CONSIDERING TIDAL MODIFICATION WHEN MAPPING INUNDATION HAZARD IN NSW ESTUARIES

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Abstract

Tidal levels in estuaries vary depending on estuary type, with some systems showing tidal amplification while others display significant attenuation compared with ocean tidal levels. This paper presents a method to incorporate varying tidal planes in coastal inundation mapping and sea level rise assessments. The method provides a more robust basis for quantitative analysis of the spatial distribution of potential estuarine inundation for use in hazard mitigation, risk assessment and coastal and catchment planning. This is achieved by improving the reliability and resolution of predicted water levels relative to simplistic bathtub models.

The method uses an interpolated tidal plane created from gauge data and known tidal limits and is applied in conjunction with the best available elevation data. The resulting spatial model of inundation greatly improves the accuracy of present inundation hazard areas and allows for improved assessments of inundation hazard associated with potential sea level rise.

High accuracy mapping of potential inundation areas requires the best available elevation data. A nested hierarchical model for collating digital elevation data has been designed to enable the swift and accurate extraction of data for NSW estuaries. The design maximises the accuracy of inundation analyses by making readily available the most recent data of the highest resolution, particularly LIDAR data.

The paper will examine a test case for the methodology, which will be applied state-wide in the future. Further research will look to extrapolate characteristic tidal modification patterns, assessed by estuary type, from systems with known tidal levels to those where no gauge data exists.

Introduction

Communities along the NSW coast are considered to be highly vulnerable to climate change with potential impacts related to both inundation and erosion associated with sea level rise and possible changes to storm intensity and frequency (DECCW 2010). Of these effects inundation due to sea level rise is likely to have the most significant impact, with the recent National Coastal Risk Assessment (DCC, 2009) identifying NSW as having the highest exposure of any Australian state to the combined effects of sea level rise and storm tide. Estuarine areas are considered to be at particular risk primarily because of the number of properties in relatively close proximity to current high tide levels.

Approaches to assessing risk associated with sea level rise vary from the simple bathtub-type approach, in which areas at risk from inundation are simply determined by adding sea level rise scenarios to offshore tide levels and overlaying the resulting surface on existing topography, to detailed coupled hydrodynamic models of tidal propagation within estuaries and morphodynamic models of future estuary response (i.e. erosion and deposition). As with any risk related issue the approach and complexity of assessment will vary depending of the level of current risk and likely future need.

Here we present an intermediate-level method for water surface and inundation mapping based on existing estuarine water levels. Novel aspects of this approach include a nested hierarchy model that maximises the accuracy and resolution of the output digital elevation data, and the consideration of spatially varying estuarine tidal ranges in inundation mapping through the derivation of a tidal plane surface. The method is capable of more accurately representing current estuary water levels and can be adapted to incorporate changes to tidal ranges under future sea level rise scenarios where these are known.

Tides and water levels in NSW estuaries

Tides along the NSW coast are semi diurnal with a significant diurnal inequality. The mean spring range is 1.2m while the mean neap range is 0.8m (AHO, 2011). Highest astronomical tide at Fort Denison is 2.1 m above lowest astronomical tide. Tide range varies along the coast with an increase of around 0.2 m from south to north (MHL, 2011).

Variations in water level due to non-astronomic factors are relatively common along the NSW coast and are associated with several different oceanographic and meteorological processes. For example, MHL (1992) demonstrates that anomalies of 0.3 m occur at return intervals of months, and thus become a significant addition to tidal predictions. Causes of tidal anomalies include variations in air pressure and wind stress (storm surge); coastal trapped waves; ocean currents, steric effects; seiches; tsunamis; rossby waves etc. These processes operate over a wide range of timescales (MHL, 2011).

Water levels in estuaries vary from those seen offshore due to the effects of changing water depth and channel geometry (Druery et al., 1983). Water levels vary depending on estuary type (e.g. Roy *et al.*, 2001), with some systems showing tidal amplification while others display significant attenuation compared with ocean tidal levels (Fig. 1).

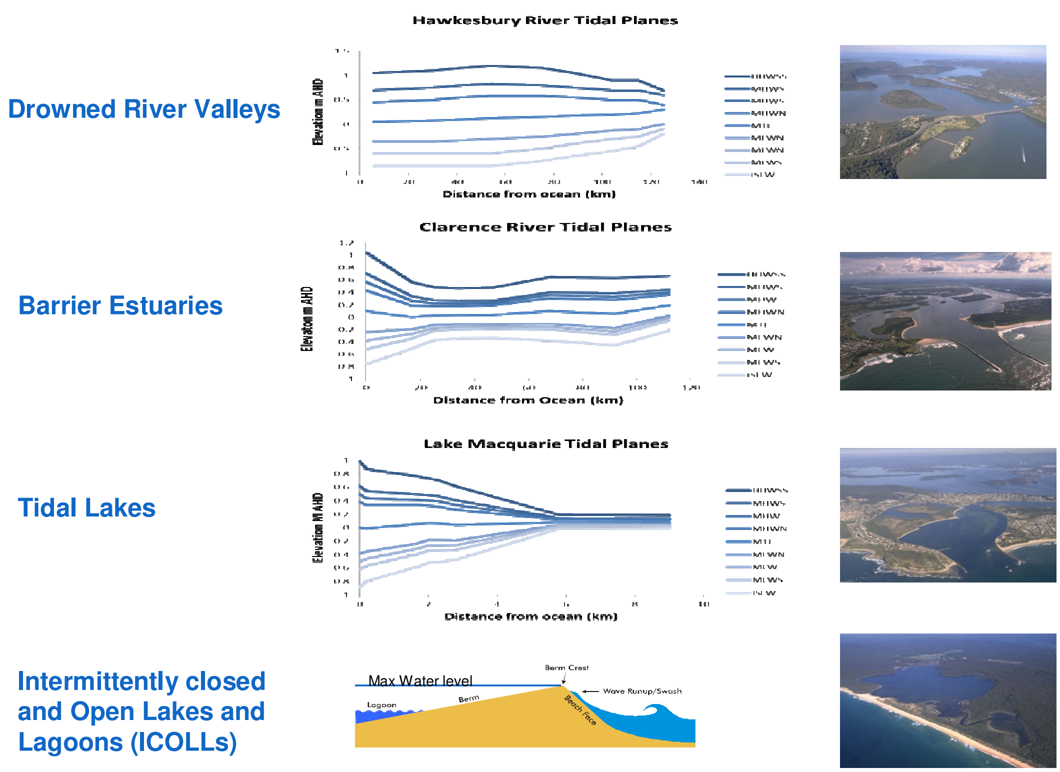

Figure 1. Variation in tidal planes within different estuary types in NSW

In drowned river-valley estuaries amplification of the tide range is observed for many kilometres inland. This results from the landward narrowing of the channel which promotes tidal amplification. Furthermore as the channel shallows, tidal resonance also contributes to maintain a high tidal range. In such estuaries, the tidal range is only attenuated in the upper reaches where the cumulative dissipative effects of bed friction dampen tidal flows (NSW Government, 1992).

In barrier estuaries an initial reduction in tide range is common due to frictional dissipation in cases where a significant marine delta complex exists. This is typically followed by mild amplification in the mid reaches of the estuary before complete damping at fluvial gravel and sand bars around the head of the estuary.

Tidal lakes usually display severe attenuation of tidal range due to frictional effects in the entrance channel. Tide ranges reduce rapidly and may be as little as 10% of the offshore tide range. In these systems tidal pumping can be significant amplifying the magnitude of the fortnightly tide.

Water levels in coastal lake systems which are subject to intermittent closure vary depending on opening and closing regimes. Whilst open they operate like tidal lakes, while closed they gradually fill with water levels influenced by inflows and evaporation. Maximum water levels are generally controlled by beach berm height (Hanslow et al., 2000).

Water surface creation and mapping

As an intermediate-level approach this method aims to improve upon simple bathtub-type approaches for mapping inundation and sea level rise in estuaries where there is sufficient water level and terrain data. Inherent in the approach is the creation of an estuary-specific digital elevation model (DEM) using the most recent high-resolution digital elevation data. A nested hierarchy model was designed to collate elevation data for the broad-scale application of this method across NSW estuaries.

A thematic depiction of the model is shown in Figure 2. The model consists of a nested series of spatial analysis functions, which are ordered to reflect the hierarchy of the elevation data, prioritising current and higher resolution data to be extracted first, and superseding any data that is older or of lower resolution. It is run within ArcGIS through the ArcToolbox (ESRI, 2012).

The nested hierarchical system ensures that there is no data overlap, that the best available data is used, and that the model is easily updated when superior data (particularly LIDAR) become available, without the need to redesign the data extraction process.

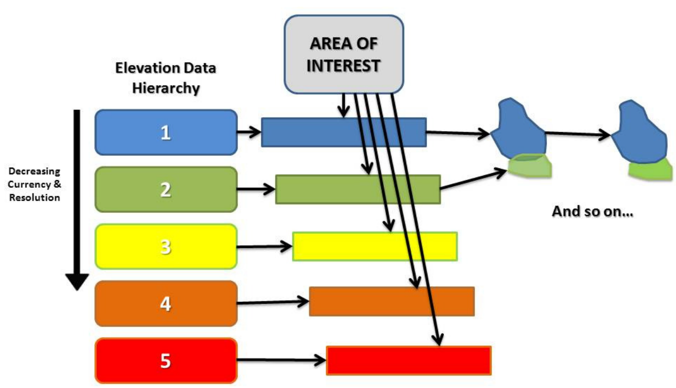

Figure 2. A thematic representation of the nested hierarchy model for digital elevation data in NSW

To apply the model an area of interest (AOI) must be defined to constrain the estuarine area being assessed. The AOI is determined using three major spatial parameters; (1) the estuary's extent, (2) its catchment area and (3) a broadscale 10 m contour. The parameters provide a sensible area for analysis and inundation mapping and are currently available or able to be determined at the state-wide scale. The AOI is defined by the spatial overlap of the estuary's extent, buffered initially by 200 m, and including all adjacent areas below the 10 m contour that are within the catchment area.

In practice, the model divides the AOI extent for a given estuary into discrete spatial parcels that define the best available data within each parcel. Within each parcel, elevation data is extracted from the raster data sources and is collated into a digital elevation surface within a three-dimensional environment (IVS3D, 2012). The resulting surface incorporates the nested hierarchy of elevation data whilst maintaining the highest resolution for any area across the AOI.

State-wide data to delineate AOI for Estuaries

To enable the state-wide application of this approach, the three primary data sources used in the delineation of the AOI have to be analysed. The Land and Property Information (LPI) 25 m regional mosaic DEM was used to extract all areas in NSW coastal catchments with elevations less than or equal to 10 m. An area of coverage was created for state-wide AOI delineation.

The spatial extent of estuaries and their catchments is defined by the NSW Office of Environment and Heritage corporate geodatabase estuary spatial data layer. Each estuary is extracted by name, and then buffered by 200 m horizontally using the ArcToolbox Proximity Buffer tool (ESRI, 2012). Adjacent areas with elevation less than or equal to 10 m are merged with the estuary buffer and then spatially restricted within the boundaries of the estuary catchment area.

Creating a tidal plane layer – water surface modelling

Tidal data and tidal harmonic analysis results for 187 gauges in 53 NSW estuaries were provided by Manly Hydraulics Laboratory (MHL, 2012). From this dataset, tidal characteristics such as Mean Sea Level (MSL), High High Water Spring Solstice (HHWSS) and Indian Spring Low Water (ISLW) were extracted along with positional data for each gauge location.

This tidal water level information from the gauge data forms the basis of the water surface modelling, supplemented by tidal water levels at the seaward and landward extremes of each estuary (although as an alternative, a statistical or extreme value approach could be used for water surface delineation). For NSW estuaries that do not have an oceanic tidal gauge at their mouth, or in close proximity, oceanic tidal water levels are derived from the OTIS (OSU Tidal Inversion Software) model (Egbert *et al.,* 1994). The results from this model show good agreement when compared to tidal characteristics derived from the NSW oceanic tidal gauge network. Known tidal limit locations are sourced from tidal limit points and the landward extents of estuarine extent polygons (DNR 2006, OEH Corporate Spatial DB, 2012).

Using this collated tidal gauge and extremity data a maximum tidal plane level is estimated for an estuary using spatial interpolation between the locations with known levels. The model utilises a minimum curvature spline technique, a method of interpolation that produces a smooth surface with the minimum curvature and is equivalent at the input data points (ESRI, 2012b), with consideration for estuary boundaries. The tidal plane level is a spatial representation of the water surface given tidal influence in an estuary. The tidal plane representation takes into consideration the elevation of the estuary system. Further development will occur to enable seamless integration of the tidal plane surface into a 3-dimensional environment, using Fledermaus (IVS3D, 2012), with the estuaries digital elevation model.

Ongoing development of the methodology will include:

- The state-wide application of general tidal plane/estuary type scenarios for estuaries across NSW.
- The development of techniques to produce inundation spatial extent given a variety of sea level rise scenarios.
- Quantitative analyses of the differences between bath-tub and tidal plane inundation approximations.

Application of the Model to the Hunter River Estuary

The Hunter River Estuary in NSW is a barrier estuary within a catchment of over 22,000 km^2 and a waterway area of 26 km^2 (MHL, 2010) as shown in Figure 3. It is a highly modified system with a trained entrance and surrounded by significant urban development, residential, manufacturing and ports usage.

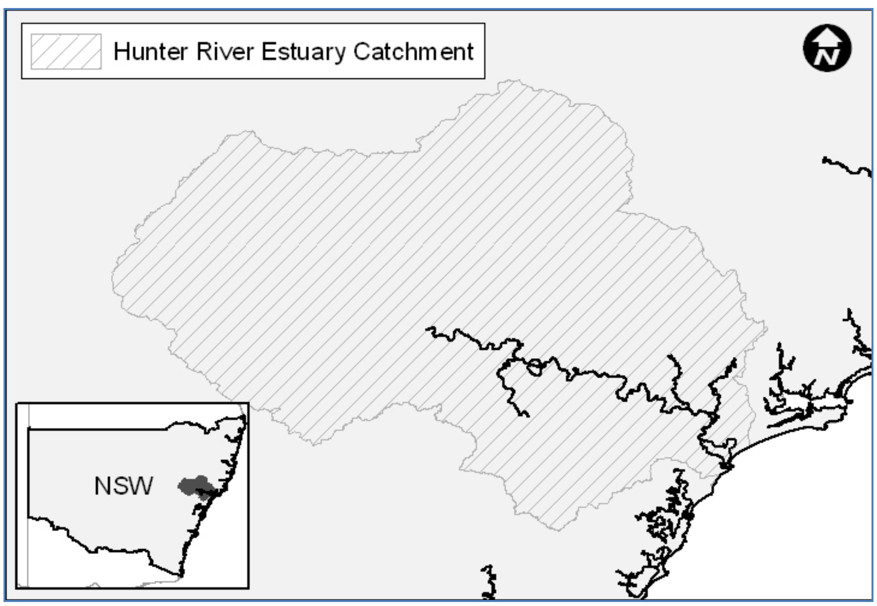

Figure 3. The Hunter River Estuary and its catchment area, NSW

This estuary was chosen as an example of the application of the intermediate-level method for assessing sea level rise inundation risk as it had good elevation data coverage, including some LIDAR data, and has ten permanent tidal gauges within the estuary (Fig. 4).

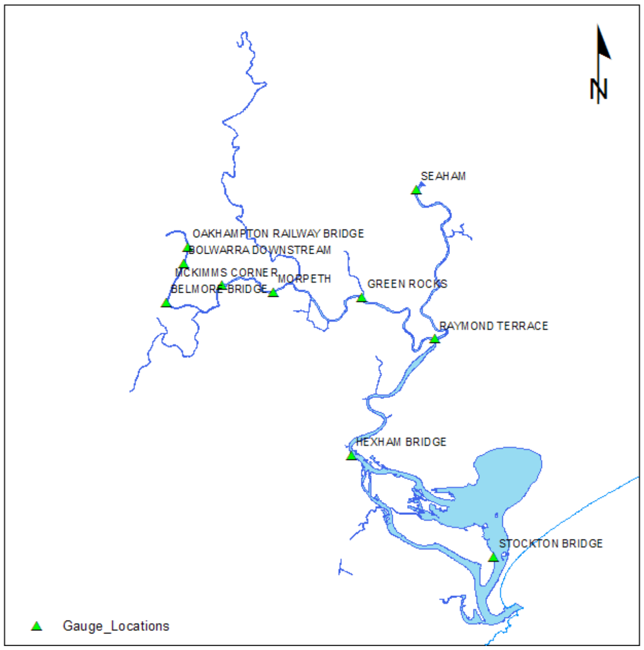

Figure 4. Location of tidal gauges and tidal extent of the Hunter River Estuary

Using the tidal characteristics from the gauge data the traditional two-dimensional approach can be taken to make a first-order assessment of the tidal plane evolution with distance upstream in the estuary (see Fig. 5).

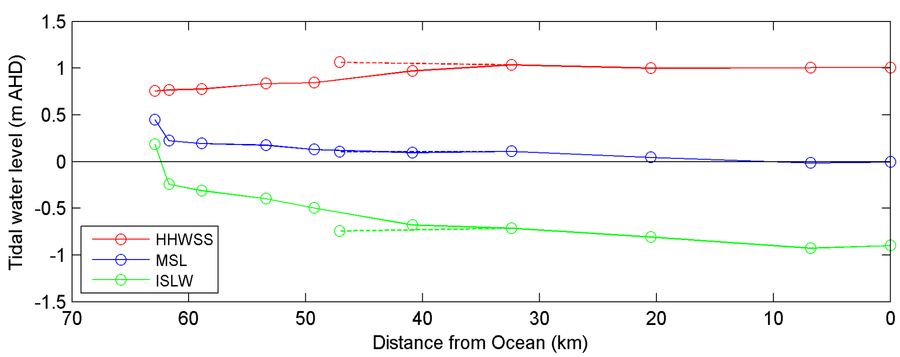

Figure 5. Tidal plane data for the Hunter River Estuary (Data sourced from MHL, 2012)

The nested hierarchy model was used to create a DEM of the Hunter River Estuary surrounds using the best available data, after using state-wide data sources to define an AOI.

Tidal levels from analysis of gauge data and tidal extremities were collated and used in the water surface modelling methodology as discussed in the water surface modelling section. Specifically, the tidal data was plotted in the World Geographic Co-ordinate System (WGS84) and their coordinate values calculated. A tidal plane surface was estimated using the ArcGIS Spatial Analyst, Interpolation tool, 'Spline with Barriers'. The 200 m buffer of the Hunter River Estuary was used as the barrier layer to constrain the interpolation to the approximate extent of the estuary, as measured currently by the gauges. Smoothing parameter was set to 0 (i.e. no smoothing was performed) and the resolution of the outputted tidal plane surface was 250 m.

The resulting tidal plane surface grid is shown in figure 6. Notwithstanding that this represents only a preliminary result from applying the water surface modelling tool to an estuary, the improved utilisation of tidal plane data in the new approach is evident when comparing Figures 5 and 6.

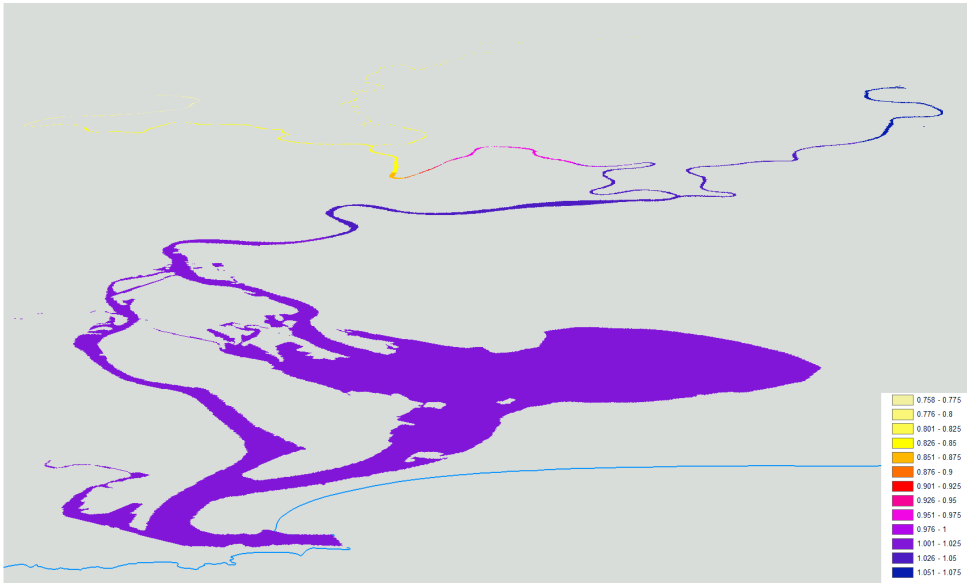

Figure 6. Depiction of the Hunter River estuarine water surface (looking westwards)

Discussion and conclusions

Considering that observed tidal planes in estuaries show both amplification and/or attenuation depending on estuary type (NSW Government, 1992), the commonly used bathtub-type approach for first order estimation of inundation is likely to either under or over estimate estuarine inundation depending on estuary type. The methodology presented here, which fits a surface to available water level data (either tidal planes or other means of water surface delineation), has the potential to significantly improve the accuracy and resolution of inundation mapping within estuaries for which existing water level data is available.

The application of this approach to the Hunter River Estuary demonstrates the substantial increase in value afforded by an estimate of the tidal plane in an estuary relative to the traditional two-dimensional approach. By adding the third dimension, including some of the complexities that are inherent in estuarine systems, the water surface model provides a useful tool for assessing the spatial distribution of the potential impacts of sea level rise in an estuary.

The extrapolation of this methodology to estuaries with no gauge data will require the analysis of common patterns and trends in estuaries with gauge data – grouped by estuary types. It is anticipated that this will enable more reliable estimations of the behaviour of tides in such estuaries, and provide the basis for intermediate-level analysis of sea level rise inundation risk in NSW estuaries.

Limitations of this intermediate-level approach include:

- The fitted water surface is created from a small number of data points, so only a broad-scale representation of the water surface in an estuary can be resolved

- For the assessment of sea level rise impacts, the method does not consider potential future changes in tidal behaviour in response to increased water levels or morphologic change (e.g. foreshore erosion or wetland accretion). However, the approach could be modified to include these effects where they have been assessed.

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