Back to
Papers

Storm Tide Threat in Queensland

Bruce A Harper[1]
Director, Systems Engineering Australia Pty Ltd, Brisbane, Queensland.

David A Robinson
Manager, Coastal Resource Assessment Section, Department of Environment, Brisbane.

Summary This paper updates and summarises the present status of knowledge regarding the potential threat posed by the occurrence of severe storm tides along the Queensland coast. It contains a summary extract from a more comprehensive report prepared for and available from the Department of Environment, Coastal Management Branch. In addition to the needs of engineering design, which have been well served for many years, the paper discusses the need for more attention to long term planning, forecasting and evacuation strategies. Recommendations for further detailed studies are also put forward.

1. INTRODUCTION

As single catastrophic events, extreme storm tides generated by tropical cyclones (hurricanes or typhoons), may be responsible for the largest known loss of human life on earth. The Bangladesh cyclone of 1970 is estimated to have drowned in excess of 300,000. More than 30,000 hurricane deaths this century have been reported in the Caribbean as well as almost 15,000 in the United States (Sheets (1994)), the majority due to the direct effects of the associated storm tide. In Australia, thankfully we have not experienced such devastating losses directly as a result of a storm tide, although a pearling fleet sheltering near Princess Charlotte Bay in 1899, some 200km north of Cooktown, was devastated with the loss of over 300 lives.

The potential exists for significant loss of life from storm tides in Queensland and the likelihood increases as our population along the coastal margin continues to increase (Harper (1997)).

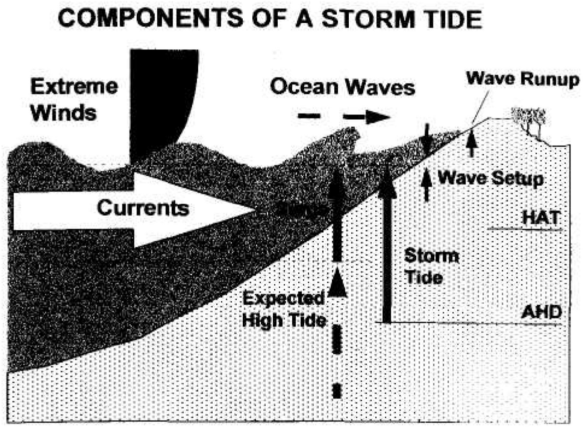

Figure 1: Components of total water level during a storm surge event.

2. DEFINITIONS

A *storm tide* is the combined effect on coastal water levels as a result of a storm surge combining with the normally occurring astronomical tide (refer Figure 1). The *storm surge* (or more correctly *meteorological tide),* is an atmospherically forced ocean response caused by extreme surface winds and low surface pressures associated with severe and/or persistent offshore weather systems (Bode and Sobey (1984)). At exposed beachside areas, an additional localised increase in water level can occur due to the effects of breaking wave setup, and wave runup can also cause severe erosion above the storm tide level. In the Queensland context, the tropical cyclone represents the principal threat to life and property in respect of storm surge. An example of the incidence of tropical cyclones along the Queensland coast is given in Figure 2 where all occurrences during the month of January since 1959 are shown

The use of the term *storm tide* is particularly relevant in that it correctly conveys the sense of a prolonged and generally gradual increase in coastal water levels, to be followed by a similar decline after the event has passed. A storm surge may influence normal water levels for several hundred or even thousands of kilometres along a coastline but the region of peak and potentially destructive surge levels is associated with the region of maximum wind speeds. Typically, relative to the centre of a tropical cyclone, this is of the order of 50 to 100 kilometres in diameter. Because of the co-incidence of severe winds and surge, any population evacuation needs to be signalled well clear of the onset of destructive winds.

Many factors influence the potential for serious storm tide events at a particular coastal site. The intensity of the tropical cyclone, its proximity to a site and the coastal characteristics of that site are prime factors in determining the potential surge level. The local astronomical tide characteristics are then important in determining the final attained

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[1] Formerly with Department of Environment

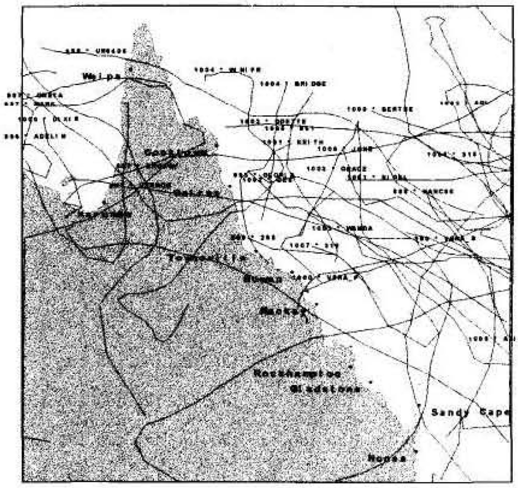

Figure 2: Cyclone tracks for January since 1959.

storm tide level. The critical storm tide level is that which exceeds the *Highest Astronomical Tide* (HAT) at any location. Along the Queensland coast, HAT levels typically vary between 0.5m to 1.0m above the mean high water spring tide value (or "high tide").

Associated with a storm surge will be the familiar *ocean waves* (sea and swell) which are also derived from the severe winds. While being an intrinsic effect of the surge generating mechanism, these waves can be regarded as largely non-interacting with the surge. As the water levels rise due to the combined effects of surge and tide, ocean waves may travel atop the storm tide to attack coastal structures or cause severe coastal erosion at elevations not normally reached in common storm events.

3. THE HISTORICAL RECORD

The first recorded instance of a significant storm tide in Queensland is the 3.1m surge in 1884 at Bowen, although Green Island, near Cairns, was reputedly overtopped by waves in 1858. Many authors have scanned both the historical literature and the record of tidal anomalies over a number of years (Harper (1997)). Much of the earliest data was collected by Herbert Whittingham, and remains in unpublished form with the Bureau of Meteorology in Brisbane. Based on these and many more recent records there have been approximately 70 known instances of tropical cyclone related storm surge events along the coast, affecting some 150 locations. While some 70% of instances were minor in terms of surge height alone (≤1m), 15 are definitely known to have resulted in the exceedance of HAT levels at a particular site by more than 0.5m, hence posing a potential threat to the community. At least 9 cyclones have produced storm tide levels of 2m or more above HAT

Table 1 lists some of the more notable events, topped by the eyewitness estimate during the infamous Bathurst Bay event of 1899. The estimate of approximately 14m stands from the literature, but is not easily supported by technical analysis. Regardless, it is clear that a quite severe surge event occurred at this site. More easily confirmed is the 1918 cyclone at Mackay where a 3.7m surge combined with the high tide to enter the town, reaching levels of 5.4m AHD and inundating parts up to 2m above HAT. In more recent history, the 2.9m *Althea* surge at Townsville in 1971 luckily coincided almost exactly with low tide. Nevertheless, large sections of The Strand seawall were destroyed and waves entered onto properties at Pallarenda.

Year	Place	Event	Est. Central Pressure	Surge Ht
			(hPa)	(m)
1884	Bowen		-	3.1†
1887	Burketown		-	5.5†
1896	Townsville	*"Sigma"*	-	>2
1899	Bathurst Bay	*"Mahina"*	914	14†
1918	Mackay		935	3.7†
1918	Innisfail		928	>3†
1923	Albert River	*"Douglas Mawson"*	974	>3†
1934	Port Douglas		968	>1.8
1948	Bentinck Is		996	>3.7
1964	Edward R.	*Dora*	974	5?
1971	Inkerman Station	*Fiona*	960	>4
1971	Townsville	*Althea*	952	2.9†
1971	Edward R.	*Fiona*	960	3
1972	Fraser Is	*Daisy*	959	3?†
1976	Burketown	*Ted*	950	4.6?†
1978	Weipa	*Peter*	980	1.2†
1987	Karumba	*Jason*	970	2
1989	Ayr	*Aivu*	935	3.2†
1995	Karumba	*Warren*	980	1.5
1996	Gilbert River	*Barry*	950	>4?†

Table 1: Some Notable Storm Surges in Queensland
(† exceeded HAT)

4. WHAT DO WE KNOW OF THE RISKS?

The historical rarity of severe storm tides along the Queensland coast, and more particularly at any specific location, precludes the use of basic statistical methods using measured water level data for the estimation of long-term risk. Notwithstanding this, methodologies developed since the late 1970's which combine complex numerical and statistical modelling have provided a robust scientific basis for making long term predictions (Sobey et al (1977, 1979), Harper et al (1977), Harper (1985), Treloar (1985), Mason et al (1992)). The majority of these studies have been commissioned by the Beach Protection Authority.

Figure 3 summarises the presently predicted inundation risk for the major coastal centres based on these studies. The results are presented as the predicted level of inundation above the local HAT (maximum tidal level) for a range of *Return Periods*. For example, the 500 yr return period inundation level is expected to be equalled or exceeded at least once on average in any period of 500 years of observations. While this seems a remote possibility it also means that there is a 63% chance of reaching or exceeding the 500yr level in any 500yr period of time. Another way of expressing this same level of risk is that there is a 10% chance of exceeding the 500yr return period level in any 50yr period of time. This would appear a much more likely scenario because it introduces a more familiar human time scale.

Figure 3 also shows that the variability of risk between coastal centres is predicted to be quite high. Taking the +0.5m to +1.0m above HAT level as a typical lowest-built-level range for more recent permanent habitation or infrastructure, only Cooktown, Lucinda and the Gold Coast are below this range at the 500yr return period risk level. By contrast, the areas of Cairns, Cardwell, Townsville, Mackay, Yeppoon, Gladstone, Hervey Bay and Brisbane are all susceptible to inundation at or above the +lm level with a return period between lOOyr and 500yr. Townsville is indicated as having the highest likelihood of significant inundation, followed by Yeppoon and Cairns, with only slightly lesser risks for Mackay, Brisbane, Gladstone and Hervey Bay. Wave setup of approximately 0.5m could be an additional factor for some beachside suburbs at these sites.

5. AN EXAMPLE STORM TIDE

The surge and resulting storm tide generated by Tropical Cyclone *Althea* at Townsville in December 1971 is a good example of a classical storm surge. Figure 4 shows a numerical model depiction of the near-circular wind pattern about the centre of *Althea* as it approached the coast north of Townsville scenario (Harper (1996).

Figure 5 presents a schematic of the time history of variation in ocean water levels during passage of the storm. The predicted astronomical tide is indicated at the base of the graph, then follows a representation of the wave setup component of water level over that period, and finally a schematic of the 2.9m surge itself. All of these components added together yield the upper line of total storm tide levels, basically as recorded on the tide gauge at Townsville harbour, peaking at 2.6m AHD.

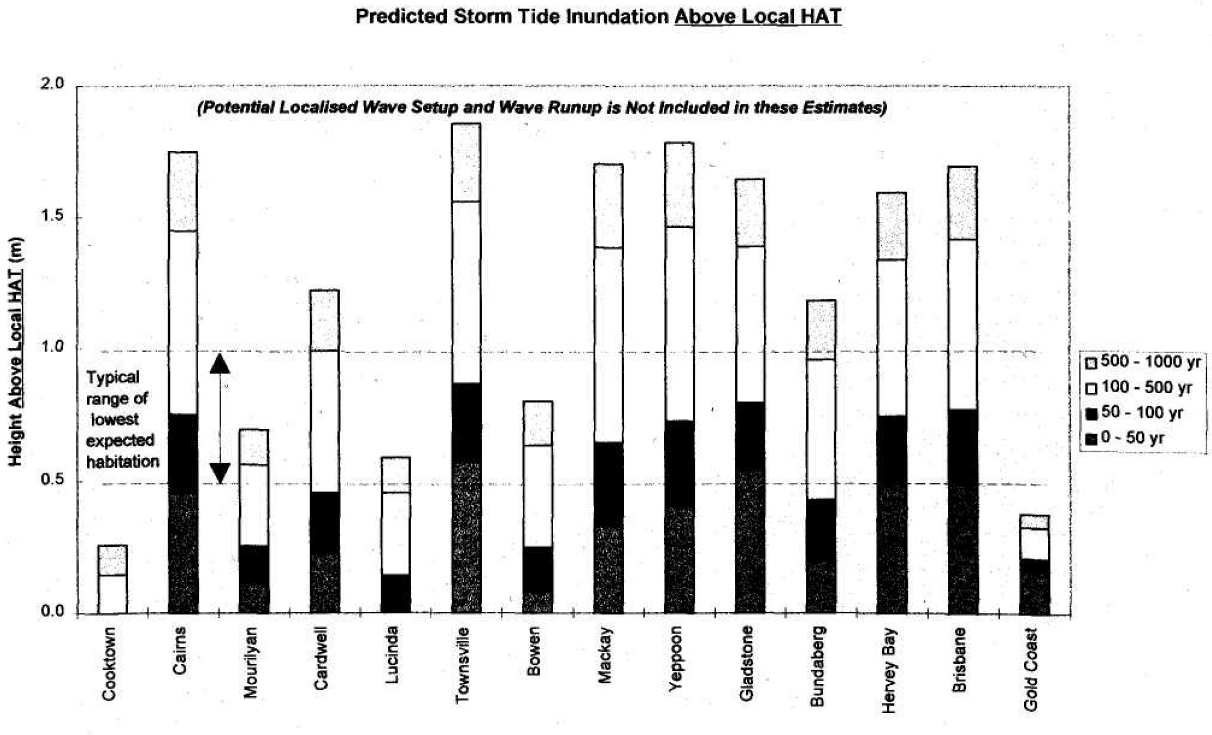

Figure 3: Summary of the predicted storm tide inundation risk at major population centres in Queensland based on present studies (after Harper (1996)).

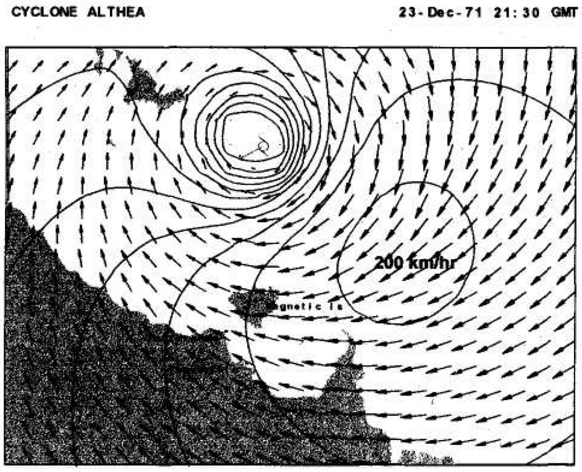

Figure 4: A numerical model depiction of Althea's windfield (after Harper (1996)).

The critical relative phasing between Jhe surge and the tide can be seen to be instrumental in determining whether a surge will be a minor inconvenience or a potential major disaster. In this case the peak surge arrived near the time of low tide and the resulting storm tide only exceeded local HAT by about 0.5m at Townsville. Had the cyclone passed 6 hours later, peak water levels could have been up to 2m above HAT at Townsville, representing a major community disaster.

6. WHY THE REGIONAL VARIATION IN RISK?

From the previous example it can be seen that storm tides result from a number of complex mechanisms which often act over different time and space scales, and can interact in specific ways depending on the exact situation (Sobey et al (1977)). To see the underlying patterns which combine to produce a state-wide variation in storm tide threat, such as that depicted in Figure 3, we need to look at the major factors on an individual basis. It should be noted that in the sections which follow, these variations are discussed in essentially a qualitative manner only.

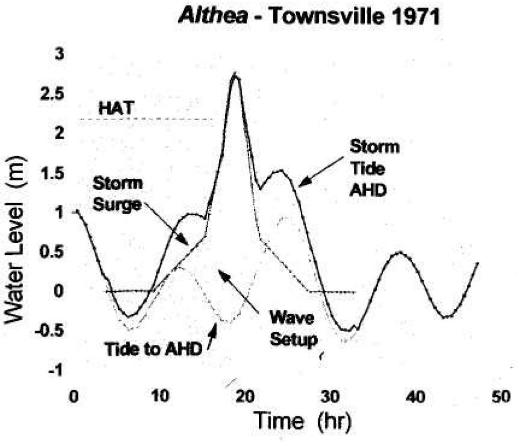

Figure 5: Schematisation of the Althea storm tide (after Harper (1996)).

6.1. Variation in Cyclone Intensity

This is perhaps the most obvious of all the factors affecting storm tide risks. Put simply, if there is a low likelihood of cyclone occurrence in a particular area then the risk of severe storm tides will clearly be low. By examining the historical record of cyclone tracks and their estimated intensities, statistical analyses can expose the underlying function of risk which exists along the Queensland coast in terms of the return period of a given central pressure within a given region. Such analyses show that the risk rises northwards from the Queensland/New South Wales border, reaching a peak between Yeppoon and Townsville but then declines once again towards Cape York.

6.2. Coastal Crossings

Because of the trapping effects of reefs, bays and headlands the coast crossing cyclone is likely to generate a more significant storm surge than a parallel to coast cyclone, which must pass close to the coast without weakening to be as effective. The relative coast-crossing occurrence along the Queensland coast has a somewhat similar response to the intensity variation, due to the preferred angles of approach at various latitudes.

6.3. Site Specific Characteristics

This reflects the relative propensity to amplify or diminish a storm surge as a result of such factors as the width, depth and slope of the continental shelf, the scale of bays, headlands and islands or the possible influence of extensive reef areas. This results in a sometimes very localised variation with areas such as Hervey Bay, Cardwell and Townsville showing high risk due to the local large scale bay effects. Weipa and Karumba are especially prone because of their extensive shallow water regions, while the Gold (and Sunshine) Coast is protected due to the narrow continental shelf. Within Moreton Bay, Brisbane by comparison is a higher risk than the adjacent open coast. Areas north of Mourilyan are given protection by the effect of a narrowing shelf. The Great Barrier Reef also has some influence, principally in retarding the passage of large swell waves.

6.4. The Role of the Astronomical Tide

Since the total storm tide level is strongly influenced by the state of the tide, it follows that locations with a large tidal range will provide a degree of statistical variability which can serve to reduce the likelihood of a severe storm tide inundation. For example, the Gold Coast, with its low tidal range, has a relatively increased vulnerability to storm tide inundation compared with, for example, Mackay, where the tidal range is quite high. While there is a degree of interaction between surge magnitude and tide level (due to the overall depth effect) it can generally be considered as a separate, independent effect.

7. PLANNING NEEDS

Studies to date have focussed on the planning issue in regard to establishing knowledge about the likely long-term water levels in the various coastal communities. This work has provided important input to the engineering design

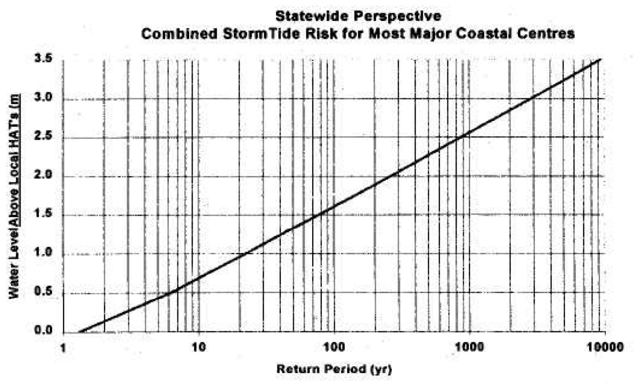

Figure 6: Combined Statewide Risk of Storm Tide Inundation for the Major Coastal Centres in Queensland

process of ports and harbours, near-coast developments and other infrastructure and services. Much can still be done in terms of investigating surge propagation in estuaries and coastal river systems and the potential for specific localised dune breaches and inundation. Another area needing to be explored is that of the direct impact of overland flooding and wave attack on domestic and commercial construction. The US experience (eg. FEMA (1986)) shows that effective planning and building design procedures can be put in place to safeguard life and property and also to gain access to insurance cover against storm tide for beachside residents - an advantage not presently available in Australia.

8. FORECASTING NEEDS

The forecasting issue has a different emphasis, concentrating on immediate community safety. This is the statutory role of the Bureau of Meteorology which, under established State Counter Disaster Organisation arrangements, advises of an impending storm tide threat. Significant improvements to the present forecasting schemes are presently underway as a part of the Tropical Cyclone Coastal Impacts Program.

Each tropical cyclone season brings with it the potential for a serious storm tide incident somewhere along the Queensland coast, even though the probability of a storm tide actually occurring at one specific location is quite low. For example, the frequency of occurrence of a Category 4 cyclone anywhere within striking distance of the Queensland coast is approximately once every 15 years, with the potential to produce a 4m surge at some locations if it were to cross the coast. Likewise, a 3.5m surge could be produced by an *Althea-Mke* cyclone which occurs every 5 years on average.

From a statewide disaster-preparedness viewpoint, therefore, the site specific surge inundation risks such as those presented in Figure 3, must be combined to determine the total community risk. This has been done in Figure 6, showing that the 0.5m inundation event has an average return period of approximately 6 years for at least one of the major coastal centres, and the 1.0m inundation event is likely to occur every 20 years on average. On this basis, extreme storm tides causing dangerous levels of inundation are not particularly rare events in Queensland. As settlement of the coastal margins increases, the likelihood of such events will similarly increase.

Disaster preparedness planning will also highlight issues such as vehicular access limitations or other constraints, and the possible need for vertical evacuation shelters or refuges in some situations.

9. POTENTIAL IMPROVEMENTS OVER PAST STUDIES

A significant investment in research and analysis into the storm tide problem has occurred in Queensland over the past 20 years. Nevertheless, it is possible to identify a number of areas where improvements could be made:

(a) Spatial Coverage
Some locations may require rework or additional studies, especially with changing demographics involving increased numbers of permanent inhabitants and visitors in risk prone areas:

- Whitsunday region
- Gulf of Carpentaria
- Moreton Bay

(b) Improved Methodology
Improved models of many aspects of the problem are now available, namely:

- tropical cyclone wind field details
- numerical model open boundary conditions
- better seabed bottom friction formulations
- allowance for coastal flooding
- three dimensional modelling where warranted

(c) Increased Computational Power
Access to increased computational power also allows

- finer scale representation of coastal forms
- wider parameter ranges
- greater numbers of scenarios
- modelling over longer periods

and inclusion of simultaneous tide, wave and currents.

(d) Increased and Better Cyclone Data It is now generally acknowledged that cyclone data in the Australian region can only be regarded as reasonably reliable when satellite surveillance commenced in 1959/60.

(e) Climate Change Scenarios
The impact of climate change and El Nino episodes on the tropical cyclone hazard have not been fully explored. If sea level rise occurs then the majority of existing predictions will need to be adjusted to compensate for the rising base water level. If Greenhouse events alter the climatology of cyclone occurrence and severity then the statistics themselves will need to be re-evaluated.

(f) Increased Measured Data on Storm Tides
Since the time of *Althea,* a number of other significant

surges have occurred or been uncovered which can be used for enhanced model verification.

(g) Wave Setup, Runup and Inundation The existing studies covered large sections of coast and many could not address fine scale wave setup, runup and overland flooding - all of which can have significant counter disaster ramifications.

(h) Non-Cyclonic Storm Tide Influences Significant non-cyclonic weather events such as monsoonal surges or deep extra-tropical systems are capable of producing smaller but often more prolonged increases in coastal water levels associated with local flooding.

10. CONCLUSIONS AND RECOMMENDATIONS

Considerable work has been done over the past 25 years since Cyclone *Althea* raised our collective conscience to the storm tide threat in Queensland. The detailed studies done to date have concentrated on the long term planning issues and subsequent engineering design aspects of the problem which ultimately address and underscore the issue of public safety. Although planning legislation in Queensland does not yet include explicit storm surge considerations this power is within the jurisdiction of local government, which could readily adopt the existing design levels.

Armed only with the present information it is possible to undertake even more detailed assessments of individual coastal communities at risk. This could take the form of specific design and planning rules covering such factors as better mapping, land use zoning, structural design requirements, shelter or refuge requirements, evacuation routing and coastal protection works.

The majority of storm tide studies were completed approximately ten years ago, subject to practical computing limits of the time, as well as the statistical cyclone record of the day. There is an emerging and relatively strong case for a comprehensive reassessment of storm tide risks along the entire coast. The opportunity now also exists for greater integration of the diverse service requirements of engineering, planning and counter disaster measures.

Much of the analysis and modelling capability needed to undertake such a reassessment is readily available at present, but some specific areas would benefit from initial research and development. These include a need for more practical methods for representing wave, current and surge interaction, localised wave setup, overtopping and transmission through community areas. Also, the likely behaviour of domestic and commercial structures in the event of surge inundation has not yet been fully examined in Australia in a manner akin to the US. In addition to specific research and development, storm tide prediction will also benefit from ongoing basic research into cyclone structure and behaviour and the likely impact of climate change on frequency, intensity and mean sea level. Finally, long term data measurement programs of water levels, winds, waves and wave setup will continue to be essential adjuncts to the quest for increased knowledge, planning and preparedness for storm tide hazards throughout Queensland.

11. ACKNOWLEDGEMENTS

The permission of the Department of Environment to publish this paper is gratefully acknowledged. The views expressed herein are not necessarily those of the Department.

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