Tropical Cyclones Modelling For Natural Disaster Risk Management

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Abstract: Burdekin Shire covers an area of approximately 5200 square kilometres, and lies along the eastern edge of the Great Dividing Range to the South of Townsville in Queensland. The Shire's wealth is based on primary production (predominantly sugar cane) and agricultural industries, with the larger urban centres located at Ayr, Brandon and Home Hill on the Burdekin River delta. The Shire has a long coastline with isolated coastal communities scattered along its length.

Burdekin Shire Council is undertaking an assessment of storm surge risk across the Shire, under the Natural Disaster Risk Management Studies Program. The primary aim of the study is to reduce/minimize the risk of death and injury due to storm surge events associated with tropical cyclone, with a secondary aim of reducing isolation and infrastructure damage resulting from surge and flood inundation.

DHI Water & Environment and Maunsell Australia were jointly commissioned to undertake the study. The adopted methodology involved application of the two-dimensional modelling system MIKE21. The MIKE21 modelling system is an engineering software package for 2D free-surface flows and is applicable to the simulation of hydraulics and related phenomena in floodplains, rivers, lakes, estuaries, bays, coastal areas and seas where stratification can be neglected or assumed vertically well mixed.

The complex ocean bathymetry off the North Queensland coast produces highly dynamic tidal conditions, which required that the model extend from the Northern Territory in the north to northern New South Wales in the south. The nested grid facility of MIKE 21 was implemented, with successively finer scale grids nested internally within a coarser grid, resulting in 5 model areas and 4 levels of grid accuracy.

One of the features of the study was the requirement to develop a forecast surge model that could be used by Council to provide storm surge predictions during future approaching cyclones. The model results were used to develop storm surge counter disaster plans, including evacuation plans and storm surge mitigation solutions for the Burdekin Shire.

Keywords: *Storm surge modelling, tropical cyclones, natural disaster risk management.*

1. INTRODUCTION

Tropical cyclones are large scale and severe low-pressure weather systems that affect the northern coasts of Australia typically between November and April. These cyclones combine strong winds, intense rainfall and induced ocean effects including extreme waves, currents and storm surge.

Tropical cyclones pose a real threat to many coastal communities along the northern coast of Queensland every year. In 1989 tropical cyclone Aivu passed through the Burdekin Shire inundating large areas of the Shire resulting in significant infrastructure and agricultural losses.

The Burdekin Shire Council decided to facilitate a disaster risk management plan to be implement in the event of future cyclones and commissioned DHI-Maunsell to develop a disaster risk management strategy. This strategy was based on the development of a storm surge forecast model to be operated by Council, which would provide storm surge prediction during cyclone events.

The storm surge model was used to develop the disaster risk management plan, including evacuation plans and storm surge mitigation measures for the Burdekin Shire. The primary aim of the study was to minimize the risk of death and injury due to storm surge events with a secondary aim of reducing flooding isolation and infrastructure damage.

2. HINDCAST MODELLING

A methodology was developed using the two dimensional coastal modelling system MIKE21. The MIKE 21 model is applicable to the simulation of hydrodynamics, waves and related phenomena in coastal areas and seas. The model allows for storm surge flows to propagate over dry land and includes momentum and wind forces on inundation flows in the coastal plains.

The complexity of the area and the tropical cyclones required the use of grid nesting facilities to define a modelling area large enough to avoid perturbations along the boundary conditions and small enough to allow accurate description of the complex reef and channel systems. Five model areas, nested in 4 levels were defined with grid scales ranging from 4050metres to 50metres. The nesting layout of the models is illustrated in Figure 1.

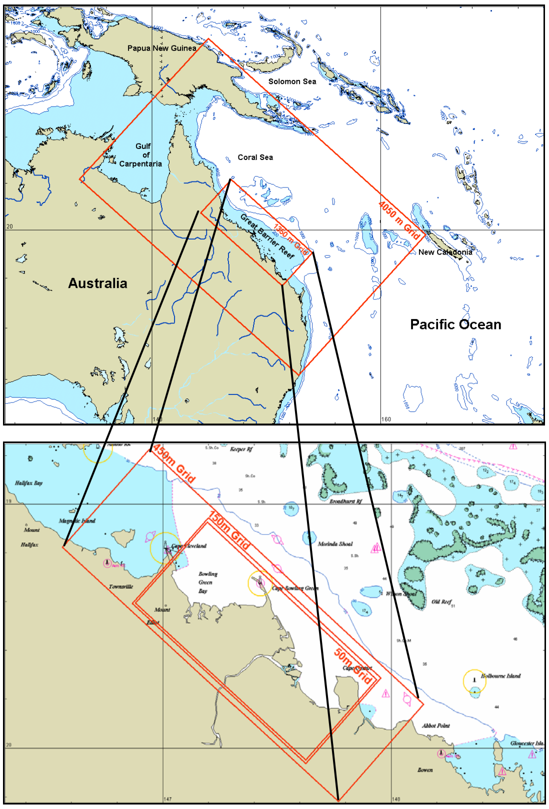

Figure 1. Overview of the model set-up.

The study area is complex due to the presence of extensive offshore coral reefs and large low-lying coastal plains. A large number of topographic, bathymetric and hydraulic data were collected from various sources with the information supplemented by detailed airborne laser scanning of the coastal plains above mean sea level. The laser scanning survey required significant editing in order to remove extensive areas of grown sugar cane and other structural features. Figure 2 illustrates the model bathymetry developed for the study area.

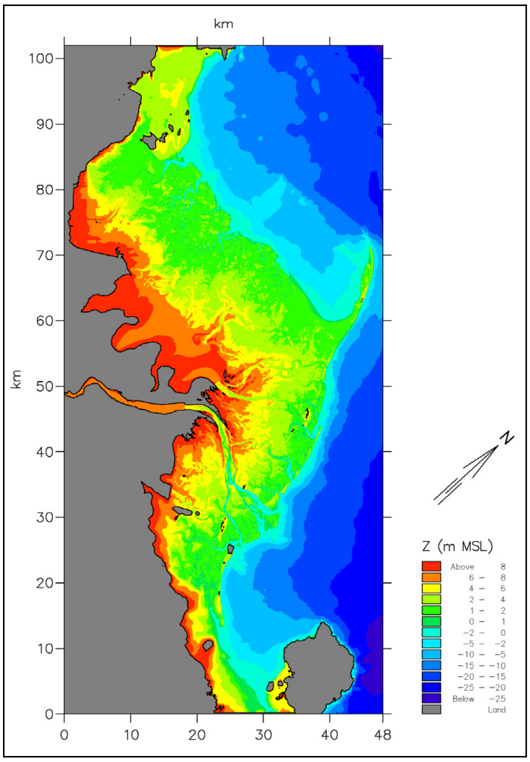

Figure 2. Overview of the study area bathymetry

The MIKE 21 model allows for automatic generation of wind and pressure fields of cyclones using a parameterised description of the cyclone shape with a predefined track. Wind and pressure fields have been generated from the parameterised data sets and incorporated as boundary conditions for the hydrodynamic and wave modelling simulations.

The impact of wave set-up on the storm surge was investigated in order to obtain the contribution of the waves on the total storm surge. The wind-induced waves were simulated using the MIKE21 spectral-wave (SW) model. The MIKE21 SW model is based on unstructured meshes, which were established for the area as part of the study. The SW model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas and is particularly applicable for simultaneous wave prediction and analysis on global, regional and local scales. The computed wave field was applied in the hydrodynamic model simulations through the transfer of radiation stresses from the wave model to the hydraulic model.

2.1. Calibration of the model

The storm surge model was calibrated for two conditions these being:

- Normal tidal conditions.
- Storm surge events.

Calibration under normal tidal conditions

The model was calibrated against predicted tidal levels through the model domain to ensure its correct behaviour under normal tidal conditions. Comparisons between modelled and predicted tidal levels at 14 locations along the Queensland coast were completed with the model demonstrating good agreement with the tidal conditions at each location. Figure 3 presents the model water level predictions (red) compared to predicted tidal water levels based on tidal constituents (black). The tidal calibration provided a good insight into the influence of the Great Barrier Reef on the tidal conditions in the area. It was observed that the Reef, with its narrow deep channels, regulates the inflow and outflow of water and consequently plays a key role on the hydrodynamic conditions of the study area. This was particularly evident in the Mackay region, where large tidal amplification is experienced due to the influence of convergence of tidal currents produced by the Reef

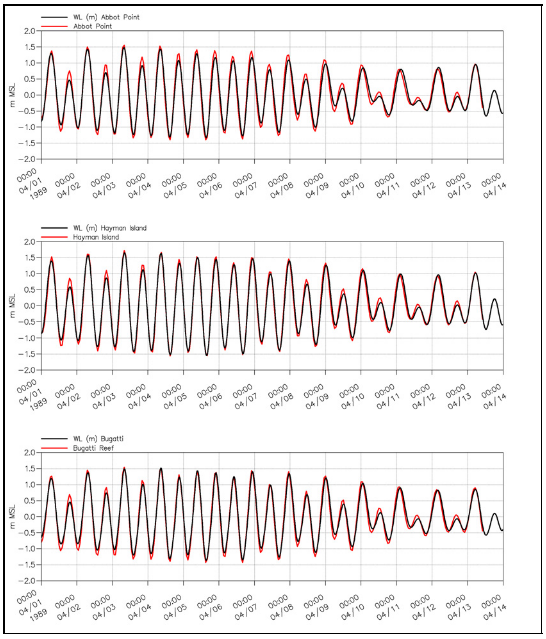

Figure 3. Water level comparisons at three locations: Abbott Point (top), Hayman Island (middle) and Bugatti Reef (bottom).

Calibration for storm surge events

The model calibration was extended to include the full storm surge model including atmospheric influences and wave setup for two cyclone events, Aivu (1989) which passed through the Burdekin region and Althea (1971), which passed Townsville to the north of the study area. A comparison of the water level predictions for tropical cyclone Althea is presented in Figure 4 for the tidal records from Townsville and Bowen. Simulated wind/pressure field and tidal levels for the study area are shown in Figure 5. The model results showed good agreement, especially during the peak surge conditions.

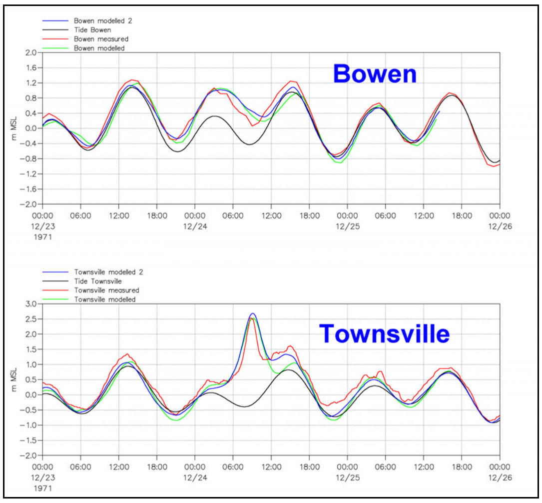

Figure 4. Comparison of the temporal water levels at Bowen and Townsville during tropical cyclone Althea.

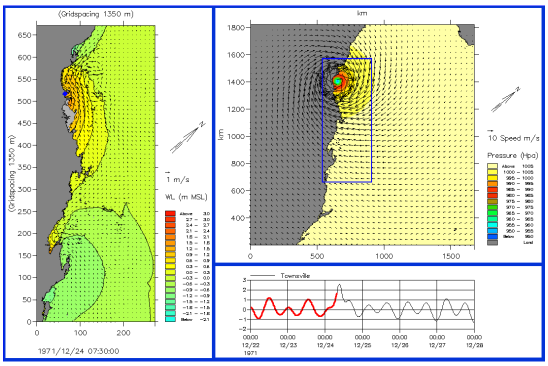

Figure 5. Overview of the tidal water levels and wind/pressure field during cyclone Althea.

3. DESIGN STORM ASSESSMENT

The assessment of storm surge levels and the associated inundation areas during design storm conditions was carried out for a range of cyclone conditions. These conditions were based on four variables, namely: cyclone strength and bearing, cyclone landfall area and tidal water level conditions. These conditions were defined based on a sensitivity analysis of likely storm conditions. In total a matrix of 36 simulations was defined to describe the range of likely and significant cyclones that could impact the region.

The results of these simulations provided the basis to determine the maximum storm surge water levels as well as the inundation areas for each of the design events. These results were applied to define the disaster risk management plan. A typical example of the inundation results from a Category 2 cyclone crossing the Burdekin River delta is presented in Figure 6. The depth of inundation is described by the blue intensity with darker areas indicating deeper flow. The figure illustrates a small area of the Burdekin Delta showing Wunjunga in the south and the Burdekin River in the north.

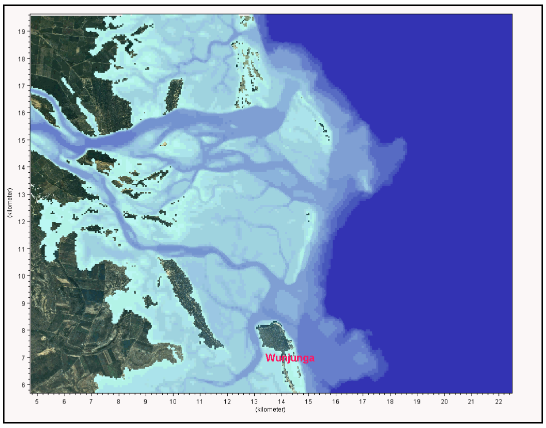

Figure 6. Typical example of the inundation mapping from model results for the Burdekin River

4. FORECAST MODEL

One of Council's requirements in this project was the delivery of a forecast model to be operated locally, in order to provide storm surge prediction capability during future cyclone events. A MIKE 21 model will be operated by the Council to fulfil these requirements. Due to the complexity of the operation of the storm surge model, training will be provided to key personnel within the Council.

For the purposes of providing effective warnings, the model must run in 1-2 hours, to allow dissemination of surge warnings and, if necessary, evacuation of threatened communities. To achieve this relatively short model 'run time', the forecast model was developed with a coarse grid resolution. Comparison with the fine scale hindcast model showed no significant reduction in the accuracy of predicted peak surge levels however there is a reduced resolution of the inundation areas.

5. APPLICATION TO DISASTER RISK MANAGEMENT

The Federal Government has recognised the need for a structured approach to the management of risks associated with natural disasters. No longer will they continue to commit to funding, to the same historic levels, for damage caused by natural disasters unless there are documented risk management plans in place to enable the risks to be properly managed and the overall repair/restoration costs to be significantly reduced.

With this in mind the Federal Government has established the Natural Disaster Risk Management Studies Program, its aim being to encourage State, Territory and Local Governments to undertake worthwhile studies to identify, analyse and evaluate the risks from natural disasters through the provision of Commonwealth financial assistance towards the cost of these studies. The framework for all disaster risk management studies is shown in Figure7.

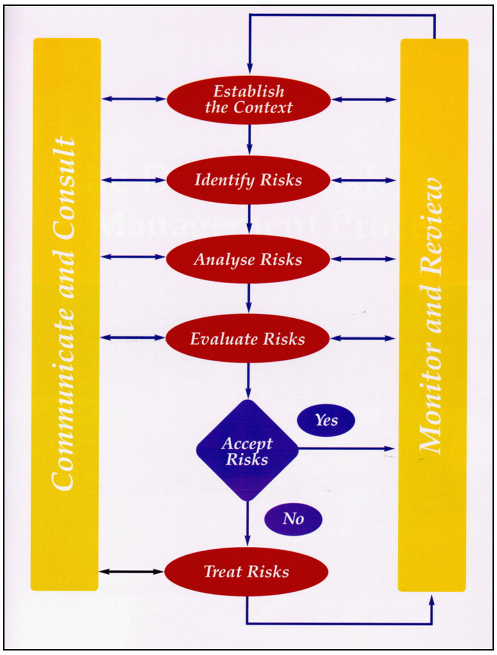

Figure 7. Overview of the framework for the disaster risk management studies.

In 2001, Burdekin Shire Council was successful in obtaining financial assistance under the program to complete a storm surge study of the Shire. Storm surges have been recorded within the Shire (like that resulting from tropical cyclone Aivu), but no major surges have occurred in recent years. The storm surge study adds to Council's already strong record in emergency response and preparedness, through the development of appropriate mitigation strategies to minimise disruption to essential services.

At the time of preparation of this paper, scenario modelling of the range of cyclones was still being completed. However, the process of community and stakeholder consultation was well progressed and it is expected that the evaluation and treatment (mitigation) of risks will be based around the inundation and hazard mapping (an example is shown below in Figure 8).

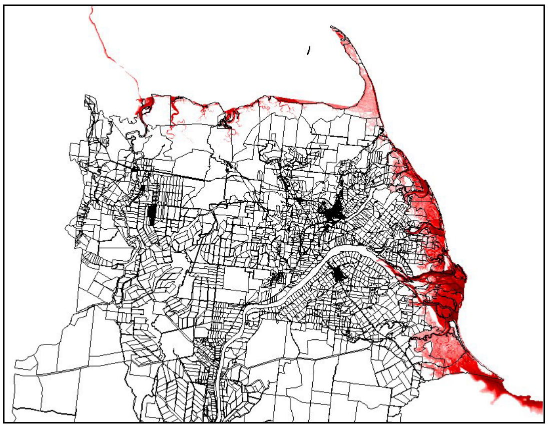

Figure 8. **Example of a hazard mapping of the study area**

Issues to be assessed will include access to coastal communities, relative timing of the passage of the cyclone and peak inundation, variability of impact depending on cyclone intensity and track, hazardous areas with excessive depths and velocities, possible mitigation measures and effective methods for providing forewarnings

6. CONCLUSIONS

A forecast surge model that can be used by the Burdekin Shire Council to provide storm surge predictions during future cyclone events has been developed. The model was calibrated and verified for normal tidal and storm surge conditions for two historical storm surge events.

The model results showed good agreement with recorded surge levels in the local area, and tidal behaviour from the Northern Territory to the north coast of New South Wales. The nesting approach used to 'zoom' in on the Burdekin Shire coastline can be applied anywhere along the Queensland coastline.

The model was run for 36 design storm combinations to determine maximum water levels and inundated areas, as input to the disaster risk management process and development of storm surge counter disaster plans for Burdekin Shire. The predictive forecast model also give Burdekin Shire Council the ability to independently assess the storm surge risk from approaching tropical cyclones well before their arrival.

The storm surge mapping will be used to update the current Counter Disaster Plan (including evacuation plans for each community). The storm surge mapping has been subjected to considerable community consultation, during calibration of the model and on delivery of the Draft Report.

7. ACKNOWLEDGEMENTS

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