# STORM TIDE RISK ASSESSMENTS IN TROPICAL AND SUB TROPICAL AREAS INCLUDING CONSIDERATION OF CLIMATE CHANGE IMPACTS AND EMERGENCY MANAGEMENT NEEDS

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## Abstract

The assessment of tropical cyclone related storm tide risks is an essential planning tool for coastal councils in northern Australia, made even more critical due to the possible impacts of sea level rise and the climate change modification of storm intensity and frequency. With rapidly increasing coastal based centres of population, emergency managers are also under pressure and in need of better information and advice on how to cope with potential large scale disasters. This paper outlines key issues and approaches in dealing with the potential impacts of storm tide through reference to a number of recent studies in Queensland (in particular the Whitsunday, Townsville, South East Queensland and Innisfail regions). For each of these locations, climate change considerations have been fully built-in to storm tide study methodologies providing the opportunity to also service emergency management planning and training needs. The studies are based on the best practice methodology recommendations from the Queensland Climate Change Study conducted 2001 – 2004 . Aspects of these studies are presented, focussing on a blend of method and function, including best practice methodology, the importance of model calibration and testing, preparing results for emergency and planning functions, and the provision of insights into the specific likely climate change impacts for each region.

**Key Words: climate change, sea level rise, tropical cyclones, storm tide, emergency management**

## Introduction

Tropical cyclones generating storm tides and flooding in Australia rank on top of the list of extreme events (geohazards), with Queensland, Western Australia and the Northern Territory particularly exposed. When population is taken into account, Queensland coastal communities account for a high proportion of the population at risk from such events. Despite the existence of this risk, the theory and application of storm tide predictions are generally poorly understood by those most likely to have a need to apply the results. The need for informed studies to be undertaken is therefore of paramount importance.

When sea level rises associated with climate change and increasing cyclone intensity are also considered, the risk to Queensland coastal communities is potentially significantly increased, with areas of cities such as Cairns and the Gold Coast having a large number of low lying properties. Key infrastructure (water, power, airports) will also be subjected to higher risk, with implications for emergency management.

## Storm Tide and Impacts

The definition of storm surge and storm tide is now generally well understood by emergency management and planning personnel, as is the range of potential risks to population and infrastructure as indicated above. However, the process of estimating storm tides, and how to best make use of such studies is not understood to the same degree.

Extreme storm tide levels caused by tropical cyclones cannot be estimated solely on the basis of historically measured water levels. This is because the available record of tropical cyclones affecting any single location on the coast is quite small, the resulting storm surge response is often complex and very site specific, and the final storm tide is dependent on the relative phasing with the astronomical tide. Hence, measured storm tide data alone is typically inadequate for extrapolation to very low probabilities of occurrence.

To overcome this problem, it is necessary to formulate a statistical model of the coastal region that will attempt to re-create the observed region-wide tropical cyclone climatology and numerically generate long sequences of potential storm tide scenarios, a process that has been applied to many storm tide studies along the Queensland coast (for example, the Whitsunday, Townsville and Innisfail regions) and throughout Australia and nearby regions (Harper at al. 2007).

There remain two key aspects which are not always consistently addressed. These are: (a) understanding the relative importance of planning (as compared to emergency management), and (b) the inclusion of the potential affects of climate change (other than through a simplistic adjustment of sea level). Each issue is addressed in the following sections with an overview of the common analysis methodology is provided in Figure 1.

This approach is fully consistent with the recommendations from the Government-sponsored *Queensland Climate Change and Community Vulnerability to Tropical Cyclone – Ocean Hazards Assessment-Stage 1* (Harper 2001). This study (hereafter referred to as the “Blue Book”) provides a state-of-the-art methodology for ocean hazard assessments and a technical pathway to best practice assessment of climate change impacts. Building on the advantages of the QCC methodology, GHD teamed with SEA in 2007 to provide a revised “Blue Book” standard of service to coastal councils in order to meet their regional study requirements.

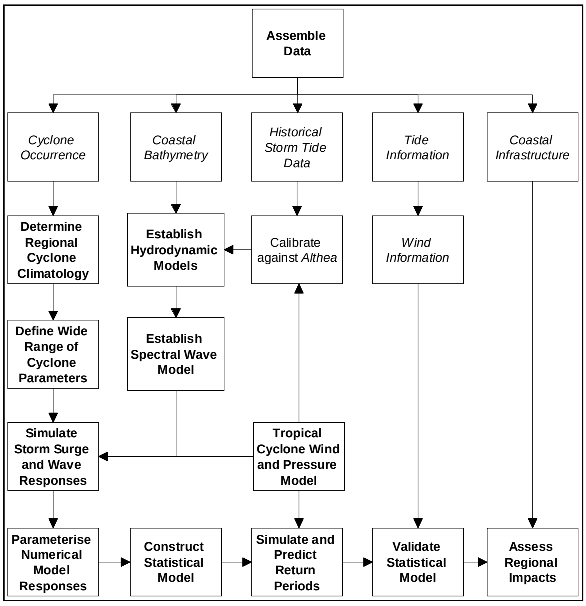


**Figure 1** Example coastal hazard study methodology.

## Planning and Emergency Management

One of the most commonly encountered queries when commencing a storm tide study is that relating to how emergency management procedures might be affected, and whether the study will deliver a better understanding of “exact” water levels for any given cyclone. This line of thought fails to recognise that during an extreme event, emergency management procedures are reliant on an inherently uncertain forecast of peak water level provided by the Bureau of Meteorology, and that the extent of areas that may require evacuation for a given storm tide level can be easily defined when needed.

Hence, it is not always apparent that a fundamental purpose of conducting storm tide studies should be to facilitate future planning. In this context, planning primarily refers to land use planning (i.e. the reduction of risk to life and property through a reduced encounter probability in the form of appropriate siting). A well conducted study will therefore provide two benefits: provision of a greater level of the understanding of risk, such that better informed decisions can then be made in both a planning and emergency context.

## Addressing Climate Change

Climate change can exert an influence on cyclonic activity, and hence storm tide in several ways. It can generally be assumed that:

- A rise in sea level will occur;
- A rise in mean sea level (MSL) will also lead to a rise in HAT and the tidal characteristics may also change slightly as a result, but this effect is commonly ignored. Also, although AHD is based on MSL, it is assumed that the AHD datum will remain where it is now.
- An increase in tropical cyclone maximum potential intensity or MPI[1] will also occur. It should be noted however, that it is not a straightforward concept to apply to the statistical description of individual cyclone central pressure values. The interpretation made here is that the most intense of cyclones may increase their intensity but that not all cyclones will be more intense.
- The way that this can be applied is illustrated in Figure 2, whereby the potential % increase (relative to $\Delta p$) is blended into the present climate description used by the statistical model.

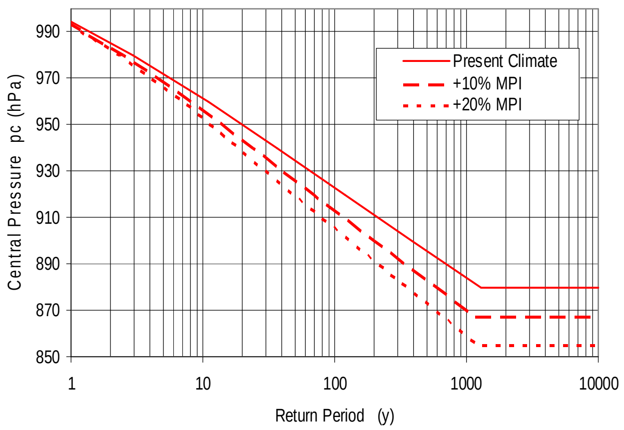


**Figure 2** Assumed Possible Changes in the Intensity of Tropical Cyclones under Enhanced Greenhouse Conditions

[1] The MPI is the theoretical peak storm intensity available from the regional thermodynamic properties of the atmosphere and ocean, subject to a range of other favourable conditions.

Details from a number of completed studies follow. The possible effects of greenhouse-induced climate change have been considered in these studies, whereby a possible future climate scenario is simulated and those results compared with the estimates for “present climate”.

## Whitsunday Region

The Whitsunday Storm Tide Study, completed in 2003, was the first to apply “Blue Book” regional standards of storm tide risk analysis to a Local Government fine scale study. A principal challenge in the area was the complex nearshore island environment and the very high tidal ranges, which vary markedly throughout the region (refer Figure 3).

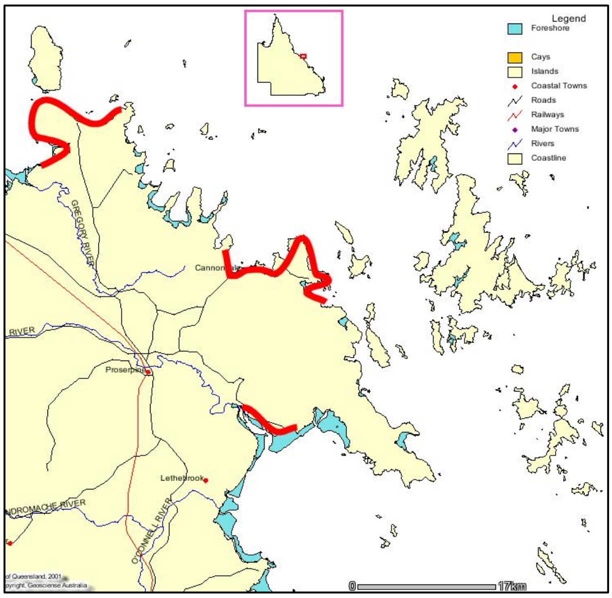


**Figure 3** The Whitsunday region study area with its complex island environment and high tidal variability

The study highlighted the principal locality at risk was the Repulse Bay area near the mouth of the Proserpine River, where the low lying land and limited evacuation routes combined with a dynamic storm surge amplification effect to produce increased risk. A secondary benefit was the increased level of understanding that the study provided: storm tide levels can be highly variable along the coastline for any given event (whether a cyclone or a defined recurrence interval such as the 1 in 100 year storm tide level).

To assist Council in their emergency planning, a series of specific cyclone scenarios were also modelled, impacting on different parts of the region. This produced results that had been unexpected by the emergency managers; namely that locations some considerable distance from the cyclone landfall position could be more adversely affected than those at the point of landfall.

## Townsville and Thuringowa Region

The Townsville-Thuringowa Storm Tide Study was completed under the auspices of the Federal Government's Natural Disaster Risk Mitigation Program (NDRMP). The aim of this program was to minimise / reduce future costs associated with the occurrence of natural disasters through better planning processes. For this study, the focus was on inundation associated with a range of statistical storm tide events, and the levels of risk and exposure associated with predicted inundation.

As with the Whitsunday project, the model development process utilised four different software packages which addressed:

- Tropical cyclone wind and pressure
- Hydrodynamics
- A spectral wave analysis
- Statistical consideration of surge and tide predictions.

These were developed using a system of nested grids. The largest of these grids (refer Figure 4), which provides data as to the sea-bed and hence water depth, extends almost 800 km off-shore, and almost 1400 km along the coastline. The smallest grid is 30km x 35km, with a grid size of 55m.

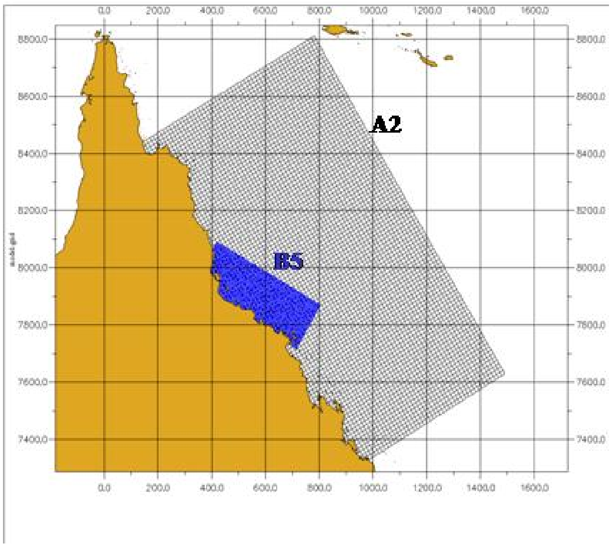


**Figure 4**. Large scale grids utilised for Townsville study

Key features of the analytical process to determine storm surge (and hence storm tide levels) for each of the nominated design events included:

- Calibration to Cyclone Althea (1971)
- Verification against Cyclone Aivu (1989)
- Completion of sensitivity analysis model runs
- Modelling of over 320 different cyclones, approaching on a number of different tracks.
- Simulation of a 50,000 year period (90,000 cyclones) using a statistical model.
- Probabilistic tide and wind verification.

Results were presented in terms of predicted surge height, wave set-up height and finally the resultant storm tide level for events ranging from the 50 year average recurrence interval (ARI) up to the 10,000 year ARI event.

A vulnerability assessment was then undertaken. This was based on a review of the predicted and mapped storm tide levels, and the implications for critical infrastructure, as identified in consultation with Townsville and Thuringowa Councils. Tables were produced which detailed items of infrastructure potentially affected. In addition, a review of the Counter Disaster Plan was undertaken, with particular attention to evacuation routes.

It was estimated that for the 100yr event, over 1000 habitable properties would be subject to some form of inundation. The population at risk was estimated at approximately three times the number of properties, with depths of greater than 0.5m associated with a higher risk of death. For the 10,000 year event, the number of properties affected would be significantly higher, with most of these subject to depths of 0.5m or more.

## Impact of Climate Change

The climate change scenarios considered in the Townsville study are summarised in Table 1.

**Table 1 Enhanced Greenhouse Scenarios**

| Year | Increase in frequency | Increase in Maximum Potential Intensity | Increase in Mean Sea Level |
|---|---|---|---|
| | % | % | m |
| 2050 | 10 | 10 | 0.5 |
| 2100 | 10 | 20 | 0.9 |

These scenarios were simulated in the storm tide modelling packages. Results for the year 2050 showed an average increase in storm tide level across all sites of 0.5 m at both the 500 yr and 1000 yr return period and 0.7 m for the 10,000 yr. The corresponding averaged results for 2100 were higher again, with increases compared to the current time of the order of 1.1 m, 1.2 m and 1.7 m respectively.

A similar approach has been adopted for the ongoing storm tide study for the Cassowary Coast region, which was subjected to Cyclone Larry in 2006.

## Enhancing Emergency Training and Awareness

As part of the study, Townsville City requested provision of a storm tide warning system. The resulting SEAtide model has the ability to readily simulate many hundreds of possible tropical cyclone scenarios on the basis of a "best estimate" forecast provided by the Bureau of Meteorology. Uncertainty in the forecast is used to produce a probability spread of various levels of inundation occurring rather than relying on a single estimate with unknown precision. As well as providing warning information, SEAtide can also applied as a realistic training tool, enabling emergency management staff to better understand the dynamic effects that can occur during extreme tropical cyclones. An example of a SEAtide output is given in Figure 5 below. This indicates which region is most likely to be impacted as the cyclone approaches, and the magnitude of storm tide predicted.

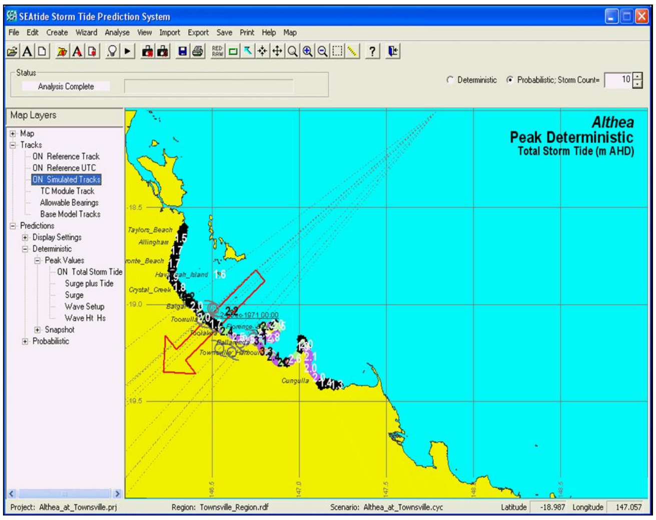


**Figure 5** Example SEATide prediction model interface for the Townsville region in North Queensland

Unlike a numerical modelling system requiring specialist long term staff training and support, SEAtide provides a user friendly interface that requires little specific training or maintenance. This approach not only allows training and a raised awareness of storm tide (from an emergency management perspective), but can also be applied to non-cyclonic storm tide, coastal wind and wave threats.

## Revisiting Best Practice Methodology

The SEQ Disaster Management Group (SEQDMAG) commissioned a study in 2007 to review a range of completed regional storm tide risk reports, and to compare the standard of each report in relation to the outcomes of the first part of the study, namely a review and update of recommended best practice methodology for assessing storm tide in the South East Queensland (SEQ) region.

The need for the study was driven in part by the recognition of increasing risk, and the recommendations of earlier studies. One of these, completed in 2001 by Geoscience Australia (GA), was the AGSO Cities Project in South East Queensland (Grainger and Hayne 2001). This earlier work examined the impact of natural hazards and the risk they posed on the communities from Caboolture Shire to the Gold Coast City Council including Ipswich City Council. Storm tide was identified in that study as a natural hazard of some significance, due to both tropical and extra-tropical storm systems.

It is clear that the region faces significant demographic changes, with an ever increasing demand for development of all kind, including residential, to be sited adjacent to the coastline. With more people moving to the coastal zone and evidence of climate change, the level of risk may rise. In this case, climate change effects are defined not only in terms of increasing water levels, but also an increase in the frequency of incidence of cyclones, as described below.

Under current climatic conditions, South East Queensland lies on the southern fringe of exposure to the most intense impacts of tropical cyclone. Uncertainties surrounding the effect of likely climate change on cyclone behaviour have raised questions of potential increase in risk to the SEQ region due to severe storm and cyclone related impacts.

## Storm Tide Studies in South East Qld

Over the past 4 to 5 years, a number of storm tide studies have been conducted for Queensland coastal councils. The complexity of storm tide has been dealt with in a different manner for many of these studies. Whilst the *QCC study (*Harper 2001) “Blue Book”, was commissioned to provide some consistency of approach, studies were delivered to different standards. Further, while applicable to SEQ, the “Blue Book” methodologies had been developed for Queensland regions not on the “fringe” but at the “centre” of cyclone related impacts.

Several factors therefore drove the need to review best practice methodology and to review completed studies against this methodology. These consisted of: a possible change to cyclone behaviour; a possible increase to SEQ storm tide risk; a need for regionally consistent outcomes (results), and the current lack of a regionally specific approach created a need to review the status and approach of the SEQ region to storm tide hazard.

### Findings

The total score across all of the six reviewed SEQ study reports was less than 50% of the hypothetical perfect score from a combined planning and emergency response perspective. This reflected the fact that several of the studies did not have a specific emergency response scope and some had no atmospheric or limited hydrodynamic modelling scope.

Whilst the QCC study itself scored high in climatology, atmospheric modelling, statistical modelling and documentation, no wave modelling south of the Sunshine Coast nor non-cyclonic events were considered in SEQ.

For each of the location specific studies, climatological and atmospheric modelling elements typically scored poorly, mainly owing to a lack of disclosure of the methodology. For example, it is considered critical that the forcing applied to the hydrodynamic modelling is representative and unbiased and that the selection of modelled events is well founded on a comprehensive storm climatology that acknowledges the need to identify different storm populations and their associated intensity and scale distributions.

In terms of the possible staging of such improvements, the need to review the historical storm data (intensity and scale) and develop representative regional storm climatologies was identified as a major critical path item that is common to all LGA regions.

Finally, the need was identified for the development of improved atmospheric models of each storm type (TC, East Coast Low etc) and the adoption of responsible Greenhouse-sensitive perturbations.

## Cyclone Larry and Innisfail

Tropical Cyclone *Larry* (Innisfail, March 2006) was the most significant event in the Queensland region for the past 20 years. Its impacts included moderate to severe wind damage to buildings in the Babinda-Tully coastal region while storm tide effects were limited to below the threshold of potential devastation, mainly due to the coincidence with neap tides (Boswood and Mohoupt 2007). The peak measured surge magnitudes were 2.3 m at Clump Point Jetty, with a total stillwater level of 2.6 m AHD, and 1.3 m at Mourilyan Harbour, being 1.6 m AHD. The peak surge was estimated to have occurred between these two gauges, which are approximately 30 km apart.

Consideration of this complex event has provided an opportunity to further test and develop the degree of wind, wave and surge accuracy that can be obtained through the adoption of a robust methodology. The ongoing work described below is being conducted for Johnstone Shire Council (now the Cassowary Coast Regional Council).

The highest astronomical tide (HAT) in the Innsifail region is around 2 m AHD. This fact, combined with the rapid movement of *Larry* (32 km $h^{-1}$), meant that beach erosion impacts were relatively minor. With wave effects not measured, the only available data relating to intermediate storm tide estimates was that from debris or inundation marks (surveyed up to 5.2 m AHD).

In terms of wind strength, the intensity of *Larry* at landfall was the subject of some debate between the meteorological, coastal and wind engineering communities. During the event, *Larry* was forecast to be a Category 5 storm at landfall, with the potential for significant and widespread destruction. After the event, damage surveys confirmed that the peak gust wind speeds experienced near ground level in standard exposure conditions were most likely in the range of 55 to 65 m $s^{-1}$ (200 to 235 km $h^{-1}$). Combined with the reliably measured central pressure of 955 hPa, this placed *Larry* potentially in the mid to high Category 3 class only.

However, the seemingly high beach debris levels in some areas, especially near the landfall, generated conjecture within the Bureau that the storm was “unusual” and may have delivered unexpectedly high surface winds. Nevertheless, officially *Larry* remains a Category 4 storm immediately prior to landfall and offshore wind and pressure calibrations conducted by SEA were consistent with that assessment.

Because the storm crossed the Great Barrier Reef lagoon it demanded hydrodynamic modelling at a scale sufficient to resolve the major reef passages. This was economically achieved using a nested regular grid in Delft3d, down to 550 m. Spectral wave modelling was also performed by SEA to the same resolution. The accurate modelling of astronomical tides over the period of neaps when the storm occurred proved difficult due to small errors in the offshore tidal boundaries. Accordingly, predicted tides were used to form a total storm tide time history.

Results of the study are summarised in Figure 6, whereby it proved possible to almost exactly reproduce the previously thought “unusual” surveyed beach levels. The various storm tide components of tide, surge, wave setup and 1% wave runup all proved reasonably consistent and reflected the complex interaction between the storm track, the wind and pressure fields and the array of reef passages.

This work again highlights the importance of building confidence in modelling methodologies so as to form a firm basis for future climate change sensitivity testing. The full study is currently being completed.

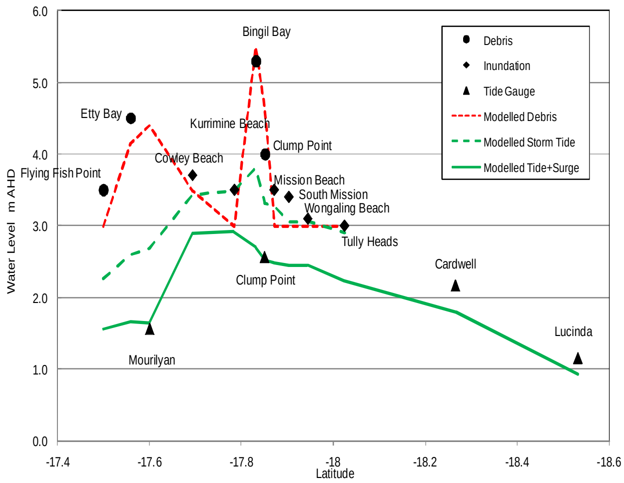


**Figure 6** Summary comparison of alongshore modelled and measured peak water levels during TC Larry

## Discussion and Conclusions

Storm tides occur as a response to severe meteorological condition. In Queensland, this is most commonly seen to be a consequence of cyclonic activity, though other low pressure systems can also generate storm tide.

As population demands imposed on coastal regions continue to grow, the inherent level of risk has also grown. This is exacerbated by climate change risk, whereby higher sea levels and more intense (i.e. lower pressure) cyclones may occur.

This paper has provided an overview of the assessment of storm tide risk through reference to a number of studies completed over the past five years. The paper has addressed in broad terms: the importance of appropriate methodology, the higher level of understanding that results, and the implications of climate change on each of these. Furthermore, the benefits that this provides to those responsible for planning and emergency management is significant.

Understanding the potential impacts of climate change and sea level rise needs to be a key factor in coping with demand on coastal centres. The tools now exist to help decision makers account for these pressures.

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## Ackowledgements


The authors would like to acknowledge each of our clients, and the efforts of Dr Ivan Botev