Sea Level Rise and the Estuarine Intertidal Zone

1 Introduction

Sea level rise as a result of climate change represents a substantial challenge for management of the ecology of the Brisbane Water estuary. This discussion paper outlines a preliminary investigation of the potential changes to the estuarine intertidal zone resulting from sea level rise. The investigation has been carried out by Cardno utilising available tidal planes information sourced from the Manly Hydraulics Laboratory (MHL, 2004), geographic information system (GIS) layers provided by Council and the sea level rise benchmarks outlined in the *NSW Government Sea Level Rise Policy Statement* (DECCW, 2009).

1.1 Sea Level Rise

The IPCC has recorded a global trend in average sea level rise over the period 1961-2003 of 1.8 mm/yr (the range being 1.3-2.3 mm/yr), with more accelerated sea level rise occurring over the period 1993-2003 with an average global rate of rise was 3.1 mm/yr (2.4-3.8 mm/yr) (Bindoff and Willebrand, 2007).

The NSW Government has prepared a *Sea Level Rise Policy Statement* (DECCW, 2009) which adopts a sea level rise planning benchmark of 0.4m by 2050 and 0.9m by 2100. Over the period 1915 to 2004 annual mean sea level estimates at Sydney (Fort Denison) showed a linear increase of 0.9 mm/yr with the 20-year running average varying between -2 mm/yr and +3 mm/yr (van Senden, 2005). The sea level rise policy translates to a linear increase of 10 mm/yr which, when compared to the Sydney data set will require a rapid acceleration of the ate of rise in sea level to attain the projected values. For this reason, an effort has been made to refer to projected sea level rise benchmarks rather than specific years (i.e. 2050 and 2100).

Further information on sea level rise can be found in DECCW (2009) and Cardno (2010).

1.2 The Intertidal Zone

1.2.1 Definition

For the purpose of this study the intertidal zone is defined as the zone within which the shoreline location varies with the rising and falling astronomical tide as defined by Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) tidal planes. Generally, the intertidal zone is that zone subject to wetting and drying by tidal motions on a roughly daily basis. The width of the intertidal zone depends on the bed slope and also varies with the spring-neap tidal cycle.

Tidal planes for a number of sites in Brisbane Water were derived from results of a water level data collection exercise carried out from 5 February to 29 April 2004 (MHL, 2004). MHWS and MLWS levels derived from this (relatively short) data set are assumed to provide a reasonable representation of the present day (2010) tidal plane levels. Further, it was assumed that the tidal characteristics of Brisbane Water will not change with increasing sea level and hence the 2010 tidal planes can be elevated by the projected sea level rise to provide projected tidal planes in the future.

1.2.2 Ecological Function

The intertidal zone is situated at the convergence of aquatic and terrestrial habitats; biota living in this zone have adapted to living in a highly variable environment. Intertidal vegetation, including mangroves and saltmarshes, plays an integral role in the ecology of the whole estuary, particularly with regards to primary production and providing habitat for fish, birds, mammals and invertebrate fauna. As described in Cardno (2010), intertidal vegetation may:

- Assist sediment accretion / trapping;
- Provide a major source of primary productivity in coastal environments and is a support resource for estuarine food webs;
- Provide shoreline protection from waves and strong currents;
- Assist nutrient cycling;
- Act as a buffer for water quality;
- Provide important nursery habitat for many marine and estuarine species, including fish and prawns;
- Act as an indicator for monitoring change in coastal environments; and
- Act as a sink for atmospheric carbon.

The intertidal ecosystem is specific to the zone that experiences periodic inundation due to the astronomical tides and varies with location on the coast and within estuaries and with proximity to catchment influences, particularly river/creek mouths. Intertidal species are typically dependent upon varying cycles of wetting and drying within the spectrum of the tides and the proximity to catchment drainage channels. This dependence upon tidal processes, combined with variations in site topography, means that the potential area for establishment of intertidal ecosystems is spatially limited. When coupled with human disturbance and fixed property boundaries, the area available for the establishment of intertidal ecosystems is particularly limited.

1.2.3 Current Threatening Processes

Intertidal ecosystems currently experience a number of direct and indirect threats due to human activities. Direct threats to the ecosystem cause a loss of habitat and include:

- Reclamation activities;
- Trampling; and
- Encroachment by foreshore development (e.g. structures and mowing).

Indirect threats include:

- Human-induced changes to the tidal prism (e.g. reclamation works);
- Human-induced changes to catchment hydrology;
- Stormwater and estuarine pollution;
- Weeds and introduced species; and
- Human-induced climate change and associated sea level rise.

An assessment of the Brisbane Water foreshore undertaken by Sainty and Roberts (2007) identified that 53% of the estuary foreshore was considered to be highly modified (i.e. consisting of seawalls with limited ecological niches, in close proximity to urban areas and with a urbanised catchment). Only 9% of the foreshore was categorised as being in an unmodified/natural condition (Sainty and Roberts, 2007).

Foreshore development may have direct and/or indirect impacts on the intertidal ecosystem. Seawalls for example, typically aim to provide protection against inundation by estuarine waters and stabilise the foreshore, but in doing so may inhibit tidal flows and restrict the landward migration of the intertidal zone, thereby causing habitat loss. These threatening processes can translate to a loss of the ecosystem services that salt marsh and mangroves provide, for example, shoreline protection, nutrient cycling, buffering water quality and sediment trapping (Cardno, 2010).

1.2.4 Sea Level Rise

Climate-change induced sea level rise presents a future risk to intertidal ecosystems due to the potential for permanent inundation of existing intertidal areas and shoreline recession. Whilst migration of these intertidal ecosystems can occur (Saintilan *et al*, 2009), migration may not be possible in all locations due to the presence of human constructs such as sea walls. In addition, the ongoing pressure from threatening processes (**Section 1.2.3**) is likely to further compromise the ability of these ecosystems to adapt to change, with subsequent implications for the ecology of the estuary as a whole.

1.3 Aims

To assist in providing a basis for further, more detailed studies on the potential impacts of sea level rise on estuarine ecology, Cardno undertook a spatial analysis of the intertidal zone for the present day and for the 0.4m and 0.9m sea level rise climate change scenarios.

The primary aims of the investigation were:

- To delineate the current intertidal zone;
- To identify the potential shift in the intertidal zone due to sea level rise;
- To identify the parts of the future intertidal zone that overlap with existing open space and foreshore development, respectively; and
- To briefly consider the potential implications for the distribution of intertidal vegetation.

This discussion paper effectively presents a preliminary risk assessment of the potential for loss of saltmarsh and mangrove areas due to the increases in average estuarine water levels. The risk of losing these habitats is likely to occur where for example, existing development may restrict the future migration of vegetation. Conversely, the results also highlight areas where migration may be possible, providing the land tenure/use can be secured into the future. The results of this investigation may then be used, together with other relevant data, to consider strategic planning for conservation purposes.

2 Methodology

2.1 Delineation of the Intertidal Zone

In accordance with the NSW *Sea Level Rise Policy Statement* (DECCW, 2009), the three scenarios investigated and their associated climate change sea level rises (SLR) were:

- Present day - 2010;
- 0.4m SLR – 2050; and
- 0.9m SLR – 2100.

The MHL (2004) data on tidal planes in the estuary were interpreted to provide present day MHWS and MLWS levels for each estuarine bioregion or zone (see Figure 1.2 of Cardno, 2010). The data is presented in **Table 2.1**. Tidal planes were assumed to be constant (ie. a level surface) within each bioregion. In addition, where MHL (2004) tidal planes were available for more than one location within a bioregion, the data were averaged.

Table 2.1: Present (2010) MHWS and MLWS Levels for each Bioregion.

Zone	MHWS (mAHD)	MLWS (mAHD)
Zone 1	0.385	-0.207
Zone 2	0.388	-0.231
Zone 3	0.376	-0.240
Zone 4	0.369	-0.227
Zone 5	0.314	-0.160
Zone 6	0.495	-0.328

A digital elevation model (DEM) of the land around Brisbane Water was generated from interpolation of the available topographic Aerial Laser Survey (ALS) elevation data (land only), bathymetric data (hyrosurvey cross sections) up to the 10m AHD contour. Where data resolution was sparse, aerial photography interpretation was employed. The challenge in generating the DEM is that the intertidal zone effectively represents a 'gap' in the spatial coverage of the available topographic/bathymetric data. This gap generally extends from above MHWS where the ALS stops to below MLWS where they hydrosurvey data begins. Through an analysis of historical water level data (MHL, 2004) and aerial photographs, a mean tide contour was generated. Linear extrapolation between the available ALS, hydrosurvey data points and the newly created mean tide level contour was then undertaken in GIS to generate the DEM. It is noted that both the horizontal and vertical resolution and accuracy of the available topographic/bathymetric data is variable; hence the accuracy of the derived intertidal zone is also spatially variable. Nonetheless, it is considered adequate to inform a preliminary risk assessment.

The intertidal zone was then delineated by the intersection of the MHWS and MLWS surfaces with the DEM. The intertidal zones for each climate change scenario were then delineated by adding 0.4m and 0.9m (respectively) for sea level rise to the present 2010 MHWS and MLWS levels.

Available mapping of estuarine vegetation from (I&I NSW, 2004) was overlaid on the present day (2010) intertidal zone extents along with mapping of SEPP14 Wetlands (Department of Planning) to assess the amount of intertidal vegetation currently found within the intertidal zone. The key vegetation groups are the saltmarsh and mangrove communities.

2.2 Designation of Developed and Open Space Areas

Using aerial photographs, areas of existing urban development located within the intertidal zone were identified and digitised into the GIS. Areas of 'urban development' included all those cadastral lots upon which buildings, roads, bridges and other man-made structures had been built. Through a similar digitisation process, areas of foreshore open space were also delineated. Foreshore open space was identified as those cadastral lots comprising grassed or bushland areas. This analysis was based on existing land use and no allowance was made for any future changes in land use.

A spatial analysis was then undertaken to determine where the future intertidal zones overlapped with existing (2010) open space and existing (2010) developed land.

3 Results

The existing areal extent of intertidal vegetation currently found in each bioregion is provided in **Table 3.1**.

Table 3.1: Current Intertidal Zone Vegetation Areas for the Brisbane Water Estuary (I&I NSW, 2004).

Zone	Mangrove (ha)	Saltmarsh (ha)	SEPP 14 Wetlands (ha)
Zone 1	1.86	0.05	3.19
Zone 2	2.10	0.19	1.26
Zone 3	0	0	7.22
Zone 4	7.68	0.48	17.33
Zone 5	7.26	0.82	7.85
Zone 6	0.88	0	0.83
TOTAL	**19.77**	**1.53**	**37.68**

The spatial extent of the intertidal zone for the present day, and projected 2050 and 2100 tidal planes is illustrated in **Figure 1** and summarized in **Table 3.2**. **Table 3.2** also provides an indication of the percentage of the future intertidal zones that coincide with areas that are presently undeveloped (i.e. open space) that may be available for vertical migration or colonization, as well as the percentage of the future intertidal zone that coincides with developed areas that will likely represent a barrier to establishment of intertidal ecosystems in future.

Table 3.2: Current and Projected Future Intertidal Zone Areas for the Brisbane Water Estuary

Zone	Total Intertidal Zone Area (ha)			2050 Intertidal Zone Area (0.4m SLR)		2100 Intertidal Zone Area (0.9m SLR)	
	2010	**2050**	**2100**	**% Open Space**	**% Developed**	**% Open Space**	**% Developed**
Zone 1	16.71	4.44	53.17	94	6	96	4
Zone 2	43.49	14.93	147.07	92	8	83	17
Zone 3	18.85	6.63	16.05	90	10	65	35
Zone 4	39.95	21.32	142.25	92	8	75	25
Zone 5	33.48	15.28	200.96	97	3	66	34
Zone 6	34.46	13.46	20.81	99	1	36	64
TOTAL	**186.94**	**76.06**	**580.31**				

The critical adjustment appears to coincide with a moderate (0.4m) SLR, when the areal extent of the intertidal zone decreases by around 60%. While the future intertidal zone under 0.4m SLR does not significantly overlap with developed lands, there remains a high risk of loss of intertidal vegetation during this period due to contraction of the intertidal zone (assuming no change in shoreline topography).

At the higher SLR of 0.9m, the potential intertidal zone increases significantly in extent to just over three times the present day intertidal zone, however, the intertidal zone is now subject to 'squeeze' due to the presence of existing development. If the developed portions of the 2100 (0.9m SLR) future intertidal area are discounted from the total intertidal area, the actual area likely to be available for migration or colonisation is 430.35ha, down from 580.31ha.

Where specific sites around the estuary are considered, there are three possible situations that may arise (assuming no intervention activities are implemented):

- The future intertidal zone may increase significantly in extent due to the availability of open space in that location (e.g. **Figure 2**);
- The future intertidal zone will likely be limited due to the presence of existing foreshore development (e.g. **Figure 3**); or
- There is little change in the extent of the intertidal zone for either 2050 or 2100 due to the site topography (e.g. **Figure 4**).

These figures also include mapping of Council owned land and other Crown land.

Figure 2 incorporates the suburbs of East Gosford, Erina, Springfield and Green Point and shows that the spatial extent of the intertidal zone at the 0.9m SLR is substantially larger than the present day (2010) zone. The dark green polygon represents the locations where the 0.9m SLR intertidal zone coincides with existing open space and there would likely be opportunities for Council to provide for natural or facilitated migration, albeit at the expense of present recreational open space. The overlay of land ownership shows that the 0.9m SLR intertidal zone in this location coincides predominately with Council-owned land.

Figure 3 incorporates the suburbs of Davistown and Empire Bay and demonstrates an area where the spatial extent of the intertidal zone is substantially larger than the present day (2010) area, overlapping significant present day areas of development. The dark blue polygon represents intertidal zone that coincides with existing development. The overlay of land ownership shows that the 0.9m SLR intertidal zone generally does not coincide with Council-owned or Crown land. Instead, the 0.9m SLR intertidal zone in this area coincides predominantly with privately owned land. In this location, facilitated migration is less feasible and an alternative approach (or combination of approaches) may be required.

Figure 4 incorporates the suburbs of Koolewong and Woy Woy Bay and demonstrates an area where the landward migration of the intertidal zone has the potential to be substantially limited by existing foreshore development (Koolewong) or by steep topography (Woy Woy Bay). Parts of the foreshore at Koolewong and adjacent to the Woy Woy rail culvert were considered to be highly disturbed in the study undertaken by Sainty and Roberts (2007). Sea walls, jetties, houses and the railway culvert are present in this area and such structures have the effect of limiting migration of the intertidal zone under the SLR scenarios unless significant conservation initiatives are implemented.

Further interpretation and discussion of the findings is provided in **Section 4**.

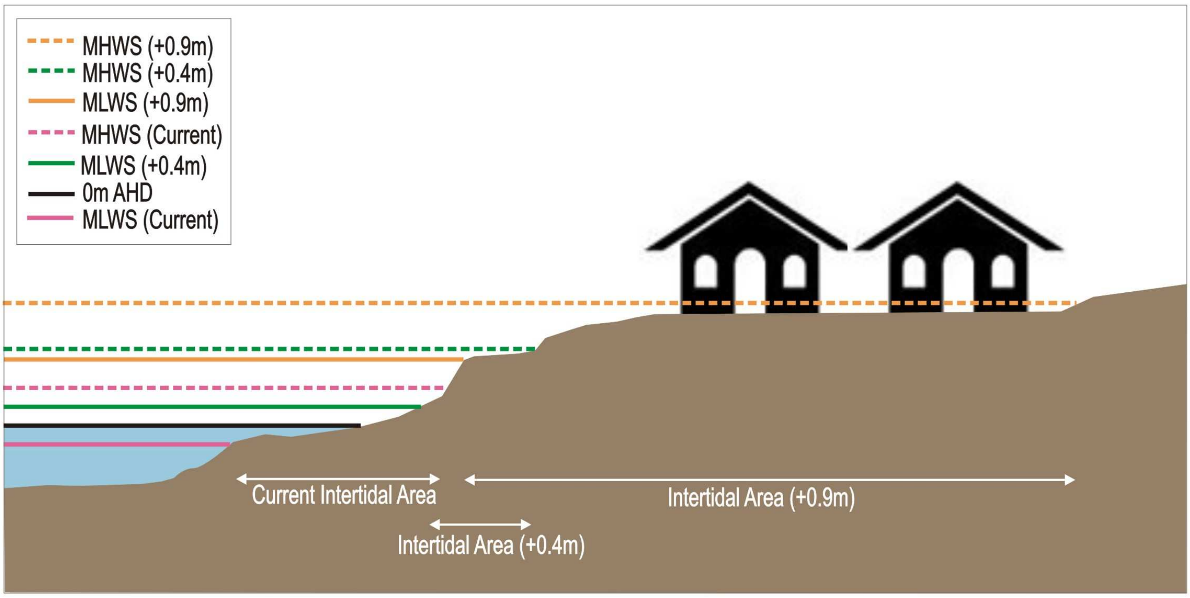
4 Discussion

The future intertidal zones described in **Section 2** give an indication of the regularly occurring tidal conditions for the estuary when subjected to changes under the projected sea level rise of 0.4m and 0.9m. The future intertidal zones mapped represent areas that may become available for the landward migration of intertidal vegetation. It is, however, important to note that there are a range of factors governing the distribution and condition of intertidal vegetation, and therefore the analysis provided herein is preliminary in nature. Further discussion is provided in **Section 5**.

4.1 Future Intertidal Zones

The mapping produced as part of this investigation gives an indication of the location and extent of the intertidal zone for SLR increases of 0.4 and 0.9 m. Where these future intertidal zones coincide with existing open space, migration of intertidal vegetation may be accommodated via either natural or facilitated (plantings) migration. Where existing development coincides with the future intertidal zone, migration would need to encroach over existing property boundaries, which may be difficult to achieve due to the presence of physical barriers. In instances such as these, more proactive conservation measures, such as land acquisitions or voluntary conservation agreements, may be considered.

In terms of trends in the data, **Table 3.2** shows that intertidal areas tend to decrease between 2010 and the 0.4m SLR scenario and then increase again to the 0.9m SLR scenario. This is due to the topography of the foreshore and adjacent areas. The results indicate that the foreshore is fairly steep up to the mean high water spring (high tide) with 0.4m of SLR and then flattens out beyond this level. This results in a constriction in the distance between the low and high tide when 0.4m of sea level rise is applied but then an expansion of this distance when 0.9m of sea level rise is applied. This is shown conceptually in the diagram below. As mentioned above, this assumes that existing foreshore structure (e.g. seawalls) and ground levels remain the same.



Based on the analysis, the critical adjustment for estuarine vegetation is for the lower SLR scenarios and management interventions would likely be required in the medium term to minimize the loss of saltmarsh and mangrove areas. Management interventions should primarily target the conservation of existing habitat (potentially at the expense of recreational uses). This would likely require a combination of engineering works (e.g. modification/retrofitting of seawalls or shoreline regrading), development controls (e.g. prohibiting filling in priority areas), facilitated migration (e.g. replanting or fencing priority areas off) and establishment of a seed bank. Similar techniques have been successfully applied as part of wetland rehabilitation works at the Sydney Olympic Park site. Over the medium to long term, land acquisitions may become the only option for preserving these habitats.

The spatial variation in the extent of the future intertidal zone also highlights the need to consider both local and estuary-wide context, particularly with reference to the potential for habitat fragmentation and biological connectivity.

4.2 Potential for Vertical Migration

Table 3.1 provides the present day areas of existing salt marsh, mangroves and SEPP 14 wetlands. It was considered inappropriate to extrapolate these results for future intertidal areas because of high levels of uncertainty relating to:

- The amount of sea level rise that will actually occur in the future;
- Changes in land use and human activities between 2010 and 2100; and
- The present day characteristics of the soils and land use that may affect the ability of biota to colonise the landward extensions under SLR and the interactions between these features and location-specific responses.

These uncertainties are briefly discussed below.

4.2.1 Sea Level Rise

The sea level rise values adopted in this study are derived from DECCW (2009); however, it will be important to monitor water levels in the future to observe the actual magnitude of change in estuarine water levels, particularly as the projected increases are significantly greater than the sea level rise observed over the past 20 years.

An option has been included in the *Estuary Management Study* to provide for ongoing monitoring of estuarine water levels into the future (Option R40), and this activity will be critical to identifying when adaptive management responses are required. Further consideration of suitable and appropriate trigger levels for action based on observed increases in mean estuarine water levels will be required.

4.2.2 Land Use and Human Activities

For the purposes of this assessment it has been assumed that there will be no change in the location and extent of developed areas in the future, and that there will not be any works that may modify the tidal prism on either a local or estuary-wide basis. However, given the long time frames being considered, land use changes are likely to occur. As such, the future intertidal zone for 0.4m SLR and 0.9m SLR may differ to that predicted in this preliminary assessment. The present day tidal range (MHWS - MLWS) at Gosford is about 50% of the nearby ocean tidal range.

4.2.3 Ecological Processes

Ecosystem dynamics represent a complex interplay of a range of biotic and abiotic factors. It was considered beyond the scope of this preliminary assessment to consider these processes in any detail; however, the potential for vertical migration and/or colonization of these future intertidal zones will be determined by these processes. The types of variables that influence this process include factors with high spatial heterogeneity such as existing assemblage structures, substrate type (soil type, etc), catchment hydrology, inter-species competition, herbivory and solar radiation/shading are likely to have a significant impact on the establishment of mangroves or salt marsh into new habitat areas. High rates of temporal variation in these and other environmental factors may also occur in relation to short term cycles (e.g. the lunar cycle), long term cycles (e.g. El Niño-Southern Oscillation), or irregular events (e.g. a storm event). As such, there will likely be some shift in the composition of intertidal vegetation communities in response to variation in these other environmental factors.

A trend of salt marsh loss to mangrove encroachment has become apparent along all east-coast bioregions of Australia (Saintilan *et al*., 2009). A number of hypotheses regarding the background processes referred to in Saintilan *et al.* (2009) include changes in rainfall patterns and nutrient and sediment interactions. It has been suggested that mangroves are more readily able to accommodate sea level rise and changes in bed elevation than saltmarshes, giving them a competitive advantage. The processes contributing to this inter-species competition are evidently complex.

There is a growing body of literature on the potential for intertidal zone elevation to keep pace with sea level rise due to a combination of sediment trapping and below-ground biological processes (Saintilan *et al.,* 2009; refer to **Plate 1**). This indicates the possibility that mangroves and saltmarshes may keep pace with rising sea levels in the future.

Alongi (2007) and Ellison (2008) have also discussed possible responses of the intertidal zone to rises in sea level. Ellison (2008) discusses variation in mangrove species distribution according to historical changes in sea levels. Fossil-based evidence and sedimentary records show historical mangrove species distribution below the lower limit of mangrove growth at current mean sea level, suggesting that mangroves have historically kept pace with rising sea levels.

Irrespective of these ecological processes, the presence of human constructs (e.g. infrastructure) and the ongoing use of the intertidal zone by humans will likely continue into the future, and therefore the pressures on intertidal ecosystems will probably intensify.

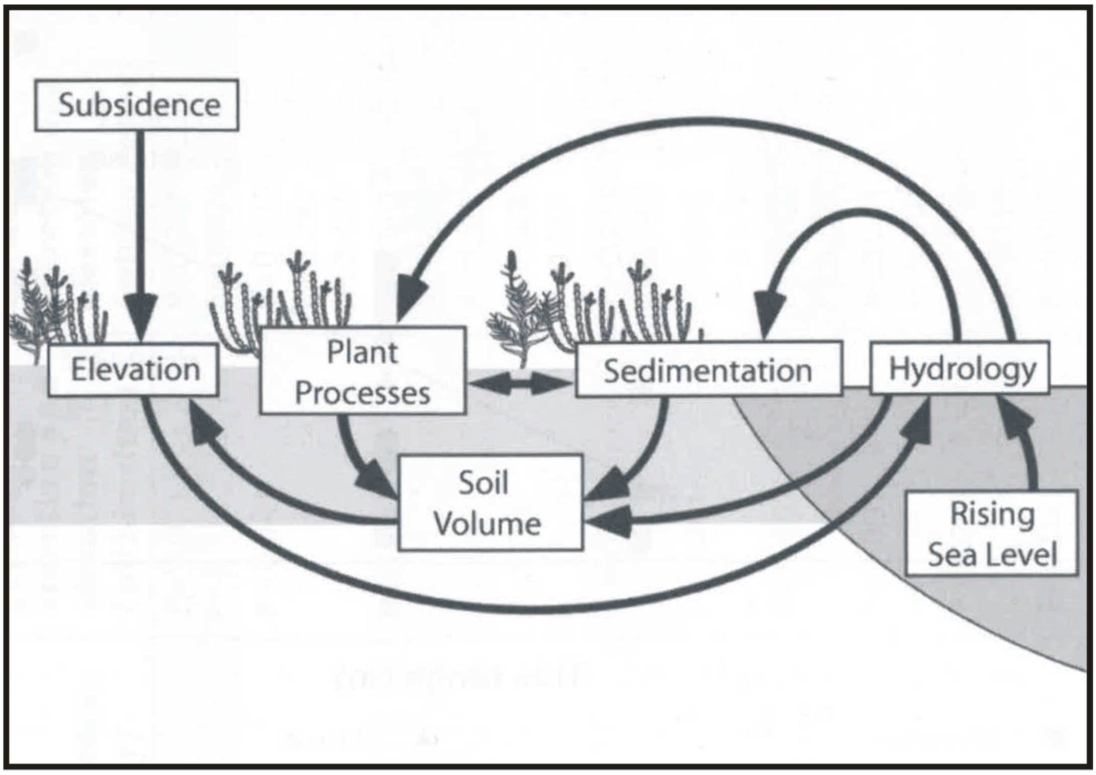


Plate 1: Processes influencing surface elevation of intertidal areas (Source: Saintilan *et al*., 2009)

Other potential impacts of climate change that have not been considered in this Discussion Paper include:

- Changes in shoreline geomorphology at higher estuarine water levels;
- Changes to the tidal prism due to increasing sea levels (and associated impacts on water quality);
- Increases in storm intensity and frequency (and therefore increased storm surge levels);
- Changes in seasonal rainfall patterns;
- Changes in water balance and baseflows;
- Increases in average and maximum air temperatures; and
- Increases in the frequency of drought.

These climate change impacts may also impact either directly or indirectly on ecological (and other) estuarine processes.

4.3 Management of the Intertidal Zone

Being the interface between the terrestrial and aquatic environments, and also subject to relatively high rates of use by the community, the intertidal zone represents a challenge for estuary management which is likely to become more pronounced with climate change and associated sea level rise. The unique nature and limited spatial availability for habitat within the intertidal zone means that the vulnerability of this ecosystem is likely to increase with sea level rise, particularly as the land available between aquatic and terrestrial habitats is further reduced due to the location and extent of human-based development and infrastructure.

4.3.1 Management of Intertidal Vegetation

Management of intertidal vegetation under sea level rise conditions presents a significant challenge. The following provides four possible management scenarios for the intertidal zone in the context of sea level rise:

- Allow natural migration of the intertidal zone into available open space areas;
- Facilitate migration of intertidal vegetation (via methods such as planting) to create an engineered intertidal zone that attempts to initiate the establishment of a relatively natural intertidal ecosystem habitat;
- Acquire privately owned land for incorporation into foreshore open space, thereby providing additional scope for migration (facilitated or otherwise); and/or
- Do nothing.

It is plausible that a combination of the first three management scenarios may be applicable dependent on the site specific constraints. Hence, management strategies would need to be considered on a location-by-location basis.

It is recommended that the *Brisbane Water Foreshore Floodplain Risk Management Study and Plan* should consider the requirement to provide intertidal estuarine habitat under climate change conditions.

4.3.2 Monitoring

Adaptive management interventions are reliant on the availability of data from which suitable triggers for action can be identified.

Monitoring sea levels over the long term is likely to be undertaken irrespective of intertidal zone management. Water level gauges operated and maintained by DECCW are located at several points around the estuary, and ongoing monitoring by these gauges will be important for identifying projected changes in tidal character in the estuary (refer to Option R40 in the Estuary Management Study prepared by Cardno, 2010).

It is noted that there currently does not exist a standard methodology for the analysis of historical changes in mean sea level and it is recommended that consultation be conducted with the relevant bodies (e.g. the National Tidal Centre) in relation to this matter.

Monitoring of estuarine vegetation is recommended to provide an appropriate means for gaining a detailed understanding of changes in species and habitat distribution and abundance. Monitoring is also likely to provide advice as to how, when and what to plant in order to facilitate successful vegetation migration. Partnership with government departments such as the NSW Department of Environment, Climate Change and Water and the NSW Department of Industry and Investment (Fisheries) may be appropriate for these monitoring activities (refer to Option R22 in the Estuary Management Study prepared by Cardno, 2010).

Periodic sample planting (e.g. every 5-10 years) may also be appropriate in monitoring the success and rate of vegetation establishment in newly created intertidal areas. Subsequent to such a program, the investigation and appropriate management of any monitored changes in the local extent of estuarine vegetation and habitats could be undertaken. Changes in mangrove distribution could be reflective of wider ecological impacts that could also have consequences for the integrity of other estuarine habitats.

5 Conclusion

The delineated intertidal zones produced as part of this investigation give an indication of the location and extent of the intertidal zone for the present day and potential future sea level rise scenarios of 0.4m and 0.9m (after DECCW, 2009). Patterns of change in the intertidal zone are, however, not easily predicted over long time scales due to a range of uncertainties (amount of sea level rise, land use change and human activities, and abiotic and biotic features) affecting the size and location of the intertidal zone.

Possible management options for the ongoing conservation of intertidal estuarine vegetation under sea level rise scenarios include:

- Allow natural migration of the intertidal zone into available open space areas;
- Facilitate migration of intertidal vegetation (via methods such as planting) to create an engineered intertidal zone that attempts to initiate the establishment of a relatively natural intertidal ecosystem habitat;
- Acquire privately owned land for incorporation into foreshore open space, thereby providing additional scope for migration (facilitated or otherwise); and/or
- Do nothing, whether migration occurs or not.

A combination of the first three management options may be applicable depending location specific features.

The *Estuary Management Study* (Cardno, 2010) includes Option P16, which relates to the identification of saltmarsh areas for acquisition by Council under policy *R0.15 – Acquisition of Wetlands*. Reference should be made to this Discussion Paper and the associated mapping of future intertidal zones when considering lands for acquisition.

A number of assumptions have been made in this investigation. These include:

- The available input data has been assumed to be accurate, including but not limited to ALS data and hydrosurvey;
- Sea level rise scenarios were based on the NSW Government's *Sea Level Rise Policy Statement* (DECCW, 2009); and
- Intertidal zone areas delineated for 0.4m SLR and 0.9m SLR have been based on existing land use conditions and no allowance for changes in land use or human intervention (e.g. increasing sea wall to inhibit inundation) has been incorporated.

6 References

Bindoff, N. L. and J. Willebrand (2007). *Observations: Oceanic Climate Change and Sea Level.* pp. 385-432.

Cardno (2010). *Brisbane Water Estuary Management Study.* Prepared for Gosford City Council.

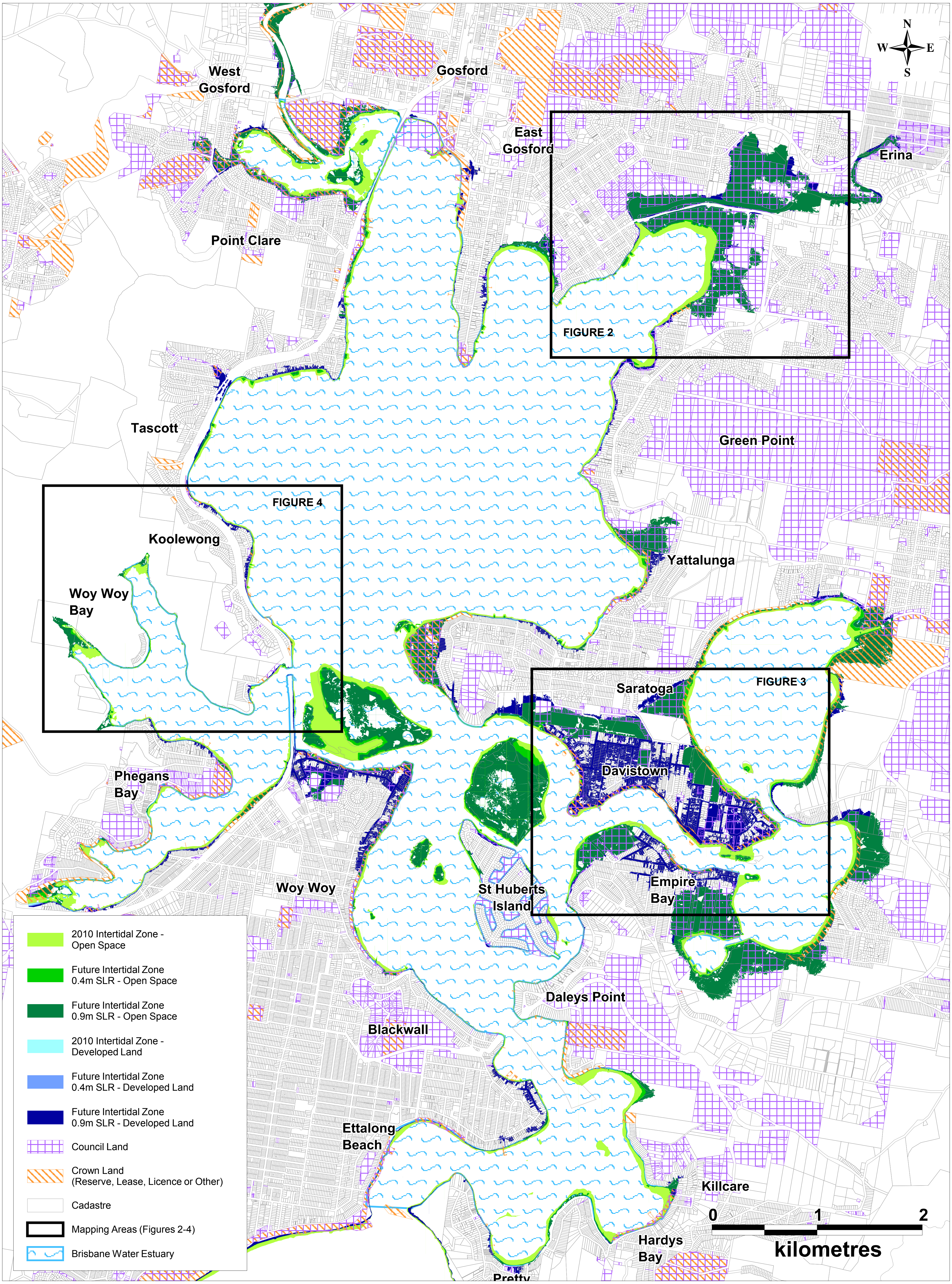
DECCW (2009). *NSW Sea Level Rise Policy Statement.* NSW Department of Environment, Climate Change and Water.

MHL (2004). *Report 1319.* Manly Hydraulics Laboratory. NSW Department of Commerce.

Saintilan, N., Rogers, K. and Howe, A. (2009). *Geomorpholgy and Habitat Dynamics*. In Neil Saintilan (Ed.) *Australian Saltmarsh Ecology*. CSIRO Publishing.

Sainty, G. R. and D. E. Roberts (2007). *Ecological Assessment of the Shoreline Around the Brisbane Water Estuary*. Prepared by Sainty and Associates and Bio-Analysis Pty Ltd, pp. 5.

van Senden, D. C., (2005). *Tsunami to Sea Level Rise - Implications for Coastal Impacts*. Presentation to the NSW Coastal Conference, Narooma, Nov, 2005



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Brisbane Water Estuary
SLR and the Estuarine Intertidal Zone

FIGURE 1:
2010 AND FUTURE INTERTIDAL ZONES

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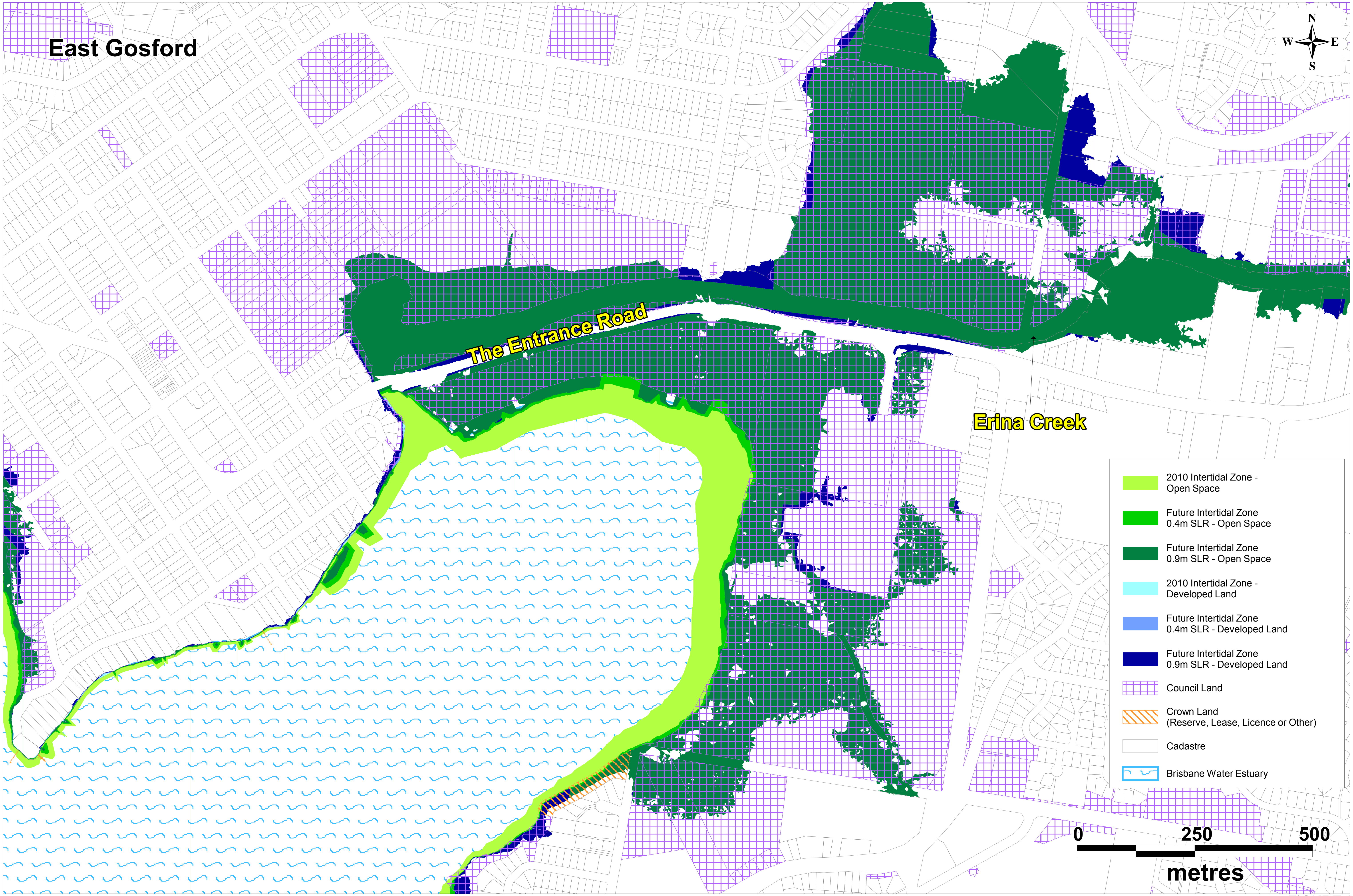

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Brisbane Water Estuary
SLR and the Estuarine Intertidal Zone

FIGURE 2
2010 AND FUTURE INTERTIDAL ZONE
EAST GOSFORD AND ERINA

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Brisbane Water Estuary
SLR and the Estuarine Intertidal Zone

FIGURE 3
2010 AND FUTURE INTERTIDAL ZONE
DAVISTOWN AND EMPIRE BAY

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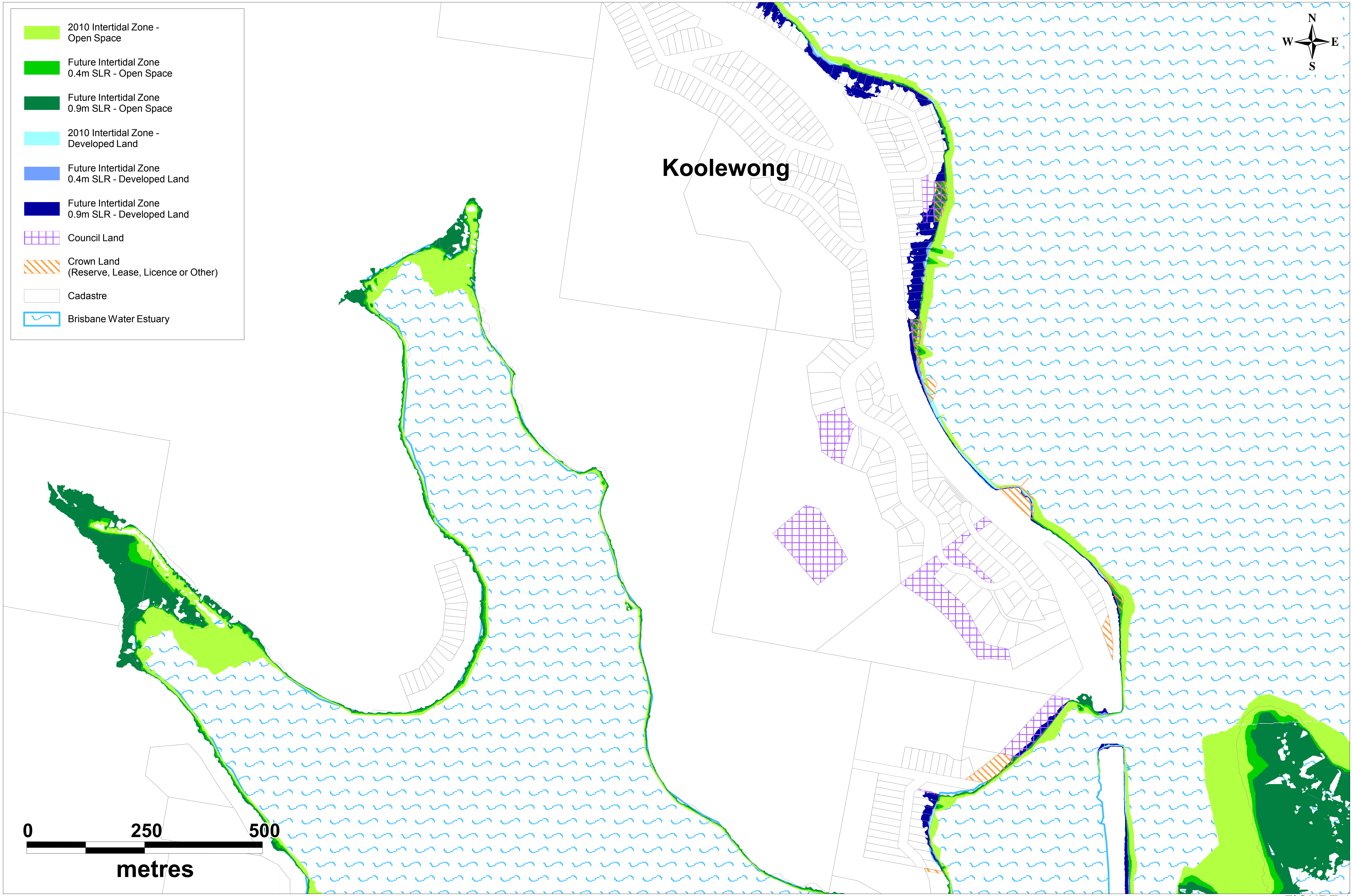

Cardno Lawson Treloar
LJ2717
October 2010

Brisbane Water Estuary
SLR and the Estuarine Intertidal Zone

FIGURE 4
2010 AND FUTURE INTERTIDAL ZONE
KOOLEWONG AND WOY WOY BAY

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