ARNHEM HIGHWAY CROSSING OF THE ADELAIDE RIVER FLOODPLAIN

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Abstract

The Arnhem Highway is the key access link between Darwin, Jabiru and Kakadu National Park. During the largest flood event in recent years in March 2007 the highway was inundated by approximately 1.8 m of water and remained overtopped for about 10 days.

The Northern Territory Department of Infrastructure, Planning and Logistics (DIPL) is planning to upgrade 6km of the Arnhem Highway to reduce the risk of flooding during the wet season. The proposed upgrade aims to improve the flood resilience of the highway by increasing its flood immunity and reducing the number and duration of highway closures due to flooding. The proposed Arnhem highway upgrade will result in major benefits for the rural areas of the Northern Territory.

A flood study of the lower Adelaide River floodplain was conducted using a large two-dimensional hydrodynamic model to understand the complex dynamics occurring within this system, which features a large low gradient floodplain with challenging flood dynamic interactions including seasonal floodplain vegetation variations and tidal influences.

Extensive hydrologic and hydraulic modelling was conducted using different computational numerical engines (GPU and CPU) to investigate the challenging flow interactions between the main rivers, tributaries/anabranches and the vast floodplains with various flow breakouts and redistributions, extensive flood wave attenuation and diverse hydrological pathways.

Introduction

The Adelaide River rises in the hills of Litchfield National Park at an altitude of 151 meters above sea level and flows northwards over its 238-kilometre length discharging into the Timor Sea at Adam Bay. The Adelaide River has several major tributaries contributing to its 7,640-square kilometre catchment including Coomalie Creek, Margaret River and Marrakai Creek.

The Arnhem Highway crosses the Adelaide River floodplain near Humpty Doo, where is frequently closed by flooding for several days considerably disrupting the primary supply line to Arnhem Land for major industries, tourism and the local population. The Northern Territory Department of Infrastructure, Planning and Logistics (DIPL) engaged SMEC to undertake an options study to increase flood resilience of this 12 km wide stretch of the Arnhem Highway between Lambells Lagoon and Warrakai.
Background

The Arnhem Highway is the key access link between Darwin, Jabiru and Kakadu National Park. During the largest flood event of recent years, which occurred in March 2007, the highway was inundated with a maximum depth of approximately 1.8 metres and remained closed for about 10 days. (SKM, 2012)

The Arnhem Highway comprises two trafficable lanes and has no emergency lane or space for a vehicle to stop or in case of a breakdown. Apart from the existing Adelaide River Bridge, cross drainage structures along the floodplain include small reinforced concrete pipes and/or box culverts. The full length of the highway across the flood plain has experienced differential settlement of the embankment.

DIPL is planning to upgrade the existing Arnhem Highway to reduce the risk of flooding during the wet season. The proposed upgrade will improve the flood immunity of the highway, reduce the Average Annual Time of Closure (AATOC), and consequently improve the safety of road users. The proposed Arnhem Highway upgrade will provide major benefits in servicing and supporting the rural areas of the Northern Territory.

Catchment Area

The catchment area of the Adelaide River upstream of the Arnhem Highway crossing is approximately 5,850 km². The Adelaide River at the location of the Arnhem Highway crossing is tidally affected and the floodplain topography in the vicinity of the highway is flat with a gradient of about 0.00004m/m. A locality plan of the Adelaide River catchment is shown in Figure 1.

Hydrologic Analysis

Hydrologic analysis for the Adelaide River catchment was carried out using the RORB hydrological modelling package and regional parameters recommended for Northern Territory as suggested in “Australian Rainfall and Runoff” (ARR) (Pilgrim, 1987). A RORB model covering the entire Adelaide River catchment draining into the Arnhem Highway was built for this study. The RORB model consists of 45 sub-catchments, strategically delineated to present flow hydrographs at relevant gauging station locations and the Arnhem Highway crossing of the Adelaide River floodplain.

The model was calibrated against flow rates recorded to the three largest historical flood events occurring during 2007, 2011 and 2014. As the subject crossing is influenced by tidal effects, the calibration focused on achieving a calibration at the Dirty Lagoon gauge (G8170020) which is located 46km upstream of the Arnhem Highway. At this gauge location historical flows recorded during the 2007, 2011 and 2014 events were large enough to drown out tidal influence. Figure 2 shows the comparison between recorded and calibrated flow hydrographs for the three flood events.
Figure 1: Study Area Locality Plan and Adelaide River Catchment Area (SMEC, 2017)
Figure 2: Hydrological Model Catchment Delineation and Gauging Stations Location (SMEC, 2017)
Once calibration to historical events was deemed acceptable, the hydrological model was used to derive design flows for the entire Adelaide River catchment up to the Arnhem Highway for events ranging from the 1% to 39% Annual Exceedance probability (AEP) events for all durations up to 72 hours.

The design flows calculated with the RORB model at Dirty Lagoon Gauge (G8170020) were compared to design flow rates estimated using three other alternative methods, including Flood Frequency Analysis (FFA) referenced by “Australian Rainfall and Runoff” (Ball et al, 2016) of the records from Year 1962, Regional Flood Frequency Method (RFFE) referenced by Rahman et al (2014) and regional flood frequency curves (CMP, 1978). Results of the comparison indicated a close correlation (See Table 1).

### Table 1: Comparison of Peak Design Flows at Dirty Lagoon Gauge (G8170020)

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>RORB</th>
<th>RFFE</th>
<th>CMP</th>
<th>FFA</th>
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<td>39</td>
<td>932</td>
<td>802</td>
<td>1100</td>
<td>930</td>
</tr>
<tr>
<td>20</td>
<td>1974</td>
<td>1520</td>
<td>2145</td>
<td>1963</td>
</tr>
<tr>
<td>10</td>
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<td>5374</td>
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</table>

Hydrographs calculated with the hydrological model (for both historical and design events) were applied onto a hydraulic model setup approximately 30 km upstream of the Arnhem Highway as part of this study to obtain flood levels at the Arnhem Highway.

### Hydraulic Modelling

Due to the flat nature of the Adelaide River floodplain terrain and the occurring breakouts and the amount of storage and attenuation in the floodplain, the site cannot be modelled in isolation. The 2D hydrodynamic modelling package TUFLOW was used to represent the complex hydraulic interactions of the Adelaide River with its floodplain.

As the closest stream flow gauge is located upstream of the extent of existing LiDAR data, the hydrodynamic model was calibrated to the recorded flood levels for 3 historic flood events at the Arnhem Highway Gauge (G8170021).

Due to the size of the floodplain being considered, a hydraulic model was setup to optimise running times whilst having a reasonable definition of the geometry of the main river, floodplain and Arnhem highway. This full-scale model has a fixed 50mx 50m grid size and covers an area of approximately 262 km². Extending 25km upstream and 5km
downstream of the highway, this model was initially setup to calibrate to peak flood levels for the historic flood events. The topography of the hydraulic model was constructed based on a combination of LiDAR, hydrographic survey and detailed survey of the Arnhem Highway to provide a more accurate definition the main river channel and existing road elevation. The extent of this model is shown in Figure 4.

Apart from using the large grid size model, simulations were also undertaken using refined model with a smaller model extent to assessed options for highway upgrade in a finer grid without compromising running times to confirm findings in the full-scale model.

As flood modelling commenced in 2016 prior to the release of a more powerful TUFLOW GPU/HPC solver, the model was initially conducted using TUFLOW classic engine. Further in time, the model was also ran using the TUFLOW GPU/HPC solver at a finer grid size to compare results.

![Figure 4: Flood modelling Computational Domain (SMEC, 2017)](image)

Model Calibration and Validation

Three historical events were simulated within TUFLOW to replicate the March 2007, February 2011 and February 2014 flood events. Observation of the results discovered that modelled water levels were slightly underestimated for the March 2007 event, and slightly overestimated for the February 2014 event at the Adelaide River Bridge. The shapes of the water levels hydrographs for the February 2014 event also showed some noticeable differences.

Apart from verification against modelled flood level hydrographs in terms of levels and timing, modelled flood velocities and stream profile were also compared to observed values where available. Model results corresponding to the March 2007 historical flood event were also visually compared with photographs during the flood (refer to Figure 5).
The observed differences were attributed to various reasons including:

- Difference in surface roughness during different flood events as a result of change in vegetation coverage;
- No available recorded flood level data downstream of the Adelaide River Bridge for the flood events to enable the model to ascertain tailwater conditions which can influence model results due to tidal conditions, especially for smaller events;
- Difference in shape and volume between the calculated and actual historical event inflow hydrographs due to insufficient sub daily rainfall data to capture the rainfall spatial distribution across the catchment;
- Transport and collection of vegetation and debris loads along channels; and
- Routing of flood hydrographs and representation of floodplain storage within models.

Adjustments were made and the model was fine tuned in terms of floodplain roughness values and selection of downstream tailwater boundary conditions.

Tailwater levels depend on a number of factors, including tide and storm surge. However, no available data further downstream of Arnhem Highway was available for this study. The use of recorded water levels at Arnhem Highway gauge as a tailwater boundary for historical event model runs was discarded as it includes both tide and flood flows and thus influences the flood levels at Arnhem Highway.

Due to the lack of historical water level records or tide information downstream of the Arnhem Highway, a number of investigation were conducted to determine suitable downstream boundary condition for the full-scale model to be used in calibration and design flood events.

A series of sensitivity testing in relation to floodplain roughness, climate change, blockage of hydraulic structures and tail water conditions were also undertaken to establish the robustness of the model results and sensitivity to changes in input parameters and various assumptions.
Results and Outcomes

Upon deemed reasonably calibrated to historical peak discharges, overall volume and water levels of historical flood events, the flood model was used to simulate the 1%, 2%, 5%, 10%, 20% and 39% AEP design storm events for existing conditions and to conduct an options analysis of several concept designs for the proposed highway upgrade and associated cross-drainage structures.

Results show that apart from the Adelaide River Bridge which has more than a 1% AEP flood immunity, flood immunity observed around most of the Arnhem Highway is generally above 39% AEP with the exception of a low spot located around chainage 34000 (Refer to Figure 6). The modelled peak flood extents in the 39% AEP and 1% AEP design flood is shown in Figure 7 and Figure 8.

An Average Annual Time of Submergence (AATOS) of 186 hours/year (7.8 days/year) was calculated for the Arnhem Highway crossing the Adelaide River floodplain at this point. Results of the assessment indicated that the low spot located at the eastern floodplain is the critical section that drives the closure of the entire stretch of Arnhem Highway. Further assessment of various highway upgrade options and corresponding drainage structures was subsequently undertaken.

Figure 6: Longitudinal Profile of Existing Arnhem Highway across Adelaide River Floodplain (SMEC, 2017)
Figure 7: 39% AEP Existing Conditions Peak Flood Extents (SMEC, 2017)

Figure 8: 1% AEP Existing Conditions Peak Flood Extents (SMEC, 2017)
Conclusion

Hydrodynamic flood modelling offers the opportunity to improve the ability to quantify flood patterns, particularly across large floodplains. For the first time, accurate simulation of flooding and drainage of the lower Adelaide River floodplain was achieved with quantification of changes in water elevation, flood extent, and river floodplain exchange. Modelling results were used to inform drainage infrastructure sizing and design requirements to improve flood immunity and resilience for this section of the Arnhem Highway.

Further modelling is currently being carried out to develop a concept upgrade targeting a 5% AEP flood immunity. This includes testing of different cross drainage structure systems not only accounting for hydraulic efficiency, but also various other factors including costs, constructability, safety, maintainability, reliability, risks and temporary works requirements.

Acknowledgements

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