VISUALISING SEA LEVEL RISE ON THE NSW COAST

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Abstract

Risk Frontiers (RF) has been working with the New South Wales (NSW) Office of Environment and Heritage (OEH) to develop a set of tools and analysis capabilities that will allow it and other Government entities to visualise the potential impacts to communities and infrastructure arising from seawater inundation and to assess the likely economic costs of this risk. These tools will allow users to exploit high-resolution data in their own applications to perform in-house analyses in order to inform actions to be taken by local communities and councils in the coastal zone.

The first three of this five-phase project identified residential exposure within elevation and distance thresholds from the NSW shoreline and built a risk register of features of interest within that coastal strip. Around 25% of all NSW addresses were identified as being situated within 1 km of the shoreline; 25,000 addresses are located within 100 m of the shoreline and with elevations of less than 3 m. In the final two stages of this project RF is estimating the potential costs of exposed assets that within the hazard layers that were identified in the first three project phases. A 'second pass' assessment of the potential costs of coastal inundation on NSW coastal communities will be delivered via a state-wide visualisation tool with analysis layers that sit within an online mapping environment (e.g. Google Maps). The analysis and reporting resolution will be State, Local Government Area (LGA) or Australian Bureau of Statistics (ABS) Statistical Area 1 (SA1). The analysis framework will give users the flexibility to integrate additional infrastructure and hazard data layers as they become available and users can modify cost values for each exposure layer.

Key words: coastal erosion, seal level rise, visualisation, GIS, economic costs, climate change

Introduction

This paper seeks to assess the risk to communities and infrastructure from due to sea level rise (SLR) in NSW. Globally, the economic cost of natural hazard events continues to rise (Swiss Re, 2013). At present the increasing costs due to weather-related events, can largely be attributed to increased exposure (more people and wealth) in disaster prone locations (e.g. Pielke Jr. et al., 1998, 2008; Crompton and McAneney, 2008; Crompton et al., 2010, 2011; Barthel and Neumayer, 2012; IPCC, 2012, 2014). While global climate change may eventually aggravate this toll, its immediate impact on rising sea levels rise due to thermal expansion of the ocean and melting of land ice seems incontestable (Church et al., 2006).

In its latest report, the IPPC (2014) states that with very high confidence, low-lying coastal areas will experience increasing adverse impacts due to SLR including submergence, coastal flooding and coastal erosion. Recent research suggests that previous upper limit estimates of 1.5-2 m could be reached much earlier this century than previously thought. This is important because in NSW, as in many other parts of the globe, people are migrating to the coast, and with approximately 50% of the State's addresses now located within 3 km of the shoreline (Chen and McAneney, 2006) and the increasing likelihood of impacts from SLR impacts, the NSW Government is seeking to improve their knowledge and awareness of these risks. In this article, we describe work by Risk Frontiers (RF) undertaken with the NSW Government to develop a set of visualisation tools and analytical capabilities that will aid government agencies, departments and local government better understand risks of seawater inundation.

For the purposes of this paper, risk is defined as a multivariate function of the hazard, exposure and vulnerability (Figure 1). Hazard in this case refers to SLR; exposure to the people or assets (buildings and infrastructure and their values) and vulnerability refers to the sensitivity of the exposed assets to different levels of environmental stress or hazard intensity. This is the standard approach now adopted across the insurance sector for pricing catastrophe risk.

This project is being completed in five phases with the first three now complete. In what follows we outline the approach undertaken, the exposure layers considered, how economic costs will be incorporated and present an early version of the prototype visualisation tool.

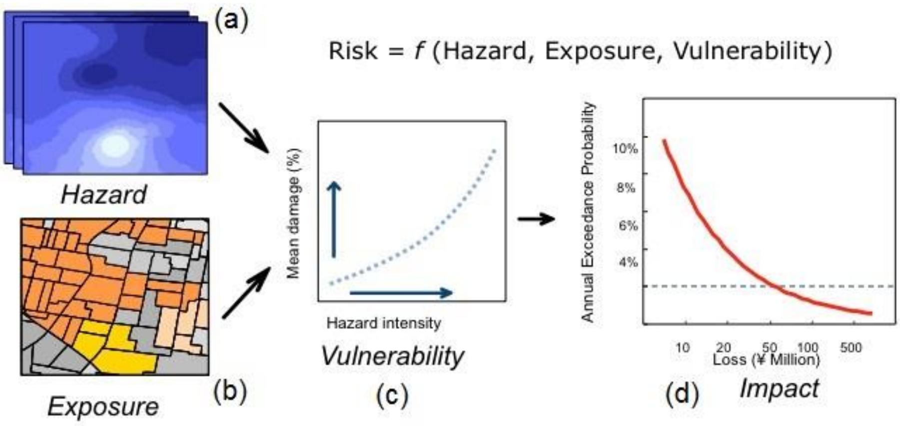

Figure 1: Major components of risk modelling: (a) Hazard modelling with shading showing spatial pattern of ground shaking, say, for each modelled scenario (b) Exposure data - the spatial distribution of the sums of assets by census collection districts (c) Building vulnerability - expected damage as a ratio of the value of the asset as a function of hazard intensity and (d) Curve showing the annual probability of experiencing a loss greater than a given dollar amount (source: Risk Frontiers).

The hazard

LiDAR-derived elevation data was provided by OEH via NSW Land and Property Information (LPI). For most of the 28 coastal areas analysed this comprised a 1 m resolution Digital Terrain Model (DTM). The only exceptions to this were the Hunter Coast and Sydney region, which had 2 m resolution DTMs, and the gap regions discussed below.

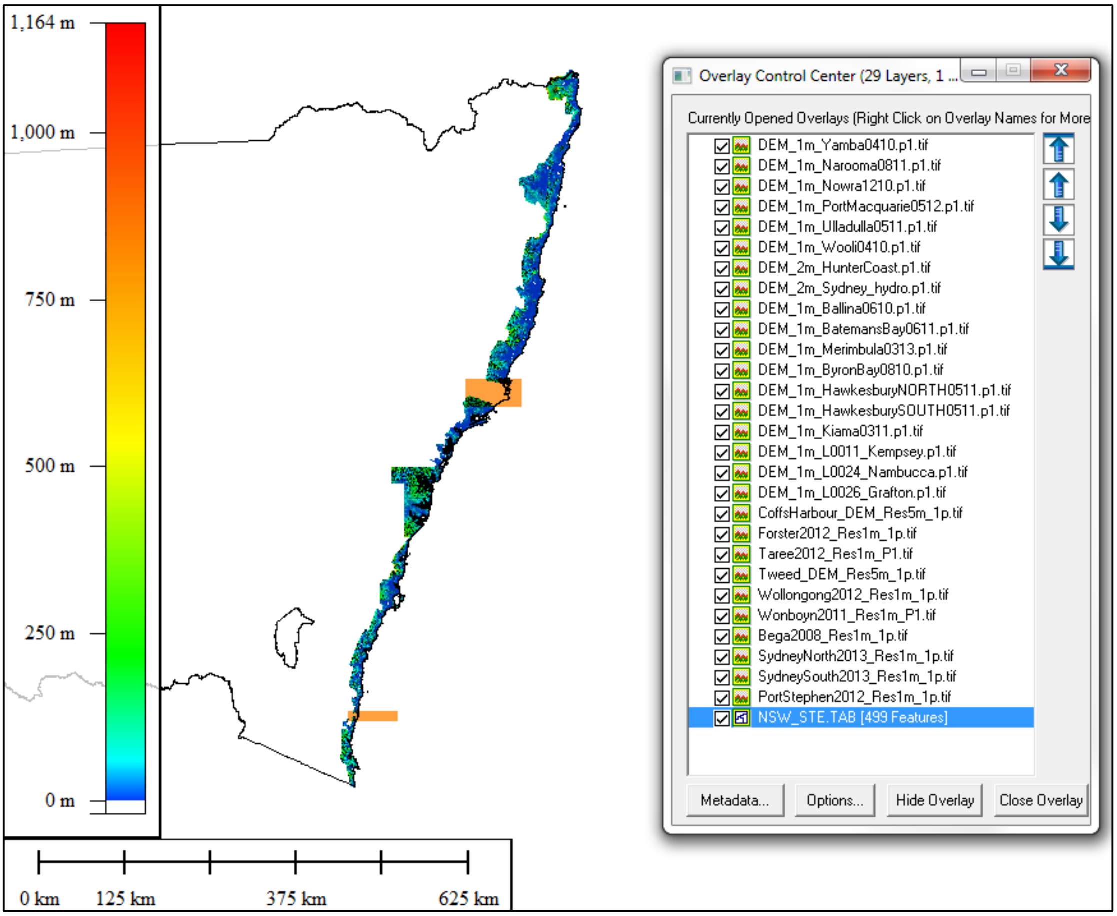

Figure 2: Coverage of LiDAR-derived DTMs for 28 coastal areas in NSW with gaps highlighted in orange.

In total there were minor coverage gaps in the DTM for four regions of the NSW coast:

- Tweed Shire Council
- Coffs Harbour City Council
- North of Port Stephens to South of Foster (Myall Lakes and Myall Lakes National Park region,
- A small area between Tathra and Bermagui on the NSW South Coast, near Wapengo

For the Tweed Shire and Coffs Harbour RF was able to obtain LiDAR-derived 5 m resolution DTM's from the respective Councils which were the best available elevation sources for the regions. The other two gaps were filled using an older 25 m DTM sourced from NSW LPI.

High-resolution shoreline representation is based on ABS census data, where the land and sea boundary is derived from 1:4,000 scale topographical maps. It includes coastal waters directly connecting to open ocean, including rivers, lakes and lagoons. We use this to derive shoreline buffers at 25 m intervals. An example for the Sydney Basin is shown in Figure 3.

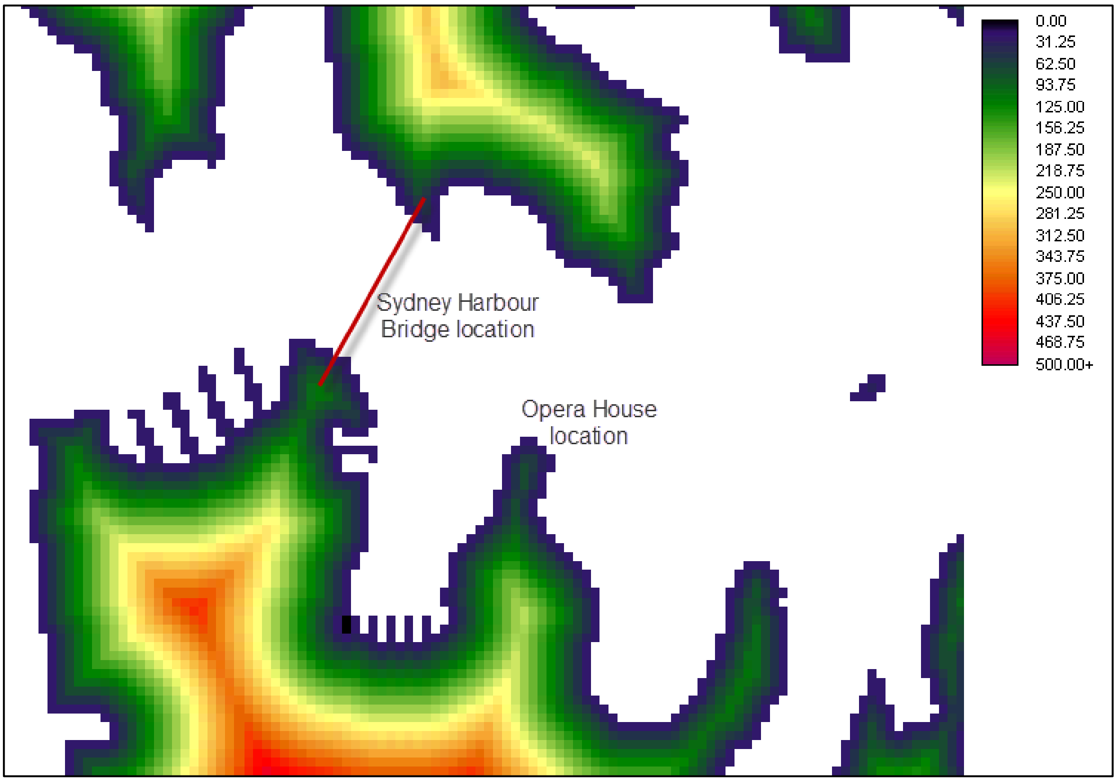

Figure 3: Shoreline buffers at 25 m intervals: a zoomed view of the Sydney Harbour Bridge area.

Based on the spatial analysis, around 27% of addresses (1,049,177) in NSW are located within 1 km of the shoreline; around 2% (73,431) are located within 100 m of the shoreline. Considering both shoreline buffers and elevation, within 1 km of the shoreline, 105,400 addresses are located in low-lying areas with elevations of less than 3 m; within 100 m buffers, 25,148 addresses are located in the low-lying areas.

Furthermore, a series of detailed digital hazard maps were produced by combining LiDAR derived data with evidence-based inundation and scenario data provided by OEH (Figure 4). These OEH data covered 184 estuarine environments along the NSW coast for four levels of SLR: 0.0 m, 0.5 m, 1.0 m and 1.5 m. Outside of these estuarine extents, the data were supplemented with elevation bands derived from the initial LiDAR data. No attempt has been made to estimate the timeframe when these SLR projected scenarios will be manifest. These locally-focused, state-wide hazard layers can provide coastal managers, scientists and the general public with a high-resolution view the risk arising from coastal inundation and future SLR.

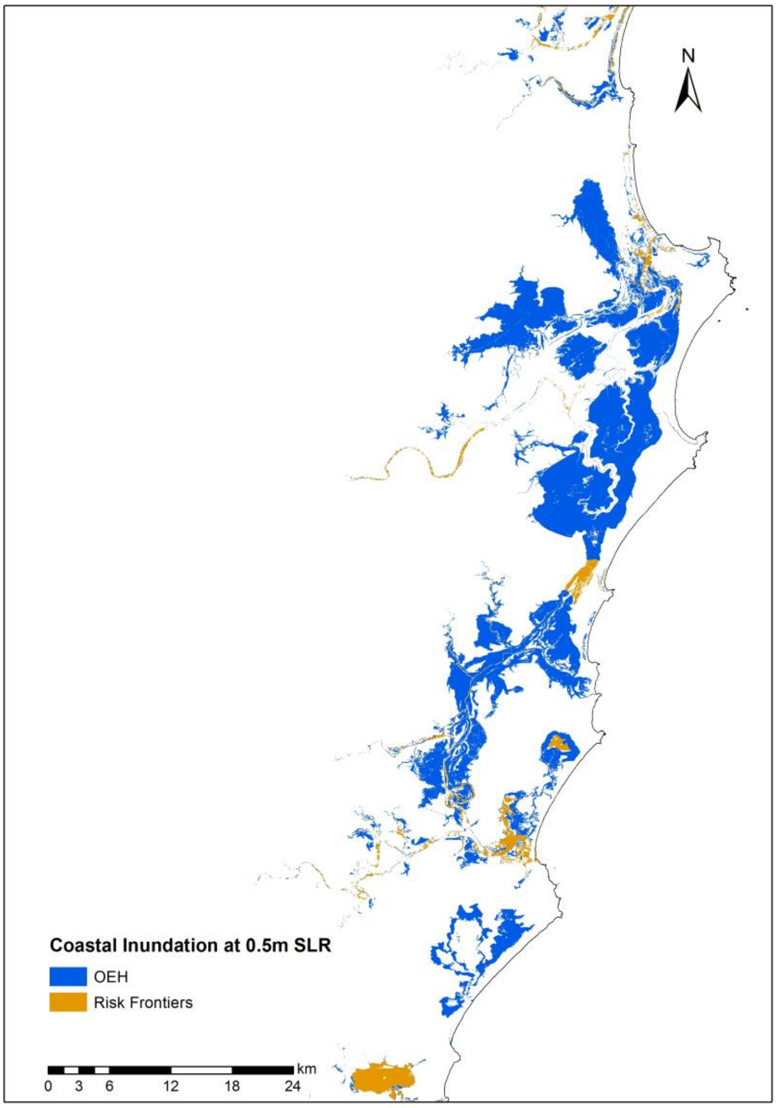

Figure 4: Sample coastal inundation map at 0.5 m SLR derived from OEH and RF data.

Exposure

In all, 41 layers of infrastructure locations have been provided by OEH for analysis. The investigation process comprises two complementary spatial scales: a sub-Local Government Area (LGA) scale, which might be thought of as a Community Exposure Register (CER) and contains risk identification information reported at ABS Statistical Area 1 (SA1) spatial units; and a Community Exposure Summary (CES) at a whole-of LGA scale. These two elements are embedded within the same spatial database structure (ESRI geo-database) to allow for summary reporting by LGA using a simple query: e.g.

How many schools fall within the 1.5 m inundation band for LGA 'X'?

The CER and CES are explicitly linked by sub-LGA spatial units (SA1) and common data standards to allow exposed infrastructure to be readily calculated by the spatially intersection of the area inundated, in this case, with the relevant infrastructure layer. A statewide risk summary comprising all LGAs provides the basis for an examination and ranking of vulnerability, and inputs for further analysis of questions pertaining to resilience, consequences, adequacy of controls, risk treatment priority, mitigation strategies and residual risk.

The CER is designed to primarily to:

- Provide an overview of community exposure to specified coastal inundation scenarios in a way that is locally relevant and facilitates strategic planning.
- Assist communication about community exposure to coastal inundation between OEH, LGAs and any other government agencies, and
- Provide a repository of community exposure information for future analyses.

The CER comprises a table and related map collection at a sub-LGA scale, and reporting tools that describe the exposure of community elements to different natural hazards scenarios. Data in the CER are summarised at sub-LGA (SA1) level, and can be aggregated to LGA or any other spatial aggregations via simple queries. For example, if a group of LGAs were to form a disaster management region, a polygon or text list of these LGAs could be used to produce an extract from the CER, or a summary using basic GIS or database operations.

SA1_7DIGIT	GUR_C0cm	ARd_C0cm	ARd_IC0cm	C_ARd_IC0c	S_ARd_IC0c	Str_C0cm	Str_IC0cm	C_Str_IC0c	S_Str_IC0c	RTrk_C0cm	RTrk_IC0cm
1139005	0	1	0.159939	Very Low	Very Low	1	0.159939	Very Low	Very Low	0	0
1139035	0	0	0			1	5.822089	Medium	Medium	0	0
1139037	0	0	0			3	7.380016	Medium	Medium	0	0
1139110	0	0	0			0	0			0	0
1139146	0	0	0			0	0			0	0
1139147	0	0	0			0	0			0	0
1139501	0	0	0			0	0			0	0
1139503	0	2	29.961088	Very High	Very High	3	67.855177	Very High	Very High	0	0
1139504	0	0	0			0	0			0	0
1139505	0	0	0			0	0			0	0
1139506	0	0	0			0	0			0	0
1139516	0	0	0			0	0			0	0
1139517	0	0	0			0	0			0	0
1139524	0	0	0			1	4.260401	Low	Low	0	0
1139526	0	0	0			0	0			0	0
1139527	0	0	0			0	0			0	0
1139531	0	0	0			0	0			0	0
1139532	0	0	0			2	23.358614	High	High	0	0
1147231	0	0	0			0	0			0	0
1147237	0	1	10.800204	Very Low	Very Low	1	10.800204	Very Low	Very Low	0	0
1147306	0	0	0			0	0			0	0
1147307	0	0	0			0	0			0	0
1147312	2	4	78.900609	Very High	Very High	8	125.877616	Very High	Very High	0	0
1147314	0	0	0			0	0			0	0
1147315	0	0	0			0	0			0	0
1147316	0	0	0			0	0			0	0
1147317	0	0	0			0	0			0	0
1147323	0	0	0			0	0			0	0
1147402	0	1	11.029994	High	High	1	11.029994	High	High	0	0
1147403	0	0	0			0	0			0	0
1123601	0	0	0			0	0			0	0
1123602	1	0	0			0	0			0	0
1123603	0	1	1.450991	Very Low	Very Low	1	1.450991	Very Low	Very Low	0	0
1123604	3	7	339.206809	High	High	22	3940.882501	High	High	0	0
1123605	3	0	0			3	248.30103	Very Low	Very Low	0	0
1123606	0	1	12.688198	Very Low	Very Low	1	12.688198	Very Low	Very Low	0	0

Figure 5: Sample OEH Community Exposure Register

In conjunction with the CER data table (Figure 5), maps centred on the LGA of interest are automatically generated. As the example in Figure 6 illustrates, each map has a descriptive title of the LGA, the infrastructure element being analysed, and the hazard under consideration. The map contains an inset highlighting the location of the LGA in greater NSW, and a legend displaying the totals of the attributes being mapped using raw numbers (rather than ratios[i]) classified into quintiles -- five classes of equal frequency.

The maps also include a shaded grey area that depicts areas beyond the extent of the hazard layer (in other words, non-impacted areas). Areas outside the LGA are shown in white/hollow. The construction of the map is customisable enabling additional contextual layers to be included (e.g. OpenStreetMap data), changes to the colour scheme, titles, legends, etc.

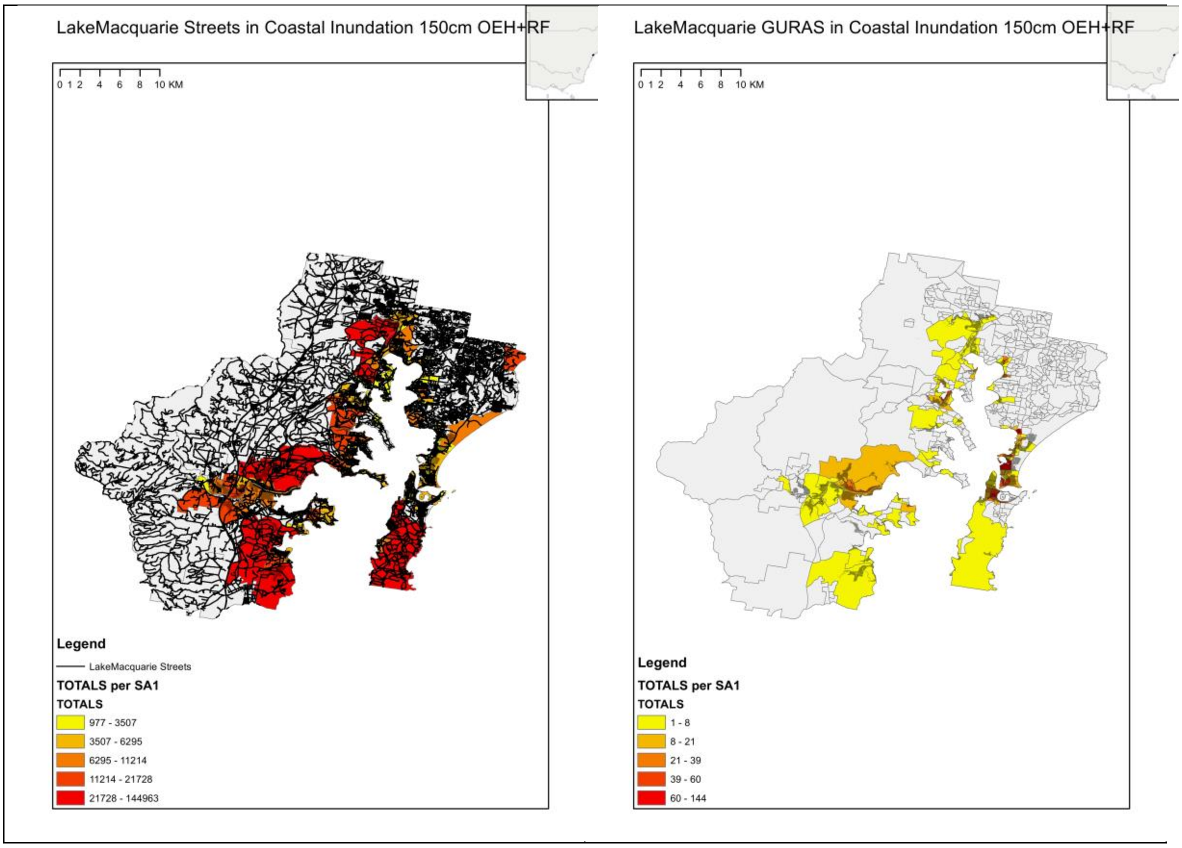

Figure 6: Sample CER maps showing Streets (left) and Total GURAS (address points) (right) in SLR 1.5 m scenario (as denoted in the map title).

Economic costs

Traditionally estimates of natural disaster losses have focussed on the direct costs (Rose, 2009) because the total economic costs are difficult to model (Kousky, 2012). In this fourth phase of the project, RF adopts a similar methodology in using the term 'economic costs' to describe the replacement costs of the impacted infrastructure elements. Broader economic costs take into account any reduction in output, caused either directly by the actual hazard event itself or indirectly by a reduction in the capital stock (people and infrastructure). These considerations are important but at this juncture lie outside the scope of this project.

The economic costing component of the tool is still under development. RF intends to provide end users with a range of possible values for each individual exposure layer, where cost information is obtained either from the literature, infrastructure managers such as Sydney Water, Energy Australia and Roads and Maritime Services or through RF's extended network. High, low and median suggested costs will be provided to the end user in the software along with some justification for these choices (see Figure 9). It is anticipated that for most asset classes costs will vary significantly across between rural and metropolitan areas. The user will have the ability to override these suggestions and input their own numbers directly into the tool. This allows users to incorporation of expert and/or institutional knowledge. Often, the end user (e.g. NSW Roads and Maritime Engineer) will have a much clearer idea of what these costs should be in a particular location, and so hence the flexibility for the user to override RF's suggestions.

Visualisation

The final component is to develop a prototype application for the visualisation of this risk. This component will provide the ‘second pass’ assessment of risk along the NSW coast, allowing a more detailed examination of the potential economic costs for coastal communities than previous estimates and giving the end user the ability to visualise this risk. This prototype will support user-definable, comparative analytics (e.g. ranking LGAs by exposure at risk for particular infrastructure types) and to identify areas most at risk (through these comparisons).

This project will identify at risk communities using broad-based assumptions and further work is recommended for communities identified. Estimating the broader economic impacts in the defined high-risk communities would comprise a “third-pass'” assessment. The tool will incorporate an online mapping environment (e.g. Google Maps). The underlying visualisation architecture will support the integration of additional infrastructure or hazard data layers and a range of vulnerability values/replacement costs for each infrastructure layer. The flexibility to have varying economic costs by spatial regions and infrastructure sub-classes will be supported.

The following screenshots from the prototype tool indicate the type of user experience the project will deliver. As user evaluation, design and testing are currently underway these figures are only representative of some of the functionality described above and are not the final design.

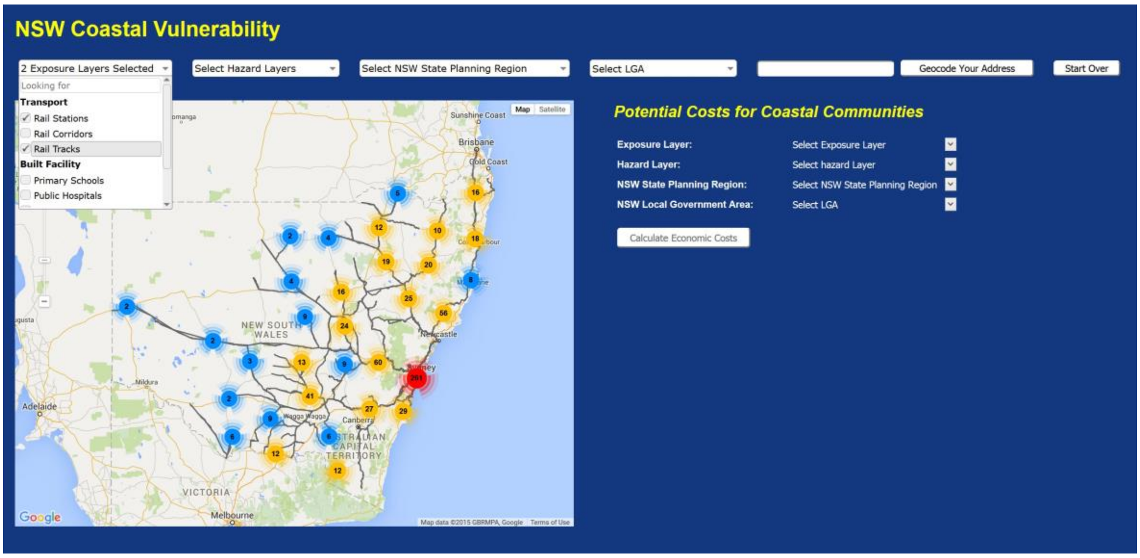

Figure 7: Prototype visualisation tool showing selected exposure layers

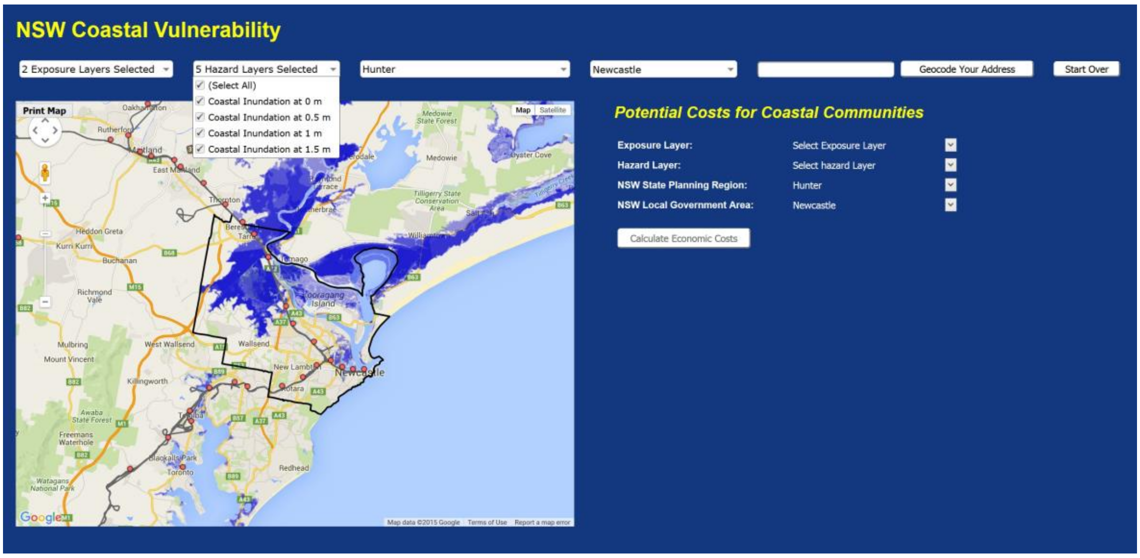

Figure 8: Prototype visualisation tool showing selected hazard layers

The tool will give the user the opportunity to select the hazard and infrastructure layers within selected regions of interest (such as LGAs). All the infrastructure exposure layers will be categorised into a number of groups using sub-headings (e.g. Built Facility, Transport, Electricity, Sewer etc.). Users will be able to select multiple layers from this exposure list (Figure 7). Eight hazard layers, derived from the 4 SLR scenarios, will be available for selection. By selecting multiple hazard layers, users will be able to see the variation of different hazard extents (Figure 8). When a specific NSW State Planning Region or LGA is selected, the map will zoom to that area to provide better visualisation of exposure and hazard layers within its boundary (Figure 8). In addition, users can geocode an address of interest on the map to see its interaction with hazard extents.

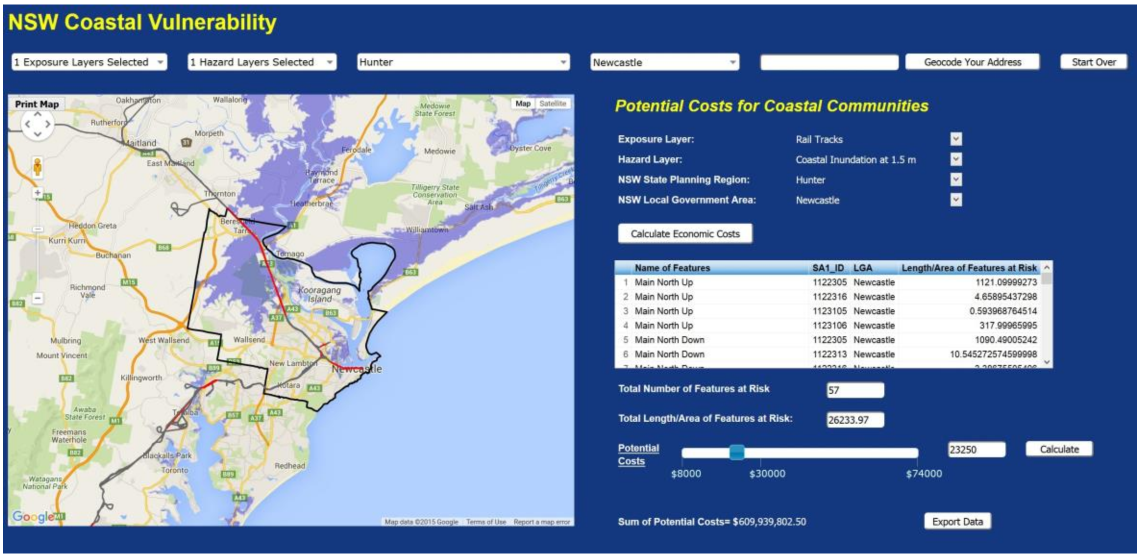

Figure 9: Prototype visualisation tool showing potential economic cost calculation

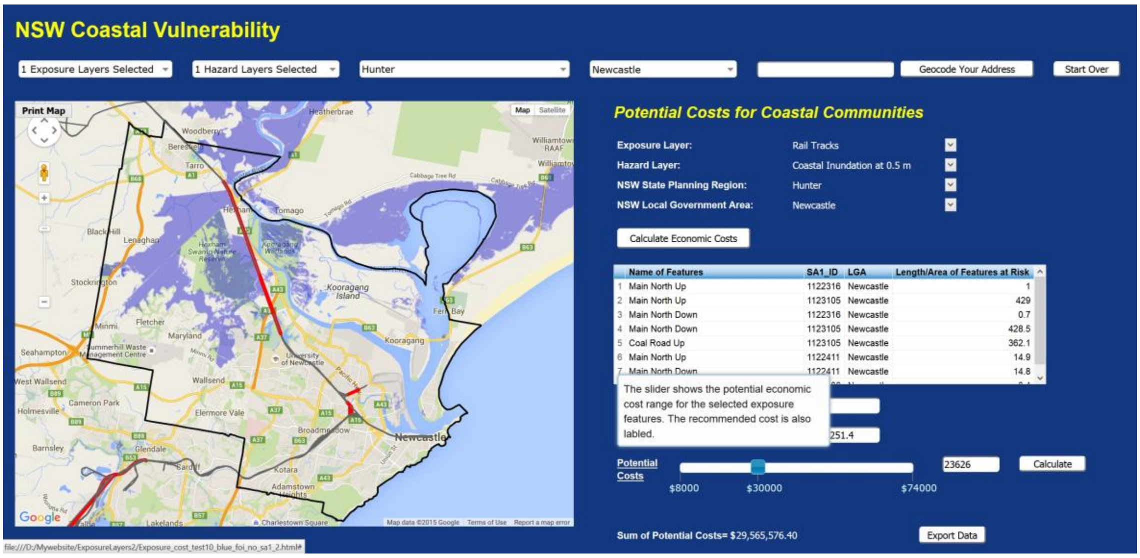

Figure 10: Prototype visualisation tool with a tooltip window showing the explanation of the potential costs

In order to calculate potential economic costs for the exposure layers due to different levels of the hazard, a panel will be provided with separate menus (Figure 9). When the specific exposure and hazard layers are defined, users can click the button to calculate economic costs. For the selected area of interest, the features from the selected exposure that are impacted by the selected hazard layer will be listed in a table. The total number and total length (for linear features only) or area (for polygon features only) will be summarised underneath the table. A slider bar will provide a range of replacement costs per unit for the exposure features. The pop-out tooltip window will show the explanation of the potential costings (Figure 10). Users will be able to make the final decision on what cost is most appropriate for what they are trying to achieve. They will then choose the value by adjusting the slider, or can just type the value into the text box to the right. The users can then do the final calculation for the exposure features based on the defined replacement values.

Finally, the tool will include export functions for both the map with selected layers and the economic cost data (Figure 11).

Exposure Layer	Rail Tracks		
Hazard Layer	Coastal Inundation at 0.5 m		
NSW State Planning Region	Hunter		
LGA	Newcastle		
SA1_Summary			
Name of Features	SA1_ID	LGA	Length/Area of Features at Risk
Main North Up	1122316	Newcastle	1 m
Main North Up	1123105	Newcastle	429 m
Main North Down	1122316	Newcastle	0.7 m
Main North Down	1123105	Newcastle	428.5 m
Coal Road Up	1123105	Newcastle	362.1 m
Main North Up	1122411	Newcastle	14.9 m
Main North Down	1122411	Newcastle	14.8 m
Port Waratah Departure - Islington No.2 Rd	1123506	Newcastle	0.4 m
Total Number of Features at Risk	8		
Total Length/Area of Features at Risk	1251.4		
Potential Costs per Unit	23626		
Sum of Potential Costs	29565576.4		

Figure 11: CSV data file exported from the prototype visualisation tool

Conclusion

In this paper we have outlined the visualisation tool that is currently being built for the NSW Government to help communities identify their exposure to coastal inundation based on 4 SLR scenarios. The tool under development utilises GIS and hazard modelling techniques and has the potential to support other natural hazards (e.g. bushfire) in the future to provide a comprehensive risk visualisation for NSW (or any other region).

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[i] This can be modified to map ratios, if preferred.