THE THREE STAGE SEA LEVEL RISE ASSESSMENT OF VULNERABILITY TO ESTUARINE SHORES (3SAVES)

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Abstract

Coastal sea level rise has been making headlines from Byron to Bega, as councils continue to focus on mitigating and adapting to coastal recession. However, with over 130 estuaries along the NSW coast, relatively little work has been done on how these unique and often heavily developed shorelines may respond to rising sea levels.

Lake Macquarie City Council, with assistance from the DECC Estuary Management Program is undertaking a study into how shoreline recession from rising sea levels may affect the lake's foreshores. The project aims to unravel the intricacies of estuarine geomorphology, and provide both the Council and other estuarine managers a basic methodology for how to predict, and ultimately manage, shoreline erosion.

The 'Three Stage Sea Level Rise Assessment of the Vulnerability of Estuarine Shores' (3SAVES) provides non-technical estuarine stakeholders a guide to understanding the complexity of estuarine recession.

3SAVES is a process methodology with three key stages. Stage one looks at the susceptibility of a shoreline to erosion by identifying the predominant sediment type. State two assesses the physical processes that may be acting against it. Stage Three is a site specific assessment that will highlight areas that may require further investigation.

The outcomes of using 3SAVES is a greater understanding of the elements that can cause shoreline change to a specific shoreline, and the potential for it to recede with rising sea levels. Understanding this potential can then give a guide for best land management, whether it be to 'protect', 'accommodate' or 'retreat' a shoreline.

This paper applies 3SAVES to a soft sediment shoreline within Lake Macquarie. The case study provides an example of how 3SAVES can be applied to a typical estuarine shore.

3SAVES assists people who are engaged with managing estuarine shores to identify the key elements driving estuarine recession. This is the first step towards developing appropriate adaptive measures. 3SAVES will give anyone with an interest in estuaries an insight into potential estuarine recession and how to manage it more effectively.

1. Introduction and purpose

The NSW coastline has over 130 estuaries, and over 1000 around Australia (CSIRO 2009). These estuaries are often places of urbanisation, industry or inhabited by significant ecological communities. However, as sea levels rise, estuaries, which are either permanently or intermittently open to the ocean will experience the full effects of this rise.

The response of estuarine shorelines to rising sea levels is intricate and dependant on the local geomorphology. However, stakeholders who are responsible for making long term decisions about estuarine shores, such as local council planners or land owners are often not experts in this field and as such may not have a clear understanding in the elements that cause shoreline recession.

This project aims to provide a first pass methodology that explains the factors that influence estuarine erosion and provide a process by which to identify shorelines that may be at risk. This paper outlines the 3SAVES process and provides a case study of the methodology to a shoreline within the Lake Macquarie Estuary.

This project has been supported by a grant from the DECCW's Estuary Management Program.

2. Estuaries and climate change:

Estuarine shores, particularly soft sandy, muddy, clayey or gravely are some of the most mobile and dynamic landforms on earth (Sharples 2006). Changes in long term sea levels has been a defining factor to the position and form of most Australian estuaries, and it would be expected that as sea levels begin to rise once more these estuarine environments will continue to change at an accelerating rate.

Predicting how a shoreline will change is a complex science. The material properties that make up an estuarine shore are diverse, and there are often several physical processes acting on them simultaneously. There has been extensive research into how open oceanic shorelines may respond to rising sea levels, however less so on estuaries. Coastal research is not easily transferable to estuaries as the material properties and physical processes are significantly different.

Estuaries are likely to experience a range of effects from climate change. Increased evaporation, change in run off rates, changes to nutrient cycling, water temperatures, acidification and increase occurrence of vector-borne diseases. (OzCoast 2008). However, of greatest significant to estuarine managers is how the effects of rising sea levels may change the position and properties of existing shorelines.

The most apparent changes to an estuary from sea level rise is that of inundation, where water intrudes into areas that are currently dry land (figure 1). Inundation that already occurs from high tides, storm surges, wind set up, wave run up and flooding will be intensified by global sea level rise.

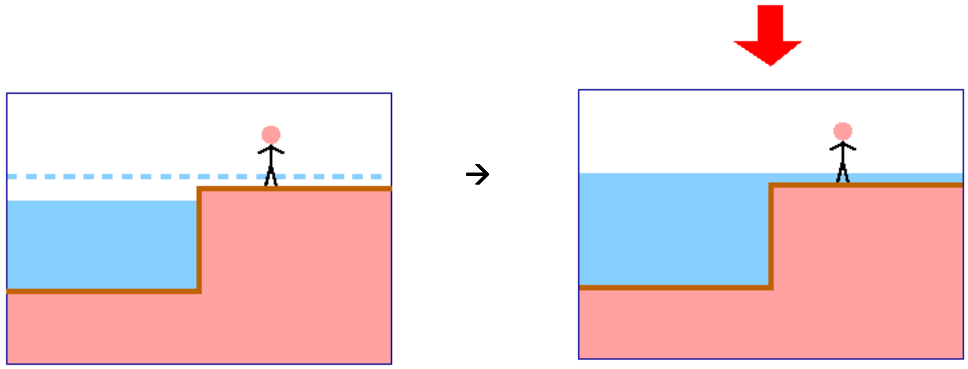


Figure 1: Inundation from Sea Level Rise (Church 2008)

However, when a shoreline has sediment that can be shifted by water energy a shoreline may experience recession, exacerbating the effects of inundation.

Shoreline recession is the progressive landward shift of the shoreline. Recession occurs when the outgoing sediment from a shoreline is greater than the incoming sediment. For oceanic shorelines, sediment that is eroded can be moved back onto the shore and re-establish the profile, into a state of equilibrium commonly calculated by beach equations such as the Brunn Rule (figure 2). However, for an estuarine shoreline, sediment is often lost to the basin and as such is dependant on other sediment sources to nourish the shore.

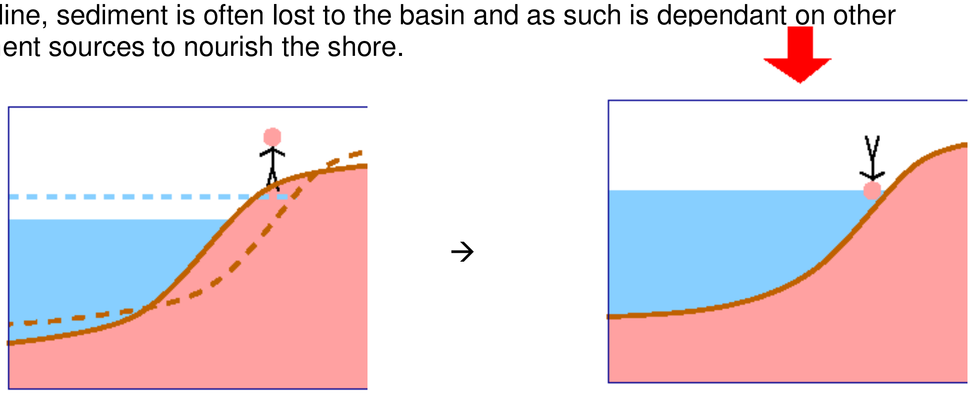


Figure 2: Shoreline recession from sea level rise (Church 2008)

The rate of change for sediment recession is hard to predict, as shoreline recession does not generally occur gradually as sea levels rise, but occurs periodically during major storm events, when energetic waves can reach the backshore to cause erosion. Therefore there is a lag between the sea level rise and corresponding degree of erosion taking place. The lag will depend on the frequency and intensity of storms affecting the shoreline (Sharples 2006).

3. Methodology – The '3SAVES' process.

Understanding the potential change of an estuary from sea level rise requires consideration of a range of factors. Each estuary is unique it its size, shape, geological make up and its relationship to the ocean. The expectation for shoreline change from sea level rise will vary, with some shorelines receding, whilst others experiencing only inundation.

The Three Stage Sea Level Rise Assessment of Vulnerability of Estuarine Shores (3SAVES) process is a simplified methodology that non-technical decision makers can use to help understand how a shore may respond to changes in water levels.

3SAVES draws on research from the 'Three Pass Approach to Coastal Risk Assessment' by Sharples et al (2008), however modified, and expanded to be applicable to estuaries.

The following is a schematic of the 3SAVES process methodology:

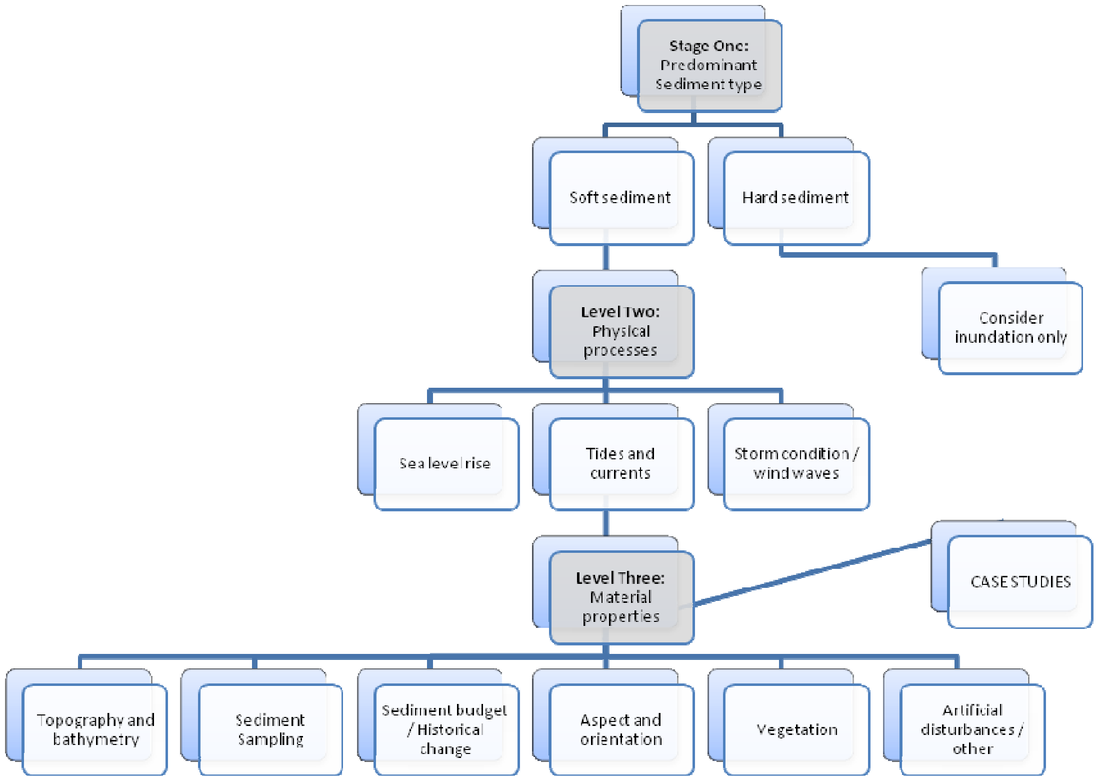


Figure 3: Three stage Sea Level Rise Assessment of Vulnerability to Estuarine Shores (3SAVES)

The stages of 3SAVES are as follows:

Stage One:

Stage one is a broad assessment of a shoreline to identify if the shoreline has material properties that could be at risk of erosion. This is by considering the predominant geological material, and classifying the shoreline into 'soft' or 'hard' material.

Estuaries can have a diverse range of shoreline sediments, influenced by the local geological make up as well as fluvial sources adding sediment and nutrients. As such, classifying an estuarine shoreline into 'soft' and 'hard' can is somewhat abstract

For clarity of this project, 'soft' shorelines are any shores that *primarily* have soft sediment along the shoreline and up into the hinterland. 'Soft' sediment is primarily unconsolidated, and may have particle size less than 40mm. On the Wentworth Udden (1922) Particle size scale, this includes sediments of pebbles, gravels, sands, silts and clays. It does not include shorelines that are predominantly boulders or hard conglomerate rock.

This scale of sediment assessment does not allow for in-depth analysis of the erodibility of the shoreline material, however it is a first pass for identifying if a shoreline has the potential to erode.

If the predominant geological type of a shoreline is hard, the potential of shoreline erosion is low. Therefore the next step for assessing risk for hard shorelines is to consider inundation based in topography only.

For shorelines that are classified as 'soft', the shoreline should be further examined by stage two.

Stage two:

Stage two is to assess the localised energy processes that are occurring on the 'soft' estuarine shore. It is these processes that will exacerbate cause any potential shoreline change. Processes include;

- Tides and currents
- Predominant weather conditions (resulting in wind waves)
- Sea level rise

These energy processes are applicable to the whole estuary, particularly sea level rise, wind directions and storm conditions. However the influence of currents and the tidal range are site specific.

If energy from tides, currents and wind waves is very low then rate of change would be much slower. As such, shorelines that do not have significant energy can be assessed only on inundation from sea level rise, in much the same way as a hard structure.

Stage Three:

Stage Three is a site specific detailed assessment of the unique elements that may cause shoreline recession.

Elements that are considered in Stage Three Assessment include:

- Topography and bathymetry
- Sediment survey, sediment budget and historical change
- Aspect and orientation to predominant winds
- Vegetation
- Bathymetry
- Boat wakes / other
- Land movement
- Artificial disturbances
- Adjacent shores

The level of detail that a Stage Three assessment warrants depends on a number of factors:

How vulnerable is the shoreline to erosion?

How ‘valuable’ is the shoreline? and,

What is the potential for management and adaptation?

Case Studies:

If a shoreline is identified as being potentially vulnerable and there are elements in Stage Three that seem likely then a shoreline should be further assessed by incorporating computer hydrological modelling with field tests. This can be a time consuming and expensive process.

As a guide, 10 case study shorelines within Lake Macquarie are currently being investigated for the rate and extend of recession from sea level rise. The case studes incorporate a range of different shore types that are typical for other estuarine environments and as such will provide decision makers with a general ‘rule of thumb’ as to how a particular shoreline type is likely to respond. These case studies will be available by the completion of the project in February 2010.

4. Limitations of the 3SAVES methodology

The 3SAVES methodology is a simplified tool which aims to assist non-technical estuarine stakeholders assess shorelines that may be at risk of erosion of sea level rise.

3SAVES provides a method for preliminary assessment and identifications of sites where further investigation is needed. It does not delve into the detail that is needed for a comprehensive shoreline assessment but rather is designed as a guide to help decision makers understand if ongoing work is necessary.

There is irreducible uncertainty in any projections of future impacts on and changes to shorelines from sea level rise. The number of variables influencing a shoreline’s behaviour and the range of uncertainties make estuarine projections extremely difficult. However 3SAVES aims to provide a guide for considering these variables.

5. Application of 3SAVES Boonai Point, Lake Macquarie:

A shoreline with Lake Macquarie has been selected as a case study to demonstrate the use of 3SAVES onto a soft estuarine shore. Boonai Point is a small shoreline located on the west side of the lake, south of Dora Creek and has typical features of many shorelines around the lake.

Lake Macquarie is a large coastal lake just south of Newcastle (Figure 5). The lake covers 112 km^2, and has 174km of foreshore. The Lake is connected to the ocean by a tidal channel at Swansea, causing water levels to lie approximately 0.1m AHD.

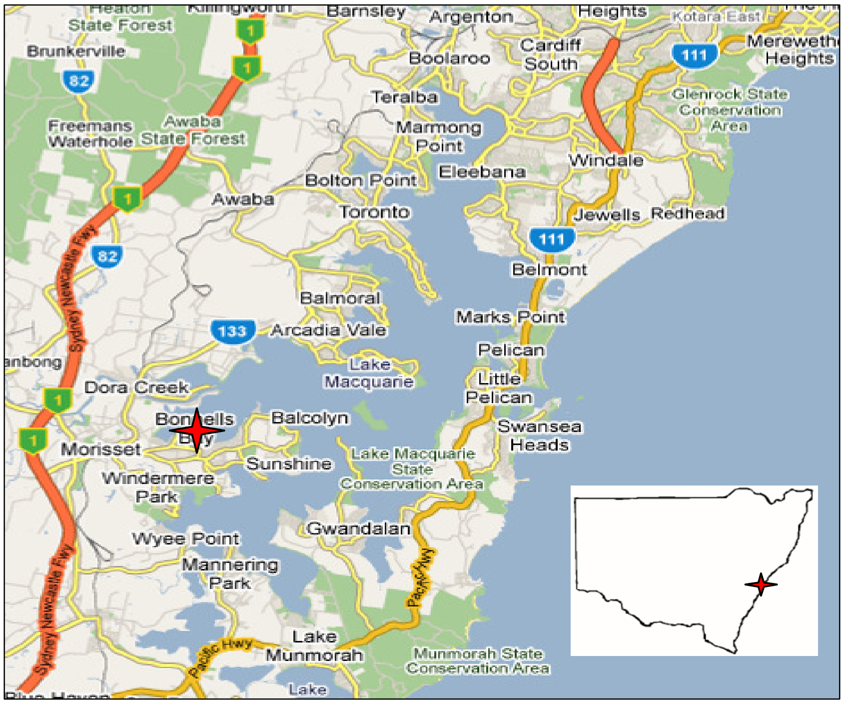
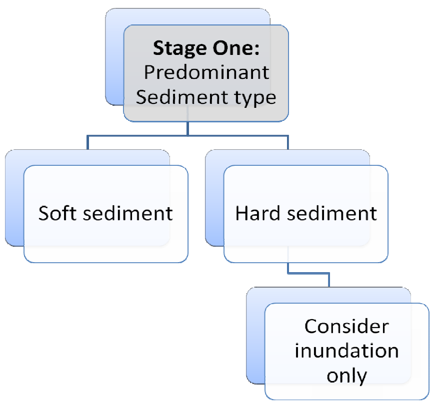


Figure 4: Lake Macquarie and Boonai Point.

The lake has a range of shoreline types, from finely sorted marine sand on the east side, rocky headlands, silty deltas and gravely shores to the west.

Stage One: Predominant Sediment Type



Lake Macquarie, like most Australian estuaries, was once a series of river valleys that were flooded during the period of rapid post-glacial sea level rise between 15,000 and 6,000 years ago (Kench 1999). The lake filled several merging bedrock valleys and small river catchments.

As a result of this geological history, shoreline deposits are generally muddy sands and sandy mud which thinly cover the bedrock valley. On the Eastern side of the lake, the shorelines that are adjacent to the ocean inlet are comprised of fairly clean marine sand. Added to this the influence of ongoing fluvial sources (mainly Cockle Creek in the north and Dora Creek to the west), the shorelines of Lake Mac include rocky boulders, gravel, sand and silty shores.

The image below from the Department of Planning (2008) shows simplified geology of the lake.

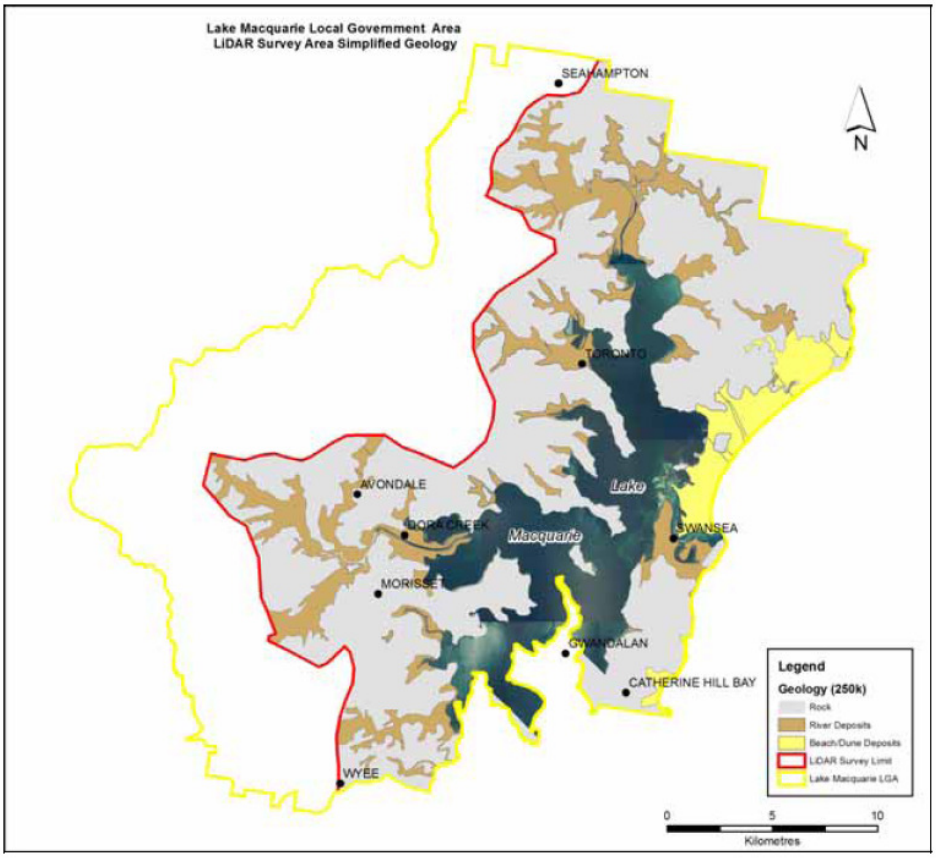
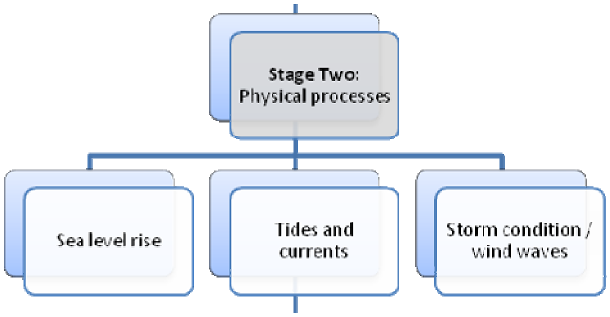


Figure 5: Simplified geology of Lake Macquarie. (Department of Planning, 2008)

This map categorises geological types into rock, river deposits or beach dune. From this mapping, Boonai Point is classified as a river deposit. A site visit doing a preliminary examination confirms this shoreline as primarily mud and silt, based on the Wentworth Udden (1922) Particle Size Scale (figure 7). Therefore it is classified as a 'soft' shore and has the potential to erode.

Figure 6: Stage One sediment assessment of Boonai Point.

Stage Two: Physical Processes



A shoreline may be classified as soft, however it is the physical processes acting against it that make it vulnerability to shoreline recession. Physical processes that are considered in a Stage Two assessment are Tides and currents, Storm conditions / wind waves and Sea Level Rise.

Although every estuary is unique in its properties, there are classification systems based on an estuaries mode of origin, physical processes and morphological characteristics. The most common classification for the development of Australian estuaries is Dalrymple et al (1992) where estuaries are positioned in their relation to rivers, waves and tides.

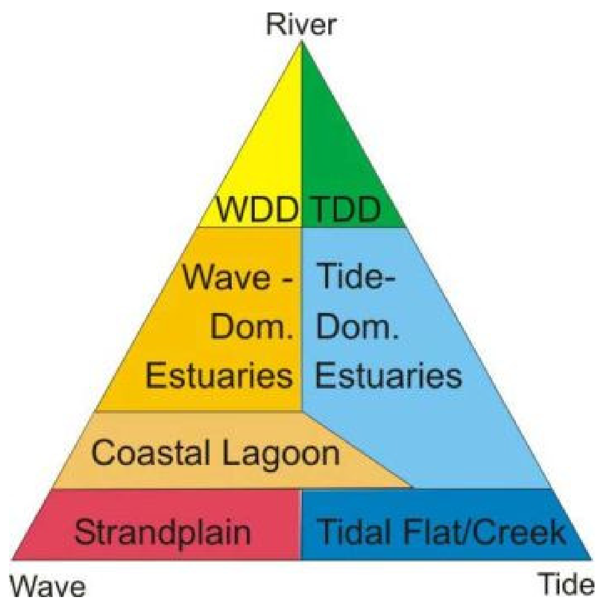


Figure 7: Estuarine Typologies – pivoting between the influence of rivers, waves and tides. WDD = wave dominated deltas, and TDD = tide dominated deltas. (Dalrymple et al., 1992, Boyd et al., 1992).

The Australian Government OzCoasts has categorized all estuaries within Australia by their typology, and provide details on how these types may behave. Lake Macquarie is a Wave Dominated Estuary, that is, while it has both tides and currents, waves are the dominating force shaping the general geomorphology (Riggs et al 1995).

Tides

The amount of water moving in and out of the estuary during a tide, known as the tidal prism can play a significant role in determining the strength of tidal currents. These currents can transport and redistribute sediment, causing erosion. If the tidal range is small, the wave energy is concentrated and as it hits the shore can cause rapid erosion. If the tidal range is larger, the wave energy will be dispersed over a greater vertical range and be a slower rate of erosion (Sharples 2006). The tidal prism is determined by the oceanic tidal range, the area and volume of an estuary and the channel that allows water to enter and exit.

Due to the narrow channel at Swansea relative to the size of the basin the tidal range in and out of the lake is constricted, and as such most areas of the lake only experience a spring tidal range of around 0.12m.

Sea level rise may change the tidal prism within an estuary, as more water is forcing into the lake. This may expand the tidal zone further into the estuary and extend the land that is affected by periodic inundation.

Currents

Most estuaries have fluvial sources. They could be large permanent rivers or small periodic channels that only run during a storm event. Regardless, fluvial sources add both sediment and energy to an estuary.

The energy of fluvial currents can move sediment, causing erosion. It can also add sediment, accreting a shoreline.

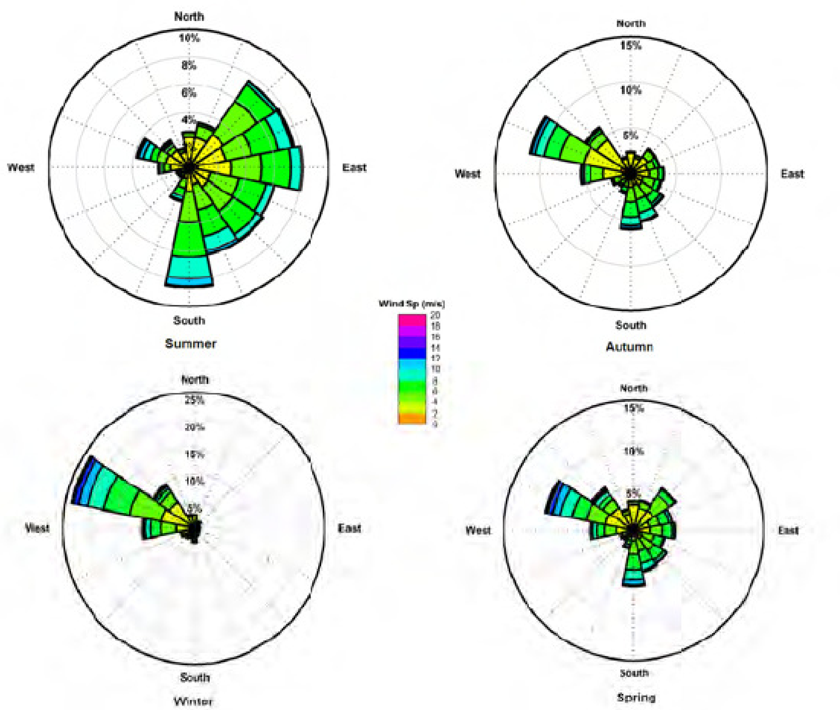
Currents within Lake Macquarie are predominantly from the two largest inflows, Cockle Creek (merging with Winding Creek) and Dora Creek. However the large size of the basin means that currents are quickly dispersed and as such generally does not have high energy away from the discharge mouth.

Waves:

Most shoreline erosion from sea level rise does not occur on a day-to-day basis, but rather become apparent during a high energy storm event. Consequently for any shoreline, recession is a process that is extremely variable from year to year and will depend upon the frequency, direction, duration and intensity of storms (Riggs 2003)

The force of wind blowing over water exerts a shear stress (wind stress) on the water surface, transferring a portion of the momentum of the wind to the lake. This energy develops into both wind driven currents and waves. Typically these currents are strongest on the surface and generally form complex eddies and current loops.

Knowing the predominant wind direction is important for understanding the likelihood and energy of wind waves and currents acting on a shoreline. Figure 9 shows seasonal wind roses based on long-term data from Williamstown, the closest monitoring station to Lake Macquarie. Ideally long term wind data should be sourced from as close as possible as wind conditions over the lake may be different from wind measurement at an onshore station and can vary greatly within an estuary.



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The stronger winds are during the summer, predominantly coming from the south east. The rest of the year experience some strong north-westerly's, however not as intense.

From past studies within the lake, it has been found that Lake Macquarie extreme wave climates, based on 20 ,50 and 100 year ARI wind statistics have found that the maximum foreshore significant wave heights are about 1.0 to 1.5m with wave periods of around 3-4 seconds.

One of the projected impacts of climate change will be an increase in the intensity of storms, a change in wave climates and the direction of wave impacts. (Pittock 2003, p. 68), For the Lake Macquarie region, the east coast low pressure system, which is currently responsible for the majority of storm surge water levels and coastal erosion within NSW may increase in intensity in the future.

<u>Sea level rise:</u>

Sea level rise has been the predominant factor shaping estuaries around Australia. It could be expected that as sea levels rise into the future, estuaries will continue to change in similar ways that they have before. The key difference however is the rate of change, with sea levels rising faster than in the past.

There are two key ways that water levels on a shoreline can rise. The first is through permanent inundation, which is dependant upon local gradient and is long term. The second is periodic inundation, such as storm surge and is not permanent. However, permanent sea level rise will exacerbate the range of periodic inundation.

<u>Permanent inundation:</u>

Lake Macquarie City Council has adopted a Sea Level Rise Preparedness Adaptation Policy, which acknowledged a rise in sea levels of 0.91m by 2100. This figure is based on figures from the IPCC and CSIRO. This figure will be reviewed to ensure it is in line with the most up to date science.

Periodic:

Persistent winds have the energy to generate storm surge, where wind pushes water along the flow, causing an increase in water levels downwind. This added storm surge will allow flooding from wind waves to reach greater depths and over greater areas of land. Storm surge can add an additional 0.1m to water levels.

Flooding will also create an increase in sea levels. The largest flood on record was in 1949 where lake water levels were elevated by 1.25m above AHD, more than 1m above normal high tide levels.

Summary of potential periodic and permanent sea level rise by 2100:

Physical Process	Potential rise in water levels (m)
Sea level rise by 2100	0.91
Astronomical tide	0.1
Maximum wind wave height	1.5
Storm surge	0.1
Total water height	**2.61**

Based on this accumulation of factors, it is expected that water levels could rise up to 3m above current levels. Figure 10 highlights areas around Lake Macquarie that have topography below 3m AHD.

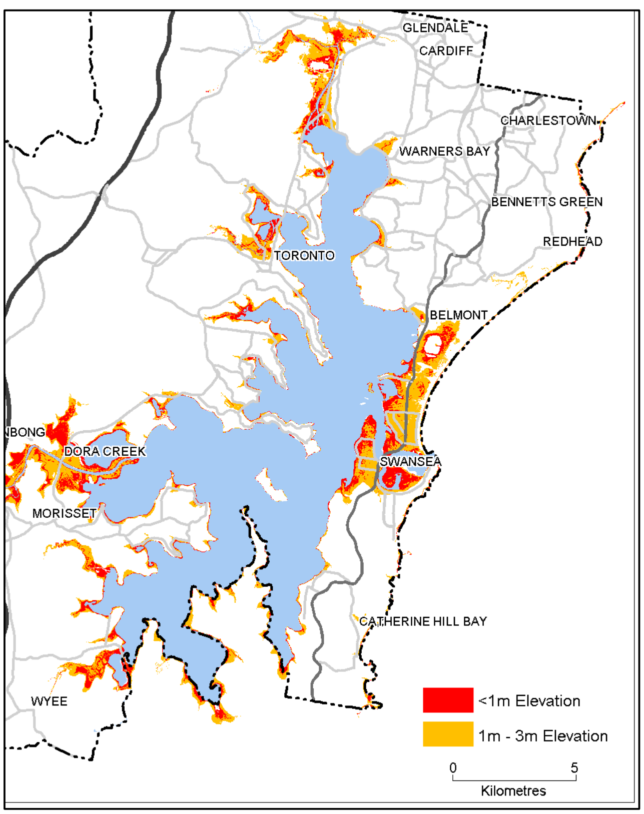
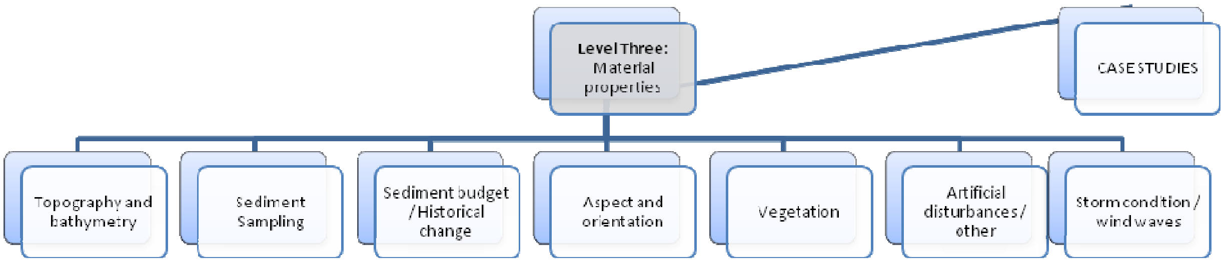


Figure 9: Low lying land around Lake Macquarie.

Now that the type of prominent energy sources have been identified for Boonai shore it moves onto a stage three assessment.

6. Stage Three:



By this stage of assessment, it has been identified that Boonai Point is a soft shore, and there are significant energy processes working against it. Therefore it has been identified as vulnerable to inundation, with risks likely to occur.

The shoreline has value in its ecological and urban landuse and at this stage there would be expected adaptation options available. Therefore further assessment of the following aspects is worth considering.

<u>Topography and bathymetry:</u>

Using topographic data from LiDAR, figure 11 shows Boonai Point with areas lying below 3m, which is the accumulation of sea level rise factors by 2100.

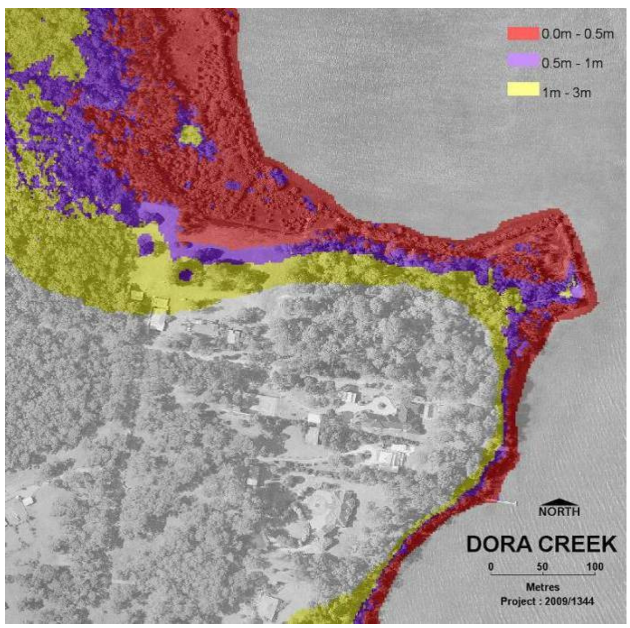


Figure 10: Boonai Point topography, highlighting areas below 3m AHD.

As well as a shorelines topography, the shape of the seabed, or bathymetry is useful in understanding how wave energy will interact with the shore. A shallow sea bed can amplify wave energy greater than a deep sea bed. (Roy et al 1994). Figure 12 shows a surveyors profile of the bathymetry of Boonai Point. The shoreline is in a large wide bay so it would be expected that wave energy moving across this shallow basin would increase its intensity.

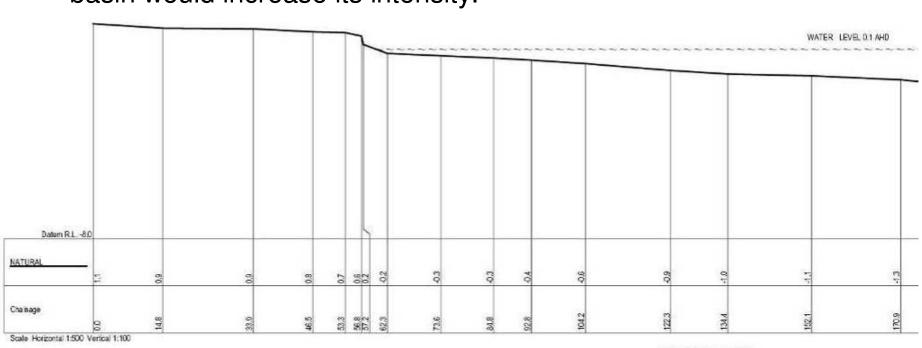


Figure 11: A profile Boonai Point bathymetry

Additional sediment studies

Stage Three assessment requires a more detailed assessment of the sediment on the shoreline to understand its erodibility.

Sampling sediments should be taken along a profile ranging from the foreshore, backshore and into the hinterland. It is important to consider where the mean high water mark will be based on projected sea level rise and sample from this point as well. In some cases this may be hundreds of meters landward of the existing shoreline. How to estimate the extent of the recession would require computer modelling and sediment sampling – 10 case studies are currently being undertaken to provide a guide to recession extent.

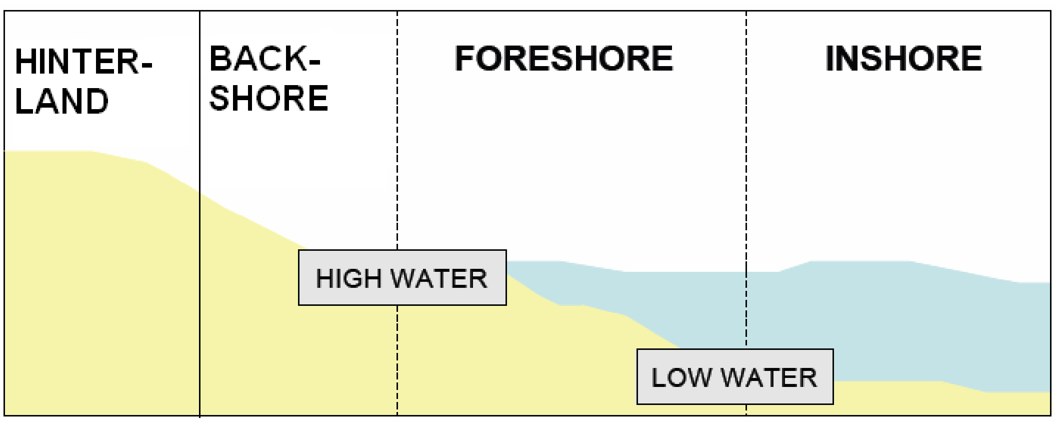


Figure 12: The zone of influence for an estuarine shoreline

Figure 13 shoes the zone of influence for an estuarine shoreline. The foreshore is the area between the low and high tide water marks. The backshore is the extend to which extreme weather events can intrude. The hinterland is land behind the shoreline, and for the purpose of this study up to 3m AHD.

The methodology of how to sample and what tests to run depends on the detail of assessment. The erodibility of a soil is based on the size of particles, the coherence between them, dispersibility of the fine fraction, and the amount of clay present.

The landscape of Boonai Shore is classified, under the Soil Landscapes of the Gosford – Lake Macquarie 1:100 000 sheet as Doyalson (Figure 14). The soils in this landscape are classified as fine grained silt and clay. The limitations of these types of soils is that they are classified as a high erosion hazard.

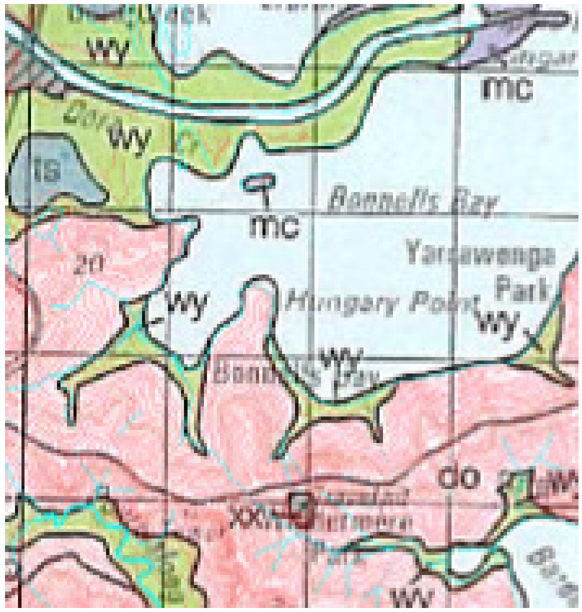


Figure 13: Boonai Shore - Soil Landscapes of the Gosford – Lake Macquarie 1:100 000 Sheet.

<u>Short term / long term erosion and Sediment Budget</u>

Most soft shorelines within an estuary are in a constant state of change as sediment is added or removed. This change is dependant on the sediment ‘budget’ available - where there is more sediment being removed than added a shoreline will recede. Conversely, when more sediment is added a shoreline will prograde.

Sediment movement can be short term, usually occurring during a severe weather event, and once the event has passed the sediment is returned, although it may take months or years (Rossington 2008). However it can also be long term, where sediment is lost to a sediment sink and does not return.

Sediment that can be added to a shoreline may be derived from a fluvial source, ie a river discharging or from within the estuarine such as another shoreline eroding adding sediment to the environment.

<u>Equilibrium:</u>

When the sediment is transportable, and the wave energy sufficient, a shoreline will try to retain a constant shape as sea levels rise. This is known as equilibrium, where a shoreline moves towards a state in which a shore would ultimately occur if water was able to carry out its work to completion. (Fenneman, 1902). This equilibrium can lead to shoreline recession.

The first and best known model relating to shoreline recession is the Bruun Rule, which can estimate the distance the shoreline may recede as water levels go up. However, the Bruun Rule is applied largely to open oceanic sandy shores, and as such it does not necessarily provide a good model of the response of bedrock, coarse sediment or very fine sediment shorelines to sea level rise. (Cooper & Pilkey 2004). Unlike ocean shores, the Bruun rule can not be applied within estuaries for a number of reasons. Firstly, the amount of sediment available is limited, and once removed is often lost to the estuarine basin. Secondly, once a severe weather event has passed, the wave energy in an estuary is not sufficient to move sediment back to its place in the profile. (Rossington 2008)

Some attempts have been made to describe equilibrium profile for muddy shores. Lee and Mehta (1997) examined the relationship between the profile shape on muddy shores and wave forcing. The dissipation of wave energy was found to be important to the profile shape. Large wave energy erodes to create concave shorelines, while low wave energy often adding sediment and creating convex shorelines.

Boonai Shoreline, due to its location to fluvial sources is slowly accreting. However it would be expectd that the rate of sea level rise will exceed the rate of accretion and therefore would not significantly protect the shoreline from recession.

<u>Aspect, fetch, exposure, orientation</u>

Boonai Point is located within a bay south of the Dora Creek entrance. Although the opening into the bay is fairly narrow, it is likely that fluvial discharge from Dora Creek would influence this shoreline.

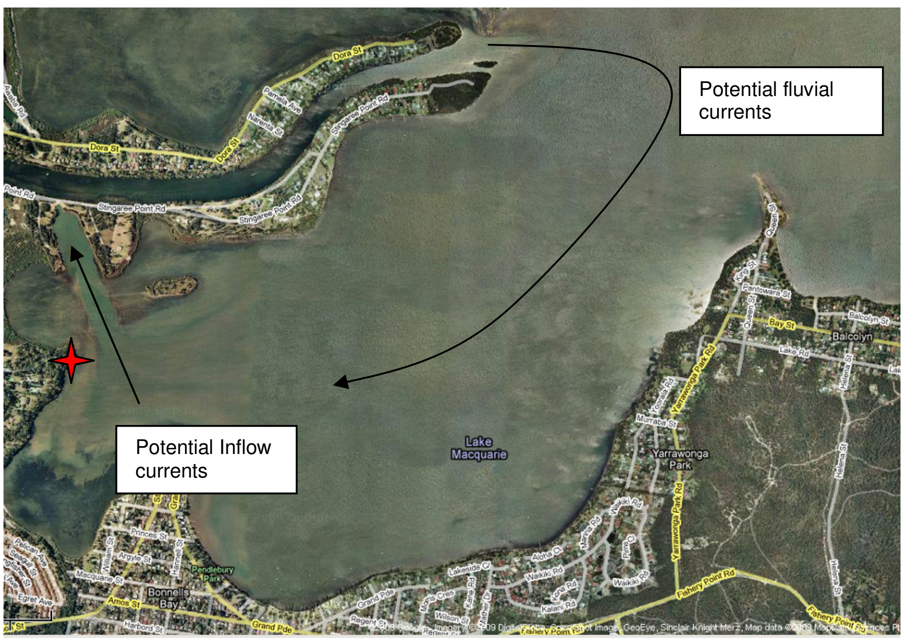


Figure 14: Potential fluvial and man-made currents circulating near Boonai Shore

A man made entrance for a local power station has also been built, potentially creating currents and sediment movement on the shoreline.

However, the rate of water movement out of Dora Creek and through the channel would not be expected to be energetic enough to cause significant sediment loss. The influence of wind waves would be the driving factor to shoreline erosion.

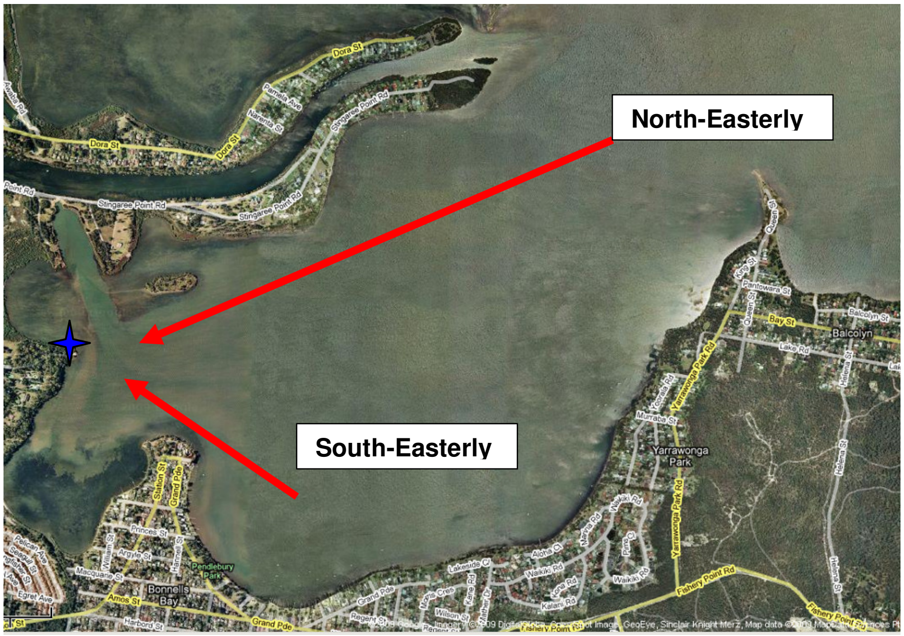


Figure 15: Predominant winds to Boonai Shore, Lake Macquarie.

The predominant winds that occur in Lake Macquarie are largely North and South Easterlies. The position of Boonai Point means that winds from the North East would have considerable fetch to generate energetic wave activity. Winds from other directions would be largely negligible for this shoreline.

<u>Vegetation:</u>

Vegetation in the nearshore and backshore can greatly reduce a shorelines susceptibility to erosion. (DNR 2008). Vegetation can effectively absorb water energy that hits a shoreline during storm events, as well as providing reinforcement in the soil through vegetation roots, keeping sediment from being removed. (Riggs 2003). The denser a vegetation and root network, the better the protection for a shoreline.

Boonai Point has a mixture of salt marsh and mangroves in the near shore and backshore.

Figure 16: Mangrove and Salt marsh vegetation at Boonai Point.

Saltmarshes in front of a sediment bank generally act as a very effective energy baffle during high storm tide conditions. Since marsh grasses grow in the high tide portion of both regularly and irregularly flooded coastal systems, marshes are capable of baffling much wave energy in all except the highest storm tide situations. Therefore very little wave energy gets to the sediment bank behind marshes. As sea levels rise the water levels will penetrate into the marshes further and therefore may push back the area the marshes inhabit (Riggs 2003), depending on the landuse and profile.

Boonai Point is also inhabited by mangroves. Mangrove communities are likely to show a blend of positive responses to climate change, such as enhanced growth resulting from higher levels of CO_2 and temperature, as well as negative impacts such as increased saline intrusion and erosion (Saenger, 2002 in Parry 2007). Studies into the movement of mangroves through-out south-east Australia have seen mangroves extend landward into salt marsh areas. However, the level of sea level rise over this period of time is minor compared to that predicted for the future. (Parry 2007)

Sea level rise will likely change or relocate estuarine vegetation. Inundation and storm events will push back the area where current high water events extend to. In the past, as sea levels rise, vegetation communities may have been able to maintain their position to the water. However, there are several reasons this may not continue to occur with the current rise in water levels; The rate of change may be too fast for some communities, not giving enough time for a community to migrate. (Nicholls 2007). Also, a community that can migrate may not be able to do so if the land they are moving into is a different aspect, soil type or there are human modifications such as roads.

Vegetation at Boonai Point has a fairly good chance of migrating. The topography of the backshore is a fairly consistent profile and there are no major human modifications. Provided that the marsh and mangroves can adapt in the time frame, it is likely they will migrate landward.

Artificial disturbances

Shoreline response to sea-level change is further complicated by human modification of the natural coast such as beach nourishment projects and engineered structures such as seawalls, revetments, groins, and jetties. Understanding how a natural or modified coast will respond to sea-level change is essential to preserving vulnerable coastal resources.

Historical photos are a good way to identify large scale changes that have taken place around the shoreline.

Figure 17: Aerial photos, 1961 and 2007.

Figure 15 show two historical photos. The left is taken in 1961 and the right almost 40 years later, in 2007. The most noticeable change is the dreding of a power station inflow channel. This potentially has altered the natural flow of sediments within the region. The landuse of Boonai Shoreline has remained relatively unchanged.

Boat wakes

In shorelines adjacent to navigational channels, boat traffic, particularly high powered recreational water craft, water skiers and wake boats can cause shoreline erosion. These vessels displace large volumes of water and create large wakes that repeatedly break on the adjacent sediment shoreline. Sea level rise will allow this wake to extend further up the shoreline. Boonai shore is not in a heavy trafficked area, and does not receive significant power boat wake.

Adjacent shorelines

Modifications to adjacent shorelines within an estuary can have a significant impact on the sediment movement of the shore. Erosion control measures such as groynes can hold sediment, helping to save the updrift side of the shore from eroding but starving the downdrift side of sediment. This can move the erosion problem to the adjacent shore. A sea wall will also affect adjacent shores by refracting wave energy and moving it elsewhere.

Boonai Point has relatively natural shorelines in the vicinity and as such would not be at risk from adjacent shoreline modifications.

7. Where to from here?

Once a Stage three assessment has been considered, an estuarine decision maker will have a better understanding into factors that may increase the vulnerability of a shoreline to erosion.

At this stage, an estuarine stakeholder has the following decisions to make:

How potentially vulnerable to is a shoreline to recession?

Is there significant 'value' in the shoreline

Are there reasonable adaption options available to the shoreline?

If the answer is yet to these questions a site specific indepth analysis may be required. The outcome to this assessment will help identify if the best method of response is to protect, accommodate or retreat:

Protect: Protection of a shoreline may be through 'hard' mechanisms such as seawalls and groins, or 'soft' protection measures such as shoreline nourishment and revegetation. The goal of protection is generally to allow existing land use activities to continue despite rising water levels. These measures may range from large-scale public projects to small-scale efforts by individual property owners. (McLean et al 2001)

Accommodate:

Accommodate involves continued occupation of a shoreline while adjustments are made to prepare for sea level changes, and thereby reduce the overall severity of the impact. Accommodation strategies may include redesigning existing structures, implementing legislation to encourage appropriate land use and enhancing natural resilience, i.e controlling sediment and developing flood warning systems. (McLean et al 2001)

Retreat:

Retreat involves avoiding the risk to eliminate direct impact. This strategy means no attempts are made to protect the land from sea level rise. Instead, land that is threatened is either abandoned when conditions become intolerable, or not developed in the first place. In some cases retreat is the most cost effective long term alternative. (McLean et al 2001)

8. Conclusion:

The 3SAVES methodology is a simplified tool which aims to assist non-technical estuarine stakeholders assess shorelines that may be at risk of erosion of sea level rise.

Although 3SAVES has its limitations in the detail that it can provide, it aims to give decision makers a framework in which is better understand the complex geomorphology of estuarine shorelines.

Applying 3SAVES to an estuarine shore is a starting point to identifying the potential for erosion and as such making decisions for its long term land usage.

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