Integrating Hydrologic and Storm Surge Models for Improved Flood Warning

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EXTENDED ABSTRACT

The Australian Bureau of Meteorology has responsibility for flood warning in Australia. In areas with a quantitative forecast service, height forecasts are provided for key locations.

The state of the ocean can have a significant impact on the height of rivers at coastal locations. Tidal influences and storm surges can lead to much higher river heights and greater areas of inundation than would be expected from flow from the rainfall alone.

The Bureau of Meteorology uses the URBS (Carroll 1998) rainfall runoff routing model to model flood heights at key locations around Australia. An important part of the forecast process is the conversion from flow to height using “rating curves”. These curves can vary depending on downstream conditions. This feature is used to more accurately model height at locations that have a tidal influence.

In this paper, the predicted height at a tidal station is modified by using the results of a dynamic storm surge model (Entel et al 2005). This is then used with a dependent rating to predict the height at a station on the lower Yarra River in Melbourne for a storm in February 2005.

Using the storm surge model improves the height prediction in this case. The forecast error was reduced from an original -0.5 metres to 0.1 metres.

This paper shows how appropriate simple integration of two models can improve forecasting.

1. INTRODUCTION

The Bureau of Meteorology (BoM) is the lead agency responsible for flood warning in Australia. Where quantitative warnings are provided, this service involves the prediction of river height forecasts at key locations. This information is then used by local authorities to plan appropriate responses. The main tool used for river height prediction is runoff routing models, with URBS (Caroll. 1998) being the most widely used model. The BoM have developed a system, HYMODEL (Malone, 1999), that can automatically access real time data, run the URBS model, and display the results. Rating curves are a key component of the forecasting process, as they are needed to convert flow to height. In coastal areas, tidal effects and storm surge can significantly affect the flow-height relationship. To accurately predict river level in coastal regions, these changes must be taken into account.

In the absence of more detailed flow/height behaviour relationships, a single relationship defined by a set of points is usually adopted, and that satisfies most needs. As a further enhancement, the URBS model has the capacity to accommodate a "dependent" rating curve, where the flow is defined by both the height at the location and the downstream conditions.

In Australia, tropical cyclones have played significant part in causing damages as well as deaths, both from the destructive winds and from flooding. Coastal regions are especially vulnerable to flooding from high river flows due to the heavy rainfall and from storm surge propelled by the winds. A secondary effect is the rise in sea level induced by the storm's low pressure. There is added complication from variations in tides and from the wave set up especially on relatively steep continental shelves. These effects can also be seen from extra-tropical low pressure systems.

One of the results of the ongoing work aimed at enhancing the existing storm-surge dynamical modelling capability at the BoM is a fully integrated interactive storm surge modelling system (Entel et al., 2005). The system calculates the sea level response (surge) to tropical cyclones or other low pressure systems, for example, mid-latitude storms. It uses as a forcing the atmospheric fields from either TC LAPS which is an atmospheric state-of-the-art forecasting system for tropical cyclones developed by BMRC, or mid-latitude limited area prediction systems (LAPS or MesoLAPS).

Other agencies, such as the USA National Weather Service (Reed and Stucky, 2005), and the Scottish Environmental Protection Agency (Kaya et al., 2005), have modelled the effect of storm surge on river height by using hydraulic models. The BoM do not use any hydraulic models for operational forecasting at present. Therefore if the impact of storm surge on coastal flooding is to be incorporated into operational forecasting, in the short term, some way of linking that effect into existing hydrologic models must be established.

The capacity of URBS to incorporate the impact on downstream boundary conditions on the flow/height rating curve relationship was exploited in this study. Here the output from the storm surge modelling performed by the BoM is used on the URBS model as a boundary condition to improve the accuracy and lead time of river height forecasts. Therefore this paper is an attempt to model complex riverine/storm surge interaction behaviour by using simpler, existing capacity to obtain acceptable results.

2. METHODOLOGY

To evaluate how integrating storm surge models can improve river height forecasts, a case study was run. This case study selected is the storm event from February 2005. This was selected as it was a recent event with output from MesoLAPS for forcing of the storm surge modelling being available. This event resulted in record rainfall totals being observed in many parts of Melbourne, among other impacts causing elevated stream levels in the Lower Yarra River by a combination of the high rainfall and storm surge. Meteorologically, the event was caused by strong southerly winds associated with a deep low moving across Port Phillip Bay.

2.1. Yarra River Basin

The Yarra River basin lies north and east of Melbourne, beginning on the southern slopes of the Great Dividing Range. It has area of approximately 4000 sq km, with a variety of land use and urban development.

The main prediction point in this paper is the Yarra River at Hanna St gauge. This gauge is the lowest gauging station on the Yarra River, and is affected by the sea level in Port Philip Bay. High stream levels at this gauge are linked to possible flooding on the commercial precinct on the South Bank of the Yarra River.

The existing hydrologic modelling system can use forecast or recorded tidal data. For this study, the forecast tidal levels were modified by the results from the storm surge model. The forecast tidal levels were derived from tide tables from the national tidal centre.

2.2. Yarra River URBS model

The URBS model uses a number of subcatchments. In the Yarra River model, subcatchments are characterised by stream length, catchment area, and the impervious fraction. The main model parameters are the Initial Loss (IL), continuing loss (CL), a catchment storage parameter (β) and a channel storage parameter (α). To better represent catchment variability, 9 submodels are used (Figure 1 below), each of which have a different set of model parameters. These sub models are shown below. In the model runs, the parameters were adjusted to give a good fit at key locations, typically the lowest stream gauge in each sub-model.

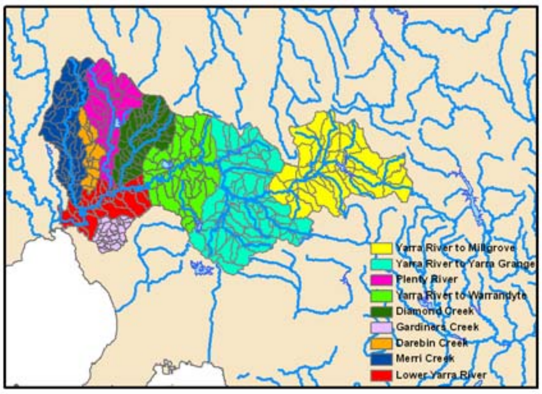

Figure 1: Sub models for the Yarra River URBS model

Dependent rating curves have been used successfully with URBS to accurately model the height at tidal locations. These use different flow height relationships for a point for different downstream conditions (typically a tidal station).

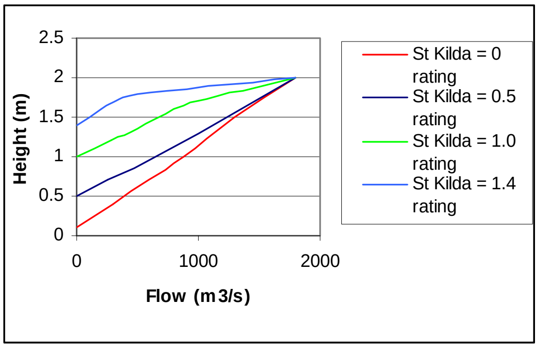

Figure 2: Rating Curves for the Hanna St Gauging Station

A dependent rating curve (Figure 2) exists for the Hanna St stream gauge. This rating curve is derived from the recorded heights and modelled flows for a few different events. This is linked to a tidal station at St Kilda Marina.

Rainfall data was available for a number of stations in the area. Rainfall for each subcatchment was calculated from the nearest 4 rainfall stations. Figure 3 below shows the rainfall stations used, and the event total for each one. In this study in running the hydrological forecasting model, observed rainfall was used so that the impact of using the storm surge model output could be separately compared.

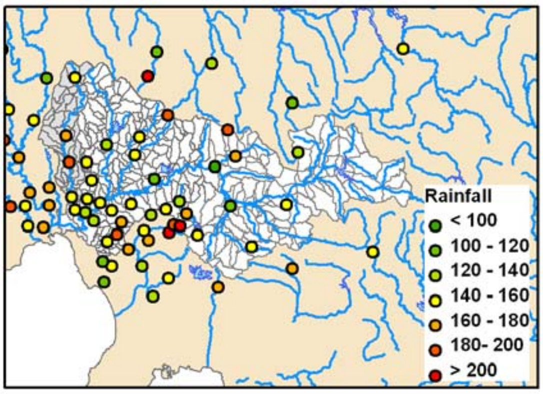

Figure 3: Event Rainfall totals for the Yarra River catchment

2.3. Storm Surge model

The ocean surge model was set up for the area covering Port Phillip Bay and the adjacent areas of Bass Strait. The spatial resolution of the numerical grid was about 1.1 km. The atmospheric forcing (wind surface stresses and sea-level pressure) used for this study was based on several consecutive 36-hour forecasts of Meso_LAPS_Pt050 for the period from 31 Jan to 5 Feb 2005. This model represents a high-resolution (0.05 degrees) version of the Limited Area Prediction System (LAPS) model described in Puri et al (1998) and is run operationally by the Bureau of Meteorology for the Victoria-Tasmania region.

3. RESULTS

The results of storm surge modelling are presented in the following Figure 4 which shows the forecast maximum surge (in cm) for the Post Phillip Bay area. A time series of the surge magnitude for the location with the coordinates approximately (37.87S 144.92E) is used for the river flow modelling discussed below.

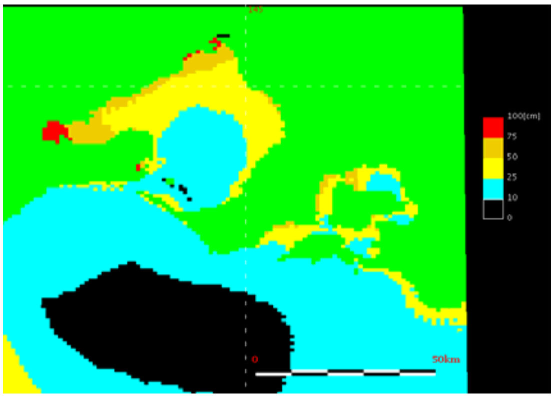

Figure 4: Peak storm surge heights

The storm surge model improved the height predictions at St Kilda Marina compared to relying on tidal data alone. This can be seen in Figure 5 below.

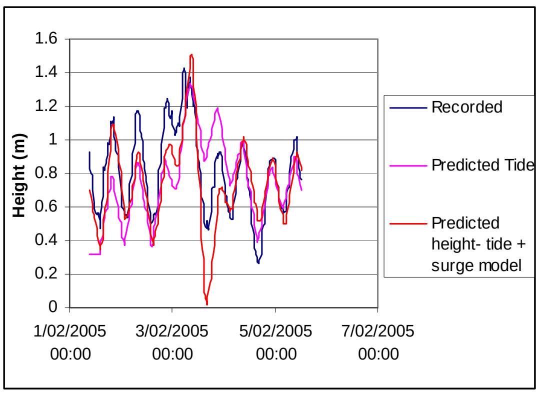

Figure 5: Heights for St Kilda Marina

Figure 6 below shows the improvement in results using the storm surge model for Hanna Street. The “URBS only” run relied on the predicted tidal data, while the run including the storm surge model used the tidal data modified with the storm surge. The improvement in the prediction of the peak is clear, with a predicted peak of 1.93 metres using the storm surge model, compared to 1.34 metres without it. The recorded peak was 1.83 metres.

Without the predicted tidal data modified by the storm surge model, the peak height at Hanna St is under predicted by around 0.5 metres. Using results from the storm surge model gives a much more accurate forecast.

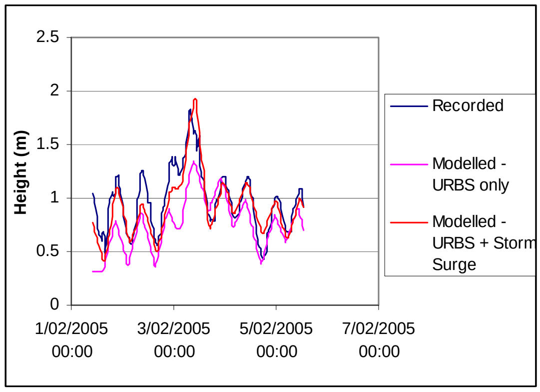

Figure 6: Heights for Hanna Street

4. CONCLUSION

Using the storm surge model significantly improves the performance of the model in the Lower Yarra River. In this case here, going from using predicted tidal data alone to modifying this data using the results from a storm surge model have a large impact on the forecast, changing it from an incorrect forecast of only minor flooding to an accurate forecast of major flooding. This shows the potential for a storm surge model to improve flood forecasting even when used in a relatively simple hydrologic/hydraulic modelling environment.

5. ACKNOWLEDGEMENTS

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