TWO DIMENSIONAL PLANNING: THE APPLICATION OF TIDAL PROJECTIONS TO DETERMINE RISK MANAGEMENT TRIGGERS

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Introduction

Strategic planning for coastal erosion is a reasonably mature process in terms of matching physical constraints to a suite of agreed behavioral responses through time.

For example, accepted best practice in managing risk presented by coastal erosion is the determination of event based physical triggers generally linked to a distance from a dune scarp. The behavioral responses familiar to all coastal managers fall into three accepted categories: avoid; mitigate and retreat (NSW Dept. of Planning 2010).

In spite of potentially having a wider impact on critical infrastructure and private housing (Dept. of Climate Change, 2009), limited planning effort has been ascribed to the equally weighted challenge of coastal and tidal inundation. With more housing located adjacent to estuaries, it is critical planners and engineers develop a technically robust method for assessing the climate change component of risk from coastal and tidal inundation. Development of flexible planning strategies that are resilient to changing scientific advice can only occur when an agreed physical parameter to benchmark a planning response has been identified.

To date, an event based strategic response to coastal inundation in temporal dimensions concurrent with projected rates of sea level rise (SLR) has not been widely investigated or applied in NSW. Currently, some coastal councils in NSW have adopted a time-limited trigger for a planning response or more commonly, rely on traditional flood planning levels derived from the 1% flood event that incorporates a sensitivity analysis of climate change impacts (eg, Pittwater City Council). Both approaches have limitations in the ability to capture a predictable but flexible benchmark for strategic planning.

Using a case study from Batemans Bay, this paper will examine the use of tide as an event based trigger for strategic coastal planning.

Case Study Site

Surfside is a suburb on the northern shore of Batemans Bay, a coastal regional centre approximately 250km south of Sydney (Figure 1).

The site has approximately 200 dwellings, a majority of which are built on land at or below 2m AHD (Figure 2).

The geomorphology of Batemans Bay has been described in numerous reports (Land and Water Conservation 2006; Short 1995) as a drowned river valley. Wright and Thom (1978) identified three distinct sediment compartments inside the bay consisting of the river channel, inner bay and the outer bay.

Surfside Beach is within the inner bay compartment, which is a large delta deposit characterized by low to moderate wave energy. Surfside is broken into two beach compartments (WRL, 2012) of low gradient and typically low dune heights of between 1.6 to 2.0 m AHD (Figure 2). Notwithstanding the low energy environment, erosion and shoreline recession has been measured inside the bay (WRL, 2012; SMEC, 2012; Land and Water Conservation 1996).

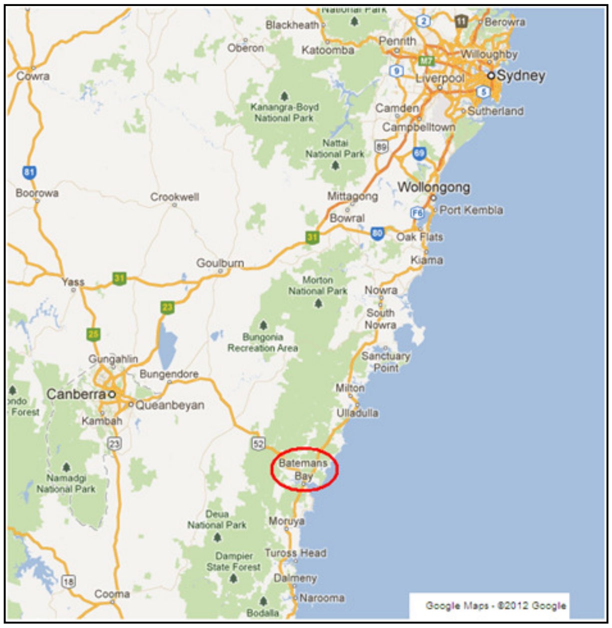
The entire landform outlined in Figure two is fluvial deposits from the inner bay sediment compartment. Short (1995) described the depositional environment of the adjoining beach compartment as a wave deposited chenier plain that formed during the recent (1,000 years) period of stable sea levels.

There is a freshwater wetland to the west of the suburb however the impact of sea level rise on the wetland and in particular, the ground water system, has not been investigated.

The planning history of the Surfside area has resulted in a settlement built entirely on low lying, porous and relatively unstable sand deposits.

Anecdotal evidence indicates the suburb was inundated during the storm events of the 1970's (Lenehan 2012 *pers com*) and current modeling indicates storms of a similar magnitude (1% ARI) will result in the suburb being fully inundated to depths greater than 30 cm (WRL 2012).

Figure 1: Case study location



The lack of any significant grade or change in elevation across the site will result in uniform timing of inundation across the suburb as tidal limits migrate landward under conditions of sea level rise. This is in opposition to a site that has significant grade and changes in elevation where inundation would be more staged over time.

Any impacts from a rising groundwater system are unknown but further investigation is needed to determine the interaction of this local system with ocean boundary conditions and how these interactions may change over time under the influence of climate change.

Figure 2: Surfside topography taken from Aerial Laser Survey (2005)

The need for inundation planning triggers

In 2009, the Department of Climate Change (DCC) published a report which identified upward of 247,600 properties at risk nationally from coastal inundation as a result of rising sea levels (DCC, 2009). Although the method applied to illustrate the potential risk from coastal inundation was relatively crude, the report did succeed in highlighting that the greater challenge of coastal climate change adaptation is presented by inundation as opposed to coastal erosion.

The Eurobodalla Shire was identified as being among a group of local government areas in NSW that are most vulnerable to inundation; with approximately 2,000 properties potentially at risk from a rise in seal level of 1.1 m (DCC, 2009). Council currently has approximately 4,500 properties noted as being at immediate risk from flooding, tidal and coastal inundation. In contrast, the same 2009 DCC report identified approximately 70 Eurobodalla properties within 55 m of a soft shoreline and therefore potentially at risk from coastal erosion. The contrast between properties potentially at risk from coastal inundation compared with coastal erosion clearly illustrates the need to examine the methodology for setting management triggers that respond to the inundation risk.

A preliminary draft technical report (WRL, 2012) prepared to inform the preparation of the Batemans Bay Coastal Zone Management Plan (in prep, Umwelt, 2012) confirmed the vulnerability of the Surfside area to coastal inundation under current oceanic conditions and projected conditions for sea level rise. This study follows on from previous studies such as the Batemans Bay Oceanic Inundation Study (Public Works, 1989) and the Batemans Bay Vulnerability Study (DLWC, 1996) that both identified the inundation hazard.

The historical evidence and empirical investigations unequivocally conclude Surfside, along with many other areas of Australia, is at risk from coastal inundation. The likelihood of the risk compounding over time due to projected sea level rise clearly determines the need for a structured planning response to coastal inundation.

Technical derivation and method

Tidal Inundation

The extent to which land around the coastline is inundated by a regular tide event without any further allowance for additional elevated components (storm surge, river flooding, wave setup, wave run-up) is of interest to ESC. In consultation with ESC, it was agreed that it would be appropriate to examine inundation under the high high water summer solstice (HHWSS) tidal level. This tidal level is exceeded by the higher of the two daily spring high water heights around the solstices in December and June each year. Colloquially, such astronomical tidal events are described as “king tides”.

The HHWSS tidal level is defined in MHL Report 604 (1995) as 0.94 m AHD at Batemans Bay and has been used as a tail water condition for backwater analysis in several ESC flood studies (Willing and Partners, 1989a, 1989b, 1989c and 1991). This tidal water level is expected to occur approximately three times per year (Willing and Partners, 1989a) and is locally equivalent to +1.83 m Batemans Bay Hydro Datum (BBHD). In these previous flood studies, this tidal level was considered reasonable for the derivation of flood levels due predominantly to rainfall related flooding. Note that the HHWSS tidal level is approximately 0.3 m lower than the 1 year ARI storm surge water level which includes both astronomical tide and anomaly components. This higher water level is also being mapped state-wide at the direction of OEH.

The HHWSS tidal plane calculations are based on the amplitude components of the major astronomical constituents in Equation 1.1.

Equation (1.1)

$$HHWSS = Z_0 + M_2 + S_2 + 1.4(K_1 + O_1)$$

Where:

$HHWSS$:	High High Water Summer Solstice	[m AHD]
Z_0:	Mean Sea Level	[m AHD]
M_2:	Principal Lunar Semi-Diurnal Constituent	[m]
S_2:	Principal Solar Semi-Diurnal Constituent	[m]
K_1:	Lunisolar Diurnal Constituent	[m]
O_1:	Lunar Diurnal Constituent	[m]

The SLR projections for the 2050 and 2100 planning periods adopted in this study were derived from the NSW Sea Level Rise Policy Statement (DECCW, 2009a) and are shown in Table 1.1. These benchmarks were established considering the most recent international (Intergovernmental Panel on Climate Change, IPCC, 2007a and 2007b) and national (McInnes, 2007) projections.

Table 1.1 Sea Level Rise Projections (source DECCW, 2010)

Planning Period (year)	(1)Sea Level Rise (m)
2050	0.40
2100	0.90

Notes: (1) increase above 1990 Mean Sea Level

The design still water levels adopted for 2050 and 2100 also require a reduction of 66 mm to accommodate the estimated amount of global average sea level rise that has occurred between 1990 and the present (2012). This is estimated at approximately 3 mm/year from satellite altimetry (DECCW, 2009b).

Projected inundation levels incorporating the HHWSS astronomical tide but excluding storm effects for the present day and the 2050 and 2100 planning horizons are presented in Table 1.2. These same tidal levels are plotted with respect to time for the present day and the 2050 and 2100 planning horizons in Figure 3 to allow interpolation between stated planning periods. Based on these HHWSS levels, mapping of inundation was undertaken using the 2005 LIDAR topographic data (provided by NSW LPI) and GIS modelling.

Table 1.2 Present Day, 2050 and 2100 High High Water Summer Solstice Tidal Levels

HHWSS Tidal Level	Elevation (m AHD)	Elevation (m BBHD)
Present Day	0.94	1.83
2050	1.27	2.16
2100	1.77	2.66

Notes:

(1) BBHD = Batemans Bay Hydro Datum = -0.889 m AHD.
(2) AHD = Australian Height Datum ≈ Mean Sea Level (MSL).

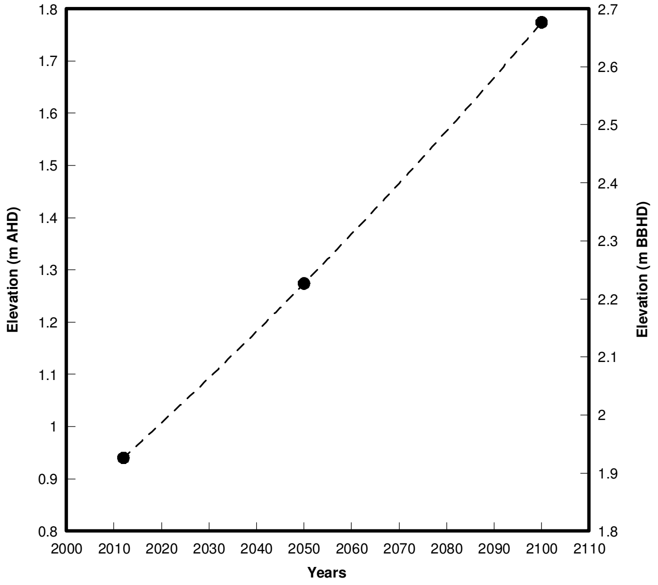
After a detailed consideration of the application of the HHWSS tide as a planning benchmark, the project team will now apply the same technical approach to investigate estuary penetration and landform inundation from the predicted annual tide (1 year ARI storm surge water level).

It is anticipated the annual tide will be a more useful benchmark for land use planning benchmark for the following reasons:

- Higher than the HHWSS tides
- Single measureable event.

The merits of the application of the annual tide will be discussed in more detail under the next section.

Figure 3: Projected Tidal Inundation Levels with respect to time for Batemans Bay



Justification for HHWSS or the Annual Tide as a planning benchmark

Tide as a planning bench mark satisfies two key planning criteria: measureable and predictable. Having satisfied these criteria; the next question to address was selecting the most appropriate benchmark tide for strategic planning. Or put more simply; which tide?

As previously described, tides occur in cycles of spring and neap which can fluctuate seasonally around different lunar and solar cycles. The influence of these cycles on tidal levels can be predicted and are published each year as the astronomical tides. The height observed for each tide on any given day can vary from the predicted astronomical tide due to local influences such as swell and atmospheric pressure. For this reason, tidal planning bench marks have been based on the astronomical, or predicted tidal levels.

The decision to adopt the high high water summer solstice astronomical tide without any anomalies was arrived at after considering the aims of developing a tidal inundation benchmark.

Of primary concern to land managers was the need to either withdraw from or protect areas vulnerable to coastal inundation. A strong case can be presented for protecting against storm events through investment in infrastructure such as rock walls or constructed dunes that are aimed at armoring against erosion and possibly inundation. Planning for such a contingency is focused on rare but high consequence events.

The rare event\high consequence method is a valid approach to risk management but it overlooks the smaller but regular events that will eventually begin to impact on our communities.

The case study site is built on a very low landform that is vulnerable to gradual and less dramatic inundation events. Inundation from tides will “creep up” on buried infrastructure, storm water capacity, ground water tables and eventually road surfaces and private yards. Although the initial damage from tidal inundation may appear minor, there is limited recovery time between such a regularly recurrent event. It is the recurrence of these events that presents the real risk from “tidal creep” to settlements and infrastructure.

When presented with the likelihood of regular recurrence intervals between tidal inundation events, the planning challenge was to select a benchmark planning event that satisfied three key aims:

1. Identification and recognition of the risk over time
2. Tool for strategic forward planning
3. Accommodation of a range of adaptation strategies and contingencies that can be applied over different time scales.

Three tidal events were considered against the keys aims:

- Daily tide
- High High Water Summer Solstice
- Annual Tide.

All three events satisfied the aim of identifying and recognizing the risk from tidal inundation over time.

The daily tide was considered unsuitable as a planning benchmark because the site will have been inundated a minimum of three times per year by the HHWSS tides before any management response was initiated. This undermines the aim of having a tool for strategic forward planning. Notwithstanding this, mapping the extent of daily tide penetration within an estuary under different conditions of sea level rise, over a range of time periods is a useful exercise in examining the sensitivity of a site to climate change impacts. This exercise was conducted for the Surfside case study site to demonstrate the vulnerability of the site to high recurrence interval events in the future.

The HHWSS tidal level was adopted for the initial analysis because it was considered to satisfy the aim of having a tool for strategic forward planning while still being flexible enough to accommodate a range of adaptation strategies. The HHWSS tides are predicted to occur three times per year, therefore providing a recurrent event that is useful for strategic planning along with more detailed responsibilities of local Councils such as conditioning of building consents.

Another consideration was the likely increased recurrence of events such as ocean inundation and flooding under elevated ocean boundary conditions. It was considered that the HHWSS tides would be a good proxy to forecast the increased risk and nuisance from minor flooding when the free capacity of storm water infrastructure servicing low lying settlements was lost. The HHWSS tides could be applied as an alternate ocean boundary condition in flood studies to run a sensitivity analysis in addition to that prescribed in the current flood risk management guide published by the State Government (DECCW, 2010).

The Annual Tide only came into consideration when the initial analysis and mapping based on the HHWSS tidal level had been completed. The annual tide has the same advantages of the HHWSS tide as a planning benchmark, but provides further refinement to the aim of providing a tool for strategic forward planning given that it is the highest predicted tide for any one calendar year. The same rationale for overlooking the daily tide as a planning benchmark can again be applied to considering adopting the annual tide as opposed to the HHWSS tides. It is proposed to complete further analysis of tidal penetration into Batemans Bay to investigate the extent of inundation from the annual tide event and the subsequent application of this event as a planning benchmark. It is considered that the previous analysis of HHWSS tides provided sufficient proof of method to support the ongoing investigation of tidal penetration in Batemans Bay.

Analysis Outputs and Planning Applications

Mapping and plotting

The results of the analysis have been plotted (Figure 3) and mapped (Figures 4,5) for the planning periods coincident with the sea level rise projections outline in the document formerly known as the *NSW Sea Level Rise Policy Statement* (DECCW, 2009).

The mapping illustrates that land at or below 1.77 m AHD will be inundated by the HHWSS tides by the year 2100 and any land at or below 1.27 m AHD will be inundated by the year 2050, based on the projections outlined in the now abandoned *NSW Sea Level Rise Policy Statement* (DECCW, 2009).

The mapped results appear to indicate that a majority of Surfside will not be at risk from tidal inundation between now and the year 2100 (Figure 5). However, the following points need to be carefully considered before determining the level of risk:

- The road crest averages 1.8 m AHD (3 cm above projected tides)
- Storm water outlets are at 0.89, 0.84, 0.76 and 0.75 m AHD (above current mean high water springs)
- Most properties are at or below 2 m AHD.

The results have been plotted to allow interpolation over different time periods (Figure 3). This frees planners from being locked into pre-determined planning periods and therefore facilitates a more flexible event based approach that can be easily adjusted as new information arrives.

Figure 4: Potential Inundation areas for HHWSS tides – Wharf Road, Surfside
(*Source*: *CZMP for Batemans Bay – Preliminary Draft Technical Report, WRL 2012)*

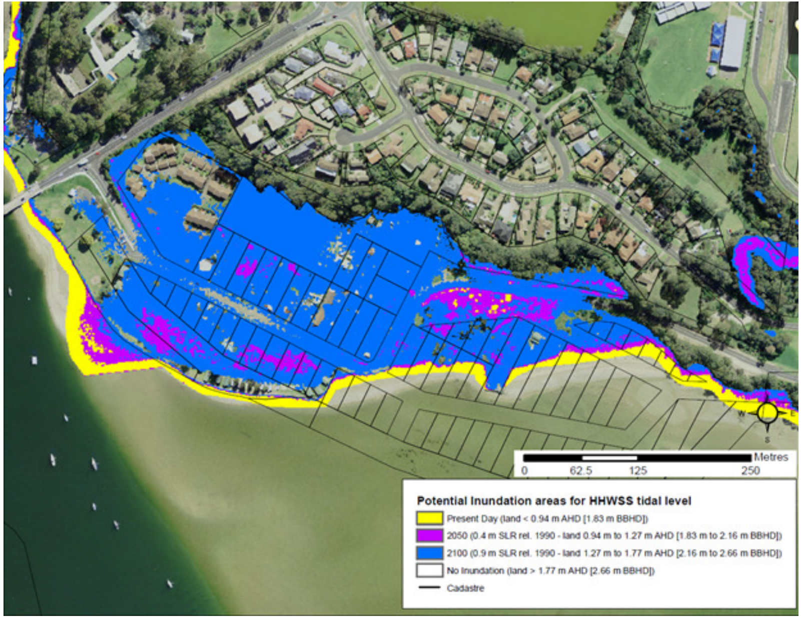
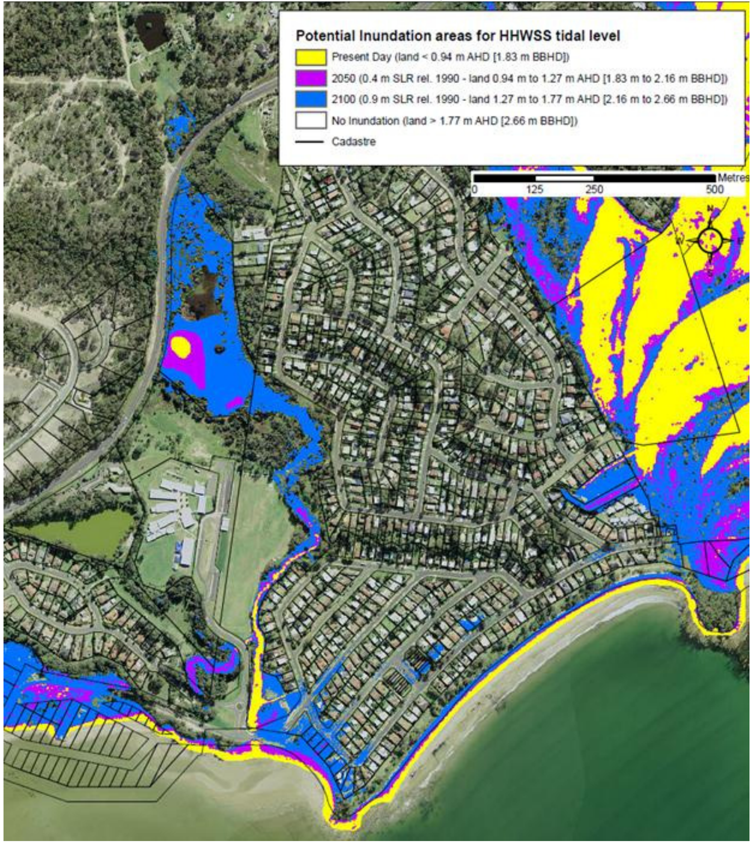


Figure 5: Potential Inundation areas for HHWSS tides – Surfside
(*Source*: *CZMP for Batemans Bay – Preliminary Draft Technical Report, WRL 2012)*



Triggers for Retreat or Infrastructure investment

Identifying and adopting an inundation event that triggers a pre-determined planning response is the key output of completing a tidal analysis. Planners in Eurobodalla can now apply the same strategic approach and planning principles for coastal inundation that have, for a long time, been applied to coastal erosion. This consistency in process not only refines the higher order strategic planning for climate change; it also simplifies the process of immediate planning needs such as assessing Development Applications (DAs).

Eurobodalla Shire Council currently has two options for conditioning development consents in areas at risk from coastal hazards. The options are based on staged retreat from areas based on a pre-determined event for:

- Coastal erosion
- Tidal inundation.

A development consent in Surfside could be conditioned with one or both of these triggers depending on the set back of the property from the waterfront.

Identifying a trigger for retreat is by no means an innovation in coastal planning; however coupling a tidal trigger to the existing process is at this stage a relatively novel application of an accepted practice.

A secondary application of the method is planning for infrastructure provision, servicing and renewal. Knowledge of the approximate period when infrastructure will be compromised by tidal intrusion or rendered inoperable by ocean boundary conditions will be useful to determine the life of investment costs, when or if to invest in infrastructure, maintenance methodology or the timing of relocation. A practical example of how the method has been applied to maintenance schedules in the Eurobodalla is the re-sheeting of Beach Road, Batemans Bay.

Council engineers have been able to apply the tidal projections in the decision matrix for determining the method of maintenance and renewal of the road surface. The road will not be excavated in the future to renew the base material. Rather, each maintenance cycle will simply add a new surface to the existing road, slowly building up the road at a pace ahead of existing SLR projections.

Discussion

Advantages of secondary or primary planning triggers based on tidal inundation

The extent of the projected risk from tidal inundation under conditions of climate change required a method to better inform the development of responses linked to: strategic land use planning; infrastructure investment and; planned retreat (plan, defend, and retreat). The same considerations and responses typically linked to coastal erosion must be linked to a broader consideration of coastal hazard response planning. The inclusion of tidal analysis as a bench mark in the risk assessment process can fill this need and provide a trigger for a pre-determined behavioral response.

Adopting a planning trigger anchored to a tidal benchmark is one approach to determining the “When” and “How” of considering adaptive management strategies for coastal inundation. Tidal benchmarks can facilitate adaptive and flexible management of the built landscape within a range of time-scales. Being event based, the method does not lock planners into a fixed time or ocean level. Planners can respond to real events in time, allowing the flexibility of when response triggers are implemented. The best example may be the triggering of conditions of consent linked to removal of a private residence.

The flexibility of the approach adds to the resilience of the methodology to updated information such as changing rates and projections of SLR. The processes and analysis would remain unchanged regardless of the inputted projections.

Conversely, tidal triggers can inform processes where flexibility may not be an advantage. Decisions linked to the relocation of critical infrastructure can be made in advance of a projected event occurring to avoid losses through damage or the need to relocate fixed infrastructure with a long asset life. There are considerable advantages for life of asset planning in applying the tidal analysis scenarios.

An unforeseen advantage of tidal analysis as a planning benchmark may be in the space of community knowledge building. Unlike coastal erosion that may cause severe damage in a single rare event, tidal inundation will creep up over longer time periods as a series of regularly occurring events. The recurrence of the event can be more easily communicated to the community as likely, or real, events in time.

Plotting and mapping could possibly be incorporated at a local level into the work initiated by the Office of Environment and Heritage (Watson & Frazer, 2009) on capturing elevated water events. Wider knowledge and acceptance of the risk may increase the capacity of communities to prepare in advance for a more staged response to not only the inundation threat, but climate change in general.

Limitations of method

Future refinement and future information requirements

The technical derivation of the inundation mapping could be refined further through deployment of flood modeling software routed through a more accurately forced digital elevation model. Eurobodalla Shire Council is currently preparing a flood study for Wagonga Inlet, Narooma, where a 2D hydrodynamic flood model will be forced through a more accurate terrain model that incorporates hydraulic linkages such as the local storm water system and overland flow paths. This more refined model will include better assumptions of tidal behavior and how it impacts on the local landform and infrastructure.

The response of the groundwater system and how it may impact on settlements such as Surfside has not been investigated. For example, will coastal groundwater tables rise with elevated ocean boundary conditions? Additional specialized advice will need to be sourced to determine if this is an issue for low lying settlements built over coastal groundwater aquifers.

A third dimension to this matrix is currently being researched that will add infrastructure investment triggers to the coastal risk management decision framework. This work was initiated by Gorddard et al (2011) as a pilot research program to investigate the application of economic modeling to inform future infrastructure investments. The refined economic approach is anticipated to form a structured framework for decisions relating to the timing of investment in coastal infrastructure where it has been identified as a possible future adaptation option. A parallel focus of the economic analysis is to investigate methods for determining the legitimacy of investing in coastal infrastructure to defend against coastal hazards when the full range of costs is considered. The tidal analysis is proposed as one method to benchmark the change in the coastal environments that will trigger the need for a response.

Future research partnerships are being sought to investigate the livability of the landscape as tidal incursions begin to impact on local communities. Areas of interest where the tidal analysis could be applied include community health impacts and building designs focused on occupant health and adaptable housing.

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