Insurance Council of Australia

Climate Change Impact Series: Actions of the Sea and Future Risks

October 2021

insurancecouncil.com.au

Contents

Top takeaways

1

Climate change is driving rising sea levels and exacerbating coastal hazards known as "Actions of the Sea" such as coastal inundation, erosion, and recession.

This is leaving Australian communities, properties, and critical infrastructure increasingly vulnerable. As these events increase in frequency and intensity, a growing number of exposed properties in Australia will become uninhabitable. Insurance coverage is limited in these areas due to the high and growing risks, creating a protection gap.

2

Significant additional investment will be required to mitigate the risks of coastal inundation and sea level rise.

It is estimated that Australia will require at least $30 billion (net present cost) of investment in large scale coastal protection and adaptation projects over the next 50-years. This is approximately 1.2% of all of Australian Governments (States, Territories and Federal) general infrastructure average yearly spend.[1] Whilst a modest amount, this spend will deliver returns on investment attributed to avoided damage and financial loss and additional economic loss due to community disruptions. There are, however, limits to mitigation and in some cases adaptive management and planned retreat from the coastal hazard zone may be the best option for communities over the long term.

3

Urgent action is needed at all levels of government, in collaboration with industry, to build a national picture of coastal hazard risks and how to address it.

This could be achieved via federal and state collaboration to build a Coastal Hazard Information Database to measure and monitor actions of the sea as sea levels rise; this should include a Coastal Defence Register.

4

The insurance industry stands ready to collaborate with government to share our risk intelligence to help mitigate these growing challenges.

Public/private partnerships can work together to set robust land planning and building codes which play a critical role in reducing risk to property holders and enabling affordable insurance.

[1] Infrastructure Partnerships Australia (2021) Australian Infrastructure Budget Monitor 2020-21. Accessed at Australian-Infrastructure-Budget-Monitor.pdf

Introduction

Climate change is driving rising sea levels and exacerbating coastal hazards known as “Actions of the Sea.” This is leaving Australian communities, properties, and critical infrastructure increasingly vulnerable. This risk management challenge will only grow bigger as climate change impacts worsen.

Actions of the sea include the risks of tidal inundation, coastal and estuarine inundation, coastal erosion, shoreline recession, sea level rise, tsunami.

As sea levels rise, Australia’s exposure to coastal erosion and inundation will increasingly render exposed properties uninhabitable. In the context of the insurance industry, “Actions of the Sea” represent a protection gap, where insurance coverage has limited availability due to the inevitable nature of the risk to exposed properties. The insurance industry seeks to reduce this protection gap by raising risk awareness and advocating for risk mitigation and adaptation with communities and governments.

Industry considerations

Australia’s population and major economic infrastructure and assets are concentrated along the coast, resulting in Australia having a very high vulnerability to current and future risks from Actions of the Sea. The Insurance Council of Australia (ICA) commissioned a detailed investigation into Actions of the Sea (see *Technical Report*) to highlight the increasing coastal hazard risks that will be exacerbated by climate change and to identify the next steps required to address the urgent and growing protection gap and build a more resilient and insurable Australia.

It is not standard practice for insurers to offer cover for Actions of the Sea globally. There is currently a lack of data and knowledge to understand the risks, and until there is a better understanding of these risks, insurers will be unable to adequately assess, quantify and consider underwriting. Even then, there is no guarantee that insurers would be able to provide products to cover Actions of the Sea. We recognise that Actions of the Sea present broader community issues, and that there is considerable uncertainty about the best way to address these risks. Many communities are at risk now, as a significant amount of property and assets have been built in exposed areas around Australia’s coast.

Although the risks and issues are complex, our report highlights that there are clear data and knowledge gaps. Urgent action is needed at all levels of government, in collaboration with industry, to build a national picture of coastal hazard risks and how to address it. At risk communities need Government action and planning now.

In a climate changed future these risks will be exacerbated by Sea Level Rise. Planners, and particularly land use planners, will need knowledge of best practice options to mitigate these risks.

There is an urgent need to open conversations of possible retreats. The community needs to be informed about the risks at play so that they can be incorporated into purchasing decisions, emergency response plans or future decisions.

The ICA will continue to raise awareness regarding coastal hazard risk and work to educate the community; we will also engage key stakeholders to catalyse action on specific initiatives to mitigate risks.

Actions of the Sea from a changing climate will bring about increasing risk, not all of which will be insurable. Government and Industry must collaborate now to build our knowledge and develop a path forward, to avoid, or at least reduce, this growing protection gap.

Snapshot of the technical report

The ICA Climate Change Action Committee investigated community concerns regarding coastal hazards and sea level rise by commissioning an issues paper into Actions of the Sea. This report, delivered by Baird Australia, identified key issues and associated recommendations that would improve Australia's resilience against coastal hazards in the context of rising sea levels.

The key issues are summarised into three themes:

1. Scale of Mitigation Investment
2. Data and Risk Assessment
3. Consistent and Risk Based Land Planning and Engineering Design Standards

Outcomes from the investigation

Scale of Mitigation Investment required

The Scale of the problem is yet to be appreciated

Sea level rise has the strongest confidence of future climate projections and will continue to rise over the next 100 years and beyond regardless of our future emissions pathway (IPCC AR6 2021).[2] As sea level rises, communities are faced with options to defend or retreat from the impending hazard. Australia has very high exposure to current and future risks from Actions of the Sea, and government and communities generally do not understand the scale of investment in mitigations and responses to sea level rise that will be required. For example, based on relative population and GDP, it is estimated that Australia will require at least $30 billion (net present cost) of investment in large scale coastal protection and adaptation projects over the next 50-years.

National Scale Response - Local Scale Mitigation

The cost of mitigation against coastal hazards in the context of sea level rise often exceeds the economic value of individual assets protected on an annualised basis over the asset life. For example, recent seawall defence works at Collaroy/Narrabeen in Sydney has cost an average of $230,000 per property that has been borne by property owners. Property protection at this cost is unaffordable to many in less prestigious areas. The economic impacts from actions of the sea need to be considered on a regional basis, with regional responses funded by federal, state and local government. Coastal defence options are also highly localised, so locally appropriate responses need to be funded on a priority basis.

It's not all about engineered defences

There are practical limits within the current land use planning regimes and property tenure arrangements for long-term protection from sea level rise. Simply put, there are limits to the effectiveness of engineered or natural mitigation efforts as sea levels rise and coastal hazards worsen. Adaptive management and planned retreat from the coastal hazard zone may be the best option for community over the long term. It is important that Actions of the Sea and sea level rise is managed by government, so it is in the best interests of the wider local community, not just landowners in the coastal impact zone. These approaches need to be accommodated in planning controls and land tenure and funded from sustainable schemes at the state or federal level.

Recommendations:

- That the federal and state governments:
  - **Collate** the available coastal mitigation options and priorities from local council and coastal management studies to provide a high-level view of the scale of the assets at risk and mitigation options and investment required to protect Australia's coastline.
  - **Fund:** establish long term funding mechanisms for coastal mitigation priorities through the peak infrastructure bodies (e.g. Infrastructure Australia, Infrastructure NSW) to local governments.

---

[2] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

- ◦ **Pilot** adaptive management and retreat schemes and use lessons learnt to make amendments to land use planning controls to enable retreat as a viable option.

1. Data and Risk Assessment

What is our National Level risk to coastal hazards?

A plan to address Australia's exposure to coastal hazards as sea level rises requires national level view of risk. Whilst many local councils have completed coastal hazard studies and coastal management plans, the data is not collated at a state or federal level, available for other stakeholders and is often inconsistent between jurisdictions. Limited available and accessible hazard data and vulnerability data makes quantifying risk from an insurance perspective extremely difficult and limits assessment of improved coverage for some hazards.

Recommendations:

- **Coastal Hazard Information Database:** That federal and state agencies (e.g. the National Recovery and Resilience Agency (NRRA), the Australia Climate Service, Resilience NSW) collate available local government coastal hazard information into databases and make it publicly available including to the community and financial services industry.
- This should include an understanding of exposure to coastal hazards to a worst-case scenario (beyond the 1% AEP) and sea level rise beyond 2100.
- **Asset Register:** establish and maintain a National Exposure Dataset that captures property attributes relevant to coastal vulnerability such as height above ground level, nature of substrate, construction type, building location, foundation type.
- **Coastal Defence Register:** establish a database of coastal defence works including the standard of protection offered to different hazards, age, maintenance regime and cost.
- **Event Monitoring:** Understanding of coastal hazards would be improved by periodic and post-event high-resolution survey by Light Detection and Ranging (LiDAR) or UAV (drone).

2. Consistent and Risk Based Land Planning and Engineering Design Standards

The insurance industry advocates for robust land planning and building standards that minimises risk to property holders. There should be consistency in state and government risk-based approaches to sea level rise scenarios and defining acceptable hazard levels for inundation. The insurance industry would like to be engaged in the setting of land planning and building codes so that the residual risk is manageable to enable affordable insurance. However, this will first require appropriate availability of hazard and asset register data sets to quantify the risk from a financial perspective.

Recommendations:

- **Greenfields Development - *Don't make a bad problem worse*:** Establish consistent risk-based principals for location of new development considering sea level rise beyond 2100.
- **Legacy stock issues:** Adopt resilient building practices for renovations and rebuilt existing developments.
- **Community awareness:** Property owners should understand their risk and be informed of the planning and development controls that apply to their land and also the long-term mitigation strategy that affects their properties and communities.
- **Engineering standards:** Promote the establishment of new national standards for coastal protection and climate change mitigation works. Develop registration and certification requirements for engineers designing and constructing coastal protection works.

Conclusion

Climate change is driving rising sea levels and exacerbating coastal hazards, leaving Australian communities, properties, and critical infrastructure increasingly vulnerable. As these events increase in frequency and intensity, a growing number of exposed properties in Australia will become uninhabitable. The ICA is working to build a more resilient and insurable Australia and the investigation and technical report commissioned by the ICA makes it clear that there are a number of critical steps required to better protect communities, strengthen resilience and enable affordable insurance.

There is a clear role for all levels of government to collaborate, in consultation with industry, to build a national picture of coastal hazard risk and how to address it. It will also be vital to bolster investment in large scale coastal protection and adaptation projects and pilot adaptive management and retreat schemes. Setting robust land planning and building codes will also play a critical role in reducing risk to property holders and enabling affordable insurance.

Insurance Council of Australia

The Insurance Council of Australia is the representative body for the general insurance industry of Australia. Our members represent approximately 95% of total premium income written by private sector general insurers, spanning both insurers and reinsurers.

General insurance has a critical role in the economy, insulating individuals and businesses from the financial impact of loss or damage to their insured assets.

Our work with our members, consumer groups and all levels of government serves to support consumers and communities when they need it most.

We believe an insurable Australia is a resilient Australia – and it's our purpose to be the voice for a resilient Australia.

insurancecouncil.com.au

Actions of the Sea Data and Knowledge Development

Summary Report

29 October 2021 | 13465.101.R4.Rev1

Innovation Engineered.

baird.com

Prepared for:	Prepared by:

Insurance Council of Australia
Level 4, 56 Pitt Street
Sydney, NSW, 2000

Baird Australia Pty Ltd as Trustee for the Baird Australia Unit Trust
ACN 161 683 889 | ABN 92 798 128 010

For further information, please contact
David Taylor at +61 2 8278 7266
dtaylor@baird.com
www.baird.com

13465.101.R4.Rev1

Z:\Shared With Me\QMS\2021\Reports_2021\13465.101.R4.Rev1_ICAActionsoftheSea_SummaryReport.docx

Revision	Date	Status	Comments	Prepared	Reviewed	Approved
A	11 Jun 2021	Draft	Issued for ICA Review	DT / LC / CS	GB	DT
0	28 Jul 2021	Final	Issued to ICA	DT	GB/LC	DT
1	29 Oct 2021	Final	Issued to ICA for Public Release	DT / CS	LC / GB	

Executive Summary

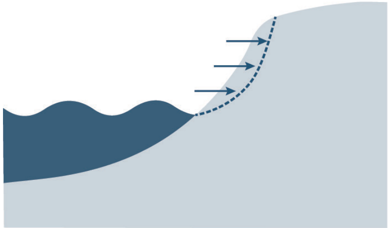
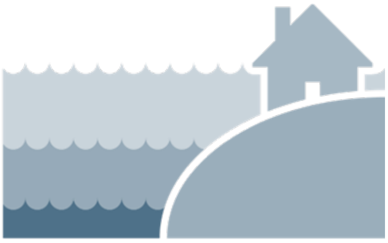
The Insurance Council of Australia's (ICA) *Actions of the Sea Data and Knowledge Development* project has been undertaken to identify key issues related to Actions of the Sea, principally coastal erosion, inundation, and sea level rise, and to provide recommendations related to risk awareness in the broader community. With insight into the issues related to Actions of the Sea, the insurance industry can engage with business, communities and governments on risks associated with Actions of the Sea and climate change to stimulate discussion and inform solutions to the current and future management of Actions of the Sea. The project has also examined options for mitigation of current and future risks from Actions of the Sea.

The detail presented in this report explores Actions of the Sea on properties from three perspectives: engineering, land-use and risk awareness of the financial and economic impacts. The project has included engagement of the insurance industry through the ICA. During the engagement process it was apparent that the insurance industry and broader community need to have clear and consistent definitions and process descriptions for Actions of the Sea.

This study has defined Actions of the Sea in the simple manner outlined in Table E.1. Section 3 of this report provides detailed process descriptions for the Actions of the Sea.

Table E.1: Summary of key Actions of the Sea processes.

Action of the Sea		Description of Process
Tidal Inundation		Inundation of normally dry land caused by elevated coastal water levels which are above Highest Astronomical Tide (HAT) levels due to variations in coastal water levels that occur outside a severe weather event. Tidal inundation excludes other flooding that is associated with severe weather including rainfall run-off or riverine flooding or ocean storms. Tidal inundation of land that is not currently impacted by seawater, except in severe weather events, will be an increasing risk with future sea level rise.
Coastal and Estuarine Inundation		Inundation of normally dry land caused by elevated coastal water levels which are above Highest Astronomical Tide (HAT) levels due to severe weather event processes. Inundation of this type can be a result of any single (one) or combination of the following processes: elevated coastal water levels including storm surge, wave action, rainfall run-off and/or riverine flooding.

Action of the Sea		Description of Process
Coastal Erosion		Scour of material (such as sand) primarily due to wave action resulting from a severe weather event. Erosion can cause damage to structures, including buildings, landscaping and supporting structures. Erosion during severe storms can result in movement of the beach and shoreline, landslide and subsidence.
Shoreline Recession		The erosion of shorelines from ongoing coastal processes and sea level rise. Shoreline recession can lead to damage to structures, including buildings, landscaping and supporting structures. Recession is inter-related with beach and shoreline erosion, landslide and subsidence.
Sea level rise		Sea level rise is not a distinct process causing impact on its own, but rather increases properties' exposure and impacts from other coastal processes (including tidal inundation, coastal inundation, coastal erosion and shoreline recession).
Tsunami		A tsunami event that impacts on the Australian coastline, typically from distant sub-sea earthquakes, that may cause inundation, coastal erosion or structural damage.

This project has examined Actions of the Sea and the responses to those actions from the perspectives outlined above using a case study approach. The case studies presented in the report have drawn on contemporary examples around Australia. The primary case study examined in this project was Collaroy-Narrabeen in the northern suburbs of Sydney and the impact from Actions of the Sea and responses to the damage resulting from a severe storm event that occurred in June 2016. That storm resulted in a 1 in 50-year (50-year Average Recurrence Interval, ARI) erosion and wave-dominated inundation event in the case study area causing damage to several coastal properties. The insurance industry identified that at that time, typical policy definitions did not adequately address damage from Actions of the Sea and policy owners did not understand intended policy inclusions and exclusions. The case study summarised in Section 4.2, and presented in detail in Appendix A, includes details on the process and actions that have been implemented by government and landowners to mitigate impacts from future storm events. Section 5 presents a general summary of mitigation measures for Actions of the Sea based on a number of examples from around Australia that build on the knowledge base established from the case study.

This project has identified the following key issues for the insurance industry and wider community with respect to Actions of the Sea. A series of specific recommendations for all levels of Government and industry to consider for each issue is presented in the following sections.

Issue 1: Following a severe event, a range of factors need to be considered to assess the value of re-building existing property.

The examples presented in Sections 4 and 5 of this report highlight that there is no precise trigger where rebuilding property after a severe event becomes unfeasible. The viability of maintaining coastal property is dependent on a number of site-specific factors including the coastal processes, the exposure of property to specific Actions of the Sea, the local economy and property land value, and the community and environmental values of particular areas. The case study example for Collaroy-Narrabeen (see Section 4.2.4) indicated that where properties are at risk of severe damage from coastal erosion in a 50-year to 100-year ARI storm event, the cost for individual property owners to protect property over a 50-year economic period frame based on current risk and sea level rise over the next 60-years has positive investment return on a net present value perspective for owners of properties. However, the properties examined in the Collaroy-Narrabeen case study are typically high-value, prestige properties that have a current market value that is significantly above the median property value and the investment return for medium and high-standard properties that have similar risk exposure would be marginal or negative from a net present value perspective. There are a large number of coastal properties at risk around Australia from current and future coastal hazards where property values are not as high as at Collaroy-Narrabeen and the economic assessment indicates that there is at best only a marginal investment case for property owners to fund the protection of their properties from Actions of the Sea. With future sea level rise beyond a 50 to 60-year timeframe, the economic case for property protection only of individual properties will only further reduce. It should also be noted that although the Collaroy-Narrabeen case study properties generally have a have a positive investment return over the economic life of the property for owners funding protection works, there are still significant challenges for property owners to fund their 80% share of the costs for coastal protection which are projected to cost on average $230,000 per property owner (based on submitted Development Application information).

This project has highlighted that coastal protection for Actions of the Sea with future sea level rise will increasing rely on combined government funded programs and projects that provide effective, adaptable and sustainable mitigations to actions of sea for large groups of properties. It should be noted that the economic assessment for the case study example (Section 4.2.4) and other examples presented in Section 5 are limited by the currently available information on damage and impacts from Actions of the Sea on properties and this is addressed in the recommendations below.

Recommendations

Key recommendations to support improved understanding of the viability of rebuilding property after a severe event include:-

1.1 All levels of Government and the community should be informed of the potential cost of mitigation to Actions of the Sea and that they typically have negative or marginal economic investment metrics for individual properties except for high-value coastal property.

1.2 State government agencies (see Table 6.5) and industry should invest in the development of improved damage estimates for different coastal hazard event return periods (referred to as ‘damage curves’) to understand the relationship between hazard and loss from Actions of the Sea. Key data gaps at present include:

   a) Lack of data on the damage from coastal inundation with salty ocean water compared to the effects of inundation by freshwater;

   b) Lack of data on damage from wave-runup and overtopping-dominated inundation compared to inundation from storm surge (with tide); and

   c) Damage and impact from coastal erosion, including loss of services making buildings unhabitable, needs to be defined in economic and practical terms.

1.3 To assess the magnitude of the economic impact on property owners and communities, government and stakeholders in the wider financial services industry to develop cadastral-based data sets (asset register) that have property valuation and building type / quality data included. The information presented in Section 4.2.4 and Section 5 provide a reasonable basis for the insurance industry to assess the cost to protect property based on the linear length of property boundary requiring protection from Actions of the Sea. The data can also be used by governments to identify risk, prioritise responses and shortlist risk mitigation responses (i.e. including protect, adapt, retreat).

Issue 2: Understanding options and process for reinstatement of land following an "Actions of the Sea" severe event.

The conditions and process for the reinstatement of land, defined as restoring pre-storm / erosion ground elevations within a property, are subject to local and/or state government planning and development controls. As a general guide, property owners may be permitted to reinstate land after a severe erosion event, but local and/or state government planning and development controls are often triggered if there is the potential for impact on the local environment or adjoining properties as a result an individual landowner undertaking reinstatement works. There is typically limited knowledge and understanding in the community and financial services industry in relation to the conditions and process to undertake reinstatement works. It is important to note that there are some circumstances where erosion in a single event may be so severe that tens of metres of landward movement of the coastline might occur, ruling out the possibility for reinstatement for individual properties.

Recommendations

2.1 State government agencies (see Table 6.5), local government and industry should provide information to promote education of property owners as to the development conditions and controls in relation to coastal hazards and reinstatement works. This should highlight the importance of property owners being informed and understanding the planning and development controls that apply to their land.

Issue 3: How to differentiate/allocate damage to between different Actions of the Sea.

In order to understand the processes that contribute to hazard and loss, and to support the development of clear policy terms, it is important that the insurance industry can understand how each separate Actions of the Sea (see Table E.1) impacts on the risk of particular properties, before and after major events. In addition, following a major event, the insurance industry needs to understand the contribution of each Action of the Sea to the damage and loss experienced at a particular property to support claims assessment.

The case study presented in Section 4.2 has identified that post-event impact surveys and analysis of high-resolution aerial or UAV (drone) imagery can allow impacts from different Actions of the Sea including erosion impacts on properties to be differentiated. However, there is a strong inter-dependency between different actions that contribute to the overall damage and impact on a property. For example, coastal erosion and the encroachment of the active shoreline on the primary structure on a property, increases the risk of inundation impacts on that property. With currently available measured and hindcast/forecast data of coastal actions, there is reasonable data available to define the coastal processes that drive impacts on properties and their magnitude in particular events for most populated regions of Australia.

Recommendations

3.1 State government agencies should lead the collection and maintenance of high-quality, publically available event data sets to assess damage and over-time improve understanding of hazard.

3.2 State government agencies (see Table 6.5) should implement the collection of high-resolution survey and data capture including periodic and post-event high resolution aerial (or UAV) imagery and LiDAR survey data. State and local governments should have programs and funding in-place to support long-term periodic and post-event data collection and information dissemination.

Issue 4: What do property owners and the wider community need to know to be assured that coastal mitigations and defences will be effective at mitigating Actions of the Sea, including sea level rise.

It is important that the community and financial services sector has confidence in mitigation measures for Actions of the Sea. The community and financial services sector have a level of confidence in building design and construction which is underpinned by state and national building codes and standards. For coastal protection works, there is no defined set of codes and standards that provide the same confidence in functional performance over time, particularly with climate change causing changes to processes and hazard levels. Whilst structural and civil components of coastal defences may be subject to the specifications and requirements of various design codes, including design criteria requirements of AS4997-2005, the overall functional performance of coastal defences at protecting properties and communities from current and future Actions of the Sea is generally not consistently addressed in national building codes and standards.

Currently the most robust examples of local and state development controls for coastal mitigations to Actions of the Sea require experienced professional engineers to assess and sign-off on the expected performance of coastal structures from a hazard mitigation and coastal processes perspective. The Queensland framework for Registered Professional Engineers (RPEQ) is the most established and comprehensive regulatory framework in Australia to ensure that engineering works are assessed, reviewed and signed-off by qualified and experienced professionals. Most coastal engineering works in Queensland require a registered (RPEQ) professional to sign-off on studies and design documents. There are examples of similar design verification by experienced coastal engineers in local (government) development controls, including in the case study example local in the Northern Beaches Council local government area (see Section 4.2).

Recommendations

All levels of government and industry should promote short and long-term actions to improve the quality and level of confidence that financial services and the community has in mitigations to coastal hazards and Actions of the Sea. Specific recommendations include:

4.1 Encouraging state governments (see Table 6.5) to adopt consistent registration processes for engineers and broaden registration and certification requirements for engineers that are designing and constructing coastal protection works. The requirement for certification of coastal protection should include fixed structures, beach / sand nourishment and managed retreat.

4.2 State and local governments should develop spatial databases of coastal mitigations and defenses using a consistent standard that include:

- a) Details on the location and type of coastal protection;
- b) References to studies assessing the function and intended hazard mitigation performance of the coastal structure;
- c) Key design parameters including design storm return period and allowance for future sea level rise; and
- d) Construction cost and design life information.

4.3 State and local government (see Table 6.5) in the short-term should require qualified structural and coastal engineers to approve the design of actual coastal structures, and their intended hazard reduction for current and future climate conditions (as is the requirement from Northern Beaches Council for the case study example).

4.4 All levels of government and industry should promote the upgrade and establishment of new national standards to cover coastal protection and climate change mitigation works over the long-term.

Issue 5: The suitability of different types of coastal defences at mitigating Actions of the Sea.

The case study summarised in Section 4.2 and the broader discussion of engineering responses to Actions of the Sea in Section 5.3 have highlighted that coastal defences can be very effective at mitigating damage to property from Actions of the Sea. However, there is a wide variation in the design parameters and intended functional performance for coastal structures. For example, the case study example in Section 4.2.3 presents a seawall structure that is under construction that has been designed to provide coastal protection for extreme erosion events, including for the 100-year ARI erosion event, and accommodate the impact of sea level rise over a 60-year time period that is aligned with the time-limited development consent for the structure. An example of a smaller scale coastal protection structure which is designed to reduce the hazard and impact from coastal erosion is presented from the Geraldton region in Section 5.3. The structures in the Geraldton example reduce the hazard, particularly from smaller, more frequent storm events, but would be expected to have reduced performance and provide less protection in the event of extreme storm events, for example the 100-year ARI storm event. The two examples presented above highlight the importance of informing community and stakeholders, including the insurance and financial services industry, as to the intended performance of coastal protection structures.

The case study example presented in Section 4.2 focused solely on the potential to reduce damage to property as a result of the seawall currently under construction. It is important that community and environmental factors are considered in the assessment of new coastal protection structures, and are included in broader economic assessment of coastal protection options.

A key issue highlighted in the case study, and which has been observed at other sites subject to severe coastal erosion, is that planning requirements which require deep foundations for buildings to prevent significant structural damage in the event of severe erosion, can be effective at preventing major structural damage. However, buildings can still be unhabitable for significant periods of time following a severe event due to loss of essential services (electricity, water and sewage) to buildings. This is an issue that needs greater awareness within regulatory agencies, particularly local government and the wider community to ensure that service provisions following major events are considered in planning and development approvals.

Future sea level rise will significantly reduce the effectiveness of current and planned coastal defences for protecting properties from Actions of the Sea. Most engineering responses, including beach nourishment, will have practical limits with respect to the level of sea level rise that can be accommodated before they are ineffective or unsustainable based on environmental, community and cost factors. It is only in recent times that coastal hazard planning and risk mitigation studies have examined the potential uncertainty in future sea level rise, particularly for higher sea rise scenarios. Providing adequate coastal buffers in the form of dunes, intertidal areas and coastal vegetation (for example mangroves) will be increasingly the most sustainable response to continued sea level rise.

Recommendations

In addition to the Recommendations 4.1 to 4.4 highlighted for Issue 4, specific recommendations for Issue 5 are:

5.1 Government, industry and the community need to be informed that all engineered mitigations to Actions of the Sea have practical limits with respect to the sea level rise allowance that can be practically accommodated within the current land use planning regimes and property tenure arrangements. Where engineered mitigations are not practical or sustainable, the obvious management response is adaptive management or managed retreat to provide increased natural buffers to Actions of the Sea.

5.2 The position paper should highlight to property owners and the community that they should be informed on options and details of coastal protection works that affect their properties and communities.

Issue 6: The scale of coastal mitigations and defences required in Australia to address current and future risks from Actions of the Sea, including sea level rise.

Despite Australia's large landmass, the concentration of our population and major economic infrastructure and assets within the coastal zone results in Australia having a very high vulnerability to current and future risks from Actions of the Sea. Future sea level rise and its resulting impact on property, infrastructure and communities will require significant investment in mitigations and defences for Actions of the Sea. Section 5.3 highlighted the example of the City of Busselton in southwestern Western Australia. This region, with a population of approximately 39,600 people and a gross regional product of over $2.1 billion (City of Busselton, 2015), is estimated to require $1.6 billion for their tailored option to address future coastal hazards with sea level rise that includes coastal protection and measures to accommodate Actions of the Sea (City of Busselton, 2021). This compares to an estimated $8.2 billion for a managed retreat option undertaken in accordance with Western Australia government policy (City of Busselton, 2021).

In conjunction with the relevant overseas examples presented in Section 5.3, this highlights the major investment that will be required for coastal protection and adaptation works over the next 100-years. Based on the City of Busselton example, assuming current population and Gross Domestic Product (GDP), City of Busselton (2021) estimates that coastal management will require a budget of 0.6% p.a. of Gross Regional Product over the next 100-years. Based on present population and development, this would require investments in protection and adaptation measures over a 100-year period of approximately $400 per annum (p.a.) per person or $800 p.a. per rateable property. The expected acceleration in sea level rise and climate change impacts will result in the future costs, for example after 2050, being significantly greater than the average investment over the next 100-years (which includes the period from now to 2050).

Section 5.3.4 presents some examples of large scale protection and adaption projects in the USA for coastal inundation and sea level rise. Based on relative population and GDP, it is estimated that Australia will require at least $30 billion (net present cost) of investment in large scale coastal protection and adaptation projects over the next 50-years.

Recommendations

All levels of government and the community should understand the scale and cost of protection and mitigation works that will be required to address Actions of the Sea with future sea level rise. Key recommendations include:

6.1 The government should inform the community of the potential costs to protect and mitigate impacts from Actions of the Sea with future climate conditions. The community currently has low awareness of the mitigation and adaptation costs for Actions of the Sea with future sea level rise.

6.2 State government agencies (see Table 6.5) should develop databases of current, planned and considered coastal protection and adaption measures to address Actions of the Sea. It would be highly beneficial if government and the community had access to up-to-date information on the cost and timing of potential protection and mitigation works to improve awareness of the risks and to regularly review and assess the cost of mitigation on state and national scales.

6.3 Federal and state governments need to coordinate programs to provide the public investment that will be required to address Action of the Sea. The includes the establishment of long-term funding mechanism to address coastal hazard risk mitigation and adaptation. Risk mitigation and adaptation options need to be assessed and determined on a local and regional scale but will include protect, accommodate and/or retreat depending on the factors that are discussed in Section 5.

Issue 7: Planning and development controls to address re-development or new development within the coastal zone.

Planning and development approval processes for properties in the coastal zone are generally under the jurisdiction of local governments in-accordance with their local and (applicable) state planning policies. There are typically two key types of developments that need to be considered in the context of future risk from Actions of the Sea. For existing property that is being renovated or rebuilt (or built back after an event), development approvals typically consider medium-term planning horizons, for example 20 to 50 years from the time of application or approval. This was the approach taken in the case study example for Collaroy-Narrabeen following the updated risk management strategy and development approval requirements following the June 2016 storm. For the case study properties, the integrated coastal protection works that are under construction to protect existing property have been approved with a time-limited consent of 60-years, at which time their performance and impact will need to be assessed in accordance with the NSW Coastal Management Act (2016). Whilst several state and local government planning controls have been introduced to manage existing development in the coastal zone, overall, the trend with sea level rise is that there is increasing exposure of existing development to Actions of the Sea over the next 50-years. Presently, there is a lack of understanding in the wider community of the level of risk, and implicit economic cost associated with current and future hazard from Actions of the Sea for existing development in the coastal zone.

For new developments (including land subdivision), the general approach in Australia is to consider hazards from Actions of the Sea over a long-term planning horizon, for example 100-years from the time of application or approval. There is variation in the level of risk that is considered over the planning period. For example in NSW, new development commonly needs to consider coastal inundation and erosion from a 100-year Average Recurrence Interval (ARI) event, whereas in Western Australia the requirement is to consider inundation from a 500-year ARI event and erosion from a 100-year ARI event. There is also variation in how sea level rise is accommodated in planning approvals. However, the general approach across Australia is not to permit new development in areas that are at high-risk of coastal hazard impacts over the identified planning period.

Depending on the local conditions, this is potentially a significant impediment to further development of some regions and communities, particularly remote and regional communities where all existing development is generally concentrated in the coastal zone. Over the last 10-years, several planning studies have considered how future coastal hazards can be accommodated within new developments. For example, for properties that are potentially protected from the open coast effects of erosion and wave-induced inundation but are exposed to the risk of extreme storm surge, consideration to having development made more resilient to this type of coastal inundation has been considered. Examples of resilient buildings that can accommodate inundation include elevated properties that can accommodate inundation at ground level but have all habitable areas and contents on the second floor.

A significant issue with current planning controls, is that planning and development approvals for new development are provided without time limits on tenure (granted in perpetuity), but the development requirements and approvals framework only considers risk from Actions of the Sea over a finite planning period (i.e. 100-years from the date of the assessment accompanying the development application or from the date of the approval). The case study example in Section 4.3 presents a recent example where time-limited development approvals can be issued to manage current risk from Actions of the Sea but provide flexibility to re-consider those approvals in the future when sea level rise may have significantly increased the risk to properties or the impact of development on the wider environment. Whilst time-limited planning consents would be a significant deviation from traditional freehold land title approvals that would require extensive community consultation and increased awareness, this approach to approval of new development within the coastal zone may have application in particular situations.

Recommendations

All levels of government, industry and the community need to be informed of the risk of existing property to current and future Actions of the Sea. Key recommendations include:

7.1 All levels of government and industry need to inform communities of the current risk and economic costs from Actions of the Sea.

7.2 State and local governments need to develop updated planning policies for development at risk from Actions of the Sea. Key items to be addressed by governments include:

a) Requirements for renovated or rebuilt existing development to adopt resilient building practices that can accommodate Actions of the Sea without severe loss.

b) Exploring options on tenure and time-limited development consents for re-development, particularly in regional areas where alternative accommodation options may be limited in the short to medium term.

c) Advocate for state and national consistency in relation to sea level rise scenarios and acceptable hazard levels for inundation.

Summary of Data Audit

Section 6 presents the data review and audit that was completed for this project. This study recommends that the insurance industry advocate and support the development of a National Actions of the Sea Information Database (NASID), similar to the ICA's National Flood Information Database. The NASID should include data in a suitable format for insurers to assess Actions of the Sea exposure for different return periods including:

- Inundation levels from storm surge, wave runup and overtopping;
- Description of coastal exposure for each property, for example inundation from storm surge or wave dominated processes;
- Shoreline erosion vulnerability; and
- Details on coastal protection structures (private and public).

As a starting point, the NASID could be populated from local and regional coastal hazard studies; however, there is a large variability in technical methods, assumptions and quality of the existing data sources. Also, the hazard information is normally only available for up to 100-year ARI events in most states, except for Western Australia and higher cyclone hazard areas of Queensland. It is recommended that governments and industry coordinate and fund projects to develop improved nationally consistent data sets with respect to coastal inundation and erosion. A key existing data gap is the definition of wave dominated inundation exposure, which has a strong correlation on the potential for coastal erosion. This study recommends that the insurance industry advocate for improved state and national data sets on extreme near-coast wave conditions and centralised data sets for coastal protection assets. A summary of details to developed improved wave runup and overtopping data sets is presented in Section 6.3.1. A high-level audit of key data sets for each state is presented in Section 6.3.2.

The data audit has identified existing data sets that can be utilised by the insurance industry to undertake event impact and pricing assessments. Further work by governments is recommended to coordinate regular updates of spatial data available from government and other organisations that can assist with defining exposure to Actions of the Sea. State and local governments (see Table 6.3, Table 6.4 and Table 6.5) around Australia have a vast collection of high-resolution data that can assist with assessing exposure and consider mitigation options for Actions of the Sea. It is recommended that the lead state government agency in each state responsible for coastal hazard management (Table 6.5) should work in a coordinated manner to implement systematic and best-practice collation and distribution of data with consistent data formats. A data repository, similar to the Australian Flood Risk Information Portal (the portal) or the NSW State Emergency Services Flood Data Portal is a potential concept for an Actions of the Sea data portal on a national scale and could then be integrated into the NASID.

Table of Contents

Tables

Figures

1. Introduction

This document forms Baird Australia Pty Limited's (Baird) main report for the Insurance Council of Australia's (ICA) Actions of the Sea Data and Knowledge Development project. Baird was engaged by the Insurance Council of Australia to complete this project which is intended to inform and educate the ICA and its members, government, as well as the wider community, about the impact on property and infrastructure from Actions of the Sea.

This report addresses the whole scope of the project including:

- Presenting a set of definitions of the processes that lead to damage and loss associated with *Actions of the Sea;*
- Identifying key issues for the insurance industry from Actions of the Sea and exploring those with respect to a case study at Collaroy-Narrabeen.
- Identifying and assessing a range of options for mitigation to Actions of the Sea from a planning, engineering and financial perspective;
- Completing a data audit for key data sets that are recommended to assess Actions of the Sea; and
- Provide recommendations to the ICA on the items addressed in this report.

During the initial stakeholder consultation held in December 2020, it was noted by a range of participants that there is a lack of understanding of what processes are associated with Actions of the Sea, and how those processes can be defined in terms that are suitable for the development of insurance policy terms. A key component of this project is the process descriptions presented in Section 3.

The report is presented in the following sections:-

- Section 2 presents an overview of Actions of the Sea;
- Section 3 presents a description of each individual action of the sea and considerations for the insurance industry and summary of data requirements
- Section 4 Identifies key issues for the insurance sector and is focused on the case study example of the June 2016 storm that impacted on Collaroy-Narrabeen;
- Section 5: Overview of mitigation options for Actions of the Sea from planning, engineering and financial perspectives;
- Section 6: A preliminary data audit for the insurance industry; and
- Section 7: Conclusions.

A range of literature, reports (industry and government) and regulatory documentation has been reviewed in the development of these definitions and is documented in the reference list in Section 8. Appendix A presents the detailed case study report prepared on the June 2016 storm that impacted on Collaroy-Narrabeen and the subsequent reinstatement and mitigation works that have been undertaken at that location.

2. Overview of Actions of the Sea

Over the last 15-years, particularly in response to a number of large damage events, the general insurance market in Australia has expanded coverage to include flood insurance as a standard or optional item in most policies. The expansion of insurance coverage to include flooding was undertaken in partnership between government and the insurance industry and supported by the development and maintenance of national data sets, including the National Flood Information Database (NFID) that was developed by the ICA in 2007. Despite similar large damage events arising from coastal hazards over this same period of time, Actions of the Sea, as described below, are generally not insurable, except in some circumstances.

"Actions of the Sea" refers to a range of hazards that coastal and near-coastal property can be exposed to including:

- Tides, including "king tides";
- Storm surge;
- Wave impact and inundation (flooding) from wave penetration to property;
- Erosion of the coastline;
- Tsunami; and
- Sea level rise

It is typical for home insurance policies to now include coverage for storm surge and tsunami but exclude flood impacts from tides (including king tide). Most policies exclude wave impacts but may provide coverage when wave impacts on property are assessed as being the result of waves impacting unexpected areas as a result of storm surge. Over the last few years, there have been several notable events that have highlighted the impact of Actions of the Sea on residential property, including the June 2016 storm that caused damage along the NSW coastline where impacts were particularly severe at Collaroy-Narrabeen. Recently, a series of storms, including one in July 2020, have caused damage to property at Wamberal Beach to a similar extent seen in the June 2016 event due to wave impacts and the erosion resulting from those waves coupled with elevated water levels.

A significant issue with the current insurance coverage available in the market is that the Actions of the Sea outlined above are often inter-related and occur in combination within a single event. Other hazards, including rainfall and wind, can also contribute in-combination with Actions of the Sea to cause damage to property, providing further ambiguity to which hazard has caused the damage.

A key objective of this project is to provide standard definitions for the Actions of the Sea and to examine specific events and instances where combined Actions of the Sea contribute to damage, and to quantify the various actions that most contribute to damage in different scenarios.

In relation to the joint influence of wave impacts and inundation on property, the key challenges with defining 'hazard' across the whole of Australia relates to:

- The contribution of erosion and changes to shorelines to the impacts of shoreline and infrastructure exposure to wave processes;
- The extent of wave induced inundation and impact is based on elevation and horizontal distance from the shoreline and is strongly influenced by the shoreline conditions and geometry; and
- There is a large variance in the calculation of wave impact elevations and horizontal distances depending on the methods and models that are adopted.

Ultimately, it would be beneficial to the insurance industry to have a data set for Actions of the Sea that defines hazard at the property scale for a range of return period (likelihood) scenarios, similar to the National Flood Information Database (NFID) which was developed by the ICA in 2007 to define overland flow flood hazard on a national scale. The NFID provides clear and quantitative estimates of flood hazard for property by providing estimates of depth of flooding for specific return periods (5%, 2%, 1% Annual Exceedance Probability and Probable Maximum Flood) for all addresses in the national address data base.

This project aims to provide the ICA with the following key outcomes:

1. An industry position statement on Actions of the Sea that defines the hazard(s) and provides a summary of the responses to Actions of the Sea as they relate to engineering, planning and financial measures;
2. An audit of available data to assist in defining exposure to Actions of the Sea and provide recommendations on data set(s) required to define exposure on a national scale; and
3. A case study on Actions of the Sea which details the assessment of exposure and impact for a particular site (Collaroy-Narrabeen) and event (June 2016), and presents the engineering, planning and financial controls and measures that have been implemented, or are planned to be implemented, to address future Actions of the Sea.

This report is a summary report for whole scope of the project.

3. Actions of the Sea: Standard Definitions

3.1 Overview

The following sections present the process descriptions and proposed definitions for the insurance industry in relation to the following Actions of the Sea:

- Section 3.2: Inundation with separate sections for tidal inundation (Section 3.2.1) and inundation as a result of severe weather (Section 3.2.2);
- Section 3.3: Shoreline Erosion;
- Section 3.4: Shoreline Recession;
- Section 3.5: Sea Level Rise; and
- Section 3.6: Tsunami.

Based on the detailed information presented in Sections 3.2 to 3.6, Table 3.1 presents a summary of the proposed technical process definitions and guidance for community (customer) facing wording that could be used in policy definitions in plain language. Sections 3.2 to 3.6 also raises issues for the insurance industry to consider with each Action of the Sea. The technical definition is intended to be an accepted description by qualified experts in the field and has been drawn down from reputable references and experienced practitioners in coastal processes. The considerations for insurance definitions and policy terms in this report are intended as a starting point for the industry to assess and register issues and considerations as the insurance industry tests the opportunities and risks of providing cover for Actions of the Sea.

Table 3.1: Summary of Actions of the Sea Definitions

Action of the Sea	Technical Process Definition	Suggestions for Community Facing Wording	Issues for Insurance Industry to Consider
Tidal Inundation	Inundation of normally dry coastal land caused by elevated coastal water levels caused by high astronomical tides and other processes not related to a severe weather event. A number of processes can contribute to elevated water level unrelated to a severe weather event including coastal trapped waves and seasonal or climatic weather and oceanographic changes (i.e. La Nina / El Nino) in combination with high astronomical tide levels.	Inundation of normally dry land caused by elevated coastal water levels which are above highest tide levels. Tidal inundation excludes other flooding that is associated with severe weather including rainfall run-off or riverine flooding or ocean storms.	The likelihood of water levels above highest tide level can vary significantly around Australia. Some locations experience tidal inundation above HAT at least once a year, other locations may only experience those water levels every 10 to 20 years. The likelihood of tidal inundation of property increases with sea level rise. Extremely low tides and water levels may also cause damage to assets including pontoons and boats due to loss of underkeel clearance.
Coastal and Estuarine Inundation	Inundation of normally dry land caused by elevated coastal water levels that occur during a severe weather or wave event. Severe weather could be caused by a number of different weather systems including tropical cyclones and mid-latitude lows (including east coast lows). A severe wave event may include long period swells or freak waves which can impact on coastlines without concurrent rainfall or severe winds. Inundation of land and property could be the result of three processes that can be concurrent: • Elevated (steady) coastal water levels as a result of tide and storm surge;	Inundation of normally dry land caused by elevated coastal water levels which are above highest tide levels. Flooding can be a result of any single or combination of the following processes: elevated coastal water levels, wave action, rainfall run-off and/or riverine flooding.	Coastal and estuarine inundation can be caused by a number of different processes and can also be exacerbated as a result of local rainfall and catchment flooding. Coastal erosion that may occur during a severe weather event can increase the exposure to inundation for near-coast properties. The effects of coastal inundation can be concentrated near the coast, for example with wave dominated events. However, for tropical cyclone storm surge, inundation impacts can extend a long distance from the coastline. Several different weather systems can cause coastal inundation including mid-latitude lows and tropical cyclones. The most definitive source of a severe

Action of the Sea	Technical Process Definition	Suggestions for Community Facing Wording	Issues for Insurance Industry to Consider
	• Elevated (steady) shoreline coastal water levels as a result of tide, storm surge and wave setup; • Elevated (instantaneous/transient) water levels as a result of tide, storm surge and wave runup (where wave runup includes wave setup).		weather event for Australia would be an event that is declared by the Bureau of Meteorology. However, there are wave events that can cause damage at locations which are not declared or identified as experiencing a severe weather event. Infrastructure which is located on jetties or over-water (i.e. bridges) are not technically located on 'normally dry land'. Insurance industry will need to consider how inclusion or exclusion of such properties is addressed.
Coastal Erosion	Landward movement of shorelines caused by a severe weather and/or wave event(s) causing erosion of land normally landward of tide and wave impact levels. Definition of shorelines includes coastal cliffs which may be subject to landslide or subsidence due to coastal processes.	Damage to structures, including buildings, landscaping and supporting structures caused by erosion of shorelines caused by a severe weather event. Erosion coverage includes beach and shoreline erosion, landslide and subsidence.	Properties that are impacted by coastal erosion will often experience coastal inundation impacts and there may be a need to attribute damage to inundation or coastal erosion. Coastal erosion impacts can be highly variable even within a small section of beach and impact assessments may need to be considered on a property-by-property basis. Several different weather systems can cause erosion including mid-latitude lows and tropical cyclones. The most definitive source of a severe weather for Australia would be an event that is declared by the Bureau of Meteorology. However, locations that may be impacted by a severe wave event that causes coastal erosion may not be identified as subject to severe weather.

Action of the Sea	Technical Process Definition	Suggestions for Community Facing Wording	Issues for Insurance Industry to Consider
			There are a number of complexities associates with coastal erosion including: • Properties can be protected by coastal protection structures but these are not typically a standard policy term. • If a property has a coastal protection structure, would that be included or excluded from coverage. • Landslide or subsidence caused by other processes needs to be considered and addressed in policy wording.
Shoreline Recession	Continuing loss of land over the longer term caused by prevailing coastal processes and sea level rise causing erosion of land landward of normal tide and wave impact levels.	Damage to structures, including buildings, landscaping and supporting structures caused by erosion of shorelines from ongoing coastal processes and sea level rise. Erosion coverage includes beach and shoreline erosion, landslide and subsidence.	For the insurance sector, shoreline recession will likely be considered in conjunction with coastal erosion as a result of a severe weather or wave event. Properties that are impacted by shoreline recession will become more exposed to coastal inundation. Properties may become at risk of more frequent inundation, not only during severe storm events. Shoreline recession impacts can be highly variable, temporally and spatially, exposure of the insurance industry to erosion and/or inundation impacts can significantly increase over short (1-2 year) and medium (10-year) time horizons.
Sea level rise	Global rise in sea water levels which is projected to accelerate for future climate change scenarios. Global and regional sea level rise is normally defined by the guidance from Intergovernmental Panel on Climate	Sea level rise is not proposed as a distinct policy term, but is rather a process that increases the exposure of the insurance industry to increased claims over	Sea level rise will interact with all other Actions of the Sea increasing hazard and the property risk to inundation and coastal erosion from all Actions of the Sea. The insurance and financial services industries

Action of the Sea	Technical Process Definition	Suggestions for Community Facing Wording	Issues for Insurance Industry to Consider
	Change (IPCC) or national and state regulatory agencies.	time from other coastal processes (including coastal inundation and coastal erosion).	have key roles in planning and mitigation to sea level rise and other climate change impacts.
Tsunami	Long period waves generated by earthquake, volcanic eruptions or landside.	Tsunami event that impacts on the Australian coastline and may cause inundation, coastal erosion or structural damage.	Tsunami impacts on populated areas of mainland Australia are infrequent and there is significant uncertainty in the definition of tsunami hazard around Australia. Whilst near-coast property and infrastructure around Australia has relatively low vulnerability to tsunami inundation, speciality insurance areas including recreational boating, marine and port markets have higher vulnerability and current exposure is not well defined. Sea level rise will increase tsunami risk.

3.2 Inundation

Inundation, in the context of Actions of the Sea, refers to flooding of coastal land that would otherwise remain dry. In a coastal context, there are a number of processes that can contribute to elevation of water levels that can result in inundation of low-lying areas. Two separate inundation definitions are described in the following sections to characterise areas that may be exposed to regular tidal processes, as compared to less frequent, but potentially more severe inundation as a result of severe weather.

3.2.1 Tidal Inundation

3.2.1.1 Process Description

Every coastal waterway is exposed to periodic variation in water levels that are governed by gravity interactions between the earth, moon and sun. Whilst these forces act over all large water bodies, tidal processes can vary significantly on regional and sometimes local spatial scales. Typically, the interacting gravitational forces result in water levels varying through two periodic cycles per day (approximately) which result in a high water condition every 12 to 12.5 hours, and a low water condition every 12 to 12.5 hours. This primary cycle is governed by the earth's rotation around its own axis in relation to the sun. A secondary process occurs as a result of the moon's orbit around the earth which causes period of larger tide variation during 'spring tide' periods, and smaller tide variations during 'neap tides' that typically follow a 14-day cycle. In addition, the interacting gravitational forces and the characteristics of the earth's water bodies, for example geometry and depth, influence the movement of water in response to gravitational forces which results in differing magnitudes of variation in tide conditions as a result of oceanic, regional and local characteristics.

For defining Actions of the Sea, tidal inundation refers to the flooding of low-lying coastal or near coastal land, primarily as a result of tidal variation in water level, and possibly a small variation in water levels as a result of processes that are not caused by severe weather. Figure 3.1 presents examples from Hanslow *et al* (2019) of tidal inundation through an urban drainage networks from a large tide on 1 February 2018. It has been common to refer to large tide events that may cause some flooding as 'king tide' events. The general definition of a 'king tide' is the largest annual tide condition that may occur in the absence of severe weather.

Figure 3.1: Tidal inundation flooding streets during higher tides at (A) Woy Woy at 11:30 AEDT on 3/1/2018 and (B) Botany at 9:55 AEDT on 1/2/2018 (Hanslow et al, 2019).

3.2.1.2 Considerations for the Insurance Industry

In the context of insurance policy definition and wording, it is recommended that the term 'king tide' is not adopted, but rather a more formal quantitative definition of a minimum coastal water level that is considered a rare or abnormal event is adopted. For simplicity, the insurance industry could define tidal inundation as inundation of land or property above the Highest Astronomical Tide (HAT) level as a result of elevated coastal water levels caused primarily by high astronomical tides and other processes not related to a severe weather event.

It is important that the insurance industry understand that the frequency of inundation above the HAT level can be highly variable around Australia. Some locations, for example within Gulf St Vincent (South Australia) or south-west Western Australia, the HAT tide level can be exceeded at least once every year. Whereas other locations, particularly in the large tide range areas of northwest Australia, HAT may only be exceeded every 10 to 20 years.

The insurance industry will also need to consider adjusting Highest Astronomical Tide (HAT) levels in accordance with future sea level rise (see Section 3.5).

3.2.2 Coastal and Estuarine Inundation from Severe Weather

3.2.2.1 Process Description

Coastal and estuarine inundation from severe weather is normally the result of a combination of process that occur as a result of severe weather in combination with normal processes, e.g., elevated water levels caused by low pressure systems associated with severe weather combined with predicted tidal variations. Severe weather can elevate coastal water levels and can cause flooding of coastal and estuarine areas. In addition, inundation can also occur in estuarine or upstream areas outside the defined estuary as a result of combined elevated coastal water levels and catchment-based rainfall and flooding.

The specific weather systems that can cause coastal and estuarine inundation in Australia include:

- Tropical cyclones, which are severe storms that can cause large rainfall and storm surges, subsequently causing flooding of coastal and estuarine areas due to combined elevated coastal water levels and catchment flooding. Storm surge is the elevation in coastal water level as a result of reduced atmospheric pressure (inverse barometer) and wind forcing over the water causing setup.
- Monsoon lows are typically less intense tropical cyclones, but can subject large areas of coastline to heavy rainfall and generate coastal storm surges that can cause inundation above normal tide levels.
- Mid-latitude lows are large weather systems that frequently impact on the southern areas of Australia and can cause inundation via elevated coastal water levels. For some areas in Australia, e.g., southwest Western Australia and the gulf regions of South Australia, mid-latitude lows can generate coastal water levels that exceed normal tide levels several times per year and can frequently cause inundation of low-lying coastal areas.

Figure 3.2 presents an aerial photo of Tully Heads following Tropical Cyclone Yasi in 2011, which caused severe flooding as a result of storm surge from the large, severe tropical cyclone.

Figure 3.2: Damage from coastal inundation at Tully Heads, Queensland from TC Yasi (Source: ABC News).

Coastal inundation is driven by three key water level processes:

- Elevated coastal waters caused by tide and storm surge from wind and pressure forcing across the coastal shelf, embayment or estuary. This is the primary process and results in the potential to inundate large areas of low-lying land near the coastline and estuaries. Storm surge from tropical cyclones has the potential to cause inundation and damage for large distances inland from the coastline.
- For wave exposed coastlines, wave processes can significantly increase shoreline water levels as a result of wave setup generated by wave breaking processes. This phenomenon can significantly increase inundation levels and extents near the open coast, and also impact on urban drainage that discharges at the coastline.
- For wave exposed coastlines, a further source of inundation is the dynamic water level at the shoreline from wave runup which can cause inundation impacts on property and infrastructure near the coastline, even at relatively high elevation levels. Wave run-up levels on beaches with a steep eroded scarp, can be several meters above the normal water level.

The influence of wave processes on coastal inundation is illustrated in Figure 3.3 and Figure 3.4. Figure 3.3 is an example of a wave exposed coastline with relatively low elevation land behind the beach and wave runup can result in inundation of land behind the coastline. Figure 3.4 is an example of a wave exposed coastline with relatively high elevation land behind and where wave inundation impacts can extend to a high elevation for properties or infrastructure which are located close to the coastline.

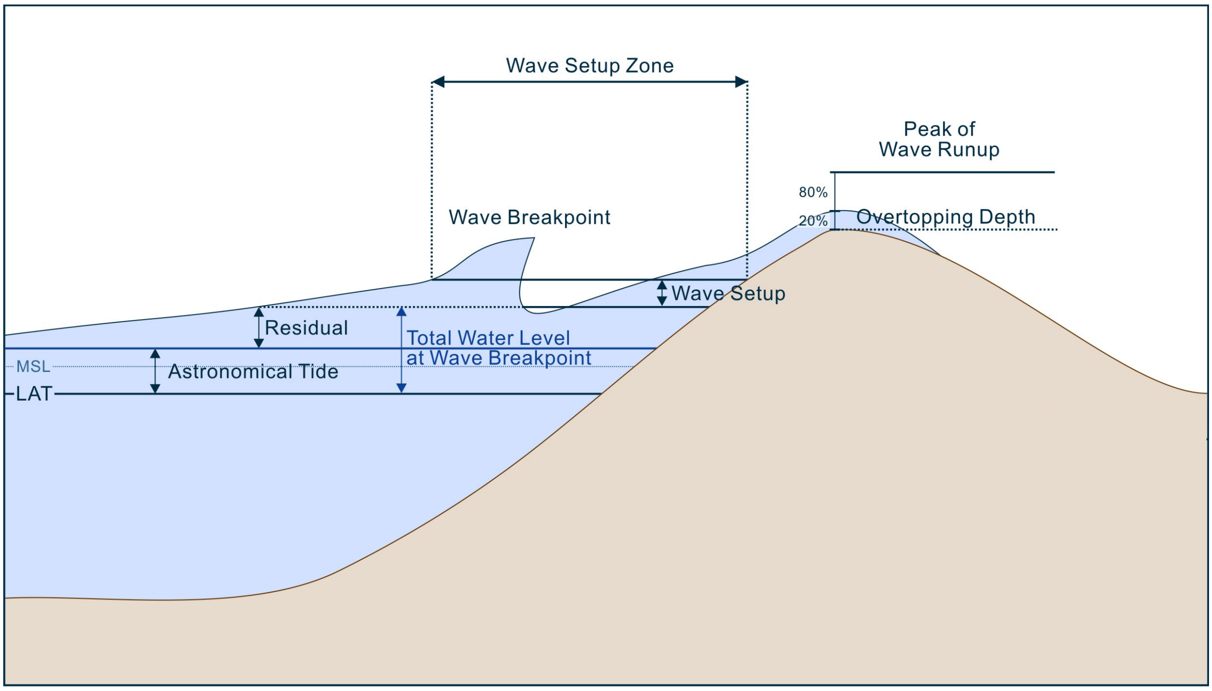


Figure 3.3: Illustration of coastal inundation processes for wave exposed coastlines where overtopping of the coastal dune can occur.

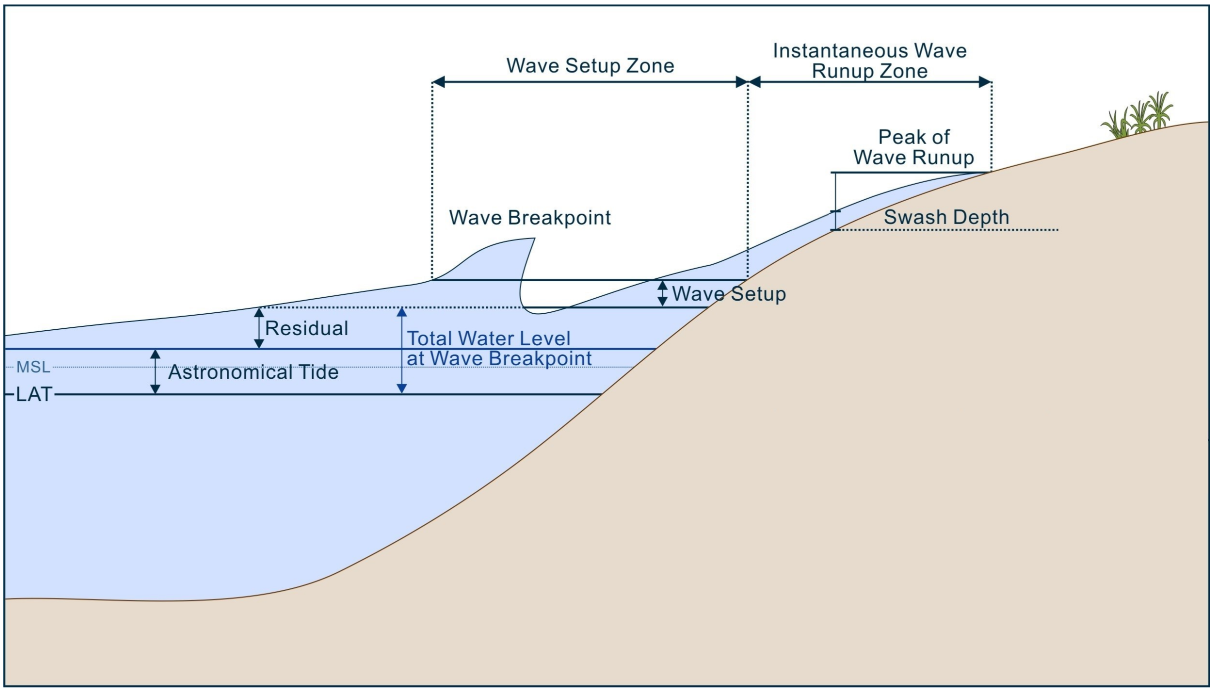


Figure 3.4: Illustration of coastal inundation processes for wave exposed coastlines where overtopping of the coastal dunes does not occur.

3.2.2.2 Considerations for the Insurance Industry

The definition of coastal and estuarine inundation for insurance purposes is coupled with the definition of tidal inundation (see Section 3.2.1) as the normal variation in tides has a significant impact on the extent and magnitude of inundation. For example, areas in Northern Australia that experience larger tide ranges can experience a severe tropical cyclone that generates a large storm surge, but that is coincident with a low tide resulting in no inundation of land above the normal tide range, whereas a moderate cyclone with a smaller storm surge can occur coincident with a high tide condition and cause extensive inundation and associated damage.

For insurance purposes, there are two key requirements that are both required to define an insurable event:

1. A defined severe weather event impacting a particular area or region, for example as classified by the Bureau of Meteorology; and
2. The inundation level during the event needs to exceed normal tidal inundation extents (as defined by some limit or level, such as HAT).

3.3 Coastal Erosion

3.3.1 Process Description

Coastal erosion is the process of the landward movement of a shoreline in the short term in response to wave action. Coastal erosion can occur on mobile, unconsolidated, or otherwise erodible shorelines; and also occur as a result of landslide or slope failure of rocky shorelines or coastal cliffs. In the Australian context, coastal erosion is most commonly observed at sandy beaches as a result of exposure to elevated water levels in combination with strong wave energy often generated by severe weather events (i.e. mid latitude lows or tropical storms, including cyclones).

Coastal erosion extents caused by a severe weather event can be highly variable on a local scale, for example along a short section of beach or within a beach compartment or particular section of coastal cliff. Variations in coastal geomorphology, the presence of natural features or built structures that alter coastal processes and local scale variation in hydrodynamics and waves within a beach compartment can all cause large variation in erosion impact over small distances.

Figure 3.5: UAV aerial view of beach erosion at Narrabeen-Collaroy in June 2016 (Source: UNSW Water Research Laboratory, 2016).

3.3.2 Considerations for the Insurance Industry

Compared to inundation as a result of Actions of the Sea (as defined in Section 3.2), defining coastal erosion for the purposes of insurance is more complex due to the range of local factors that impact on the likelihood and severity of coastal erosion. Sandy beach shorelines are continually changing and moving position as a result of regular wave, tide and sedimentary processes. For planning purposes, current practice is to define the boundary between normal shoreline variations and extreme events based on estimates of severe erosion for defined, rare storm conditions. For example, the NSW Coastal Management Manual glossary (2018) defines the normal shoreline variation area as the beach fluctuation zone which extends landward to the erosion extent for a 1 in 100-year (100-year ARI) erosion event or a more extreme event of record, whichever is the greater landward limit. For planning purposes, the specification of 100-year ARI coastal erosion extents as the basis for planning policies is consistent across many state jurisdictions including NSW, Victoria, Queensland and Western Australia.

For the insurance sector, existing planning information and definitions can be adopted to define areas subject to coastal erosion risk. However, it is more challenging to define an insurance coverage definition for existing property that is already located within 100-year ARI erosion extents. A further complexity of coastal erosion is that for many existing development areas, coastal erosion from a storm can alter the actual land area or characteristics of a particular property and the land may not recover to its pre-storm condition without intervention in the form of nourishment or restoration of the land that was eroded and potential protection of the property boundary from further erosion events, potentially changing the baseline from which insurance-based decisions can be made.

It is possible that coastal erosion could be excluded from insurance coverage. However, due the inter-relationship between erosion and risk of inundation, property may become more exposed to inundation after coastal erosion has occurred. In this situation, the insurance industry needs to assess damage to property or other insured assets as a result of erosion, compared to damage from inundation.

3.4 Shoreline Recession

3.4.1 Process Description

Shoreline recession is a continuing landward movement of the shoreline over a specified period of time in response to prevailing coastal processes and sea level rise. The dominant coastal processes for shoreline recession have been identified as variations in wave climate and sediment movements (net sediment loss from a coastal compartment). Sea level rise has been a factor in shoreline recession and will increase in significance with future expected elevated rates of sea level rise.

Shoreline recession rates can be highly variable across temporal and spatial scales. Inter-annual and inter-decadal variations in climate processes can cause fluctuations in recession rates or cause particular areas to oscillate between receding or progradation (movement seaward of shoreline). An example of this phenomena is the rotation of southeast Australian beaches in response to El Nino-Southern Oscillation (ENSO) wave climate variations (Short et al, 2001). Figure 3.6 presents an example of shoreline recession in the Geraldton region at a location that has experienced significant recession over the last 30-years.

Figure 3.6: Example of shoreline recession analysis at Drummond Cove, City of Greater Geraldton. (Source: Department of Transport , https://catalogue.data.wa.gov.au/dataset/coastline-movements)

3.4.2 Considerations for the Insurance Industry

For the insurance sector, it will be difficult to separate coastal erosion and shoreline recession effects on particular properties. To evaluate the exposure of property and infrastructure to potential shoreline recession, the insurance industry may need to understand shoreline movements that occur over climatic cycles, for example the ENSO cycle, as the exposure of properties to coastal erosion and the associated risk of inundation and property damage may be significantly altered as a result of shoreline movements over periods of 1 to 10 years. It is proposed that shoreline recession is defined over short, medium and long-term horizons as follows:

- Short term: Net movement over 2-year horizon;
- Medium term: Net movement over 10-year horizon; and
- Long term: Net movement over 30 to 50-year horizon based on available data and assessment of paradigm shifts in shoreline processes over the available data period.

It is possible that shoreline recession could be excluded from insurance coverage. However, due the inter-relationship between recession and potential impacts from storm events on further erosion and risk of inundation, property may become more exposed to coastal erosion and inundation during a severe storm event. In this situation, the insurance industry needs to assess damage to property or other insured assets as a result of recession and erosion, as compared to damage from inundation.

3.5 Sea Level Rise

3.5.1 Process Description

Sea level rise is an increase in the mean water level of the world's oceans. Sea level rise does not occur uniformly across the globe and there are a large number of atmospheric and oceanographic processes that influence sea level rise. Sea level rise has been slowly occurring over the last 200-years, but climate change from global warming as a result of increased carbon dioxide emissions have resulted in a significant increase in the rate of sea level rise, which is expected to further accelerate into the future.

IPCC (2021) provides global sea level rise projections for 2100 based on different emissions scenarios of between 0.28 and 1.01 m as presented in Figure 3.7. The latest guidance published in the *AR6 Climate Change 2021* summary (IPCC, 2021) is aligned with the previous AR5 assessment presented in IPCC (2013). Regional and local sea level rise is expected to vary from the global mean, but overall variations are estimated to be small. IPCC (2013) assessed that *"it is very likely that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience sea level change within 20% of the global mean sea level change."*

It is important to that the whole community understand that irrespective of the emissions scenario (Shared Socio-economic Pathway, SSP as defined in IPCC, 2021) that is actually achieved on Earth over the period to 2100, global sea level is expected to rise over at least the next 2,000 years and it is critical that sea level rise beyond the year 2100 is considered when evaluating impacts and responses to future sea level rise. IPCC (2021) provides insightful sea level rise scenarios extending to the year 2150 which increasingly needs to be considered when evaluate planning and engineering responses to sea level rise.

Zhang et al (2017) undertook downscaled modelling of regional sea level based on the IPCC (2013) emissions scenarios and, with the exception of the Gulf of Carpentaria, the sea level rise around the coastline of Australia was consistent with the global trend. However, Zhang et al (2017) noted that there was uncertainty in the regional projections for southeast Australia as offshore in the Tasman Sea regional sea level rises are expected to be relatively high due to changes in oceanographic currents with climate change.

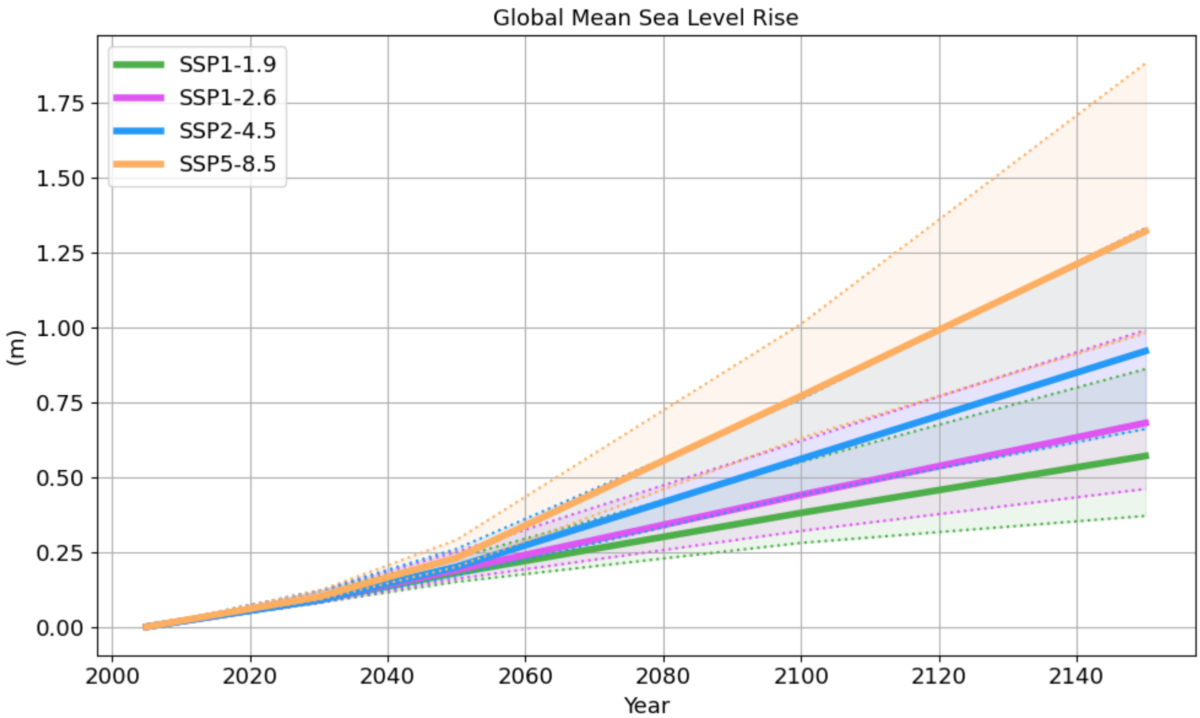


Figure 3.7: Projections of global mean sea level rise over the 21st century relative to global mean sea level 1995 - 2014 (data sourced from IPCC, 2021).

In addition to sea level rise from isothermic expansion and glacial melting as a result of climate change, relative sea level rise as a result of coastal land levels subsiding can have a significant impact on exposure to Actions of the Sea in some areas. Generally, Australia's land elevations at key coastal locations are relatively stationary, although there are areas where some slow rates of localised local and regional subsidence have been observed, for example in the greater Perth region (White *et al*, 2014).

In the context of Actions of the Sea, sea level rise will directly influence all the Actions of the Sea that impact on Australia's coastline. The frequency and extent of tidal and extreme water level inundation will increase, coastal erosion typically increases as event related elevated water levels increase, and shoreline processes will alter, resulting in increased shoreline recession in some areas.

It is important to note that climate change will have other impacts on Actions of the Sea, for example potential changes in tropical cyclone climatology with changes to event intensity and tracks. Other climate change related impacts on Actions of the Sea need to be considered in the assessment of each key process.

3.5.2 Considerations for the Insurance Industry

At present, the IPCC 6th Assessment Report (IPCC, 2021) and the soon to be published full report of IPCC Working Group I, provides the most appropriate reference for the insurance industry to assess sea level rise over medium-and-long-term horizons. It is not expected that sea level rise would be covered by insurance; however, sea level rise will increase the frequency and impact on insured property from all other Actions of the Sea addressed in this report. As a result of the feedback that sea level rise has on increasing inundation and coastal erosion and shoreline recession hazards, the insurance sector will need assess how vulnerability and exposure will increase in the future.

Regional variation in projected sea level rise will become increasing important as the state of science increases, and uncertainty in the projected global emissions timeline over the rest of the 21st century reduces.

3.6 Tsunami

3.6.1 Process Description

Tsunami is a term derived from the Japanese term 'harbour wave' which is the result of a sudden displacement of a large volume of water, that causes long period waves that can propagate long distances at high speed. Tsunamis are most commonly generated by submarine earthquakes but can also be generated by landslides (coastal and submarine) and volcanic eruptions. The key characteristic of tsunami waves in the context of actions of sea impacts on coastal areas, is tsunami waves shoal and significantly increase in height as they approach the coastline. Due to their long wavelength, rather than being short duration impact that may occur from a large wave breaking on a beach or headland, tsunamis can effectively be a wall of water that can cause extreme inundation for a long distance from the coastline and run-up to high elevations above the normal sea level.

Generally, Australia has had no significant tsunami impacts on populated areas over the last 200-years although significant coastal inundation has been observed at some remote areas in northwest Australia, including Cape Leveque. Figure 3.8 presents an assessment of the 500-year ARI tsunami hazard around Australia as presented in Davies (2019).

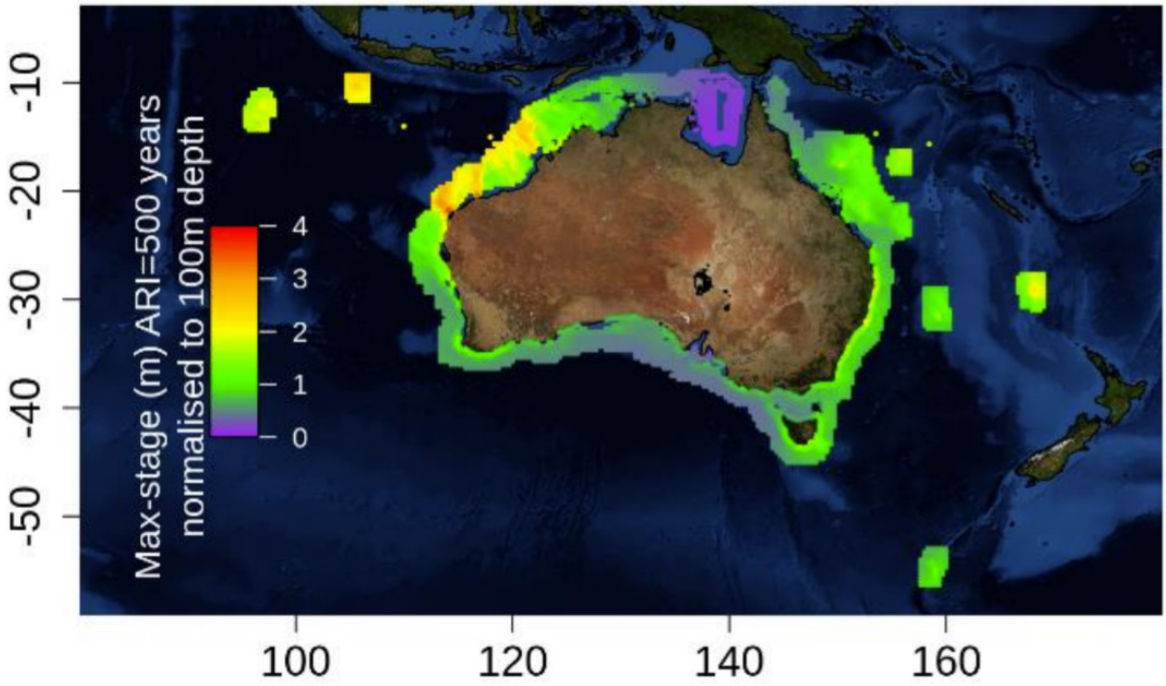


Figure 3.8: Maximum tsunami wave height above ambient sea-level at ARI=500 years normalised to 100 m depth (Davies, 2019).

Whilst the coastal inundation risk for tsunami in Australia is low to moderate, the potential impact on coastal marine infrastructure and boats is more significant. There have been several events over the last 200-years that have impacted on boat anchored or moored in harbours. For example, the 2004 Boxing Day tsunami impacts on harbour along the West Australian coastline, and the 1960 Chile earthquake that caused damage to boats in harbours along the NSW coastline.

3.6.2 Considerations for the Insurance Industry

The Australian Tsunami Warning System (ATWS) is a collaboration of the Bureau of Meteorology (BoM) Geoscience Australia (GA) and the Department of Home Affairs (Home Affairs). The ATWS (http://www.bom.gov.au/tsunami/about/atws.shtml) maintains a large deepwater warning system to identify potential tsunami's far from the coastline and provide warning for evacuation and emergency response.

The ATWS is capable of monitoring of nearly all potential tsunami sources in Australia. The system does not provide detailed coverage of potential shelf-scale submarine landslides; however, such events are considered very rare and would be expected to have localised impacts on coastlines.

4. Key Issues in Coastal Risk Management

4.1 Summary

The derivation of definitions for Actions of the Sea presented in Section 3 have highlighted a number of key issues for the insurance sector to consider regarding what insurance should cover with respect to Actions of the Sea and issues that need to be considered in policy wording. The following section summarises key outcomes from the case study completed for this project (see Section 4.2) and the insights to assist the industry to address key issues that need to be considered with respect to actions of sea coverage (see Section 4.3). A summary of data recommendations from the case study is presented in Section 4.4 and then further explored in Section 6.

A key outcome from the case study, which was undertaken at a site exposed to relatively severe erosion and wave dominated flooding, is that the damage and cost of repairs from erosion are significantly greater than inundation, even though wave dominated, or storm surge dominated inundation of properties may occur more frequently or impact a larger number of properties. Whilst it is noted that locations impacted by storm surge dominated inundation may have significantly more damage (compared to wave dominated sites) due to the extended time of inundation and uniform extent of overfloor inundation, the potential damage and repairs to properties from erosion due to extreme waves, or the cost to reduce property exposure from erosion, are likely to be significantly greater for individual properties exposed to erosion than inundation. Whilst not specifically addressed in the case study, the damage from saltwater inundation to building components can be higher than freshwater (or catchment) flooding.

4.2 Case Study

The selected case study is Collaroy-Narrabeen Beach, Sydney NSW, and the impacts of the June 2016 East Coast Low storm. That particular event was a severe storm, with a return period of 50 to 60 years (Average Recurrence Interval, ARI) based on the observed beach erosion and inundation as a result of wave overtopping. The selected case study is a site where coastal erosion and some coastal inundation as a result of wave effects are the dominant Actions of the Sea. Figure 4.1 presents a pre-and-post storm aerial impact comparison of the coastal erosion from the event for a section of the case study area. Figure 3.5 presents an oblique aerial image highlighting some of the property damage and impacts from the storm.

The case study area indicated that severe damage, primarily from erosion but also with likely inundation impacts from wave runup and overtopping, resulted in 16 properties (14%) out of a total of 114 properties assessed) having potentially significant damage to buildings and major external structures (i.e. swimming pools, decks, balconies etc). Following the storm and immediate response, the local government (Northern Beaches Council) prepared an updated Coastal Zone Management Plan (CZMP) that identified a seawall that was integrated in alignment along the whole shoreline of the case study area (Collaroy-South Narrabeen) was the best coastal hazard management response for the next 60-year period.

That seawall is now under construction in stages, with residents contributing 80% of the total cost, and government (local/state) contributing to the remaining cost. On average, the cost to residents for the seawall is $230,000 per property (as reported in the Development Application submitted to Council) and this cost represents approximately 4-5% of the market price (as at May 2021) for properties in the study area. The economic assessment of the seawall has indicated that for high-value prestige properties which dominate in the case study area, the seawall has net positive investment value. For more typical housing stock in coastal areas, the scale of structure that is being completed at Collaroy-Narrabeen has negative to marginal net economic value. This indicates that the investment cost for individual property owners to undertake major structural mitigations to Actions of the Sea is only beneficial in net economic terms for high-value coastal property. It should be noted that the scope of the economic assessment for the seawall only covered the mitigation that the structure(s) provide to protecting property, and wider community or environmental factors were not considered in this assessment.

A summary of the key outcomes from the case study with respect to impacts, planning and engineering responses to the event and economic impact assessment are presented in the following sections. The case study is presented in detail in Appendix A.

4.2.1 2016 Event and Actions of the Sea Impacts on Study Area

The June 2016 East Coast Low represented a significant coastal storm along the NSW coastline and in the context of the study area, represented a 50-to-60-year ARI (return period) event with respect to total wave run-up level. The large north-easterly offshore waves in combination with a high-water level resulted in the highest coastal water levels and wave runup levels at Collaroy-Narrabeen since May 1974. The return period of the wave runup levels in the study area are well correlated with the observed erosion, which is also an approximate 50-year event for the study area and the most significant since May 1974.

Coastal inundation of property in the study area would have been dominated by short duration, episodic flows from wave runup and overtopping of the eroded shoreline. The nature of inundation from wave runup and overtopping is significantly different to sustained inundation of property from storm surge (either on the open coast or within estuary) or catchment flooding associated with creeks, rivers or stormwater. It has become typical of home and contents insurance policies which include flood coverage to include inundation (or flooding) from storm surge, whilst excluding wave impacts. Based on the case study area, the inundation impacts on a particular property from wave dominated processes is less severe than from storm surge.

The extent of impact on property from erosion was best identified from high resolution aerial photos collected within two days of the event. The imagery provided a reliable basis to identify different levels of property impacts as presented in Section 4.2.2. Historical satellite imagery can broadly identify locations which may be susceptible to erosion, however the historical data set of high-resolution imagery is generally insufficient to define hazard area. Based on this case study, focusing on defining extreme storm wave runup levels at particular sites, and assessing those levels to the ground elevations provides a reasonable basis to identify locations at risk of erosion and/or inundation from wave dominated processes. Impacts for individual properties can only be assessed if the foreshore conditions and presence of coastal protection structures are known. In the case study area, properties with some form of coastal protection from either engineered structures or remnant structures from earlier emergency works generally significantly reduced erosion impacts on their properties.

Figure 4.1: Nearmap images for southern section of study area: Pre-storm 06/05/2016 (left) and Post-storm 08/06/2016 (right).

4.2.2 Summary of Property Damage

A summary of the damage levels observed from site observations and high-resolution aerial images for 114 ocean front properties in the Collaroy-Narrabeen embayment is presented in Table 4.1. A total of 16 properties were identified as likely requiring a structural assessment and likely some damage and these were assessed as having severe damage. A further 37 properties assessed as moderate input had a likelihood of some inundation, although inundation impacts would have been variable across that selection of properties. A further 7 properties were assessed as having property boundary impacts and having erosion on the property boundary but limited damage inland from that point. Appendix A presents a spatial overview of the impact assessment for each property in the study area.

Table 4.1: Assessment scale for property impact from Actions of the Sea.

Severity Category	Impact Potential - Inundation	Impact Potential - Erosion	Typical Post-Storm Repairs	Number of Impacted Property Lots
Severe	Likely to be some inundation of primary building.	Significant erosion which exposes primary building foundations and/or causes damage to primary building.	Significant refilling of site to restore ground elevation (also referred to as reinstatement). Repairs to landscaping and exterior structures and interior / exterior inundation damage. Structural assessment of primary building and possible structural repairs. Repair or upgrade to coastal protection structures.	16
Medium	Possible for some inundation of primary building.	Erosion impacts extend into property area but do not impact on primary building.	Refilling of site to restore ground elevation (also referred to as reinstatement). Repairs to landscaping. Possible repairs for exterior structures and interior / exterior flood damage. Repair or upgrade to coastal protection structures.	37
Boundary	Unlikely to be any inundation of primary building.	Erosion impacts limited to seaward boundary or coastal protection structure.	Repair or upgrade to coastal protection structures. Minor landscaping repairs.	7
No Actions of Sea Impacts	Very unlikely to be any inundation due to Actions of the Sea.	No noted erosion impacts within property boundary.	Any post-storm repairs that were completed are unlikely to be from damage caused by actions of sea.	54

4.2.3 Planning Framework and Engineering Responses

This storm event coincided with the advent of NSW's long awaited Coastal Management Act (2016) which provided an updated policy and planning framework for coastal management from the previous Coastal Protection Act, 1979 (now repealed). However, the Act did not effectively operate from a planning perspective until April 2018 and much of the operable planning elements were founded on the now repealed Act. The updated planning framework for the study area seeks to balance the needs of the community and the ability for property owners to protect their homes, whilst ensuring the majority cost of coastal protection is borne by the beneficiaries of the protection. This case study has shown that whilst on-the-ground coastal protection can be implemented with conditions with the intention of protecting environmental and community values, the approval timeframe can be long (2-3 years) and construction of works is expensive and subject to unique legal complexities as property owners jointly fund and oversee the design and construction of protection along a number of contiguous properties.

Whilst the engineering response is grounded in an adopted Coastal Zone Management Plan (CZMP) certified under the former Coastal Protection Act, 1979, the long-term plan to balance needs between protection of property, and community and environment values is not yet resolved with the transition to a Coastal Management Program to occur by the end of 2023. With future storms and accelerating sea level rise, additional management and engineering responses will most likely be required in the study area. Ensuring beach amenity with future sea level rise is expected to require long-term beach nourishment, which is likely to at a considerable cost.

4.2.4 Economic Impact Assessment

The economic impact assessment has highlighted the damage costs from three different factors: loss of land from erosion, damage to structures from erosion and damage to structures from inundation. The economic costs over the long-term from erosion damage to structures is significant. Whilst the damage impact from storms less than 50-year ARI return period is relatively low, the potential damage from a 100-year ARI event is significant and may require a complete re-build of a property. The information in the economic assessment will provide the insurance sector an insight into the potential cost of covering some, or all Actions of the Sea as part of general property insurance.

The economic assessment of the seawall being constructed in the study area indicates that the overall economic metrics for the seawall are only favourable for high-value, prestige properties. Medium and high-standard properties in the case study areas had Benefit-Cost Ratio (BCR) of 1 or less indicating marginal to negative net present value of the seawall on an economic cost basis. The overall cost of protection for each property owner covered by the seawall is approximately $230,000. This is a substantial capital cost and represents 4% to 5% of current property values in the study area. However, the seawall provides significant protection for the 100-year event which would be expected cause substantial structural damage to many properties. The seawall may also enhance or maintain the investment value of property as to reduces the future risk cost of ownership. An economic assessment of a managed retreat scenario has been considered, with the retreat occurring following a major erosion event. The cost of retreat per property has a present value (May 2021) of $1.4 million and an equivalent annual cost (AAD) is estimated at around $102,000.

4.3 Insights from Case Study for Insurance Sector

The case study has provided insight and recommendations to address key issues that the insurance sector needs to consider with respect to Actions of the Sea. Table 4.2 presents a summary of some key issues that the insurance industry is considering with respect to Actions of the Sea and applicable insights and recommendations coming out of the case study.

Table 4.2: Summary of risk assessment issues, insights or recommendations from the case study

Issue No.	Consideration/Issue for Risk Management	Insights / Recommendations from Case Study
1	What are the key Actions of the Sea impacts on property and which actions have higher potential for property damage and potential loss?	The case study has highlighted that Actions of the Sea contribute to three main impacts on properties: (1) inundation of land and inside buildings, (2) erosion of land and (3) structural damage to buildings from erosion. The impact of inundation can vary depending on whether the inundation causes sustained and prolonged overfloor flooding for the entire floor area of a house as occurs with a storm surge event, or if inundation is from short duration overfloor water ingress from wave dominated processes. The case study has indicated that it appears to be feasible to assess damage from the three mechanisms described above even though the forcing processes are inter-related. In terms of cost of damage, if structural damage occurs as a result of erosion, the potential repair and insured loss can be significantly higher than from inundation.
2	How should extreme weather induced Actions of the Sea be addressed, for example inundation from severe weather (see Section 3.2.2) as compared to inundation that is dominated by tide without storm surge (see Section 3.2.1).	Flooding from coastal actions, including tide dominated events or from storm surge generated from severe weather, could be addressed in insurance policies with similar wording to existing coverage for other inundation mechanisms including storm surge. To differentiate between inundation from conditions within normal tidal variation, compared to other unforeseen water level events, reference could be made to inundation as a result of water levels above the normal tide range.
3	Can impacts and damage from coastal erosion be separated from inundation impacts on property?	The case study has indicated that high resolution aerial imagery following a severe event can be used to identify properties impacted by erosion. Property impacts from inundation are distantly different from erosion. Inundation of a property may only occur after the erosion has occurred; however, the damage to the property from inundation is able to be distinguished from erosion damage.
4	What is the inundation impacts from different types of storms or processes? For example, coastal inundation from cyclone storm surge as compared to inundation behind the shoreline or structure from wave runup and overtopping.	The case study has highlighted that the inundation impacts on buildings from wave runup and overtopping dominated processes are significantly less than prolonged inundation from other inundation events including from storm surge or catchment/riverine flooding. At present the are knowledge and data gaps regarding damage curves for different types of inundation and this is an area where further research and development of methods and guidelines is required.
5	Can coastal erosion (see Section 3.3) easily be	Coastal erosion from a severe weather or wave event cannot easily be separated from shoreline recession. In

Issue No.	Consideration/Issue for Risk Management	Insights / Recommendations from Case Study
	separated from shoreline recession (see Section 3.4) in insurance policy wording?	many situations, medium- or long-term recession may contribute to the acute erosion impacts a property experiences from a severe event. Without detailed site-specific assessment or studies, it is difficult to distinguish shoreline recession from coastal erosion, and if coastal erosion were included in policy terms, shoreline recession may be effectively included as a policy inclusion.
6	How can buildings and property be made more resilient to Actions of the Sea to mitigate damage and potential insured loss?	Properties can be protected and made more resilient from Actions of the Seas in several ways; however, most measures can significantly increase cost of construction or cost to maintain a property. In NSW, it is common for properties in the potential erosion impact area have piled foundations to suitable depth to prevent structural damage from erosion. In some flood prone areas, all habitable areas of a house are elevated above specified floor levels, for example elevated houses with only parking and storage of non-valuable items on the ground floor. However, the case study has indicated that loss of services (i.e. water, electricity and sewage) to properties can still mean they are unhabitable, even though the building is structurally sound. For inundation, having property floor levels above storm surge flood levels can be effective. In locations at risk over wave runup and overtopping having floor levels 0.5 m or more above ground levels can substantially mitigate impacts from inundation.

4.4 Data Recommendations for Impact and Pricing Assessments

The case study has highlighted that there are a large number of processes and data variables that can been considered to assess impacts from severe events or to define vulnerability and hazard to Actions of the Sea. Coastal erosion (as defined in Section 3.3), shoreline recession (as defined in Section 3.4) and inundation as a result of wave dominated processes (as defined in Section 3.2.2) represent the most challenging Actions of the Sea to assess following an event, or to evaluate vulnerability and hazard to assess coverage and pricing.

The impact assessment completed in the case study has indicated that there may be pragmatic methods that the insurance sector could adopt to collate and analyse data for event impact and pricing assessments. Table 4.3 summarises the applicability of key data sets for impact (post-event) and pricing assessments (assessment of vulnerability/hazard). Quantifying erosion potential for pricing assessments can be complex and uncertain. Based on the case study and other studies completed by the study the following approach can be adopted to assess erosion vulnerability and potential hazard:

- Determine coastal water levels and nearshore wave conditions from data or numerical modelling;
- Semi-quantitatively assessing shoreline erosion potential based on historical shoreline movements analysed from satellite imagery;

- Assessing potential for wave runup and overtopping of coastal properties using high-resolution LiDAR; and
- Identify properties that are potentially in the wave impact zone and/or located landward of mobile shorelines.

Recommendations for data sets and methods to assist the insurance industry with impact and pricing assessments is further presented in Section 6.

Table 4.3: Summary of key data sets identified in the case study to assist the insurance sector with impact and pricing assessments.

Data Type	Description	Complexity for data acquisition	Applicability for use in insurance sector	
			Impact Assessment	Pricing Assessment (Vulnerability/Hazard)
Aerial / UAV Photography	High-resolution aerial photography post event to assess impact and damage.	Low – Government agencies and commercial service providers capable collecting high quality.	High	Moderate
Coastal Water Levels	Measured water level data at sufficient sites to define event water levels.	Low – range or government and industry groups collect suitable data. National Tidal Centre (Bureau of Meteorology) can catalogue and store data.	High	High
Nearshore Wave Conditions	High resolution hindcast or measured nearshore wave conditions	Medium – requires high-resolution numerical modelling to model wave conditions to close to the coastline.	High	High
Historical satellite imagery	Historical satellite imagery to identify and analyse shoreline change.	Low – a number of tools and methods available to analyse large study area.	Low	Moderate – suitable for vulnerability assessment.
Coastal LiDAR survey	Regular coastal LiDAR survey to analyse elevation of coastal zone and property ground levels.	Moderate – LiDAR survey is routine now but has higher cost and complexity compared to aerial photography.	Moderate	Moderate
Shoreline erosion modelling	Process based numerical model to predict or assess erosion	High – variable numerical methods available. Large variation in model results and accuracy. Requires extensive site data.	Low	Low

5. Mitigation Measures for Actions of the Sea

5.1 Overview

A range of approaches and measures are available to mitigate and management Actions of the Sea. Many of these actions are not the responsibility of the insurance industry, but due to the potential to reduce damage and impacts from Actions of the Sea, the insurance industry is a key stakeholder and interested party in effective management and mitigation measures that are implemented by government or landowners to reduce exposure.

The following section summarises mitigation measures for Actions of the Sea in three distinct areas:

- Landuse planning (see Section 5.2);
- Engineering to protect property or increase resiliency (see Section 5.3); and
- Financial measures to address risk from impacts to Actions of the Sea (see Section 5.4).

Around Australia, there is a prevailing approach by state and local governments to manage and mitigate impacts on property and infrastructure by avoiding exposure to unacceptable risk. An example of a typical coastal management and adaption approach is illustrated in Figure 5.1 from the Western Australia coastal hazard and risk management framework (WAPC, 2014). It is consistent across Australia that new development is expected to avoid unacceptable risk from Actions of the Sea as a planning and development constraint.

Figure 5.1: Coastal adaptation hierarchy (WAPC 2014)

Managed retreat is a concept that has been part of the coastal management framework over the last 30-years and is included in many coastal management plans. The concept of managed retreat is that the financial costs and non-financial impacts of maintaining property in the area exposed to Actions of the Sea is unacceptable, and that property and infrastructure will be progressively moved landward in response to increasing impacts from Actions of the Sea. In the context of this assessment, managed retreat has been considered as a planning and a financial measure to address Actions of the Sea. Despite being an important management measure and enacted into coastal planning for over 30-years, the overall experience over that time is that managed retreat to mitigate Actions of the Sea has had limited application.

Accommodate and protect are two mitigations that are focused on engineering responses to reduce exposure to Actions of the Sea. The case study included a detailed assessment on engineering options to protect against Actions of the Sea as summarised in Section 4.2.3. Effective engineering measures can be implemented to accommodate and protect against Actions of the Sea but as the case study highlighted, the cost of those measures can be significant. Protection options, in particular seawalls or hard structures to protect against erosion or overtopping, also have to consider other issues that are fundamental in coastal management legislation including public access to the coast, potential impacts to adjacent land, and overall amenity of the shoreline.

5.2 Landuse Planning

5.2.1 Overview

Land use planning is one of the risk controls that can be used to address risks associated with Actions of the Sea and can be used to mitigate the full range processes defined in Section 3.

5.2.2 Common Aspects of Land Use Planning Across Australia

The specifics of contemporary land use planning in the coastal zone varies between the states and territories in Australia and commonly links to historical experiences of coastal events, where patterns of settlement, land ownership and subdivision commonly failed to recognise the risks present in the landscape. There are no overarching provisions at a Commonwealth level for land use planning that inter-relates with insurance for residential and business purposes.

Section 5.2.3 provides a summary overview by state and territory of the land use planning context in each jurisdiction. New South Wales (NSW) and Western Australia (WA) are two states where coastal planning is directed on a common basis at the state government level, but largely driven at the local government level. The key aspects of how these states manage land use planning are presented below.

NSW enacted a new coastal legislative framework under the Coastal Management Act, 2016 with an intended outcome of compiling coastal vulnerability mapping under the State Environmental Planning Policy Coastal Management (2018) (CM SEPP) (noting that the assessment and delineation of coastal hazards currently varies substantially between local government areas). The SEPP came into force in April 2018. Prior to this time, the Coastal Protection Act, 1979 was in force and resulted in the preparation of Coastal Zone Management Plans (CZMPs), which needed to be certified. These CZMPs included mapping of the extent of coastal hazards, however, the consistency of approach varied from place to place. One of the outcomes of the 2018 SEPP provisions is to improve the consistency of coastal hazard assessments and mapping across the state to inform the coastal vulnerability mapping that the SEPP is reliant on (mapping which does not currently exist). However, it would be expected that a meaningful vulnerability map on a state-wide basis is likely to be a five-year horizon (and may have gaps in some localities, where local provisions would instead apply). At present, there is a ‘land application map’ which gives some guide to the extent of the coastal zone, but this includes areas related to protection of the coastal environment and the regulation of coastal uses which sit beyond the actual extent of areas that are directly vulnerable to key coastal processes such as erosion and/or inundation.

WA adopted a State Planning Policy (SPP 2.6) in 2005 to guide coastal hazard management across the state. A significant revision was enacted in 2013 and the policy specifies a proscriptive and consistent approach to define and quantify coastal hazards for the whole state. A feature of SPP 2.6 is that it is applied across a wide range of coastal environments from the cyclone prone, macro-tidal Kimberley and Pilbara region, through to small, diurnal tide regions in the southwest that are subject to frequent annual frontal storms. The outcome of SPP2.6 at a local level for land use planning is local planning scheme provisions (referred to as Special Control Areas), which can be used to designate coastal hazard risk areas, and to control land use and trigger the need for planning approval for developments. Mapping of coastal hazards in WA to identify Special Control Areas and the like is commonly completed through the Coastal Hazard Risk Management and Adaption Planning (CHRMP) process, in accordance with the CHRMAP Guidelines (2019).

However, in the absence of a CHRMAP endorsed by the relevant decision-making authority, there are some cases where an applicant for development may need to prepare a CHRMAP to support their application, or where required by the relevant decision-making authority.

5.2.3 Summary of Coastal Planning Policy and Laws around Australia

Table 5.1: Summary of Australian State and Territory Policy and Law Relevant to Coastal Australia (Source: Adapted from CoastAdapt (2 May 2017) and Updated)

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
NSW	*Environmental Planning & Assessment Act 1979 (NSW) and Environmental Planning and Assessment Regulation 2000 (NSW)* *Coastal Management Act 2016 (NSW)* *State Environmental Planning Policy (Coastal Management) 2018* *Local Environmental Planning Instruments*	*Coastal Management Manual (2018)* *Development Control Plans* *Coastal Management Programs (CMP)* *Coastal Zone Management Plans (CZMP)*	The *Environmental Planning and Assessment Act 1979* sets out the legislative framework for planning and development assessment in NSW. The *Coastal Management Act 2016* (NSW) sets out the framework for coastal management. It replaced the Coastal Protection Act, 1979. Under the provisions of the EP&A Act, there are a range of environmental planning instruments, including State Environmental Planning Policies (SEPPs), which generally have effect across the entire state (unless otherwise specified). SEPP Coastal Management 2018 (or CM SEPP) deals with coastal management and identifies four coastal management areas, the key one for insurance being the coastal vulnerability area. However, mapping for this area is not yet in force. Coastal hazard mapping is available for a number of areas in NSW, commonly within the CZMP prepared for a beach or stretch of coastline. CZMPs were prepared under the repealed Coastal Protection Act, 1979. CZMPs are now in the process of being adapted to Coastal Management Programs and coastal hazard mapping re-analysed in some cases to meet probabilistic approaches identified in the Coastal Management Manual (2018). Where available, coastal hazard mapping is commonly integrated for planning purposes into the relevant Local Environment Plan (LEP) and local provisions

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
			applied in accordance with the Standard Instrument. Details of how specific planning and building controls are expressed are generally found in the accompanying development control plan to the LEP.
Northern Territory	*Planning Act 1999* *Planning Regulations 2000* *Building Act 1993* *Building Regulations 1993* *Northern Territory Planning Scheme (2020)*	*Coastal and Marine Management Strategy Northern Territory 2019-2029*	The *Planning Act 1999* (NT) is the main planning legislation for the state. Amongst other things, it provides for a single Northern Territory Planning Scheme (2020) to apply to the whole Territory, except to Jabiru where the Jabiru Town Plan applies. The Scheme identifies hazards, which include: • cyclones • storm surges • riverine flooding. The Planning Scheme is linked to maps of 'primary' and 'secondary' storm surge areas, defined as having a 1% and 0.1% AEP of inundation by storm surge respectively. The Scheme places limitations on development in these areas. Coastal erosion is not defined in the Planning Scheme or within identified Building Control Areas. The Coastal and Marine Management Strategy 2019-2029 sets a ten year direction for the management and protection of coastal and marine environments.
Queensland	*Planning Act 2016* *Planning Regulation 2017* *Coastal Protection and Management Act 1995* *State Planning Policy (July 2017)*	*Coastal hazard technical guide Determining coastal hazard areas (2013)* *Guideline: State Development Assessment Provisions*	The *Planning Act 2016* sets out the legislative framework for planning and development assessment in Queensland. The *Coastal Protection and Management Act 1995* (Qld) provides the framework for coastal management. Coastal management districts are declared under the Coastal Protection and Management Act 1995. The coastal management district is a coastal area that is considered to need protection or management, especially with respect to the area's vulnerability to erosion, value in maintaining or enhancing coastal resources or for planning and development of the area. Specifically, districts generally include all lots that intersect a declared Erosion Prone

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
	Erosion prone area plans (declared under s 70 of the Coastal Protection and Management Act 1995) *Local Planning Instruments*	*State Code 8: Coastal development and tidal works (2019)*	Area (EP Area) and all tidal areas to the limit of state water. The EP Area is the width of the coast that is considered to be vulnerable to coastal erosion and tidal inundation. Erosion prone areas have been declared for all coastal local government areas in Queensland. These areas are shown on erosion prone area plans. These plans are used for development assessment purposes, and to inform the preparation of planning instruments, such as planning schemes and regional plans under the Planning Act 2016. The State Planning Policy (2017) sets out the State's interests for local governments that must be addressed when amending their planning scheme, and assessing development applications. These policies link development restrictions to the declared erosion prone areas. The State Code 8 (2019) refers to the coastal building line, which identifies areas that are vulnerable to coastal erosion. Development seaward of a coastal building line are assessed to minimise damage to buildings and other structures from erosion and to ensure that future erosion protection works can be located wholly on the freehold lot. Generally, no building work—including houses, sheds or swimming pools—are allowed seaward of a coastal building line. Erosion control structures are the only structures that can be considered seaward of a coastal building line.
South Australia	*Planning, Development and Infrastructure Act 2016*	*2019 State Planning Policy 13 (Coastal Environment)*	The *Planning, Development and Infrastructure Act 2016* and the *Coast Protection Act 1972* provide the essential underpinning legislative framework for coastal development in the state.

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
	Coast Protection Act 1972 *Coast Protection Regulations 2015* *Climate Change and Greenhouse Emissions Reduction Act 2007* *Local Planning Controls*	*Coastal Planning Information Package A guide to coastal development assessment and planning policy Revised November 2013*	The *Coast Protection Act* also established the Coast Protection Board, which develops coastal planning policy and is a referral body for coastal development. Planning authorities must refer development applications for coastal land to the Coast Protection Board. The Coast Protection Board has decision-making power in limited circumstances, otherwise their role is advisory and the planning authority must have regard to their advice. The 2019 State Planning Policy 13 (Coastal Environment) was established under the *Planning, Development and Infrastructure Act 2016 (SA)* and seeks to protect and preserve the coastal environment and ensure that new developments are not at risk from coastal hazards.
Tasmania	*Land Use Planning and Approvals Act 1993* *Building Act 2016* *Building Regulations 2016* *State Policies and Projects Act 1993* *Tasmanian State Coastal Policy 1996* *Tasmanian Planning Scheme (TPS)*	*Mitigating Natural Hazards through Land Use Planning and Building Control* *Coastal Hazards in Tasmania Summary Report Of Coastal Hazards Technical Report (2016)* *Coastal Hazards Package (2016)* *Coastal Inundation Hazard Code and Coastal Erosion*	The *Land Use Planning and Approvals Act* sets out the underpinning legislative framework for the planning in the state. The Building Act and Regulations establish building requirements. The Land Use Planning and Approvals Act is supplemented by the Tasmanian State Coastal Policy, 1996, which is given statutory effect by the *State Policies and Projects Act 1993.* The policy sets out key objectives and outcomes for local governments to consider in planning. The TPS applies to the state and comprises two parts: • the State Planning Provisions (SPPs) which includes the identification and purpose, the administrative requirements and processes, including exemptions from the planning scheme and general provisions that apply to all use and development irrespective of the zone, the zones with standard use and development provisions, and the codes with standard provisions; and

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
	Director's Determination - Coastal Erosion Hazard Areas (2020) *Local Planning Controls*	*Hazard Code (2017)*	• the Local Provisions Schedules (LPSs) that apply to each municipal area and include zone and overlay maps, local area objectives, code lists, particular purpose zones, specific area plans, and any site-specific qualifications. Specific codes include the coastal inundation hazard code and the coastal erosion hazard code. The Coastal Hazards Package (2016) sets out how the sea level rise planning allowances are to be considered in land use planning and building in Tasmania. The package includes policy maps for coastal inundation and erosion. The Directors Determination (2020) specifies requirements for building or demolition work in coastal erosion hazard areas.
Victoria	*Planning and Environment Act 1987* *Marine and Coastal Act 2018* *Climate Change Act 2017* *Victoria Planning Provisions – State Planning Policy Framework* *Municipal Strategic Statements* *Local planning schemes*	*Marine and Coastal Policy (2020)* *Victorian Coastal Strategy (2014)* *Guidelines for Developing a Coastal Hazard Assessment (2017)*	The Planning and Environment Act 1987 and Marine and Coastal Act 2018 set the underpinning legislative framework. At present there is a reported gap in available knowledge and management of coastal erosion in Victoria. As part of the implementation of the Marine and Coastal Act, 2018, the Department of Environment Land Water and Planning (DELWP) will work with agencies to establish statewide objectives, standards, databases and guidance to build understanding of coastal erosion and flooding. Additionally, Victoria's first marine spatial planning framework is an element of the Marine and Coastal Policy (2020) to help achieve integrated and co-ordinated planning and management of the marine environment. This will include the completion of a number of Coastal Hazard Assessments (CHA) under the provisions of the Marine and Coastal Act 2018 and in accordance with the Guidelines for Developing a Coastal Hazard Assessment (DELWP, 2017). Pilot CHAs were completed some

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
			years ago to inform the Victorian Coastal Inundation Data Set (VCIDS), which was released in 2013. The Climate Change Act, 2017 includes a requirement to consider climate change in developing coastal strategies/actions plans). Under the Planning and Environment Act, the Victoria Planning Provisions (VPP) provide a set of standard planning scheme provisions, which must be integrated into local planning schemes. Chapter 13 addresses coastal hazards and coastal impacts of climate change. The Victorian Coastal Strategy (VCS) (2014) is a more detailed document outlining principles for planning and development decision-making. The VCS was prepared under the now-repealed Coastal Management Act 1995 but will remain in place during a transitional period with a new Marine and Coastal Policy and Strategy in preparation at the time of preparation of this document. The overarching principles require that decision-makers: • ensure the protection of significant environmental and cultural values • undertake integrated planning and provide clear direction for the future • ensure the sustainable use of natural coastal resources • and finally, when the above principles have been considered and addressed—ensure development on the coast is located within existing modified and resilient environments where the demand for development is evident and the impact can be managed. Some elements of the VCS had been replaced at the time of preparation of this document, but this was only a small portion of the strategy.

State/ Territory	Key legislation/ regulations/documents with binding legal effect	Key policies/strategies	Brief summary
Western Australia	*Planning & Development Act 2005* *Planning and Development (Local Planning Scheme) Regulations 2015* *State Planning Policy 2.6: State Coastal Planning Policy 2013Local Planning Controls*	*State Coastal Planning Policy Guidelines (2020) (for State Planning Policy 2.6)* *Coastal Hazard Risk Management and Adaptation Planning Guidelines (CHRMAP) (2019)* *WA Coastal Zone Strategy (2017)* *Coastal Planning and Management Manual (2003)*	The *Planning & Development Act 2005* (WA) is the overarching planning law. Local planning strategies (for each Local Government Area) are required to be prepared under the Planning and Development (Local Planning Scheme) Regulations 2015, and influence land use and development controls. Local governments are required to have regard to SPP2.6 coastal hazard risk when preparing or amending a local planning scheme. The SPP2.6 encourages future development to be concentrated in existing settlements, and also encourages local government to undertake coastal hazard risk management and adaptation planning. The Coastal Hazard Risk Management and Adaptation Planning Guidelines (2019) (referred to as the CHRMAP guidelines) are to be read in conjunction with the SPP2.6. The WA Coastal Zone Strategy (2017) establishes a vision of a sustainable coast for the long-term benefit of the community and visitors to the State. The Strategy complements the State Planning Policy No. 2.6 State Coastal Planning Policy which guides development and land-use in the coastal zone. The aim of the Coastal Planning and Management Manual (2003) is to provide community groups, local government and other land managers with a practical guide to coastal planning and management for Western Australia. The Manual sets out Planning Principles, but the practical expression of these is found in SPP2.6.

5.3 Engineering

5.3.1 Overview

Engineering mitigations for Actions of the Sea have been widely adopted in Australia and overseas. Within the context of Australia, the work that has been undertaken on the Gold Coast since the 1960's to protect long sections of coastline, property and infrastructure from erosion and coastal inundation is the most significant of its type in Australia. Engineering measures of the scale implemented for the Gold Coast, which includes seawalls, beach nourishment, sand bypassing and artificial reefs, have been typically been implemented by state and local government using taxpayer funded projects. In the general Australian-wide context, engineering responses to Actions of the Sea are undertaken on a smaller scale and funded by local government or landowners.

5.3.2 Engineering Options Summary

The case study summarised in Section 4.2 provides a current example of typical property protection for Actions of the Sea that is undertaken by local government and landowners. For an open coast location, the scale and cost of seawall structures to protect against erosion and prevent coastal inundation can range from $8,400 per m to $36,500 per m. For the case study, average cost to property owners for construction of the seawall protection which is designed for 100-year ARI storm events is estimated at $230,000 per property. The economic assessment completed in the case study of the protection costs relative to the likelihood an event causing major structural damage without a seawall, indicated that at that site the economics of the coastal protection were marginal. However, the economic assessment does not consider the impact on property value following a major storm event.

Mitigation of building structure damage from erosion can also be achieved from construction of building with suitable foundations that can accommodate effects of erosion. Over the last 30-years, many local government areas with development in the coastal zone have required nearby buildings that may be within erosion hazard areas within the planning period to have building foundations that can accommodate erosion near the building. The concept that is normally adopted in based on Nielsen et al (1992) and is schematically represented in Figure 5.2. Where properties are within the Zone of Reduced Foundation Capacity, building foundations must extend into the Stable Foundation Zone. This engineering solution can significantly reduce the damage to property from erosion but depending on the site conditions can also add significantly to construction cost.

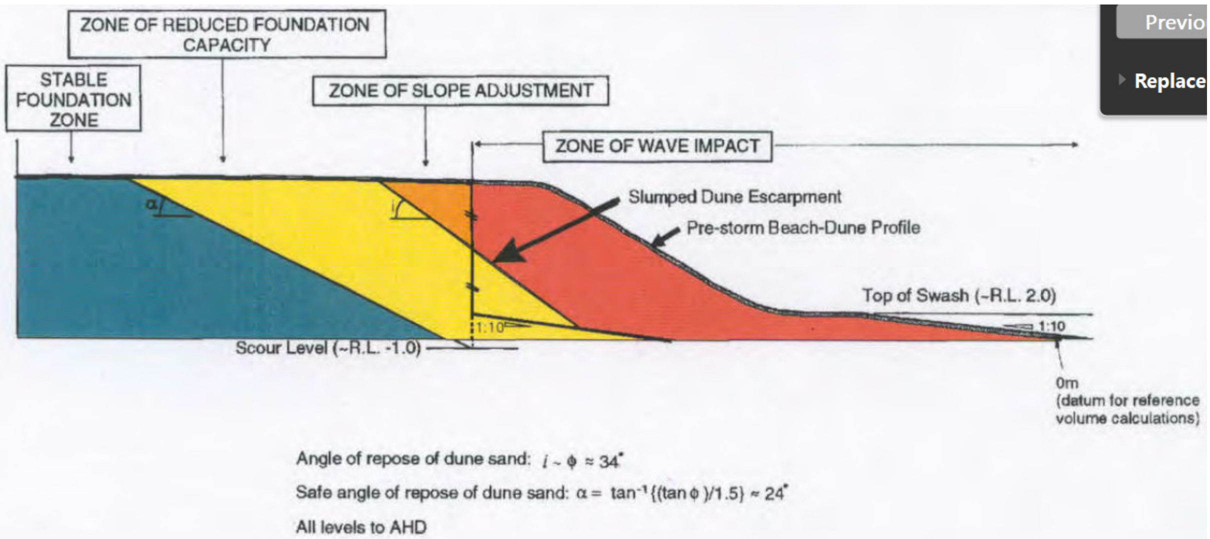


Figure 5.2: Schematic representation of coastline hazard zones based on Nielsen et al (1992)

The examples presented in this section identify engineering mitigations to the Actions of the Sea that property holders can undertake, subject to planning requirements. Local and state government may also fund and complete coastal protection works to protect infrastructure and assets, that can also protect private landholders. The *City of Greater Geraldton* (CGG) is a local government area that is subject to current and future risk from Actions of the Sea as outlined in Baird (2016). The CGG has funded and constructed a number of small, short-to-medium design life coastal structures to protect assets and land from current erosion impacts. An example of this type of protection is presented in and includes geotextile groynes illustrated in Figure 5.3. This type of approach is designed to provide protection with less impact on coastal processes compared to hard seawalls or large groynes systems and can be adapted over time to respond to changes in conditions. The basic coast of structures of this type in Geraldton are $5,000 to $7,500 per m. Structures of the type indicated in Figure 5.3 can reduce risk to property and infrastructure from Actions of the Sea for normal or low energy storm events. However, they are unlikely to afford significant protection from extreme events, for example, a 100-year ARI storm event. From an insurance industry perspective, it is essential that the design condition and reliability of particular coastal protection works are known before assessing the impact on insurance as a result of the coastal protection.

Figure 5.3: Current and proposed third Geotextile Sand Container groyne for Whitehill Road (CGG, 2020).

Beach nourishment is a well demonstrated engineering response that can protect property and infrastructure from Actions of the Sea, whilst maintaining beach function, public access and overall amenity. The Gold Coast beaches, currently overseen by Gold Coast City Council, is one of the largest and longest running sand management projects in the world. Since the 1960's, a series of projects and systems have been implemented to supply and manage sand volumes across the region to maintain beach amenity and protect coastal property and infrastructure. Major components of the sand management program include the Tweed River sand bypass that transports sand continuously from the southern side of the Tweed River entrance to the Gold Coast beach to the north. The system is jointly operated by the NSW and Queensland Governments and has been essential for restoring sand volumes to the southern Gold Coast beaches for amenity and coastal protection. Figure 5.4 presents aerial images from 1974 (top) and 2020 (bottom) which demonstrate the increased beach width and storm erosion buffer on Kirra beach as a result of the bypass system (Tweed Bypassing, 2020).

Figure 5.4: Tweed River and Kirra Beaches: (top) 1974 pre-bypass with major sand accumulation to the south of Tweed River and severe erosion of Kirra beaches; (bottom) 2020 with bypass system that has been operational since 2000.

There are large marine sand resources offshore of many coastal areas in Australia, including southeast Queensland and NSW. Large scale sand nourishment and sand management is an attractive engineering operation that can meet most of the elements of contemporary coastal planning in Australia and provides coastal protection, whilst maintaining and potentially enhancing public use opportunity for the coast. Ultimately local and state governments combined are the organisations best suited to planning, implementing and maintaining large scale sand management and nourishment programs. Significant work is being completed by government to understand available sand resources and how they could be sustainability utilised to protect against coastal erosion and sea level rise. An example of recent work includes the Guidelines for Sand Nourishment (Carley and Cox, 2017) prepared for the NSW Government. The success achieved at the Gold Coast over the last 40-years in achieving extensive coastal protection and maintaining and enhancing beach amenity highlights that the insurance industry should support sand nourishment and management as a key engineering response for present issues and future sea level rise.

5.3.3 Summary of Australian Context

A recent example in Australia highlighting the potential future scale of sea level rise protection and adaptation is illustrated by the Busselton area in south-west Western Australia. The City of Busselton release in May 2021 a strategic plan for addressing sea level rise across the whole local government area which is estimated at a current cost of $1.6 billion over the next 100-years (City of Busselton, 2021) for a region with currently 39,600 residents and Gross Regional Product of $2.1 billion AUD. On a population basis, the draft Busselton plan to respond to increased inundation risk from sea level rise is comparable to large scale protection and adaptation projects underway in the USA such as the Orange County project described in Section 5.3.4. This scale of protection will be required at numerous areas around Australia in the future and whilst the costs are significant, engineering responses can have significantly less net cost compared to other alternatives including managed retreat that is discussed in Section 5.4.

Over the next 20-years, Australia will increasingly require engineering to be considered to mitigate impacts to infrastructure and property from sea level rise. Sea level rise has the potential to permanently impact on sites because of regular inundation of land that is currently dry during normal tide conditions and/or significantly increase the likelihood of coastal inundation as storm water levels are increase proportional to sea level rise. Following on engineering developments in Europe and North America, governments around Australia will increasingly have to consider engineering mitigations for sea level rise in the form of levees and coastal protection. The insurance industry will need to be engaged with government and the wider financial sector in planning and mitigation for sea level rise as it is material to the future viability of insurance coverage for Actions of the Sea.

5.3.4 Examples of Large-Scale Engineering Solutions in USA

Coastal adaptation and sea level rise mitigation works that are being planned and in-construction in the USA provide a good reference point for the challenges and decisions that need to be addressed within Australia over the next 5-to-10-years. It is conservatively estimated that the USA will invest in at least $300 billion (USD, net present cost) on protection from sea level rise (Hummel *et al*, 2021). Based on comparative GDP and population, in the Australian context this would equate to at least $25 to $35 billion (AUD) net present for Australia. However, with the concentration of our population in the coastal zone, and the key maritime trade links essential for our export industries, Australia would likely require more investment in adaptation and mitigation to sea level rise. Examples of the scale of projects in the USA to address sea level rise include the Orange County flood protection project being undertaken in Texas by the US Army Corp of Engineers (Galveston District). In total, it is estimated that by 2050, 350,000 people in Texas will be at high risk of coastal inundation within increase sea level rise with the majority of those in the greater Houston and Galveston districts. The Orange County project involves 43 km (26 miles) of levees and 50 flood control structures and will cost more than $4 billion USD for a population of approximately 84,000. Figure 5.5 presents a plan view of the overall Orange County Coastal Storm Risk Management project. The project is part of the integrated Coastal Spine Gulf Coast Protection Project to protect the greater Houston and Galveston area from coastal flooding and rising sea levels over the next 50-years that may cost more than $30 billion USD (net present cost).

The largest integrated storm surge and sea level rise protection and mitigation project in the USA at present is the New York / New Jersey Harbour and Tributaries (NYNJHAT) protection project being undertaken by the US Army Corp of Engineers. A combination of hard engineering in the form of storm surge barriers and levees, with nature-based solutions to restore shorelines, are being evaluated to provide storm surge and sea level rise mitigation for a region with a total population of 16.2 million people (USACE, 2019). The average annual damage for the region from coastal flood is estimated at approximately $5 billion (USD, net present cost) increasing to $13.7 billion (USD, net present cost) by 2100 due to sea level rise (USACE, 2019a). The NYNJHAT project is evaluating five alternative concepts that would reduce average annual damage between 25% and 92% (USACE, 2019a) which vary in cost between $10 billion to $62 billion (USD, net present cost) which equates to between $600 to $4000 per person (USACE, 2019b) within overall impacted area. It is also important to note, that the NYNJHAT project along with numerous coastal flood and sea level rise protection projects across the USA have an increasing focus on nature based solutions, including beach nourishment, barrier island protection and inter-tidal habitat restoration in combination with physical structures.

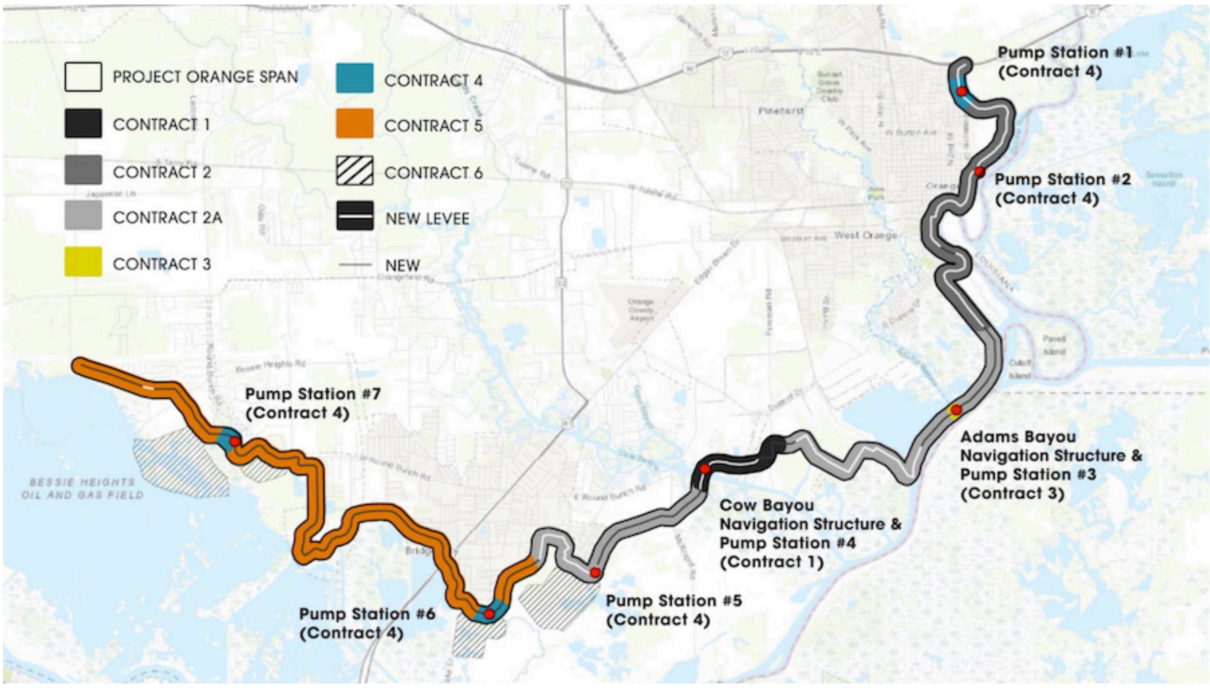


Figure 5.5: Orange County Coastal Storm Risk Management project (Copyright: Galveston Coastal Services Joint Venture - Stantec/Jacobs)

5.4 Financial

Financial products and tools are emerging as a key measure in addressing climate change risk and future impacts. In the context of this project, licenced financial services companies are increasingly having to consider current and future climate risk, including Actions of the Sea and sea level rise, on the risk of their products and/or operation as a regulated financial services provider. The APIA is currently in the draft consultation phase for an industry-wide Prudential Practice Guide on Climate Change Financial Risks (CPG 229).

With respect to Actions of the Sea, the financial services industry is expected to drive cost-based mitigations to Actions of the Sea as it considers climate risks when providing mortgages of 25-to-30-year duration to properties that may be at current risk of Actions of the Sea and/or impacted by sea level rise impacts over the term of a loan. The insurance industry is subject to similar requirements and drivers for climate risk management, although the risk assessment horizon for insurance companies is typically lower than loan providers. It is possible that people will find it increasingly difficult to obtain finance for properties which are a high risk from Actions of the Sea, either now or over the expected life of the loan. The insurance industry has to engage with government, financial services industry and the community of the financial and insurance risks from Actions of the Sea. The social licence that the insurance and financial services industry has is essential to the sustainable performance of the industry over time and any public or government opinion that investment values or future development is being unduly restricted by limited funding or excessive insurance costs will have significant impacts on the insurance industry as a whole.

Local and state governments can also have financial measures to support mitigation from current and future Actions of the Sea. In certain situations, planning controls and title conditions can allow local government to levy property owners within coastal hazard areas to fund coastal protection and management. Considering future beach nourishment and sand management opportunities to mitigate Actions of the Sea including sea level rise, levies and cost recovery from the broader community that benefits from coastal protection and maintaining coastal values are a reasonable manner to secure funding. Any levies that are raised to fund mitigations to Actions of the Sea should be equitable to the whole community and efficient in their collection.

Section 5.1 identified that managed retreat has been a component of contemporary coastal management in Australia for over 30-years. Whilst managed retreat is initially a planning control or response, it can become a financial mitigation if government pays to acquire properties that are subject to managed retreat. The case study example for Collaroy-Narrabeen (see Section 4.2.4), which is characteristic of a high-cost, prestige property location, indicated that managed retreat had significant economic cost compared to a do-nothing, or alternative seawall protection management option.

The experience of planned retreated in Australia is still limited; however, there are particular locations where managed retreat has been underway for several years and has been a financial mitigation measure for government and exposed property owners. In those areas, managed retreat has material costs to government, and often requires landowners to consider future costs and returns if they maintain a property exposed to high risk or whether they accept a government acquisition offer for a particular property. An example of managed retreat that is being implemented by local government is the City of Greater Geraldton. This local government has a CHRMAP that was endorsed by Council in November 2018 (Baird, 2018). The CHRMAP identifies a number of properties that will be subject to managed retreat in accordance with Western Australia's managed retreat guidelines (DPLH, 2017). The CHRMAP identifies 15 properties at extreme risk to Actions of the Sea that are intended to be acquired in accordance with DPLH (2017) before 2030. The City of Greater Geraldton has already acquired several properties that were at immediate risk and this strategy has generated significant mixed emotion and responses within the community and in wider Western Australia.

The City of Busselton in Western Australia has also released a draft CHRMAP that includes a cost estimate for a managed retreat option for all properties that are vulnerable to erosion and inundation (City of Busselton, 2021). The net present cost over the next 100-years for the managed option is estimated at \$8.3 billion (net present cost), compared to the cost of \$1.6 billion for the engineered adapt and protect option presented in Section 5.3. It is obvious that for some communities, the extreme impacts of sea level rise on their current asset base will result in managed retreat having very high economic costs to government and properties owners.

Ideally, managed or planned retreat provides an equitable outcome for landowners and government, but there are many challenges to its effective implementation, and it comes with significant cost to government and can diminish the economic capacity of communities.

6. Data Audit

6.1 Overview

This study has reviewed available data to assist the insurance industry with respect to Actions of the Sea and prepared a prioritised list of data recommendations to support the insurance industry undertaking pragmatic assessments of Actions of the Sea to support vulnerability and pricing assessment, and also post event impact assessment.

Based on the case study, and a review of the state of play with respect to the prediction and modelling of shoreline changes or storm impacts, this study recommends that the insurance industry does not focus on process-based shoreline or sediment transport modelling, but rather focuses on the following primary data variables:

- Tides and extreme water levels, noting that there are differing data requirements for tropical cyclone prone regions, compared to locations impacted by mid-latitude storms (including East Coast Lows).
- Waves, including defining waves to nearshore locations, to understand the unique exposure to wave processes at particular locations.
- Coastal landform described by high-resolution, broadscale survey data (i.e. LiDAR).
- Compilation of shoreline geomorphology data and broadscale analysis of historical satellite imagery to semi-quantitatively define shoreline erodibility for particular sites.
- High-resolution aerial or Unmanned Aerial Vehicle photography post-event for impact assessment and storm event classification.

The report also provides a high-level summary of various data sets that are available or should be developed to assist the industry assess vulnerability and exposure. Table 6.1 presents a summary of data requirements and an assessment of current data availability.

Table 6.1: Summary of Actions of the Sea Data Requirements

Action of the Sea	Data Requirements	Current Data Availability	Data Quality and Reliability
Tidal Inundation	Medium to long term coastal water level data and coastal land elevation data	Good availability for populated areas of Australia.	High quality national tidal data set is maintained by the Bureau of Meteorology. Tidal conditions can vary significantly between open coast and estuarine locations which needs to be considered by the insurance industry. Seasonal and inter-annual variations in mean sea level can also be significant and needs to be considered in the assessment of the frequency and impact of tidal inundation. State governments now generally provide high quality coastal elevation data that is essential for inundation assessments.
Coastal and Estuarine Inundation	Medium to long term coastal water level data, coastal land elevation data and long-duration synthetic inundation data sets for tropical cyclone regions.	Good availability for historical water level and land elevation data sets for populated areas of Australia exposed to mid-latitude storms. Limited inundation data available for most tropical cyclone exposed areas.	High quality national tidal data set is maintained by the Bureau of Meteorology. Tidal conditions can vary significantly between open coast and estuarine locations which needs to be considered by the insurance industry. Seasonal and inter-annual variations in mean sea level can also be significant and needs to be considered in the assessment of the frequency and impact of coastal inundation. State governments now generally provide high quality coastal elevation data that is essential for inundation assessments.

Action of the Sea	Data Requirements	Current Data Availability	Data Quality and Reliability
			Limited long duration data sets (i.e. 30 to 50-year duration) for tropical cyclone areas; those areas will typically require longer duration synthetic or modelled data sets. For areas not exposed to tropical cyclones, many locations with large population centres have long term water level measurement sites that are suitable to determine extreme water levels with a 50 to 100-year ARI.
Coastal Erosion	Historic and contemporary coastal erosion hazard spatial extents derived from local elevation, geomorphology and coastal processes data.	Variable between local and state government jurisdiction. High quality data of erosion hazard extents is available for a large number of vulnerable locations, but data is normally prepared for particular local government areas in a reactive manner.	Variable data quality and reliability. Significant variation in methods, planning periods and assumed rates of sea level rise across local and state government jurisdiction.
Shoreline Recession	Same requirements as beach erosion. Robust methods for continual large scale and high-resolution analysis of satellite imagery.	As for beach erosion, existing are available for particular local government areas. Reliable methods for high-resolution analysis of satellite imagery is available, for example the CoastSat toolbox (Vos et. al., 2019).	Variable data quality and reliability for existing local scale data sets. The suitability of large scale and high-resolution analysis of satellite imagery has been recently demonstrated in research and practice.
Sea level rise	Sea level rise predictions for a range of possible future emissions scenarios. Regional measured sea level rise data as it becomes available.	IPCC (2013) provides the latest range of global sea level rise scenarios.	There is a wide range of scenarios in the IPCC (2013). Regional sea level rise projections currently have more uncertainty than global average projections. For infrastructure and land use planning, there is limited information for sea level rise scenarios beyond 2100.

Action of the Sea	Data Requirements	Current Data Availability	Data Quality and Reliability
Tsunami	National scale data on tsunami wave heights and inundation extents.	A national Australian probabilistic tsunami hazard assessment exists at a depth of 100 m. Limited at-coast tsunami level and inundation extent data is available.	High quality data for offshore areas at depths of 100 m is available around Australia. Limited high-quality data for at-coast tsunami wave height and inundation is currently available. State governments now generally provide high quality coastal elevation data that is essential for inundation assessments.

6.2 Summary of Data Requirements for Actions of the Sea

6.2.1 Inundation

6.2.1.1 Tidal Inundation

Tide conditions and extreme tide levels are very variable around Australia. For most of Australia's coastline, there is limited long-term data, and modelling and interpolation of available data is required. However, for most of Australia's residential infrastructure areas measured coastal water level data is available, and most of the data that is nationally available can be sourced from the Bureau of Meteorology's National Operations Centre Tidal Unit (http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml).

To define an exposure of tidal inundation for insurance purposes, the frequency of exceedance of Highest Astronomical Tide (HAT) levels needs to be analysed. There are three key data items that need to be considered to achieve this outcome:

1. Defining data specification, for example the duration of measured data required to determine the threshold for inundation coverage;
2. Define suitable methods and procedures for data analyses; and
3. Define how climatic variations in coastal water levels as a result of inter-annual, inter-decadal and longer-term sea level changes is accounted for in assessment of inundation levels and insurance coverage.

6.2.1.2 Coastal and Estuarine Inundation from Severe Weather

Potential coastal and estuarine flood levels around Australia are variable because of tide levels, event severity and event frequency variations. For many populated areas of southern Australia, medium and long term measured coastal water level data can be used to define flood levels with a reasonable confidence limit. For estuarine locations, the combination of catchment and coastal flooding often requires local or regional modelling studies to define appropriate flood levels for different frequency of occurrence. Studies of this type are most commonly undertaken by local or state governments and as a result there can be considerable variation in the assumptions, methods applied and data outputs from those studies. For the insurance industry, the data requirements for areas exposed to mid latitude storms (i.e. those most frequently impacting southern Australia) is aligned with the assessment of tidal inundation as outlined in Section 6.2.1.1.

For tropical regions of Australia, where many populated areas across northern Western Australia, Northern Territory and north Queensland have large tide ranges in combination with the potential for large storm surges, historical data available for defining coastal inundation frequency and severity as a result of tropical cyclones or monsoon lows is less reliable. The data requirements for tropical cyclone regions depends on the definition of an insurable event. For example, if a simple definition of an inundation event is adopted (as proposed below), historical data and data defining regional variation in maximum tide levels can be used to define an insurable event. A simple definition that would align with current data sets could be:

1. A severe weather event as defined by the Bureau of Meteorology; and
2. The inundation level during the event exceeds normal tidal inundation extents. or have a defined probability of occurrence.

For the purposes of the insurance industry understanding risk and exposure in tropical cyclone exposed regions of Australia, historical data is insufficient for estimating higher return period events. In this instance, long term synthetic or probabilistic data is required, for example the Tropical Cyclone Hazard Assessment prepared by Geoscience Australia (http://www.ga.gov.au/about/projects/safety/tcha). The challenge in determining storm surge levels from synthetic cyclone data sets is the enormous modelling and data analysis exercise required to estimate concurrent tide and wave effects from tropical cyclones. A range of industry data sets have been developed, for example the Australian tropical cyclone hazard data set described in Burston et al (2017) and Taylor et al (2018), that can provide cyclone wind, rainfall and coastal inundation hazard data for whole lengths of cyclone exposed coastline.

6.2.2 Coastal Erosion

Section 3.3.2 noted that planning controls for coastal areas around Australia normally consider 100-year ARI coastal erosion extents. As a result, many developed areas of Australia have local and regional hazard data for 100-year ARI coastal erosion extents which is defined on local development control maps. This data can be aggregated together to form state and national data sets, but there is a significant variation in the methods and assumptions adopted for different study areas and state jurisdictions. It is important that sea level rise and shoreline recession assumptions are defined for each individual erosion hazard data set at the time it is integrated into a consolidated data set.

It is recommended that coastal erosion information in the insurance industry be consolidated from local and regional planning and hazard studies to define state-wide and national scale exposure information. For high exposure areas, for example Collaroy-Narrabeen beach in Sydney, more detailed assessments of coastal erosion frequency and consideration of property protection from structures (i.e. seawalls) may be required.

Remote sensing data to define sandy beach erosion frequency and severity has been available at selected locations around Australia over the last 20-years including the Gold Coast and Collaroy -Narrabeen. In the future, improvements in satellite imagery capabilities may provide improved data for understanding beach erosion on smaller spatial and temporal scales. The methods described in Vos *et al* (2019) are increasingly being applied to define long-term shoreline recession at high resolution over large spatial areas as discussed in Section 6.2.3. An emerging area of application is to look at short-term beach erosion extents when suitable image resolution (spatial and temporal) is available.

6.2.3 Shoreline Recession

Shoreline recession can be analysed by a variety of methods including mapping of changes in mean water levels, foreshore elevation, beach volume, or vegetation line. Shoreline recession is normally considered in the development of long-term coastal erosion hazard mapping that is available for a large number of local government areas around Australia, with examples of some of the data that is available provided in Section 6.2.2. If ongoing compilation of local government coastal hazard mapping is maintained, this data can be used to inform the insurance industry on coastal erosion and shoreline recession hazard. However, variations in hazard study methodology and completion and result delivery dates for different studies results in a wide variation in the reliability, availability, and quality of coastal hazard mapping to inform the insurance industry on current exposure.

The recent emergence of high-quality and reliable methods to analyse short, medium and long-term shoreline changes can provide the insurance industry with the ability to assess shoreline changes on an annual basis. The CoastSat toolbox (Vos et. al., 2019) has been used to examine the Collaroy-Narrabeen coastline over the last 30-years and comparison has been made of the data obtained from the satellite analyses and detailed survey data. CoastSat is an open-source software toolkit that enables a time-series of shoreline positions to be obtained at any sandy coastline from approximately 30 years of publicly available satellite imagery. Whilst the CoastSat analysis is dependent on the quality and resolution of the available imagery, benchmark studies have demonstrated that it is able to produce a shoreline positional accuracy of less than 10m and as good as 2m (Vos et. al., 2019). The CoastSat toolbox is increasing being adopted in coastal hazard studies to understand shoreline recession and estimate future shoreline position. Machine learning methods can also be coupled to the historical satellite analyses to estimate future shoreline position. Figure 6.1 presents an example of predicted shoreline evolution of a coastal sand spit near Port Hedland that was derived from machine learning algorithms applied to 23-years of satellite data.

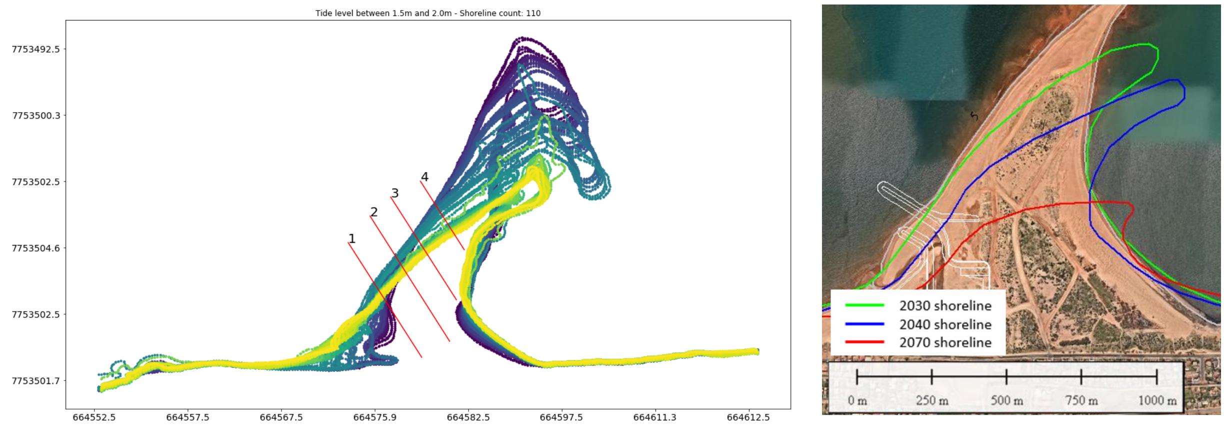


Figure 6.1: Mapped shorelines (left) from the CoastSat Toolbox for tide ranges for Spoilbank, Port Hedland (1986 – blue, 2019 – yellow) and predicted evolution (right) from machine learning for future planning periods (Baird, 2020).

6.2.4 Sea Level Rise

Currently the latest version of the IPCC 5th Assessment Report (IPCC, 2013) is the latest source of global sea level rise projections. The IPCC 6th Assessment Report is expected to be published in 2022. Some state governments provide specific guidance on sea level for planning and hazard assessments. For example, Queensland (Queensland Government, 2018) and Western Australia (Western Australia Government, 2013). However, to date those planning requirements and guidelines have been based on IPCC (4th and 5th editions).

In the future, as further information on spatially downscaled sea level rise for the Australian region becomes available, this will need to be considered. The effect of sea level rise on inundation risk (Section 3.5) and the associated increase in exposure for the insurance industry should be reviewed with sea level rise adjustments to hazard levels and data sets. The impact of sea level rise on coastal erosion and shoreline recession is more uncertain and requires a significant assessment effort. Local government and regional hazard studies that are described in Sections 6.2.2 and 6.2.3 normally account for sea level rise in the assessment of future coastal erosion hazard and shoreline recession extents, however, noted variability in methods, planning time horizons and sea level rise assumptions between studies and state jurisdiction pose a challenge for collating a national insurance data set.

Detailed studies of the impacts of sea level rise on coastal erosion and shoreline recession are best completed at local and regional levels. The insurance industry may identify value in completing detailed hazard, impact and mitigation studies for key locations with high vulnerability; however, the industry will often rely on local and state governments to complete high resolution assessments for coastlines under their jurisdiction. To address the issue of data consistency, the insurance industry should advocate for consistency in planning horizons and the basis of sea level rise scenarios (i.e. selected emissions scenarios from IPCC reports), even if regional sea level rise scenarios are considered in particular hazard studies.

Future land use and infrastructure planning will need to consider sea level rise scenarios beyond 2100 and there is currently limited information available for longer-term sea-level rise scenarios.

6.2.5 Tsunami

Each state has its own emergency responder, for example the SES in NSW, who are responsible for tsunami emergency planning and response. Those agencies are responsible for assessing risk and developing emergency response plans. Overall, the vulnerability of Australia's populated coastline to tsunami is relatively low, but for events within the 200-to-500-year Average Recurrence Interval (ARI) range, there are low-lying coastal and estuarine areas at risk of inundation and damage. The data that is available on tsunami hazard extents is variable between states and detailed information may only be available for selected locations identified as high risk.

An initial data set of tsunami hazard could be compiled from each state's emergency planning information and the 2018 Australian probabilistic tsunami hazard assessment (Davies and Griffin, 2018). The probabilistic tsunami hazard assessment provides a basis to define variation in tsunami hazard levels at the open coastline, however the data is provided at only the 100 m depth contour and the ultimate impact of events on coastal and estuarine areas can be significantly different to the wave characteristic at that depth. If the insurance sector required a detailed assessment of tsunami hazard levels at the coast and potential inundation extents, the data from Davies and Griffin (2018) and the supporting databases provide that basis for high-resolution downscaled modelling.

The insurance sector will have some tsunami exposure in the maritime sector. There is limited data available for marine and coastal waterway exposure to tsunami but major trans-oceanic tsunami's have caused marine impacts on Australia as noted in Section 3.6.1.

6.3 Recommended Data Sources and Data Sets

A summary of recommended data sources and compiled data is presented in Table 6.2. Those data sources could be the building blocks to developing a National Actions of the Sea Database, similar to the ICA's National Flood Information Database. The National Actions of the Sea Information Database (NASID) should include data in a suitable format for insurers to assess Actions of the Sea exposure for different return periods including:

- Flood levels from storm surge, wave runup and overtopping;
- Description of flood exposure for each property, for example flooding from storm surge or wave dominated processes; and
- Shoreline erosion vulnerability; and
- Details on coastal protection structures (private and public).

As a starting point, the NASID could be populated from local and regional coastal hazard studies; however, there is a large variability in technical methods, assumptions, and quality of the existing data sources. Also, the available hazard information is normally only available for up to 100-year ARI events in most states, except for Western Australia and higher cyclone hazard areas of Queensland.

It is recommended that federal and state government agencies should fund programs for improved nationally consistent data sets with respect to coastal inundation and erosion. A key existing data gap is the definition of wave dominated inundation exposure. A summary of details to developed improved wave runup and overtopping data sets is presented in Section 6.3.1. A high-level audit of key data sets for each state is presented in Section 6.3.2.

6.3.1 Wave setup, runup and overtopping

The case study has indicated that at some sites, erosion hazard can be estimated by understanding the erosion vulnerability of a particular location by calculating extreme wave run-up levels and overlaying elevation data to identify shoreline locations that have high erosion vulnerability. The case study (see Appendix A) adopted the wave setup and runup model of Nielsen and Hanslow (1991) for an eroded beach and obtained estimates of wave runup that agreed very well with the impact survey completed following the June 2016 storm. Similarly good agreement has been found at Port Hedland Spoilbank (Baird, 2020) following Tropical Cyclone Veronica. For impermeable, irregular shorelines the model of Hughes (2005) has been adopted in hazard assessment, including for the Wollongong area as presented in Cardno Lawson Treloar (2010).

A pilot study could be undertaken to evaluate automated methods to calculate wave runup and overtopping, and to assess the risk of erosion. This type of study could be completed for Collaroy-Narrabeen and compared to the detailed data sets available to assess if large-scale, automated methods are accurate and robust for assessing wave runup and overtopping.

Table 6.2: Summary of data recommendations to support assessment of Actions of the Sea.

Variable	Description	Example Data Sources	Recommendations for Compiled Data Sets useful for insurance sector	Priority / Value
Ground Elevation	High resolution digital elevation models from high-quality LiDAR (or similar) survey.	High resolution data is provided by most state government agencies. Some states have coverage across the whole state (NSW, Victoria), whilst others have data for most populated areas (WA).	High-resolution models should be developed, including down to 1 m DEM. Automated processing to identify shoreline and near-coast high spot elevations (i.e. top of dune) should developed to support inundation assessments.	High
Bathymetry	High resolution digital bathymetry models from high-quality survey data sets.	Compiled bathymetric data sets are provided by some state government agencies and digital elevation models are available from Geoscience Australia and other research and commercial data providers. Satellite derived bathymetry is improving in coverage and quality.	High resolution bathymetry models are useful for nearshore wave calculations, and assessment of wave runup and overtopping. Format and resolution of bathymetry data sets will depend on modelling requirements.	Medium
Water Level – All Regions	Measured tide and water level from tide and storm surge gauges around Australia.	Long term data is available from state government agencies and the National Tide Centre (Bureau of Meteorology).	ICA should advocate for measured water level data sets to be compiled nationally with consistent data standards. ICA could consider a briefing note on processing and analysis of measured water level data.	High
Water Levels – Cyclone Prone Coastlines	Hindcast and synthetic storm surge, waves and tides for cyclone prone regions., including water level data	Data is typically available for regions or local government areas. For some states, for example Queensland, there are statewide assessments of storm surge and tide levels. Some insurers and commercial providers have propriety data sets.	High resolution data covering the whole cyclone prone coastline with wave conditions. Water level output locations should be at the shoreline and wave conditions for 5 m and 10 m water depths. The data set could be a building block for a National Actions of the Sea Database including coastal inundation from surge and wave processes.	Medium

Variable	Description	Example Data Sources	Recommendations for Compiled Data Sets useful for insurance sector	Priority / Value
Nearshore Waves	Nearshore waves for severe events including wave period, direction and height.	NSW is the only state in Australia where high-resolution nearshore (10 m depth) wave data is available on a large scale.	ICA should advocate for similar wave data to NSW (https://forecast.waves.nsw.gov.au/) to be provided by government agencies for all of Australia	High
Shoreline Geomorphology	Spatial description of shoreline conditions and properties including classification if shorelines are rocky or sandy.	Smartline data set has been maintained over the last 10-years and provides an Australia wide data set on coastline properties. Local and state government http://coastadapt.com.au/coastadapt-interactive-map. State and local government also have relevant data, including on coastal structures.	ICA to promote that Smartline should be maintained and enhanced with inclusion of coastal structure data.	Medium
Shoreline Change	Long-term, high resolution analysis of shoreline change from satellite or aerial imagery	State government agencies have compiled data for many years. Recent developments with satellite image analysis allows big data sets and large coverage areas to be analyzed. Publicly available data available from Digital Earth Australia (https://www.ga.gov.au/dea/products/dea-coastlines)	The insurance industry should undertake a pilot project to understand if analysis of large-scale, long-term shoreline data can be used to assess vulnerability of coastlines to erosion.	High
Aerial Photography	High-resolution post event photography.	Various government, research and commercial suppliers of data including Nearmap (https://view.nearmap.com/) that was used in the case study.	State government agencies should undertake routine and systematic collection of high-resolution aerial photography immediately after a severe event.	High

Variable	Description	Example Data Sources	Recommendations for Compiled Data Sets useful for insurance sector	Priority / Value
Coastal Hazard and Flood Studies	High resolution coastal hazard assessments to support planning and development. Studies typically address erosion hazard and inundation hazard.	Large section of examples are available. For the case study site adopted in this project, the Coastal Zone Management Plan (CZMP) is available here.	Coastal hazard studies have wide variation in methods adopted, variation in assumptions (i.e. sea level rise) and variation in outputs. ICA to advocate for greater consistency and adopting national data sets for GIS data. The insurance industry should develop or advocate for a program to compile hazard studies available from local and state government similar to the Australian Flood Risk Information Portal.	Medium
Beach Survey Data	Regular shoreline surveys for sandy beaches and other erodible shorelines.	The case study used the long-term beach survey data for Collaroy-Narrabeen (http://narrabeen.wrl.unsw.edu.au/)	Data sets of the duration and quality of Collaroy-Narrabeen are valuable but cannot be implemented on a large scale. The insurance industry should use the Collaroy-Narrabeen data (and from similar data collection sites) to validate analyses that can be undertaken on a large scale using remote-sensed data (see shoreline change).	Low

6.3.2 Data Audit

The coverage and availability of particular data sets for each state and coastal territory of Australia is presented in Table 6.3, where a priority/value of 1 indicates good quality data with high spatial resolution, and a value of 3 indicates less data available, at a low resolution. The most significant data gap is that apart from NSW, high resolution nearshore wave data is not available for any other state or territory.

Table 6.4 presents a summary of coastal hazard study requirements with respect to inundation (flood), erosion and sea level rise with a summary of key data sources for each state. With respect to inundation and coastal erosion, planning requirements are typically based on 100-year Average Recurrence Interval (ARI) events, normally with sea level rise allowances up to the year 2100. In Western Australia, the 500-year ARI inundation level is used for planning and controls for new developments. Queensland usually considers 500-year ARI inundation levels for cyclone hazard, although this not necessarily a requirement. In mid-latitude regions, including South-East Queensland, NSW, Victoria, Tasmania and southern WA, there is not normally a large variation in coastal flooding and erosion hazard between 100-year and 500-year ARI events based on current data sets and understanding of historical climatology.

Table 6.3: State and Coastal Territories of Australia Actions of the Sea data coverage and availability.

Variable	State/Territory	Description	Data Value	Source
Ground Elevation	All	High resolution LiDAR data (1m DEMs, 5m DEMs). Provided by all state government agencies; some states have coverage across the whole state (NSW, Victoria, QLD), whilst others have data for most populated areas (WA, SA, NT, TAS).	1	https://elevation.fsdf.org.au/ https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/89644 https://datasets.seed.nsw.gov.au/dataset/marine-lidar-topo-bathy-2018
	NT, WA, SA, TAS	Where there is no LiDAR data available, Shuttle Radar Topographic Mission (SRTM) data is provided, at 1 arc second resolution (~30m).	3	https://data.gov.au/dataset/ds-ga-aac46307-fce8-449d-e044-00144fdd4fa6/details?q=
Water Levels	NSW, Southern QLD, Southern WA	Numerous tide gauges are located along the NSW, southern QLD and southern WA coastlines, with minute to hourly data available.	1	http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml http://www.bom.gov.au/oceanography/projects/abslmp/data/index.shtml https://www.mhl.nsw.gov.au/Data-OceanTide

Variable	State/Territory	Description	Data Value	Source
	Northern Qld	Lower spatial resolution. Tide gauges available at: Abell Point, Bundaberg	3	http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml https://www.qld.gov.au/environment/coasts-waterways/beach/tide-sites
	Northern WA	Lower spatial resolution. Tide gauges at all standard and most secondary ports.	2	http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml https://www.transport.wa.gov.au/imarine/tide-data-real-time.asp
	VIC	Lower spatial resolution. Tide gauges available at: Portland, Melbourne, Gippsland, Geelong, Hastings	2	https://vrca.vic.gov.au/quick-links/tide-gauges/ http://www.bom.gov.au/oceanography/projects/ntc/monthly/
	TAS	Lower spatial resolution. Tide gauges available at: Burnie, Spring Bay, Hobart	3	http://www.bom.gov.au/oceanography/projects/abslmp/data/index.shtml
	SA	Lower spatial resolution. Tide gauges available at: Port Stanvac, Thevenard, Port Adelaide	3	http://www.bom.gov.au/oceanography/projects/abslmp/data/index.shtml
	NT	Lower spatial resolution. Tide gauges available at: Darwin, Groote Eyland, Melville Bay	3	https://apps.aims.gov.au/metadata/view/dc5902b6-bc5a-4c79-8bf5-614bebbf7325 https://water.nt.gov.au/Data/DataSet/Summary/Location/G8150029/DataSet/Tidal%20Level/Publish/Interval/Latest
Waves	NSW	High-resolution nearshore (10 m depth) wave data across entirety of NSW coastline	1	https://www.nswaves.com.au/index.php?init=1&cont=10&zoom=7&mod=20

Variable	State/Territory	Description	Data Value	Source
	NSW, QLD, Southern WA	Numerous wave buoys that provide hourly or 3-hourly data.	1	https://www.nswaves.com.au/index.php?init=1&cont=10&zoom=7&mod=20 https://www.transport.wa.gov.au/imarine/wave-data-real-time.asp https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring/waves-sites
	NT, TAS, VIC, SA, Northern WA	Sparse wave data available; predominantly wave buoys in offshore locations	3	http://www.bom.gov.au/products/IDT65014.shtml

Table 6.4: Summary of coastal hazard, management and/or adaptation studies.

State	Description of Hazard Studies	Coastal management and adaptation studies	Average Recurrence Interval (yrs) for erosion	Average Recurrence Interval (yrs) for inundation	Weblinks to studies and information
WA	Coastal Vulnerability Studies (CVS) which assess inundation, including combined catchment and coastal inundation, coastal erosion and recession, and sea level rise.	Coastal Hazard Risk Management and Adaptation (CHRMAP) studies.	100-years with a planning period to up to 2110 for sea level rise.	500-years with a planning period to up to 2110 for sea level rise.	Western Australia studies are completed in accordance with State Planning Policy 2.6 (https://www.dplh.wa.gov.au/spp2-6-coastal-planning). Sea level rise of 0.9 m for the year 2110 is required to be considered. Summary and links to completed studies: https://www.dplh.wa.gov.au/getmedia/40376515-9249-4e4a-9903-3e0a3c9d24ff/CHRMAPs-in-WA-table-(March-2021)

State	Description of Hazard Studies	Coastal management and adaptation studies	Average Recurrence Interval (yrs) for erosion	Average Recurrence Interval (yrs) for inundation	Weblinks to studies and information
NT	Northern Territory Planning Scheme provides storm surge mapping, limiting development in these areas	Dhimmiru Arnhem Land Sea Country Plan 2015- 2022 Darwin Coastal Erosion Hazard Plan		100-yr ARI (1% AEP) for storm surge inundation with 0.8 m SLR by 2100.	Planning Act (NT) Northern Territory Planning Scheme: https://nt.gov.au/property/building-and-development/northern-territory-planning-scheme. Inundation: https://depws.nt.gov.au/water/water-resources/flooding-reports-maps/storm-surge-inundation-maps
QLD	Coastal Hazard Technical Guide	Coastal Hazard Adaptation Study (CHAS) for local councils	100-yr ARI (1% AEP) as a minimum with a planning period up to 2100 with a sea level rise of 0.8 m, and an increase in the maximum cyclone intensity by 10%.	100-yr ARI (1% AEP) as a minimum but may include 200 and 500 yr ARI (0.5 and 0.2% AEP), particularly in relation to cyclonic storm surge. SLR of 0.8 m by 2100 with h	QLDS studies are completed in accordance with State Planning Policy 2016 https://www.qcoast2100.com.au Coastal Management Plan 2014 https://www.qld.gov.au/environment/coasts-waterways/plans/coastal-management/management-plan Coastal Hazards: https://www.qld.gov.au/__data/assets/pdf_file/0025/67462/hazards-guideline.pdf Mapping: https://www.data.qld.gov.au/dataset/storm-tide-queensland-series https://www.data.qld.gov.au/dataset/coastal-plan-series

State	Description of Hazard Studies	Coastal management and adaptation studies	Average Recurrence Interval (yrs) for erosion	Average Recurrence Interval (yrs) for inundation	Weblinks to studies and information
NSW	NSW Coastal Inundation Hazard Study: Coastal storms and extreme waves, Coastal Erosion in NSW Statewide Exposure Assessment	Coastal Management Programs for each coastal council Coastal Management Manual 2018 NSW Coastal Planning Guideline: Adapting to Sea Level Rise (2010)	100-year ARI and a SLR allowance specified by local government.	100-year ARI and a SLR allowance specified by local government.	Coastal Management State Environmental Planning policy (SEPP) 2018 (under Environmental Planning and Assessment Act 1979): https://www.environment.nsw.gov.au/topics/water/coasts/coastal-management/framework The Coastal Management Act 2016: https://legislation.nsw.gov.au/view/html/inforce/current/act-2016-020 Progress: https://www.environment.nsw.gov.au/topics/water/coasts/coastal-management/programs/coastal-management-program-progress
VIC	Coastal Hazard Assessments	Coastal Management Plans for select foreshore areas	100-year ARI storm event or 2 consecutive 50-year ARI storm events. Sea level rise of not less than 0.8 meters by 2100.	Modelling up to.2% AEP coastal storm, or coincident 1% coastal storm AEP and 1% catchment flow AEP. Sea level rise of not less than 0.8 meters by 2100.	Coastal Management Plans: https://www.marineandcoasts.vic.gov.au/coastal-management/coastal-management-plans Guidelines: https://www.marineandcoasts.vic.gov.au/__data/assets/pdf_file/0033/84957/DELWP-LCHA-Final-Version-1.01.pdf Policy Summary: https://www.marineandcoasts.vic.gov.au/__data/assets/pdf_file/0027/456534/Marine-and-Coastal-Policy_Full.pdf

State	Description of Hazard Studies	Coastal management and adaptation studies	Average Recurrence Interval (yrs) for erosion	Average Recurrence Interval (yrs) for inundation	Weblinks to studies and information
SA	Coastal Vulnerability Studies	Coastal Action Plans Coastal Planning Information Package: A guide to coastal development assessment and planning policy 2013c	Requires development to be safe from recession/erosion rates with SLR up to 2100. A SLR policy of 0.3 m by 2050 and 1 m by 2100	100-year ARI with SLR. A SLR policy of 0.3 m by 2050 and 1 m by 2100	A SLR policy of 0.3 m by 2050 and 1 m by 2100 Link to reports: https://data.environment.sa.gov.au/Coast-and-Marine/Coast-Marine-Management/Pages/home.aspx
TAS	Erosion for whole coastline: "Coastal erosion susceptibility zone mapping for hazard band definition in Tasmania" Inundation for whole coastline: "Coastal Inundation Mapping for Tasmania - Stage 4" Coastal Hazards Technical Report, 2016	Communities and Coastal Hazards Project	100-year ARI storm bite erosion hazard with shoreline recession to 2100	1% AEP event for 2050 and 2100, and areas vulnerable to mean high tide by 2050.	Erosion: http://www.dpac.tas.gov.au/__data/assets/pdf_file/0004/222925/Coastal_Erosion_Susceptibility_Zone_Mapping.pdf Inundation: http://www.dpac.tas.gov.au/__data/assets/pdf_file/0009/412848/Coastal_Inundation_Mapping_Stage_4.pdf Coastal Hazards: http://www.dpac.tas.gov.au/__data/assets/pdf_file/0014/312143/Coastal_Hazards_Report_version_7_-_20161201.pdf

6.3.3 Government Contacts for Information

A summary of contacts for coastal hazards and planning / policy in each state is presented in Table 6.5.

Table 6.5: Summary of state government agencies and contacts for coastal hazards, planning and policy.

State	Coastal Hazards		Planning and Policy	
	Department	Contacts	Department	Contacts
NSW	Department of Planning, Industry and Environment	coastal.management@environment.nsw.gov.au	Department of Planning, Industry and Environment	coastal.management@environment.nsw.gov.au https://www.planning.nsw.gov.au/Contact-Us?
Victoria	Environment, Land, Water and Planning	https://www.marineandcoasts.vic.gov.au/	Environment, Land, Water and Planning	https://www.marineandcoasts.vic.gov.au/coastal-management/marine-and-coastal-policy
Queensland	Queensland Government	https://www.qld.gov.au/environment/coasts-waterways/coast-hazards	Queensland Government	https://www.qld.gov.au/environment/coasts-waterways/plans
Northern Territory	Environment, Parks and Water Security	https://depws.nt.gov.au/water/water-resources/flooding-reports-maps	Environment, Parks and Water Security	https://depws.nt.gov.au/programs-and-strategies/coastal-and-marine-management

State	Coastal Hazards		Planning and Policy	
	Department	Contacts	Department	Contacts
Western Australia	Department of Transport – Marine	https://www.transport.wa.gov.au/imarine/marine-information.asp	Department of Planning, Lands and Heritage	https://www.dplh.wa.gov.au/coastal-planning
Tasmania	Office of Security and Emergency Management	http://www.dpac.tas.gov.au/divisions/osem/coastal_hazards_in_tasmania	Department of Primary Industries, Parks, Water and Environment	https://dpipwe.tas.gov.au/conservation/coastal-management
South Australia	Department of Environment and Water, South Australia	https://www.environment.sa.gov.au/topics/coasts	Department of Environment and Water, South Australia	https://www.environment.sa.gov.au/topics/coasts/coast-protection-board

6.4 Data Framework and Flow

A conceptual data framework and flow chart has been developed from this project focusing on: property exposure data; storm erosion / shoreline movement vulnerability and flooding from Actions of the Sea as presented in Figure 6.2. Climate change and sea level rise are processes that impact on most of the base data sets and changes in hazard and overall exposure to insured loss needs to be evaluated in an iterative manner which accounts for the changes in all base data sets as a result of the climate change scenario.

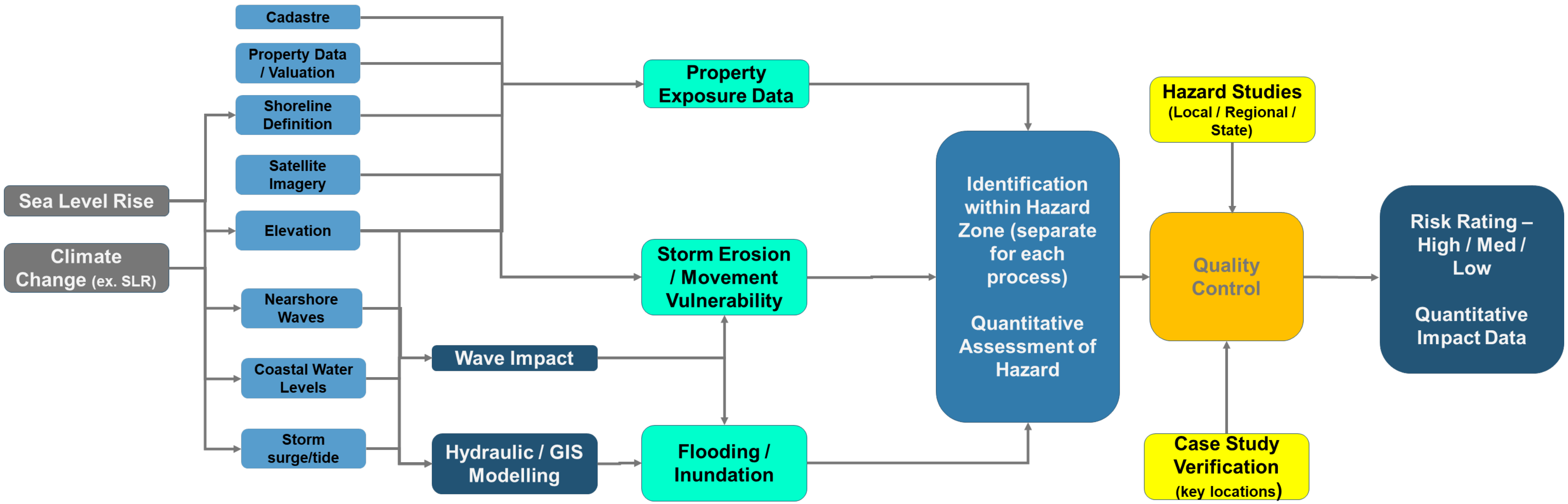


Figure 6.2: Concept framework for process and data flow to assess exposure to Actions of the Sea focusing on inundation from all Actions of the Sea and vulnerability to shoreline erosion.

6.5 Data Standards

It is recommended that the insurance industry collaborate with industry, government and research groups that have common data requirements and implement consistent data standards in accordance with ISO 19115:2014. Geoscience Australia has a range of resources and information on data standards are applicable to the types of data sets required for the insurance industry to assess Actions of the Sea – see https://www.ga.gov.au/data-pubs/datastandards

7. Conclusions

The ICA's *Actions of the Sea* project is intended as an initial scoping and case study to provide technical definition of Actions of the Sea as they relate to the insurance sector, and broadly identify planning, financial and engineering responses to manage current and future exposure to Actions of the Sea. It is anticipated that further studies and broader consultation with government, financial and community stakeholders will be required.

The executive summary of this report has framed 17 recommendations in relation to the following issues identified in this study:-

- Issue 1: At what point does rebuilding property after a severe event become unfeasible from the perspectives of engineering, landuse planning and risk management?
- Issue 2: Understanding options and process for reinstatement of land following an "Actions of the Sea" event severe event.
- Issue 3: How to differentiate/allocate damage to between different Actions of the Sea.
- Issue 4: How can property owners and the wider community be assured that coastal mitigations and defences are effective at mitigating Actions of the Sea, including sea level rise?
- Issue 5: The suitability of different types of coastal defences at mitigating Actions of the Sea
- Issue 6: The scale of coastal mitigations and defences required in Australia to address current and future risks from Actions of the Sea, including sea level rise.
- Issue 7: Planning and development approval processes to address new developments that are within the coastal zone.

In addition to the recommendations in relation to the issues identified in this study, it is recommended that the insurance industry progress the following:-

- The develop a concise and easy to understand issues paper for government, financial and community stakeholders to inform the understanding of Actions of the Sea and how they impact on risk to property and infrastructure. It will be important for this paper to present challenges facing property and asset owners, and the insurance industry from the different Actions of the Sea. A comprehensive consultation process with government, financial and community stakeholders should be undertaken following release of this paper.
- Following the consultation of the issues paper, the insurance industry should prepare a broad industry position paper on Actions of the Sea and its potential coverage by general insurance. The position paper will need to define the possible inclusion or exclusion of particular actions, for example the possible inclusion of coastal inundation, but exclusion of coastal erosion and shoreline recession, from standard policy terms. Further consultation with government, financial and community stakeholders would be required following release of this paper.
- If the insurance industry moves towards standard definitions for Actions of the Sea, customer facing wording must address policy inclusions and exclusions. Any proposed policy wording must be communicated during consultation with stakeholders to ensure that policy coverage is judged by the community and regulatory authorities as is intend by the insurance industry.

Section 6 presents the data review and audit that was completed for this project. This study recommends that the insurance industry advocate and support the development of a National Actions of the Sea Information Database (NASID), similar to the ICA's National Flood Information Database. The NASID should include data in a suitable format for insurers to assess Actions of the Sea exposure for different return periods including:

- Flood levels from storm surge, wave runup and overtopping;

- Description of flood exposure for each property, for example flooding from storm surge or wave dominated processes;
- Shoreline erosion vulnerability; and
- Details on coastal protection structures (private and public).

As a starting point, the NASID could be populated from local and regional coastal hazard studies; however, there is a large variability in technical methods, assumptions and quality of the existing data sources. Also, the hazard information is normally only available for up to 100-year ARI events in most states, except for Western Australia and higher cyclone hazard areas of Queensland. It is recommended that federal and state governments should coordinate the development of improved nationally consistent data sets with respect to coastal inundation and erosion. A key existing data gap is the definition of wave dominated inundation exposure, which has a strong correlation on the potential for coastal erosion. This study recommends that the insurance industry advocate for improved state and national data sets on extreme near-coast wave conditions and centralised data sets for coastal protection assets.

8. References

Baird (2019). Geraldton Coastal Hazard Risk Management and Adaptation Planning Project: Part 2: Coastal Adaptation Report. Prepared for the City of Greater Geraldton. Ref: 12693.101.R2.Rev0. 7 January 2019.

Baird (2020). Port Hedland Spoilbank Marina Metocean Design Criteria and Coastal Process Studies. Prepared for Department of Transport, Western Australia. Ref: 13143.101.R1.Rev1, 31 March 2020.

Burston, J.M., Taylor, D.R., Dent, J.M., Churchill, J.W. (2017). Australia-wide Tropical Cyclone Multi-hazard Risk Assessment. Proceedings of Coasts and Ports 2017. Cairns, June 2017.

Cardno Lawson Treloar (2010). Wollongong City Council Coastal Zone Study. Prepared for Wollongong City Council. Ref: Rep2564v2. 30 June 2010.

Carley J and Cox R (2017). Guidelines for Sand Nourishment - Science and Synthesis for NSW. Prepared for the NSW Office of Environment and Heritage's Coastal Processes and Responses Node. University of New South Wales Water Research Laboratory. WRL Research Report 263.

City of Busselton (2021). Strategic Plan to Protect Our Coastal Community. https://www.busselton.wa.gov.au/news/strategic-plan-to-protect-our-coastal-community/174

City of Busselton (2016). City of Busselton Economic and Demographic Profile: 2014/15. https://www.busselton.wa.gov.au/documents/211/economic-and-demographic-profile-2016

City of Greater Geraldton (2020). State Government funds coastal works. City of Greater Geraldton. https://www.cgg.wa.gov.au/news/state-government-funds-coastal-works/13897

Davies, G., Griffin, J. (2018). The 2018 Australian probabilistic tsunami hazard assessment: hazard from earthquake generated tsunamis. Record 2018/41. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2018.041

Davies, G. (2019). A New Probabilistic Tsunami Hazard Assessment for Australia. *Proceedings of Australasian Coasts & Ports 2019 Conference*. Hobart, 10-13 September 2019.

Department of Transport, WA (2016). Mapping Coastlines in WA Over 75 Years Capturing the Coastline. Available at: https://www.transport.wa.gov.au/mediaFiles/marine/MAC_P_CapturingtheCoastline.pdf

Department of Planning Lands and Heritage (2017). Draft Planned or Managed Retreat Guidelines. Western Australian Planning Commission. August 2017.

Hanslow, D. J., Fitzhenry, M. G., Power, H. E., Kinsela, M. A. & Hughes, M. G. (2019). Rising tides: Tidal inundation in South east Australian estuaries. Australasian Coasts and Ports 2019 Conference (pp. 520-526).

Hughes S. A. (2005) Estimating Irregular Wave Runup on Rough, Impermeable Slopes. U.S Army Corp of Engineers ERDC/CHL CHETN-III-70. July 2005.

Hummel M. A, Griffin R., Arkema K., and Guerry A.D. (2021). “Economic evaluation of sea-level rise adaptation strongly influenced by hydrodynamic feedbacks.” *Proceedings of the National Academy of Sciences of the United States of America.* Vol. 118 No. 29. https://doi.org/10.1073/pnas.2025961118

IPCC, (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y.

IPCC, (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

NCCARF (2017). Jurisdictional differences. National Climate Change Adaptation Research Facility, Gold Coast. Available from: https://coastadapt.com.au/sites/default/files/tables/T5I3_Jurisdictional_differences_Table%201.pdf. Accessed 23 October 2020.

Nielsen, AF; Lord, DB and HG Poulos (1992), "Dune Stability Considerations for Building Foundations", Australian Civil Engineering Transactions, Institution of Engineers Australia, Volume CE34, No. 2, June, pp. 167-173.

Queensland Government (2018). Sea level rise projection. Available at: https://www.qld.gov.au/environment/coasts-waterways/plans/hazards/sea-level-mapping#:~:text=The%20projected%20sea%2Dlevel%20rise,released%20in%202014%20(AR5). Assessed 9 Feb. 2021.

Short, A., Trembanis A., & Turner, I., (2001). Beach Oscillation, Rotation and the Southern Oscillation, Narrabeen Beach, Australia. 276. 2439-2452. 10.1061/40549(276)191.

Taylor, D.R., Aldridge, J.M., Dent, J.M., Churchill, J.W. (2018). National Scale Multi-Hazard Model Platform for Extreme Cyclone Impacts on Coasts and Infrastructure. Proceedings of International Coastal Engineering Conference (ICCE). Baltimore, USA, August 2018.

Tweed Bypassing (2020). Project background. NSW and Queensland State Government. https://www.tweedsandbypass.nsw.gov.au/why-tweed-sand-bypassing/project-background.html

UNSW Water Research Laboratory (2016). Incredible drone footage of the destruction along Narrabeen-Collaroy. https://www.wrl.unsw.edu.au/news/incredible-drone-footage-of-the-destruction-along-narrabeen-collaroy Accessed: 13 February 2021.

Vos, K., Splinter, K.D., Harley, M.D., Simmons, J.A., Turner, I.L, (2019). CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. Environmental Modelling and Software 122 (2019) 104528.

USACE (2019a). New York / New Jersey Harbour and Tributaries Coastal Storm Risk Management – Interim Report. United States Army Corp Engineers, February 2019.

USACE (2019b). New York / New Jersey Harbour and Tributaries Coastal Storm Risk Management – Interim Report and Status Update Summary. United States Army Corp Engineers, October 2019.

Western Australian Planning Commission (WAPC) (2014). Coastal Hazard Risk Management and Adaptation Planning Guidelines. September 2014. http://www.planning.wa.gov.au/dop_pub_pdf/CHRMAP_Guidelines.pdf

White N.J., Haigh I. D., Church J. A., Koen T., Watson C. S., Pritchard T. R., Watson P.J., Burgette R. J., McInnes K L., Zai-Jin You, Zhang X., Tregoning P., (2014). Australian sea levels—Trends, regional variability and influencing factors. *Earth-Science Reviews,* Volume 136, 2014, Pages 155-174, ISSN 0012-8252.

Western Australia Government (2013). State Planning Policy, No. 2.6. Planning and Development Act, 2005.

Zhang, X., Church, J. A., Monselesan, D., and McInnes, K. L. (2017), Sea level projections for the Australian region in the 21st century, Geophys. Res. Lett., 44, 8481– 8491, doi:10.1002/2017GL074176.

Appendix A

Case Study: Collaroy-Narrabeen June 2016 Storm

Actions of the Sea Data and Knowledge Development

Case Study Report: Collaroy-Narrabeen June 2016 Storm

27 October 2021 | 13465.101.R3.Rev1

Innovation Engineered.

baird.com

Actions of the Sea Data and Knowledge Development

Case Study Report: Collaroy-Narrabeen June 2016 Storm

Prepared for:

Insurance Council of Australia
Level 4, 56 Pitt Street
Sydney, NSW, 2000

Prepared by:

Baird Australia Pty Ltd as Trustee for the Baird Australia Unit Trust
ACN 161 683 889 | ABN 92 798 128 010

For further information, please contact
David Taylor at +61 2 8278 7266
dtaylor@baird.com
www.baird.com

13465.101.R3.Rev1

Z:\Shared With Me\QMS\2021\Reports_2021\13465.101.R3.Rev1_ICA_ActionsoftheSea_CaseStudy.docx

Revision	Date	Status	Comments	Prepared	Reviewed	Approved
0	28 July 2021	Final	Issued to ICA following Review	CS/RT	DT	
1	27 Oct 2021	Final	Issued to ICA for Public Release	CS / LC	DT	

Executive Summary

This report presents the case study component of the Insurance Council of Australia's (ICA) Actions of the Sea Data and Knowledge Development project and was prepared by Baird in collaboration with our project team partner Rhelm. The case study focuses on the impacts from actions of sea on the properties adjoining Collaroy-Narrabeen Beach from the June 2016 storm event. The June 2016 East Coast Low (ECL, the Storm) was a significant event for coastal erosion and inundation along the NSW coastline, and in particular Collaroy-Narrabeen Beach. Collaroy-Narrabeen has a long history of erosion events that have damaged coastal property dating back to at least the 1920's as a result of properties being located within the active coastal zone at the time they were first established.

The June 2016 storm represented a significant erosion and coastal inundation event for the study area and is estimated at a 50-to-60-year Average Recurrence Interval (ARI, return period) event with respect to total wave run-up level. The large north-easterly offshore waves in combination with a high-water level, resulted in the highest coastal water levels and wave runup levels at Collaroy Narrabeen since the May 1974 storm. The return period of the wave runup levels in the study area are well correlated with the observed erosion which is also an approximate 50-year ARI event in the study area and the most significant erosion to occur since May 1974. Figure E.1 presents an example of the erosion impacts on the study area from high-resolution post-storm aerial photography.

Figure E.1: Nearmap images for southern section of study area: pre-storm 06/05/2016 (left) and post-storm 08/06/2016 (right).

Coastal erosion resulted in the shoreline receding up to 50 m in the case study area and caused the most significant impacts on property and 60 of the 114 properties in the case study area had some level of erosion impact within their property boundary. Most of those properties experienced erosion that was limited to the seaward edge of the property and had minor damage to landscaping. There were 16 properties where erosion caused major damage to items external to the house, including swimming pools and decks, and the erosion generally exposed the foundations of the primary buildings. Some of those properties required substantial repairs to the primary building. The extent of impact on property from erosion was best identified from high resolution aerial photos collected within two days of the event. Inundation of property in the study area was limited to individual properties and would have been dominated by short duration, episodic flows from wave runup and overtopping of the eroded shoreline. The nature of inundation from wave runup and overtopping is significantly different to sustained inundation of property due to riverine or stormwater flooding.

Within the case study area, there were 114 coastal properties assessed for likelihood of erosion and coastal inundation damage. The details on the property impact assessment are presented in Section 3.4 and Appendix B. The impact assessment is summarised as follows:

- 14% of properties (16 total) had severe erosion impacts that exposed building foundations and the primary building is likely to have damage from erosion and inundation. These properties experienced the majority of property damage and loss within the case study area.
- 32% of properties (37 total) had medium impacts where erosion extended into the property boundary and there was the potential for inundation (flood) damage to the primary building.

- 6% of properties (7 total) had erosion impacts on the property boundary including damage to coastal protection and landscaping.
- 47% of properties (54 total) had no observed erosion impacts and those properties were also unlikely to have experienced any inundation impact to the primary building.

During the storm, emergency services and government agencies assisted to protect properties and infrastructure. This includes using sandbags and rock to assist with stabilising eroded areas. Immediately post-storm, a Natural Disaster Declaration was issued for Collaroy-Narrabeen and the recovery effort for the study area was overseen by the Northern Beaches Local Recovery Committee.

This case study had only limited information on insurance claims that were processed in the Collaroy-Narrabeen following the storm. The general information provided from insurers indicated that there was ambiguity or conjecture as to whether actions of the sea, including erosion and wave-dominated inundation, were included in policy wording and that most insurance claims that were settled were done on an ex-gratia basis.

Northern Beaches Council (NBC) led the coastal management and planning response to the storm which included finalisation and endorsement of a Coastal Zone Management Plan (CZMP) (Haskoning Australia, 2016). The key coastal management response in the CZMP for the case study area is an integrated series of seawalls to protect property and infrastructure exposed to high erosion risk. The CZMP formally abandoned managed retreat for Collaroy Narrabeen due to the small lot sizes of properties and that it was cost prohibitive. The seawalls are currently being constructed (at the time of preparation of this case study) and have been granted development approval on a time-limited consent of 60-years, after which time landowners may be required to remove the seawall on their property.

This case study has shown that whilst on-the-ground coastal protection can be implemented with conditions that seek to protect environmental and community values, the approval timeframe can be long (2-3 years) and construction of works is expensive and subject to unique legal complexities as property owners jointly fund and oversee construction of protection along a number of properties.

The economic impact assessment, which solely focused on the impact to properties in the case study area, has highlighted the damage costs from three different factors: loss of land from erosion, damage to structures from erosion and damage from inundation of homes. The economic costs over the long-term from erosion damage to structures is significant. Whilst the damage impact from storms less than 50-year ARI return period is relatively low, the potential damage from a 100-year ARI event is significant and may require a complete re-build of a property.

The economic assessment of the seawall being constructed in the study area focused on the reduction in damage to property and did not consider wider community or environmental factors. The assessment indicates that the overall economic metrics for the seawall are only favourable for prestige properties. Medium and high-standard properties in the case study areas had Benefit-Cost Ratio (BCR) less than 1 indicating a negative net present value of the seawall on an economic cost basis. The overall cost of protection for each property owner covered by the seawall is approximately $230,000. This is a substantial capital cost and represents 4% to 5% of current property values in the study area (as at May 2021). However, the seawall provides significant protection for the 100-year event which would be expected cause substantial structural damage to many properties. The seawall may also enhance or maintain the investment value of property as to reduces the future risk cost of ownership. An economic assessment of a managed retreat scenario has been considered, with the retreat occurring following a major erosion event. The cost of retreat has a present value of $1.4 million (per property, May 2021) and an equivalent annual cost (AAD) is estimated at around $102,000 (per property, May 2021).

The case study has highlighted that seawall protection is likely to be an expensive option for mitigating actions of the sea and the performance of these structures will reduce with future sea level rise. Further mitigation measures for actions of the sea will be required in the case study area in the future, including potential large scale beach nourishment to counter impacts from sea level rise. This a key reason why the development approvals for the coastal protection works along Collaroy-Narrabeen have been granted a time-limited consent. This seawall is designed to withstand changes in coastal hazard due to sea level rise over the design life; however, future erosion in combination with increasing sea levels will impact on the beach dynamics and likely reduce the amenity and community access to the beach without nourishment. Mitigating the impacts on beach amenity and function with future storms and sea level rise is a key item that needs to be addressed in future by NBC. The overall technical report for the actions of the sea project (Baird, 2021) discusses managed retreat and beach nourishment (sand management) as mitigations for current and future actions of the sea impacts.

Outcomes and recommendations from this case study include:

- Coastal erosion caused the most significant property damage in the case study area. A number of properties also experienced damage from inundation; however, the amount of damage from inundation was significantly less than erosion. The damage cost estimates presented in this case study provide the insurance industry with relative data to assess the potential for insurance coverage for different actions of the sea.
- High resolution aerial images and LiDAR survey immediately post-storm provide the most reliable way to quantify storm erosion and potential impact to property. The insurance industry should liaise with government agencies to establish comprehensive post event data capture programs focused on those data types.
- Information on formal or informal coastal protection structures for individual properties is valuable to assess vulnerability of particular properties. The insurance industry should liaise with local and state government agencies to establish regional and state-wide data bases on coastal structures. The data base should also include information on the foundations for beachfront building structures as the type of building foundation, for example whether shallow footings or piles, is also important in the assessment of the vulnerability of individual structures.
- The planning framework for the study area has demonstrated that property owners, at least in NSW, are able to undertake works to reduce the vulnerability of their properties to erosion and flooding from actions of the sea. However, the Collaroy-Narrabeen example highlights the complexity, time and costs incurred under the current NSW Coastal Management Act. The insurance industry should be involved in wider stakeholder discussions with all levels of government regarding simplifying the process to achieve risk mitigation from actions of the seas and increasing flexibility to address current hazards and manage transition to future conditions where sea level rise may reduce the sustainability and/or effectiveness of particular risk mitigation measures.
- To assess hazard to actions of the sea for open coast properties such as the case study area, the insurance industry should focus on compiling high-resolution data sets for water levels, near-coast extreme waves, shoreline elevation and erodibility potential to define wave runup potential and the likelihood of erosion. Recently available historical satellite image analysis techniques, for example CoastSat (Vos *et al,* 2019) provide quantitative methods to assess the erodibility of shorelines, but those methods are not yet developed enough, nor have long term data, to assess actual storm erosion extents.

Table of Contents

Tables

Figures

1. Introduction

This document forms Baird Australia Pty Limited's (Baird) deliverable for the case study component of the Insurance Council of Australia's (ICA) Actions of the Sea Data and Knowledge Development project. This report, prepared in collaboration with our project team partner Rhelm, focuses on the impacts from actions of sea on the properties adjoining Collaroy-Narrabeen Beach from the June 2016 storm event. The June 2016 East Coast Low (ECL, the Storm) was a significant event for coastal erosion and inundation along the NSW coastline, and in particular Collaroy-Narrabeen Beach as defined in Figure 1.1.

Properties adjoining Collaroy-Narrabeen beach have a long history of erosion and inundation impacts and the June 2016 East Coast Low represented the most severe erosion event since the 1960's and 1970's. Collaroy-Narrabeen Beach and the June 2016 East Coast Low storm were selected for the case study due to three key factors:

- June 2016 East Coast Low was a severe impact event from actions of the sea and a comprehensive data set of the impact on Collaroy-Narrabeen Beach is available.
- Collaroy-Narrabeen Beach is one of the most studied beach systems in the world with respect to coastal processes including shoreline changes from climatic and storm processes. The available data for the beach is extensive and allows the June 2016 East Coast Low to be put in context with respect to frequency and level of impact.
- Following the June 2016 storm, there has been extensive work led by Northern Beaches Council, NSW government (Department of Planning, Industry and Environment, DPIE), and property owners to repair from the damage of the storm and improve the protection of coastal properties from the impacts of severe storm events.

Collaroy-Narrabeen has a long history of erosion events that have damaged coastal property dating back to at least the 1920's (NBC, 2016) as a result of the original properties being established within the active coastal zone. Between 1920 and 2016, there are at least ten documented storm events that have damaged property (NBC, 2016). The original zoning and issuing of tenure to land that was within the active coastal zone is a key driver to the damage that has been regularly encountered in the case study area. The erosion and coastal water levels associated with the June 2016 storm event were the most severe since the May 1974 event and the 2016 event is estimated to be a 1 in 50-year event with respect to erosion and inundation from actions of the sea.

This case study for the June 2016 East Coast Low provides a contemporary event which exposed a relatively large number of properties to significant actions of the sea, principally inundation and erosion as defined in Baird (2021). The case study examines the type and magnitude of the actions of the sea from this event, its impact on property, and provides an assessment of the planning and engineering controls that can mitigate future storm impacts at the site. A preliminary economic assessment has examined damage to property as a result of loss of land, damage to buildings from erosion and damage from inundation of houses. The results from this case study have been incorporated in the overall Actions of the Sea study report (Baird, 2021).

The case study report is separated into the following sections:

- Section 1: Introduction and context.
- Section 2: Overview of the June 2016 storm event.
- Section 3: Detailed assessment of the actions of the sea on the case study site and impacts to property including emergency response during and post-event.
- Section 5: Assessment of economic impacts.
- Section 6: Planning responses following the Storm.
- Section 7: Engineering responses following the Storm.

- Section 8: Conclusions and Recommendations.

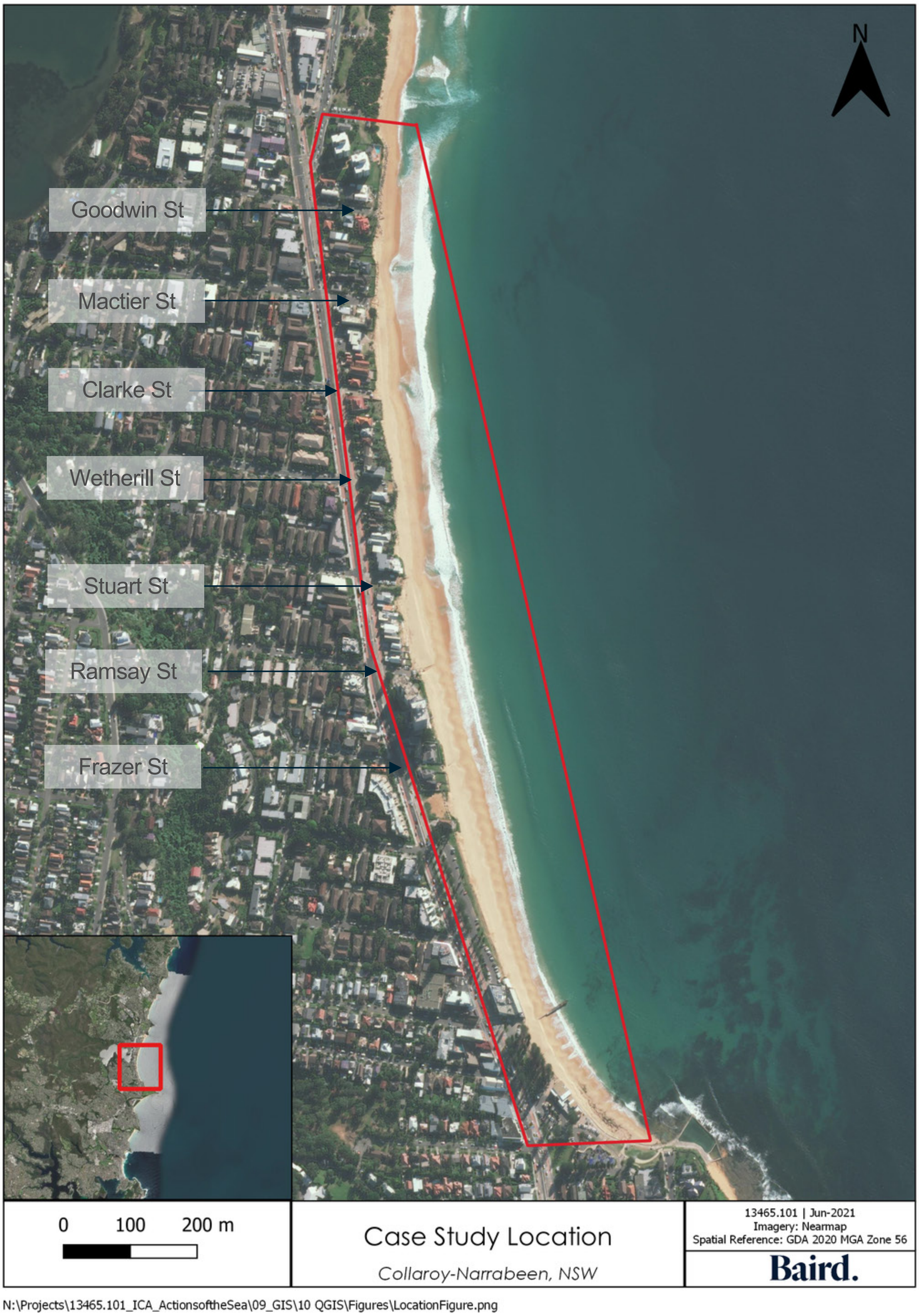


Figure 1.1: Locality plan and case study area

2. Overview of the June 2016 Storm Event

The June 2016 East Coast Low storm impacted on Queensland, NSW, Victoria and Tasmania with a combination of severe wind, heavy rainfall and associated urban and fluvial flooding, and coastal impacts from high water levels and large wave conditions causing erosion and inundation. The weather system was a complex intense east coast low system with peak impacts occurring from 4th to 6th June 2016.

East coast lows are low pressure cyclones occurring off the eastern coastline of Australia with the potential for rapid intensification, generating gale force winds, heavy rainfall, heavy sea and swells and some storm surge. They may form in a variety of synoptic situations, including embedded within an easterly low-pressure trough, an inland trough low, a continental low, a southern Tasman low, a southern secondary low or from an ex-tropical cyclone (Shand et al. 2010). In terms of climatology, ECLs can occur throughout the year with more frequent occurrence in Autumn and Winter (BoM). They frequently develop in association with warm sea surface temperatures that form in some southward propagating eddies of the East Australian Current.

The June 2016 East Coast Low occurred as an upper atmospheric cold air mass over central Australia collided with a deep and extended easterly low-pressure trough that formed along the very warm East Australia Current (Figure 2.1). The east coast low tracked southward along the NSW coastline from 4th to 6th June before impacting Victoria and Tasmania (Figure 2.2). The low had multiple low-pressure centres, with one closer to the coast producing heavy rainfall and extreme winds, and another further offshore generating large north-easterly to easterly ocean swell impacting the NSW coastline. The meteorological and oceanographic conditions that occurred during this event are described further in Sections 2.1 and 2.2, respectively. The datasets compiled for use in this study are summarised in Section 3.2.

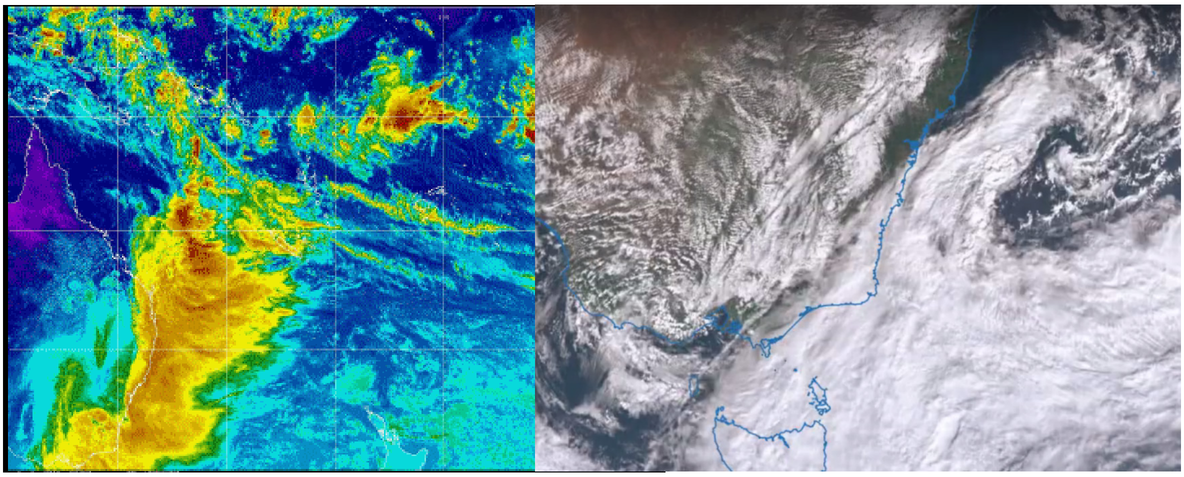


Figure 2.1: Satellite imagery of the June 2016 East Coast Low: (left) false colour image (NOAA); (right) Hiramari satellite image (BoM).

2.1 Meteorological Summary

The June 2016 East Coast Low was characterised by heavy rainfall and strong winds along the east coast of Australia from SE Queensland to Tasmania. Daily cumulative rainfall occurring across eastern Australia attributable to this event exceeded of 100 mm of rainfall across most of the east coast from SE Qld to Tasmania, with very high accumulation of rainfall in coastal pockets including the Gold Coast, NSW Northern Rivers, Sydney Basin and South Coast. The cumulative rainfall totals over the week encompassing the event (Thursday 2nd June to Wednesday 8th June) were very large, well exceeding the monthly mean rainfall for June at most locations.

Strong winds were experienced along the whole NSW coastline, with peak gusts exceeding gale force occurring along the central Hunter-Sydney-Illawarra coastline. The peak wind direction was east-northeast to north-northeast along the NSW coastline.

Low atmospheric pressures were also recorded at all coastal locations. Low minimum atmospheric pressures (more typical of tropical cyclones than mid latitude systems) were recorded at a number of locations including:

- 993 hPa at Narrabeen;
- 989 hPa at Currarong Creek, Jervis Bay and;
- 991 hPa at Tuross Heads, South Coast.

These low atmospheric pressures, which are very low compared to historical records along the central and southern NSW coastline, contributed to the elevated ocean water levels through the inverse barometric effect.

2.2 Oceanographic Summary

The June 2016 East Coast Low event was notable for its coastal inundation and erosion impacts along the NSW coast and has been compared in some locations to the May 1974 east coast low event. However, the impacts of the 2016 event were not as widespread as the May 1974 event. Both events coincided with a king tide. While the deepwater wave heights in the June 2016 event were lower than the 1974 event, the unique aspect of the June 2016 event was the persistent wind and wave direction from the north-eastern to east direction, causing high wave conditions in northerly facing bays which do not frequently experience high wave conditions. High swells and coastal water levels (including residuals) exceeding Highest Astronomical Tide were observed from southeast Queensland and along the entire NSW coastline. Figure 2.2 presents a wave height and direction contour map from the storm near the time of peak impact on the study area.

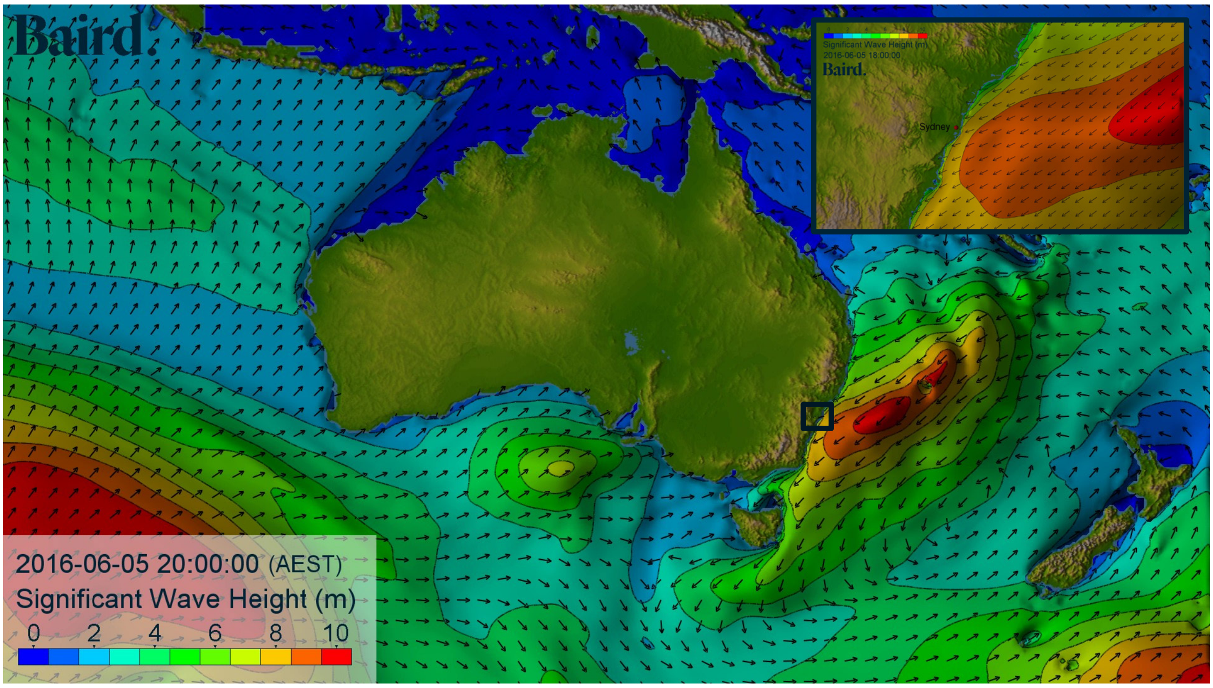


Figure 2.2: Hindcast wave conditions at time of peak impact on study area: 20:00 EST 5/6/2016.

3. Detailed Assessment of the Actions of the Sea and Impacts to Property

3.1 Summary

Collaroy-Narrabeen was one of the most impacted locations along the NSW coastline from the June 2016 event. Overall, the June 2016 East Coast Low was a 50-year Average Recurrence Interval event in the context of coastal erosion and potential for coastal inundation at the study site. In terms of both of those processes, it was the most severe coastal storm event to impact on the case study area since May 1974.

The combination of large nearshore waves and elevated water levels resulted in erosion of the beach and adjoining land, causing coastal inundation and damage to property and infrastructure. The most common impact on property was the erosion of land on the seaward side of the property, and damage to property external to the primary building including seawalls and the famous pool that was scoured away from its foundations as indicated in Figure 3.1. Several properties in the most impacted area had some structural damage that required repair along with the need for reinstatement of ground levels in the eroded areas following the storm.

Figure 3.1: UAV aerial view of beach erosion at Collaroy-Narrabeen in June 2016 (Source: UNSW Water Research Laboratory, 2016).

The following assessment of the of actions of the sea during the June 2016 storm and their impact on Collaroy-Narrabeen is focused on property east of Pittwater Road between the Collaroy Surf Life Saving Club in the south, and Devitt Street in the north. An outline of the case study area is presented in Figure 1.1.

3.2 Data Sources

A range of data sources have been used in this assessment

Table 3.1: Summary of data sources used in this case study.

Data Type	Location	Data Source	Description
Ocean Tide and Water Level	Fort Denison (Sydney Harbour)	Port Authority of NSW (through BoM National Tidal Centre)	Predicted tide and measured water level from long term measurement site. Data is a good representation of coastal water levels without the impact of wave effects.
Wind	North Head	BoM	Wind speed (10-min average and 3-sec gust) and wind direction from the Bureau of Meteorology (BOM) North Head station 066197.
Rainfall	Avalon	MHL	Hourly rainfall data
Ocean Waves – Measured Deepwater	Long Reef	MHL	Directional WRB data with time series of wave height, period and direction. Directional wave spectra also available.
Ocean Waves – Hindcast Deepwater	Long Reef	Baird	Hindcast model from the NSW Wavewatch-III model described in Baird Australia (2015). Directional wave spectra processed into time series of wave height, period and direction.
Ocean Waves – Hindcast Nearshore	Collaroy-Narrabeen Beach (10 m Depth)	Baird	Hindcast model from the NSW Wavewatch-III model described in Baird Australia (2015). Directional wave spectra processed into time series of wave height, period and direction.
Coastal Water Levels	Collaroy-Narrabeen Beach	Baird	Hindcast peak coastal water levels including wave setup using methods described in Burston *et al* (2016).
LiDAR	Collaroy-Narrabeen Beach	Spatial Services, NSW Government	Digital elevation data at a resolution of 1 m was obtained from Spatial Services, NSW Government.
Wave Run-up Levels	Collaroy-Narrabeen Beach	Baird	Hindcast peak wave run-up levels (elevation) using methods described in Burston *et al* (2016).
Beach Profile Survey	Collaroy-Narrabeen Beach	UNSW-WRL	Monthly beach survey profiles of Collaroy-Narrabeen beach since April 1976 (Turner et al. 2016).

Data Type	Location	Data Source	Description
Shoreline Position	Collaroy-Narrabeen Beach	CoastSat (Vos et. al., 2019)	Python toolkit used to obtain timeseries of shoreline position using publicly available satellite imagery.
Aerial Photography	Collaroy-Narrabeen Beach	Nearmap Australia	5.5-7.5 cm resolution from airplane-mounted camera systems.

3.3 Actions of the Sea

Baird (2021) provides a description of actions of the sea and their context to the insurance industry. The following sections provide summary of the actions of the sea that impacted on Collaroy-Narrabeen during the June 2016 storm (Section 3.3.1) with a particular focus on coastal inundation from elevated waves and water levels (Section 3.3.2) and erosion (Section 3.3.3).

3.3.1 Overview of Coastal Processes

The following sections summarises the key coastal processes that contributed to the actions of the sea impacting on Collaroy-Narrabeen during the June 2016 storm.

3.3.1.1 Wind

Wind conditions measured at North Head during the June 2016 East Coast Low are presented in Figure 3.2. The peak sustained wind speed was 17 m/s (33 knots) from the east-northeast which is just below gale force strength. Peak gust speed was 26.7 m/s (52 knots).

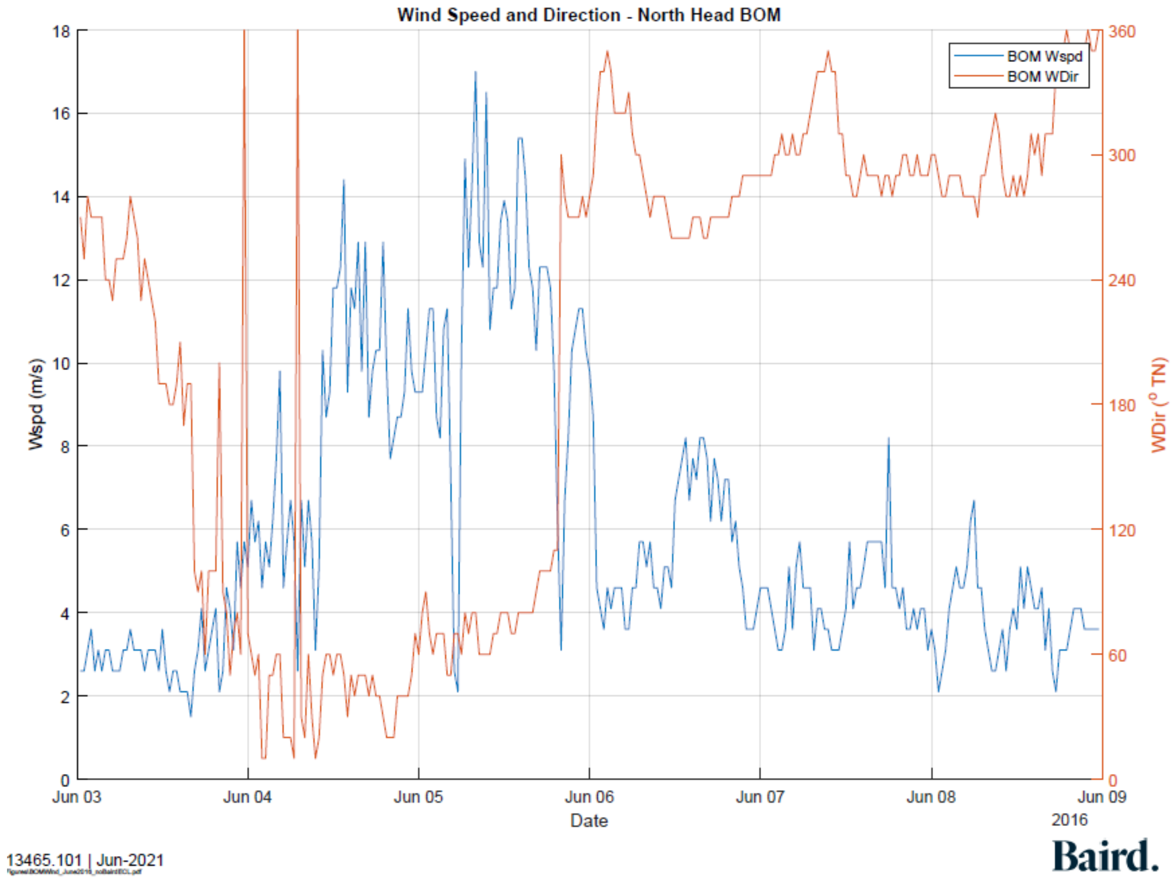


Figure 3.2: Wind speed (10-min average) and direction time series, BoM North Head (066197).

3.3.1.2 Water Levels

Predicted tide, measured water levels and residual from the Fort Denison tide gauge is presented in Figure 3.3. Fort Denison water level measurements are recognised as a reliable source of coastal water levels excluding effects from wave processes. The Storm occurred during a spring tide period when predicted tide levels were peaking above 1 m AHD. Storm surge from wind stress and inverse barometer effect increased water levels up to 0.25 m above predicted astronomical tide levels. Peak water levels occurred in the evening of June 5th with measured water levels peaking at 1.27 m AHD. Whilst the measured water levels were significantly higher than normal tides, analysis completed by Baird on the long-term tide record the return period for water levels of this magnitude at Fort Denison is less than 5-years Average Recurrence Interval (ARI) and is 0.2 m below the peak measured water level of 1.475 m measured in May 1974.

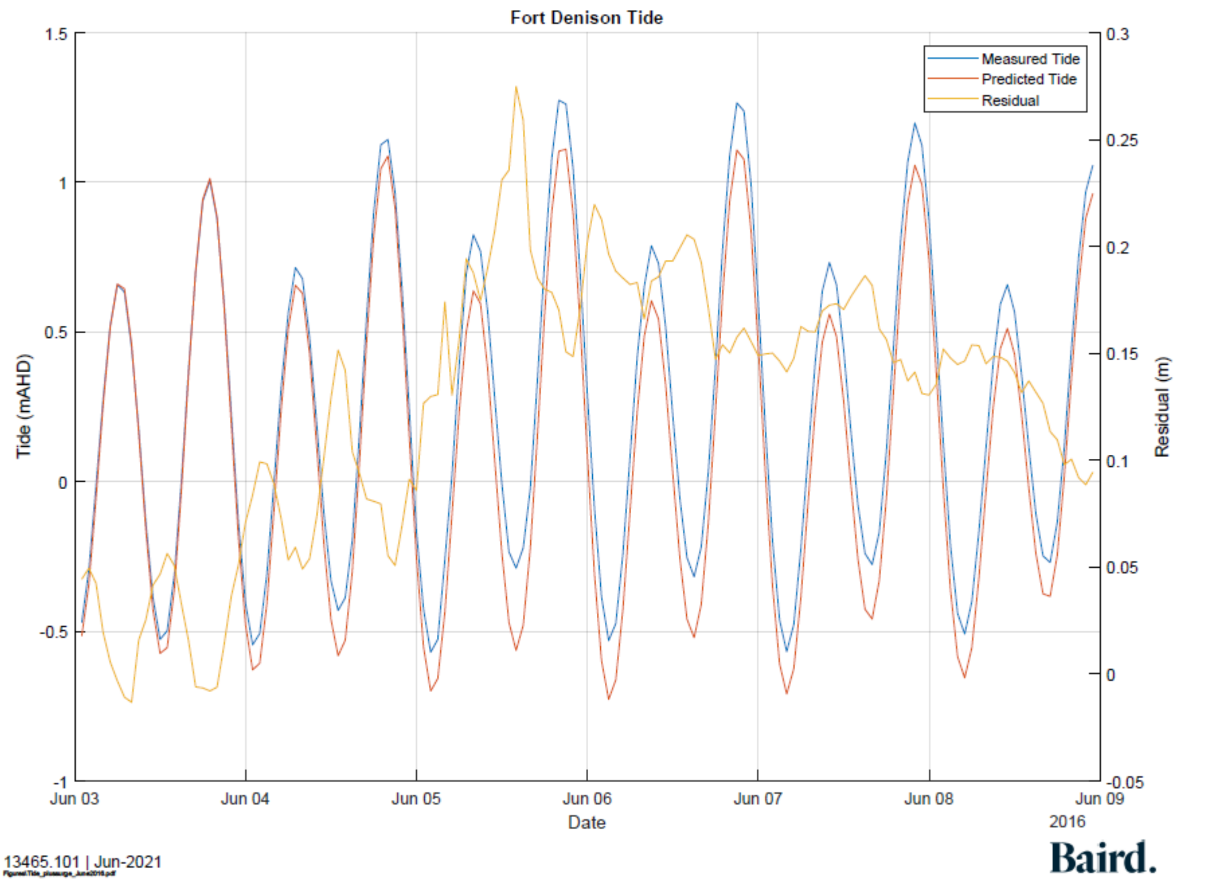


Figure 3.3: Fort Denison tide timeseries, June 2016 storm.

3.3.1.3 Waves

A range of different wave data sources are available to define the June 2016 storm. For defining the impact of actions of the sea on Collaroy-Narrabeen, nearshore waves modelled at a depth of 10 m below AHD from the high-resolution wave model described in Baird Australia (2015) has been adopted. Due to the east-northeast deepwater wave direction offshore of Sydney, there was significantly less loss of wave energy due to refraction as waves transitioned from deepwater to the nearshore compared to typical storm waves offshore of Sydney which have a south to southeast offshore wave direction. Figure 3.4 presents a time series of wave height period and direction from the Baird hindcast model at a depth of 10 m below AHD.

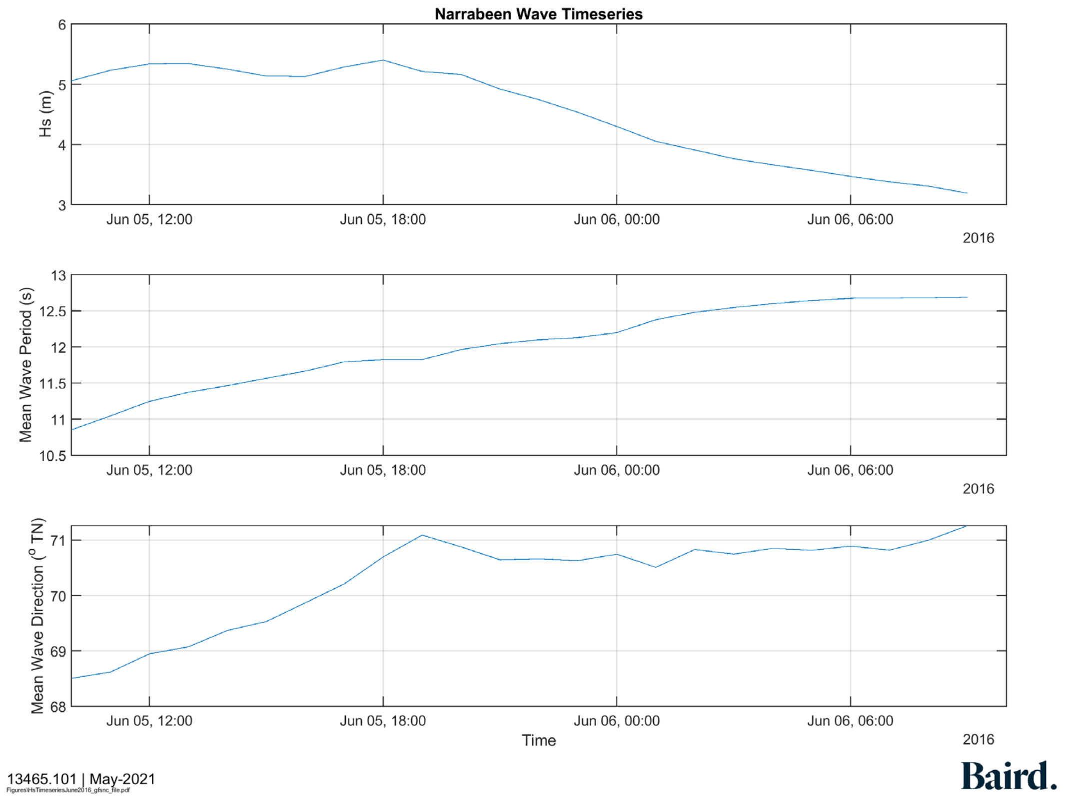


Figure 3.4: Wave height (top), period (middle) and direction (bottom) time series hindcast at -10 m AHD depth offshore of Collaroy-Narrabeen during June 5 and 6 2016.

3.3.1.4 Rainfall

The local rainfall gauge providing 1-hourly rainfall during the June 2016 East Coast Low was the MHL measurement site at Avalon as summarised in Table 3.2. The maximum daily rainfall at this gauge was 157.5 mm and maximum hourly rainfall was 28.5 mm.

Table 3.2: Hourly and daily total rainfalls during June 2016 East Coast Low Event. MHL rainfall gauge, Avalon

Time	03/06/2016	04/06/2016	05/06/2016	06/06/2016
00:00	-	0.5	3.0	-
01:00	-	1.0	7.5	-
02:00	-	0.5	1.5	-
03:00	-	-	7.5	-
04:00	-	-	11.0	-
05:00	-	1.5	5.0	-
06:00	-	1.5	17.0	-
07:00	-	2.0	6.0	-

Time	03/06/2016	04/06/2016	05/06/2016	06/06/2016
08:00	-	3.5	7.5	-
09:00	-	7.5	4.0	-
10:00	-	1.5	9.0	-
11:00	-	3.0	6.0	-
12:00	-	0.5	5.5	-
13:00	-	-	16.5	-
14:00	-	1.5	28.5	-
15:00	-	1.5	4.0	0.5
16:00	-	2.5	0.5	-
17:00	-	1.0	2.5	-
18:00	2.5	1.0	3.0	-
19:00	0.5	0.5	-	-
20:00	5.0	-	-	-
21:00	-	-	8.5	-
22:00	-	-	1.5	-
23:00	2.0	3.0	2.0	-
Daily Totals (mm)	**10.0**	**34.0**	**157.5**	**0.5**

3.3.1.5 Summary of Coastal Conditions at Collaroy-Narrabeen

A summary of the peak coastal conditions at Collaroy-Narrabeen is presented in Table 3.3. Peak water level including wave setup and peak wave runup levels are included in Table 3.3 and the description and calculation of those parameters is discussed Section 3.3.2.

Table 3.3: Summary of Collaroy-Narrabeen Coastal Processes - Peak Values reached during the June 2016 East Coast Low storm

Coastal Process	Peak Value	Time of Peak Value (EST, +10 hr UTC)
Predicted Tide (Fort Denison)	1.11 m AHD	05/06/2016 21:00
Measured Tide (Fort Denison)	1.27 m AHD	05/06/2016 20:00
Storm Surge (Fort Denison)	0.27 m	05/06/2016 14:00
Peak Shoreline Still Water Level (SWL including wave setup)	2.85 m AHD	N/A
Wave Runup Level	6.4 m AHD	N/A

Coastal Process	Peak Value	Time of Peak Value (EST, +10 hr UTC)
Max Inshore Significant Wave Height	5.4 m	05/06/206 18:00
Co-incident Mean Wave Period	11.8 s	05/06/206 18:00
Co-incident Mean Wave Direction	71 °TN	05/06/206 18:00
Wind Speed	17 m/s	05/06/2016 08:00
Peak Wind Gust	26.7 m/s	05/06/2016 08:00
Wind Dir at Peak Wind Speed	80 °TN	05/06/2016 08:00
Pressure	993 hPa (min. pressure)	5/6/2016 23:00
Maximum Daily Rainfall	157.5 mm	05/06/2016
Maximum Hourly Rainfall	28.5 mm	05/06/2016 14:00

3.3.2 Coastal Inundation

Coastal inundation impacts were observed in the study area as a result of the June 2016 storm event. The inundation of shoreline properties was caused by the combination of large, long period waves coincident with high coastal water levels as a result of tide and storm surge.

The various components which contribute to inundation on a wave exposed beach where wave run-up can overtop the dune and primary shoreline is illustrated in Figure 3.5. In Figure 3.5, the astronomical tide and residual components combined are represented by the measured water level at Fort Denison which had a peak value of 1.27 m AHD (see Table 3.3). The additional wave setup component represents the peak still water level that would be observed at Collaroy-Narrabeen which had an estimated peak value of 2.85 m AHD (including tide and residual, see Table 3.3). Finally, the estimated peak wave run-up level at 6.4 m AHD (including tide and residual, see Table 3.3) unless the foreshore is lower elevation and then runup can overtop and propagate as a shallow depth flow as illustrated in Figure 3.5.

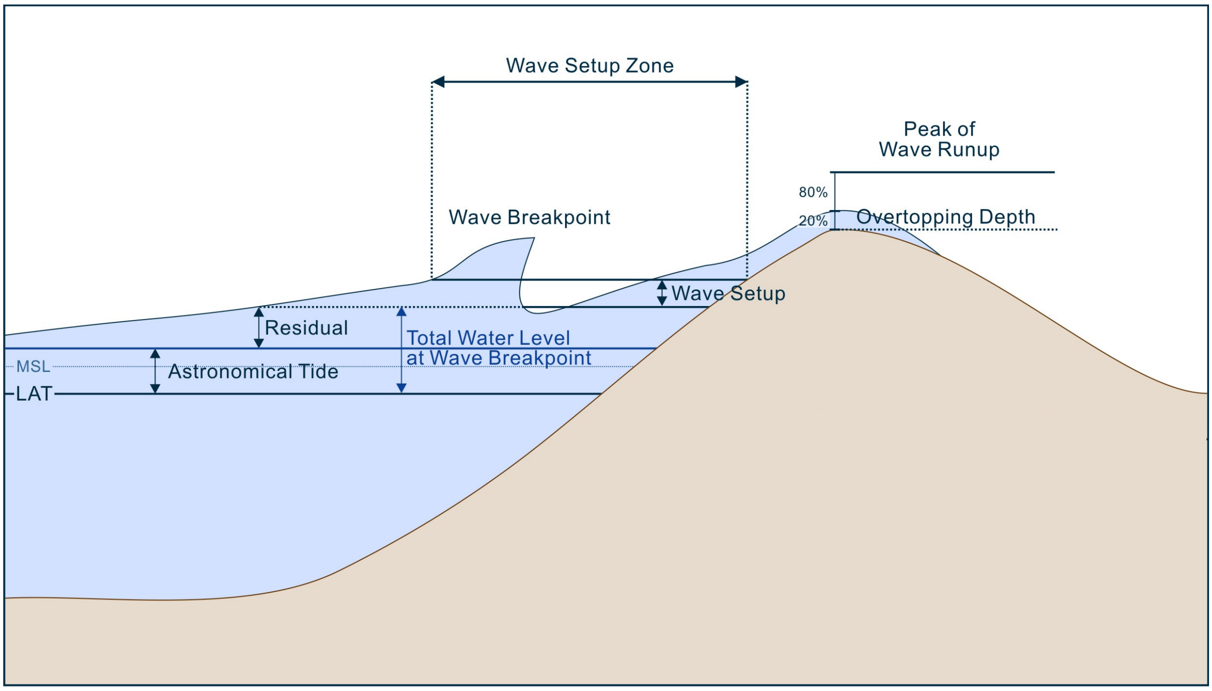


Figure 3.5: Illustration of coastal inundation processes for wave exposed coastlines where overtopping of the coastal dune can occur.

Following the storm, Baird inspected Collaroy-Narrabeen and observed evidence of wave run-up and overtopping to a level of between 5.5 m and 8 m AHD in the worst-affected locations due to the June 2016 East Coast Low. The variation in wave runup observation is due to the impact of beach face slope: wave run-up increases significantly in elevation with increased beach slope that often occurs with a highly eroded beach. The methods used to calculate wave setup and runup in this case study are presented in Section 3.3.2.1.

3.3.2.1 Calculation of Wave Setup and Run-up

Wave breaking in the surf zone causes dynamic variation in water level at the shoreline from two processes: wave runup and wave setup. Wave runup (R) is the maximum elevation of the ocean at the shoreline above the stillwater level and is a dynamic, time-varying process that is occurring at the same frequency (period) as the wave forcing. It results from wave energy that is not dissipated in wave breaking, and instead converted into potential energy.

Wave setup is a more prolonged elevation of water level that occurs inside the surf and is generated as a result of the momentum flux dissipation that occurs in the zone of wave breaking, leading to an increase in the water level to the shoreline. In this case study, the estimated wave setup at the shoreline has been included in the peak coastal water level parameter that is presented in Table 3.3.

Wave runup levels will only result if there is a sufficient elevation of the dune, otherwise overtopping occurs. In this study, wave setup and runup is quantified using the equations of Nielsen and Hanslow (1991), which were established for open sandy beaches in NSW. However, these equations have not been validated for storm conditions.

Following the June 2016 ECL, Baird Australia completed an event assessment along the whole NSW coastline, including specific site inspection and verification at Collaroy-Narrabeen where the most severe coastal impacts were observed. In that assessment, the Nielsen and Hanslow (1991) model for an eroded beach with a steep dune scarp produced wave runup levels that agreed well with observed wave runup levels that could be referenced to accurate ground levels from LiDAR data.

For this data set, the wave and water level conditions calculated for each event storm has been applied to the Nielsen and Hanslow (1991) model, assuming a beach slope of 1V:6H which is typical of an eroded beach profile that may develop during a severe storm event.

3.3.2.2 Assessment of Coastal Inundation along Collaroy-Narrabeen

In order to assess which properties may have had inundation impacts during the Storm, a spatial analysis of wave runup levels and ground elevations available from LiDAR survey data was completed. The desktop assessment completed for the case study provides a general assessment of properties that may have been impacted from coastal inundation, but the overtopping of the dune or foreshore as illustrated in Figure 3.5 is complex and can only be accurately quantified with high-resolution process-based modelling. For this assessment the schematic model presented in Figure 3.5 has been implemented in a GIS processing routine which identifies dune or primary foreshore elevation, and then applies appropriate reduction factors in inundation depth behind the overtopped foreshore. Adopting the pre-storm ground elevations from 2011 LiDAR data (assumed to be representative of the pre-storm conditions), clearly indicated that wave overtopping impacts were most concentrated on the heavily impacted properties between Ramsay Street to Stuart Street (see Figure 1.1). Figure 3.7 presents a spatial map of the estimated peak wave runup impact area during the June 2016 East Coast Low on the most impacted area of Collaroy-Narrabeen.

The inundation that would have been experienced by some properties in the case study area during the Storm would have been very episodic in nature, and therefore this most likely limited the floor area that would have been damaged. Unlike riverine or even urban overland flow flooding, severe overtopping to a level that impacted on primary structures would have occurred for very short durations, for example a few minutes, at a low frequency during the peak water level and wave conditions.

An assessment of the potential financial impact of this type of short duration coastal inundation on properties located between Ramsay Street and Stuart Street is presented in Section 6.4.3 as part of the economic analysis.

The coastal inundation potential from the June 2016 storm was one of the most significant for Collaroy Narrabeen and the most severe since May 1974. Based on Baird's hindcast data set of wave and water levels for east coast low storms along the NSW coastline, analysis indicated that the June 2016 event produced the third largest nearshore wave height in the event set at Collaroy (after the May 1974 and June 1975 events) and the second largest coastal water level (including wave setup) and wave run-up levels after the May 1974 event (Burston et al, 2016). The estimated return period of the June 2016 storm based on wave run-up levels is 50 to 60 years Average Recurrence Interval (ARI). The recurrence interval of wave runup for the study area agrees well with the return period of the erosion assessment presented in Section 3.3.3.

N:\Projects\13465.101_ICA_ActionsoftheSea\09_GIS\10 QGIS\Figures\WaveInundation.png

Figure 3.6: Assessment of wave inundation impact area based on 2011 ground elevation LiDAR survey and conceptual model presented in Figure 3.5. Pre-storm (left, 06/05/2016) and post-storm (right, 08/06/2016).

3.3.3 Erosion

The erosion impacts on Collaroy-Narrabeen were particularly severe and resulted in extensive erosion of titled land and damage to property. Shoreline survey data collected and reported by the Water Research Laboratory (http://narrabeen.wrl.unsw.edu.au/) as part of the long-term shoreline data set described in Turner *et al* (2016) measured up to 50 m of shoreline recession at the 0 m AHD contour. The survey profile locations along Collaroy-Narrabeen are presented in Figure 3.8, with profiles PF6 and PF8 within the case study area. Figure 3.9 presents the survey data from pre-storm (18 May 2016 and 3 June 2016) and then daily surveys between 6 and 8 June 2016. Extensive erosion is observed along all profiles, but for profiles PF6 and PF8 in the South Narrabeen and Collaroy sections of the beach, the storm erodes back to the landward limit of the survey data highlighting the erosion impacts in those areas. The erosion on profile PF6 up to a level of approximately 6.5 m AHD, has good agreement with the estimated wave runup levels presented in Table 3.3.

Figure 3.7: Long-term beach survey profile locations for Collaroy-Narrabeen (Turner *et al*, 2016).

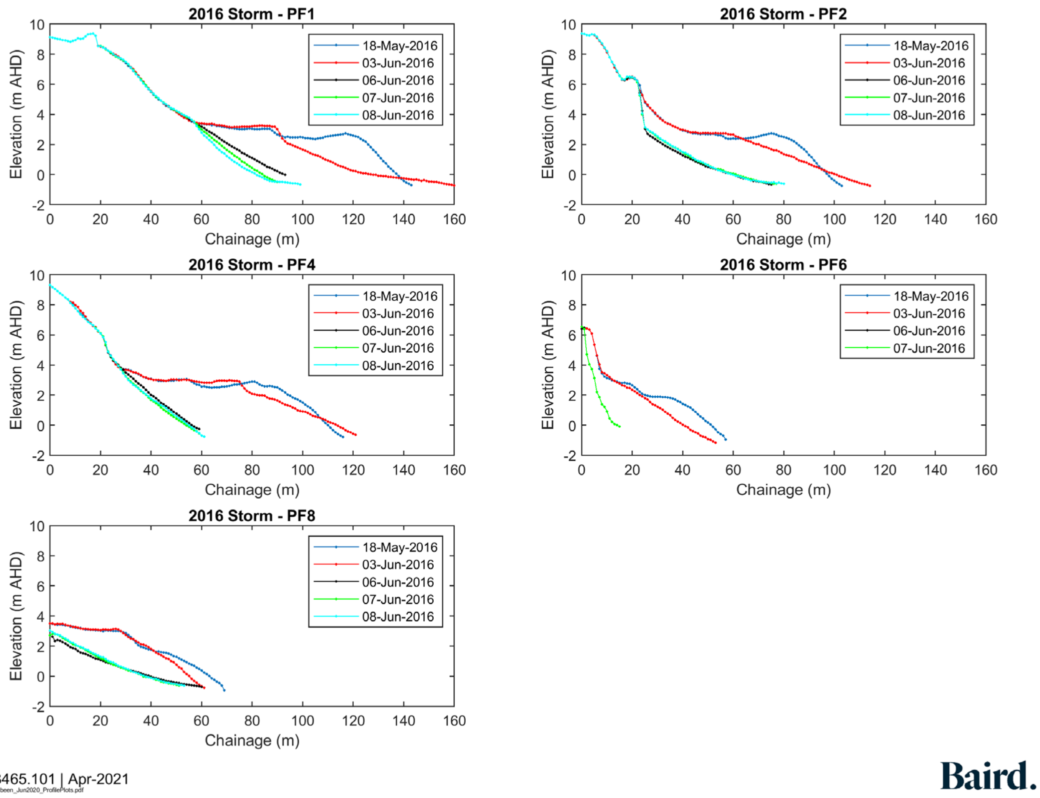


Figure 3.8: Change in elevation pre- and post-storm event June 2016 from the monthly beach monitoring surveys (Turner *et al*, 2016).

The spatial impact of erosion on the study area has been examined from analysis of shoreline position using high-resolution satellite imagery and the CoastSat toolbox (Vos et al, 2019). Figure 3.10 presents time series of relative shoreline position at the long-term monitoring profiles. The impact of the storm is seen by a 30 m shoreline shift between May and June in most profiles; however, this data analysis method is not as accurate or conclusive as the survey elevation analysis presented in Figure 3.9. The CoastSat toolbox did not analyse an image of the study area that was immediately after the storm. The nearest available aerial image after the storm was 15 June 2016 and by that time emergency works and also some natural beach profile recovery will have reduced the erosion extent compared to the maximum erosion extent immediately following the storm.

Figure 3.11 presents the pre-and-post storm shoreline from the CoastSat toolbox. Figure 3.11 indicates up to 35 m shoreline change and is well correlated with the high-resolution survey profile data presented in Figure 3.9.

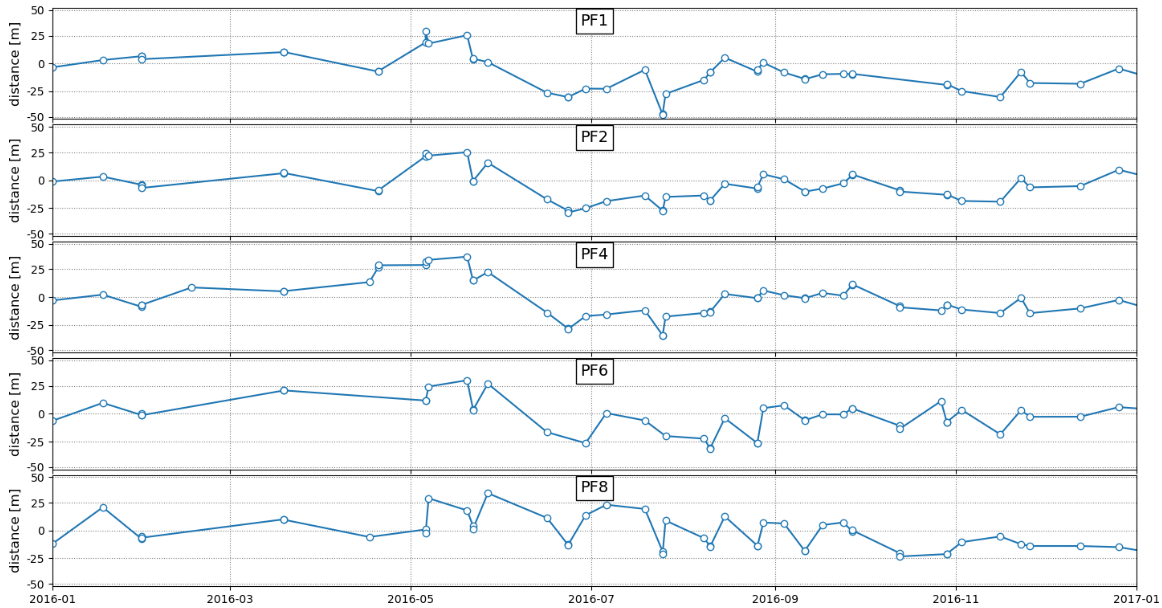


Figure 3.9: Shoreline Position timeseries for 2016 using CoastSat (Vos et al, 2019).

Figure 3.10: Analysis of pre-and-post storm shoreline position using CoastSat (Vos et al, 2019).

A more granular assessment of the erosion impacts on properties in the study area was completed using high-resolution Nearmap aerial photos available pre-storm, and immediately post-storm (06/05/2016 and 08/06/2016) (Nearmap, 2021). Figure 3.12 to Figure 3.15 present high-resolution pre-and-post storm images along the study area which highlight the impact of erosion on some properties. The erosion impacts varied significantly within the study area, even between adjacent properties. Coastal protection of varying design and condition provided protection to some properties from the most severe erosion impacts.

In Baird's post-storm inspection of Collaroy-Narrabeen, the following factors were noted to be important with respect to the erosion impacts on properties:

- Extent of erosion impacts were highly variable, with a range of factors influencing the extent of erosion including;
  - Immediate presence of coastal protection in the form of large armour stones or block walls near the seaward edge of the property;
  - Presence of coastal protection of surrounding properties; and
  - Soil conditions in the erosion zone.
- Coastal protection structures were observed to be both effective and ineffective in protecting property from erosion and inundation. Coastal protection structures at the time of the June 2016 storm along Collaroy-Narrabeen were irregular and variable in construction, quality and condition. In several locations, it was obvious that protection structures had failed and armour had been moved to lower elevations. However, even failed structures afforded a degree of protection to many properties. It is noted that the most impacted properties in the case study area between Ramsay Street to Stuart Street did not have any coastal protection works prior to the storm.
- Evidence of scouring from wave action was evident near some properties.
- At many locations, the extent of seawater inundation was indicated by die-back of grass and vegetation from exposure to saline water.

A summary of the storm erosion from the June 2016 event relative to the last 40-years of available data is presented in Section 3.3.3.1. Within the study area, if the data for profile PF6 is considered, the June 2016 storm caused this profile to be in its most eroded state compared to all other surveys in the data set from 1976 to 2020. This observation indicates supports the conclusion that the June 2016 event was the most severe erosion event since May 1974 for the study area and the recurrence interval of wave runup of 50 to 60 years ARI (see Section 3.3.2.2) has good agreement with the recurrence interval of the observed erosion impacts.

Figure 3.11: Nearmap images for northern section of study area: 06/05/2016 (left) and 08/06/2016 (right).

Figure 3.12: Nearmap images for middle section (1) of study area: 06/05/2016 (left) and 08/06/2016 (right).

Figure 3.13: Nearmap images for middle section (2) of study area: 06/05/2016 (left) and 08/06/2016 (right).

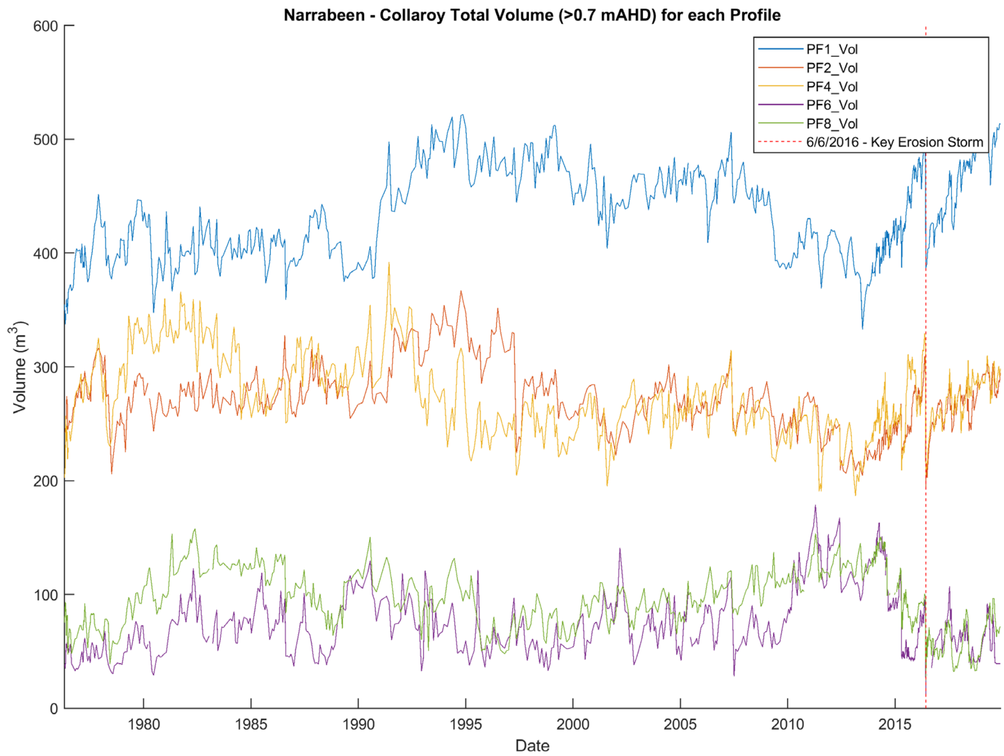
Figure 3.14: Nearmap images for southern section of study area: 06/05/2016 (left) and 08/06/2016 (right).

3.3.3.1 Event Impact Relative to Historical Shoreline Changes

The June 2016 was noted as the most severe erosion event to impact Collaroy-Narrabeen since May 1974 (UNSW-WRL, 2016). The extent of erosion can be understood from assessment of historical shoreline changes over the data record stretching back to 1976. The post June 2016 storm volume for profile PF6 was the lowest in the data record indicating the severity of the event. It is also interesting to note that by the end of 2020, sand volume for the northern and middle sections of Narrabeen Beach had recovered to near pre-storm 2016, whereas volumes for PF6 and PF8 at the southern end and in the case study area remain below historical averages. The June 2016 event occurred during a period when sand volumes in the southern half of Collaroy-Narrabeen were below average and was noted by UNSW-WRL as a period when there was significant clockwise rotation of the beach.

Figure 3.17 presents cross-plots of the position of the 0.7 m AHD contour on the survey profile, and the sand volume above 0.7 m AHD. The extent of erosion from the June 2016 storm is evident but it is interesting that the largest changes in shoreline position are profiles PF2 and PF4. However, at neither profile does the erosion go landward to the edge of the dune system or a coastal structure and the survey profile recovers at a relatively rapid rate following the storm. Profiles PF6 and PF8 have the least sand volume buffer and have recovered at a much slower rate.

Figure 3.18 presents the long term shoreline position from the CoastSat toolbox for the six reported survey profile locations. The CoastSat shoreline position is more variable between adjacent satellite images and does not have the range of variation in shoreline position as the survey data set. However, the slow recovery of the southern section of Collaroy-Narrabeen is clearly indicated in the post 2016 shoreline positions at PF6 and PF8.



13465.101 | Jun-2021

Baird.

Figure 3.15: Total beach volume above 0.7 mAHD for each profile, Collaroy-Narrabeen Beach, from monthly beach profile surveys (Data source: Turner *et al*, 2016).

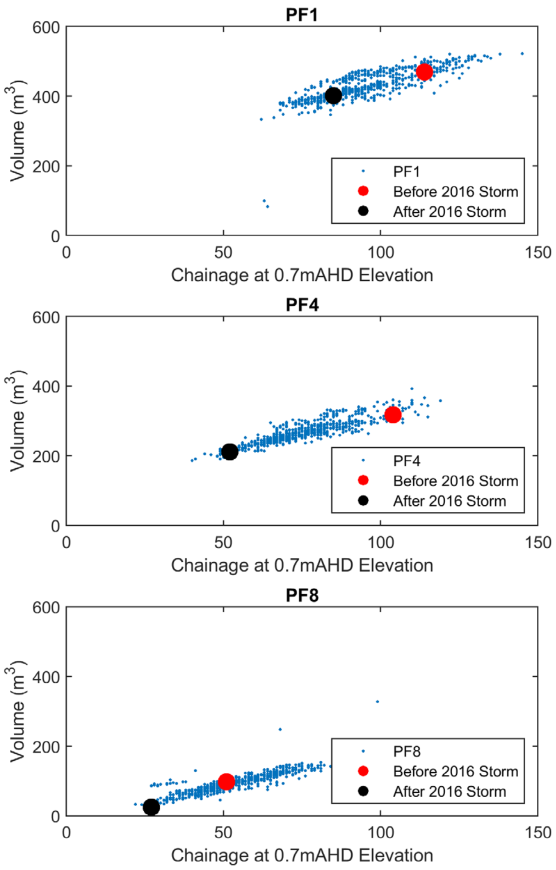


Figure 3.16: Beach volume as a function of location (chainage) of the 0.7 m AHD contour. Red circle indicates most recent survey prior to the June 2016 event, whilst black indicates the closest survey post event.

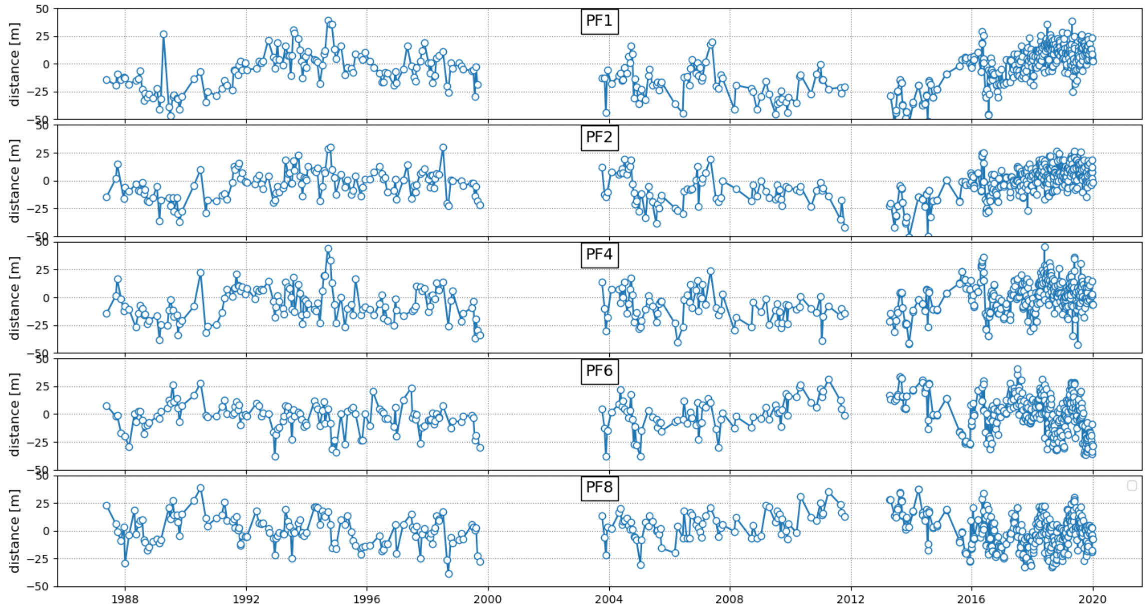


Figure 3.17: Shoreline position for long-term profiles from CoastSat toolbox: 1988 to 2019.

For the most impacted properties in the June 2016 storm, there been significant loss of ground elevation at the seaward end of property boundaries. Figure 3.19 presents a comparison of the 2011 and 2020 LiDAR survey ground elevations along properties between Ramsay Street to Stuart Street.

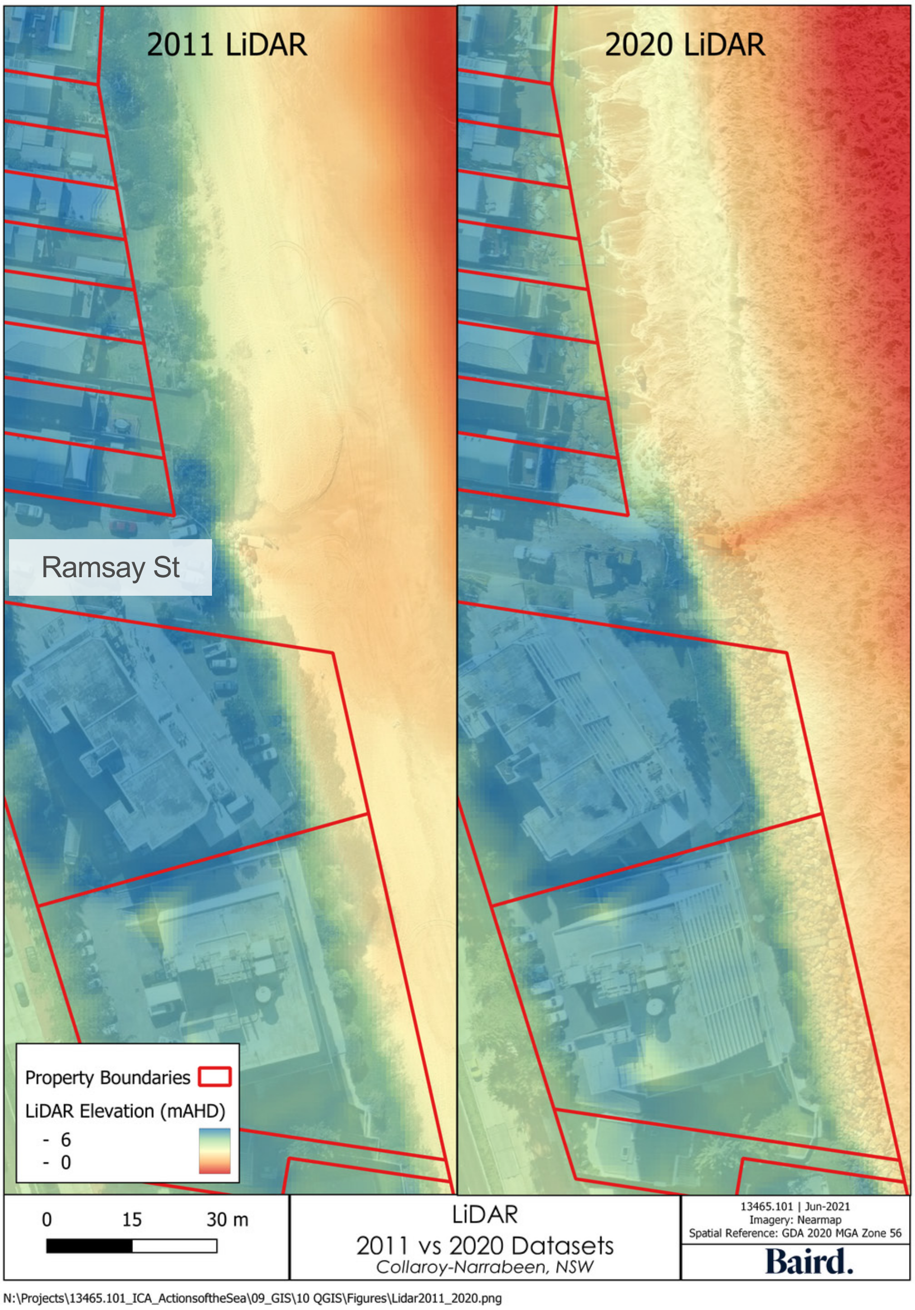


Figure 3.18: Comparison of LiDAR survey ground elevation (Ramsay Street to Stuart Street): 2011 and 2020.

3.4 Property Impact Assessment

Based on the data and assessment presented in Section 3.3, an assessment of the impact on 114 ocean-front properties within the study area has been completed based on the degree that inundation and erosion impacted on a particular property. The assessment framework and description of expected post-storm repairs is summarised in the Table 3.4. Appendix B presents a spatial overview of the impact assessment for each property in the study area.

Table 3.4: Assessment scale for property impact from actions of the sea.

Severity Category	Impact Potential - Inundation	Impact Potential - Erosion	Typical Post-Storm Repairs	Number of Impacted Property Lots (with dwellings)
Severe	Likely to be some inundation of primary building.	Significant erosion which exposes primary building foundations and/or causes damage to primary building.	Significant refilling of site to restore ground elevation (also referred to as reinstatement). Repairs to landscaping and exterior structures and interior / exterior inundation damage. Structural assessment of primary building and possible structural repairs. Repair or upgrade to coastal protection structures.	16
Medium	Possible for some inundation of primary building.	Erosion impacts extend into property area but do not impact on primary building.	Refilling of site to restore ground elevation (also referred to as reinstatement). Repairs to landscaping. Possible repairs for exterior structures and interior / exterior flood damage. Repair or upgrade to coastal protection structures.	37
Boundary	Unlikely to be any inundation of primary building.	Erosion impacts limited to seaward boundary or coastal protection structure.	Repair or upgrade to coastal protection structures. Minor landscaping repairs.	7
No Actions of Sea Impacts	Very unlikely to be any inundation due to actions of the sea.	No noted erosion impacts within property boundary.	Any post-storm repairs that were completed are unlikely to be from damage caused by actions of sea.	54

3.5 Emergency Response

The June 2016 storm required a major emergency response across NSW with 41 local government areas included in Natural Disaster Declarations. This included Northern Beaches Council where Collaroy-Narrabeen was a key site for emergency response. During the storm, NSW Government declared an emergency under the State Emergency and Rescue Management (SERM) Act 1989. A Local Emergency Operations Controller (LEOCON) was appointed, who was the most senior NSW Police officer in the area, and they were responsible for controlling the response in the emergency. During the storm, the LEOCON made decisions to protect but takes advice from Council and coastal experts. Following the emergency response, the disaster recovery effort for the study area was overseen by the Northern Beaches Local Recovery Committee (Chaired by Northern Beaches Council).

Approximately 10 properties were issued with Emergency Orders to cover evacuation and emergency works to remove parts of properties that were a public safety risk. Immediate coastal protection works were completed in the 2-days post event (6 to 8th June 2016) and a 110 m long, 5 m high temporary geobag wall constructed from 1600 tonnes of sand (Department of Justice NSW, 2016). Figure 3.20 is a photo of volunteers and local residents assisting with the emergency seawall protection comprising sandbags. There were several types of emergency works constructed at different locations along Collaroy-Narrabeen including a geobag wall (installed by contractor), sandbags (installed by volunteers/residents) and rock protection (installed by Council/contractors). The emergency works were essential to protect the shoreline and property from further damage to proceeding periods of high-water levels and wave conditions.

Figure 3.19: Emergency volunteers and local residents assisting with construction of sandbag temporary protection (Department of Justice NSW 2016, Source Huffingtonpost.com.au).

Apart from structural risk to some properties, damage to potable water and sewer systems rendered properties inhabitable. Work was completed within 12-days of the storm to provide temporary sewer pipes to numerous properties in the case study area (Department of Justice NSW, 2016).

4. Planning Framework

As a part of the case study, Rhelm has undertaken a review and assessment of the planning framework for Collaroy-Narrabeen (Section 4.1) and a summary of the planning process for rebuilding after a storm (Section 4.2).

4.1 Land Use Planning for the Collaroy-Narrabeen Embayment

The Collaroy Narrabeen coastal embayment lies wholly within the Northern Beaches Local Government Area (LGA), which is managed by Northern Beaches Council (NBC) under the NSW *Local Government Act*, 1993. Land below mean high water (MHW) mark is owned by the Crown and managed by the NSW Government (Department of Planning, Industry and Environment – Crown Lands) in accordance with the *Crown Lands Management Act*, 2016. Land above the MHW mark is primarily in private ownership, with some pockets of land owned by Council (public or road reserves). The case study area is outlined in Figure 1.1.

There are a multitude of environmental planning instruments (EPIs) that apply to land under the *Environmental Planning and Assessment Act*, 1979 in New South Wales. To determine which EPIs apply to a land parcel, a landowner, or other interested party, can apply for a Section 10.7 certificate from the relevant local government authority (for example, Northern Beaches Council). Council has the option to apply a range of types of notifications with respect to coastal hazards but the most common one is a Section 10.7(2) notification, which identifies whether or not there is an exposure and whether development controls are imposed on the land. In this certificate, Council commonly identifies land as *having a current and/or future exposure to a certain type of hazard*.

For most lands, the land is zoned in accordance with the relevant Local Environment Plan (LEP), which at the time of preparation of this report was the *Warringah Local Environment Plan* 2011 (WLEP2011). This is related to the history of the locality, which was previously located within the Warringah Local Government Area. Warringah, Pittwater and Manly were amalgamated into the Northern Beaches Local Government Area in 2016.

The majority of lots within the case study area are zoned *Low Density Residential – R2* under the WLEP2011. The WLEP2011 has a zoning table which identifies permissible and prohibited uses of the land. The Warringah Development Control Plan 2011 (WDCP2011) provides the detail with regard to specific requirements for development. These are discussed below. The land use zoning table for R2 zoned land is reproduced as Table 4.1.

Table 4.1: Low Density Residential Land Use Zoning Objectives

1 **Objectives of zone**	**To provide for the housing needs of the community within a low density residential environment.** **To enable other land uses that provide facilities or services to meet the day to day needs of residents.** **To ensure that low density residential environments are characterised by landscaped settings that are in harmony with the natural environment of Warringah.**
2 Permitted without consent	Home-based child care; Home occupations
3 Permitted with consent	Bed and breakfast accommodation; Boarding houses; Boat sheds; Building identification signs; Business identification signs; Centre-based child care facilities; Community facilities; ***Dwelling houses;*** Educational establishments; Emergency services facilities; Environmental protection works; Exhibition homes; Group homes; Health consulting rooms; Home businesses; Hospitals; Oyster aquaculture; Places of public worship; Pond-based aquaculture; Recreation areas; Respite day care centres; Roads; ***Secondary dwellings;*** Tank-based aquaculture; Veterinary hospitals
4 Prohibited	Any development not specified in item 2 or 3

The provisions of the zoning table are modified by Clause 6.5 of the WLEP2011 which has the objectives:

- to avoid significant adverse impacts from coastal hazards,
- to enable evacuation of coastal risk areas in an emergency,
- to ensure uses are compatible with coastal risks,
- to preserve and protect Collaroy Beach, Narrabeen Beach and Fishermans Beach as national assets for public recreation and amenity.

The clause applies to the land shown on the Coastline Hazard Map, which is reproduced in Figure 4.1. Note that this only covers the Collaroy-Narrabeen embayment of the LGA.

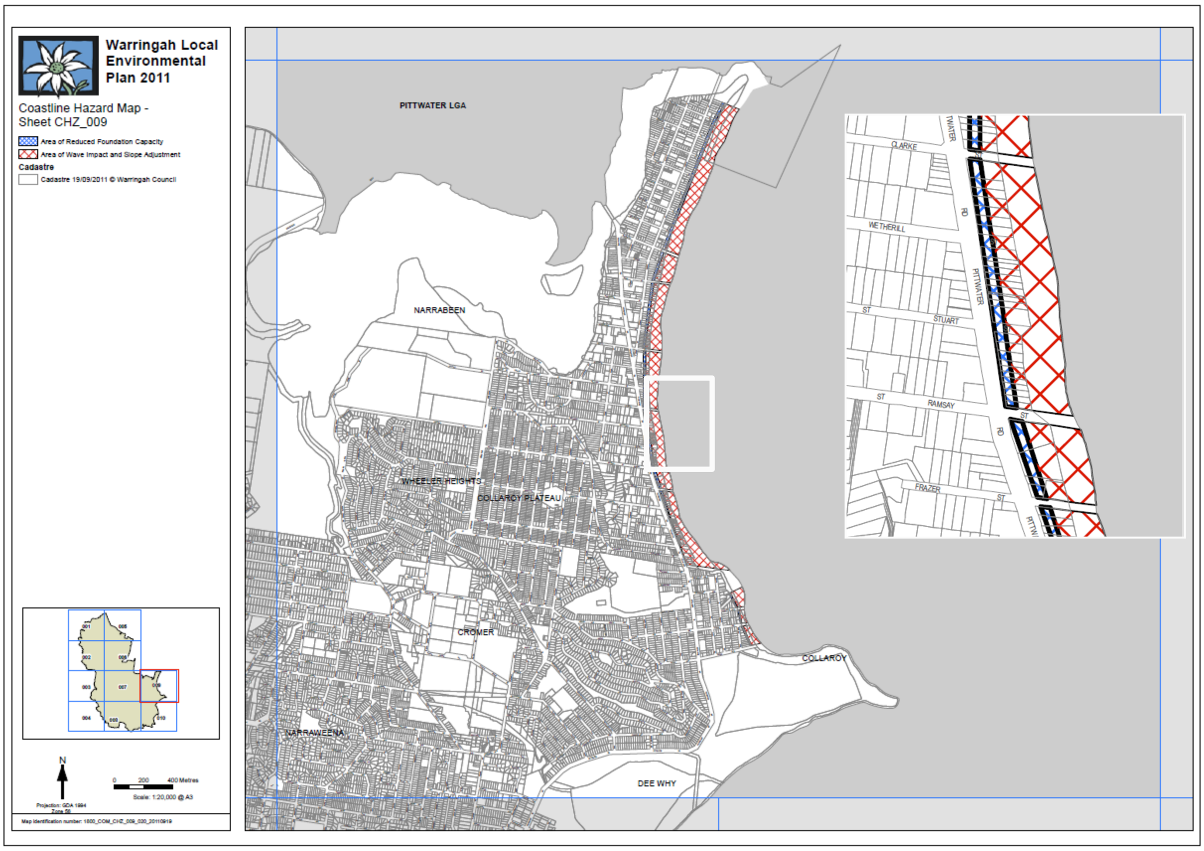


Figure 4.1: Coastline Hazard Map Accompanying WLEP2011 (Accessed 26 April 2021)

Clause 6.5(3) of the WLEP2011 states that development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development:

- will not significantly adversely affect coastal hazards, and
- will not result in significant detrimental increases in coastal risks to other development or properties, and
- will not significantly alter coastal hazards to the detriment of the environment, and
- incorporates appropriate measures to manage risk to life from coastal risks, and
- avoids or minimises exposure to coastal hazards, and
- makes provision for relocation, modification or removal of the development to adapt to coastal hazards and NSW sea level rise planning benchmarks (noting these relate to those adopted in 2010 by the NSW, which in essence assume a sea level rise of 0.9 m by 2100).

Clause 6.5(4) of the WLEP2011 states that development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the foundations of the development have been designed to be constructed having regard to coastal risk. Within the case study area, property development and redevelopment must consider the coastal erosion zone and zone of reduce soil capacity using the model of Nielsen *et al* (1992) if the property is within the erosion hazard zone defined in the CZMP (NBC, 2016). Whilst the foundation design requirements for new or redeveloped property in the case study area provides protection from severe structural damage, properties can be unhabitable after severe erosion events due to damage to services (i.e power, water and sewage) connected to the property and this occurred following the June 2016 storm.

It is noted that the coastal areas do not fall within the exemption of environmentally sensitive lands for the purposes of Section 3.3 of the WLEP2011. The implications of this are that some development may be constructed without regard to the acceptable limits of risk. However, Clause 6.5 should ensure that affected properties in the Collaroy-Narrabeen area meet the relevant provisions.

Note that whilst the R2 zoning applies across the majority of the embayment (for residential properties), there are many existing residential flat buildings (RFB) present. Planning provisions for these operate under existing use rights provisions within the *Environmental Planning and Assessment Act,* 1979 (Division 4.11 of the Act). Essentially, this means that the existing RFBs could be retained or replaced with a similar structure. However, it would highly unlikely that any new RFBs could be constructed in an R2 zoned area under the WLEP (where a house is currently present).

Note that at the time of preparation of this report, a Northern Beaches Local Environment Plan was in preparation (NBLEP, *in prep*) to replace the WLEP2011. It would be expected that the coastal planning provisions within the NBLEP would be similar or potentially more stringent with respect to those that currently operate in the WLEP2011.

In addition to local planning provisions under the WLEP2011, there are a range of over-riding and/or complementary state environmental planning provisions (SEPPs). The most relevant being the *State Environmental Planning Policy Coastal Management* 2018 (CMSEPP2018). There are three key types of planning controls in this SEPP, which are related to whether the land falls within the coastal vulnerability area, the coastal environment area, the coastal use area and/or the coastal wetlands and littoral rainforests area. The extent of mapping for these different areas are shown in Figure 4.2, with the exception of the coastal vulnerability mapping, which had not yet been adopted for the case study area at the time of preparation of this report.

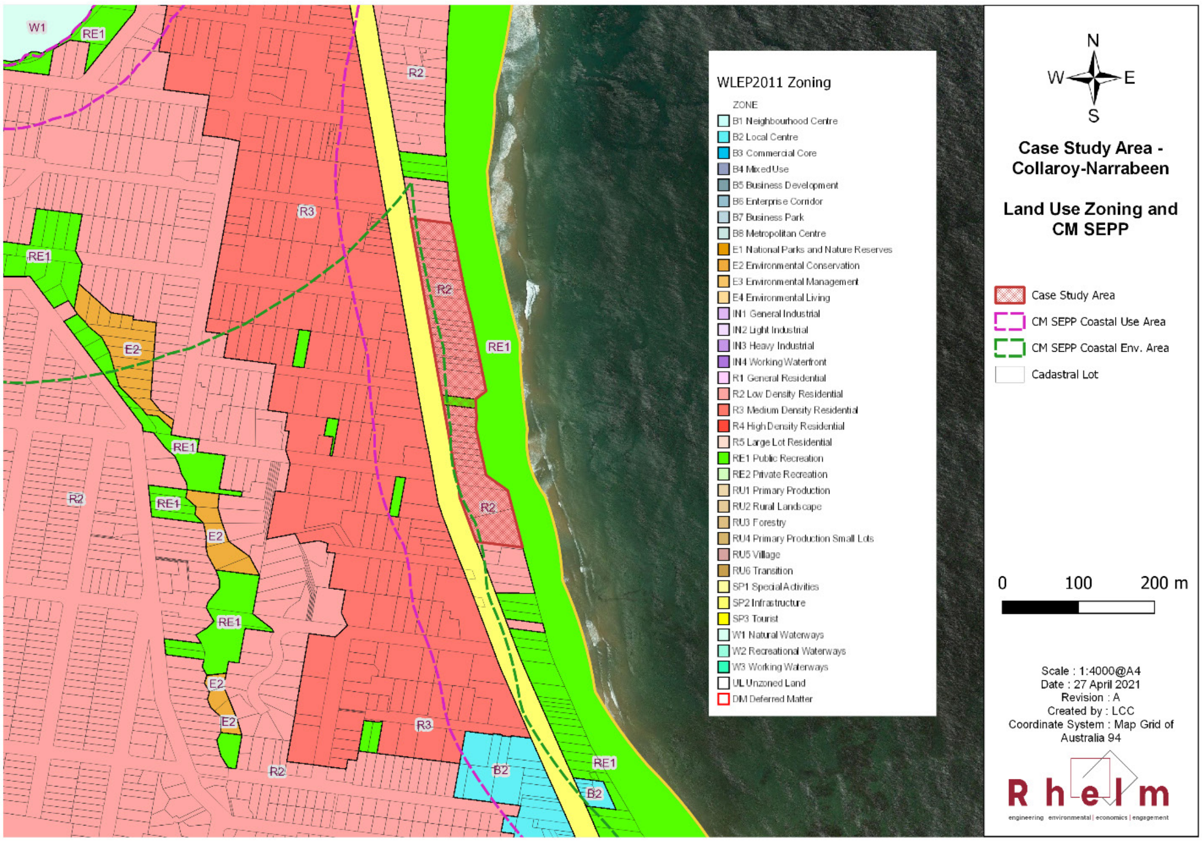


Figure 4.2: Land Use Zoning and Coastal SEPP 2018 Application Areas

As identified above, the Warringah Development Control Plan 2011 (WDCP2011) provides the detail with regard to specific requirements for development. Control E9 specifically deals with Coastline Hazard.

The objectives of control E9 are:

- To minimise the risk of damage from coastal processes and coastline hazards for proposed buildings and works along Collaroy Beach, Narrabeen Beach and Fisherman's Beach.
- To ensure that development does not have an adverse impact on the scenic quality of Collaroy, Narrabeen and Fisherman's Beaches.
- To ensure that development does not adversely impact on the coastal processes affecting adjacent land.
- To retain the area's regional role for public recreation and amenity.

The key requirements are generally met for residential development in having appropriate building setbacks (from the seaward limit of the land parcel) and building foundations and being able to demonstrate compliance with a range of documents including:

- Northern Beaches Coastal Erosion Policy (the latest version being December 2016);
- the Coastal Zone Management Plan (being that prepared by Haskoning Australia, 2016); and
- the Collaroy-Narrabeen Protection Works Design Specifications (as amended from time to time) (noting that these design specifications relate to protection works that are intended for the most affected properties and are identified in the CZMP described above). These works are intended to be entirely on private property and are for the benefit of that property or group of properties).

Key aspects of the design required are:

- Suitable floor level, considering the risk of coastal inundation for severe coastal storms occurring over the next 50 years (noting that an actual design floor level is not specified by Council);
- Site layout and design that minimises the risk of coastal inundation for severe coastal storms occurring over the next 50 years;
- Foundations generally being piled into a stable foundation area (noting that rock can be at considerable depth); and
- Specialist engineers will need to be retained by any applicant to provide design advice and reporting on the design of the building and its foundations (coastal, structural and geotechnical engineers).

As noted also above, at the time of preparation of this assessment, a Northern Beaches Development Control Plan was in preparation (NBDCP, *in prep*) to replace the WDCP2011. It would be expected that the development control provisions within the NBDCP would be similar or potentially more stringent with respect to those currently operational in the WDCP2011.

4.2 Processes for Rebuilding After an Event

Following a coastal event where erosion and/or inundation occurs, a range of features on a property could potentially be damaged (part or all):

- Boundary/internal fencing
- Garden/soft landscaped areas
- Hard landscaped areas (paving etc)
- Decks
- Swimming pools/spa
- Habitable areas of a dwelling (non-structural components)
- Non-habitable areas of a dwelling (underbuilding storage) (non-structural components)
- Dwelling structure (such as foundations, floor, walls)
- Coastal protection works (being those on the property itself).

Depending on the extent of damage, which depending on the storm event, could result in failure or loss of the entire building, the process of recovery would involve some or all of the steps below:

- Identification of the extent of damage to the property and removal/repair of damaged elements (it is assumed that removal/repair of damaged elements would be exempt development as identified as *Emergency Work and Repairs* under Section 15AA of the *State Environmental Planning Policy (Exempt and Complying Development Codes* (2008) where an area is identified to be declared that a state of emergency exists) meaning no development consent would be needed)
- Identification of the extent of damage to any coastal protection works and determination of the need for any repair works
- Preparation of a development application for repair to the structure/rebuild works (where exempt and complying development provisions do not apply) and lodge application with Council. The application would need to be consistent with:
    - Northern Beaches Coastal Erosion Policy,
    - Collaroy-Narrabeen Protection Works Design Specifications,
    - Provisions in the Coastal Management Act, 2016
    - Provisions in the relevant LEP and DCP (for example the WLEP2011 and WDCP2011)
    - Provisions in the adopted CZMP (or Coastal Management Program when it replaces the CZMP).

Note that it is possible that some elements that are lost may not be able to be replaced in a like for like fashion if they cannot meet the relevant planning and development control requirements (for example development in area of wave impact and slope adjustment see Figure 4.1 or development where the existing floor level is too low or development where foundations could not be designed to meet the requirements).

- Expected a minimum of 40 days assessment of the development application by the relevant Council
- If consent is issued, then preparation of Construction Certificate related documentation and sign off by a Principal Certifying Authority (PCA)
- Completion of repairs to any coastal protection works on the property (e.g. rubble mound wall)
- Completion of the approved building works on the property.
- Obtaining an Occupation Certificate to allow for the occupation of the completed works.

The development process outlined above assumes that servicing/access infrastructure supporting the development is not damaged in such a fashion that it can no longer support the development. For example, in some severe situations, there may be the case where access (roads), electricity, water, gas or sewer may not be able to be reconnected in a timely fashion and it may not be possible to occupy a dwelling in these circumstances.

5. Engineering Response

Following completion of the immediate emergency response in the aftermath of the June 2016 storm, a significant engineering and now construction process has been implemented for the case study area to provide erosion protection to private and public properties along Collaroy-Narrabeen. This process has been led by Northern Beaches Council but has required joint agreement between NBC, NSW State Government and 49 private property owners.

Coastal protection works for Collaroy-Narrabeen has been a long studied and recommended action to protect property and infrastructure along the coastline. Many of the properties in the case study area have some form of coastal protection structure, either a formal engineered structure, or remnant ad-hoc rock armour from previous emergency stabilisation efforts (NBC, 2016). The majority of the structures are ad-hoc and cannot be certified. Figure 5.1 presents the location of known coastal protection structures in the study area prior to the June 2016 storm (NBC, 2016).

Figure 5.1: Location of known coastal protection structures in study area prior to June 2016 storm. Source: Figure 10 NBC (2016).

Over recent decades, there have been a number of proposals for a formal engineered seawall covering the whole length of the case study shoreline but none proceeded for a combination of reasons including cost of the works, concerns surrounding impact on beach amenity and other community opposition. Most notably in 2002, a protest was held on the beach along the entire length of the proposed seawall being planned at that time. The severe impact on Collaroy-Narrabeen from the June 2016 storm and the certification of the Coastal Zone Management Plan (CZMP) in late 2016 (NBC, 2016) subsequently provided the context for an engineered response to coastal erosion for the study area.

The CZMP seeks to protect and preserve the beach environment, ensure public access and manage current and future impacts from coastal hazards. The CZMP identified that over a planning period to the year 2100, sea level rise in combination with storm erosion would result in the coastal hazard area extending to Pittwater Road for many locations within the study area. In conjunction with the CZMP, a coastal protection assessment for Collaroy-Narrabeen was completed by Manly Hydraulics Laboratory (MHL) in December 2016. Included in that study were recommendations for an integrated alignment of protection structures as illustrated in Figure 5.2, and concept designs for coastal protection of council and crown land properties in the study area as illustrated in Figure 5.3.

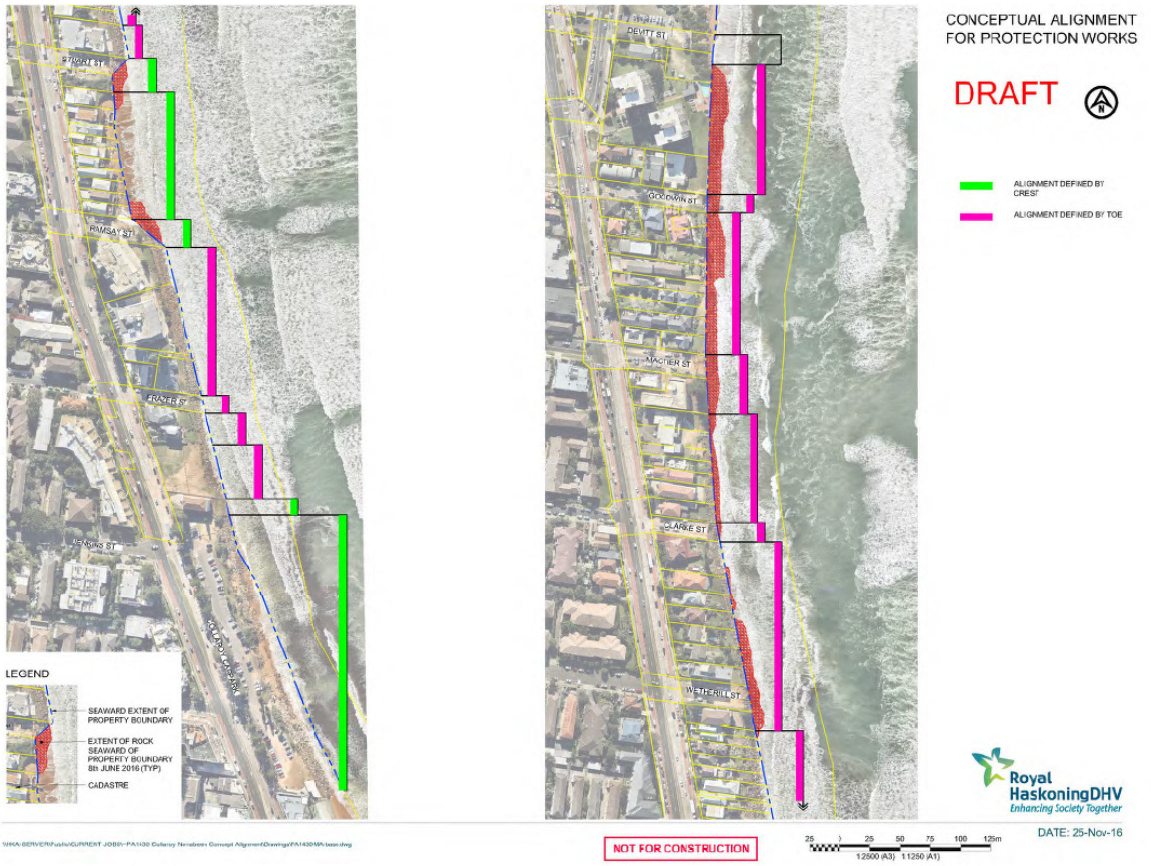


Figure 5.2: Recommended alignment of protection works for Collaroy Narrabeen (Royal Haskoning, 2016).

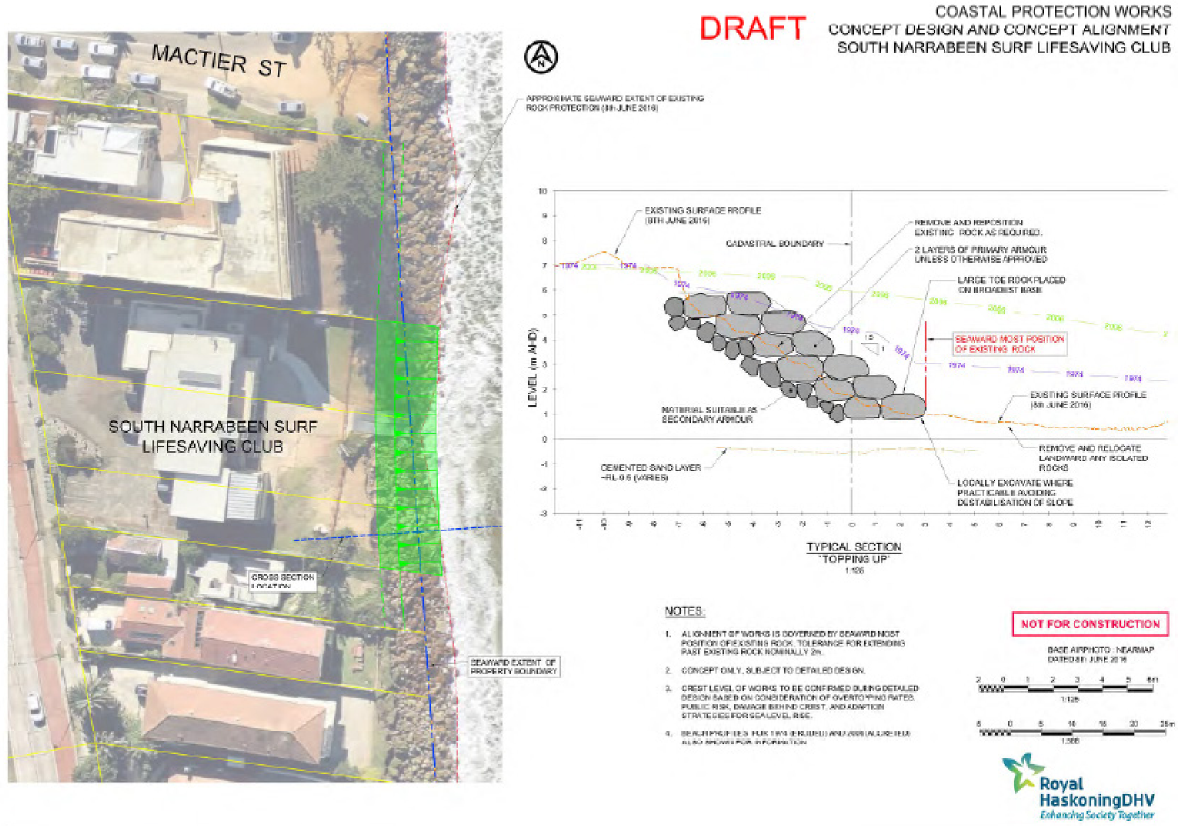


Figure 5.3: Concept design for seawall protection of South Narrabeen Surf Club (Haskoning, 2016).

Following the CZMP being adopted in December 2016 and certified by the Minister for Planning in April 2017, the planning, design and approval for coastal protection works in the study area have progressed in accordance with the planning framework outlined in Section 4. A novel aspect of this process is that development applications were prepared by groups of adjacent property owners located between the various roadheads along the study area. This combined approach was to support the construction of appropriate structures that met the requirements of the CZMP and other relevant documents. Collaroy-Narrabeen was the first coastal protection works of this type to proceed under the auspices of the new NSW Coastal Management Act and has required property owners, local government and state government to coordinate in a way different from previous concepts. Groups of owners submitting DA's (see Table 5.1) have had to form legal companies in-order to tender and construct the works.

Adjacent property owners between roadheads working together in a coordinated manner, rather than taking a piecemeal approach, has the advantage of achieving a contiguous alignment for the works, mitigating 'end effects' to adjacent land, reducing the impacts of the works on the public beach, and reducing costs to property owner (avoiding for example the need for multiple returns at individual property boundaries and enabling sharing of mobilisation/demobilisation costs of construction plant). Council has also worked closely with the individual groups of residents to resolve the design and construction of the works at the boundaries between private land and roadheads.

To date, NBC has approved seven Development Applications for coastal protection works that include private property and cover 28 of the 49 properties (total) that are proposed to be protected by the structure(s). Table 5.1 presents a summary of the five development applications that were reviewed in this case study with details on the approximate structure length and construction cost listed in the development application. The approved DA's include various designs, that conform with the integrated alignment that was specified in the CZMP. Figure 5.4 is an example structure section from the approved plan covering the properties 1154 to 1166 Pittwater Road.

The majority of the funding for the protection works will be borne by property owners (80%) with NBC and the NSW Government funding 10% each for the works. The construction cost summary in Table 5.1 is specified for the case study area and its site conditions and available construction materials. However, the range in unit cost (per metre) of the protection works from $8,400 per m to $36,500 per m provides a reasonable assessment of the cost range for major coastal protection structures to protect against erosion and inundation on the open coast. It is noted that the higher unit costs in Table 5.1 correspond to the construction of new coastal protection works comprising vertical piled structures incorporating permanent ground anchors whereas the lower unit costs correspond to either upgrading of existing rock revetment structures or construction of new rock revetment structures.

Table 5.1: Summary of coastal protection Development Applications in the study area approved by NBC.

Structure Extent	Sea Wall Value (DA) ($ AUD)	Approval Year	Adjusted Value 2020 ($ AUD)	Length (m)	Cost per metre ($ AUD)
1174 to 1182 Pittwater Rd	$1,969,472	2020	$1,969,472.00	76	$25,914
1154 to 1166 Pittwater Rd	$2,876,387	2019	$2,846,605.60	78	$36,495
1126 to 1154 Pittwater Rd	$1,708,739	2018	$1,719,231.26	176	$9,768
1122 Pittwater Road	$521,840	2020	$521,840.00	45	$11,596
1114 to 1118 Pittwater Rd	$483,577	2019	$478,570.16	57	$8,396
				Average	$18,434

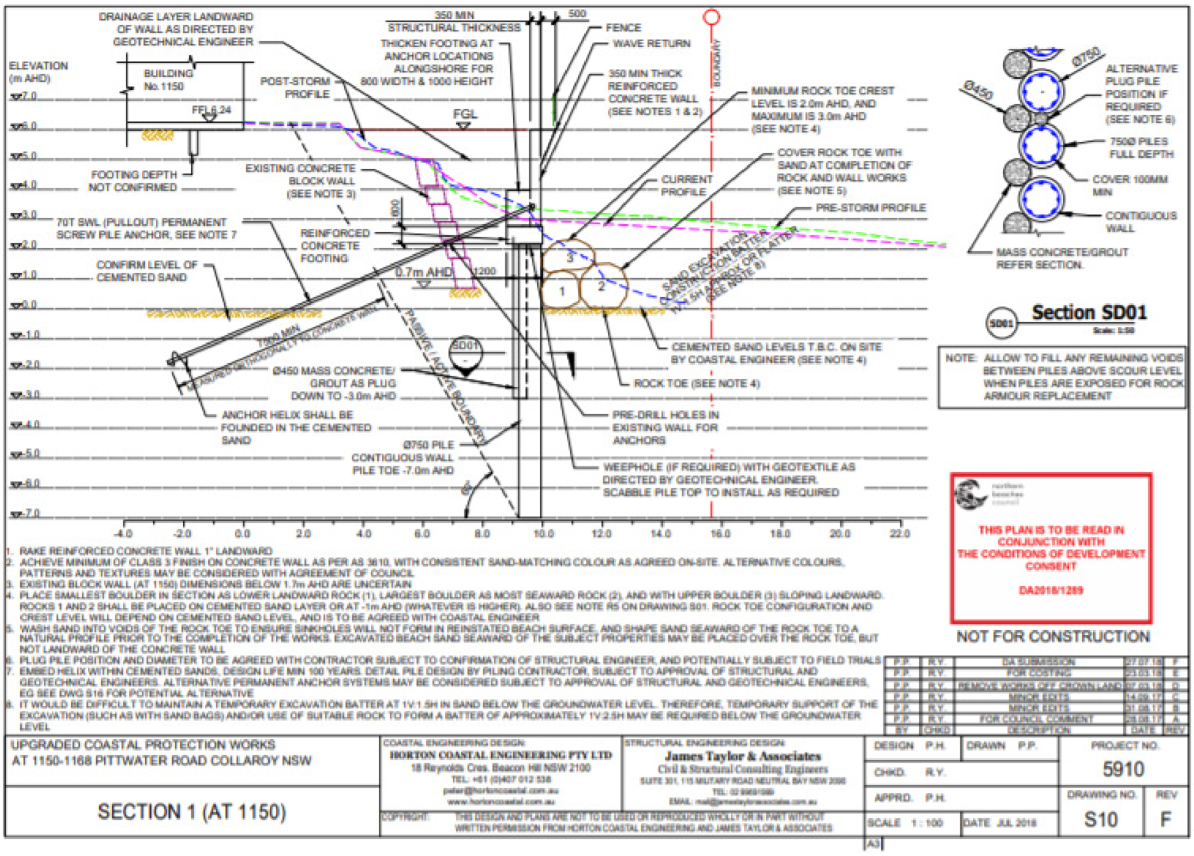


Figure 5.4: Example structure section for DA2018/1289 covering 1154 to 1166 Pittwater Rd.

Construction of coastal protection works commenced with works on public lands in 2019 in front of the major carpark at Collaroy Beach (comprising a new rock revetment). Works protecting some private property owners commenced in 2021 (vertical wall) as shown in Figure 5.4. The total cost of the coastal protection works in the case study area is projected to be $24.85 million and the average cost to property owners will be $282,000 (SMH, 2021).

Figure 5.5: Example construction of the coastal protection works covering 1154 to 1166 Pittwater Rd, February 2021 (Source: SMH 2021, James Brickwall).

6. Economic Analysis

As a part of the case study, Rhelm has undertaken a preliminary economic analysis for the case study area. This assessment has been undertaken to provide an understanding of the typical order of magnitude losses associated with coastal events within the case study area. The analysis has only focused on the reduction in damage to property and did not consider wider community or environmental factors.

6.1 Study Area

For the purposes of the analysis, a sub-set of the wider case study area was adopted. The assessment has been completed for the properties that were most impacted from the storm between Ramsay Street to Stuart Street. These properties did not have any formal engineered coastal protection measures at the time of the June 2016 event, nor any ad-hoc protection measures, and therefore are a good representation in the study area of unmitigated coastal erosion and damage.

An aerial overview of the case study area, both before the 2016 event and after the 2016 event, is shown in Figure 6.1. The erosion in the 2016 event was roughly to the seaward edge of the building footprint for most of these properties, with significant loss of seaward garden areas and some structures including decks, pergolas, sheds, fences and a swimming pool.

While reviews were undertaken on development application information in the public domain and other sources, there was limited information on the magnitude of actual building and garden damage for individual properties from this event. Therefore, we have used a range of sources to undertake this representative economic assessment.

Figure 6.1: Economic Case Study Area

6.2 Erosion Extents

Figure 6.1 shows the extent of the erosion that occurred during the June 2016 event. Roughly, the extent of the observed erosion corresponds to Council's planning minimum setback line – where protective works are required.

The following key assumptions in regards to the frequency and extent of erosion were adopted:

- The 2016 event roughly correlates to a 2% AEP event;
- Council's planning layer for the piled foundation (purple line in Figure 6.1) is roughly a 1% AEP event; and
- That there would unlikely be any damage to the pre-2016 property in the 10% AEP event (i.e. the erosion limit would be seaward of the property boundary).

6.3 Scenarios

In order to undertake the economic assessment, scenarios need to be defined against which benefits and costs can be compared. There are two scenarios considered in this analysis:

- Base Case Scenario – under this scenario, it is assumed that no coastal protection works are in place. The owner would be required to undertake repairs to their land and building whenever an erosion or inundation event occurred. It should be noted that in reality Council's policies would likely require the construction of coastal protection works and piled foundations for the building once major damage had occurred and a development application for redevelopment was required. However, for the purposes of defining a comparative base case, we have assumed that this would not be undertaken.
- Sea Wall Scenario – under this scenario, the property has a sea wall constructed at the start of the economic assessment period.

A coastal retreat option was also considered (where the property owners abandon their properties after a major event). However, given that there is no long-term recession (apart from that related to projected sea level rise associated with climate change), this was considered to be an extreme option for consideration.

6.3.1 Key Assumptions

The following key assumptions have been made:

- Discount rate of 7%; and
- Economic Assessment period of 50 years.

The impact of sea level rise has not been considered in this assessment. For the base case, sea level rise will cause a recession of the shoreline and increase the likelihood of erosion and inundation in the future. As a result, this economic assessment is a low range assessment of the future average damage costs.

6.4 Damage Estimates

There are three key damages to the properties that have been considered:

- Erosion of the land;
- Undermining of the building from erosion, and damage or loss of that building; and
- Inundation impacts to the building.

6.4.1 Damage to Land

For each of the properties, an estimate of the likely costs associated with reinstating the properties has been made. This has been undertaken using a range of cost assumptions, as summarised in Section 6.7. Fence areas, patios etc were estimated based on aerial imagery.

The depth of fill to reinstate the property was assumed to be approximately 2.5 metres. This is based on the information included in this case study as well as a comparison of 2011 and 2020 LiDAR data in the area.

The cost to reinstate the land has been estimated under the 2016 event (representing an approximate 2% AEP event), as well as the 1% AEP event. The storm erosion demand and Annual Exceedance Probability does not have a linear relationship; however for the purposes of this economic assessment a linear trend between the 10 % AEP and 2% AEP, and the 2% AEP and 1% AEP was assumed. An overview of the broad land re-instatement cost ranges are shown in Table 6.1.

Table 6.1: Land Re-instatement Costs, $ AUD.

10% AEP	2% AEP (2016 event)	1% AEP
$0	$20,000 - $40,000	$60,000 - $95,000[1]

6.4.2 Damage to Buildings

The types of buildings within the study area are highly variable. Rather than attempt to quantify the value of the individual buildings/dwellings in the study area, representative buildings/dwellings have been adopted based on information contained within Rawlinsons (2019). This cost estimation guide provides some useful benchmarks in terms of building costs. It was assumed that it is unlikely that a package/project home would be developed in this area, and three categories of building/dwelling type were adopted.

In addition to the cost of the buildings/dwellings, any damage or loss of the building would have an associated loss to the building contents. Based on a review of DPIE (2005) residential damage guideline, together with some recent work in this area, the contents for a typical 220m^2 house have been estimated at roughly $108,000. This is consistent with estimates from Thomson et al (2021).

The combined value of the buildings is provided in Table 6.2.

In regard to the amount of damage to the buildings, the following key assumptions were made:

- For the purposes of this analysis, it was assumed that all buildings have conventional shallow foundations. Some buildings in the case study area are founded on piles and they will generally not have structural damage as a result of erosion, provided the piles maintain load capacity.
- In the 2% AEP event (2016 event) it was assumed that structural damages may have been roughly 5% of the replacement value. This is based on anecdotal information of some damage to residential buildings (see Figure 6.2). For events more frequent than this, no damage was assumed.
- Assume that the building would be completely lost (i.e. require replacement) when more than 20% of the building is undercut. This corresponds, based on an interpolation, to an event of 1.7% AEP.

Table 6.2: Assumed Building Values, $ AUD.

Medium Finish	High Standard	Prestige
$604,500	$800,800	$1,023,000

[1] One property, with an customised swimming pool, was estimated to be closer to $140,000 for the 2% AEP and nearly $200,000 for the 1% AEP erosion event.

Figure 6.2: Example of erosion around building foundations following June 2016 storm (Source: https://newsroom.unsw.edu.au/news/science-tech/danger-extreme-storms-and-high-seas-rise).

6.4.3 Inundation of Houses

In large coastal events, in addition to the erosion and loss of land, inundation due to wave runup and overtopping can occur.

There is a reasonable amount of literature and guidance on residential flood damage curves. These relate overfloor flooding depth to the expected damage (refer Figure 6.3). However, in a coastal application the damage can vary to that of riverine flooding. Primarily, this is due to the wave action, which is not a relatively constant level of water applying at multiple entry points, but rather wave action that applies primarily to the seaward side of the dwelling. This may result in not all of the ground floor of a property being inundated, for example, and may only affect a portion. It should be noted that inundation of property from seawater due to its salt content can cause more damage than freshwater flooding.

DPIE have recently been reviewing the flood damage curves for residential properties. The draft damage curves which are to be provided in upcoming guidance were presented in Thomson et al (2021). These curves estimate a damage at 0.25 metres of overfloor flooding of around $150,000 for a single storey dwelling and around $90,000 for a double storey dwelling. On this basis, a mid-range value of $120,000 has been adopted to represent shallow overfloor inundation from coastal action.

Note that this assssment is for a “representative” house based on the revised damage curves. As a consequence it has been assumed that this is representative of a Medium Finish building (Table 6.2), and scaled the damage up based on the replacement value for High Standard and Prestige. This assumes that the contents value of the house is directly proportional to the value of the building.

The inundation is unlikely to impact the entirety of the dwelling as the wave overtopping is episodic and only persists for a few minutes at a time and the property is generally only exposed to inundation on the ocean edge of the building. For the purposes of this analysis, it has been assumed that up to 20% of the inside of the building might be affected for an inundation event (potentially one or two rooms). On this basis, the approximate damage would be around $24,000 to $40,000 depending on the value of the house.

In regard to the events at which inundation occurs, the following assumptions were made:

- No inundation up to the 10% AEP event, being the event at which erosion starts to occur;
- A linear increase in damage up to the 2% AEP event at $24,000; and
- No inundation damage is incurred after the building has been deemed to have failed (and need replacement) – i.e. the 1.7% AEP event.

6.5 Base Case Results

Based on the above key assumptions, the Annual Average Damage (AAD) was calculated for each of the properties and is summarised in Table 6.3 across the properties in the case study area.

The majority of the AAD for land repair was in the order of $1,800 to $2,500, although there was a higher value associated with a property that had a swimming pool.

The inundation damage value is relatively low. It is possible that the method for estimating the inundation damages under-estimates the total damage. Further information would be required to understand "true" inundation damages from insurance claims or similar to refine this estimate.

The building damage AAD is entirely a function of the building replacement cost. It is representative of the AAD that might be expected under a range of different building types that might be encountered. In many cases, customised/architecturally designed homes that might be expected in the case study area may exceed the estimated value of the buildings adopted for this assessment.

In this case study area, the building damage AAD is bulk of the overall damages. In other areas, this may change if the building were set further back and experienced erosion in less frequent events.

Land costs increase if there are higher value assets within the property, such as swimming pools. The maximum value in this instance is due to a property with a high value pool (approximately $100,000). Similar other high value assets within this erosion zone would influence the AAD of the land repairs.

The total AAD is in the order of $14,000 to $30,000 for these properties. If insurance were available for the land area, then insurance premiums would be in excess of these values. This suggests relatively high ongoing costs and affordability issues for these properties.

Using the AAD information, the present value across the properties was estimated, and is summarised in Table 6.4. This suggests that the total damage ranges from around $195k to $420k in present value terms. Relative to the typical house prices in this area, this is a range of around 5% to 10% of the property price.

The Annual Average Damage methodology provides an understanding of the most likely annualised damages that would likely be experienced. However, in the case of the building damage, and in particular, the complete building replacement, this is a very large cost that occurs in the estimated 1.7%AEP. Unlike traditional flood damage calculations, where the damage may increase as the event becomes rarer, this "catastrophic" failure of the building results in a very large cost that is not spread out in the same way.

From a risk perspective, a cost of around $600,000 to $1,000,000 per property may be incurred for a singular erosion event of 1.7% AEP or rarer.

Table 6.3: Annual Average Damage Ranges ($, AUD)

Range	Land Repair	Inundation	Buildings	Total AAD
Median	$2,100	$1,400	$15,000	$18,600
Minimum	$1,800	$1,000	$11,300	$14,200
Maximum	$9,300	$1,700	$19,200	$30,300

Table 6.4: Present Value of Damages for Properties ($, AUD)

Range	Land Repair	Inundation	Buildings	Total	% of Property Value[2]
Median	$28,700	$18,700	$207,500	$256,400	6.3%
Minimum	$24,800	$14,100	$156,600	$195,500	4.8%
Maximum	$128,600	$23,900	$265,000	$417,500	10.2%

6.6 Sea Wall Scenario Results

The construction of a sea wall seeks to provide protection to the properties within the study area. For the purposes of this analysis, it was assumed that the sea wall effectively prevents all erosion and inundation of the building.

Based on the rates provided in Section Table 5.1, the sea wall costs range from about $240k through to $380k, based on the length of the beach frontage of the property[3]. Using this, and an assumed maintenance cost of 3% of the capital cost, the costs of the sea wall can be compared with the relative benefit of the protection provided. These results for the properties are summarised in Figure 6.4. Generally, the BCR is about 0.8 for a medium dwelling, just over 1.0 for a high standard dwelling and just under 1.3 for a prestige dwelling. These are likely to be conservative estimates of the BCR, given the narrow focus of the assessment (for example, the exclusion of any intangible damages). However, the result indicated that the cost for a seawall engineered to protect an open coast property for at least the 1 in 100-year ARI erosion event is only economic for property owners of high-value prestige properties.

The outlier BCR identified on the figure is due to a much larger property (in terms of land area). It is likely that a larger dwelling would be constructed on this land, which has not been accounted for in this analysis.

From an affordability perspective, the cost of the sea wall has been compared to the estimated property price. The sea wall, for these properties, is estimated to be around 4 to 5% of the property price (as of May 2021).

[2] Using realestate.com.au, and estimating the price per m2 of land for the case study properties. Typical property prices or the case study area are estimated at $4.1M, as of May 2021.

[3] No residual value is assumed for the sea wall. It is assumed that the service life is around 50 years, and that there would be no significant rehabilitation required beyond the assumed annual maintenance cost over this period.

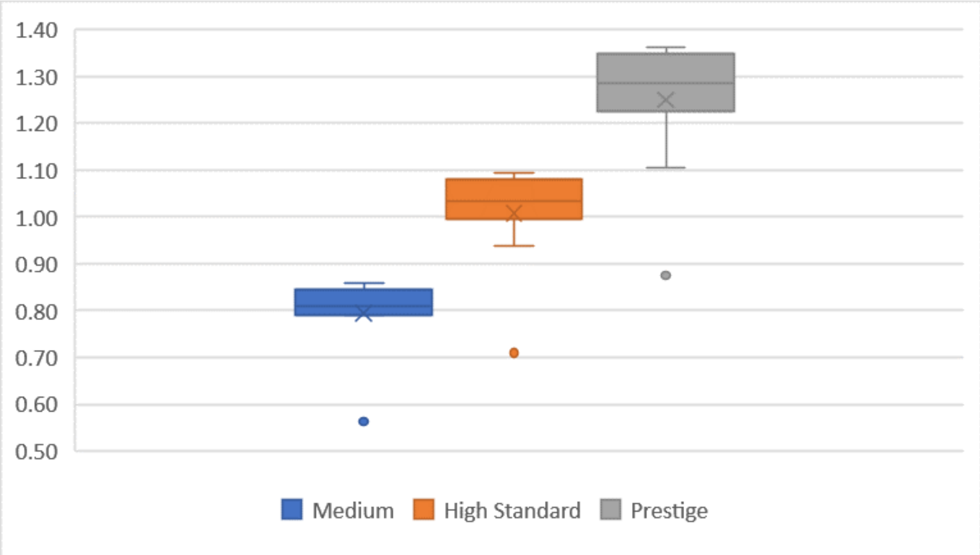


Figure 6.3: Sea Wall Scenario BCR Results

6.7 Retreat

An alternative approach to building a sea wall, or constant repair of a property, is a retreat option. Under this option, the owner would "give up" or "retreat" from the property once the erosion becomes too significant. It generally assumes that the owner would not undertake any mitigating actions (such as reinstating land). Retreat is sometimes considered as a potential option when there is coastal recession.

This was not included as a base case for the case study, as it was considered not to be reflective of current management strategy as outlined in the CZMP (NBC, 2016). As can be seen by the previous erosion events, owners and the government have undertaken various mitigating measures (such as sea walls) in order to protect their properties and Council and residents are currently constructing the large seawall described in Section 5.

However, to provide an understanding of the potential cost implications, a brief review was undertaken on the economic cost associated with retreat.

The key is the trigger point at which a property would be abandoned. For this particular case study, this may be around the 1.7% AEP, when the damage to the building structure is sufficient for the structure to require replacement. This has been assumed for the purposes of this calculation.

In events more frequent than this, with erosion of land, there may be some reduction in property value. Around 20 – 30% of the land area would be lost between a 10% and 2% AEP event, based on the assumptions in this report.

On this basis, the AAD is estimated at around $102,000 (May 2021, with a present value of $1.4M (May 2021). which is significantly higher economic cost than the base case (Section 6.5) and the seawall scenario (Section 6.6).

However, as with the building replacement, the loss of the land (via retreat) represents a significant economic cost. From a risk perspective, there is a 1.7% AEP chance that the complete loss of the property would be incurred under this scenario. That represents a significant financial cost, as well as having significant indirect and intangible costs which have not been quantified here.

6.8 Qualifications and assumptions

The above information has been prepared on the basis of the following:

- The cost and damage estimates are based on available literature and cost guidelines. No specific quantity surveyor estimates have been sourced, nor have the estimates been verified against actual insured losses which were not available for this assessment.
- These losses should be considered order of magnitude estimates, and should not be used for any financial decisions.
- The findings and any estimates which have been provided are presented as estimates only and are based on a range of variables and assumptions. The report was prepared on the dates shown and is based on the conditions encountered and information received at the time of preparation. Rhelm disclaims responsibility for any changes that may have occurred after this time.
- In this report, Rhelm or Baird does not purport to give or provide financial advice, financial modelling or forecasting. Nor does it give legal advice. Appropriate specialist advice should be obtained where required.
- Third parties should make their own inquiries and seek advice in relation to their particular requirements and proposed use of the report subject matter. To the extent permitted by law, Rhelm or Baird expressly disclaims and excludes any liability for any loss, damage, cost or expenses suffered by any third party relating to or resulting from the use of, or reliance on, any information contained in this report.

7. Conclusions and Recommendations

7.1 Conclusions

A brief summary of key conclusions from this case study are summarised below.

7.1.1 2016 Event and Actions of the Sea Impacts on Study Area

The June 2016 East Coast Low represented a significant coastal storm along the NSW coastline and in the context of the study area, represented a 50-to-60-year ARI (return period) event with respect to total wave run-up level. The large north-easterly offshore waves in combination with a high-water level, resulted in the highest coastal water levels and wave runup levels at Collaroy Narrabeen since May 1974. The return period of the wave runup levels in the study area are well correlated with the observed erosion which is also an approximate 50-year event in the study area and the most significant erosion event since May 1974.

Flood inundation of property in the study area would have been dominated by short duration, episodic flows from wave runup and overtopping of the eroded shoreline. The nature of flooding from wave runup and overtopping is significantly different to sustained inundation of property because of riverine or stormwater flooding. However, it should be noted that flooding from seawater can cause more damage than freshwater flooding.

The extent of impact on property from erosion was best identified from high resolution aerial photos collected within two days of the event. The imagery provided a reliable basis to identify different levels of property impacts as presented in Section 3.4. Historical satellite imagery can broadly identify locations which may be susceptible to erosion, however the historical data set of high-resolution imagery is insufficient to define hazard area. Based on this case study, focusing on defining extreme storm wave runup levels at particular sites, and assessing those levels to the ground elevations provides a reasonable basis to identify locations at risk of erosion and/or flooding from wave dominated processes. Impacts for individual properties can only be assessed if the foreshore conditions and presence of coastal protection structures are known. In the case study area, properties with some form of coastal protection from either engineered structures or remnant structures from earlier emergency works generally had significantly reduced erosion impacts on their properties.

7.1.2 Planning Framework and Engineering Responses

This storm event coincided with the advent of NSW's long awaited Coastal Management Act which provided an updated policy and planning framework for coastal management. The planning framework for the study area seeks to balance the needs of the community and the ability for property owners to protect their homes, whilst ensuring the majority cost of coastal protection is borne by the beneficiaries of the protection. This case study has shown whilst on-the-ground coastal protection can be implemented with conditions to protect environmental and community values, the approval timeframe can be long (2-3 years) and construction of works is expensive and subject to unique legal complexities as property owners jointly fund and oversee construction of protection along a number of properties.

The long-term plan to balance needs between protection of property, and community and environment values is not yet resolved. With future storms and accelerating sea level rise, additional management and engineering responses will be required in the study area. Ensuring beach amenity with future sea level rise may require long-term beach nourishment which will have considerable cost.

7.1.3 Economic Impact Assessment

The economic impact assessment has highlighted the property damage costs from three different factors: loss of land from erosion, damage to structures from erosion and damage from inundation of homes. The economic costs over the long-term from erosion damage to structures are significant. Whilst the damage impact from storms less than 50-year ARI return period is relatively low, the potential damage from a 100-year ARI event is significant and may require a complete re-build of a property. The information in the economic assessment will provide the insurance sector an insight into the potential cost of covering some, or all actions of the sea as part of general property insurance.

The economic assessment of the seawall being constructed in the study area, which only assessed property protection, indicates that the overall economic metrics for the seawall are neutral. However, the seawall provides significant protection for the 100-year event which would be expected now to cause substantial structural damage. The overall cost of protection for each property owner covered by the seawall is approximately $230,000 (based on information in submitted Development Applications). This is a substantial capital cost and represents 4-5% of current property values in the study area (as of May 2021). For areas with low property values, the cost of coastal protection can become unfavourable from an economic and investment perspective as the cost of coastal protection is relatively independent of property value.

7.2 Recommendations

This case study has highlighted the range of impacts that can occur from wave dominated actions of the sea on residential property. Recommendations from this study include:

- High resolution aerial images and LiDAR survey immediately post-storm provide the most reliable way to quantify storm erosion and potential impact to property. The insurance industry should liaise with government agencies to establish comprehensive post event data capture programs focused on those data types.
- Information on formal or informal coastal protection structures for individual properties is valuable to assess vulnerability of individual properties. The insurance industry should liaise with local and state government agencies to establish regional and state-wide data bases on coastal structures. The data base should also include information on the foundations for beachfront building structures as the type of building foundation, for example whether shallow footings or piles, is also important in the assessment of the vulnerability of individual structures.
- The planning framework for the study area has demonstrated that property owners, at least in NSW, are able to undertake works to reduce the vulnerability of their properties to erosion and flooding from actions of the sea. However, the Collaroy-Narrabeen example highlights the complexity, time and costs incurred under the current planning and legislative arrangements. The insurance industry should be involved in wider stakeholder discussions with all levels of government regarding simplifying the process to achieve risk mitigation from actions of the seas and increasing flexibility to address current hazards and manage transition to future conditions where sea level rise may reduce the sustainability and/or effectiveness of particular risk mitigation measures.
- The impact on beach amenity and community access to the beach as a result future sea level rise in-combination with continued storm erosion events has not been resolved for Collaroy-Narrabeen. The seawall currently being constructed has been design for sea level rise impacts over a 60-year design life but to maintain beach amenity and community access over the design life may require significant sand nourishment. The development approvals for the seawall provide a time-limited consent for the structure and terms that make property owners potentially responsible for funding beach nourishment in the future. The ICA should engage with state and local governments, and the community, to define trigger points for future mitigations against sea level rise and continued erosion and assess the feasibility of proposed works considering financial (economic), environmental and social factors.

- To assess hazard to actions of the sea for open coast properties such as the case study area, the insurance industry should focus on compiling high-resolution data sets for water levels, near-coast extreme waves, shoreline elevation and erodibility potential to define wave runup potential and the likelihood of erosion. Recently available historical satellite image analysis techniques, for example CoastSat (Vos *et al,* 2019) provide quantitative methods to assess the erodibility of shorelines, but those methods are not yet developed enough, nor have long term data, to assess actual storm erosion extents.

8. References

Baird Australia. (2017). NSW Coastal Wave Model: State Wide Nearshore Wave Transformation Tool. Prepared for the Office of Environment and Heritage, NSW. Report Ref: 12359.101.R2.Rev0. Available at: http://www.environment.nsw.gov.au/resources/coasts/nsw-nearshore-wave-transformation-tool-report.pdf

Baird (2021). Actions of the Sea Data and Knowledge Development: Technical Report. Prepared for the Insurance Council of Australia. Final Report. Ref: 13465.101.R4.Rev1.

Bureau of Meteorology (BoM). (2016). Special Climate Statement 57—extensive early June rainfall affecting the Australian east coast. Date of issue: 17th June 2016.

Bureau of Meteorology (2016). Analysis Chart Archive. http://www.bom.gov.au/australia/charts/archive/

Burston J., Taylor D., and Garber S., (2016). Contextualising the Return Period of the June 2016 East Coast Low: Waves, Water Levels and Erosion. Proceedings of the NSW Coastal Conference, 2016.

Department of Environment and Climate Change [DECC] (2007) *Floodplain Risk Management Guideline - Residential Flood Damages*, Revision 1, October.

Department of Justice NSW (2016). State Recovery Co-ordinator Report: June 2016 East Coast Low. State Recovery Co-ordinators Report.

Kinsela, M., Taylor, D., Treloar, D., Dent, J., Garber, S., Mortlock, T., & Goodwin, I. (2014). "NSW Coastal Ocean Wave Model: Investigation Spatial and Temporal Variability in Coastal Wave Climates. 2014 NSW Coastal Conference, Ulladulla, November 2014.

MHL (2016). Collaroy Narrabeen Beach Coastal Protection Assessment. Prepared for Northern Beaches Council by Manly Hydraulics Laboratory.

NBC (2016). Collaroy-Narrabeen Beach and Fishermans Beach CZMP. Prepared by Royal Haskoning for Northern Beaches Council.

Nielsen, P., & Hanslow, D. J. (1991). Wave runup distributions on natural beaches. *Journal of Coastal Research* Vol 7: 1139-1152.

Nielsen, AF; Lord, DB and HG Poulos (1992), "Dune Stability Considerations for Building Foundations", *Australian Civil Engineering Transactions*, Institution of Engineers Australia, Volume CE34, No. 2, June, pp. 167-173

SMH (2021). Construction begins on northern beaches sea wall despite 'vexed' funding issues. Written by Sarah McPhee, 25 February 2021. https://www.smh.com.au/environment/sustainability/construction-begins-on-northern-beaches-sea-wall-despite-vexed-funding-issues-20210223-p5754a.html

Rawlinsons (2019). Construction Cost Guide 2019, Edition 27, Rawlinsons Publishing.

Royal Haskoning (2016). Collaroy-Narrabeen Coastal Protection Works: Concept Design and Concept Alignment.

Turner, I., Harley, M., Short, A. et al. A multi-decade dataset of monthly beach profile surveys and inshore wave forcing at Narrabeen, Australia. Sci Data 3, 160024 (2016). https://doi.org/10.1038/sdata.2016.24.

Taylor, D., Garber, S., Burston, J., Couriel, E., Modra, B., & Kinsela M. (2015). Verification of a Coastal Wave Transfer Function for the New South Wales Coastline. Proceedings of Coasts and Ports 2015. Auckland, September 2015.

UNSW-WRL (2016). WRL coastal engineers document the worst erosion at Collaroy since 1974. https://www.wrl.unsw.edu.au/news/wrl-coastal-engineers-document-the-worst-erosion-at-collaroy-since-1974.

Appendix A

June 2016 East Coast Low Storm Data

A.1 Synoptic Charts - BOM

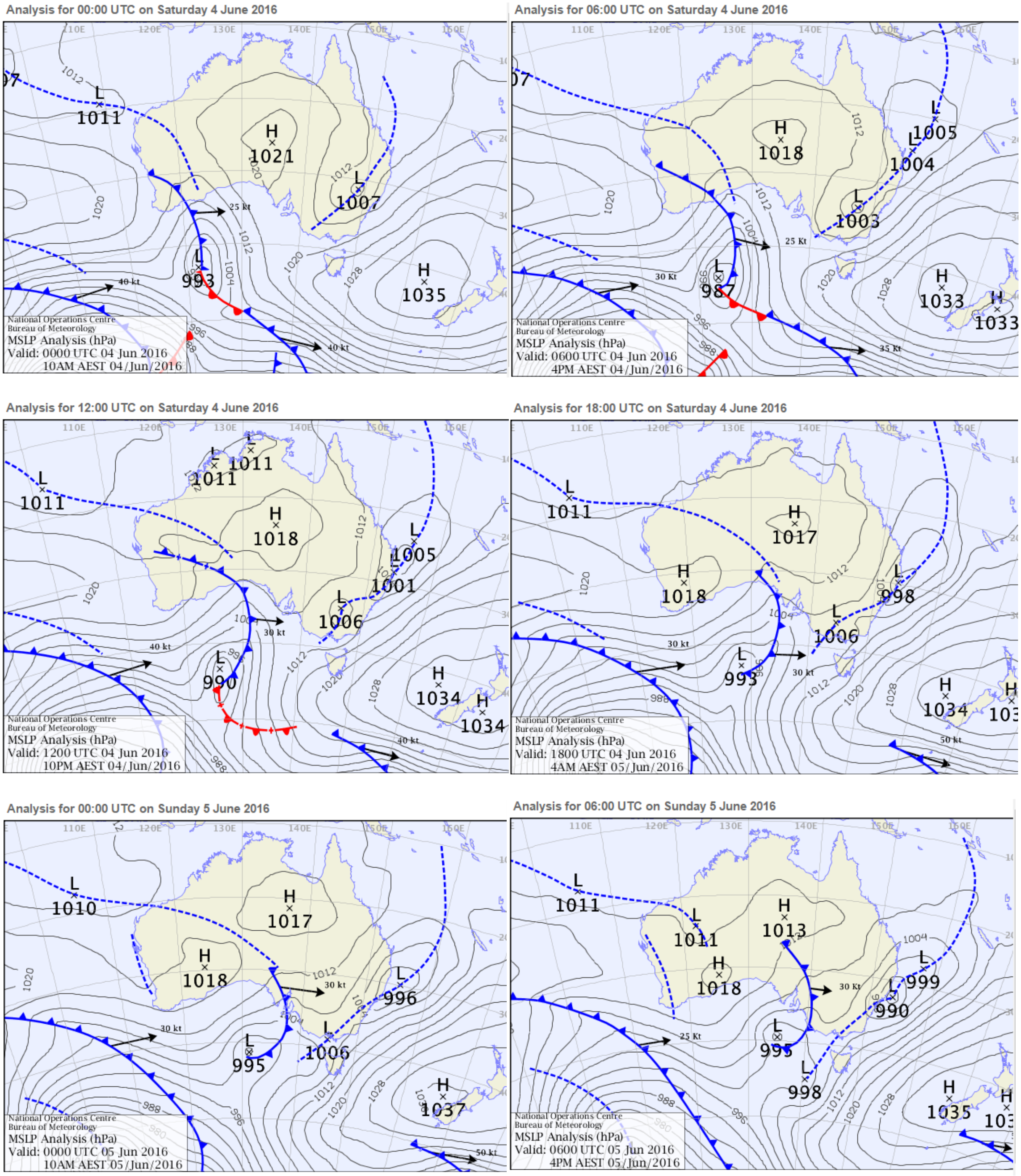


Figure A.1: Synoptic charts showing the progress of the east coast low southward along the eastern Australian seabord, 4th to 6th June 2016 (BOM).

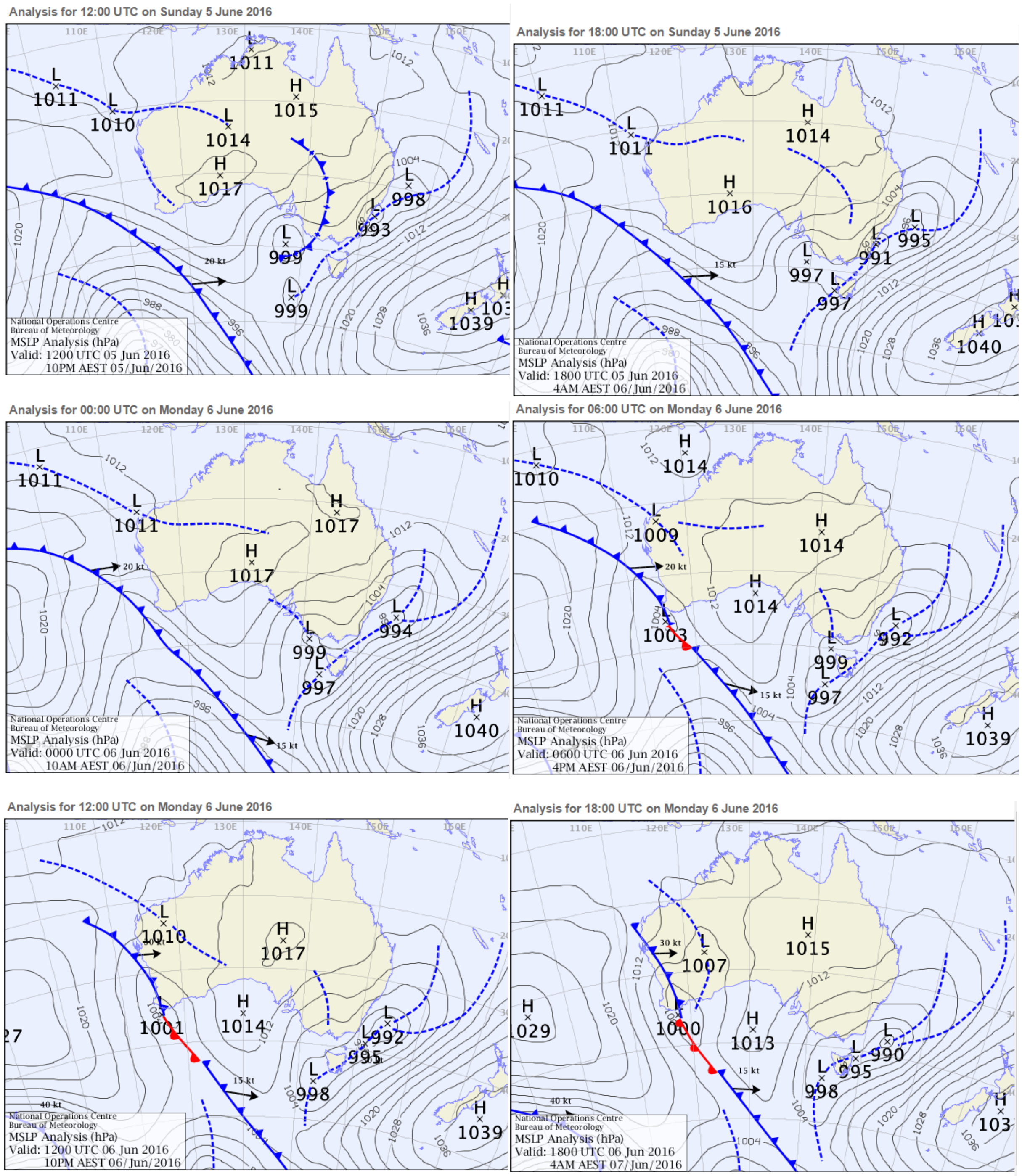


Figure A.2: Synoptic charts showing the progress of the east coast low southward along the eastern Australian seabord, 4th to 6th June 2016 (BOM).

Appendix B

Property Impact Assessment from Actions of the Sea

B.1 Impact Mapping

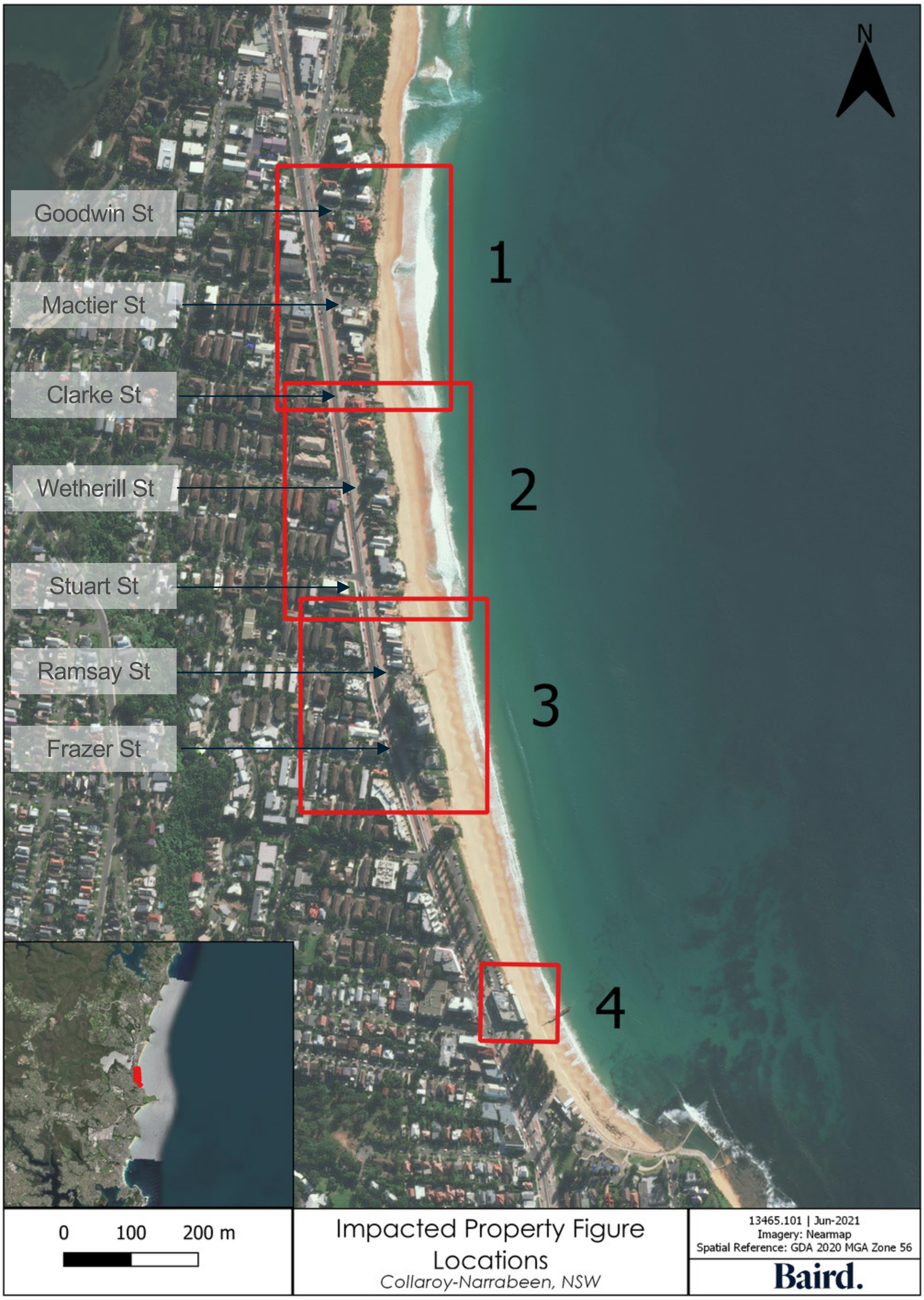


Figure B.1: Plan view of property impact assessment.

Figure B.2: Property impact assessment: Subarea 1.

Figure B.3: Property impact assessment: Subarea 2.

Figure B.4: Property impact assessment: Subarea 3.

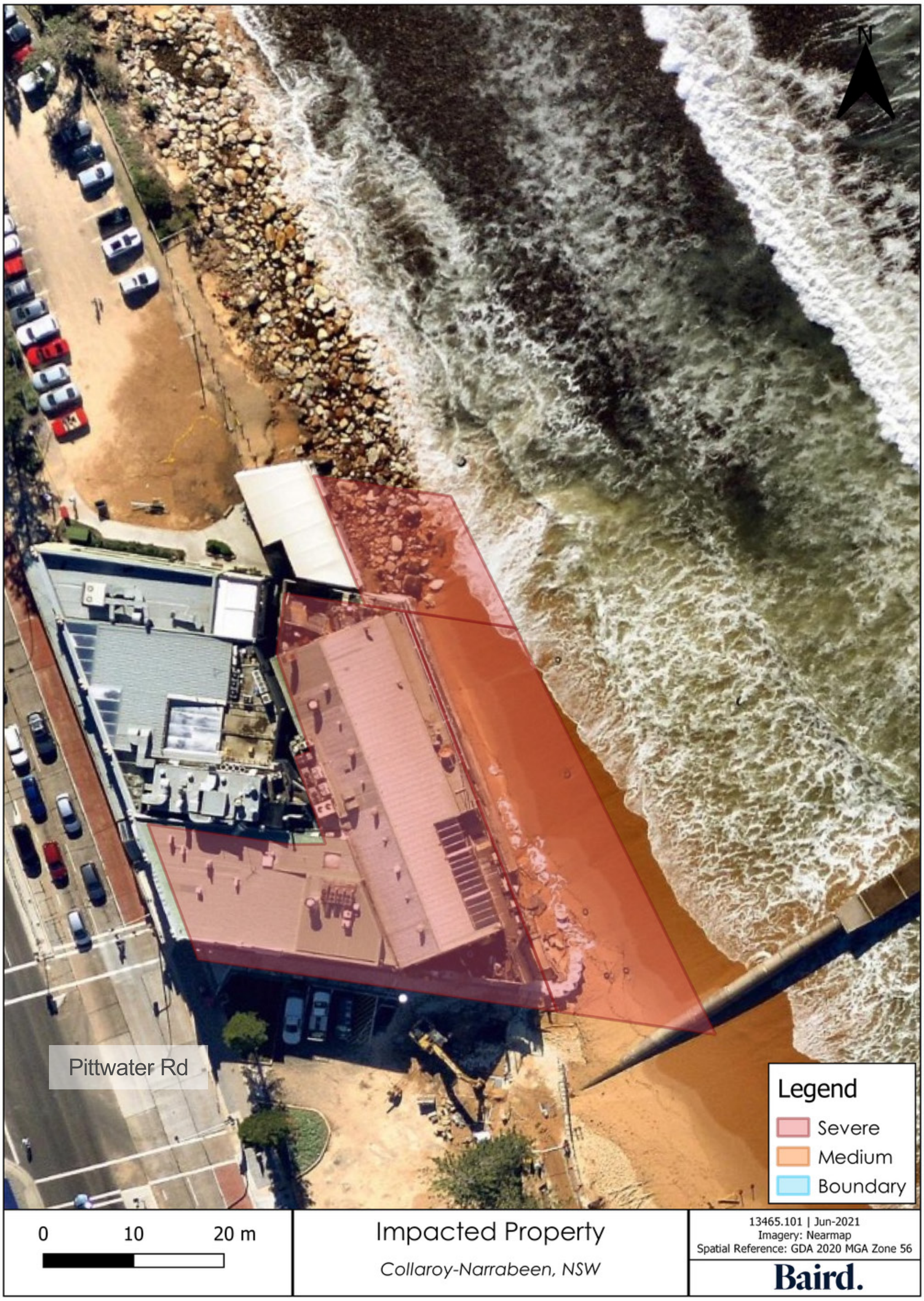


Figure B.5: Property impact assessment: Subarea 4.