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RESILIENCE TO CLUSTERED DISASTER EVENTS AT THE COAST: STORM SURGE

Annual project report 2014-2015

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Cover: A Geoscience Australia officer operating 250MHz ground penetrating radar at Old Bar Beach, NSW, March 2015.

Photo: Geoscience Australia.

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. Traditional wisdom indicated that there were two storms that led to the coastal impact (May and June). However, the reanalysis data sets indicate that between January and June of 1974, there were at least 10 events but not all of these events led to coastal erorion. These prior events would have 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.

How are you going to solve it?

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

The study will focus on two case studies determined in consultation with the project end-users. Defining the hazard is non-trivial as it may be difficult to identify clustered events in the historical record. Determining the impact from a clustered event set will need to take into account the beach recovery time for the two sites. The coastal compartment framework provides the functional unit for understanding the shoreline response at a range of spatial scales, and detailed geomorphological site investigations will be undertaken and analysed within this framework for input to the beach response modelling.

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

END USER STATEMENT

Martine Woolf, Geoscience Australia, ACT

The impacts of severe storms on coastal communities can be significant and extensive. This was demonstrated again recently by the East Coast Low in NSW in April 2015. This project aims to improve our understanding of the potential consequences when events occur in relatively quick succession. The ability to quantify the frequency and severity of event 'clusters' and their impact are key to appropriate risk management of coastal communities.

This project is a collaborative effort between Geoscience Australia and the University of Queensland. At the end of its first year, the project is well underway. As well as completion of planning and fieldwork, some first analysis results are now also available.

As for all CRC projects, engagement between end-users and researchers is a key component of the CRC philosophy. This project has sought to engage end-users in the scoping of the work and potential outputs, the selection of the study sites, and keep them up to date on high-level progress. This engagement will continue to be important as the work progresses during the next phase. While the work focuses on particular study sites, it is important that results and outputs can be generalized to all other areas where storm surge impacts are a significant issue. End-user engagement will help ensure that the outputs of this work are relevant for different practitioners throughout Australia.

INTRODUCTION

Coastal communities in Australia are particularly exposed to clustered disasters, 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 Nina 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 processes that drive the coincidence or clustering of natural disasters are reasonably well understood. However, there is as yet no clear methodology in use to quantify the elevated risk to communities from clustered or coincident events. Typically, risk assessments are based on individual hazards against a long-term frequency baseline. This is potentially misleading as it underestimates the true impacts of coincident or clustered events on the resources and resilience of communities.

While clustering of events can add significant impact to all natural hazards, coastal communities are particularly sensitive to clustering because of the dynamic nature of the coast. Coastal landforms are not static, and themselves are vulnerable to the impact of the hazards. Coastal landforms provide the physical foundation of coastal communities, as well as potentially forming natural protection to those communities. Inadequate techniques that do not take a holistic approach to the dynamic response of coastal landforms and communities to clustered events can lead to inappropriate decision-making or funding allocation.

This study will demonstrate how a methodology developed for storm surge events can be applied to better inform decisions around resource investment in terms of disaster mitigation, planning and response and thereby optimise the resilience of the communities involved. Case studies will apply this methodology to coastal communities at selected areas in eastern and southwest Australia.

This project will provide a powerful combination of two conceptual frameworks: firstly, the framework that quantifies risk as the product of severity and frequency of impact defined by hazard, vulnerability and exposure, and secondly the framework of the coastal sediment compartment as the functional unit for modelling shoreline response to storm surge. The sediment compartment framework spans a hierarchy of spatial scales, and provides a basis to enable robust and consistent modelling of shoreline response. Furthermore, the conceptual framework places local studies into a regional context for improved coastal risk management. Geoscience Australia recently developed a national classification of coastal compartments for the entire Australian coast, and this study will build and extend that work to integrate with the risk assessment framework, supporting outcomes with applications at a national, regional and local level.

PROJECT BACKGROUND

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:

- Examine the physical characteristics of coastal landforms at study sites that are vulnerable to storm surge erosion, as identified by end-users;
- Develop and validate an approach to model the frequency and severity of storm surge events, incorporating clustered events;
- Critically assess available conceptual and numerical models describing and quantifying physical responses of coastal landforms to storm surge;
- Demonstrate the value of an integrated methodology to quantify the impact of clustered storm surge events on coastal assets (buildings and infrastructure);

To meet these objectives, the project will be undertaken through a number of phases:

1. Project planning
    a. Engage State and Territory end-users to revise and refine the project plan
    b. Select study sites to ensure the utility of outputs for emergency management and land-use planning. Study sites based on the following criteria:
        i. Availability of data, including:
            1. Elevation – access to LiDAR derived elevation surfaces is key, both topographic and bathymetric.
            2. Geomorphology – including datasets such as the NSW Coastal Geomorphology Classification.
            3. Stratigraphy – subsurface studies to help inform estimates of sediment volumes in beach-barrier systems
            4. Access to previous local studies – where available. In particular, any sediment transport or process modelling studies in the region.
        ii. Areas that are of interest to end-users – particularly sites where a better understanding of shoreline response to coastal storms, and impacts on infrastructure is needed for land use planning.
        iii. Representative of a common coastal (beach-barrier) morphotype – this will ensure applicability of developed approach to other locations. Morphotype(s) that are more likely

to experience significant erosion and damage to infrastructure will be selected.

iv. Where storms, and in particular, sequences of storms have occured and where we have some understanding of the metocean drivers of these events.

v. Political sensitivity/iconic sites – these issues may need to be considered when selecting a site.

2. Model coastal susceptibility/vulnerability to hazards for the Case Studies
    a. Work with the end-users to establish a lexicon of scientific nomenclature to describe coastal landforms across a predetermined hierarchy of scales, applicable to all coastal regions around Australia;
    b. Describe the study sites in terms of their location in the Primary/Secondary and Tertiary Compartment level and where possible the Sediment Compartment.
    c. Identify landforms on unconsolidated sedimentary coasts in each case study region, and assess their context in terms of the characteristics of the Secondary and Tertiary Compartment level.
    d. Rate the indicative vulnerability/susceptibility of coastal landforms to inundation and erosion hazards.
3. Critical assessment and development of conceptual and numerical shoreline response models
    a. Identify and critically evaluate conceptual and numerical models used to describe inundation and erosion and their impact on the developed coast;
    b. Develop a set of modelled storm surge 'events' that reflects the full range of historical and potential events at the study regions;
    c. Develop and implement a methodology that reflects the impact of clustering on the distribution of severity and frequency of storm events.
    d. Reconstruct historical shoreline responses to storm surge inundation based on existing databases and identify key data gaps;
    e. Fill any essential data gaps using field investigations in collaboration with existing State, Territory and Commonwealth Government, and University programs.
4. Assess the impact and risk of hazards
    a. Categorise exposure (buildings/infrastructure/coastal defences) on each sedimentary coast morphotype in the study area;
    b. Determine management problems specifically related to coastal infrastructure which were encountered during historical storm passage; relate the historical events to the frequency/severity distribution developed above;

c. Develop site-specific vulnerability models to inundation based on empirical data and existing vulnerability models;

d. Resolve the magnitude and rate of shoreline change and determine the impact zone for each event/cluster of events in the modelled event set;

e. Quantify the risk on coastal communities (including infrastructure and habitats) in terms of probability of (economic) impact and loss.

5. Synthesis

a. Apply results to coastal hazard planning at local and regional scales by evaluating the effectiveness of a range of adaptation/mitigation responses. Adaptation/mitigation responses could include e.g. retreat, beach nourishment, zoning, and improved infrastructure, and would be scoped in collaboration with end-users.

b. In consultation with end-users, develop communication material to include:

i. Identification how the results from this study can be incorporated into a comprehensive assessment of the resilience of coastal communities and infrastructure to natural hazards.

ii. Recommendations for a national approach to the acquisition of coastal data and recommend to be considered by COAG to minimise the impacts of coastal risks.

The outcomes of this project include:

- Support for an improved ability of coastal managers and planners to make informed decisions and prioritise resource investment, based on appropriate, quantitative information regarding clustered storm surge events;
- A conceptual framework for integrating coastal studies across a range of spatial scales (local/regional/national);
- A demonstrated methodology for quantifying the impact of clustered events on coastal infrastructure;
- Recommendations for a national approach to the acquisition of coastal data and recommend to be considered by COAG to minimise the impacts of coastal risks;
- The development of a nationally consistent methodology to assess the potential impact of coastal hazards.

WHAT THE PROJECT HAS BEEN UP TO

The project officially started in July 2014 and the first year of the project has focused on refinement of project objectives with end-users, selection of study sites, desktop data collection and analysis, and field work.

WORKSHOPS

The first **end-user workshop** was held at Geoscience Australia on 14 October 2014 with the purpose of:

- Selecting two study sites for the project, and;
- Determining a way forward to establish a schema for describing coastal landforms across a hierarchy of scales, applicable to all coastal regions around Australia.

The workshop outcomes were:

- Identification of two (2) case study sites; one in South Australia (Adelaide Metropolitan Beaches) and the other in New South Wales (Old Bar - NSW mid-north coast).
- Agreement to develop a schema that will be used to characterise the two study sites at a level that is meaningful and useful for coastal managers. This characterisation and supporting fieldwork will also provide context to the shoreline response modelling component as well as a level of verification.

A summary of the workshop was distributed to end users and submitted to the CRC as part of Q2 reporting (Geoscience Australia 2014a). The selection of study sites then focused the data collection process, summarized in Geoscience Australia 2015a and 2015b.

The project also participated in the **coastal cluster workshop** (3 December 2014) at the BNHCRC Research Advisory Forum at RMIT in Melbourne. Here a greater understanding of the two coastal projects was gained, dependencies between the projects identified, approaches to identifying clustered events discussed, and end-user requirements further refined. The project's science plan (Geoscience Australia 2014b) was revised following this workshop and submitted to the CRC as part of Q2 reporting.

RECRUITMENT

The research team is from Geoscience Australia (GA) and the University of Queensland (UQ). GA and UQ operate through a Collaboration Agreement (initiated February 2015) and through this agreement, Uriah Gravois was formally recruited as a post-doctoral fellow (starting June 2015). Uriah recently completed his PhD at the University of Florida and brings expertise in wave modelling and beach morphodynamics to the project.

FIELD WORK

Field work was completed in Adelaide from 16–19 February 2015 and at Old Bar from 2–5 March 2015. The Coastal Protection Board (SA Department of Environment, Water & Natural Resources) in South Australia was engaged in the planning for the investigations in Adelaide and accompanied the field team on the first day of the survey. Similarly, the Greater Taree City Council was consulted and provided access permissions for Old Bar beach as well as providing in-field guidance to the field team.

The field investigations collected ground-penetrating radar (GPR) data from the two study areas with the aim of identifying and defining a minimum thickness for beach and dune sediments (Figure 1). An additional goal was to determine the presence and depth to any identifiable competent substrate (e.g. bedrock) or pre-Holocene surface which may influence the erosion potential of incident wave energy. Surface elevation data was co-acquired and used to topographically correct the GPR profiles.

FIGURE 1: FIELD INVESTIGATIONS TEAM CONDUCTING THE GPR SURVEY AT OLD BAR IN MARCH 2015. LEFT-HAND IMAGE: ANDREW MCPHERSON AND SCOTT NICHOL, RIGHT-HAND IMAGE: FLOYD HOWARD.

An example GPR radargram (with interpretation) from Old Bar Beach is shown in Figure 2. The image shows the dissected nature of the buried bedrock and the infilling of voids with sediment. This interpretation has been verified by subsequent ground-truthing using a sand probe. Sedimentary structures revealed by the GPR data also provide insight into the evolution of the beaches. Sediment samples for grain size analysis were also collected from the beach face below the berm at several of the GPR profile locations. These samples are being processed by the University of Queensland, and provide additional data for characterising the beach environment.

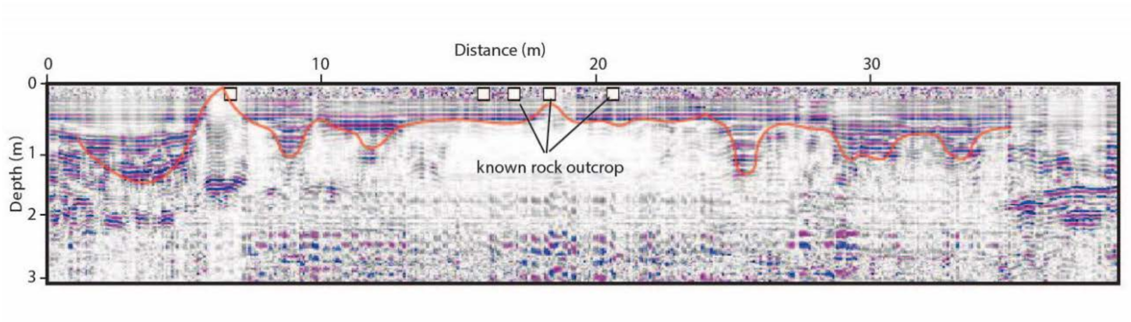

FIGURE 2: GPR RADARGRAM (250 MHZ) SHOWING THICKNESS OF BEACH SAND ABOVE BURIED DROCK ALONG A SHORE-PARALLEL TRANSECT SOUTH OF THE SURF CLUB AT OLD BAR. WHITE SQUARES SHOW LOCATIONS OF ADJACENT ROCK OUTCROP.

The field investigations were complemented by desktop geomorphic mapping as part of Q4 reporting (Geoscience Australia 2015d). The geomorphic mapping used the coastal sediment compartment (CSC) framework and applied the National Coastal Geomorphology Classification (NCGC). Within the CSC, Primary and Secondary compartments have been mapped nationally, and an application at the tertiary compartment scale at the Old Bar site was included as part of Q4 reporting (Geoscience Australia 2014c). It is at this local Tertiary scale, that the classification readily permits first pass assessments of relative landform dominance, providing an immediate sense of potential landform vulnerabilities and offering a means of prioritising sections of coastline for further investigation. While the NCGC units provide important information on the nature and location of the landforms themselves, the classification offers further benefits by providing process-based units which can be populated with additional data and information to assist in refining an understanding of risk to a given hazard.

The report describing the field investigations and the geomorphic mapping has been targeted to inform the shoreline response modelling component to the project. This modelling work is now underway, with a draft literature review completed that will inform an evaluation of the available models for use in this project (University of Queensland, 2015). These shoreline response models will be driven by a statistical event set that has been developed by the project using observational data from wave-buoys for the two study sites. The statistical analysis approach has been submitted for publication at the MODSIM conference in December 2015 (see Papers and Conferences section).

No major equipment purchases have been necessary for this project, as GA or UQ already have the necessary equipment – GA owns the Ground Penetrating Radar (GPR) and UQ owns the grain-size analyser.

INSIGHTS FROM STORMS IN 2015

The project has gained valuable insights from storm events that impacted both study sites in early 2015. During April, a storm generated by an East Coast Low offshore Sydney led to erosional impact in the Sydney area and central coast, including Narrabeen Beach. The Sydney Morning Herald reported 25 metres retreat of the Narrabeen shoreline after the storm event, with a maximum wave height of 14.9 metres offshore on April 23, 2015. Pre- and post-storm shorelines at Narrabeen are shown in Figure 3[1].

FIGURE 3: COMPARISON OF NARRABEEN'S COASTLINE PRIOR AND POST TO THE SEVERE STORM IN APRIL 2015. THE SHORELINE RETREAT IS MEASURED AT 25 METRES. *(PHOTO: DR MITCHEL HARLEY)*

Following this event, staff from the NSW Office of Envrionment & Heritage measured run-up limits and conducted post storm beach surveys between Wollongong and Jimmy's Beach (near Hawks Nest, Newcastle region).

The impact of this event at Old Bar was less than in Sydney due to distance from the storm centre. Changes observed by the Greater Taree City Council included minor undercutting of dune supported by geotextile bags in front of the Meridian Resort (Figure 4), exposure of rock on the upper beach to the south of the surf club (Figure 5) and minor erosion near the lookout to the north of the surf club (Figure 6).

1 http://www.smh.com.au/environment/weather/sydney-weather-waves-break-records-as-erosion-sees-narrabeen-retreat-25-metres-during-storm-20150422-1mqqjc.html (last accessed 2 July, 2015)

FIGURE 5: ROCK EXPOSED TO THE SOUTH OF THE SURF CLUB AT OLD BAR BEACH FOLLOWING THE APRIL STORM. COURTESY OF MICHAEL GRIFFITHS, GREATER TAREE CITY COUNCIL.

FIGURE 6: EROSION NEAR THE LOOKOUT TO THE NORTH OF THE SURF CLUB, OLD BAR BEACH FOLLOWING THE APRIL STORM. COURTESY OF MICHAEL GRIFFITHS, GREATER TAREE CITY COUNCIL.

South Australia also experienced storms in April and May 2015, with the 6 May event resulting in coastal erosion. The 6th May event coincided with high tides as shown Figure 7. The surge height equates to approximate a 1 in 2, or 1 in 3 year ARI event.

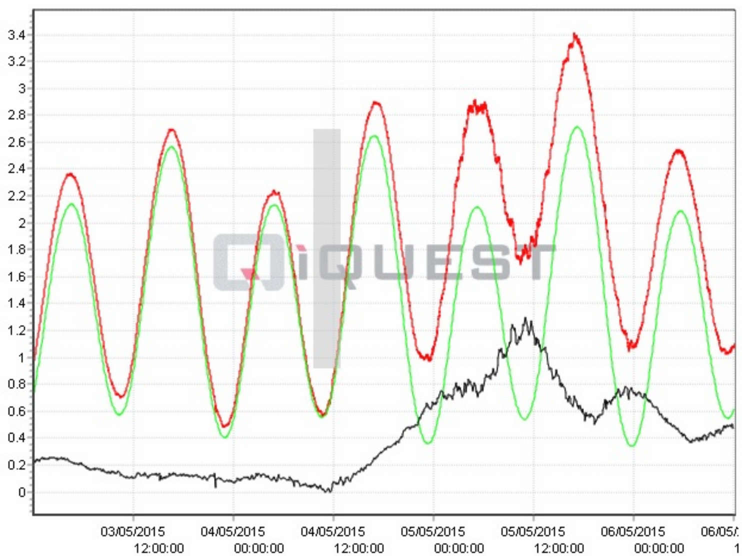

FIGURE 7: TIDE RECORD FROM OUTER HARBOUR AT THE ADELAIDE PORT INDICATING A 0.6 M SURGE AT HIGH TIDE.

The Adelaide beaches were still low from the April event and dune erosion on the order of 4 to 5 metres occurred in some locations along the metro coast (and elsewhere). There was some relatively minor infrastructure damage at Henley Square where concrete access steps under construction were damaged[2].

There was also a moderate storm on Easter Monday (April 6th), however the main surge occurred during low tide. This resulted in a lowering of beach levels by at least 1.0 metre overnight, but no dune erosion.

LINKS TO OTHER RESEARCH PROGRAMS

The project leader is a named participant on an Australian Research Council Discovery Grant led by Professor Colin Woodroffe, University of Wollongong, titled 'Sedimentary processes on sandy coasts in southern Australia'. The ARC project complements the BNHCRC project in that it will generate valuable background information on the evolution of coastal barrier systems over geological timescales and include case studies at sites in NSW and SA. As such, this will contribute to our contextual understanding of the Old Bar and Adelaide coastal compartments. The ARC project is also using ground penetrating radar technology to map the internal structure of coastal dune and beach systems at selected sites that will add to our understanding of the impact of storm events on beach barrier evolution.

The project leader is also in contact with researchers at the University of NSW and Macquarie University who have separate ARC Discovery Grants to examine sediment transport and shoreline dynamics on east coast beaches. While not directly involved, this connection provides the opportunity to share knowledge at an informal level.

PAPERS AND CONFERENCES

Abstracts for three conferences have been prepared:

- MODSIM 2015 (accepted)
    - Jiang, W., Davies, G., Callaghan, D., Baldock, T. and Nichol, S. *Statistical modelling of extreme ocean climate with incorporation of storm clustering.*
- AFAC 2015 (accepted as poster)
    - Nichol, S., McPherson, A., Howard, F., Jiang, W., Davies, G., Moore, D., Baldock, T., Callaghan, D., Woolf, M., Hanslow, D. and Guy, J. *Progress on BNHCRC project "Resilience to clustered disaster events on the coast: storm surge".*
- International Coastal Symposium 2015 (submitted)

[2] http://www.adelaidenow.com.au/messenger/west-beaches/how-tuesdays-storm-in-adelaide-has-destroyed-a-building-site-delayed-work-on-84m-henley-square-revamp/story-fni9llx9-1227338742385 (last accessed 2 July, 2015)

  - Nichol, S., Baldock, T., Callaghan, D., Davies, G., Howard, F., Jiang, W., McPherson, A. *A Framework for Modelling Shoreline Response to Clustered Storm Events: Case Studies from Southeast Australia*.

The MODSIM abstract has been accepted as a paper which has been prepared for submission (due July 2015) for the December 2015 conference to be held on the Gold Coast. If the International Coastal Symposium abstract is accepted, a paper will be submitted for publication in the proceedings of the conference in the Journal of Coastal Research.

PUBLICATIONS LIST

Jiang, W., Davies, G., Callaghan, D., Baldock, T. and Nichol, S. 2015. *Statistical modelling of extreme ocean climate with incorporation of storm clustering*. Abstract accepted by MODSIM2015, 21st International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2015.

Nichol, S., McPherson, A., Howard, F., Jiang, W., Davies, G., Moore, D., Baldock, T., Callaghan, D., Woolf, M., Hanslow, D. and Guy, J. 2015. *Progress on BNHCRC project "Resilience to clustered disaster events on the coast: storm surge"*. AFAC 2015, poster session.

Nichol, S., Baldock, T., Callaghan, D., Davies, G., Howard, F., Jiang, W., McPherson, A. *A Framework for Modelling Shoreline Response to Clustered Storm Events: Case Studies from Southeast Australia*. Submitted to International Coastal Symposium, 2016.

CURRENT TEAM MEMBERS

Researchers:

Geoscience Australia

- Scott Nichol,
- Andrew McPherson,
- Floyd Howard,
- Wenping Jiang,
- Gareth Davies,
- Duncan Moore,
- Katherine Owens (graduate on rotation)
- Jane Sexton (project manager).

University of Queensland

- Tom Baldock,
- David Callaghan,
- Uriah Gravois (post-doctoral fellow).

End-users:

- David Hanslow (NSW Office of Environment and Heritage),
- Kaylene Jones (NSW State Emergency Services),
- Robert Schwarz (QLD Department of Science, Information Technology, Innovation and the Arts),
- James Guy (SA Department of Environment, Water and Natural Resources).

FIGURE 8: SOME OF THE PROJECT TEAM AT A MEETING AT OLD BAR, FROM LEFT TO RIGHT, GARETH DAVIES, TOM BALDOCK, DAVID CALLAGHAN, URIAH GRAVOIS, DAVID HANSLOW, SCOTT NICHOL AND WENPING JIANG.

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3 Geoscience Australia. 2014a. *Summary report from end-user workshop 14 October 2014 Site Selection and Approach to Coastal Landforms Schema*. Quarter 2 Milestone Report.

4 Geoscience Australia. 2014b. *Project Plan - Resilience to clustered disaster events on the coast – storm surge.* Quarter 2 Milestone Report.

5 Geoscience Australia. 2015a. *Identified data on study sites: Old Bar and Adelaide Beaches.* Quarter 3 Milestone Report.

6 Geoscience Australia. 2015b. *Identified data on study sites: Old Bar and Adelaide Beaches - Supplement.* Submitted to CRC at Quarter 4.

Geoscience Australia. 2015c. *Application of the National Coastal Geomorphology Classification in a Coastal Sediment Compartment Framework.* Quarter 4, Milestone Report.

7 Geoscience Australia. 2015d. *Coastal geomorphology of Old Bar and Adelaide Metropolitan Beaches: considerations for coastal erosion modelling*. Quarter 4. Milestone Report.

8 University of Queensland. 2015. *Review of beach profile and shoreline models applicable to the statistical modelling of beach erosion and the impacts of storm clustering*. Quarter 4, Milestone Report.