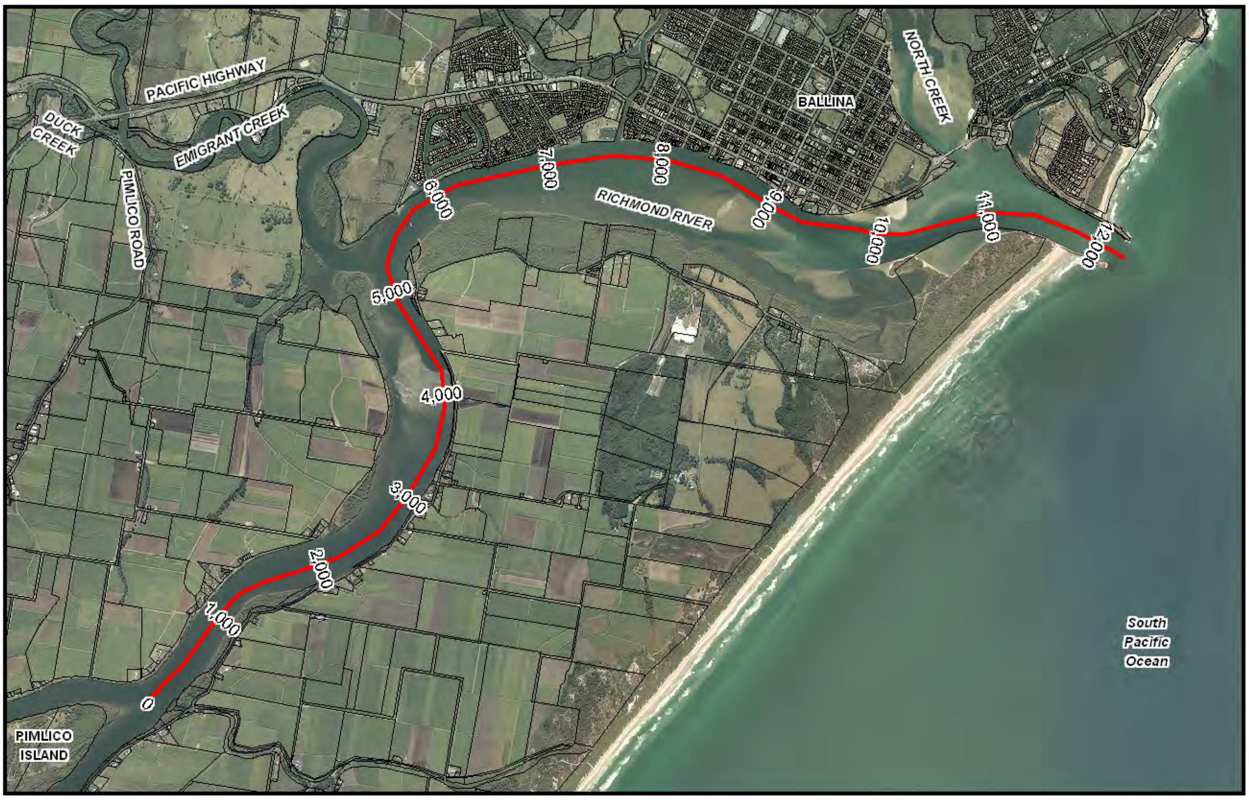
20 year ARI existing peak flood level

7,000 Centre line and chainage (metres)

NORTH

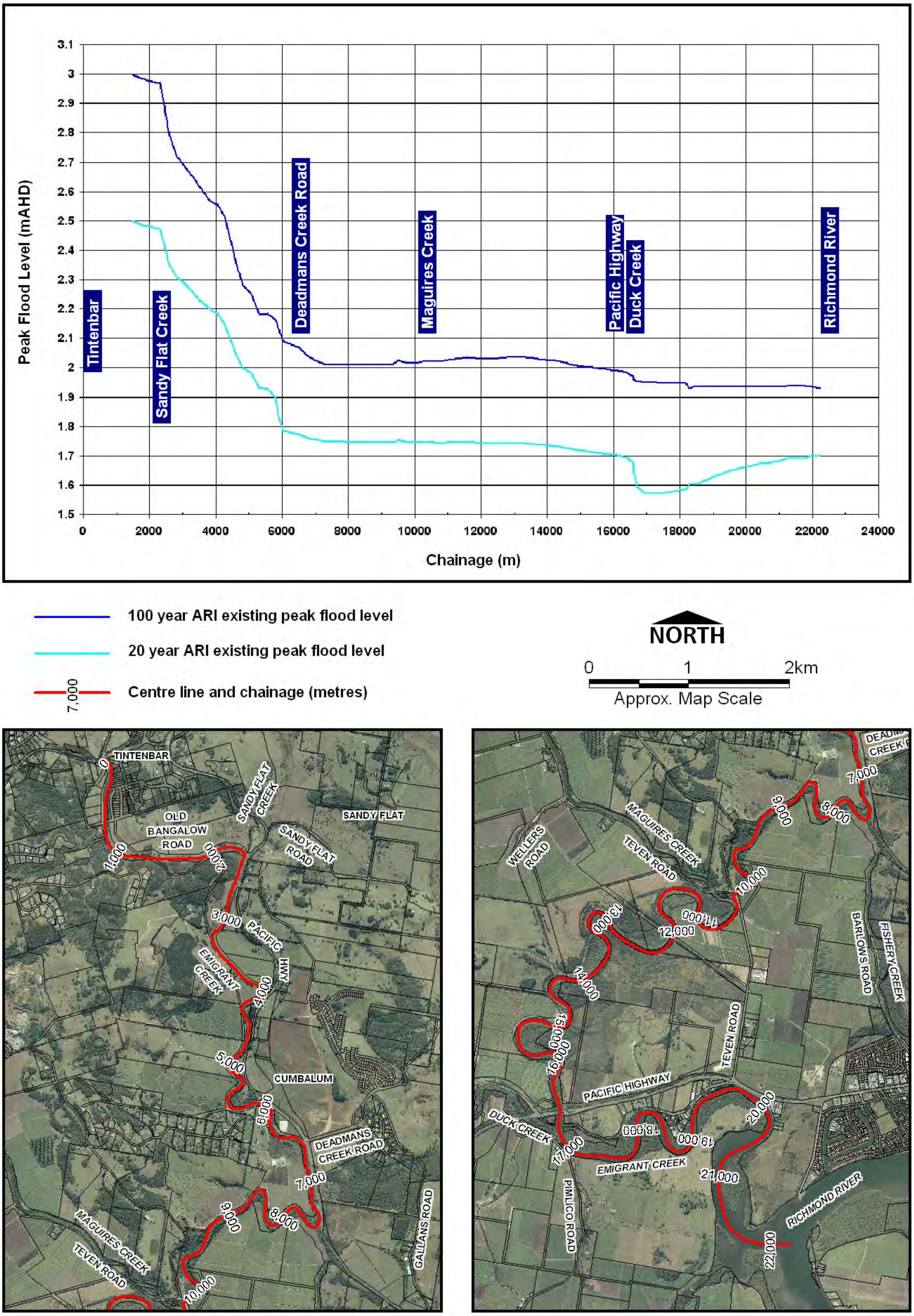
0 1 2km

Approx. Map Scale



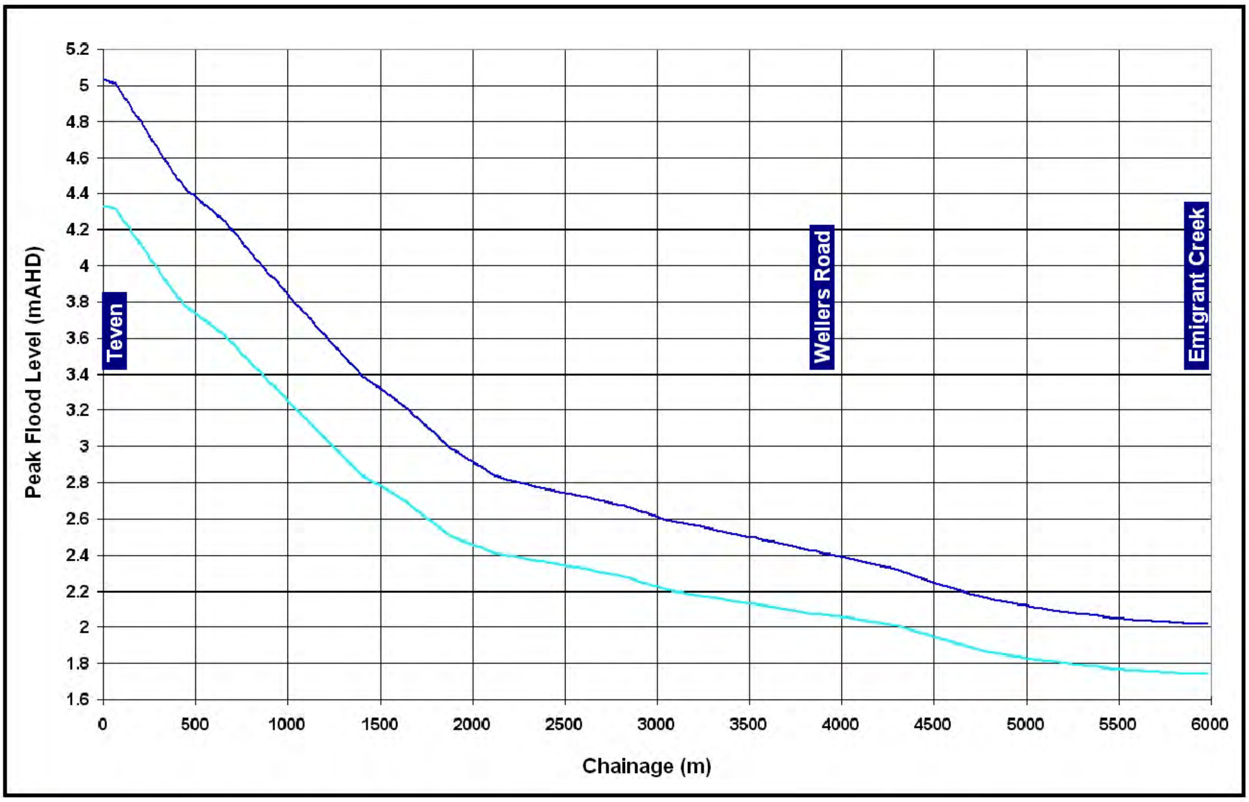
Existing Peak Flood Level Long Section - Richmond River

Figure 7-7



Existing Peak Flood Level Long Section - Emigrant Creek

Figure 7-8



100 year ARI existing peak flood level

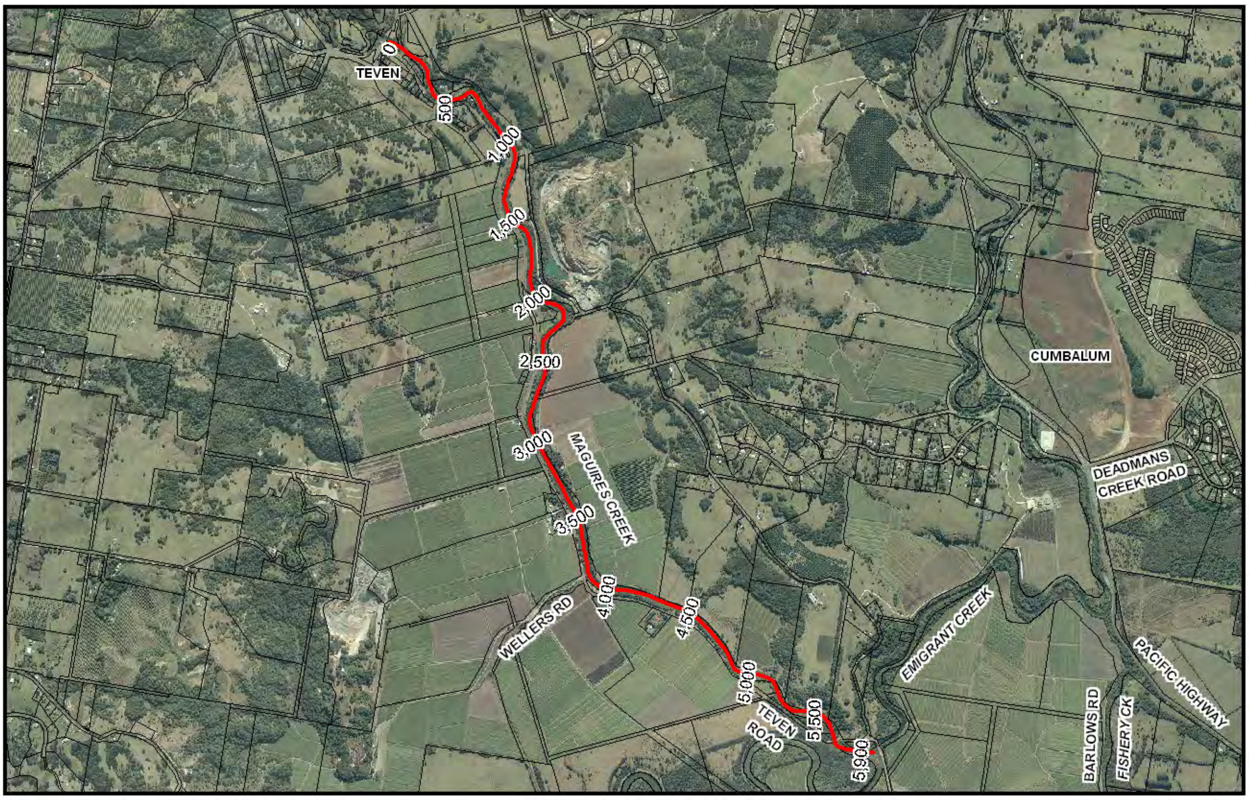
20 year ARI existing peak flood level

2,000 Centre line and chainage (metres)

NORTH

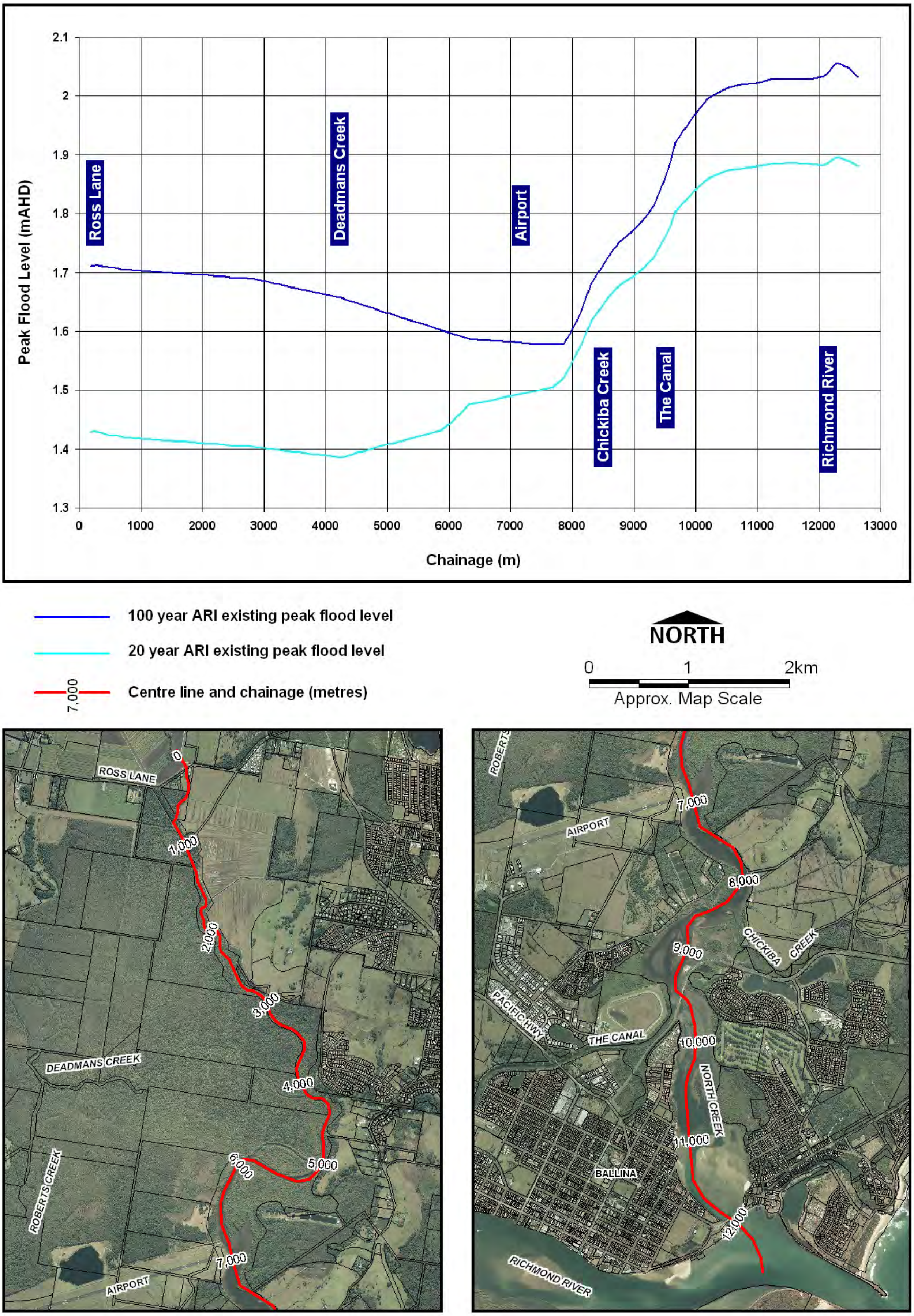
0 1 2km

Approx. Map Scale



Existing Peak Flood Level Long Section - Maguires Creek

Figure 7-9



Existing Peak Flood Level Long Section - North Creek

Figure 7-10

7.5 Comparison with Previously Published Values

Peak flood levels across the existing catchment determined during this study were compared to those determined during previous studies. The peak flood levels for the 20 and 100 year ARI events are presented in Table 7-1.

Table 7-1 Comparison of Existing Floodplain Peak Flood Levels at Selected Locations with Other Published Values

	Peak Flood Level (m AHD)							
	Ballina Flood Study Update (2008)(1)		Ballina Floodplain Management Study (1997)		Wardell & Cabbage Tree Island Flood Study (2004)		Mid-Richmond Flood Study (1999)	
Location	**100 year**	**20 year**	**100 year**	**20 year**	**100 year**	**20 year**	**100 year**	**20 year**
Broadwater	3.86	2.53	3.84	2.76	3.78	2.98	3.80	
D/S Wardell Bridge	3.07	2.07	3.00	2.12	2.88	2.13	3.10	
U/S Pimlico Island	2.47	1.76	2.68	1.90	2.69	1.99		
Confluence Emigrant Creek & Richmond River	1.94	1.71	1.86	1.65				
Pacific Ocean	2.20	2.00	2.00	1.80				
Emigrant Creek at Deadmans Creek Rd	2.07	1.77	2.94	2.24				
Confluence Emigrant Creek & Maguires Creek	2.02	1.74	2.24	1.88				
Emigrant Creek U/S Pacific Highway, west of Ballina	1.98	1.69	1.84	1.67				
West Ballina	1.92	1.73	2.15	1.80				
North Creek (airport)	1.59	1.48	1.76	1.65				
Confluence North Creek & Canal	1.95	1.82	1.81	1.68				
Missingham Bridge	2.04	1.89	1.86	1.70				

(1) Includes effects of 200mm ocean level increase due to climate change

The peak flood levels are similar across the four different studies. Most of the differences can be attributed to:

- Physical changes to the catchment, as detailed in the following section;
- Improved survey, as detailed in Appendix A;
- The modelling techniques and method, as detailed in Chapter 1 and Chapter 3.

- The boundary conditions applied, as detailed in the previous chapter, and specifically including the new flood-frequency relationship at Broadwater and ocean tide boundary increases to account for climate change.

7.5.1 Physical Changes to the Floodplain Since the 1997 Study

There have been six key changes to the floodplain since the 1997 study was undertaken as summarised below. All changes have been applied to the model unless otherwise noted.

- **Ballina Heights and Cumbalum Way**

  As part of the future stages of the Ballina Heights development, fill has been placed on the floodplain to the north of Deadmans Creek Road. The fill is having little impact upon flood conveyance, primarily due to the higher elevation of the Deadmans Creek Road embankment. The placement of the fill is, however, reducing the available flood storage. Hence it is having an impact on flooding upstream in Emigrant Creek.

  Also part of the Ballina Heights development is the proposed Cumbalum Way. This road will connect the Pacific Highway to Ballina Heights and is intended to replace Deadmans Creek Road. Due to the soft soils in the area, the future road embankment has been built up to above the 100 year ARI flood level for pre-loading reasons. The temporary embankment is causing a significant barrier to flows across the floodplain, thus creating an unacceptable increase in flood levels upstream in Emigrant Creek.

  The temporary embankment will be removed during the final construction of Cumbalum Way. Hence, it has not been included in the existing catchment model. This is to ensure the model for the developed catchment is compared to pre-embankment conditions.

- **RTA Trial Pads**

  Over the past eight years, the RTA has installed trial embankments at Cumbalum, Emigrant Creek south and Duck Creek. The purpose of the trial embankments is to investigate consolidation of the soft soils for the RTA's bypass construction.

- **Urban Development at West Ballina**

  Since the 1997 study, further urban development has occurred at West Ballina. Surface elevations and land uses have been applied to the model.

- **Gallans Road cycleway**

  Since the 1997 study, works have occurred along the cycleway increasing the elevation of the embankment. Increasing the elevation was necessary to provide cover to services located within the embankment. The cycleway crosses the low lying land that provides connectivity between the North Creek and Emigrant Creek floodplains. Hence, an increase in elevation has further reduced the ability of flood waters to pass between the two floodplains.

- **Additional placement of fill at Fairwinds Property**

  Additional fill has been placed at the Fairwinds property (Koellner Steel) between Emigrant Creek and the base of the hill to the west. This is immediately to the south of Cumbalum. The fill has reduced the flood conveyance through the area and is likely to have caused an increase in flood levels upstream in Emigrant Creek. An assessment of the fill has not been undertaken in isolation from other changes to the floodplain.

- **Council bridgeworks at Teven Road crossing of Emigrant Creek**

  Since the 1997 study, Council commenced works upgrading the Teven Road bridge crossings of Emigrant Creek and Maguires Creek. Settlement of the southern abutment occurred on Emigrant Creek, resulting in remedial works being required along Emigrant Creek at the confluence with Maguires Creek.

7.6 Design Event Flood Behaviour

7.6.1 Ballina Island

Flooding on Ballina Island can occur from each of the three dominant sources of flooding. Generally, in events up to and including the 100 year ARI event, flooding is less than 500mm deep across most of the urban area. Flow velocities across Ballina Island will also be low in these events.

Ballina Island has a Low Hazard category in the 100 year ARI event in accordance with the NSW Floodplain Development Manual.

7.6.2 West Ballina

The dominant source of flooding in West Ballina is from the Richmond River, although some parts do experience higher flood levels from local catchment flooding or from elevated ocean levels. Similar to Ballina Island, the flood prone urban areas of West Ballina generally experience flood depths of less than 500mm and low velocities in a 100 year ARI event.

West Ballina has a Low Hazard category in the 100 year ARI event.

7.6.3 Maguires Creek and the Teven Valley

Flooding in the Teven Valley is typically characterised by high velocity, deep flow within the banks of Maguires Creek and slower moving shallower waters across the floodplain. The presence of sugarcane plantations across the floodplain significantly slows down the velocity of flow.

Almost the entire Maguires Creek floodplain is a High Hazard category area in a 100 year ARI event. Across the floodplain, this is predominantly due to depths in excess of 1.2m.

7.6.4 Emigrant Creek Valley

Generally flooding in the Emigrant Creek Valley has slightly higher velocities across the floodplain than in Maguires Creek. This is partly due to the floodplain being narrower than that of Maguires Creek. Additionally, there are various controls for flow within Emigrant Creek, such as the Pacific Highway, Deadmans Creek Road and the Cumbalum Road bridge.

The entire Emigrant Creek floodplain is a High Hazard category area. This is due to a combination of higher velocities and depths.

During larger flood events, such as the 100 year ARI, flows from Emigrant Creek fill the Sandy Flat basin, then break out across Sandy Flat Road, flowing into Deadmans Creek to the east.

7.6.5 Emigrant Creek Floodplain (South of Cumbalum)

To the south of Cumbalum, flow across the Emigrant Creek floodplain is slow moving. Depths generally exceed 1.2m in a 100 year ARI event. Therefore a High Hazard category applies to this area. It should be noted that the type of event determines the flow patterns across this part of the floodplain. Flow may be observed flowing in different directions during different times throughout the event depending upon whether the flood is rising or receding. Different flow patterns are also likely during different dominating flood events.

7.6.6 North Creek

The Ballina Nature Reserve area is a large basing serving as a flood storage zone for both North Creek and the Richmond River. Flow velocities in most areas, except for the main channels, are generally low, although depths exceed 1.2m across the majority of the floodplain.

The North Creek floodplain has both High and Low Hazard category areas during a 100 year ARI event.

8 MODELLING OF THE BASE CASE

8.1 Introduction

Following on from the existing catchment modelling, a series of scenarios have been modelled to investigate the impacts that future development will have upon flooding. Future development includes public infrastructure, such as the RTA's Ballina Bypass and Council's Western Arterial, and urban development currently approved, but not constructed. These are described in the following sections.

During the 1997 Ballina Floodplain Management Study, a series of mitigation options were recommended to mitigate the adverse flooding impacts of the proposed development. These mitigation options (primarily floodways) were again investigated using the more detailed 2D modelling approach. This chapter contains a detailed summary of the mitigation options investigated and reasons for each being adopted or rejected.

The Base Case model is, therefore, defined as:

"the existing catchment conditions including all proposed public infrastructure works, currently zoned or approved urban development and mitigation measures designed to minimise adverse flooding impacts to acceptable levels"

It is intended that the Base Case model will be used by Council as a tool for assessing flooding impacts due to future infrastructure and rezoning across the floodplain. The base case model will be continually updated and compared with the design event model results to ensure flood impacts of all future development are assessed on a cumulative basis (i.e. not individually assessed for impacts).

Ballina Shire Council, in conjunction with the Department of the Environment and Climate Change (DECC), plan to follow up the Ballina Flood Study Update with the Floodplain Risk Management Study. This Floodplain Risk Management Study will follow the recommendations of the NSW Floodplain Development Manual (2005) and will investigate a wider range of strategies for managing flooding problems. This includes emergency management, house purchase and house raising through to improved flood warning and community education. Options will be studied in consideration of social, economic and ecological factors and will go through a formal public consultation process.

8.1.1 Infrastructure

The following proposed public infrastructure works have been included in the current base case model:

- RTA's Ballina Bypass – the base case model presented in this report includes the latest concept design for the bypass, referred to as the Improved Concept Design. This design was placed on public exhibition by the RTA in June 2007. As the design of the RTA's Ballina Bypass continues, it is proposed that the base case model will be updated with the latest design. To the north of Cumbalum, the bypass is proposed to have 100 year ARI immunity. To the south, across the Emigrant Creek floodplain, the bypass will have 20 year ARI immunity as specified by the RTA.

- Council's Western Arterial and North Creek Road – these local arterial roads will be constructed by Council. The latest alignments and cross drainage have been included in the Base Case model. All local arterial roads have been assumed to have 20 year ARI flood immunity.
- North Creek revetment wall –this revetment wall is proposed on the western bank of North Creek at the end of the Ballina Airport runway.
- Sewerage Treatment Works – works are proposed for the expansion of the existing sewerage treatment works to the west of Ballina Island.
- Waste Management Centre – works are proposed for the expansion of the existing waste management centre to the north of the existing Pacific Highway.

All infrastructure works have been assumed to have a 100 year ARI flood immunity except where noted for the RTA's Ballina Bypass and the local arterial roads. Refer to Figure 8-1 for locations of proposed public infrastructure.

8.1.2 Urban Development

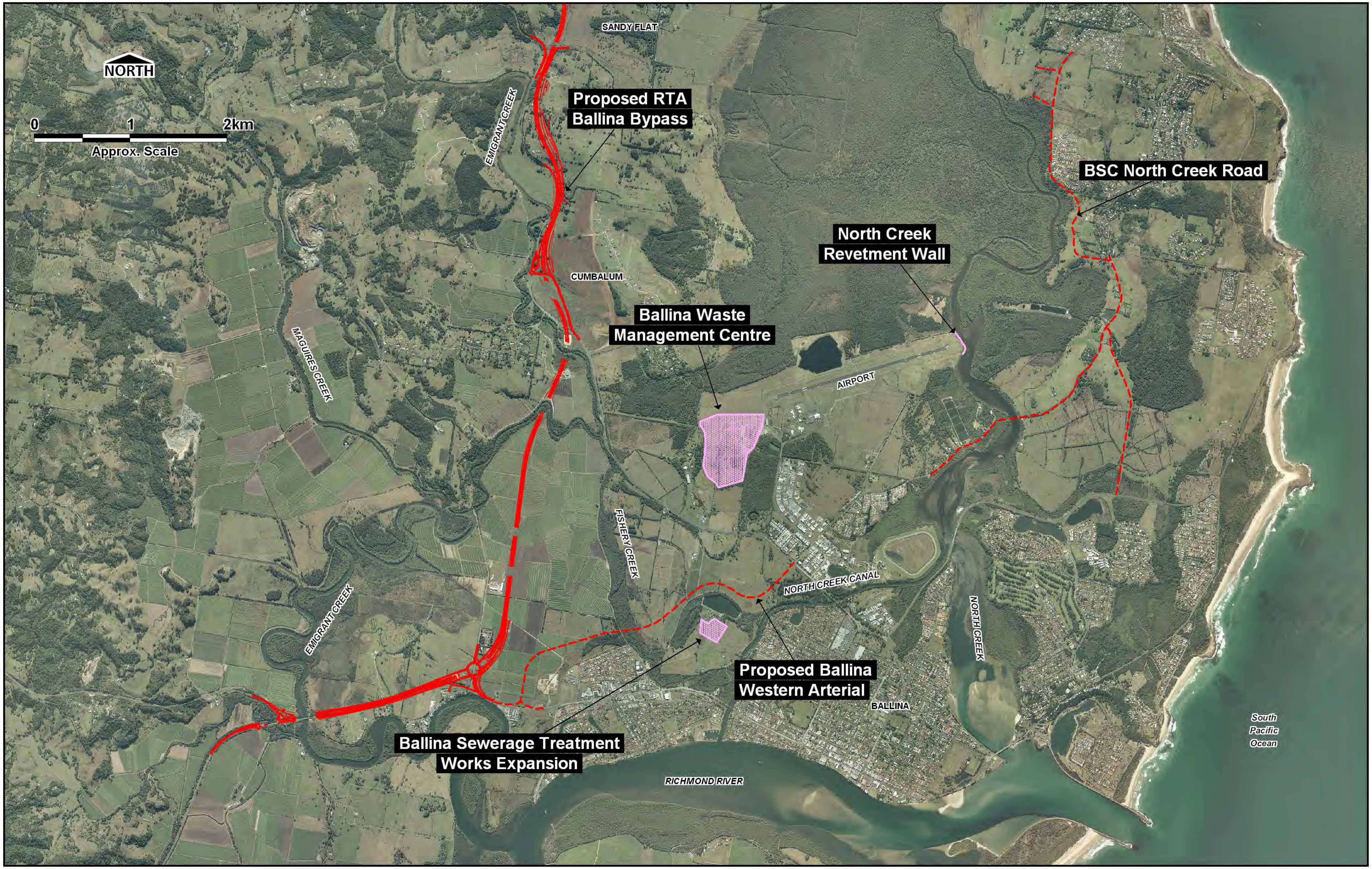
In addition to the public infrastructure works described in the previous section, various parcels of land have been zoned for urban development. These parcels are shown on Figure 8-2.

8.1.3 Flood Impact Assessment Criteria

Ballina Shire Council has been consistent with the 1997 study and for a 100 year ARI event, future development works shall cause no more than 50mm increase in peak flood levels. This criterion is in comparison with 2005 floodplain conditions and will apply on a cumulative basis. Hence, the combined effect of all future development in the Ballina region shall not cause greater than 50mm increase to peak 100 year ARI flood levels.

8.2 Unmitigated Modelling Results

Should all the development described above take place without any mitigation works, then peak flood levels will increase across the catchment to unacceptable levels. Figure 8-3 presents the results of this scenario in the form of a flood impacts map. The map illustrates the many areas where greater than 50mm impacts will occur during the 100 year ARI flood event.

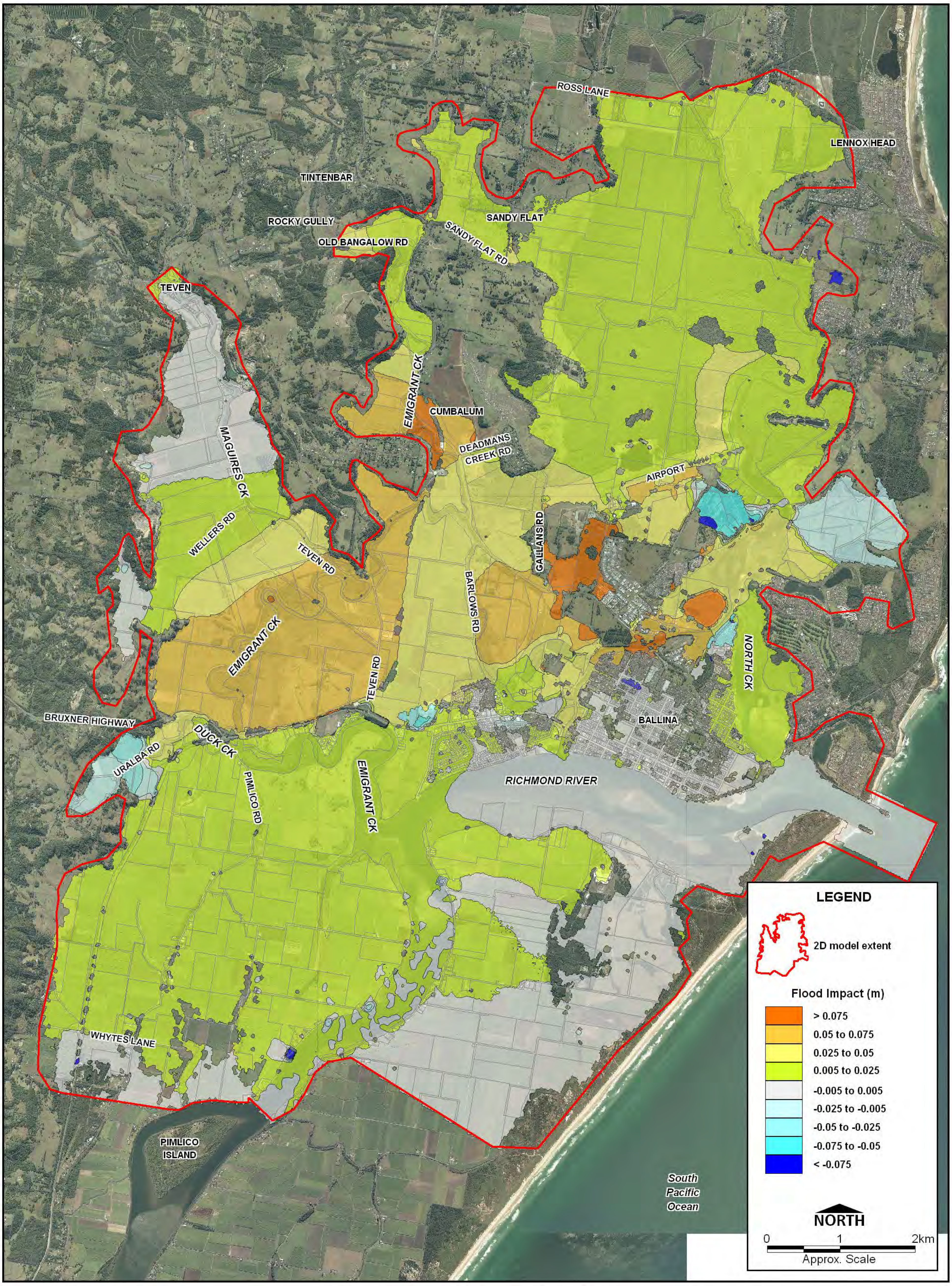


Future Public Infrastructure

Figure 8-1

Future Urban Development

Figure 8-2



Unmitigated Scenario Impact Results
100 Year ARI Flood Event

Figure 8-3

8.3 Mitigation Measures

8.3.1 Definitions

Mitigation measures covered in this Ballina Flood Study Update are generally limited to floodways, culverts or channel improvement works, such as dredging.

In this report the following definition of a floodway is used in accordance with the NSW Floodplain Development Manual (2005):

> *"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 flow, or a significant increase in flood levels."*

8.3.2 General Approach

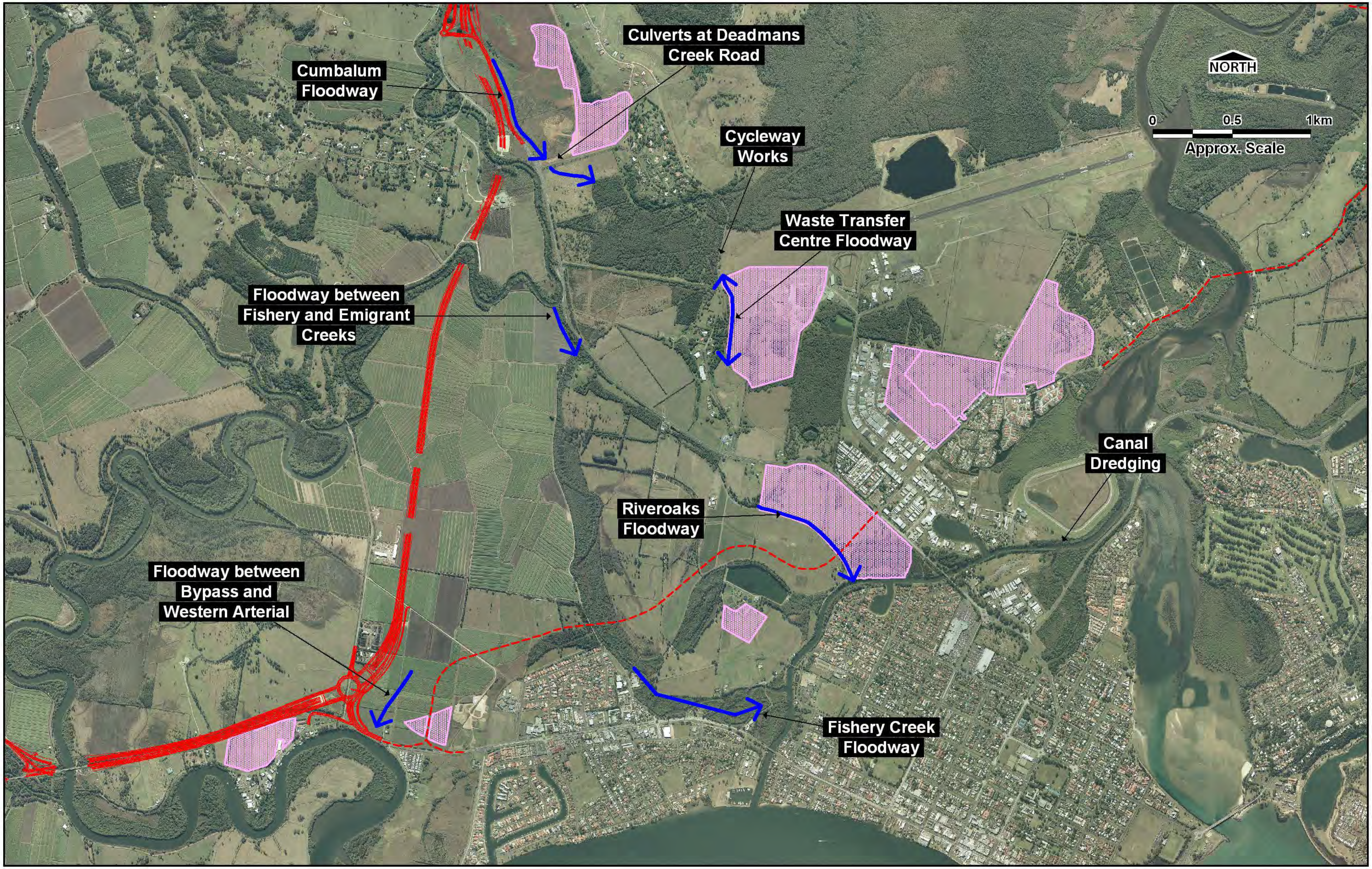
As discussed in Section 8.1, numerous mitigation measures have been investigated. Of these mitigation measures, some have been rejected due to their limited benefit to flood mitigation, whilst others have been considered to form a vital part of the overall flood mitigation strategy for the Ballina area. All measures are discussed in the following sections. Refer to Figure 8-4 for mitigation measure locations.

Whilst approximate dimensions of mitigation structures have been specified, it is important to note that the analysis undertaken to date is conceptual, and is not intended to constitute the ultimate design. All mitigation structures will require detailed design and analysis taking into account factors including but not limited to:

- Ecological impacts;
- Land ownership;
- Social impacts;
- Ground water;
- Potential acid sulphate soils (PASS);
- Tidal intrusion; and
- Construction methodology and cost.

Considering these factors, the alignments and details shown are subject to optimisation at later stages in the design process.

For the Base Case modelling assessment, the 5, 20, 50, 100 and 500 year ARI flood events together with the PMF were analysed.



Mitigation Measures Investigated

Figure 8-4

8.3.3 Cumbalum Floodway and Culverts

8.3.3.1 Description

As Emigrant Creek flows through Cumbalum, a significant portion of the floodplain only becomes active for flood storage and conveyance once the existing Pacific Highway is overtopped from west to east. Refer to Figure 8-5. At the downstream end of this narrow section of the floodplain, Deadmans Creek Road also forms a barrier for flow. Once this basin has filled, overtopping of Deadmans Creek Road and the adjacent Pacific Highway occurs for flood waters to return to the Emigrant Creek floodplain or flow to the south into Roberts Creek. The construction of the temporary pre-loading embankment for the proposed Cumbalum Way, parallel to Deadmans Creek Road, has exacerbated the problem. Flows are now only able to breach the Pacific Highway and return to Emigrant Creek. Since the pre-loading embankment is only temporary, this has not been included in the existing case model.

Numerous options for flood mitigation have been investigated in the Cumbalum area as part of this study, the proposed RTA Ballina Bypass and the adjacent Ballina Heights development. This area is still the subject of further investigation. However, for this study, the following design criteria have been adopted:

- The proposed Cumbalum Way will have a maximum level equal to the existing Pacific Highway at the proposed intersection, i.e. 1.4m AHD;
- The RTA Ballina Bypass Improved Concept Design has been adopted as placed on public exhibition by the RTA in June 2007; and
- The proposed sports fields, north of Deadmans Creek Road, to be constructed as part of the Ballina Heights development have been included in the base case flood assessment as partly filled (as at 2005).

The solution presented in this study is for a 40m wide floodway parallel to and on the eastern side of the RTA Ballina Bypass Service Road. The floodway, at an approximate invert level of 0m AHD, will start adjacent to the flood relief bridges beneath the RTA's Ballina Bypass and continue south to the proposed Cumbalum Way. Beneath Cumbalum Way, a series of culverts will need to be provided. Preliminary analysis indicates an approximate cross sectional area of 81m^2 will be required for the culverts, i.e. 30 x 3m wide x 0.9m high at an invert level equal to the approach floodway. On the downstream side of Cumbalum Way, a further floodway at similar invert level, will need to connect the culverts to the existing low lying area of Roberts Creek. Refer to Figure 8-5.

8.3.3.2 Modelling Results Summary

Flood mitigation works at Cumbalum are critical to ensuring peak flood levels do not increase further upstream in Emigrant Creek as a result of local development and the RTA's Ballina Bypass. The floodway and culverts presented here give an indication of the scale of mitigation structures required.

8.3.4 Gallans Road Cycleway

8.3.4.1 Description

Construction of the Gallans Road cycleway embankment has provided a barrier for flows passing between Emigrant Creek and Roberts Creek to the east. Since the 1997 Floodplain Management Study, further filling has been applied to the embankment to provide cover for services within the embankment. This has further reduced the ability for floodwaters to transfer between the two floodplains. The inability for floodwaters to drain from the Emigrant Creek floodplain between the Pacific Highway, Deadmans Creek Road and Gallans Road, has increased flood levels in the area. The level of the embankment varies approximately from 1.2m to 1.8m AHD for its 610m length across the floodplain. Refer to Figure 8-6.

For this mitigation option, a reduction in the elevation of the cycleway to 1.4m AHD is proposed where this level is exceeded. Additionally, the existing minor culverts at the northern end of the cycleway above Roberts Creek, are proposed to be replaced with 5 x 2.4m wide x 0.9m high box culverts.

8.3.4.2 Modelling Results Summary

Reduction in elevation of the embankment and the improvement of cross drainage has been investigated during this study. Although the works are shown to reduce peak flood levels to the west, as a result, flood levels increase in the North Creek catchment to the east. Refer to Appendix F for flood impact maps of the cycleway modelling.

Since there is uncertainty regarding how much the embankment can be lowered, and the ability to construct the cross drainage structures due to clashes with the services, these works have not been included in the final base case mitigation scheme. It is recommended that this area is subject to further investigation once further detailed survey and services potholing is available.

8.3.5 Waste Management Centre Floodway

8.3.5.1 Description

The existing waste management centre is located between Gallans Road and the Ballina Airport. On the eastern side of Gallans Road is a low lying strip of land which connects the Roberts Creek floodplain to the low lying area in the vicinity of the Bicentennial Gardens. This strip of land allows floodwaters to enter the Bicentennial Gardens area during the early stages of a flood and then drain in the opposite direction into Roberts Creek once floodwaters recede. Thus, the Bicentennial Gardens area is an important flood storage zone. Refer to Figure 8-7.

Proposed expansion of the waste management centre may block this flowpath, preventing the Bicentennial Gardens area from filling for flood storage, and also preventing local rainfall to escape. It is therefore necessary for a floodway to be constructed parallel to Gallans Road to ensure hydraulic connectivity is maintained. A 30m wide floodway is proposed with an approximate invert level of 0.5m AHD.

8.3.5.2 Modelling Results Summary

Modelling has confirmed the requirement for this floodway.

8.3.6 Riveroaks Floodway

8.3.6.1 Description

Riveroaks is a proposed urban development located on the southern side of the existing Pacific Highway to the north of Ballina Island. The development is located across the existing low-lying land, which forms a flowpath between the Fishery Creek floodplain to the North Creek Canal. Refer to Figure 8-8 for the topography of the area and a representation of the existing flowpath.

To compensate for filling the existing flowpath, a floodway is required to maintain the connectivity between the Fishery Creek floodplain and the North Creek Canal. Although this floodway will be cut through the higher ground to the south, it is a critical component of the flood mitigation strategy for Ballina. The requirement for this floodway was identified in the 1997 Floodplain Management Study.

A 30m wide floodway is proposed with an approximate invert level of 0.0m AHD.

8.3.6.2 Modelling Results Summary

The provision of a floodway to compensate for filling the flowpath at Riveroaks is required to ensure that floodwaters can freely drain from the Fishery Creek and Emigrant Creek floodplains.

8.3.7 Pacific Highway Floodway and Culverts

8.3.7.1 Description

During the 1997 Floodplain Management Study, it was identified that a floodway would be required between the RTA's Ballina Bypass and Council's Western Arterial to convey floodwaters from the Emigrant Creek floodplain into Emigrant Creek at the Teven Road, Pacific Highway intersection. Refer to Figure 8-9. Currently the Pacific Highway forms a barrier for flows to enter this section of Emigrant Creek. The floodway would require culverts beneath the Pacific Highway, designed to prevent tidal intrusion into the floodplain. This could be achieved using floodgates or an upstream weir structure.

Currently 10 x 3.6m wide x 1.2m high box culverts are proposed with an invert level equal to 0.0m AHD.

This floodway would only become operational once flood levels in the Emigrant Creek floodplain become high enough to fill the higher elevation land to the north of the Pacific Highway.

8.3.7.2 Modelling Results Summary

The culverts included in the model are required to reduce peak flood levels in the Emigrant Creek floodplain. The culverts are not operational for flood relief during the 5 year ARI event, since flood levels in the floodplain do not reach a sufficient elevation for submergence of the higher ground. The culverts are operational in the 20 year ARI event.

A floodway reserve must be maintained between the RTA Ballina Bypass and Council's Western Arterial to provide connectivity between the Emigrant Creek floodplain and these proposed culverts.

8.3.8 Fishery Creek Floodway

8.3.8.1 Description

During the 1997 Floodplain Management Study, it was also identified that a floodway would be required adjacent to Fishery Creek. The proposed floodway was intended to improve the conveyance of floodwaters between the Fishery Creek floodplain and the North Creek Canal. Refer to Figure 8-4.

8.3.8.2 Modelling Results Summary

Modelling results indicate that this mitigation measure is beneficial to reduce peak flood levels in the Fishery Creek and Emigrant Creek floodplains to the east of the proposed Ballina Bypass. However, it was determined that the floodway at Riveroaks was sufficient to ensure the maximum impact criterion was achieved for the same area. Whilst the Riveroaks floodway is able to manage peak flood level impacts without the need for the Fishery Creek floodway, the Fishery Creek floodway is not able to achieve the same objectives in isolation, hence the Riveroaks floodway is required.

Therefore, the Fishery Creek floodway has not been adopted in the base case mitigation scheme.

8.3.9 Emigrant Creek to Fishery Creek Floodway Link

8.3.9.1 Description

Improving the hydraulic connectivity of Emigrant Creek and Fishery Creek was investigated using a floodway between the two creeks on the southern side of the existing Pacific Highway. Refer to Figure 8-4. The intention of this floodway is to relieve flooding on the Emigrant Creek floodplain by facilitating floodwaters to flow into Fishery Creek.

8.3.9.2 Modelling Results Summary

The results of the analysis indicated no significant difference to peak flood levels for a range of design flood events. No further consideration to this option is therefore warranted.

8.3.10 North Creek Canal Dredging

8.3.10.1 Description

Improving the conveyance capacity of the North Creek Canal was investigated to determine whether this would improve drainage from the Riveroaks development area. Dredging was assumed between the Riveroaks development and North Creek.

8.3.10.2 Modelling Results Summary

Results of the analysis indicated these works had an insignificant impact upon local flooding. No further consideration of this option is, therefore, warranted.

8.3.11 Richmond River, North Creek and Emigrant Creek Dredging

8.3.11.1 Description

During Council's Civil Committee meeting held on 19 May 2007, it was queried whether dredging the Richmond River and North Creek would have flood mitigation benefits. Following discussion, it was agreed that a dredging assessment would be undertaken as part of this flood study update.

Council and DECC prepared a brief including the following:

- Dredging in the Richmond River between the entrance and the confluence with Emigrant Creek;
- Dredging in North Creek between Prospect Bridge and the Richmond River; and
- Dredging Emigrant Creek immediately upstream of the confluence with the Richmond River.

The extents and depth of dredging was determined during liaison between BMT WBM, Council and DECC. The extents are shown in Figure 8-10. Dredging to these extents would require removal of approximately 4.2 million cubic metres of material.

8.3.11.2 Modelling Results Summary

All three sources of flooding were assessed during this investigation. However, unlike the investigations for the other base case mitigation measures, the peak flood level impacts for the dredging assessment were undertaken for each dominant source of flooding. This enabled a greater understanding of the impacts of dredging based on the different types of flooding that can be expected to occur in Ballina.

Additionally, the dredging assessment was only undertaken for the 20 and 100 year ARI flood events.

The revised bathymetry due to dredging was applied to the fully mitigated base case model. Resulting peak flood levels were compared with the base case flood levels to enable the impacts of the dredging to be considered in isolation from other mitigation measures. This was considered necessary for numerous reasons including:

- The scale of the dredging operations and the time frames associated with undertaking the works; and
- Dynamic nature of the river bed material, resulting in the dredging not being a reliable mitigation measure.

Figures G-1 and G-4 in Appendix G show the peak flood level impacts for the 20 and 100 year ARI local catchment dominating events. The results are similar, displaying an increase in peak flood levels around the Ballina Island and lower North Creek areas. Decreased flood levels are displayed elsewhere. This is primarily due the 10 year ARI ocean level applied to this design event. By dredging the Richmond River entrance, conveyance is improved. Hence, when the sea levels are elevated, more water is able to flow in through the entrance.

Figures G-2 and G-5 in Appendix G show the peak flood level impacts for the 20 and 100 year ARI Richmond River dominating events. The results display greater similarity than the local catchment dominated events. The most significant increases are in the lower north Creek area to the southeast of the Ballina Airport. Again, the increases can be attributed to the 10 year ocean levels. Hence, there is an increase in the volume of water entering the Richmond River and North Creek during high tide.

Figures G-3 and G-6 in Appendix G show the peak flood level impacts for the 20 and 100 year ARI Ocean dominating events. As can be expected, dredging has allowed an even greater volume of water to flow into the Richmond River and North Creek from the ocean. Significantly increased peak flood levels have resulted in the Richmond River and North Creek.

The above analysis has demonstrated that during elevated ocean levels, dredging has caused peak flood levels to increase in all events. It is, therefore, recommended that dredging is not undertaken.

8.3.12 Widening of the Pacific Highway Bridge at Emigrant Creek

The existing bridge for the Pacific Highway crossing of Emigrant Creek is 190m wide and is a control for flooding across the Emigrant Creek floodplain as far north as Cumbalum. During the Community Reference Group meetings, the members of the group requested that enlargement of the waterway opening should be investigated.

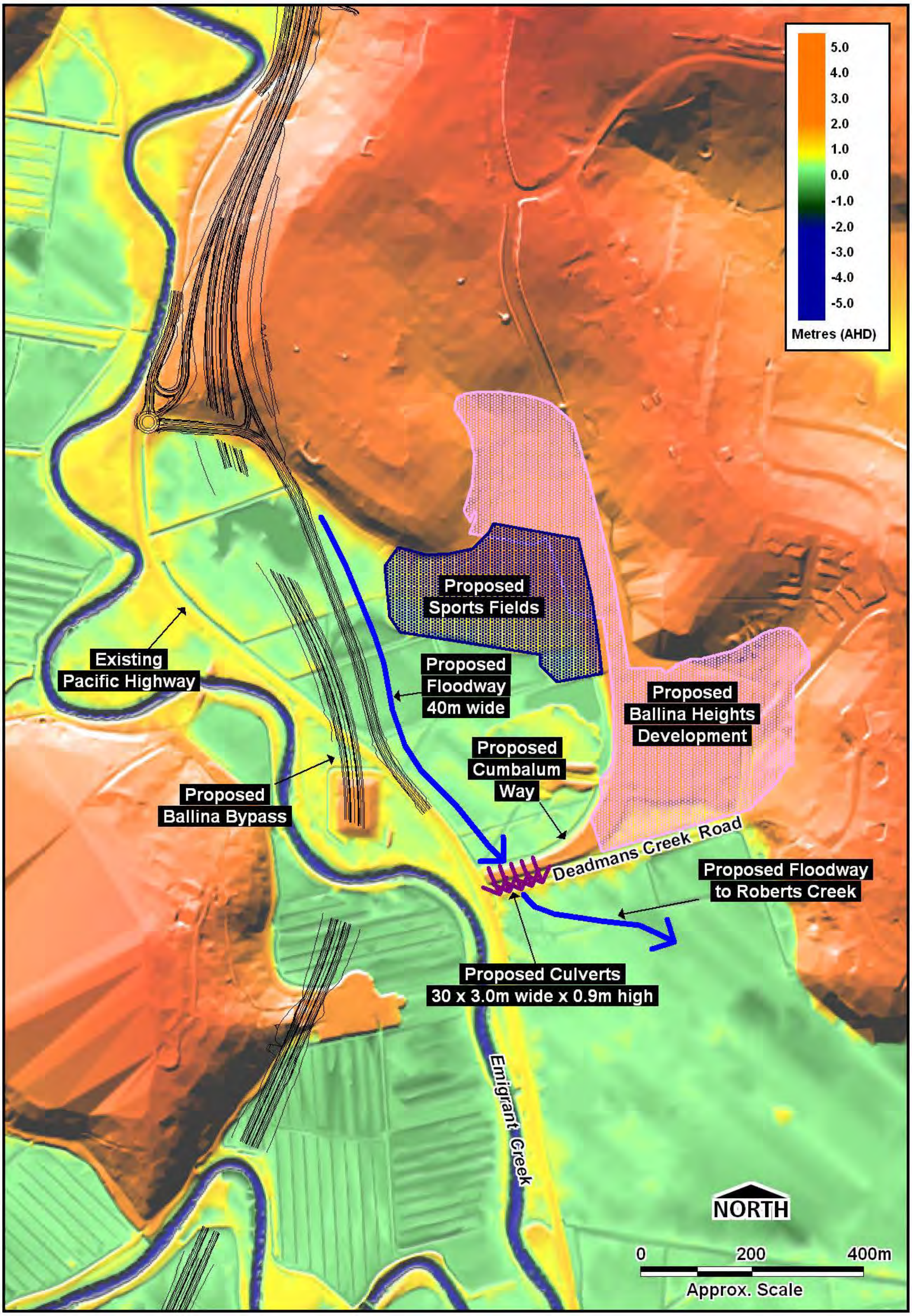
Preliminary flood modelling has indicated that upgrading the existing Emigrant Creek bridge and/or proposed RTA drainage structure midway between the Bruxner Highway and Teven Road, can be potentially beneficial in reducing upstream flood levels.

An assessment of the flood mitigation benefits by widening the Pacific Highway Bridge at Emigrant Creek by 50% was undertaken. This assessment assumed the following:

- the bridge is widened to 290m, with widening on the eastern side;
- the obvert of the bridge is 3.7mAHD;
- the floodplain level under the widened section is 1.0mAHD;
- an area upstream and downstream of the bridge is also lowered to 1.0mAHD; and
- vegetation underneath the structure is assumed to have a Manning's roughness of 0.07.

Figure H-1 in Appendix H shows the peak flood level impact for the 100 year ARI combined events, with a 50% widening of the Pacific Highway Bridge at Emigrant Creek. Peak water levels upstream and downstream of the bridge occur at different times. Peak water level downstream is dictated by the Richmond River levels. Predicted head drops across the bridge at the time of the upstream peak are 0.143m and 0.126m for the base case and widened bridge respectively; this is a decrease in impacts of 17mm upstream of the bridge. These decreases are minor and affect large areas upstream, including north to Cumbalum. In the area, near Lennox Head, a decrease of less than 5mm is predicted. This is most likely due to a slight decrease in flow across the cycleway.

Council has initiated discussions with the RTA with respect to potentially upgrading these cross drainage structures. Further investigation is currently being undertaken as part of the RTA's Ballina Bypass project and the ongoing investigations for the Ballina flood mitigation strategy.



Cumbalum Floodway and Culverts **Figure 8-5**