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Source: Journal of Coastal Research, 75(sp1) : 987-991

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/SI75-198.1

Journal of Coastal Research	SI	75	987 - 991	Coconut Creek, Florida	2016

Regional Scale Coastal Mapping to Underpin Strategic Land Use Planning in Southeast Australia

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ABSTRACT

Hanslow D.J.; Dela-Cruz J.; Morris B.D.; Kinsela M.A.; Foulsham E.; Linklater M., and Pritchard T.R., 2016. Regional scale coastal mapping to underpin strategic land use planning in southeast Australia. *In:* Vila-Concejo, A.; Bruce, E.; Kennedy, D.M., and McCarroll, R.J. (eds.), *Proceedings of the 14th International Coastal Symposium* (Sydney, Australia). *Journal of Coastal Research*, Special Issue, No. 75, pp. 987-991. Coconut Creek (Florida), ISSN 0749-0208.

In the current study we develop spatial data to inform strategic land use and coastal planning which considers coastal hazards and the protection, maintenance and in some cases, restoration of our waterways. The benefits of sustainable coastal development underpinned by a well-established understanding of coastal processes and our ability to avoid negative impacts from inappropriate placement of development are well understood. With climate change and increasing use of coastal systems there is increasing need to identify and manage both current and possible future risk exposure. Mapping is undertaken to allow upfront identification of risks and benefits associated with potential future land use as well fundamental data to help inform coastal assessments. This will help ensure impacts on the coastal environment are minimised and impacts on proposed development from coastal hazards are avoided. The study has several parallel components addressing estuarine water quality and ecosystem health, sea level rise inundation, coastal erosion and sediment/geomorphic setting. Additional benefits of the project include risk based assessment to enable prioritisation of effort to address existing development which is either exposed to coastal hazards or having an impact on coastal waterways.

ADDITIONAL INDEX WORDS: *Coastal management, ecologically sustainable development, coastal hazards, coastal risk.*

INTRODUCTION

The benefits of sustainable development of the coast based on a sound understanding of coastal processes and avoidance of negative impacts from inappropriate placement of development are well understood. These benefits are likely to grow significantly over time with climate change and increasing use of coastal systems. Presently, considerable development in South East Australia is exposed to coastal hazards, while impacts from previous poorly considered development have included habitat degradation, declining water quality, resource depletion, and loss of coastal amenity.

Coastal development in New South Wales is subject to various controls through both coastal and estuarine planning and local and regional land use planning. The planning framework operates at different spatial scales and has been in place for some time through both coastal management legislative provisions (Coastal Protection Act, 1979) and environmental legislation (Environment Environmental Planning and Assessment Act, 1979). Under its coastal zone management program, the Office of Environment and Heritage (OEH) aims to reduce the impact of coastal hazards and maintain the ecological health of estuaries. The program has a long history of state and local government working collaboratively on coastal zone management. Much of this work is incorporated into coastal zone management plans (CZMPs), which are a requirement of the Coastal Protection Act 1979.

CZMPs can address risks from coastal hazards, threats to estuary health, and projected impacts of climate change such as sea level rise and risks of coastal erosion. The CZMPs are developed for local scale application, typically individual estuaries or beaches. They have been instrumental in providing detailed assessments of coastal and estuarine processes. However, not all estuaries and beaches have a CZMP to date, and there is limited ability to upscale existing assessments for use in strategic state-wide or regional planning and decision making due to inconsistencies in approach. There is a current pressing need for state-wide or regional assessments to help manage the regional growth that will occur over the next 20 years. Most of this growth is projected for the Greater Metropolitan Region, with continued demand for development along the coast placing increasing pressure on estuaries and coastal catchments.

The need for mapping at different spatial scales to inform national, regional and local risk assessment and management has been recognised previously both in the US and Australia (Titus and Richmond, 2001; Sharples *et al.*, 2008).

DOI: 10.2112/SI75-198.1 received received 15 October 2015 accepted in revision 15 January 2016.
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In this study, we fill the information gap by undertaking regional mapping of coastal erosion and inundation hazard and threats to estuary health. Results are presented for a case study location at Lake Illawarra on the south coast of NSW. For coastal erosion we developed a probabilistic approach that considers both short and long term sediment transport processes including storms, sediment supply and loss and response to sea level rise. For inundation we addressed differences in tidal processes between individual estuarine systems as well as along coast variability in tides and the longer term implications of sea level rise. For estuarine health we developed an effects based assessment, consisting of a coupled series of catchment, hydrodynamic and ecological response models, to predict the likely impact of coastal developments on the ecological condition of estuaries. Our overall objective was to provide maps that allow upfront identification of risks and benefits associated with planned future coastal development.

Regional Setting

The New South Wales (NSW) coastline stretches for over 1590 km (Figure 1) and has more than 750 sandy beaches (Short, 2007) and more than 184 significant estuaries (Roper *et al.*, 2011). Over 85% of the population live within 50 kilometres of the coast (ABS, 2004) which is known to be highly vulnerable to both erosion and inundation (DCC, 2009; Cechet *et al.*, 2012) and subject to various land use pressures which impact ecological health.

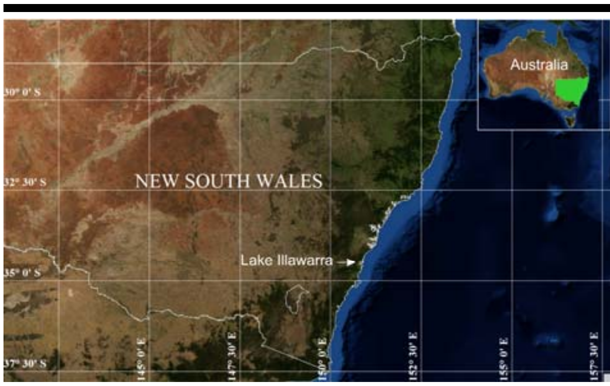

Figure 1. The NSW coast and case study location at Lake Illawarra.

The coast is aligned to the predominant south east swell and experiences a moderate to high energy wave regime (Shand *et al.*, 2011). Tides are microtidal and semi-diurnal with a pronounced diurnal inequality. The mean spring range is 1.2 m while the mean neap range is 0.8 m (AHS, 2011; MHL, 2012). Tidal range varies slightly along the coast with an increase of around 0.2 m from south to north (MHL, 2011).

The shoreline is comprised of areas of rocky cliffs and headlands joined by sandy beaches. On the south coast, the beaches are predominantly pocket beaches isolated by rocky headlands with little alongshore sand exchange from compartment to compartment. In the north of the state, these beaches tend to be longer and alongshore rates of sand movement are higher with sand moving from compartment of compartment, predominantly from south to north. Beaches are typically backed by high dunes which provide some protection against storm surge and wave runup.

Estuaries vary in shape and function along the NSW coast (Roper *et al.*, 2011) and have been classified by several authors using a variety of approaches (*e.g.* Roy, 1984; Roy *et al.*, 2001 and NSW Gov., 1992). These include drowned river valleys, tidal rivers, tidal lakes, intermittently open and closed lakes (ICOLLs) and lagoons and ocean embayments.

METHODS

Three types of maps were produced for all significant estuaries and beaches in NSW using the methods described below: i) maps showing the risk of coastal development on the ecological condition of estuaries under current and future regional growth scenarios, ii) maps showing the extent of inundation for 3 sea level rise scenarios of 0.5, 1 and 1.5 m, and iii) maps showing the potential extent of coastline change in the immediate and potential future coastal erosion and recession scenarios.

Estuary health (ecological condition)

Effects based assessment (EBA) focusses on the effect of management, that is, what we are trying to achieve (Scanes *et al.*, 2014). EBA is usually applied at the local scale but for this study, we adapted the assessment to produce maps at the subcatchment scale. The maps identify subcatchments upland of the estuary, where development controls would have the most benefit for protecting ecological condition. Typically, these are equivalent to areas that pose the highest risk of impact on ecological condition. The maps integrate the outcomes of sub-catchment scale surface runoff models that predict the quality and volume of runoff from land use (including new developments), and the outcomes of hydrodynamic and empirical ecological response models that predict the transport, retention and impact of the runoff within the major tributaries, reaches and basins of estuaries. Our EBA approach differs from current practice, which focusses solely on source control irrespective of the sensitivity of the receiving environment and/or the impacts on ecological condition.

The model outcomes were integrated using the ISO 31000 risk analysis approach, and included additional information on environmental assets that may be affected by the development and/or other processes not captured in the models. These included, for instance, the presence of ecologically endangered communities, acid sulfate soils, and proximity of the development to the estuary. We constrained the risk analysis to three risk levels corresponding to greater potential for impact on ecological condition. The risk levels can be matched with different types and levels of development and/or in intensity of water sensitive urban design to alleviate impact from both current and potential future development.

Inundation

To incorporate tidal and ocean inundation, we mapped estuarine inundation at the High High Water Solstice Springs (HHWSS) level. We used a mid-level approach to the modelling and mapping of water levels as outlined in Foulsham *et al.*, (2012) and Morris *et al.*, (2013). The approach is based on measured tidal plane data or berm heights for intermittently closed and open lakes and lagoons (ICOLL's). The method allows for variation in tidal levels both between and along estuaries and thus improves on simple bathtub type approaches used in previous assessments (e.g. DCC, 2009; Cechet *et al.*, 2012).

For gauged estuaries we used tide gauge data from MHL (2012) to create interpolated tidal planes. These data are also used to categorise NSW estuary planes and identify characteristic tidal plane types for application to non-gauged estuaries. Within ICOLL's we adopt berm height to approximate inundation extent. The berm height was based on measured data or a formulation ($BH = 3.92*D_{50} + 1.12$) derived from Hanslow *et al.,* (2000) where no data were available.

Tidal planes were overlain on 1m resolution digital elevation models derived from high resolution LiDAR data. The liDAR data have a vertical accuracy of 0.3 m (95% CI). The resulting spatial model of inundation, greatly improves the representation of current inundation hazard areas and allows for improved assessment of the inundation hazard associated with potential sea level rise.

The impacts associated with sea level rise scenarios of 0.5 m, 1.0 m and 1.5 m were mapped and inundation extents were used to quantify risk, based on data from the geo-coded urban and rural addressing system database. The 0.5 m water level offset also allowed a first order estimation of effects of storm surge and other non-tidal processes (excluding wave setup and runup effects).

Erosion

We developed a volumetric coastal response model applied within a Monte Carlo statistical approach to map forecasts of immediate and potential future coastal erosion and recession (Kinsela *et al.*, 2016). The modelling builds on the approaches of Cowell *et al.*, (2006); Woodroffe *et al.*, (2012); and Mariani *et al.*, (2013). A probabilistic approach was adopted to help overcome uncertainty in historical measurements, understanding of coastal processes, potential future changes to environmental forcing, and our capacity to predict coastal responses. The method uses repeated random sampling of inputs to generate a probability distribution of model predictions based on the combined uncertainty spaces of the model inputs. In this application, the coastal response model is run repeatedly for each scenario, with model inputs chosen at random from their respective probability density functions (pdfs). Model inputs include variables such as sea level rise, and parameters of the coastal response model that is used to predict the potential extent of coastal erosion.

Model inputs include pdfs for short term storm response, sediment budget considerations including longshore transport, and predicted coastal response to sea level rise calculated from the sampled values of: sea level rise, shoreface closure depth and the surface area of connected and estuarine flood-tide deltas. The sea level rise and profile closure depth determine the theoretical shoreface sediment-accommodation volume generated by sea level rise. The shoreface accommodation volume can be scaled to account for the extent of shoreface reefs or other hard substrate, where present, which occupy volume in the water column above the shoreface and thereby reduce the theoretical accommodation volume. The scaled shoreface accommodation volume is then applied to the LiDAR beach-dune profiles to determine the coastline recession in response to sea level rise.

To parameterise the geomorphology and sediment budget of each sediment-sharing system along the NSW coast, a hierarchy of sediment cells were identified and mapped. These sediment cells reside within the secondary sediment compartments mapped by Geosciences Australia (McPherson *et al.*, 2015). They include primary, secondary and tertiary cells which define the boundaries of sediment-sharing systems at short to intermediate timescales.

The three levels of sediment cells allow for different sediment budget components to be defined along the coastline at spatial and temporal scales that are consistent with the scale of variation in the sediment transport processes that drive exchanges between sources and sinks. For example, sediment budget components that vary over short space and time scales (*e.g.* storm-induced beach erosion) can be defined at the tertiary cell resolution, whereas components that vary over longer timescales might be defined at the secondary or primary cell resolutions. The sediment cells framework supports further development of the coastal erosion hazard mapping approach described here, which may extend to higher resolution modelling and mapping based on a more refined parameterisation of coastal sediment budgets, and the inclusion of additional sediment budget components.

The sediment cells also provide a means to derive a regional shoreface bathymetry profile for each beach. Specifically, the average distance from sandy shorelines to the offshore depth limit of each primary (40 m), secondary (20 m) and tertiary (10m) cell was calculated, along with the average distance to the 30 m depth contour. An idealised shoreface bathymetry profile was then generated for each beach using the average distances to the 10, 20, 30 and 40 m depth contours, and the profiles were then used to calculate the theoretical shoreface sediment-accommodation volume generated by sea level rise. The resolution of the idealised shoreface profiles derived using that procedure is consistent with the regional-scale mapping approach.

RESULTS

The results described here are for Lake Illawarra, located ~100 km south of the Sydney Metropolitan Area (Figure1). We chose Lake Illawarra as a case study because of the large area of urban development in the west of the catchment (Figure 2), which will take place in the next 20 years to accommodate regional growth (Department of Planning and Environment, 2015).

Estuary health

Figure 2 shows the outcomes of the EBA under the future regional growth scenarios. The three colours on the map correspond to the three risk levels in the risk analysis. Developments in subcatchments that have been coloured red pose the greatest risk of impact on the ecological condition of the lake. These subcatchments are where management, such as water sensitive urban design or integrated water cycle management, will be of most benefit for protecting the ecological condition of the lake. Management in subcatchments coloured in yellow will have the next best benefit, and management in subcatchments in blue the least benefit because they pose the lowest risk of impact on ecological condition.

Inundation

Figure 3 shows the inundation map for Lake Illawarra. The varying shades of blue denote varying inundation levels corresponding to the existing surface area of the estuary (lightest blue) and the three sea level rise scenarios 0.5, 1.0 and 1.5 m (darkest blue). The map shows low lying areas such as the lake foreshores and major tributary inflows are the most vulnerable to future inundation.

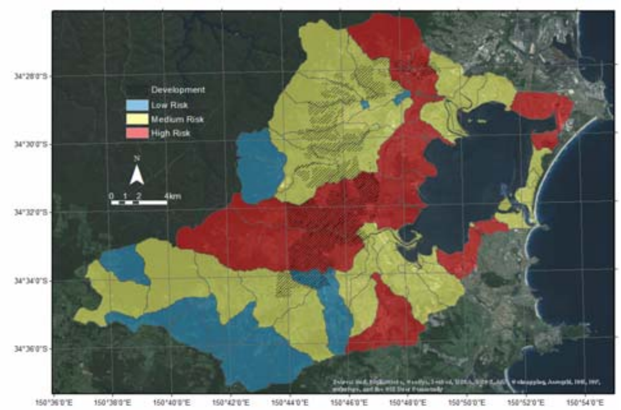

Figure 2. Estuary risk map for Illawarra showing low (blue), medium (yellow) and high (red) risk of impact of developments on estuary health.

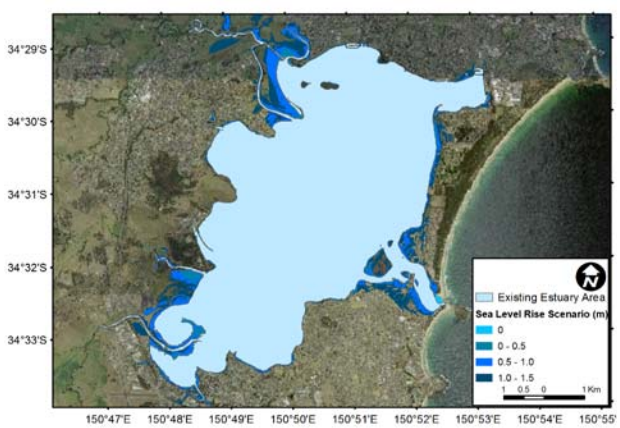

Figure 3. Inundation for different sea level rise scenarios around Lake Illawarra.

Erosion

For erosion the probabilistic modelling provides for the mapping of predicted coastal erosion and recession hazards at chosen confidence levels for each forecast period.

Figure 4 shows map output for a 50 year forecast of coastal change at Windang Beach, north of the entrance to Lake Illawarra. The blue hazard zone blue zone includes the erosion hazard zone mapped up to the 0.1% exceedance level. The red and green lines have a 50% and 1% chance of exceedance respectively, thus capturing the likely maximum reach of coastal erosion and recession over the next 50 years. The green line indicates a position consistent with 99% confidence that the coastline will not reach landward beyond that point.

DISCUSSION

In this study we developed maps showing the risks from subcatchment inflows, inundation and coastal erosion, which will allow upfront consideration in regional planning to enable impacts on the coastal environment to be minimised and potential

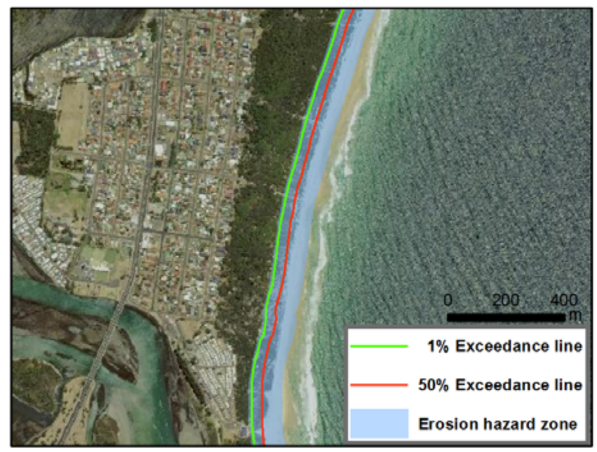

Figure 4. 50-year forecast of coastline change at Windang Beach. The blue zone includes the erosion hazard zone mapped up to the 0.1% exceedance level. The red and green lines have a 50% and 1% chance of exceedance respectively.

future impacts on new development from coastal hazards to be avoided. Some potential uses of the mapping for management of ecological health include the provision of spatial information to inform:

- strategic planning including information to help inform where developments are better placed. For example, blue and/or yellow subcatchments could be favoured over red subcatchments to reduce the potential impacts on estuary health.
- guidance in strategic impact assessments as part of preparations for Neighbourhood Plans. For example, knowledge of the required level of stormwater controls for a subcatchment can assist discussions between developers on optimal locations for the controls, and potentially reduce the number of future assets that Council will need to maintain.
- investigation of offset options in situations where management targets cannot be met at the site of development. The yellow areas within the same tributary as the site of development are potential offset sites. These are especially useful in situations where runoff from upstream land use activities impact on the effectiveness of stormwater controls at the development site.
- directions for setting management targets and options. For example, developments in red areas could be used to help improve the condition of the estuary through stringent

controls, whereas developments in yellow or blue areas could simply apply minimum controls such as used currently.

For inundation and erosion the mapping provides information to help decide where developments are better placed so as to avoid future impacts from coastal hazards. The mapping also provides information to inform risk scoping to identify the need for detailed risk assessment and need for detailed adaptation planning.

CONCLUSIONS

The maps are intended to guide strategic decision making at the regional level and to provide risk information to enable prioritisation of more detailed risk assessment. The mapping may form a default planning layer where risk is low or be refined though more detailed local process modelling and investigation.

ACKNOWLEDGMENTS

Part funding for the inundation mapping undertaken for this study was provided by the NSW Government Natural Disasters Resilience Program. Part funding for the erosion model development was provided through the NSW Environment Trust. Water level data was kindly provided by Manly Hydraulics Laboratory. Terrain data was provided by NSW Land and Property Information.

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