MANAGING IMPACTS OF STATE SIGNIFICANT MAJOR ROADS WITHIN THE RICHMOND RIVER FLOODPLAIN

PACIFIC HIGHWAY UPGRADE – WOODBURN TO BALLINA

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Presenter’s Profile

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Abstract

The Richmond River floodplain is one of the largest on the eastern coastline of northern New South Wales, Australia. The planning for critical national infrastructure, such as main roads, along the north-coast needs to recognise and manage the unique flooding regimes that occur in this floodplain.

As part of the planning for the Woodburn to Ballina Pacific Highway Upgrade being undertaken on behalf of the Roads & Traffic Authority (RTA), hydraulic modelling of the Richmond River was required to aid in the selection of route options, flood mitigation options and ultimately a preferred route. The hydraulic modelling utilised a fully integrated 1D/2D hydraulic model (SOBEK). Prior 1D and 2D modelling undertaken within the Richmond River floodplain was integrated into the SOBEK hydraulic model to form a ‘whole of river’ model that extends for approximately 100 km inland from the confluence with the Pacific Ocean at Ballina.

This approach has proven to be highly effective, allowing the rapid assessment of route options and detailed hydraulic modelling of the preferred route to meet the project timeframe. The results of the study concluded that substantial capital works are required to mitigate flooding impacts and could have a wide application to any major road construction within large floodplains.

Key Words: hydraulics, major roads, levees, floodplain, mitigation, SOBEK

1. Introduction

The planning process associated with the construction of major roads within the floodplains of major rivers can be significantly influenced by the need to minimise impacts on existing flood behaviour. To identify the potential impacts on flood behaviour and associated mitigation works requires the use of hydraulic models with the capability to model two dimensional (2D) solution schemes over all of the floodplain.

Fully 2D solution schemes and quasi 2D representations of the floodplain using a 1D model have inherent disadvantages within this application, given the large model area to be covered and the significant setup time involved in representing the river channel adequately within the model. In comparison, fully integrated 1D/2D models such as SOBEK allow a much coarser model to be used in the planning process while still adequately resolving the hydraulics of major hydraulic controls, the river and its floodplain.

2. Overview of the Pacific Hwy Upgrade – Woodburn to Ballina

Planning for the proposed Woodburn to Ballina highway upgrade is being undertaken by the Roads and Traffic Authority on behalf of the NSW State Government, as part of the Pacific Highway Upgrading Project. The study area identified for the Woodburn to Ballina upgrade is a 32 km section of the highway which extends from the southern side of the point where the existing highway crosses the Tuckombil Canal (just south of Woodburn) to intersection of the Pacific Highway and the Bruxner Highway (just south of Ballina).

Within the study area, the existing highway generally runs parallel with the Richmond River. From a flooding perspective a primary design objective of the upgrade project is to provide a minimum of 1 in 20 year ARI flood immunity to the highway. This would then require the highway to be raised up on embankments. As a result the proposed highway upgrade has the potential to have major impacts on the floodplain.

3. The Richmond River Catchment

The Richmond River Catchment covers an area of approximately 6,850 square kilometres, extending from the Nightcap, McPherson and Richmond Ranges to the ocean at Ballina. The Richmond River itself (often referred to as the main arm) is 170 km
in length, with the tidal limit being 90km from the ocean, extending past Lismore on the Wilsons River to beyond Tatham on the Richmond River.

4. The Route Option Development Process & Objectives

The Pacific Highway upgrade project has a number of objectives at different levels; National, State and local. From the range of objectives the principal flood management objectives are to provide 1 in 100 year ARI flood immunity where practical or as minimum provide 1 in 20 year ARI immunity to the road carriageway and the proposed highway is to minimal change on existing conditions.

The hydraulic modelling objectives for the route options, included:

- Ensuring flood level increases during a 100 year ARI flood were restricted to 50mm.
- Limit the effects on flood inundation times across the floodplain – this is particularly relevant to sugar cane farmers where inundation time causes more crop damage than flood depths.
- In areas outside of the floodplain, cross drainage is to convey the 100 year ARI peak flow.

5. Community Consultation for the Route Option Development

The community and stakeholders have been involved in an extensive consultation program. The key part of the consultation process was the formation of a Community Liaison Group (CLG). The CLG provided the opportunity for the two way exchange of information between the project team and the community.

From the CLG three smaller groups were formed to focus on specific issues. One of these groups was a flooding focus group. In addition to community members representatives from other stakeholders were invited to join the group. The focus group met on several occasions during the process which allowed detailed presentation and discussion of the flooding issues in the valley.

6. Hydraulic Modelling of the Route Options

6.1 SOBEK

The hydraulic modelling of the route options was undertaken using SOBEK, an integrated 1D/2D fully dynamic hydraulic model developed by Delft Hydraulics. This model enables efficient integration between river hydraulics, where flow can be considered 1D, and the floodplain where flows are best described by a 2D model (see Plate 1). The hydraulic model uses a grid based solution scheme (finite difference) for the 2D component and both the 1D and 2D components use the complete de Saint Venant Equations.

6.2 Development of a ‘Whole of River’ Integrated 1D/2D Hydraulic Model

The hydraulic modelling of the route option development process required the integration of existing site specific flood studies undertaken along the Richmond River. These studies included:

- Cabbage Tree Island Flood Study (Patterson Britton & Partners, 2005) – undertaken in RMA2 between Broadwater and Pemlico Island. Although the use of a pure 2D model may have had application to this study, the vast amount of effort and hence time required to establish the grid (particularly for the river) over such a large study area excluded the use of this model, or any other pure 2D model. In addition, their were concerns regarding whether the 2D elements would satisfactorily model conveyance within the river channel given that most of the discharge in the Richmond River lies within the river banks where flow can effectively be described as one-dimensional.
Mid Richmond Flood Study (WBM, 1999) – A Mike11 model setup as a quasi 2D to represent breakouts over levees etc. This is the only other ‘whole of river’ model that currently exists, extending from Coraki to Ballina. This model was not used for the route options assessment due to the inherent difficulty of cross sectionally averaged flow and velocity within a 1D model that would provide little information in regard to the effects of floodplain modification. In addition, modification of the model to examine all of the route options would require more set-up time comparative to altering a 2D surface.

Ballina Floodplain Management Study (WBM 1996) – ESTRY 1D model – This study was undertaken from Pemlico Island to Ballina using ESTRY, a 1D model. Due to the overlap with the Mid-Richmond Flood Study, only the hydrology was used from this study for the major creeks entering around Ballina towards the downstream end of the study area.

The various base survey sources used to originally establish the above mentioned hydraulic models were integrated along with additional photogrammetry into a TIN representing the terrain using ArcGIS. This TIN was used as the base for developing a raster grid, often referred to as a digital elevation model (DEM).

6.3 ArcGIS Spatial Analysis

The primary objective at the route option development stage was to develop an alternative to the coarse quasi 2D Mid Richmond Mike-11 model, from which large scale changes to floodplain hydraulics and preliminary mitigation options could be estimated.

The Spatial Analyst component of ArcGIS was utilised to aggregate a relatively coarse raster grid from a much smaller raster resolution, which resolved hydraulic controls. This spatial analysis function ensured that the maximum cell height of a hydraulic control was translated to the larger ‘aggregated’ grid cell. In selecting the final raster grid size (resolution) a quantitative assessment was undertaken using the GIS to select the largest grid size possible which would still resolve the hydraulic controls such as the Pacific Highway and other roads acting as levees. This involved extracting cross sections for various grid sizes over various major levees and comparing the estimated heights. Where necessary, raster cells were manually lifted to provide an adequate representation of hydraulic controls.

A final raster grid size of 100m x 100m was adopted for the modelling of the route option development, resulting in a raster surface containing 418,914 cells of which 53% are active. The result was a hydraulic model that broadly depicted major hydraulic controls and resulted in manageable model run-times, given the large number of model iterations required to model mitigation measures for each proposed route option in the short timeframe available.

It should be noted that for the concept design of the selected preferred route the SOBEK model will use a finer 2D grid of approximately 60m resolution.
7. Hydraulic Modelling Results – Key Findings

7.1 Comparison to Existing Studies
Flood level differences between the Mid Richmond Flood Study (WBM 1999) and the SOBEK model within the study area are shown in Plate 2. In general, flood levels are similar to the Mid Richmond Flood Study (WBM Oceanics Australia 1999), with a mean difference between estimated 100 year ARI flood levels of 23mm and standard deviation of ±160 mm. Differences are attributable to the fact that the SOBEK model is most likely representing floodplain storage more accurately, as it is currently the only integrated 1D/2D model used within the entire study area.

7.2 Boundary Conditions
Selection of boundary conditions can have significant impacts on the level of flood mitigation works required. The boundary condition used in this study was a 100 year ARI storm tide boundary condition at Ballina, as that used for the Mid Richmond Flood Study (WBM 1999). This boundary consisted of a stage vs time boundary offset sufficiently so that the storm tide peak occurred approximately 3 days prior to the river peak at Broadwater (approximately half way through the study area), as shown in Figure A1.

This boundary condition is conservative in that much of the low lying areas within the study area, many of which are below 1 m AHD, are inundated before the flooding occurs in the Richmond River. This effective reduces available floodplain storage, which in turn influences the extent of flood mitigation works required and their relative capital costs.

7.3 River versus Floodplain Discharge
The Richmond River floodplain is extensive, comparative to the river itself. However, within the study area much of the discharge from the river is conveyed within the river banks, as shown in Figure A2.

As a result, models which incorporate a 1D component for the river sections are likely to accurately model flood behaviour. More importantly, an integrated 1D/2D model can also describe floodplain behaviour adequately.

8. SOBEK Modelling of the Route Options
The advantage of using an integrated 1D/2D hydraulic model is that the route options were able to be analysed with minimal model modification by inserting the proposed horizontal alignments of the routes options into the 2D component of the model. The route options and existing 100 year ARI flood depths are shown in Figure A3.

Flood mitigation options were modelled by incorporating viaduct areas along the route at strategic locations (i.e. by lowering the cells to match the surrounding surface) such as within low lying areas that provided active floodplain storage, or where major drains passed through the road alignment.

Each viaduct was represented in the 2D surface only, as all routes provided for 100 year ARI flood immunity. For lower flood immunity standards, the viaduct would be modelled in the 1D component, while the road weir flow represented in the 2D surface.

Plate 2. Standard Deviation of Error Between Mid Richmond River Flood Study (WBM 1999) Flood Levels

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<tr>
<th>Field</th>
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</thead>
<tbody>
<tr>
<td>Count</td>
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</tr>
<tr>
<td>Minimum</td>
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<tr>
<td>Standard Deviation</td>
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Statistics of Z_Error_of_0100_Levels_in_Study_Area
9. Floodplain Mitigation
Requirements for Route Options

For the route options the following flood mitigation scheme has been developed to ensure that the objectives of the project were met:

Richmond River Bridge Crossing – in the modelling of the route options development a bridge span of approximately 720m to 850m was required to minimise afflux. This allowed some encroachment into the Richmond River floodplain. However, geotechnical and highway design issues will result in the bridge spanning all floodplain areas (approximately 1,000m span).

Tuckombil Canal Bridge Crossing – a 350m span bridge was proposed for all route options along this crossing to facilitate conveyance of Richmond River flows through to Evans Head along Tuckombil Canal and the Evans River.

Floodplain Viaduct – between 880m (Option 1c) and 1350m (Option 1a) of viaduct was required for the section of floodplain between Woodburn and Broadwater Towns.

10. Conclusions

Important outcomes from the SOBEK modelling are:

- Significant benefits of using an integrated 1D/2D modelling approach for the route options development in terms of number of options that could be examined in the short timeframe.
- Pure 2D models are often associated with slow simulation times, where this approach provides shorter simulation times.
- Quicker setup time than using a quasi 1D model approach, and produces a more reliable estimation of impacts of the proposed routes on the floodplain hydraulics.
- Integrated 1D/2D models appear at the very least to be able to generate similar results to existing 1D and 2D models given similar base survey, hydrology and downstream boundary conditions.
- Issues of scale in relation to a ‘significant impact’ – 50mm allowable afflux results in a significant change in storage volume, but has little impact on floodplain hydraulics, planning and development.
- Choice of boundary conditions can affect the extent of mitigation options required (increase capital costs) due to pre-filling of floodplain storage areas.
- Development of a whole of river model allows various areas to be readily modelled in much finer detail, while integrating hydrology from the larger base model.
- Where full 100 Y ARI flood immunity is desired the extent of capital works required for flood mitigation is substantial. It has been estimated that the capital works for viaducts alone would be in excess of $35 Million.
- Lower standards of flood immunity may provide significant cost savings both in terms of embankment fill depths and capital works (viaducts).
- The level of model detail will be increased for modelling of the preferred route, as more information is required around viaduct areas etc. This can be facilitated by using nesting of finer resolution grids.

References


Appendix A

Figure A.1  Discharge at Broadwater -100 year ARI flood

Figure A.2  Richmond River 100 Y ARI Discharge Downstream of Broadwater/Tuckean
Figure A3 - 100Y ARI Flood Depths & Route Options - Southern to Mid Section
Figure A4 - Northern Section of the Preferred Route & Bruxner Hwy Interchange – 100Y ARI Local Flood with 10Y ARI Ocean Storm Tide