Managing Storm Tide Inundation Risk in a Changing Climate

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Many of the communities along the Sunshine Coast are located on low lying foreshores, or are adjacent to large river floodplains and coastal lagoons. The communities and their access roads are subject to flood and storm tide inundation, directly affecting the residents in the community and sometimes resulting in extended periods of isolation. Future projected sea level rise conditions will exacerbate the storm tide risks to which these communities are exposed.

Sunshine Coast Regional Council has undertaken a comprehensive inundation risk assessment, detailing the current threats and identifying the future inundation risk areas under changing climatic conditions. The assessment has been based on locally observed storm surge behaviour, both due to East Coast Lows and cyclone generated conditions, to develop a locally unique Sunshine Coast storm surge.

Detailed numerical modelling of the combined influence of the storm surge and astronomical tide has been undertaken for current as well as future projected sea levels. The inundation risks to communities are identified to allow the development of appropriate controls on planning and development in the identified at-risk areas.

The results will also inform Emergency Management planning.

INTRODUCTION

Storm tide is the combined influence of astronomical tide and storm surge. Storm surge can include increased sea level due to low barometric pressure (association with a low pressure system), wind set up, associated with the wind stress on the water surface, and wave setup (due to wave breaking).

When considering storm surge inundation of areas inland from (but nearby) the shoreline, wave run up is generally excluded from the peak water level projections as this over-estimates the hydrostatic water level driving the inundation event. However, at the shoreline, wave runup is an important consideration in assessing the risk for properties, people and the environment. When considering storm surge inundation of estuaries, both wave run up and wave setup are generally excluded from the definition of the ocean condition, as these influences do not propagate beyond the estuary entrance and/or the surfzone (see Dunn & Nielsen et al 2000).

Coastal communities are exposed to both inundation and wave overtopping risks, and both can lead to and/or exacerbate shoreline erosion. Council requires accurate and timely information regarding current and future risks to vulnerable coastal communities to facilitate robust local planning and preparedness, and to guide emergency management actions.

LEARNING FROM THE PAST

Since the mid 60's, the Sunshine Coast has experienced 18 tropical cyclones and over 70 East Coast Lows resulting in a tidal anomaly or storm surge of greater than 0.25m. This historical storm tide record holds valuable information on the incidence of these events, and their effect on coastal processes. In particular, East Coast Lows occur much more commonly than cyclones, and account for almost two thirds of the highest 30 recorded surge events since 1965 (see Table 1 below).

Table 1 Highest 30 Tidal Anomalies since 1965 Recorded at Mooloolaba

Event	Surge	Date	Event	Surge	Date	Event	Surge	Date
TC Dinah	0.870	Jan-67	TC Pam	0.437	Feb-74	ECL	0.340	Apr-88
TC Daisy	0.652	Feb-72	TC Nancy	0.410	Feb-90	ECL	0.335	Mar-04
TC David	0.597	Jan-76	ECL	0.410	Feb-92	ECL	0.331	Nov-05
ECL	0.510	Apr-89	TC Roger	0.410	Mar-93	ECL	0.330	Sep-88
ECL	0.500	Feb-96	ECL	0.400	May-96	ECL	0.320	Feb-88
ECL	0.493	Apr-80	ECL	0.400	May-97	ECL	0.320	Jun-90
ECL	0.459	May-09	TC Betsy	0.390	Jan-92	ECL	0.320	Aug-07
TC Zoe	0.457	Mar-74	ECL	0.380	Jun-88	ECL	0.319	Mar-10
TC Wanda	0.447	Jan-74	TC Cliff	0.377	Feb-81	ECL	0.318	Dec-10
ECL	0.441	Jan-11	ECL	0.358	Nov-05	TC Lance	0.310	Jul-84

Tropical cyclones borne in the Coral Sea that propagate as far south as the Sunshine Coast tend to be much less severe than their northern cousins, and generally present with higher central pressure and slower rates of propagation. Collectively, these southern cyclones, and the east coast lows, manifest as slow moving meteorological phenomena, that result in lengthy periods (several days) of increased mean sea level and increased wave energy influencing coastal processes.

The timing of the peak of the surge and the tide can have a devastating result. However, it is important to recognise these as independent processes, with just as much chance of the surge coinciding with low tide (see Figure 1 below for a surge event on the Sunshine Coast coinciding with low tide). In this case, although the surge was over 0.4m, the coincidence with low tide had limited impact on the coastal communities.

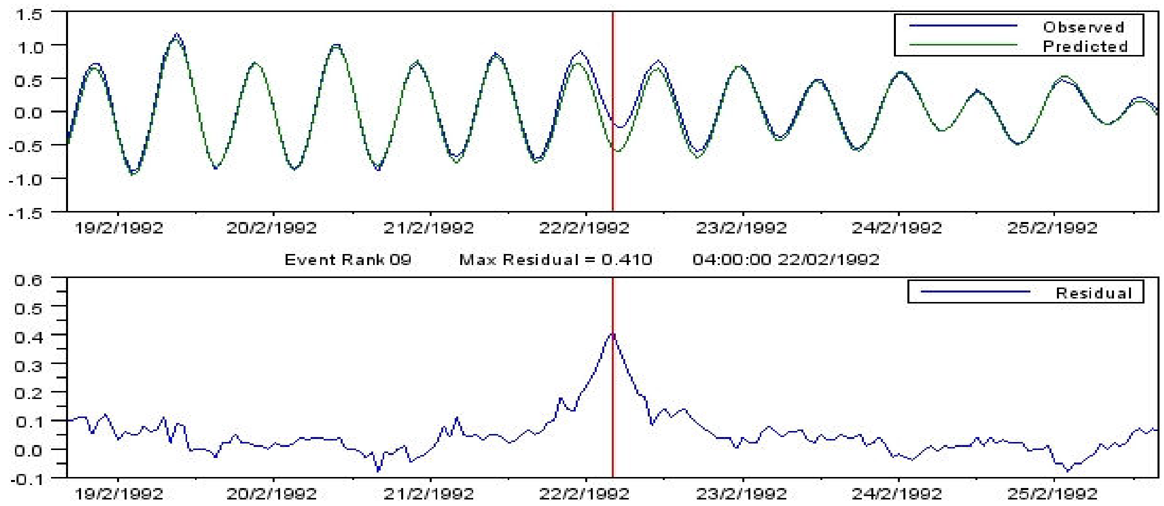

Figure 1 Surge Event Coinciding with Low Tide

To account for timing effects, joint probability analysis is undertaken to determine the design *Storm Tide* elevation statistics as the combination of the storm surge anomaly and the tidal elevation. The statistical representation of the storm surge and the tide are determined from the historical record, and these distributions are sampled to from a synthetic history of 10,000 surge and tidal events. The design storm tide statistics are derived from this synthetic data.

To gain a better understanding on the profile of the storm surge, a time series history of 60 of the largest surge events since 1980 has been extracted from the data record. The records are normalised around the peak surge elevation, and time-centred around the peak tidal elevation. The resulting data series is illustrated in Figure 2 along with 50th and 75th percentile profiles.

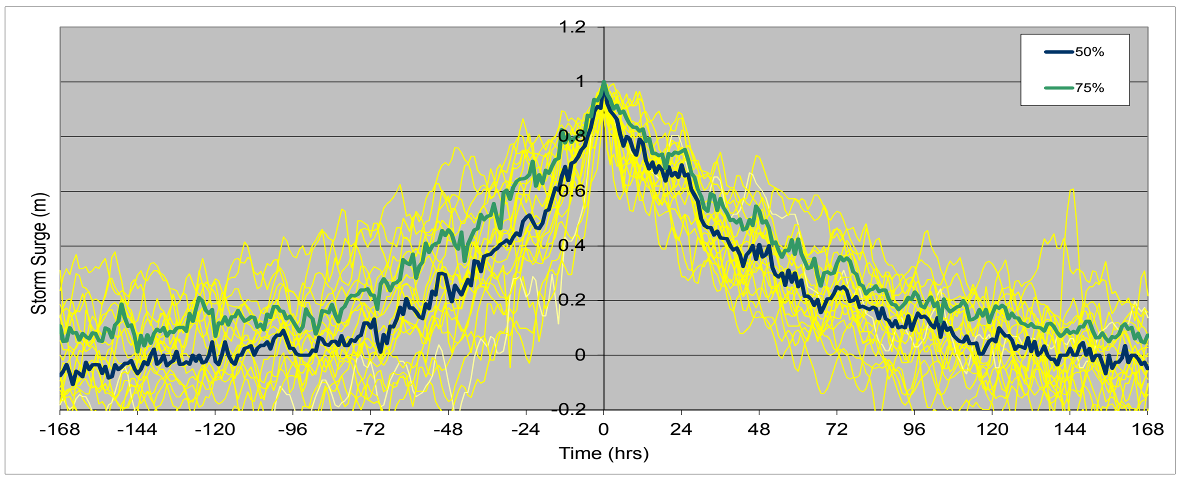

Figure 2 Recorded Time Series Histories of Storm Surges on the Sunshine Coast

Sensitivity testing of the 75th and 50th percentile storm tide shapes was undertaken with the 75th percentile shape showing up to 250mm higher peak storm tide levels within the affected estuaries. The 250mm difference corresponds to around 50% of Council's freeboard. Thus, the adoption of the 50th percentile storm tide shape and later finding this assumption to be in error would significantly compromise the safety of development approved based on this decision. This was considered an unacceptable consequence from a risk perspective. Accordingly, the 75th percentile storm surge shape has been adopted to represent the time varying mean sea level associated with a storm surge event.

SCRC consider this to be an appropriate assumption on the basis of the previous experience with Total Probability Theorem for joint probility analysis. This experience has shown that a 50th percentile assumption underestimates a joint probability outcome obtained using Total Probability Theorem (in the context of analysing Dams) and thus is not an AEP neutral assumption. A 75th percentile assumption does provide an outcome that is considered closer to an AEP neutral assumption as determined by Total Probability Theorem (in the context of analysing dams).

A 75th percentile storm tide shape assumption does provide an outcome that is considered closer to an AEP neutral assumption as determined by Total Probability Theorem (in the context of analysing dams).

A smoothed and idealised surge shape has been developed based on the 75th percentile shape. To generate the ocean storm tide condition, a synthetic mean spring tide is superimposed on the surge. The design storm tide condition at the entrance to each estuary within the district is prepared as the superposition of the synthetic mean spring tide and the idealised surge shape, with the surge component scaled such that the design storm tide level is represented.

CURRENT RISKS

The historical information has been analysed in consideration of the coincident probability of surge and tidal elevation and provides the current conditions risk profile for the Council district. Design 100 year storm tide levels range from 1.60 to 1.75m AHD. When considered in combination with wave setup of up to 0.5m in some locations, many areas along the coast are at risk of inundation, as these events result in water levels 1m higher than local Highest Astronomical Tide (HAT). These legacy issues are extremely challenging, and require active management to maintain acceptable levels of community risk, while retrofitting increased protection and/or championing alternative risk management approaches.

Within the estuaries, calibrated 2D tidal models are driven by the design ocean storm tide conditions, and inundation extents evaluated for various return period events. It is especially important to consider the influence of the choice of design surge shape on peak levels within the estuary. On the Noosa River system, characterised by large tidal lakes, the peak surge elevation is strongly influenced by the tidal pumping associated with differences in mean water elevation (see Figure 3).

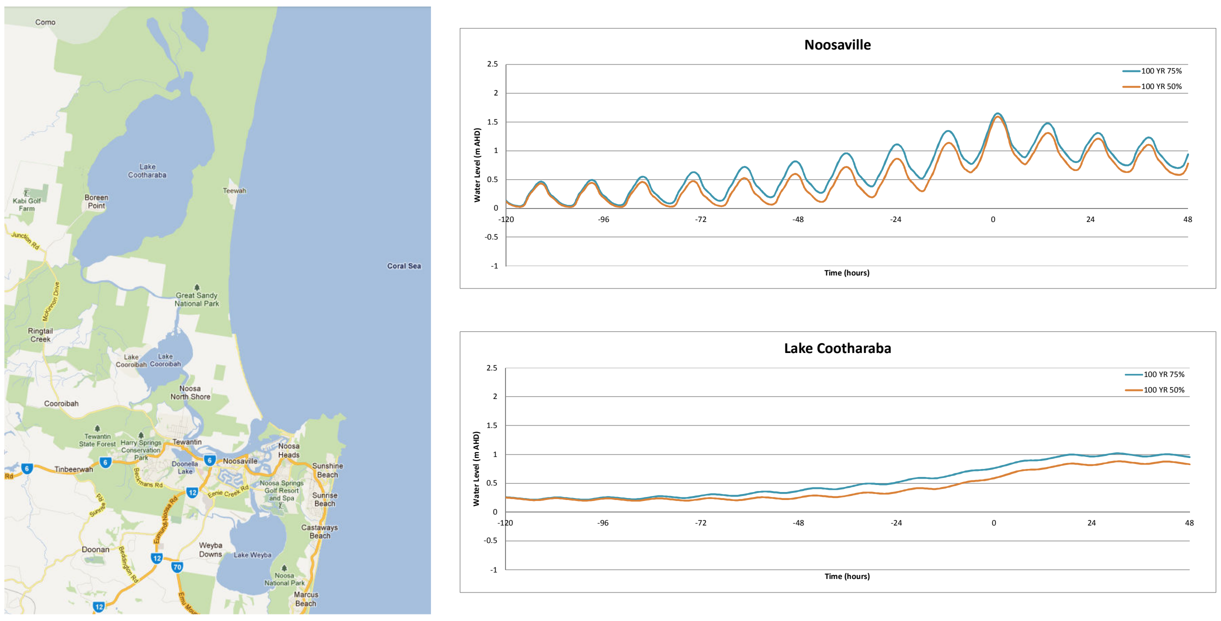

Figure 3 Effect of Storm Tide Shape on Peak Levels in the Noosa River System

The 50th vs 75th storm tide profile results in an increased peak storm tide level of around 6cm at Noosaville. However, in Lake Cootharaba, even though the storm tide influence is much more attenuated (resulting in lower peak levels than those at Noosaville), the 75th shape results in an increase in the peak level of 14cm above that of the 50th profile.

LOOKING TO THE FUTURE

Climate change is projected to influence the behaviour of events driving storm surges. While there remains significant uncertainty as to the meteorology of 2100, projected impacts include sea level rise, increased intensity and/or frequency of storms, and increased southerly tracking of cyclones. Of these factors, increased mean sea level appears to result in the most severe impacts for the Sunshine Coast. While the Queensland Coastal Plan nominates 0.8m of sea level rise at 2100 (based on the IPCC findings) , other commentators have noted that observed sea level rise is tracking on the upper boundary of the IPCC 4th Assessment (IPCC 2007), and that a projected increase of 1.1m at 2100 may be more prudent (see Steffen 2009).

The Sunshine Coast Regional Council has prepared a forward looking Climate Change and Peak Oil Strategy 2010-2020, and has nominated consideration of sea level rise of 1.1m by 2100, providing strong leadership in defining and managing future risks.

FUTURE RISKS

With sea level rise, inundation water levels at the shoreline increase by at least as much as the rise in mean sea level. This rise in surge levels at 2100 of 1m+ increases the depth of inundation for infrastructure and properties already at risk, as well as increasing the inundation extent (and duration) resulting in heightened risk exposure.

Coastal recession continues to be recognized as a major problem for Sunshine Coast beaches. Barnes et al (2011) note annual recession rates along much of the Sunshine Coast at up to 50cm per year, while on Bribie Island spit, recent recession rates of up to 1.0m per year have been observed (*PPATF 2009*). Based on observed rates of erosion, it is possible that the spit may be lost to natural erosion within the next 30-50 years, which could expose the currently protected low lying residential areas to oceanic storm surge and wave processes.

Figure 4 Example Storm Tide Inundation Map

RISK MANAGEMENT

Knowledge of these current and future risks provides Council with data to inform and guide planning decisions, and prioritise risk response activities. The depth and the period of inundation is determined from the modelling, and these parameters are highly dependent on the choice of storm surge profile (duration of influence, shape and peak elevation). Set against agreed criteria, zones of high/moderate/low risk profile can be classified and areas of unacceptable risk can be identified.

A significant challenge for land managers and planners is providing a suitable mechanism to account for uncertainty, both in terms of future sea level rise projections and in forecasting the geomorphological response by the coastline. For example, a review by Knutson et al (2010) suggests globally an increase in cyclone intensity of 2-11% by 2100 coupled with an annual average decrease in frequency of occurrence of 6-34%.

Moreover, it is not so much an issue of what will be the storm tide elevation at 2100, but rather, how to plan and adapt towards a time when storm tide levels are significantly higher than current estimates. Risk continuum tools can be used to nominate where effort should be applied, and at what "tipping point" does a protect/defend strategy need to be progressively abandoned in favour of a retreat option. This is especially useful in planning and managing change as it applies to legacy risks.

EMERGENCY MANAGEMENT

The vulnerability of critical and community infrastructure has been assessed by overlaying the inundation modelling outputs on aerial photography and infrastructure layers in a GIS environment. Where practical, a threshold depth is nominated for each at-risk asset, to quantify the level of inundation, duration and risk exposure.

To assist during emergency response, threshold depth that limits trafficability of access routes to and from the isolated communities can been identified. The time to exceedance of the threshold depth (relative to the storm tide peak) can been determined for each design event, along with the duration of exceedance. This is valuable information for successfully planning and staging evacuations.

TAKE HOME MESSAGES

The key take-home messages are:

- Adopt a proactive attitude to estimating and accounting for climate change influences and the inherent uncertainty in these estimates
- Undertake a collaborative approach to planning and emergency management
- Ensure that decisions about risk and emergency management are undertaken with adequate knowledge of the storm tide and hydraulic processes at play

REFERENCES

Dunn S.L., P. Nielsen, et al. (2000). Wave Setup in River Entrances. Proceedings of the 27th International Conference on Coastal Engineering. Sydney, Australia.

Gould, M., Colleter, G., and Erpf, M. (2008). Sunshine Coastal Regional Council Strom Tide Management. Proceedings of the IPWEA National Conference on Climate Change *Responding to Sea Level Rise*, Coffs Harbour, NSW 3 - 5 August 2008.

Barnes, M.P., Andrews, M., and Fisk, G. (2011). Managing the Sunshine Coast Shoreline Erosion Threat. Proceeding of Coasts and Ports 2011; an amalgamation of the 20th Australasian Coastal and Ocean Engineering Conference and the 13th Australasian Port and Harbour Conference, September 2011.

Steffen, W. (2009). *Faster Change and More Serious Risks* Australian Government Department of Climate Change.

Intergovernmental Panel on Climate Change (IPCC) (2007) Climate Change 2007: The Physical Science Basis – Summary for Policy Makers. Intergovernmental Panel on Climate Change Working Group One. 2007.

Knutson T. R., McBride J. L., Chan J., Emanuel K., Holland G., Landsea C., Held I., Kossin J. P., Srivastava A. K. and Sugi M. (2010). Tropical cyclones and climate change, Nature Geoscience, Feb 2010.

PPATF (2009). Erosion Fact Sheet 01: Erosion on the Ocean Side of Bribie Island. Prepared by the Pumicestone Passage Advisory Task Force on behalf of the Sunshine Coast Regional Council.