Challenge of Mapping Coastal Hazard Risk in Queensland

Paul Prenzler[1] B.Eng.(Env.), M.Eng.(Coastal), RPEQ
Sel Sultmann[1] B.Sc.(AES)
Evan Jackson[1] B.App.Sc.
[1] Department of Environment and Resource Management GPO Box 2454 Brisbane Qld 4001

ABSTRACT
The Queensland coast is exposed to coastal hazards which can pose a risk to life and property. In the longer term, the impact of climate change is expected to worsen coastal hazards due to rising sea levels and an increase in cyclone intensity and frequency. The challenge is defining and quantifying the area of the coast exposed to this risk and how it is managed into the future.

The Queensland Coastal Plan recognises the potential adverse effects of coastal hazards and seeks to manage development in these areas to minimise social, environmental and economic costs. Coastal hazard mapping has been prepared to support the Queensland Coastal Plan and to assist coastal planners prepare for coastal hazards. The coastal hazard mapping is based on coastal erosion and storm tide inundation risks. The impact of climate change has been incorporated into these two components of the coastal hazard mapping.

This paper will introduce the coastal hazard mapping products supporting the Queensland Coastal Plan. It will also explore the complexity of mapping coastal hazards on a State-wide scale and the challenges associated with incorporating climate change impacts into the coastal hazard mapping.

INTRODUCTION
The Queensland coast is subject to extreme weather conditions that can cause coastal erosion and storm tide inundation. These naturally occurring events can pose a significant threat to life and property and are collectively described as ‘coastal hazards’ in the Queensland Coastal Plan (QCP). In the future, rising sea levels and more severe weather events associated with climate change are expected to increase the risks posed by these hazards.

It is estimated over 80 percent of Queenslanders live on or near the coast. Further population growth will increase demand for new urban development and place additional pressure on coastal land. Decision makers need to be aware of coastal hazard risks when considering the use of coastal resources. Accurate assessment and determination of coastal hazard areas is critical for coastal development assessment, planning, mitigation and response activities.

The QCP recognises the need to both avoid and minimise risk to people and property and to allow coastal processes to occur naturally. To assist decision makers and inform the public, coastal hazard mapping has been prepared based to a great extent on the high resolution coastal digital elevation model – a $7M project funded by Commonwealth, State and local governments. This data provides an unprecedented level of accuracy for the 35,000 square kilometres of coastline. These maps show the areas where the coastal hazard policies of the QCP apply.

The State-wide mapping of coastal hazard areas has posed a number of challenges associated with the spatial extents of the area at risk and the science behind determining the shoreline response to sea level rise. This paper will outline the mapping methodology adopted for determining coastal hazard areas. It will also identify gaps in our understanding of future coastal hazard impacts and the initiatives DERM is proposing to build knowledge, improve hazard mapping quality and increase public awareness in this area.

BACKGROUND
Coastal erosion and storm tide inundation are naturally occurring coastal processes that can pose a significant risk to life and property and are collectively described as coastal hazards in the QCP.

In the future, climate change is predicted to have a significant impact on existing coastal hazards. Atmospheric warming associated with climate change is predicted to raise sea levels due to thermal expansion of oceans and ice sheet melt. It is also predicted that the changes in atmospheric conditions associated with climate change will lead to more intense and more frequent storm events.

The QCP provides greater policy depth on climate change than provided by its predecessor, the State Coastal Management Plan. One of the key policy advancements is the consideration of climate change impacts up to 2100 and specifies climate change factors to be used for planning and development assessment purposes – the key one being a sea level rise of 0.8m by the year 2100.

The following section provides background information on coastal hazards, inclusion of climate change impacts and the key challenges in mapping coastal hazards areas.

CHALLENGE OF MAPPING COASTAL HAZARDS

The mapping of coastal hazards has posed a number of challenges associated with the spatial extents of the area at risk and the science behind determining the shoreline response to sea level rise. The following sections describe some of the key challenges and the initiatives DERM is proposing to build knowledge and improve hazard mapping quality into the future.

Storm Tide Inundation

As a severe storm or cyclone approaches land, water levels may be elevated due to the effects of reduced atmospheric pressure, strong winds and waves. The elevation of the sea surface is referred to as a storm surge and when combined with the normal tide results in a storm tide. Figure 1 shows the storm tide components and the potential risk to low-lying coastal land.

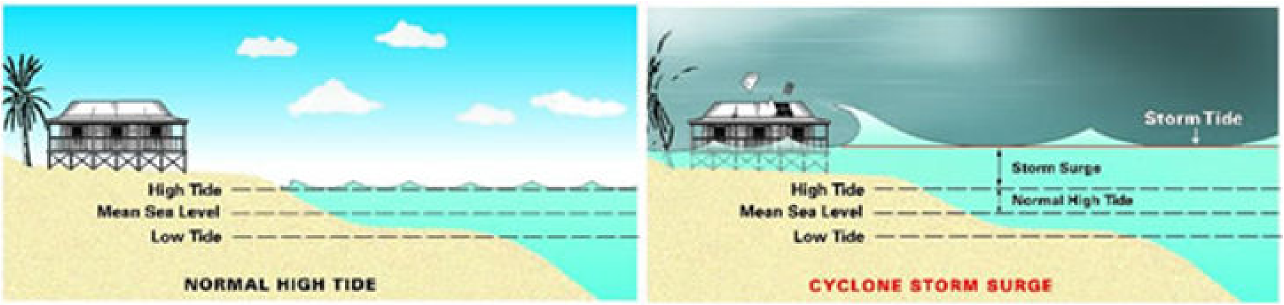

Figure 1: Components of a storm tide (source: http://www.bom.gov.au/cyclone/about/)

The storm tide inundation area is determined by the area of land inundated by a defined storm tide event which can be based on a detailed storm tide hazard study or adoption of default values.

A storm tide hazard study must include an allowance for future sea level rise of 0.8m by 2100 and also consider climate change effects on future storm climatology. While little is known about the likely effects of climate change on the frequency and intensity of storm events it is prudent to adopt some appropriate assumptions, such as:

- southward latitude shift in the tropical cyclone climate of approximately 1.3 degrees; and
- 10% increase in cyclone intensity relative to maximum potential intensity.

Alternatively, if a storm tide hazard study has not been completed for a region, then the storm tide inundation area is taken to be all land below a default defined storm tide event of:

- 1.5m above highest astronomical tide (HAT) in south-east Queensland; or
- 2m above HAT in the rest of Queensland.

A number of storm tide hazard studies exist for various regions across Queensland. However, these studies may not include an appropriate allowance for future sea level rise or storm climatology. Therefore, the initial coastal hazard mapping product supporting the QCP has been based on the default defined storm tide event specified above.

The primary challenge in mapping storm tide inundation areas based on the default criteria was associated with creating a State-wide definition of the HAT tidal plane. The level of HAT can vary considerably over relatively small spatial extents due to the effect of landforms and the seabed on tide hydrodynamics.

The development of a hydrodynamic model to define a HAT surface elevation was considered. However, due to the spatial extents of the area being assessed, possible difficulties in calibration and time constraints, the use of hydrodynamic modelling was seen as impractical.

A more simplistic approach to estimate the extent of HAT inundation was adopted using existing tidal plane data published by Maritime Safety Queensland. This involved creating a polygon network based on tide stations and refined where necessary to reflect geographic features or to allow a more gradual transition of HAT levels along the coast. Figure 2 shows the adopted HAT polygon network.

Figure 2: Highest Astronomical Tide polygon network for Queensland

The level of HAT for each tide station was then applied as a surface to the respective polygon and combined to create a HAT surface elevation. The accuracy of the HAT surface elevation was verified through a comparison with existing estuarine vegetation mapping held by the Department of Environment and Resource Management (DERM). Figure 3 shows an example of the comparison between the HAT extents (blue) estimated by the HAT surface elevation and the estuarine vegetation mapping (green).

In general the estimated HAT inundation extent provides a good representation of the mapped estuarine vegetation. However, as indicated there is a tendency for the HAT surface elevation to overestimate the extent of HAT in the upper reaches of larger estuaries. This is due to the inability to replicate the hydrodynamic effects within the waterway in the mapping for the present day.

The mapping of storm tide and sea level rise is based on a projection of these levels onto the land (i.e. steady state “bathtub” mapping). The hydrodynamics of overland flow has been ignored due to uncertainties relating to how the coastline will respond to sea level rise which may result in channel widening, dune overtopping and development of new flowpaths. The mapping of sea level rise and storm tide inundation areas using the default defined storm tide event levels specified previously would therefore provide a conservative estimation for the inundation areas. .

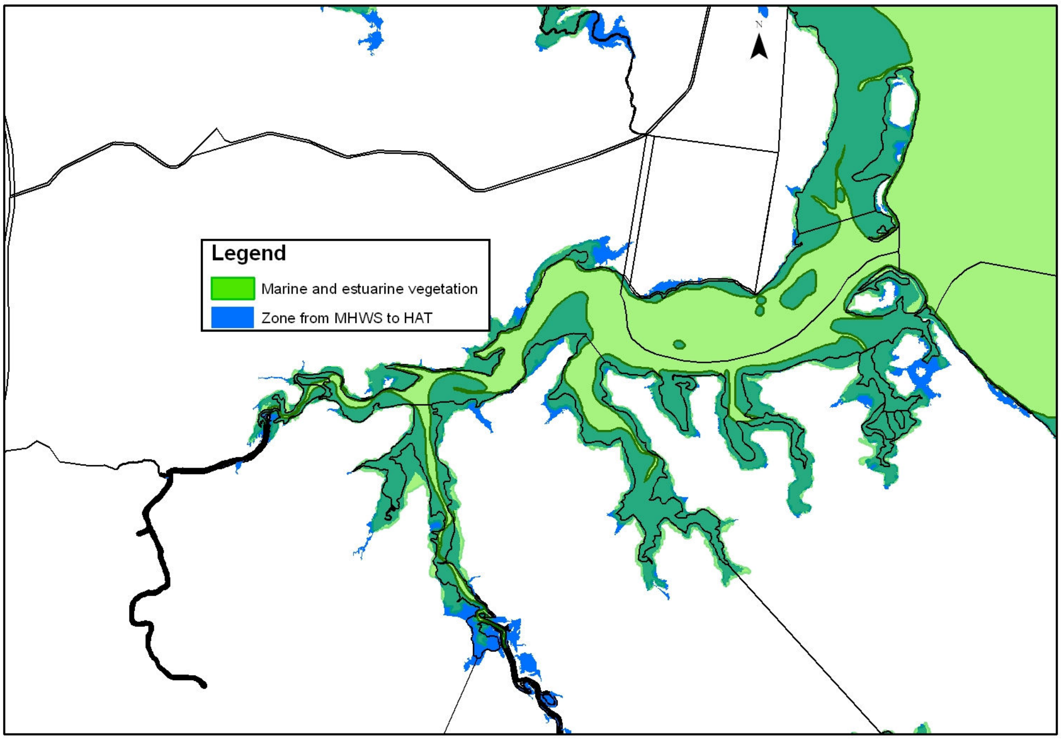

Figure 3: Comparison of marine vegetation mapping with HAT determined from tidal planes

Coastal Erosion

In the past, development has occurred within areas vulnerable to coastal erosion and this development amounts to a substantial private and public investment. Coastal protection works for the built environment are costly and can result in adverse impacts on coastal resources and their values. In Queensland, the erosion prone area policy has been used as a planning tool for almost 30 years to assisting in maintaining development free buffer zones.

Erosion prone areas estimate the vulnerability of a coastline to inundation from the tidal waters or erosion from the sea over a 50-year planning period, allowing for long-term erosion trends, short-term storm erosion, dune scarping, and recession due to sea level rise. Figure 4 shows an extract of the current erosion prone area. When used as a planning instrument, erosion prone areas can maintain a development free buffer allowing natural fluctuations of the coast to occur without the need for intervention to protect human life and property. Figure 5 shows a full width erosion prone area buffer zone on the Sunshine Coast.

For tide dominated coasts (e.g. estuaries) the erosion prone area is described as a buffer to high water mark and is intended to accommodate tidal inundation of land. On the open coast the erosion prone area is calculated using the following formula to estimate erosion vulnerability:

$$E = [(N \times R) + C + S] \times (1 + F) + D \qquad (1)$$

Where:

E	-	erosion prone area width (metres)
N	-	planning period (years)
R	-	rate of long-term erosion (metres/year)
C	-	short-term erosion from the “design” cyclone (metres)
S	-	recession due to sea level rise (metres)
F	-	required factor of safety
D	-	dune scarp component (metres)

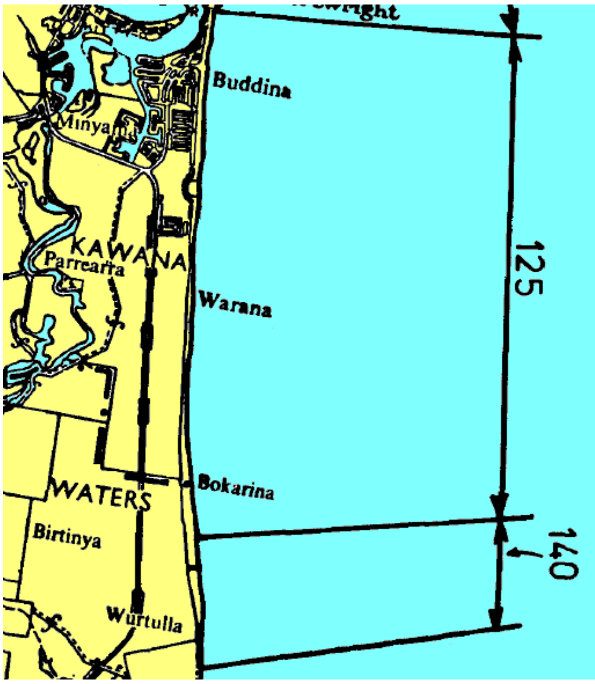

Figure 4: Current erosion prone area plans

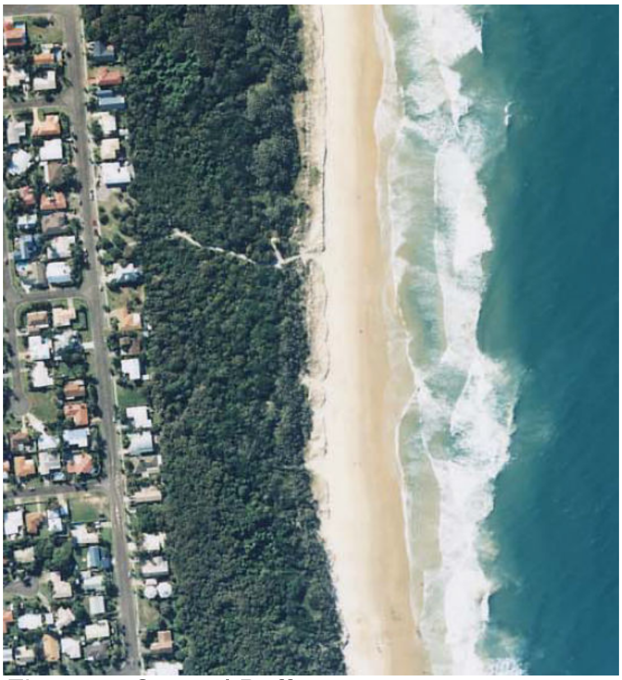

Figure 5: Coastal Buffer zone

The vulnerability of coastal areas to erosion is likely to be worsened by climate change which is predicted to raise mean sea level and change the frequency and intensity of future storm events. Existing erosion prone areas (refer Figure 4) were calculated up to 30 years ago and may not include any allowance for shoreline recession associated with sea level rise.

A significant challenge in this project has involved combining the impact of climate change with coastal erosion. This has required revision of erosion prone area widths to accommodate predicted sea level rise taking into account variations in beach morphology.

The methodology for calculating erosion prone areas recommends using the semi-empirical "Bruun Rule" (Bruun, 1962) to determine shoreline recession due to sea level rise. The Bruun Rule is based on the concept of an equilibrium beach profile which is maintained during sea level rise by transferring material from the upper beach to the nearshore zone. The beach profile is therefore maintained through a landward shift of the shoreline as shown in Figure 6.

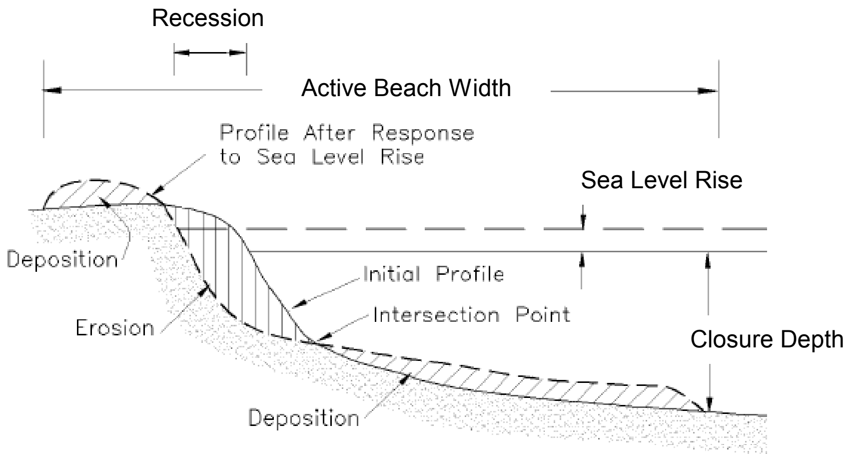

Figure 6: Beach profile response to sea level rise (Modified: Coastal Engineering Manual)

The Bruun Rule is subject to several limitations (Bruun, 1962 and 1988) as it assumes:

- uniform sediment grading across the profile and no sediment is lost from the coastal system;
- constant long-shore and cross-shore sediment transport rates; and
- The shoreface profile is constant relative to mean sea level.

The Bruun Rule is the subject of criticism due to these limitations (Cooper & Pilkey (2004), Stive, Ranasinghe & Cowell (2009) etc.) and it is recognised that the Bruun Rule is not a universal tool for estimating coastline recession. However, the model has been previously validated by Bruun (1962), Dean (1990), Mimura & Nobuoka (1995) and others for specific site that comply with the limitations.

When used in an appropriate context the Bruun Rule provides a reasonable approximation of coastline recession due to sea level rise. The limitations suggest that the Bruun Rule can be reasonably applied to wave dominated beaches which accounts for approximately a quarter of the Queensland coastline. The remainder of the Queensland coastline from Hervey Bay to Cape York is largely protected from ocean waves and as such the tide has a more significant role in beach morphology creating tide modified and tide dominated beaches.

Tide modified and tide dominated beaches typically consist of a steep high tide beach formed by wave action and a wide low gradient intertidal zone formed by the tide. The sediment on the high tide beach is often coarse in comparison to the sediment in the intertidal zone. The application of the Bruun Rule to these beaches conflicts with the model limitations. However, a search of scientific literature does not provide any alternative model to assess shoreline recession due to sea level rise for these beach types.

A preliminary investigation of the shoreline response to sea level rise for tide dominated beaches of Hervey Bay, Queensland. The investigation examined shoreline position over the last 30 years and compared this to the shoreline retreat estimated using the Bruun Rule (Prenzler, 2011). The investigation determined that the application of the Bruun Rule to the entire beach profile significantly overestimated the shoreline retreat when compared to observed retreat. However, a modified approach to the Bruun Rule which considered only the equilibrium profile of the upper portion of the beach profile (i.e. the component of the profile formed by wave action) provided retreat estimates similar to the observed retreat.

While preliminary investigations suggests that this modified approach to Bruun Rule can be applied to tide modified and tide dominated beaches further research is required. The Queensland Climate Change Centre of Excellence is currently developing a project to investigate the shoreline response to sea level rise for tide modified beaches. The aim of the research is to improve our understanding of the response of these beaches to sea level rise.

In the interim the modified approach to the Bruun Rule has been applied to all tide modified and tide dominated beaches of central and north Queensland to estimate a shoreline response to a sea level rise of 0.8m by 2100. This approach will be reviewed once further scientific information becomes available for these beach types.

COASTAL HAZARD MAPPING PRODUCTS

The mapping of coastal hazard areas on a State-wide scale has not been previously available and this posed some challenges. The response to these challenges was to ensure the methodology adopted provided a conservative and robust mapping product to support the QCP and provide a valuable tool for planning of the coastal zone.

The coastal hazard mapping is now available from the DERM website on a lot based scale. Figures 7 and 8 provide samples of the erosion prone area and storm tide inundation area mapping, respectively.

Figure 7 shows the storm tide inundation area divided into high hazard (i.e. greater than 1m of water depth over land) and medium hazard (i.e. less than 1m of water depth over land) areas which are further reflected in the policies of the QCP. Figure 8 shows the erosion prone area divided into the area considered vulnerable to coastal erosion and the area vulnerable to tidal inundation. A set of statutory erosion prone area plans similar to Figure 4 will also be produced in the near future.

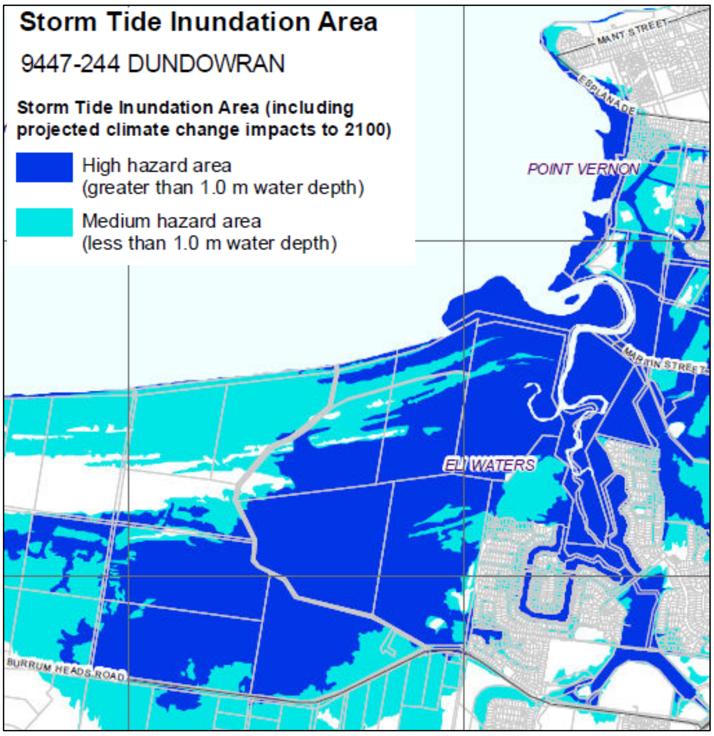

Figure 7: Storm tide inundation area mapping

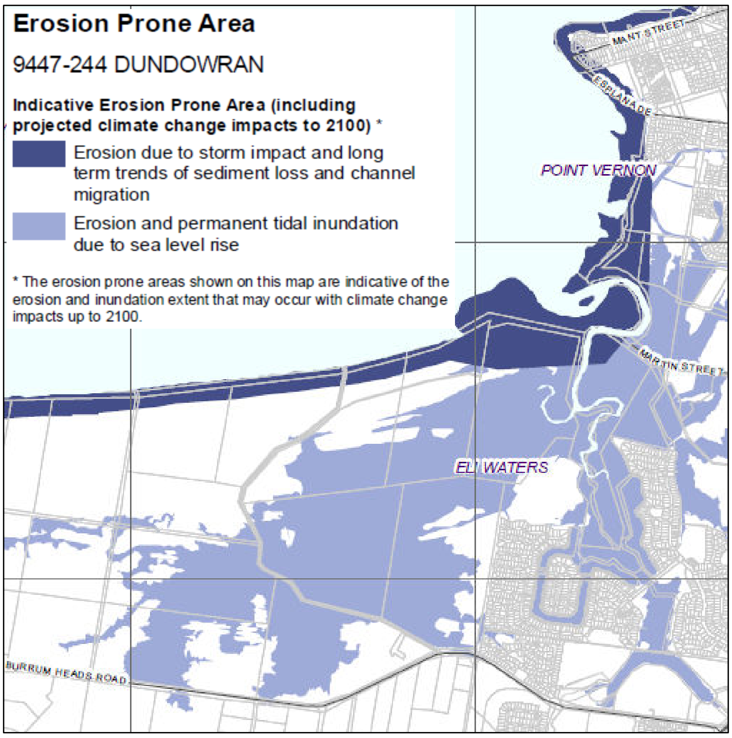

Figure 8: Erosion prone area mapping

TAKE HOME MESSAGES

- Detailed mapping of coastal hazard areas is now available for the majority of Queensland and has been produced to support the Queensland Coastal Plan.

- This type of mapping has not been previously available and its production posed some challenges. The challenges were primarily associated with defining a HAT surface elevation for the entire State and estimating the shoreline response of tide modified and tide dominated beaches to sea level rise.

- The storm tide inundation area mapping has been based on default levels selected to provide a conservative estimate of the risk – mapping can be updated to reflect more detailed information made available by storm tide hazard studies

- Storm tide hazard studies need to comply with the minimum requirements set out in the QCP with respect to climate change

- The response of tide modified and tide dominated beaches to a rise in mean sea level is poorly understood and future research in this field is required.

- It is important to note that this mapping is for land-use planning and development assessment purposes. These maps are not an emergency response plan.

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