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RESILIENCE TO CLUSTERED DISASTER EVENTS AT THE COAST: STORM SURGE

Annual report 2016-2017

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Cover: Drone vision over Lamberts Beach after Cyclone Debbie.
Credit: Michael Kennedy, chief operator National Drones Mackay

TABLE OF CONTENTS

EXECUTIVE SUMMARY

What is the problem?

Coastal communities in Australia are particularly exposed to clustered disaster events, due to the impact of cyclones and extra-tropical storms when there can be coincidence of severe wind damage, storm surge, coastal flooding and shoreline erosion. Because the climatic drivers of cyclones and severe storms are stronger during or across specific years (e.g. during La Niña periods), these events often repeatedly impact the coast over periods of weeks to months. The consequences of individual events are therefore exacerbated with little or no opportunity for recovery of natural systems or communities.

The storm events that occurred on the southeast coast of Australia during 1974 are the most significant and recent in memory in terms of coastal impact associated with clustered events. The clustering in that year occurred as a series of at least 10 storms between January and June. Not all of these events led to coastal erosion, but the sequence likely played some role in setting the pre-conditions of the beach that ultimately led to the erosion towards the end of this six month period. The question therefore is to determine the beach response to clustered event sets and the nature of how those events ultimately lead to erosion.

The problem is complex as the response to the forcing will vary – there will be a spectrum from inundation to erosion, and further, there will be varying factors that drive the erosion (e.g. long-shore, cross-shore) that are functions of the location and the event.

Why it is important?

Australia's population is concentrated along the coastline, with over 85% within 50 km of the coastline (Australian Bureau of Statistics 2001). In New South Wales for example, the NSW Government has identified 15 erosional hotspots (Kinsela and Hanslow 2013), along its 2000 km of coastline. Of the approximately 1000 km of erodible sandy beaches (open coast only), 28% is within 220 m of property. In addition to the severe wind and flooding impacts that Tropical Cyclone Debbie imparted in Queensland and New South Wales in March and April 2017, TC Debbie also caused erosion from Mackay to the Gold Coast. Any subsequent storm(s) will potentially worsen the situation at these locations, particularly if they occur before the beaches have had time to rebuild naturally. A coastal engineer at Mooloolaba (Sunshine Coast) indicated that beaches had been protected by the available large volumes of sand as the summer has been absent of the usual consistent storms[1].

How have we approached the problem?

The study will quantify the risk of these clustered events by determining the nature of the hazard, the elements that are exposed to this hazard and their resultant vulnerability. Combining the frequency of the hazard with its impact will enable

[1] Beach erosion to continue in ex-TC Debbie's wake 1 April 2017 Sunshine Coast Daily https://www.sunshinecoastdaily.com.au/news/beach-erosion-to-continue-in-ex-tc-debbies-wake/3161769/

the risk to be quantified. This risk can then be managed through the coastal and disaster management processes of all stakeholders.

The study has been focused on two case studies, Old Bar beach in NSW and the beaches of metropolitan Adelaide. These sites were selected in consultation with the project end-users on the basis that they are actively being managed as erosion 'hotspots'. The physical setting of each site also presents an opportunity to advance our understanding of shoreline processes. The project has adopted the coastal compartment framework as the functional unit for understanding shoreline response at a range of spatial scales, and detailed geomorphological site investigations are being used as input to the beach response modelling.

Together, the risk and coastal compartments framework are powerful in terms of situating the assessment at local, regional and national scales.

END USER STATEMENT

Miriam Middelmann-Fernandes, *Geoscience Australia, ACT*

This project is a collaborative effort between Geoscience Australia and the University of Queensland. At the end of its third year, the project has reflected on its progress and identified areas where work is required to enable national application of the method. The first year focused on project planning, fieldwork and data collection, with preliminary modelling already underway. By the end of the second year, the modelling had significantly matured with high quality modelling and analysis being conducted. At the end of its third year, the project has finalised the statistical storm event set generation, published the work in an international journal and continued to refine the shoreline response modelling.

As for all CRC projects, engagement between end-users and researchers is a key component of the program. This project has capitalised on the early productive end-user engagement with end-users involved in driving the requirements for the modelling (i.e. including climate variability into the wave climate). The project has utilised NSW state level data directly in the modelling framework, thereby demonstrating how NSW could then apply the method within their state.

The project's utilisation plan is focused on ensuring the body of knowledge (data, information and tools) is discoverable, accessible and useable by end-users. Continued end-user engagement will help ensure that the outputs of this work are relevant for different practitioners throughout Australia, and that awareness is raised on the identified gaps that may limit the national application of the methodology and restrict the benefits being realised.

REFLECTION ON PROJECT PROGRESS

The aim of this project is to develop a new methodology to quantify the impact and risk of coincident and clustered disasters on the coast, with an initial focus on storm surge, associated erosion and reshaping of the coastline and the resulting inundation and damage to buildings and infrastructure.

As a basis for risk management at a range of scales suited for use by National, State and Local Government agencies, the objectives of this project are to:

1. Identify coastal landform systems that are vulnerable to erosion and inundation during storms
2. Develop modelled storm surge events to represent clustering at study sites
3. Model shoreline response to storm time series
4. Incorporate information on coastal geology, geomorphology & sediments in assessments of shoreline response modelling
5. Quantify the impact of clustered storm surge events on coastal assets (buildings and infrastructure)

Two case study sites were selected; Old Bar in NSW and Adelaide Metropolitan Beaches in SA. The aim of the project is therefore to develop a methodology that is national in application and demonstrated through the two case study sites.

A review of the progress against the project's objectives as of 30 June 2017 follows.

OBJECTIVE 1

Identify coastal landform systems that are vulnerable to erosion and inundation during storms

Data availability was a criterion for the original site selection process (undertaken in Oct 2014 with end-users) and the project has collated a range of available data (e.g. elevation, bathymetry, geomorphology, geology, wave, wind), collected additional data as required (i.e. ground penetrating radar) and conducted site surveys. This data has been used in various ways for contextualising the modelling, simulating the clustered storm wave sets and running the shoreline response model.

Data products developed through this project include:

- Australian coastal sediment compartments
    - Methodology report. (McPherson et al. 2015)
    - Data available as webservices (WMS and WFS), geodatabase, kmz, pdfs, http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_87838
- Geomorphic classification for Old Bar

    - Milestone 1.4.4 report (June FY 1415): Application of the National Coastal Geomorphology Classification in a Coastal Sediment Compartment Framework (internal report to the Bushfire and Natural Hazards CRC)

- Ground penetrating radar data
    - http://www.ga.gov.au/metadata-gateway/metadata/record/100224
- Sediment analysis
    - Discoverable via the Marine Sediments database (MARS)
    - http://dbforms.ga.gov.au/pls/www/npm.mars.search

The next step for the project is to develop the impact assessments. Impact will be considered for coastal erosion and associated storm surge inundation. The National Exposure Information System (NEXIS) provides comprehensive and nationally consistent exposure information enabling users to better understand the potential elements of infrastructure at risk in Australia. It uses publicly available information, statistics, spatial and survey data to model exposure information about residential, commercial and industrial buildings, institutions (public), infrastructure assets and agricultural commodities. Whilst NEXIS contains some infrastructure data, it does not contain coastal infrastructure assets such as storm water outfalls, coastline protection elements and beach access paths and stairs.

There is a paucity of coastal infrastructure datasets at the jurisdictional level (that is discoverable and accessible) and there is no nationally consistent coastal infrastructure dataset. Given the expected impact of coastal erosion at the study sites is likely to be localised to infrastructure such as seawalls and access paths, an approach was tabled at the Research Advisory Forum held in Brisbane in November 2015 to develop the exposure data for this project for each study site.

National application of the project's methodology requires this exposure data. Each jurisdiction will be at a different state of maturity with regard to their coastal infrastructure asset management and this project has not conducted any investigation to determine the availability of such data. A national agenda would be required to develop such a national dataset and this agenda would likely be driven through either policies dealing with open data or climate change and disaster risk.

OBJECTIVE 2

Develop modelled storm surge events to represent clustering at study sites

This objective provided the input data on storm events for shoreline response modelling and has been completed for both study sites.

Products (publications and data) developed through this project include:

- A conference paper in MODSIM 2015 proceedings (Jiang et al. 2015)
- A paper in the international journal Coastal Engineering (Davies et al. 2017)

- NSW Coastal Conference presentation and paper "Probabilistic modelling of storm wave clustering at Old Bar, NSW, including the impacts of seasonal and ENSO cycles" (Davies et al. 2016)
- Australian Meteorological & Oceanographic Society (AMOS) conference presentation "Integrating ENSO and seasonal non-stationarities in probabilistic storm wave models for erosion hazard assessments" (Davies et al. 2017)
- Clustered storm event sets have been developed for Old Bar and Adelaide Beaches.

National application of the project methodology requires wave and sea level observations or model hindcasts. There are currently multi-decadal wave and tidal observations available for NSW and parts of Western Australia and Queensland, however wave observations are lacking in other areas (e.g. St Vincent Gulf near Adelaide). Installing wave observation infrastructure now will be beneficial in the longer term. However, the statistical modelling ideally requires decades or more of observations. NSW invested in this infrastructure in the 1980s following the 1974 series of storms and therefore this project has benefited from its availability. In SA the project has used modelled wave data because observations were unavailable, but in the absence of long-term historical measurements it is difficult to assess the reliability of these modelled inputs, especially in relation to more extreme wave events which are of most significance for our project. Investment in this infrastructure is a matter for the jurisdictions and a function of the risk that they are exposed to. A national forum that determines whether this risk is sufficient to seek national support would be required.

Applying the method defined in the publications above (and using the soon to be released open source software) requires a high level of statistical modelling knowledge and a willingness to work with sometimes incomplete datasets. To date, the modelling approach has been developed for a local scale model and it would be possible to extend this approach nationally by developing a set of local scale models for each site of interest, for example.

OBJECTIVE 3

Model shoreline response to storm time series

This objective has taken the synthetic time series of storm surge events as a forcing condition to model shoreline response to successive storms at the two study sites.

Products (publications) developed through this project to date include:

- Extended Abstracts
    - Investigating Site Specific Directional Wave Measurement Bias Using Inverse Ray Tracing (Gravois et al. 2015, International Conference on Coastal Engineering)
- AFAC posters

- Improving resilience to storm surge hazards: assessing risk through wave simulations, shoreline modelling and field observations. (Gravois et al. 2017 and 2016)

- NSW Coastal Conference presentations/posters:
  - Blue water waves: Inverse wave ray tracing of waverider measurements to deep water and comparison with global climate models. (Gravois et al. 2016)
  - Physical modelling of the effect of storm sequences on beach profile evolution and beach erosion (Baldock et al. 2016)

National application of the project's methodology requires high resolution bathymetry and elevation which is becoming increasingly available nationally. Conducting this kind of modelling is by necessity always going to be site specific, and will require detailed site surveys to contextualise the site within the coastal sediment compartments and geomorphic setting. This type of modelling would typically be conducted by coastal engineers who have experience in model testing and validation.

OBJECTIVE 4

Incorporate information on coastal geology, geomorphology & sediments in assessments of shoreline response modelling

This objective has provided for site specific characteristics of each study area to provide context and better constrain the modelling of shoreline response.

Products (publications and conference posters) developed through this project include:

- A paper in Journal of Coastal Research (Nichol et al. 2016)[2]
- AFAC poster - Progress on BNHCRC project "Resilience to clustered disaster events on the coast: storm surge" (Nichol et al. 2015)

OBJECTIVE 5

Quantify the impact of clustered storm surge events on coastal assets (buildings and infrastructure)

Work against this objective relates to integrating the model results with the exposure information to determine the impact of coastal erosion and inundation on coastal properties and infrastructure. Results from the clustered event modelling (objective 2) and the shoreline response modelling (objective 3) will be used to identify and map assets at risk using the approach outlined to end-

[2] Nichol, S., McPherson, A., Davies, G., Jiang, W., Howard, F., Gravois, U., Callaghan, D. and Baldock, T. (2016) A Framework for Modelling Shoreline Response to Clustered Storm Events: Case Studies from Southeast Australia. Journal of Coastal Research. Special Issue 75, 1197-1201 DOI: 10.2112/SI75-240 http://www.jcronline.org/doi/pdf/10.2112/SI75-240.1

users in December 2015 (objective 1). The extent of impact is likely to be less than initially anticipated and so there may be some minor modification made to the approach. Pending the result of the shoreline response modelling further variation to the exposure analysis method will be considered. Examples of variation to the method could include:

- where there is minimal building exposure a proximity analysis of buildings to the most landward extent of the future coastline could be calculated/summarised, and/or;
- a hybrid assessment considering the exposure of building footprints, as digitised from aerial photography, and NEXIS building/contents costs via the building point in the respective cadastral parcel containing the impacted building.

PROGRESS DURING 2016-2017

During 2016-2017, the project has completed the statistical event set generation and published the work in an international journal (Davies et al., 2017). As part of this work, the software for the statistical analysis has been developed (in draft) with user manuals and case studies developed.

Work continues on the shoreline response modelling. The Old Bar study site has confounded coastal managers for decades and this has also been borne out through the modelling exercise which has required multiple iterations to optimize model performance. This has taken longer than planned, but has provided valuable insights into the coastal dynamics of Old bar, particularly with regard to the sensitivity of wave refraction on sediment transport directions. Progress on the Adelaide Metropolitan beaches study site has been delayed due to the challenges of modelling the Old Bar site. However, lessons learned can be applied to Adelaide such that model setup will be more efficient and wave data is ready to be applied to the model.

As part of the shoreline modelling effort, the project has obtained historical data and information from NSW Office of Environment and Heritage (OEH) to build a knowledge base on historical erosion rates and changes to the shoreline. This information is of value to "ground-truth" the shoreline response modelling. The specific activities have been:

- Analysis of the Old Bar photogrammetry and Adelaide survey data to derive historical erosion rates (Figure 1)
- Geo-referencing of the scanned aerial photos from OEH and overlaying contours from photogrammetry (Figure 2)

The project will report on these activities during next FY and include in publications where applicable.

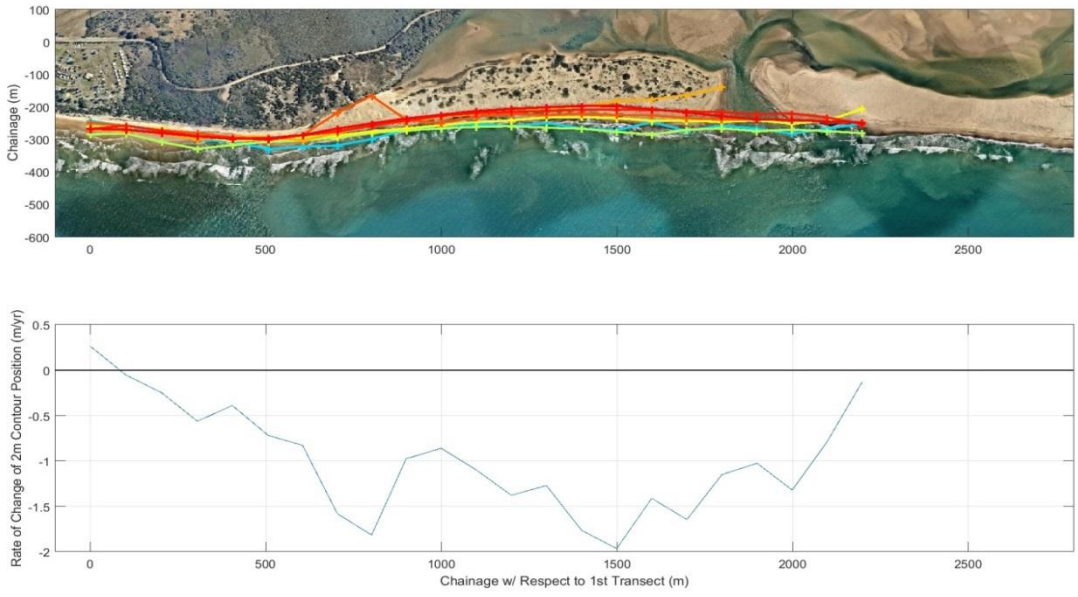

FIGURE 1: ESTIMATING HISTORIC EROSION RATES AT OLD BAR BEACH, NSW

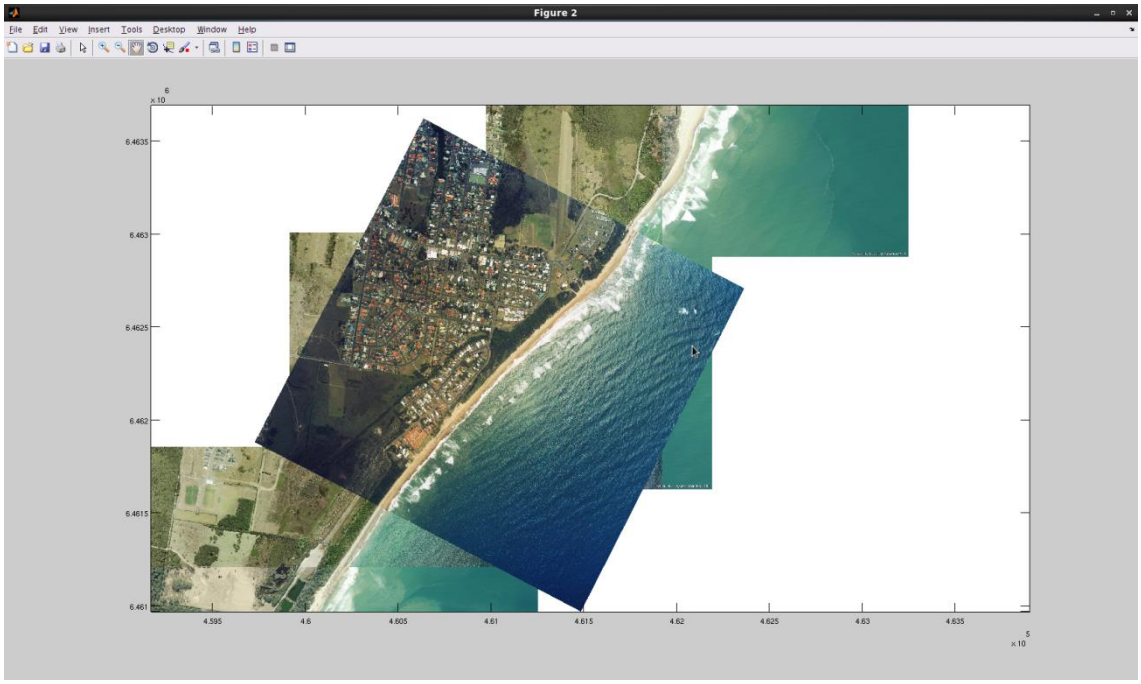

FIGURE 2: EXAMPLE OF GEOREFERENCED AERIAL PHOTOGRAPHS FROM OLD BAR BEACH, NSW

PUBLICATIONS, CONFERENCES AND MEETINGS IN 2016-17

Journal publication:

- Davies, G., Callaghan, D., Gravios, U., Jiang, W., Hanslow, D, Nichol, S. and Baldock, T. Improved treatment of non-stationary conditions and uncertainties in probabilistic models of storm wave climate. Coastal Engineering. Volume 127, 1-19. https://doi.org/10.1016/j.coastaleng.2017.06.005

NSW Coastal Conference:

- Baldock, T., Gomez, C., Gravois,U. and Callaghan. D. (2016) Physical modelling of the effect of storm sequences on beach profile evolution and beach erosion. Presentation at the 25th NSW Coastal Conference, Coffs Harbour, November 2016.
- Davies, G., Callaghan, D.P., Gravois, U., Hanslow, D., Jiang, W., Nichol, S. and Baldock, T. (2016) Probabilistic modelling of storm wave clustering at Old Bar, NSW, including the impacts of seasonal and ENSO cycles. Presentation and paper at the 25th NSW Coastal Conference, Coffs Harbour, November 2016. http://www.coastalconference.com/2016/papers2016/Gareth%20Davies.pdf
- Gravois, U., Baldock, T., Callaghan, D., Davies, G., Jiang, W. and Nichol, S (2016). Blue water waves: Inverse wave ray tracing of waverider measurements to deep water and comparison with global climate models. Poster at the 25th NSW Coastal Conference, Coffs Harbour, November 2016.

AMOS:

- Davies, G., Gravois, U., Callaghan, D.P., Baldock, T., Hanslow, D. and Nichol. S. (2017) Integrating ENSO and seasonal non-stationarities in probabilistic storm wave models for erosion hazard assessments.

AFAC:

- UQ attended AFAC 2016 and participated in the poster session (Gravois et al. 2017 Improving resilience to storm surge hazards: assessing risk through wave simulations, shoreline modelling and field observations).

Bushfire and Natural Hazards CRC Research Advisory Forum:

- The Project Leader presented an update at the November 2016 RAF held in Canberra. Given availability of the second project in the coastal cluster, a coastal cluster meeting was deferred to April 2017.

UTILISATION

The project held a coastal cluster meeting and utilisation workshop on 3 April 2017 at GA in Canberra. The end-users confirmed that utilisation should be focused on ensuring the package of data, information and tools are packaged and disseminated to relevant stakeholders and made discoverable and accessible online. The end-users identified opportunities for promotion through, for example, the National Committee of Coastal and Ocean Engineering and their associated seminars. The utilisation plan is included in Appendix A. The project showed how the newly released NSW wave transformation data can be used within the modelling framework which thereby means that state-wide application with this data is achievable.

LINKS TO OTHER RESEARCH PROGRAMS

The project is collaborating with the University of Wollongong on a three year ARC Discovery Grant 'Sedimentary processes on sandy coasts in southern Australia' that commenced in January 2015. The ARC project team completed their first field work campaign in early December 2015 in Gippsland, Victoria. This involved reconnaissance Ground Penetrating Radar surveys of the coastal barrier systems in Gippsland with participants from University of Wollongong and University of Melbourne. Additional fieldwork on the NSW south coast was undertaken in March-April 2016, with collection of sediment cores from low lying barriers. During 2016-2017, the ARC project has focussed on analysis of sediment cores (grain size and optical dating) to develop a chronology for prograded coastal sand barriers on the NSW south coast with a focus on the transition from shoreline retreat to shoreline advance during the mid-Holocene period. This information will be of value to this BNHCRC project and end-users in adding to the overall understanding of shoreline response to sea-level change at the scale of coastal sediment compartments.

In collaboration with CSIRO and the ANU, GA has developed the Australian Geoscience Data Cube (AGDC) that contains the historical archive of Landsat satellite data for Australia. While the spatial resolution of the Landsat archive is

not sufficient to map coastal erosion in detail, new satellites such as Sentinel 1 will present opportunities to explore this issue in the future. The AGDC has also been used to produce the National Intertidal Extents Model (ITEM). This is a continental-scale model that maps the spatial extents of the exposed intertidal zone at various stages of the tidal cycle[3] and will be of value for understanding nearshore wave processes and sediment dynamics (erosion and accretion) at the scale of primary and secondary coastal compartments.

Building on the Australian Geoscience Data Cube, the Australian Government has invested in Digital Earth Australia to deliver a unique capability to process, interrogate, and present Earth observation satellite data for analysis. This capability will support responses to issues such as environmental management, resource development and optimizing agricultural potential. This platform[4] will become publicly accessible that will enable research and innovation to investigate coastal impact and risk questions.

LINKS TO GOVERNMENT POLICIES

New South Wales

The NSW State Government is progressing its Coastal Reforms with the passing of the Coastal Management Bill and release of a draft Coastal Management State Environment Planning Policy (SEPP) and draft maps of the coastal management areas that make up the coastal zones for public consultation. This program incorporates consideration of the National coastal sediment compartment framework and formally requires councils in the same secondary compartment to consult before adopting a coastal management program. The reforms include significant investment funding for the mitigation of future coastal risks and in data collection and science including offshore mapping of sediment compartments. During 2016-2017, the NSW Nearshore Wave Forecast tool was released[5]. The tool was developed in collaboration between NSW Office of Environment and Heritage, Baird Australia and NSW Public Works Manly Hydraulics Laboratory. The project has utilized this data as described earlier in the report.

Queensland

Following Tropical Cyclone Debbie in March 2017, the Queensland Fire and Emergency Services launched a review of the disaster management system[6]. Coastal erosion and storm surge damage from this event was assessed by Queensland Department of Science, Information Technology and Innovation which could be drawn on for any future studies in those affected regions. Queensland Government held a public consultation process to remake the Coastal Protection and Management Regulation that closed in February 2017.

[3] http://www.ga.gov.au/metadata-gateway/metadata/record/100600
[4] http://www.ga.gov.au/about/projects/geographic/digital-earth-australia/?utm_source=2017-promotion&utm_medium=Sliderbanner-DEA&utm_content=DataCube-WebContentPage&utm_campaign=DigitalEarthAustralia
[5] http://www.environment.nsw.gov.au/research/ocean-and-coastal-waves.htm
[6] http://statements.qld.gov.au/Statement/2017/4/9/major-review-of-disaster-management-effectiveness-announced

South Australia

The results from this study are intended to improve the assessment of erosion buffers in protecting future development and improving the management of Adelaide's beaches as part of Living Beaches strategy (2005-2025).

Victoria

The Victorian Department of Environment, Land, Water and Planning is currently scoping the use of coastal compartments to undertake a coastal erosion study in prirority areas of Victoria. The work would adopt similar methods employed in this project, including mapping of coastal and nearshore geomorphology and sediment transport modelling.

National

The National Climate Change Adaptation Research Facility (NCCARF) has released the final version of the CoastAdapt tool[7]. The tool will host a range of information, data and tools to provide practical guidance on how to manage the risks from climate change and seal-level rise around Australia. Following consultation in late 2016, the tool included a range of improvements and changes, including a guide to hazard mapping and additional research reports. The project will engage with NCCARF during 2017-2018 to gauge interest in promoting this project's outputs via the CoastAdapt tool.

[7] https://www.nccarf.edu.au/content/coastal-tool-overview

APPENDIX A - UTILISATION PLAN