# Risk Identification

## Princess Royal Harbour Coastal Hazard Risk Management and Adaptation Plan

CW1200123

Prepared for
City of Albany

5 December 2022

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## Document Information

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## Document History

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# Executive Summary

This report presents the Risk Identification for the Princess Royal Harbour (PRH) Coastal Hazard Risk Management and Adaptation Planning (CHRMAP), in accordance with the *CHRMAP Guidelines* (WAPC, 2019). The PRH CHRMAP is being developed in a staged approach, with various stages documented in standalone technical chapter reports. These reports are structured as follows:

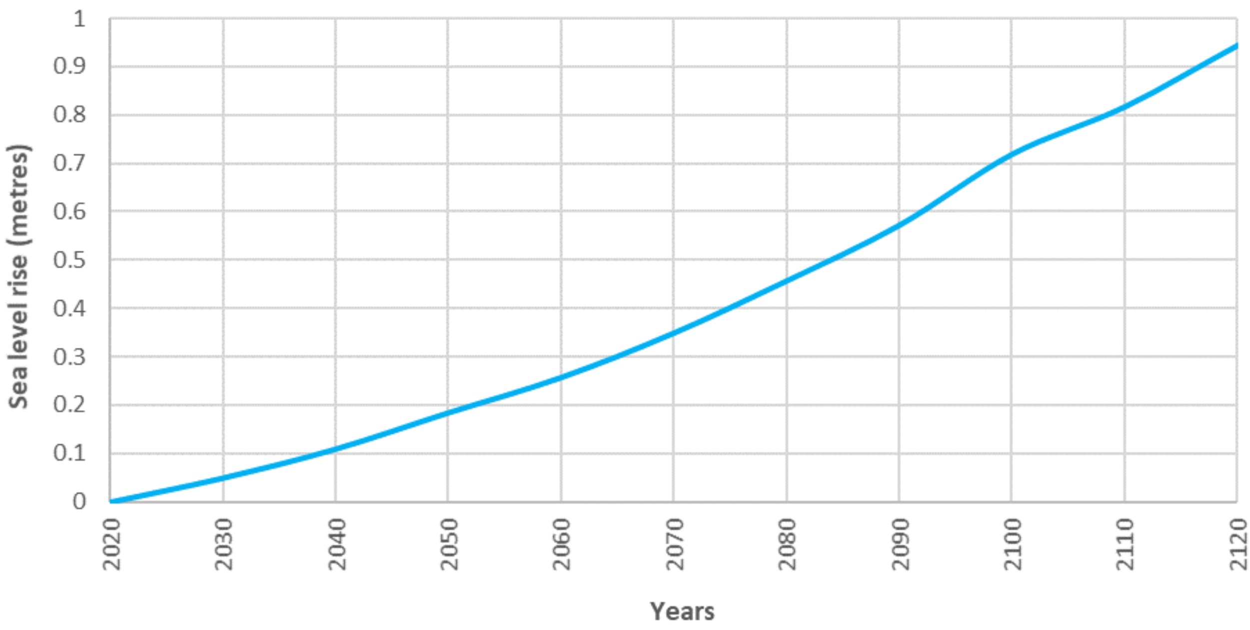
- Establish the Context: Stage 1 (Water Technology, 2022)
- **Risk Identification: Stage 2**
- Risk Analysis and Evaluation: Stages 3 & 4
- Adaptation Planning: Stages 5, 6 & 7
- Final CHRMAP.

The key purpose of this stage is to undertake the coastal hazard risk identification for present day (2022), 2047, 2072 and 2122 planning timeframes. This document also includes coastal hazard mapping and the identification of assets that may be impacted by coastal hazards over the next 100 years.

### Background

Globally, mean sea level (MSL) has risen since the nineteenth century and is predicted to continue to rise, at an increasing rate, through the twenty first century (Intergovernmental Panel on Climate Change [IPCC], 2021), bringing changes to the Western Australian (WA) coastline over the coming decades. To prepare for sea level rise (SLR) and related coastal hazards, such as coastal erosion and inundation, all levels of government are putting processes in place to ensure that communities understand the risks to values and assets on the coast, and to plan to adapt over time.

The PRH coastline features a mixture of sandy, rocky, and artificially hardened shorelines, with substantial intertidal areas and shallow seagrass assemblages. For sandy coastlines, increases in local MSL generally result in shoreline recession, with a conservative “rule of thumb” often used, that every 1 cm rise could result in 1 m of landward recession of the average shoreline position.




Projected sea level rise in Western Australia (based on DoT, 2009 & IPCC, 2021)

### Study Approach

The State Coastal Planning Policy (SPP2.6) provides guidance on the planning principles and guidelines required for coastal development in Western Australia. A key policy objective of SPP2.6 is the provision of a coastal foreshore reserve. The coastal foreshore reserve is essentially a 'space' between the ocean and private land. It should accommodate a range of functions and values such as geomorphological integrity, biodiversity, heritage, public ownership, and access.

The component of the coastal foreshore reserve to allow for coastal processes should be sufficient to mitigate the risks of coastal hazards by allowing for landform stability, natural variability, and climate change. The coastal foreshore reserve is a critical input into the coastal hazard risk management and adaption planning framework outlined in SPP 2.6. The assessment considers allowances for coastal erosion and storm surge inundation in parallel.

The natural coastline is, in general, very responsive to the climate and any changes that occur. The allowance for erosion on sandy coasts has been calculated as the sum of the S1, S2 and S3 Erosion allowances, plus a 0.2 m per year allowance for uncertainty:

- (S1 Erosion) Allowance for the current risk of storm erosion
- (S2 Erosion) Allowance for historic shoreline movement trends
- (S3 Erosion) Allowance for erosion caused by future sea-level rise

The erosion allowances have been applied from a horizontal shoreline datum (HSD), defined by the active limit of the shoreline under storm activity.

The allowance for the extent of coastal inundation has been calculated as the maximum extent of storm inundation during the 500-years average recurrence interval (ARI) storm event. This was defined as the peak steady water level, plus an allowance for wave set-up. An allowance for catchment inundation has also been provided, to account for freshwater runoff from adjacent land catchments. This was calculated using hydrological and hydraulic modelling to estimate the localised increase in water level at the major surface water discharge locations within PRH.

The hazard extents have incorporated projected sea level rise (IPCC, 2021) across each of the future planning horizons assessed, as presented in the table below.

Sea level rise allowances adopted for this study, with respect to 2022 (IPCC, 2021)

| Timeframe | Present day (2022) | 2047 | 2072 | 2122 |
|---|---|---|---|---|
| Sea Level Rise (m) | 0.00 | 0.15 | 0.35 | 0.94 |

To ensure a useful outcome from the CHRMAP with respect to the Port's maritime and coastal assets, an additional coastal hazard termed 'wave attack' has been incorporated in the study. Wave attack hazards have been calculated based on an estimate of changes to the assets underlying design basis, as a result of projected climate change effects. The changes in the underlying design basis have included consideration for metocean forcing and impact, including an assessment of the joint probability between wave and water level along the relevant sections of the PRH shoreline. The wave attack hazards provide an indication of what timeframe an asset might be considered 'under-designed'.

### Outcomes

A key outcome of the coastal hazard assessment was the confirmation that both coastal erosion and coastal inundation hazards are present along the PRH shoreline. The interpreted risk levels that will guide adaptation planning for future stages of the project will be governed by either the coastal erosion and coastal inundation extents, depending on the section of the harbour.

Erosion hazard extents have been calculated, comprising:

- S1 storm erosion allowances, calculated by transferring design storm conditions to the nearshore area and applying shoreline response modelling, as recommended in SPP2.6. The S1 erosion allowance was calculated at 20 cross shore profiles within PRH and 1 cross shore profile on the eastern side of the isthmus, which extends between the rocky outcrops of Quarantine Hill and Bramble Point. The allowances were relatively small within PRH, ranging from 0 m to 12 m, due to the protected wave climate and presence of long, shallow terraces along the PRH shoreline. The allowance on the eastern side of the isthmus was 30 m.
- S2 allowance for historical shoreline movement trends, which have been based on assessment of vegetation lines (where available/appropriate), and contextual chart data dated 1814. This allowance ranges from 0.0 to 1.1 m/year.
- S3 allowance for erosion due to future sea level rise, calculated using the formula stipulated in SPP2.6 (1 metre recession per 1 cm SLR). This component extends to 94 metres by the 100-year (2122) planning timeframe.
- An allowance for uncertainty of 0.2 m/year. Contributing 20 m to the overall extent by the ultimate planning timeframe.

Where shoreline controls such as seawalls and breakwaters exist, these structures have been incorporated in the erosion hazard extents for the anticipated design life of the structures.

Inundation hazard extents have been calculated, comprising:

- An allowance for extreme water levels attributed to the astronomical tide and inverse barometer effects, calculated based on an extreme value analysis of measured water level data between 1987 and present, within PRH.
- An allowance for wave set-up, which ranged between 0.1 m and 0.7 m, depending on incidental wave conditions and the slope and form of the nearshore seabed and shoreline.
- An allowance for catchment inundation to account for freshwater runoff from adjacent land catchments. The allowance for catchment inundation was found to be relatively minor, in the order of 0.02m, and highly localised to the discharge locations.

Wave attack hazard extents have been calculated, comprising:

- Estimates in changes to the contextual design basis for the Port's coastal and maritime infrastructure. The wave attack hazards show that projected climate change effects including an increase in MSL, and minor increases in Southern Ocean swell, are more likely to affect assets in depth limited (shallow water) environments. Assets located in deeper water and outside of the impact of swell propagation into PRH are likely to be more resilient to certain aspects of climate change.

**Hazard Extent Mapping**

Coastal hazard extents have been mapped for each of the assessed planning timeframes. Full map sets have been provided in appendices to this document, as follows:

Appendix C: Coastal Erosion Hazard Mapping

Appendix D: Coastal Inundation Hazard Mapping

Appendix F: Wave Attack Hazard Mapping

### Asset Identification

All significant assets located within the most advanced hazard extent (i.e., 2122 erosion or inundation) have been identified and characterised in this report. A total of 96 assets have been identified as being at risk of coastal hazards, including:

- 8 assets in the Port of Albany
- 21 assets at Albany
- 9 assets at Mount Melville
- 3 assets at Mount Elphinstone
- 14 assets at Robinson
- 8 assets at Torndirrup
- 19 assets at Little Grove
- 7 assets at Big Grove
- 10 assets at Vancouver Peninsula

The assets have also been characterised in accordance with the City of Albany Local Planning Scheme. The asset categories include residential, commercial, developed foreshore, public and community, roads, environment, and heritage.

### Next Steps

The next step for the PRH CHRMAP is to undertake the Risk Analysis and Evaluation (Stages 3 & 4), which will be documented in the third chapter report. The key activities and outcomes of this stage will include:

- Characterising risk for each asset or asset group by combining the likelihood of impact (from the hazard extents presented in this *Risk Identification Chapter Report*) with the consequence of such impact.
- Determining each asset's adaptive capacity.
- Assessing overall asset vulnerability by introducing the adaptive capacity of each asset to its risk rating.

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# 1 Introduction

## 1.1 Overview

Princess Royal Harbour (PRH) is a semi-enclosed, natural harbour in Albany on the south coast of Western Australia (**Figure 1-1**). The harbour is approximately 4 km wide and 8 km long, with an approximate area of 28 $km^2$, including 8 $km^2$ of intertidal flats, and a length of coastline of about 25 km. The harbour is relatively shallow with typical depth less than 10 m below lowest astronomical tide (LAT), but includes a deeper dredged access channel and port basin ranging from -10m to -13m LAT. It is oriented in a north-west to south-east direction and is connected via the Ataturk entrance to the more exposed coastal waters of King George Sound and the southern Indian Ocean.

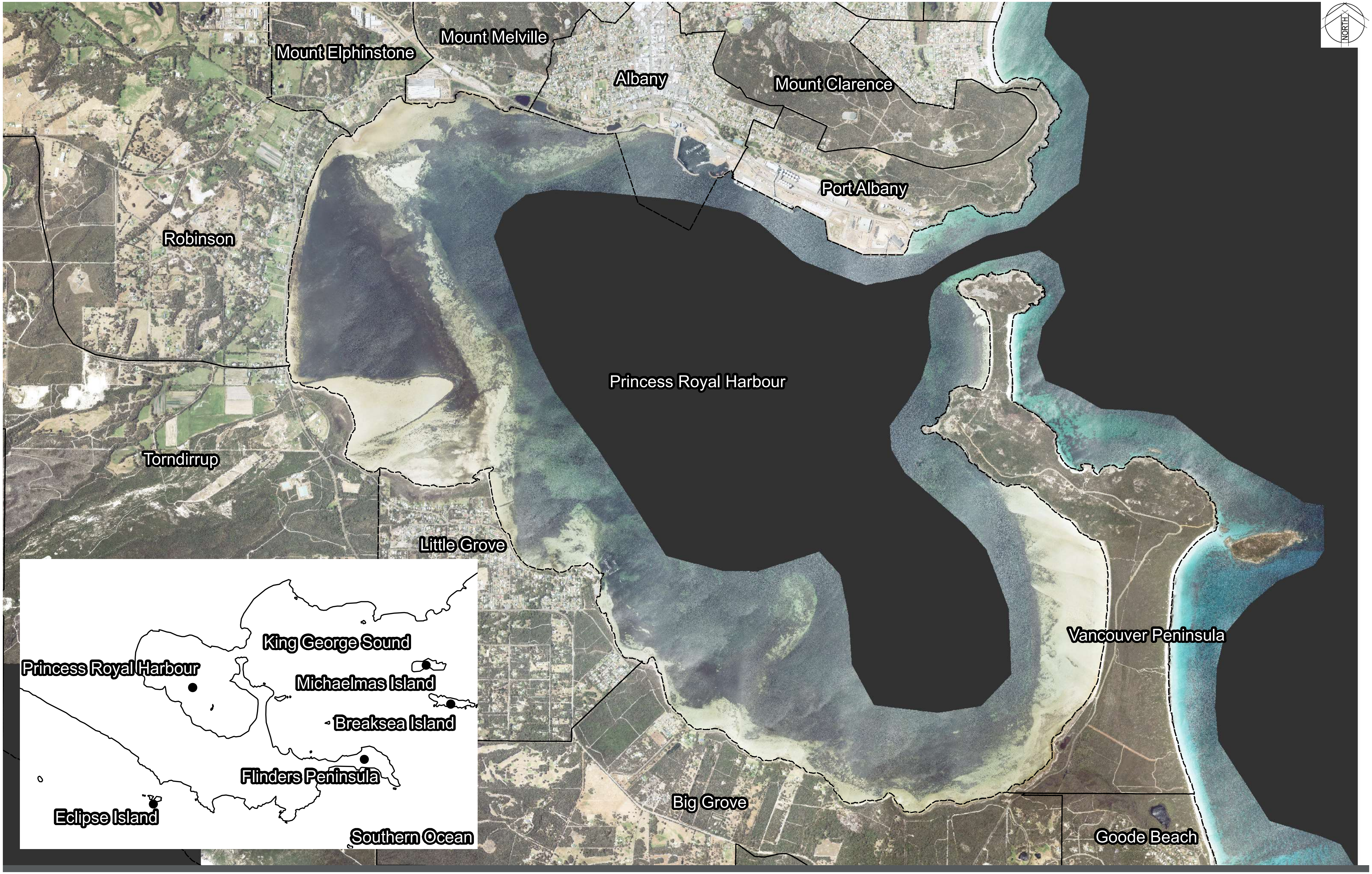
The harbour is not connected to any rivers but receives freshwater inflow from rainfall runoff, groundwater seepage and drainage discharge associated with the adjacent land catchment and drainage infrastructure. The harbour contains substantial subtidal seagrass meadows and the working Port of Albany, which is a bulk products port, exporting mainly grain and woodchips, in the order of 3 to 4 million tonnes per annum. Other smaller trades are the export of silica sand and the import of fertiliser and fuel.

The City of Albany (the City) is undertaking a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) to provide strategic guidance for coordinated, integrated and sustainable land use planning and management along the PRH coastline. The CHRMAP will inform the City's future decision-making with respect to areas and assets identified as being at risk of coastal hazards. The project area, background and context is outlined in detail in the CHRMAP's first *Chapter Report: Establish the Context* (Water Technology, 2022). That report also explain the State's Coastal Planning Policy (SPP2.6) and the CHRMAP guidelines and process.

## 1.2 Background

Globally, mean sea level (MSL) has risen since the nineteenth century and is predicted to continue to rise, at an increasing rate, through the twenty first century (Intergovernmental Panel on Climate Change [IPCC], 2021), bringing changes to the Western Australian (WA) coastline over the coming decades. To prepare for sea level rise (SLR) induced coastal hazards, such as coastal erosion and inundation, all levels of government are putting processes in place to ensure that communities understand the risks to values and assets on the coast, and to plan to adapt over time.

Changes to MSL over the past century have been observed along the WA coastline (CSIRO, BoM, 2015). *Sea Level Change in Western Australia – Application to Coastal Planning* (Department of Transport [DoT], 2010) reviewed information relating to SLR at a local scale and recommended an allowance for SLR be adopted for planning purposes. Recommendations were based on the upper bound of the global average SLR projections from *IPCC's Fourth Assessment Report* [AR4] (IPCC, 2007). In the intervening years, following release of the DoT document, advances in climate change science have been reflected in revisions to SLR projections, such as those documented in *IPCC's Sixth Assessment Report* [AR6] (IPCC, 2021). Current guidance on global SLR projections is derived from Shared Socioeconomic Pathways (SSP), characterising the trajectory of global society, demographics, and economics over the coming century. Analogous to that used in DoT's recommendation is SSP5, which forecasts an average SLR of 0.94m between 2020 and 2120 (**Figure 1-2**). SSP5 corresponds to the highest emission scenario cited in AR6, forecasting $CO_2$ emissions to triple by 2075, and a global temperature increase of 4.4 C relative to 1950.

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**Legend**

- Suburb Boundaries
- Study Area

Date
5/12/2022

Size
A3

Scale
1:30,000

0 250 500 750 1,000Meters

# PRINCESS ROYAL HARBOUR

OVERALL MAP VIEW

FIGURE 1-1: SITE LOCALITY PLAN

CW1200123-GS-001-SITE LOCALITY PLAN

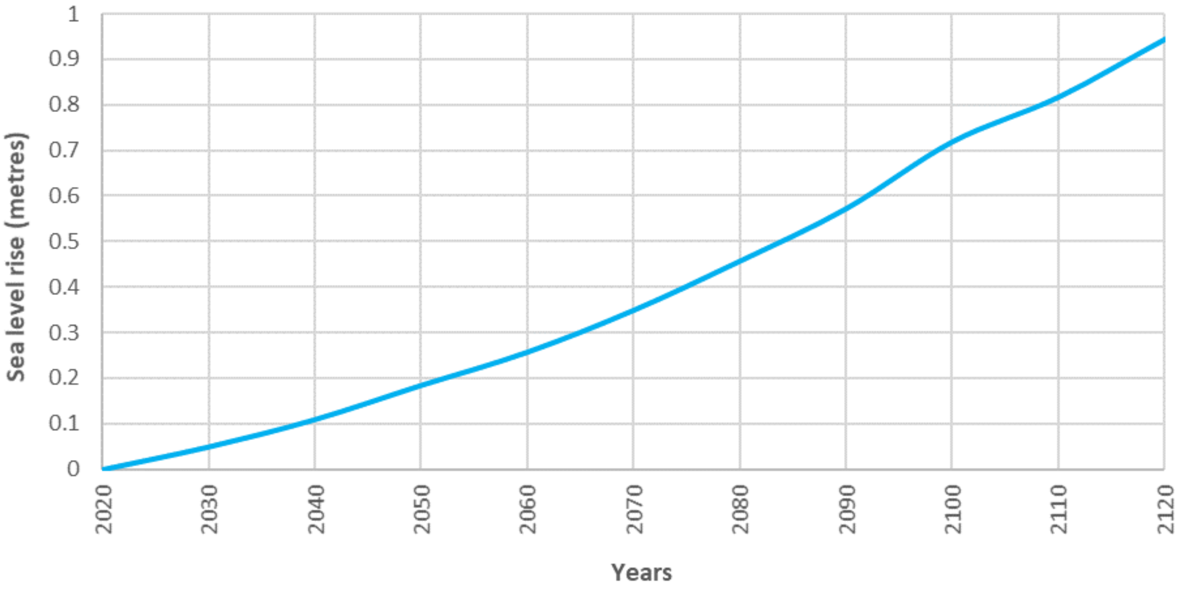



Figure 1-2 Sea level rise for planning purposes in Western Australia (based on DoT, 2010 and IPCC, 2021).

## 1.3 Overview of the CHRMAP Process

The key policy governing coastal planning in WA is the *State Planning Policy No. 2.6: State Coastal Planning Policy* (Western Australian Planning Commission [WAPC], 2013a) (SPP2.6). SPP2.6 recommends that management authorities develop a CHRMAP, using a risk mitigation approach to planning, that identifies the hazards associated with existing and future development in the coastal zone. SPP2.6 and the *State Coastal Planning Policy Guidelines* (WAPC, 2013b) contain prescriptive details, for example in relation to scales of assessment, storm event types and SLR allowances.

The WAPC (2019) has also developed the *Coastal hazard risk management and adaptation planning guidelines* (the CHRMAP Guidelines) which are less prescriptive in terms of technical assessment of coastal processes, but are aimed to ensure that planning is carried out using a risk-based approach. This includes paying due regard to stakeholder engagement, community consultation and education, and requires that a full range of adaptation options is considered.

Coastal planning in accordance with SPP2.6 also needs to take into consideration the requirements of other planning policies, including *Statement of Planning Policy No. 2: Environment and Natural Resources Policy* (WAPC, 2003) and *Statement of Planning Policy No. 3: Urban Growth and Settlement* (WAPC, 2006).

## 1.4 Purpose of this Report

The purpose of this report is to document the Risk Identification for the PRH CHRMAP, in accordance with the *CHRMAP Guidelines* (WAPC, 2019). The PRH CHRMAP is being developed in a staged approach (**Figure 1-3**), with various stages documented in standalone technical chapter reports. These reports are structured as follows:

- Establish the Context: Stage 1 (Water Technology, 2022)
- **Risk Identification: Stage 2**
- Risk Analysis and Evaluation: Stages 3 & 4
- Adaptation Planning: Stages 5, 6 & 7
- Final CHRMAP

The key purpose of this stage is to undertake the coastal hazard risk identification for present day (2022), 2030, 2047, 2072 and 2122 planning timeframes. This document also includes coastal hazard mapping and the identification of assets that may be impacted by coastal hazards over the next 100 years.

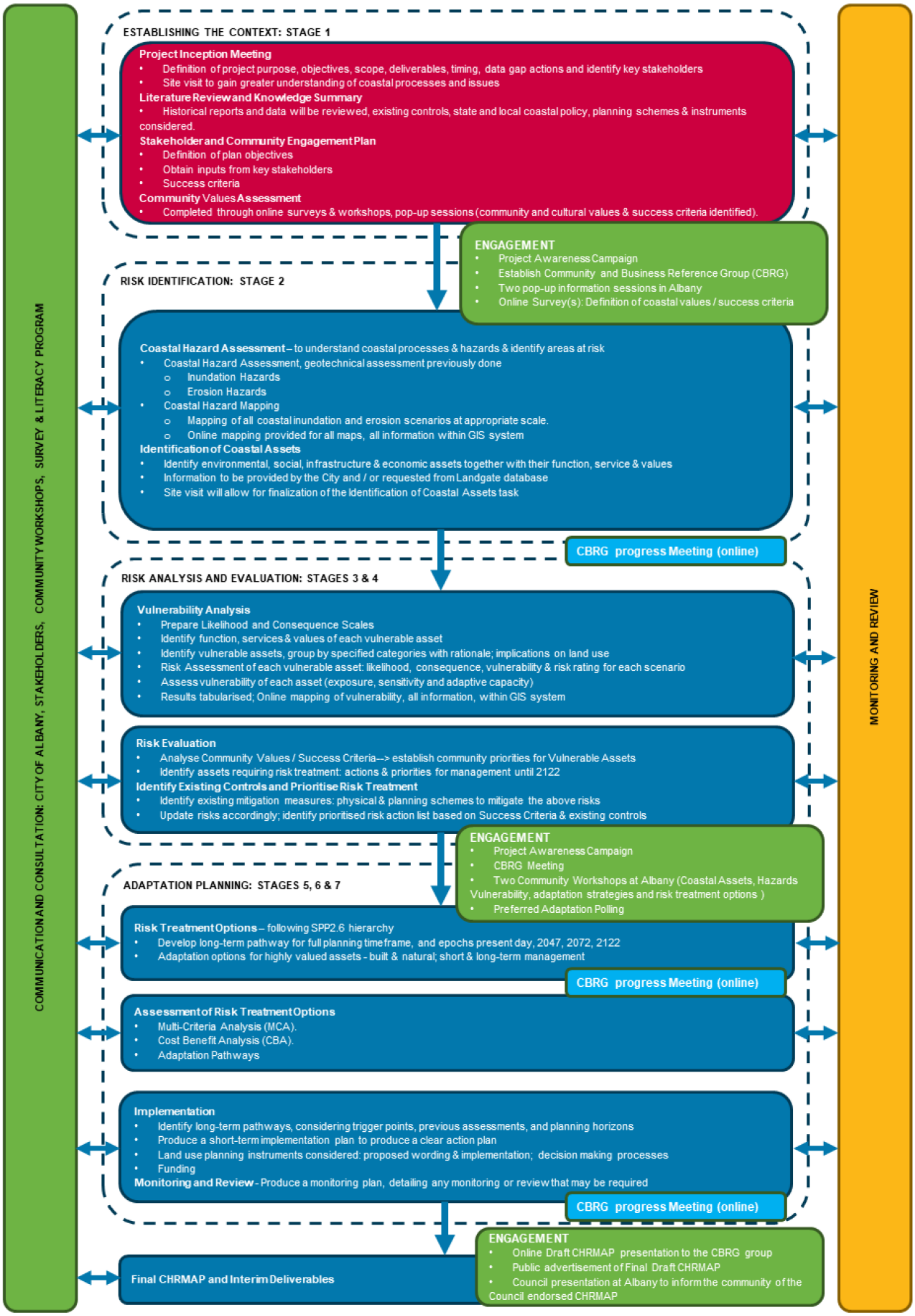



Figure 1-3 CHRMAP methodology summary (Water Technology, 2022)

# 2 Study Approach

## 2.1 Coastal Foreshore Reserve

SPP2.6 provides guidance on the planning principles and guidelines required for coastal development in WA. A key policy objective of SPP2.6 is the provision of a coastal foreshore reserve. The coastal foreshore reserve is essentially a 'space' between the ocean and private land. It should accommodate a range of functions and values such as geomorphological integrity, biodiversity, heritage, public ownership, and access.

Schedule One of SPP 2.6 provides guidance for calculating the coastal foreshore reserve to allow for coastal processes, incorporating acute (storm-based) erosion, historical shoreline movement trends, the future effects of sea level rise and storm tide inundation. The coastal foreshore reserve should be determined on a case-by-case basis and include allowances for additional functions provided by the coastal foreshore region associated with environmental, social, and indigenous values.

The component of the coastal foreshore reserve to allow for coastal processes should be sufficient to mitigate the risks of coastal hazards by allowing for landform stability, natural variability, and climate change. The coastal foreshore reserve is a critical input into the coastal hazard risk management and adaption planning framework outlined in SPP 2.6. The assessment considers allowances for coastal erosion and storm surge inundation in parallel.

## 2.2 Tidal Reach of Inland Waters

Under SPP2.6, PRH is classified as a 'tidal reach of inland waters'. These are inland water bodies that are predominantly controlled by coastal related processes, particularly tides and fluctuations in sea level. They include river mouths and estuaries and generally comprise flat to gently sloping shores, often containing high percentages of finer sediments. These shorelines are strongly influenced by inundation and tidal processes.

## 2.3 Maritime and Coastal Assets

Given that port infrastructure necessarily resides and operates in the coastal zone, port authorities are generally exempt from adhering to SPP2.6. Notwithstanding this, climate change effects, such as rising mean sea level and changes to storm frequency and intensity, have the potential to increase the risk of damage and operational downtime for the Port's assets and operations over time. As such, SPP2.6 has been adapted to the Port context, in terms of types of risk, assets and available adaptation options and pathways. This allows continuity between the Southern Ports and adjacent City of Albany land in terms of assessing coastal hazard risk.

## 2.4 Coastal Erosion

### 2.4.1 Sandy coasts

Sandy coastlines are, in general, very responsive to the climate and any changes that occur. The allowance for erosion on sandy coasts is calculated as the sum of the S1, S2 and S3 Erosion allowances, plus a 0.2 m per year allowance for uncertainty:

- (S1 Erosion) Allowance for the current risk of storm erosion
- (S2 Erosion) Allowance for historic shoreline movement trends
- (S3 Erosion) Allowance for erosion caused by future sea-level rise
- (Su Erosion) Allowance for uncertainty.

The erosion allowances are applied from a horizontal shoreline datum (HSD), defined by the active limit of the shoreline under storm activity. The HSD should be determined against the physical and biological features of the coast.

#### 2.4.2 Rocky coasts

Rocky coasts comprise a continuous rocky substrate which extends to an elevation above the active limit of the shoreline. In most instances this elevation should be defined as at least one metre above the HSD. Portions of the PRH shoreline are comprised of naturally occurring granite, while others, such as the shoreline along the Port boundary, comprise of granite placed artificially to protect adjacent infrastructure ('hardened/protected shoreline'). Under the classifications of SPP2.6, portions of the study area comprising natural or artificially occurring granite have been classified as 'hard rock'. Negligible shoreline change is expected over the 100-year planning timeframe for hard rock coasts. Hardened shorelines are not expected to experience change up until the end of the structure's design life, and likely beyond this.

#### 2.4.3 Mixed sandy and rocky coasts

Coasts with discontinuous or low elevation rock shall be classified as mixed sandy and rocky coasts. This is the case for much of the island's coastline, which would be described as discontinuous rocky shorelines. These coasts comprise discontinuous subtidal or intertidal rock on a predominantly sandy shoreline. The subtidal rock may be present as a pavement or discontinuous outcrops of reef close to the shore. Erosion of such coasts are to be considered on a case-by-case basis.

## 2.5 Coastal Inundation

#### 2.5.1 Storm Surge Inundation

The allowance for the extent of coastal inundation (S4) is calculated as the maximum extent of storm inundation, defined as the peak steady water level, plus wave run-up, for a 500-years average recurrence interval (ARI) ocean water level event. Consideration must be given to the likelihood of breaching any manmade structures (overtopping), such as seawalls, or natural barriers, such as dune systems.

#### 2.5.2 Catchment Inundation

PRH receives freshwater inflow from adjacent land catchments. As such, consideration should be given to the statistical dependence between extreme rainfall and extreme storm surge, as both physical processes can be driven by common meteorological forcings. Low pressure systems for example, may produce strong onshore winds and an inverse barometric effect, leading to an extreme storm surge, while simultaneously generating large quantities of rainfall on the adjacent coastal catchments.

## 2.6 Wave Attack

To ensure a useful outcome from the CHRMAP with respect to the Port's maritime and coastal assets, an additional coastal hazard termed 'wave attack' has been incorporated in this study. Wave attack refers to damage to coastal and maritime infrastructure, due to projected changes to metocean forcing and impact. This can include rare events leading to major damage, or more frequent events leading to minor damage which compound over time. Wave attack may also identify premature weakness in infrastructure that may not have included sufficient allowances for the effects of climate change over the assets design life.

## 2.7 Climate Change Considerations

It is widely recognised in the scientific community that climate change is occurring and, as a result, possible effects must be considered when planning for the future. For PRH, the relevant effects will most likely be an increase in MSL, as well as possible changes to storm frequency, direction and intensity, changes to precipitation patterns, increased ocean acidification and increased temperatures (CSIRO & BoM, 2015). This CHRMAP will focus on the potential effects due to projected SLR and any potential changes to storm frequency and intensity.

Adhering to the requirements of SPP2.6, this study will consider the present day (2022) timeframe, as well as SLR for planning purposes for the years 2047, 2072 and 2122.

### 2.7.1 Sea Level Rise

Previously recommended allowances for SLR, to be adopted for planning purposes in WA (DoT, 2010), have been updated to reflect advances in climate change science (as recommended by that report). The allowances adopted in this study are provided in **Table 2-1** and have been informed by IPCC (2021). Adhering to the requirements of SPP2.6, the upper bound of the SSP (SSP5-8.5) predictions has been adopted, analogous to that used to inform DoT (2010). Specifically, the medium confidence and 50$^{th}$ percentile of the SSP5-8.5 predictions has been adopted.

Table 2-1 Sea level rise allowances adopted for this study, with respect to 2022 (IPCC, 2021 – SSP5)

| Timeframe | Present day (2022) | 2047 | 2072 | 2122 |
|---|---|---|---|---|
| Sea Level Rise (m) | 0.00 | 0.15 | 0.35 | 0.94 |

### 2.7.2 Winds

Wind fields across Australia are associated with large-scale circulation patterns and their seasonal movement. Across the southern half of Australia, average wind conditions are influenced by the seasonal movement of the subtropical ridge that separates the mid-latitude westerly winds to the south and the south-east trade winds to the north (CSIRO & BoM, 2015).

Climate change effects of relevance to PRH are the projected southward movement of the subtropical ridge and strengthening of mid-latitude westerlies over the Southern Ocean. The results of this are predicted to reduce mean and extreme wind speeds between latitudes 30°S and 40°S during the winter months and increase mean and extreme wind speeds below latitude 40°S overall (CSIRO & BoM, 2015). Projected increases in the temperature differential between the land and sea during the summer months is also predicted to result in increased onshore wind speeds during summer (CSIRO & BoM, 2015).

While there is relatively high confidence in the projected changes to large-scale circulation patterns, it should be noted that there is large uncertainty in projected changes to extreme near surface winds. This is due to the inability of global climate change models to resolve small scale meteorological systems. The projected changes in mean and extreme wind speeds adopted for the wave attack component of this study are provided in **Table 2-1**.

Table 2-2 Changes in mean and extreme wind speeds adopted for this study (CSIRO & BoM, 2015b)

| Timeframe | Present day (2022) | 2047 | 2072 | 2122 |
|---|---|---|---|---|
| Local wind speed – Winter (%) | 0.0% | -1.0% | -2.0% | -3.0% |
| Local wind speed – Summer (%) | 0.0% | +1.0% | +2.0% | +3.0% |
| Offshore wind speed (%) | 0.0% | +1.0% | +2.0% | +3.0% |

## 2.8 Coastal Setting

### 2.8.1 Geomorphology and Bathymetry

Princess Royal Harbour is a shallow, natural basin with gently sloping, sandy margins. The site's geology is associated with the Nornalup Complex of the Albany Belt, which is dominated by granite. This granite is prominent along the edge of the harbour in several areas, including the formation of the entrance between the rocky outcrops of King Point and Possession Point. Sediment within the harbour is likely to be derived from a combination of silica-based lithogenic (broken down geological material) and calcium carbonate-based biogenic (remains and products of marine organisms) sources, though testing of the composition of sediment has not been undertaken. A range of sediment grain size is found around the shoreline of the harbour, ranging from fine at Shoal Bay to medium within Hanover Bay (Travers et al, 2010).

The deepest natural portions of the harbour, in its north and near its entrance, reach approximately -10 m LAT, with the entrance channel and port berthing areas dredged to below -12 m LAT. Shoreline profiles range from relatively steep either side of the entrance (along the harbour's north-east) to areas of long, gentle slopes for major portions of the harbour in its south (e.g. Shoal Bay) and north-west (e.g. between Rushy Point and the Woolstores). The bathymetry of PRH is presented in **Figure 4-1**. An overview of the geological units of PRH is provided in **Figure 2-2** (summarised from GSWA, 2001).

### 2.8.2 Wind

Albany has a variable wind climate in terms of both direction and strength. Strong winds can be experienced year-round, though the windiest period is during winter (June to September). Wind direction during this period is predominantly westerly to north-westerly. During the summer months (November to March), winds are lighter and predominantly easterly to south-easterly (Bureau of Meteorology, 2022). Seasonal wind rose within King George Sound are provided in **Figure 2-1**.

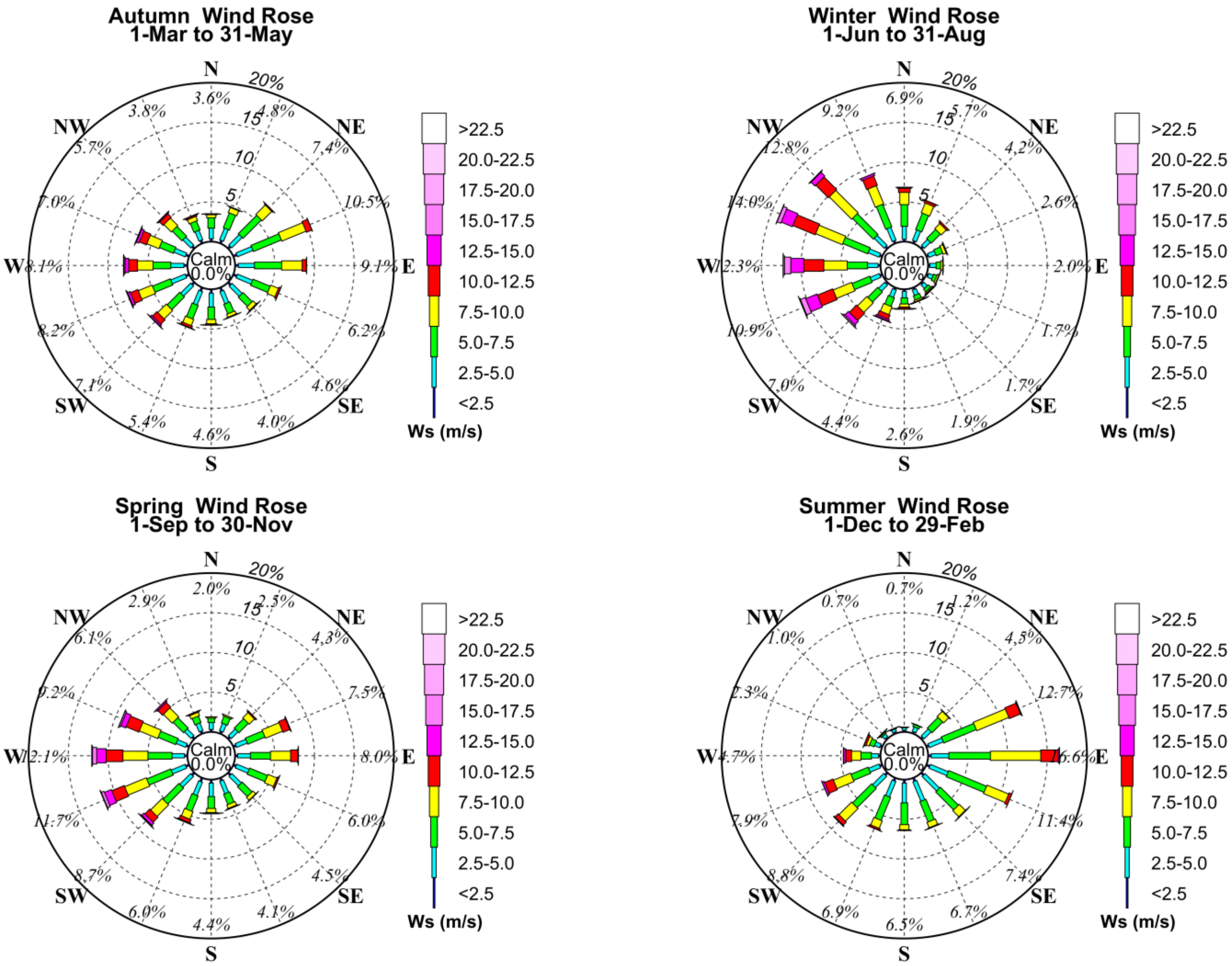
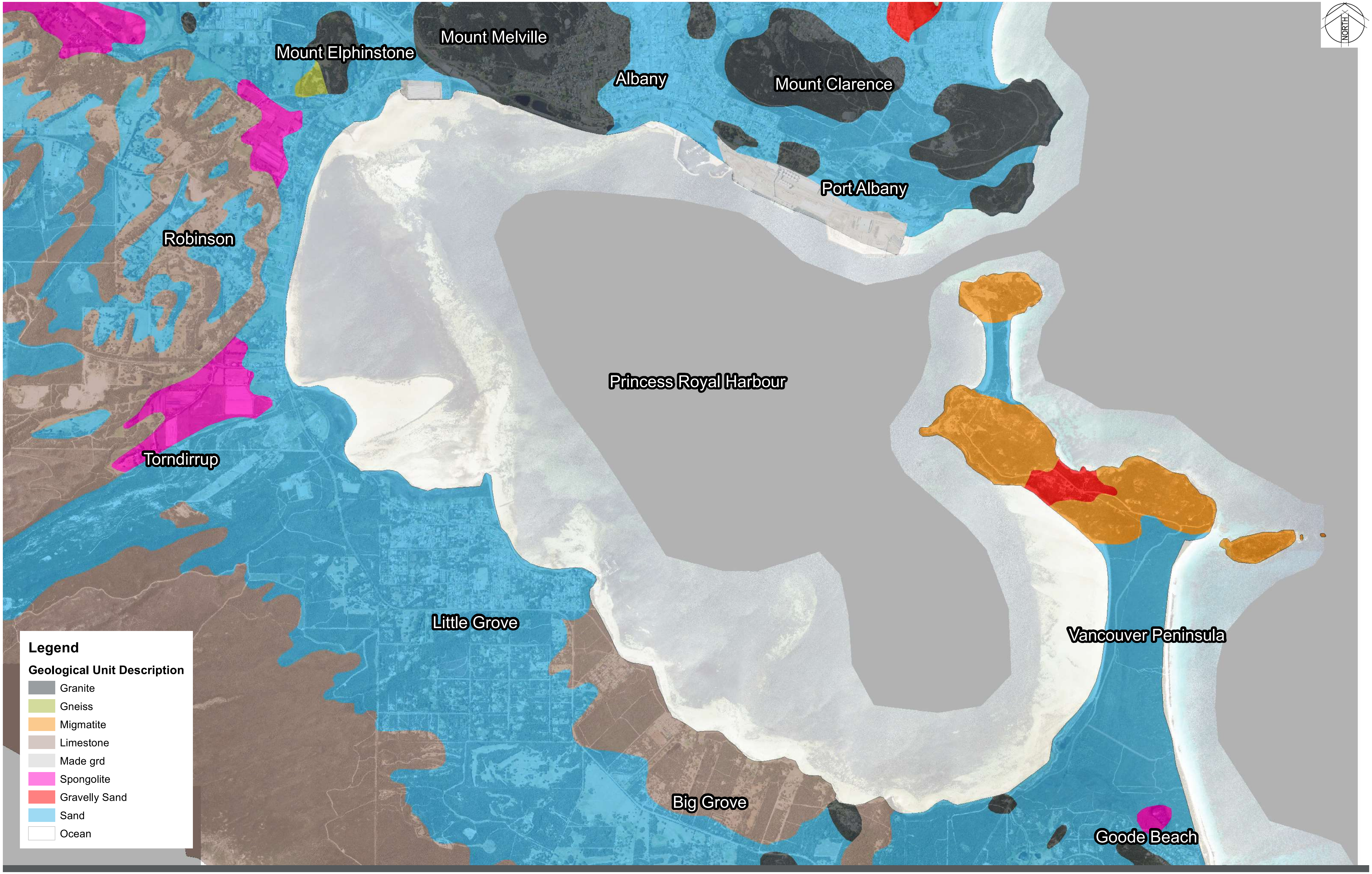



Figure 2-1 Seasonal wind rose in King George Sound, data period from 1979 through 2022 (CSIRO)

### 2.8.3 Rainfall

Albany experiences rainfall year-round with an annual average of 925 mm. The lowest rainfall month is February, averaging 23 mm, and the highest rainfall month is July, averaging 143 mm (Bureau of Meteorology, 2022).

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Date
5/12/2022

Size
A3

Scale
1:30,000

0 250 500 750 1,000Meters

# PRINCESS ROYAL HARBOUR

FIGURE 2-2: GEOLOGICAL UNITS OF PRINCESS ROYAL HARBOUR

SOURCE: GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

CW1200123-GS-005-GEOLOGICAL UNITS

### 2.8.4 Water Level

Tides in the study area are predominantly diurnal (one high- and one low-tide per day) but briefly become semi-diurnal (two high- and two low-tides per day) during spring and autumn. The highest recorded water level was 1.79 m in 2007, and the lowest recorded water level was -0.24 m in 1951, relative to chart datum (CD); equivalent to lowest astronomical tide (LAT) 2006. Tidal datums are presented in **Table 2-3**.

Other factors that can affect the water levels in the harbour include wind- and wave-driven setup, storm surge within King George Sound transmitted through the entrance to the harbour and, to a minor extent, freshwater input from rainfall.

Table 2-3 Astronomical tide regime at Princess Royal Harbour, Albany (DoT, 2020)

| Tidal Water Levels | m CD (LAT 2006) | m AHD |
|---|---|---|
| Highest Astronomical Tide (HAT) | 1.44 | 0.79 |
| Mean High High Water (MHHW) | 1.14 | 0.49 |
| Mean Low High Water (MLHW) | 0.99 | 0.34 |
| Mean Sea Level (MSL) | 0.73 | 0.08 |
| Australian Height Datum (AHD) | 0.65 | 0.00 |
| Mean High Low Water (MHLW) | 0.47 | -0.18 |
| Mean Low Low Water (MLLW) | 0.32 | -0.33 |
| Lowest Astronomical Tide (LAT) | 0.07 | -0.58 |

### 2.8.5 Wave Climate

Princess Royal Harbour has a sheltered wave climate, with the narrow entrance channel restricting penetration by seas and swell from King George Sound and the open ocean. This restriction means that the major driver of wave energy within the unprotected shoreline of the harbour is locally-generated wind-waves (Travers et al, 2010).

Travers et al (2010) analysed the wind regime at Albany to estimate the generation of waves at a range of sites around the harbour. This assessment included waves generated for the prevailing (most common), dominant (strongest) and maximum fetch (stretch of water before land) wind directions and speeds. They found the highest waves were generated to propagate towards Hanover Bay and the Woolstores for both dominant and prevailing conditions, with lower respective wave conditions propagating towards Shoal Bay. The range of wave heights estimated at the -2m AHD contour around the harbour for the dominant wind conditions was from 25 cm to 85 cm. Empirical calculations indicate that fetch limit conditions within PRH could exceed this range at deeper depths. Bathymetry was found to be a key factor in determining the transfer of this wave energy to the shoreline, with the long, shallow terraces attenuating wave energy significantly. For example, the shallow nearshore area at the Woolstores reduced wave height by up to 75%, compared to just a 15% reduction at nearby Hanover Bay, with its steeper nearshore profile.

### 2.8.6 Currents and Sediment Transport

Currents and sediment transport within Princess Royal Harbour have not been measured or investigated to any great extent, to the author’s knowledge. The low energy environment in terms of wave climate and low water level fluctuations suggest that the drivers of sediment movement are subtle. Significant seagrass meadows, where present, are also likely to help stabilise the seabed sediments. The relatively infrequent maintenance dredging requirements for the port support the notion that sediment transport loads are low.

Given the low tidal regime and lack of substantial terrestrial inflow to the harbour, wind-driven currents are likely to predominate when winds are strong. This may set up circulation patterns within the harbour, moving sediment gradually around the shoreline. Modelling conducted by Mills & Brady (1985) of wind driven water circulation in Princess Royal Harbour indicated that west to north-west winds in winter generate predominantly anti-clockwise circulation. The variable wind climate and harbour bathymetry suggests that circulation patterns could be established in both directions, though likely for brief periods.

# 3 Study Area

## 3.1 Overview

Princess Royal Harbour is classified as a ‘tidal reach of inland waters’ according to the coastal classifications defined in SPP2.6 Schedule One (WAPC, 2013). This means that it is an inland waterbody that is predominantly controlled by coastal related processes, such as tides and sea level variations. Within the harbour there are sections of ‘sandy’, ‘rocky’ (generally ‘hard rock’) and ‘mixed sandy and rocky’ coast per the definitions in SPP2.6, as well ‘hardened’ shorelines being controlled by coastal structures (see **Section 3.3**).

The harbour’s coastline has been divided into five Management Units (MUs) for further shoreline description and classification in the following section (see **Figure 3-1**). The MUs have been defined at this stage by considering shoreline orientation and natural and manmade shoreline features, such as extended shoreline hardening (e.g., seawalls) and points established by geological features and/or localised sediment transport regimes. This is a similar process to that applied for the definition of ‘coastal sediment cells’ (see Stul, 2015), which have not been defined previously for PRH.

## 3.2 Site Description

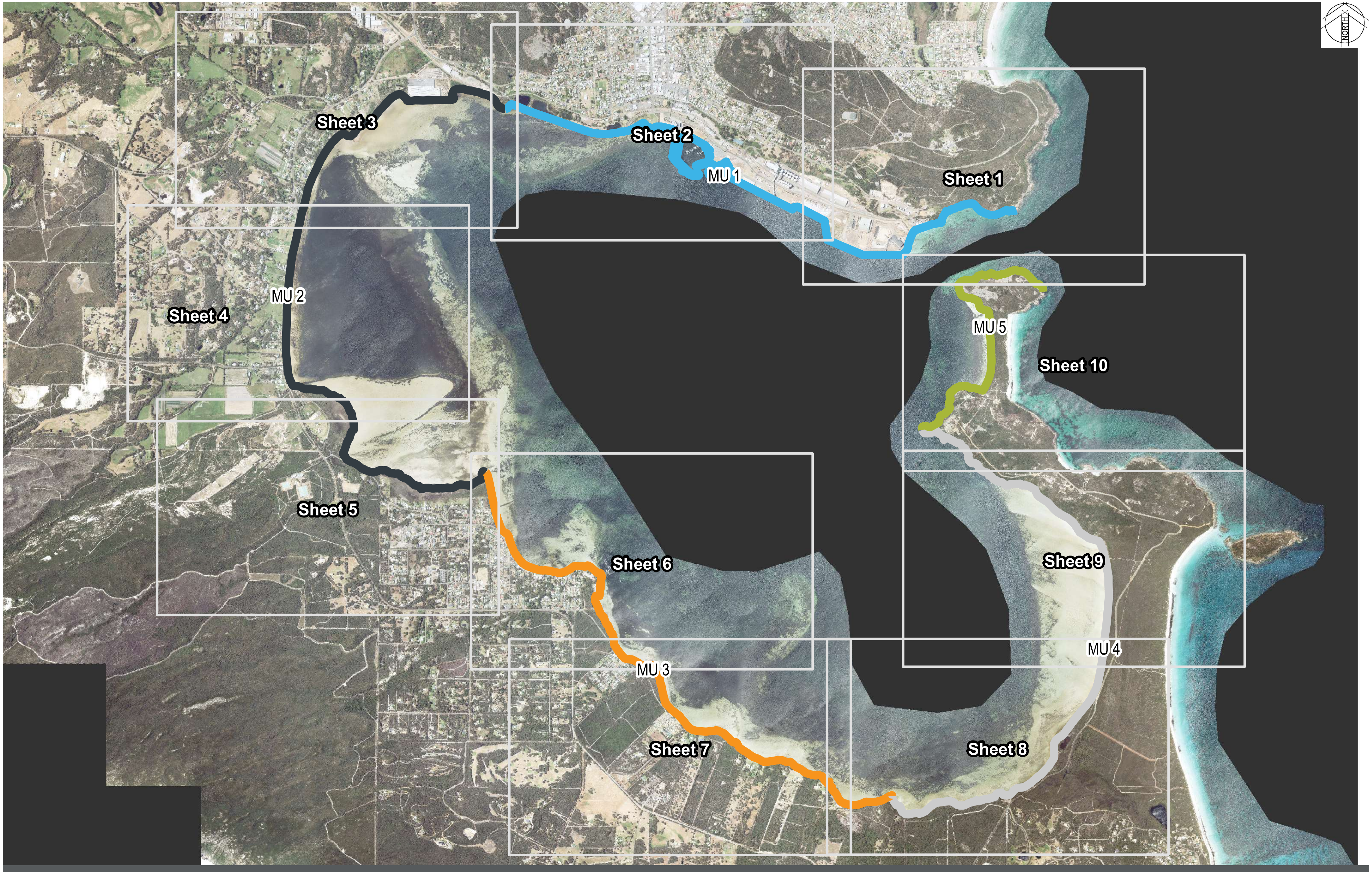
### 3.2.1 Management Unit 1: Point King to Melville Point

MU1 extends from Point King to Melville Point and is almost entirely hardened shoreline, due to naturally occurring rock or the installation of coastal rock protection (**Figure 3-2** and **Figure 3-3**). A natural rocky coastline is present from the edge of the study area at King Point to the edge of the Port of Albany at Spit Head. From here the coastline is protected by rock structures to Melville Point including, consecutively:

- Rock seawalls and sheet-piled revetments adjacent the Port infrastructure (**Figure 3-2**)
- Albany Waterfront Marina rock breakwaters and internal seawalls (**Figure 3-2**)
- Seawall from the marina to Melville Point, along Point Frederick and adjacent Hanover Bay (**Figure 3-3)**

For the purpose of coastal hazard assessment/identification in the CHRMAP, the coastline protected by these structures is assumed to be sandy. The control exhibited by the structures will be considered when calculating hazard extents, based on the profile, effectiveness, and remaining design life of the structures.

The bathymetry adjacent this MU has also been modified extensively by dredging for the port’s facilities. The shipping channel through the Ataturk Entrance is approximately 200 m wide and maintained to a depth of around 13 m. The manoeuvring and berthing areas directly adjacent the port are twice the width of the channel, extending alongshore nearly 2 km, and are maintained to depth between 10 and 12 m.





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FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-001-Overview.mxd


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Phone: +61 8 9273 3888
Web: www.cardno.com.au

Aerial Imagery supplied by MetroMap (19/12/2021)



**Legend**

- MU 1
- MU 2
- MU 3
- MU 4
- MU 5

Date
5/12/2022

Size
A3

Scale
1:30,000

0 250 500 750 1,000 Meters

# PRINCESS ROYAL HARBOUR

OVERALL MAP VIEW

FIGURE 3-1: SECTION MAP

CW1200123-GS-001-OVERVIEW

Figure 3-2 Albany Waterfront Marina and Port of Albany captured in November 2016 (image source: airviewonline, 2022)

Figure 3-3 Hardened shoreline (seawall) between Point Frederick and Melville Point captured in January 2022 (image source: City of Albany, 2022)

### 3.2.2 Management Unit 2: Melville Point to Rushy Point

MU2 extends from Melville Point to Rushy Point and has been assessed as a gentle-sloping, sandy coastline (**Figure 3-4**). The shoreline is vegetated up to the water's edge and includes intertidal flats. This is suggestive of a low-energy shoreline. Portions of the shoreline have been hardened by rock protection, adjacent the Woolstores and Frenchman Bay Road (see **Section 3.3**). Small rocks and gravel were found to be present among finer sediment at some areas of the shoreline, which may be naturally occurring or present due to infrastructure constructed in close proximity to the shoreline (e.g. paths and roads).

Figure 3-4 A section of shoreline in Lockyer Bay captured in December 2021

### 3.2.3 Management Unit 3: Rushy Point to Limekilns Point

MU3 extends from Rushy Point to Limekilns Point and contains both rocky and sandy coastlines (**Figure 3-5**). Much of the coastline in this MU is fronted by private property, which prevented proper inspection during the site visit. The undulating nature of the shoreline is likely due various rocky outcrops acting as controlling features, among sandy sections of shoreline. The northern half of the MU contains several continuous stretches of sandy coast, facing eastwards. This include the stretch directly south of Rushy Point, where erosion was evident and ad-hoc protection (placed boulders) had been implemented along the high-water line. The southern portion of the MU appears be predominantly rocky, with intermittent sections of sandy beach. A seawall is present in the MU, defending a short stretch of shoreline at the Princess Royal Sailing Club.

Figure 3-5 A section of shoreline to the south of Rushy Point captured in December 2021.

### 3.2.4 Management Unit 4: Limekilns Point to Geake Point

MU4 extends from Limekilns Point to Geake Point and contains distinct sections of sandy and rocky coastline (**Figure 3-6**). The MU includes a major portion of the Vancouver Peninsula, which forms the shallow waters of Shoal Bay. The wide shallow bay is suggestive of a low energy environment. The coastline is rocky from Limekilns Point to Jessica's Beach (approximately half of the MU), then sandy for a continuous stretch along Vancouver Beach, before becoming rocky again at Quarantine Hill.

Figure 3-6 Vancouver Peninsula and Shoal Bay captured in November 2016 (image source: airviewonline, 2022)

### 3.2.5 Management Unit 5: Geake Point to Possession Point

MU5 extends from Geake Point to Possession Point and contains distinct sections of sandy and rocky coastline (**Figure 3-7**). The sandy coastline is an isthmus extending between the rocky outcrops of Quarantine Hill and Bramble Point and is also likely to be underlain by rock at some level, given its stability. A seawall has been installed to control the shoreline at Camp Quaranup – Geake Point (**Figure 3-8**).

Figure 3-7 Vancouver Peninsula captured in November 2016 (image source: airviewonline, 2022)

## 3.3 Existing Physical Controls

Existing controls should be identified and considered in the Coastal Hazard Identification, as recommended in the CHRMAP Guidelines (WAPC, 2019). In the context of coastal processes, controls are physical and include structures that currently interact, or have the potential to interact in the future, with oceanographic conditions and coastal processes. Such structures include seawalls, groynes, and breakwaters. Controls also include ongoing management/intervention activities, such as beach nourishment, dredging and sand by-passing. The existing physical controls identified for the study area are outlined in **Table 3-1** below. It is understood that a once off dredging campaign was also undertaken approximately 300 m south of Rushy Point, to allow boats to transit to and from the shore. This dredging is not routine and has not been considered as an existing physical control.

Table 3-1 Existing physical controls in the study area

| Control | Location | Purpose | Approximate Year implemented | Assumed design life / management timeframe |
|---|---|---|---|---|
| **'Hard' engineering controls** | | | | |
| Port of Albany rock seawall and sheet-piled wharf (**Figure 3-1**) | Along the northern side of the entrance to Princess Royal Harbour, between Spit Head and Albany Waterfront Marina | Stabilise the shoreline and protect landside Port assets, as well as facilitate vessel berthing. | 1930's | 50 years |
| Albany Waterfront Marina – breakwaters and seawalls (**Figure 3-1**) | Adjacent Port of Albany to the north-west | Create a safe harbour and protect landside assets and development. | 2011 | 50 years |
| Hanover Bay Seawall (**Figure 3-2**) | From Albany Waterfront Marina to Melville Point | Stabilise the shoreline and protect landside assets, such as Princess Royal Drive | 1970's | 50 years |
| Seawall in front of Albany Wool Stores | Adjacent Albany Wool Stores, Lockyer Bay | Land reclamation/retention and protection of landside assets | 1970's | 25 years |
| Rock protection along Frenchman Bay Road | Adjacent the intersection of Princess Avenue | Protect landward assets – footpath and road | 2014 | 25 years |
| Informal rock protection along Rushy Point shoreline (**Figure 3-4**) | Approximately 400m south of Rushy Point | Protect properties from erosion | Unknown | NA |
| Princess Royal Sailing Club Seawalls | Shoreline directly to the south of Princess Royal Sailing Club | Land reclamation/retention and protection of landside assets | 1980's | 50 years |
| Camp Quaranup Seawall (**Figure 3-7**) | Geake Point | Stabilisation of shoreline and protection of landside assets | Unknown | 50 years |
| **'Soft' management controls** | | | | |
| Dredging Ataturk Entrance and Port of Albany vessel berths | Princess Royal Harbour entrance and adjacent Port of Albany wharves | Maintain navigable depth for vessel attending the Port | Ongoing | Ongoing |

Figure 3-8 Camp Quaranup Seawall captured by Peter Bowdidge – date unknown (Department of Local Government, Sport and Cultural Industries, 2022)

# 4 Coastal Hazard Assessment

## 4.1 Overview

The potential extents of present day and future coastal hazards for the study area have been defined using available data and adhering to the methodologies specified in SPP2.6. This section details the calculation of various coastal hazard extents and their components, over the 100-year planning time frame, to define the width of the coastal foreshore reserve that should be incorporated to allow for coastal hazards.

## 4.2 S1 Erosion Allowance

### 4.2.1 Design Storm Event

Schedule One of SPP2.6 describes four different geographical areas for the definition of the design storm event for the assessment of coastal erosion. Princess Royal Harbour lies in area four, which requires the application of a mid-latitude depression or extra-tropical low storm event for coastal erosion. Policy guidance for coastal erosion is that an event corresponding to the 100-year ARI ocean forces and coastal processes should be selected.

The allowance for erosion on tidal reaches of inland water should generally be determined using the methods specified for sandy, rocky, and mixed sandy and rocky coasts. It is however, acknowledged that these methods are principally derived for open ocean coast and consideration should be given to the variation in underlying coastal processes and driving forces within sheltered inland waters. For such locations, the storm event should be defined on a case-by-case basis either by the transformation of the offshore storm event or, for fetch limited locations, the hindcasting of an equivalent storm event based on recorded or modelled winds.

No recorded long-term wave or acute storm erosion data was available within PRH. As such, numerical wave modelling was forced by wind conditions assessed as being representative of the required fetch limited design storm event. The numerical modelling systems applied to this investigation are discussed below.

For locations of the study area that may be exposed to offshore swell propagation from the Southern Ocean, such as the entrance to PRH and the eastern side of the isthmus within MU5, DoT has generated a synthetic storm based on analysis of actual events for use in the application of SPP2.6 (MPRA, 2018). The storm event applicable to the study area was generated at the location of the Albany Wave Buoy, and comprises a large south south-westerly swell, coinciding with strong west north-westerly winds. Given the alignment of the entrance to PRH, as well as the protection afforded by Flinders and Vancouver Peninsulas, such an event is unlikely to impact the study area. In order to derive representative storm conditions for such areas, an equivalent design event has been synthesised based on a swell wave penetration investigation. The numerical modelling systems applied to this investigation are discussed below.

### 4.2.2 Model Systems

*SWAN Wave Modelling System*

The broad-scale wave model Cardno applied in this study is based on the third-generation wind/wave modelling system, SWAN, which is incorporated as a module into the Delft3D modelling system. This model was developed at the Delft University of Technology and includes wind input (local sea cases), offshore wave parameters (swell cases), combined sea and swell, refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. SWAN also includes phase-averaged diffraction based on the model of Holthuijsen et al (2007).

SWAN includes a nested grid capability that allows coarser grids in deeper water and finer grids in shallow water, where better definition of the seabed form and depth are required. Output from the model includes significant wave height, dominant wave direction, spectral peak and mean periods and (optionally) the full directional wave spectra.

*SBEACH*

The current risk of storm erosion was examined using the SBEACH (Storm-induced BEAch CHange) numerical model. SBEACH is an empirically based two-dimensional model used to examine the short-term response to beach, berm and dune profiles during storm events (Larson and Kraus 1998). The model has been widely applied at sites all over the world and has demonstrated good levels of calibration. The model can simulate a temporally varying breakpoint which produces offshore bar migration under acute storm wave events.

### 4.2.3 SWAN Model Set-Up

*SWAN Grids*

The model grid system was prepared with the main objective of providing good resolution along the PRH coastline. As such, the SWAN model setup for this study has adopted a nested grid system and is comprised of two nested rectilinear grids of increasing grid cell resolution. The outermost grid has a resolution of 100 m and enables the complex bathymetric features and land masses within King George Sound to be adequately resolved. The outer grid also enables the investigation of swell propagation into PRH. Within this outer grid is nested a grid of 20 m resolution, covering PRH. The SWAN grid extents and model bathymetry are shown in **Figure 4-1.** The bathymetric data applied to the SWAN model has been derived from the following data sources, listed in order of highest to lowest precedence:

- City of Albany LiDAR from 2021.
- Navigation charts for coastal regions from the Australian Hydrographic Service.
- Albany Port Authority Clearance Survey from May 2017.

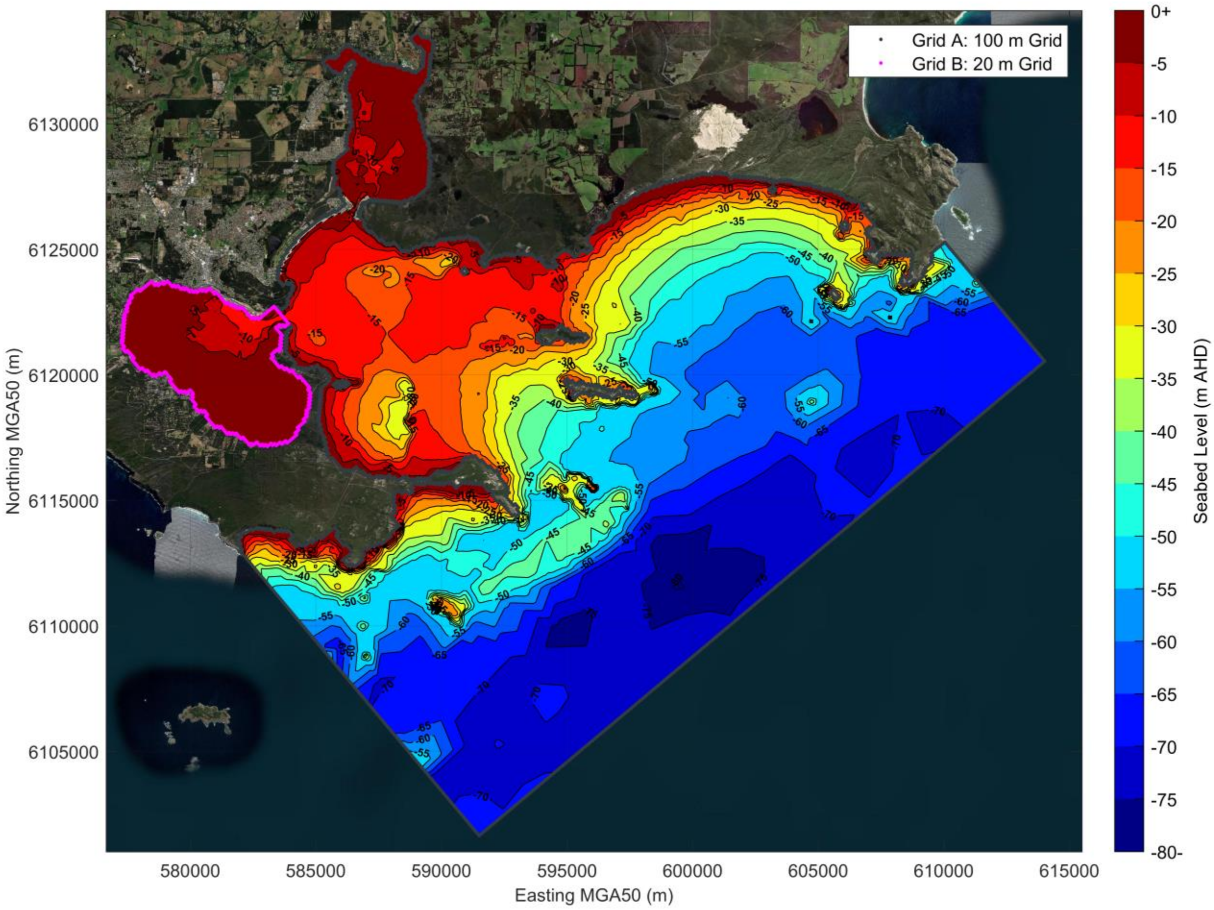


Figure 4-1 SWAN model domain & bathymetry

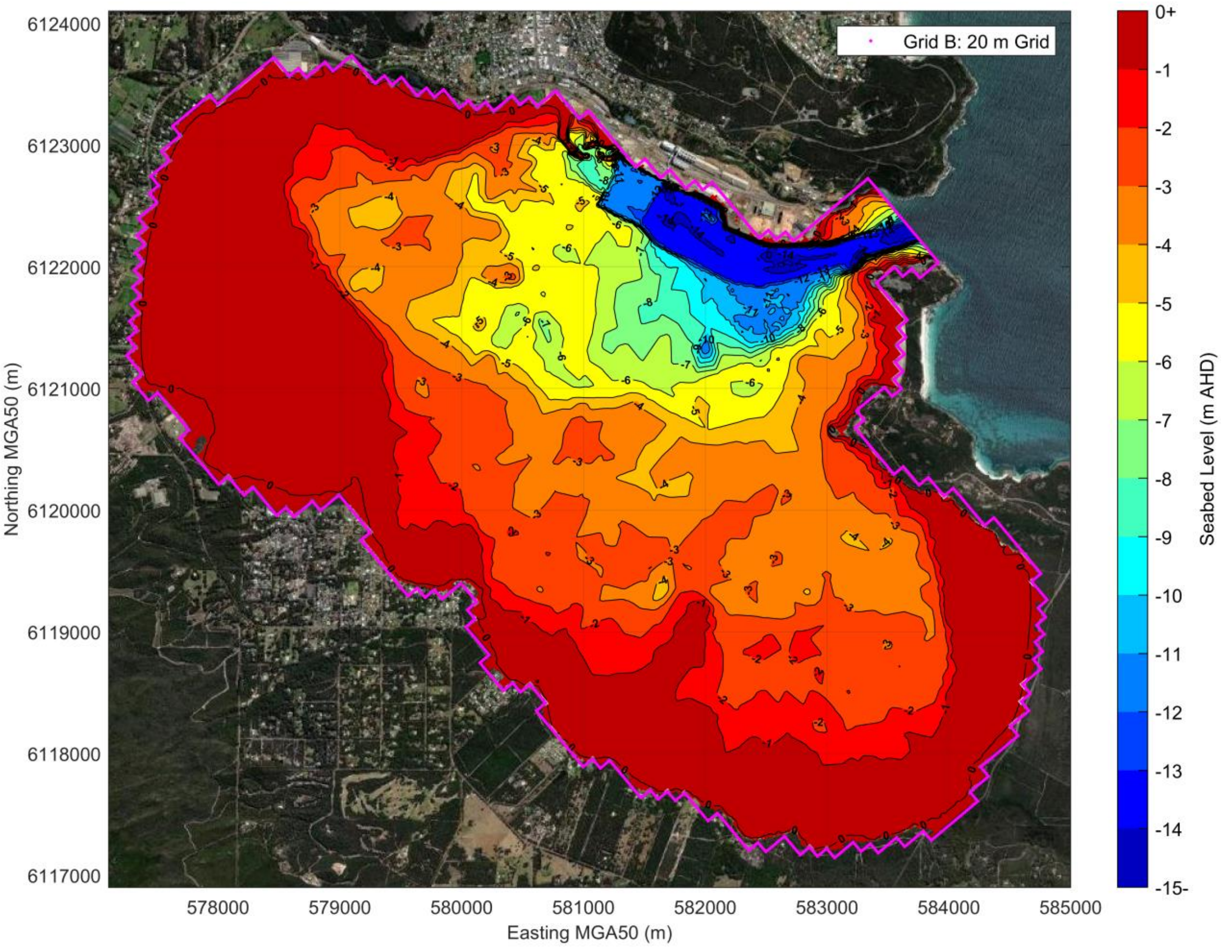


Figure 4-2 SWAN model domain & bathymetry

*SWAN Numerical Parameters*

JONSWAP bottom friction was applied, and depth induced wave breaking was addressed using the model of Battjes and Janssen (1978). A default wave breaking (height to depth ratio) coefficient of 0.73 was adopted. Wave breaking coefficients can be important when modelling waves within semi-enclosed water bodies such as PRH, where the depth limited breaking has a major influence on the modelled wave conditions

For wave growth generation, the formulation described in Komen et al (1984) was adopted and white-capping dissipation was activated, using SWAN's default SWAN model of Hasselmann (1974).

### 4.2.4 Swell Wave Penetration

Over large water bodies (such as the Southern Ocean), waves will travel beyond their area of generation. As swell waves propagate over long distances, they will be transformed by the process of velocity dispersion (also known as frequency dispersion), because low frequency wave components will propagate faster than high frequency components of the sea state. Consequently, swell waves off the Albany coast generally have longer wave periods, in the order of 8 to 25 seconds, and arrive from the southwest to south-southwest directional sectors.

In order to characterise the influence of swell waves on the PRH shoreline, a wave propagation investigation was undertaken based on a suite of offshore hindcast wind and wave conditions. In the first instance, 42 years (1979 through 2021) of hindcast global model wind and wave data was obtained from the CSIRO CAWCR WaveWatch III Australian wind and wave model system, at a location within King George Sound (CSIRO 1 in **Figure 4-3**). The modelled data included bulk spectral wave parameters, namely: significant wave height, peak wave period, mean wave direction, peak wave direction, as well as vectorized wind speeds and wind directions at 10 m above the surface. The temporal resolution of the time-series is 1 hour.

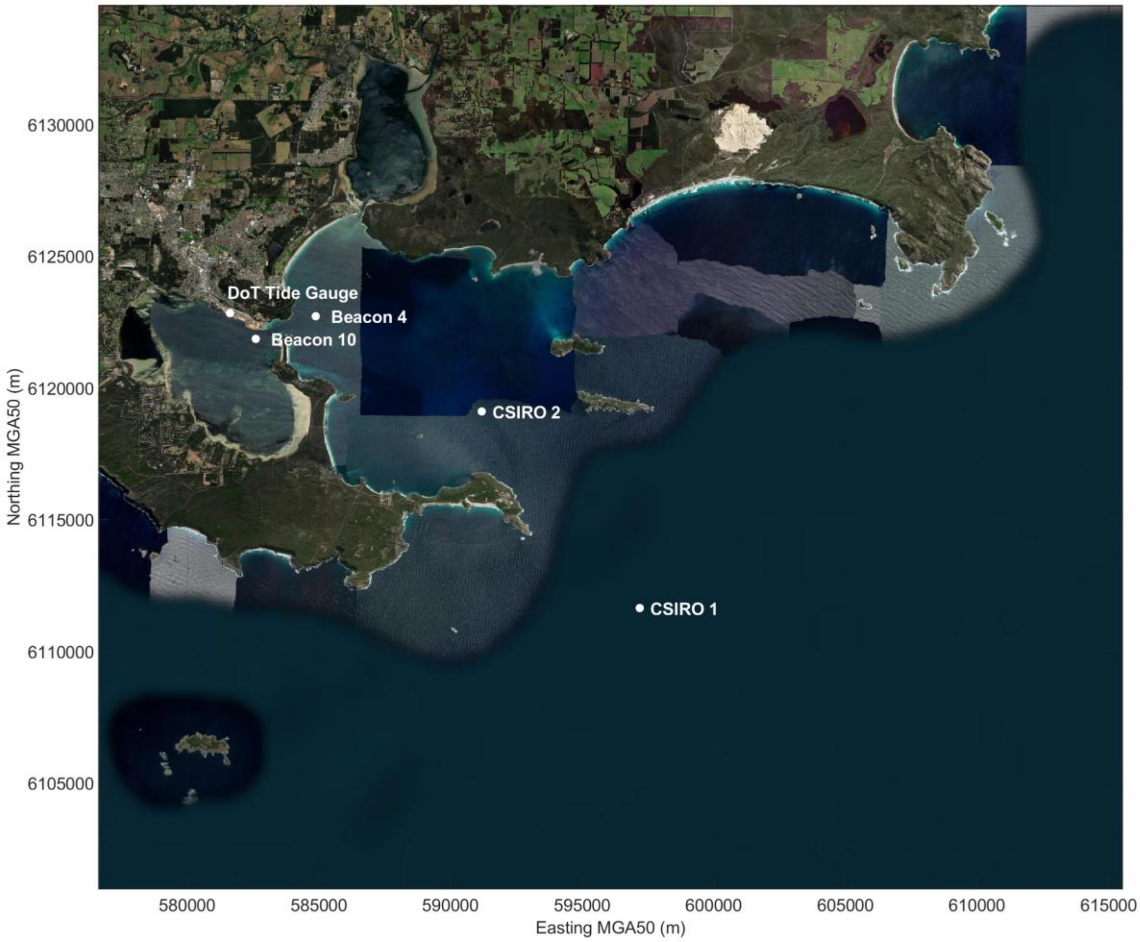


Figure 4-3 Metocean data locations

Using the CSIRO modelled wave data, independent peak significant wave heights were identified, and a directional extreme value analysis was undertaken using the maximum likelihood method, fitting to the Weibull distribution. Independent events in each octant required 72 hours of separation between peaks. These techniques were used to estimate directional 100-year average recurrence interval (ARI) significant wave height for east through west south-westerly directional sectors. Jointly occurring peak wave periods have been derived from a correlation analysis between significant wave height and peak wave period. The results of the extreme value analysis are presented in **Table 4-2**.

The results from the extreme value analysis were subsequently applied to the boundary of a SWAN (Simulating WAves Nearshore) wave model, to investigate the propagation of swell waves into PRH. The significant wave height was extracted at four locations at the entrance of PRH (Location 1 to 4 in **Figure 4-4**). Based on the outcomes of the investigation, the propagation of swell waves into the harbour is predominantly confined to the protected shoreline within MU1. This is demonstrated in **Figure 4-6** and **Figure 4-7**, which show the propagation of the 100-year ARI east south-easterly scenario, which resulted in the largest significant wave height at all four output locations. In addition to the five output locations, the significant wave height was also extracted in approximately 10 m of water depth offshore from the isthmus with MU5 (Location 5 in **Figure 4-4**).

The results of the swell penetration investigation were used to define the design storm for assessment of coastal erosion on the eastern side of the isthmus. This involved scaling the stipulated design storm (MRA, 2018) to peak at the modelled 100-year ARI wave parameters at Location 6 in **Figure 4-4**. The timeseries was subsequently used to investigate short-term acute (storm-induced) erosion on the eastern side of the isthmus (see **Section 4.2.7**). An example of the pre-scaled is provided in **Figure 4-5**.

Table 4-1 Extreme significant wave heights within King George Sound (CSIRO 1 in **Figure 4-3)**

| Directional Sector | | 1 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| Omni | Hm0 (m) | 6.4 | 7.5 | 7.8 | 8.1 | 8.4 |
| | Tp (s) | 16.2 | 16.4 | 16.5 | 16.6 | 16.7 |
| E (90°TN) | Hm0 (m) | 1.3 | 3.0 | 3.2 | 3.2 | 3.3 |
| | Tp (s) | 8.0 | 9.7 | 9.9 | 9.9 | 10.0 |
| ESE (112.5°TN) | Hm0 (m) | 3.0 | 4.2 | 4.7 | 5.1 | 5.5 |
| | Tp (s) | 10.0 | 10.3 | 10.4 | 10.6 | 10.7 |
| SE (135°TN) | Hm0 (m) | 3.1 | 4.9 | 5.6 | 6.1 | 6.6 |
| | Tp (s) | 10.5 | 10.7 | 10.8 | 10.9 | 10.9 |
| SSE (157.5°TN) | Hm0 (m) | 3.3 | 4.9 | 5.8 | 6.5 | 7.3 |
| | Tp (s) | 13.7 | 13.5 | 13.3 | 13.2 | 13.0 |
| S (180°TN) | Hm0 (m) | 4.1 | 5.9 | 6.7 | 7.4 | 8.0 |
| | Tp (s) | 14.2 | 14.0 | 13.8 | 13.7 | 13.6 |
| SSW (202.5°TN) | Hm0 (m) | 6.2 | 7.3 | 7.7 | 7.9 | 8.2 |
| | Tp (s) | 16.2 | 16.4 | 16.5 | 16.6 | 16.7 |
| SW (225°TN) | Hm0 (m) | 6.2 | 7.2 | 7.5 | 7.7 | 7.9 |
| | Tp (s) | 15.2 | 16.0 | 16.3 | 16.5 | 16.6 |
| WSW (247.5°TN) | Hm0 (m) | 3.6 | 4.6 | 5.0 | 5.2 | 5.5 |
| | Tp (s) | 12.8 | 12.7 | 12.6 | 12.6 | 12.6 |


Figure 4-4 Output locations for swell penetration investigation

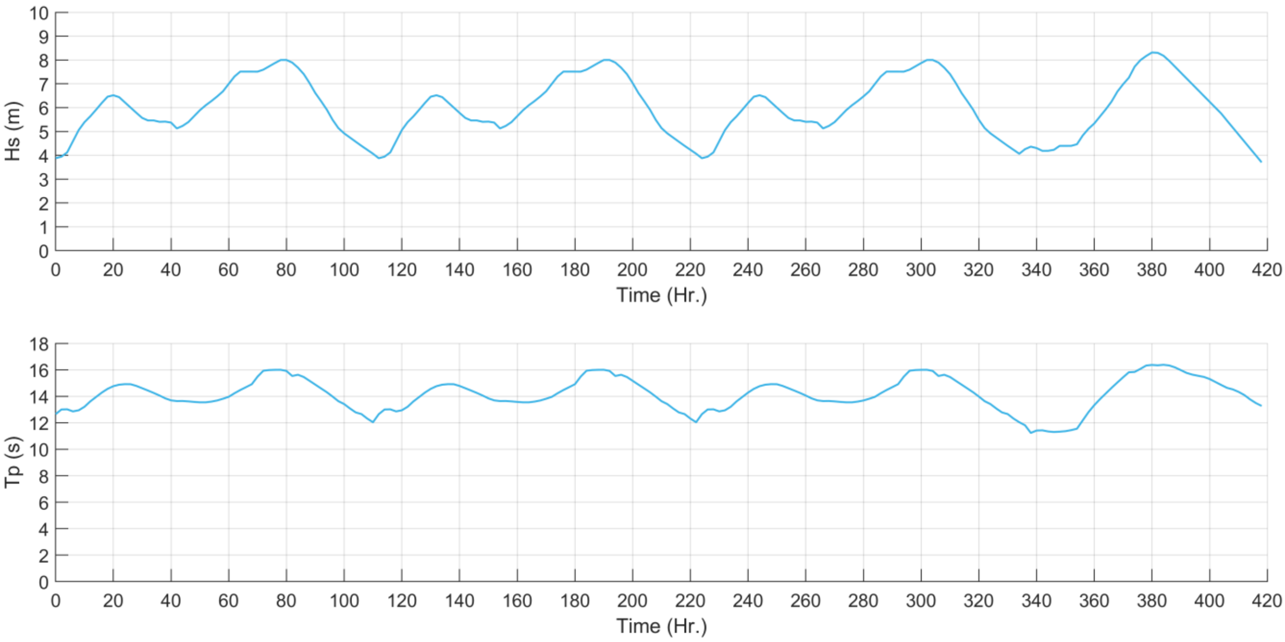


Figure 4-5 Pre scaled storm sequence at the location of the Albany Wave Buoy

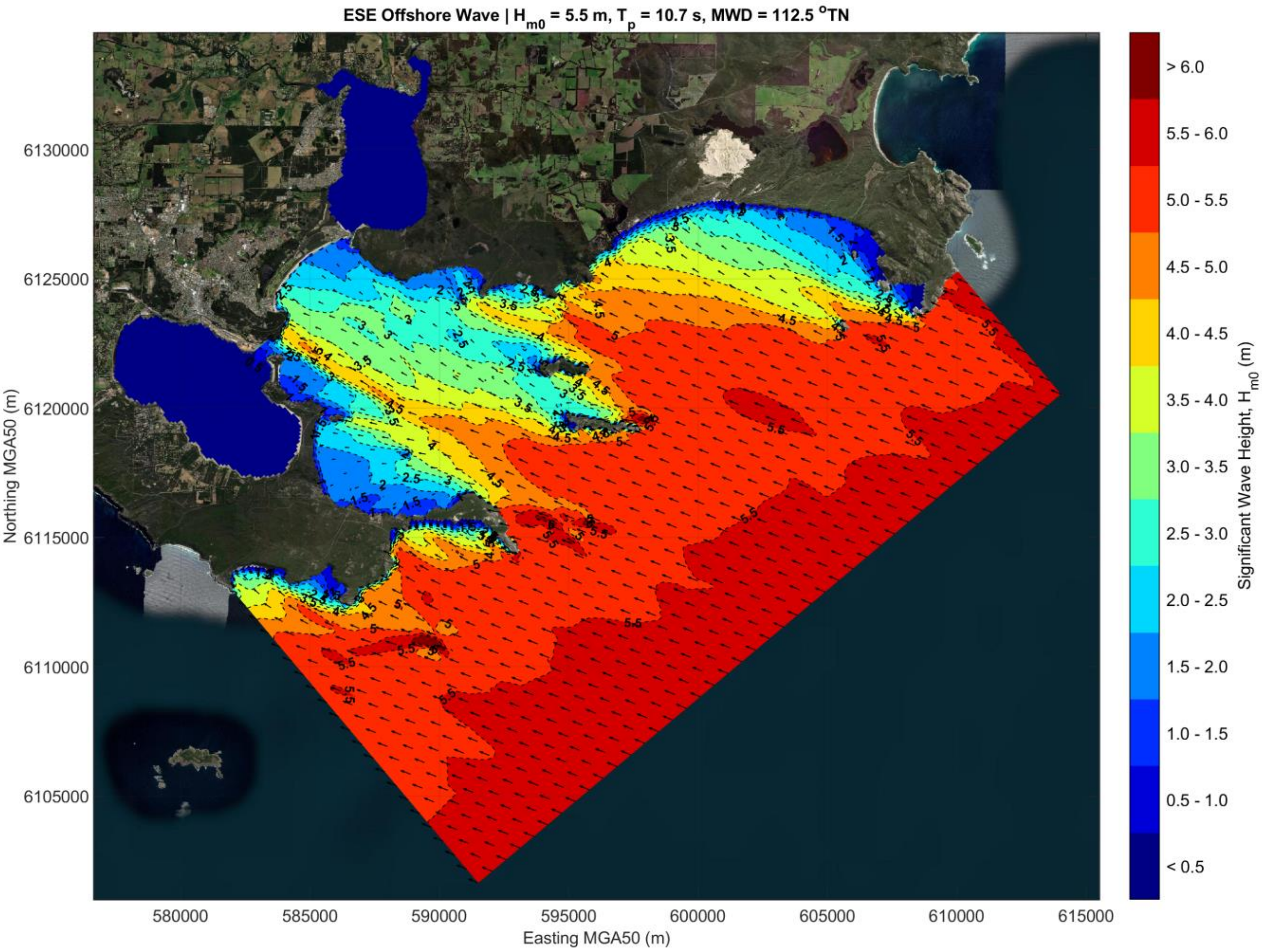
ESE Offshore Wave | Hm0 = 5.5 m, Tp = 10.7 s, MWD = 112.5 °TN
Northing MGA50 (m)
Easting MGA50 (m)
Significant Wave Height, Hm0 (m)
> 6.0
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
1.5 - 2.0
1.0 - 1.5
0.5 - 1.0
< 0.5

Figure 4-6 Coarse SWAN grid showing the propagation of east south-easterly swell waves into Princess Royal Harbour

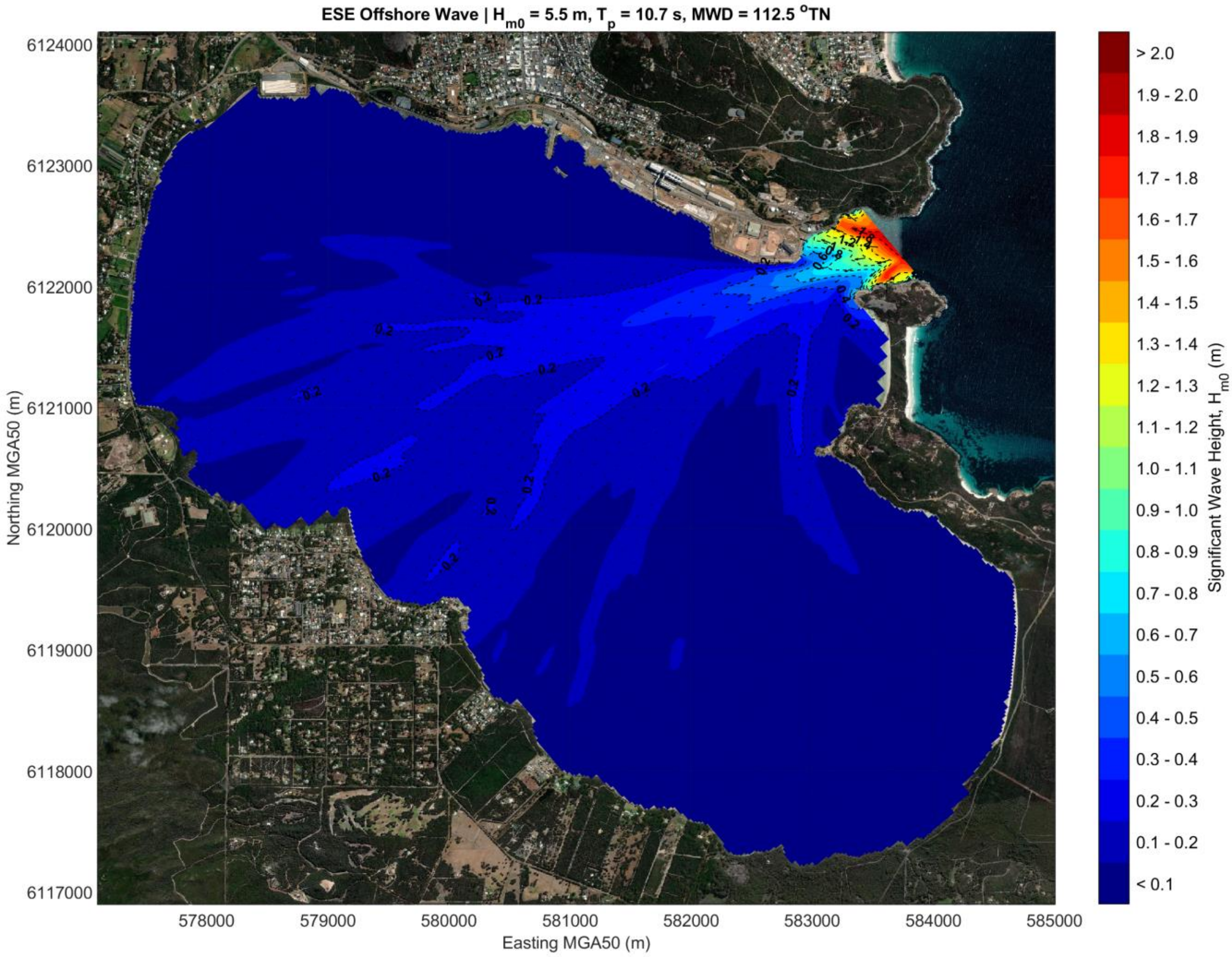


Figure 4-7 Fine SWAN grid showing the propagation of east south-easterly swell waves into Princess Royal Harbour

### 4.2.5 Local Sea Waves

Local sea waves within PRH are generated by winds blowing across the harbour. These are governed by fetch (the distance across the water body over which the wind blows), as well as the wind speed and direction.

Based on the outcomes of the swell wave penetration investigation, the local wave climate within PRH has been assumed to be predominated by local seas. Accordingly, the design storm for assessment of coastal erosion on protected sections of shoreline has been defined based on a hindcast of available wind data. The dataset used for analysis was obtained from the CSIRO CAWCR WaveWatch III Australian wind and wave model system, at a location within King George Sound (CSIRO 2 in **Figure 4-3**). The modelled data included 42 years (1979 through 2021) vectorized wind speeds and wind directions at 10 m above the surface, at a temporal resolution of 1 hour.

The modelled dataset was validated against approximately 6 years of measured wind data between November 2016 and April 2022, obtained from the Port's meteorological stations on Beacons 4 and 10 (**Figure 4-3**). The measured data includes 10-minute averaged wind speed, direction, and maximum gust. Comparisons of wind parameter datasets indicate that, overall, the hindcast CSIRO winds agree well with the measurements at Beacon 10, both in terms of wind speed and direction (**Figure 4-8**). Generally, 10-minute average wind speeds measured at Beacon 10 are higher than those hindcasted in CSIRO, most notably during periods of moderate wind speeds, between high wind speeds. This may be attribute to the relatively broad spatial scale of the CSIRO modelled wind data (approximately 7 km resolution), compared to the specific conditions encountered at the Beacon 10 location. The location of Beacon 10 may also be subject to wind tunnelling through the PRH entrance, and sheltering effects from adjacent land masses, depending on the wind direction. Given that the strongest wind speeds are relatively well represented by the modelled data, the long-term dataset is considered suitable for extreme value analysis of winds likely to drive the locally generates sea climate within PRH.

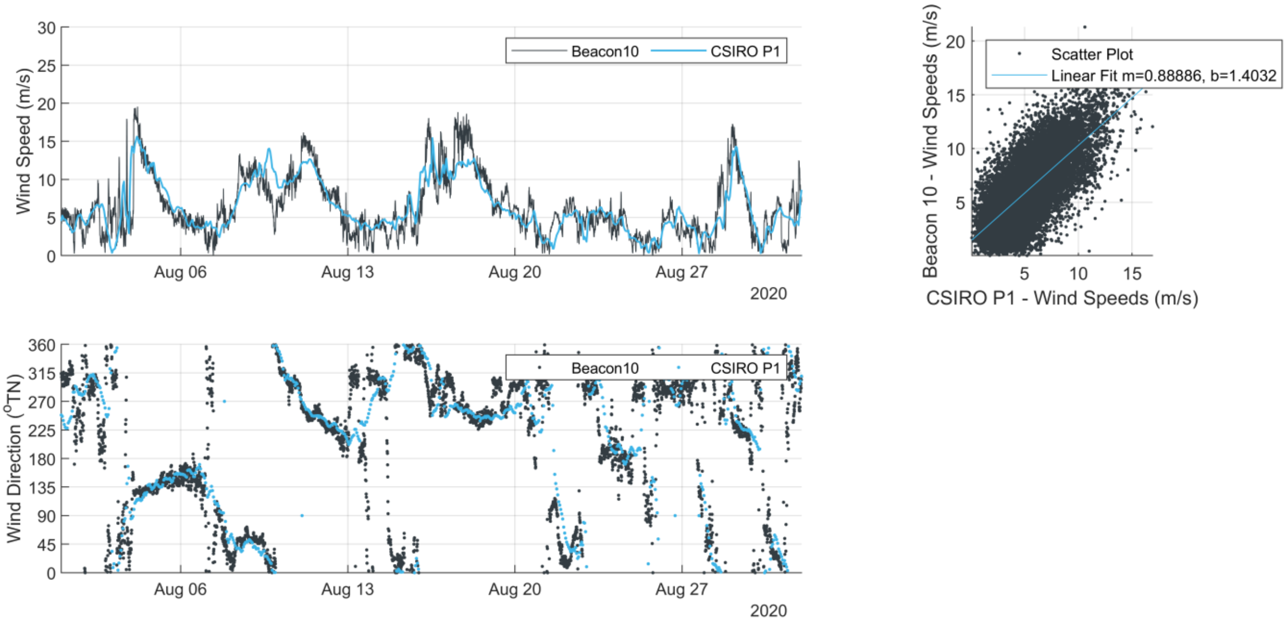


Figure 4-8 Wind comparison

Using the CSIRO modelled wind data, independent peak wind speeds were identified, and a directional extreme value analysis was undertaken using the maximum likelihood method, fitting to the Weibull distribution. Independent events in each octant required 24 hours of separation between peaks. These techniques were used to estimate directional 100-year average recurrence interval (ARI) wind speeds. The results of the extreme value analysis from each of the eight cardinal and intercardinal directions are presented in **Table 4-2**.

These peak event wind speeds are generally lower than those presented in the Australian wind code, AS1170. This outcome arises, to some extent, because the wind data used in the preparation of the wind code design parameters are based on data from more than one anemometer site in a region. Hence, for a selected data period, more storm events occur, thereby raising the design wind speeds. This effect will be different for different directions.

Table 4-2 Extreme wind speeds for Princess Royal Harbour – 10-minute average wind sped (m/s)

| Directional Sector | 1 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|
| Omni | 19.9 | 23.0 | 24.3 | 25.2 | 26.2 |
| NE (45°TN) | 14.1 | 16.4 | 16.9 | 17.2 | 17.4 |
| E (90°TN) | 16.4 | 18.0 | 18.7 | 19.3 | 20.0 |
| SE (135°TN) | 15.2 | 22.2 | 25.4 | 28.5 | 31.7 |
| S (180°TN) | 14.6 | 20.8 | 24.4 | 27.4 | 30.5 |
| SW (225°TN) | 18.1 | 21.5 | 22.8 | 23.8 | 24.8 |
| W (270°TN) | 19.7 | 22.2 | 23.6 | 24.6 | 25.7 |
| NW (315°TN) | 16.5 | 18.6 | 19.2 | 19.6 | 19.9 |
| N (360°TN) | 16.6 | 20.9 | 21.8 | 22.4 | 22.9 |

The results from the extreme value analysis were used to scale representative storm sequences to peak at the 100-year ARI wind speed. For each wind direction, the representative storm sequences were derived by extracting up to five directional hindcast storm events from the CSIRO modelled wind dataset. The extracted storm events were then ranked, based on peak and sustained wind speeds, and a preferred event was selected. The representative storm sequences, scaled to peak at the 100-year ARI wind speed are shown in **Figure 4-9**.

The representative storm sequence for each of the eight cardinal and intercardinal directions were applied uniformly across the SWAN model domain. For each storm event, timeseries of significant wave height, peak wave period and water level were extracted in a water depth of approximately 0.5 m, offshore the PRH shoreline. The timeseries were subsequently used to investigate short-term acute (storm-induced) erosion (see **Section 4.2.7**).

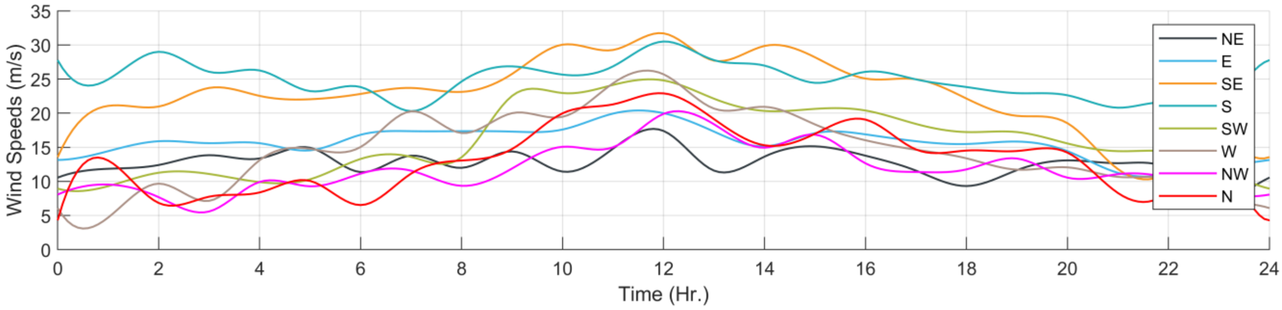


Figure 4-9 Representative storm sequences scaled to peak at the 100-year ARI wind speed and water level

### 4.2.6 Water Level

Extreme water levels within PRH are comprised of several components, including the astronomical tide, inverse barometer effects, wind- and wave-driven set-up, and to a minor extent, freshwater runoff from adjacent catchments.

In order to estimate extreme water levels within PRH, measured water level data between January 1987 and present was obtained from the Department of Transport's tide gauge located in approximately 12m of water depth within PRH (**Figure 4-3**). An extreme value analysis of the dataset was undertaken using the maximum likelihood method. A 48-hour constraint (1 day either side of a peak water level) was applied to ensure all observations used in the EVA were statistically independent. These techniques were used to estimate offshore extreme water levels within PRH. The results of the extreme value analysis are presented in **Table 4-3**.

The results from the extreme value analysis are expected to accurately account for local variations in the astronomical tide and inverse barometer effects. However, given the water level dataset has been measured in a water depth of approximately 12m, the extent of wind and wave set-up that would occur in shallower sections of PRH would not have entirely been accounted for.

Table 4-3 Present day extreme water levels at PRH from EVA analysis (excluding set-up)

| ARI (years) | Extreme Water Level at PRH (mAHD) (m AHD) |
|---|---|
| 1 | 0.79 |
| 10 | 0.93 |
| 50 | 1.05 |
| 100 | 1.08 |
| 500 | 1.14 |

The water level coinciding with the design storm was selected based on a representative storm sequence extracted from the Port's tide gauge data. As a conservative approach, the representative storm sequence was scaled to peak at the 100-year ARI water level (**Figure 4-10**). An example of the peak significant wave height modelled within the fine grid, during the westerly storm event, is presented in **Figure 4-11**.

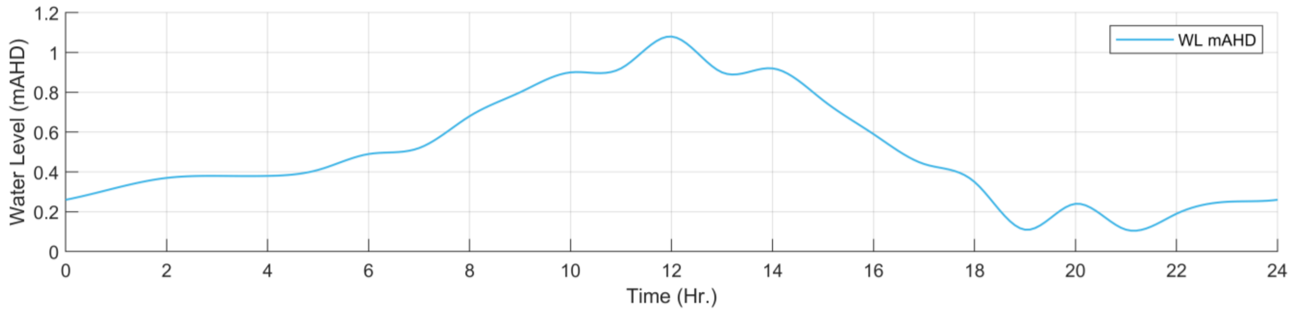


Figure 4-10 Representative storm sequences scaled to peak at the 100-year ARI wind speed and water level

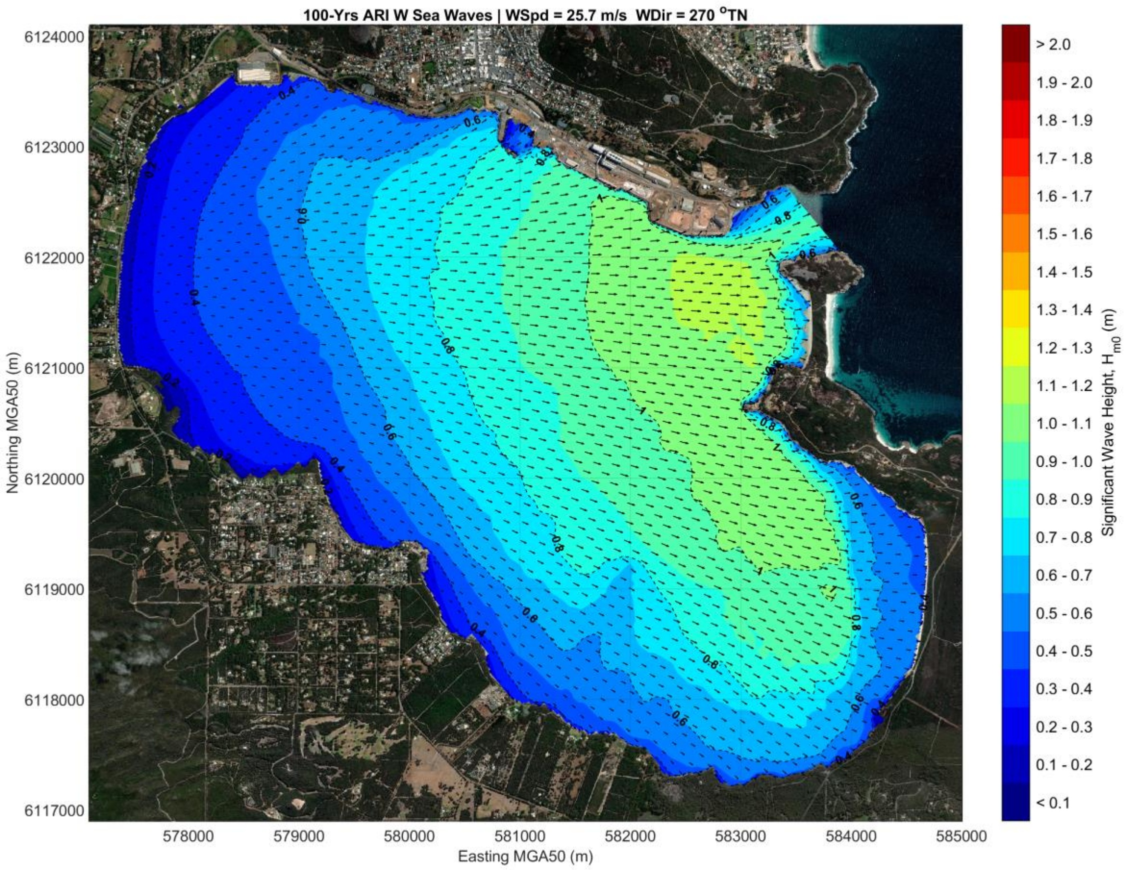


Figure 4-11 SWAN wave field modelled within the 20 m grid during the westerly storm event

### 4.2.7 Storm Erosion Modelling

Short-term acute (storm-induced) erosion across the study site was investigated using the SBEACH numerical, model as recommended in SPP2.6, for calculation of the S1 coastal processes allowance. A total of 20 shore-normal beach profiles were applied in the simulation of S1 storm erosion within PRH, extending offshore to approximately the -0.5m AHD contour. Given the width of the isthmus, there is potential for erosion of the eastern and western shorelines to contribute to a breach of the feature. As such, 1 additional shore-normal beach profile was applied to simulate the S1 storm erosion on the eastern side of the isthmus. The location and length of each profile was based on an assessment of the study area, coastal topography, and nearshore bathymetry. The length of the SBEACH profiles have been minimised to allow time for wave refraction processes to be resolved in SWAN. The locations of the 21 SBEACH profiles are shown in **Figure 4-12**.

Based on the results from the SWAN modelling, the critical storm event was identified for each shoreline MU. The critical storm event was defined based on the maximum modelled significant wave height at the offshore boundary of each SBEACH profiles.

The median sediment grain size ($D_{50}$) used for the SBEACH modelling was based on sediment sampling undertaken during April 2021. Particle Size Distribution (PSD) analysis was undertaken on representative sediment samples collected at each of the four sections of coastline. Observations from the field, as well as results of the PSD analysis, showed in situ sediment in some locations comprised of two distinct sediment classes. This included fine to medium grain sand, as well as fragments of larger material, such as gravel, organic material, and shells. As a conservative approach, the PSD data has been filtered to remove large fragments of material, prior to characterising the $D_{50}$.

The results from the PSD analyses are generally comparable across the study area and to those documented in Seashore (2020). suggesting that there is low spatial and/ or temporal variability in sediment characteristics within PRH. While no PSD analyses is reported, Travers et al (2010) also suggests that sediments within PRH ranged from fine to medium (0.19 to 0.5mm).

In accordance with SPP2.6, the representative storm sequences have been applied three times in succession, simulating the shorelines response to 72 hours of elevated wave and water level conditions. The storm was applied as being perpendicular to the coast at each profile, which is a conservative, however not unrealistic, assumption. The results of the SBEACH simulation for each profile were analysed in order to determine the HSD elevation and the S1 storm erosion allowance for each profile as per SPP2.6. Plots showing the results of the SBEACH simulation for each profile are presented in **Appendix A**.

Table 4-4 Wave conditions and sediment sizing adopted for SBEACH modelling

| Profile | Peak significant wave height, Hs (m) | Peak wave period, Tp (s) | Critical Storm Direction | D50 (mm) |
|---|---|---|---|---|
| T01 | 0.6 | 3.6 | S | 210 |
| T02 | 0.5 | 3.3 | S | 370 |
| T03 | 0.5 | 2.1 | SE | 370 |
| T04 | 0.6 | 2.3 | SE | 370 |
| T05 | 0.6 | 2.1 | SE | 270 |
| T06 | 0.5 | 2.5 | E | 270 |
| T07 | 0.5 | 2.5 | NE | 360 |
| T08 | 0.7 | 3.0 | SE | 380 |
| T09 | 0.6 | 2.7 | N | 360 |
| T10 | 0.9 | 2.7 | SE | 360 |
| T11 | 0.6 | 3.0 | N | 310 |
| T12 | 0.6 | 2.7 | E | 310 |
| T13 | 0.6 | 2.7 | N | 310 |
| T14 | 0.6 | 2.7 | N | 310 |
| T15 | 0.6 | 2.7 | N | 310 |
| T16 | 0.6 | 2.7 | W | 310 |
| T17 | 0.6 | 3.0 | W | 320 |
| T18 | 0.6 | 2.7 | W | 320 |
| T19 | 0.5 | 2.5 | SW | 210 |
| T20 | 0.7 | 3.3 | W | 210 |
| T21 | 1.6 | 10.8 | ESE | 350 |


# PRINCESS ROYAL HARBOUR

FIGURE 4-12: SBEACH PROFILE LOCALITY PLAN

**Legend**

- SBeach Profiles
- Suburb Boundaries

Date
5/12/2022

Size
A4

Scale
1:45,000

0 250 500 750 1,000 Meters

CW1200123-GS-006-SBEACHTRANSECTLOCALITYPLAN_A4

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Aerial Imagery supplied by MetroMap (19/12/2021)



DATE PLOTTED:5/12/2022 5:38:34 PM BY: CORY SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-006-SBEACHTransectLocalityPlan_A4.mxd

## 4.3 S2 Erosion Allowance

An analysis of historical vegetation lines based on aerial photography has been undertaken in order to estimate the historical shoreline movement trends and thus an appropriate S2 erosion allowance, in line with the requirements of SPP2.6. This analysis method assumes the movement of the vegetation line is a valid proxy for shoreline movement.

### 4.3.1 Analysis of Historical Shoreline Movement

Analysis of historical shoreline movement has been undertaken based on historical aerial imagery for the following years: 1943, 1976, 1997, 2004, 2007, 2011, 2014, 2016 and 2021. The analysed vegetation line for each year covered varying proportions of the study area; some years covered the entire study area while many others covered only small sections. The position of the vegetation line for all years for which data was provided was analysed at 200 m intervals along the length of the study area (**Figure 4-13**).

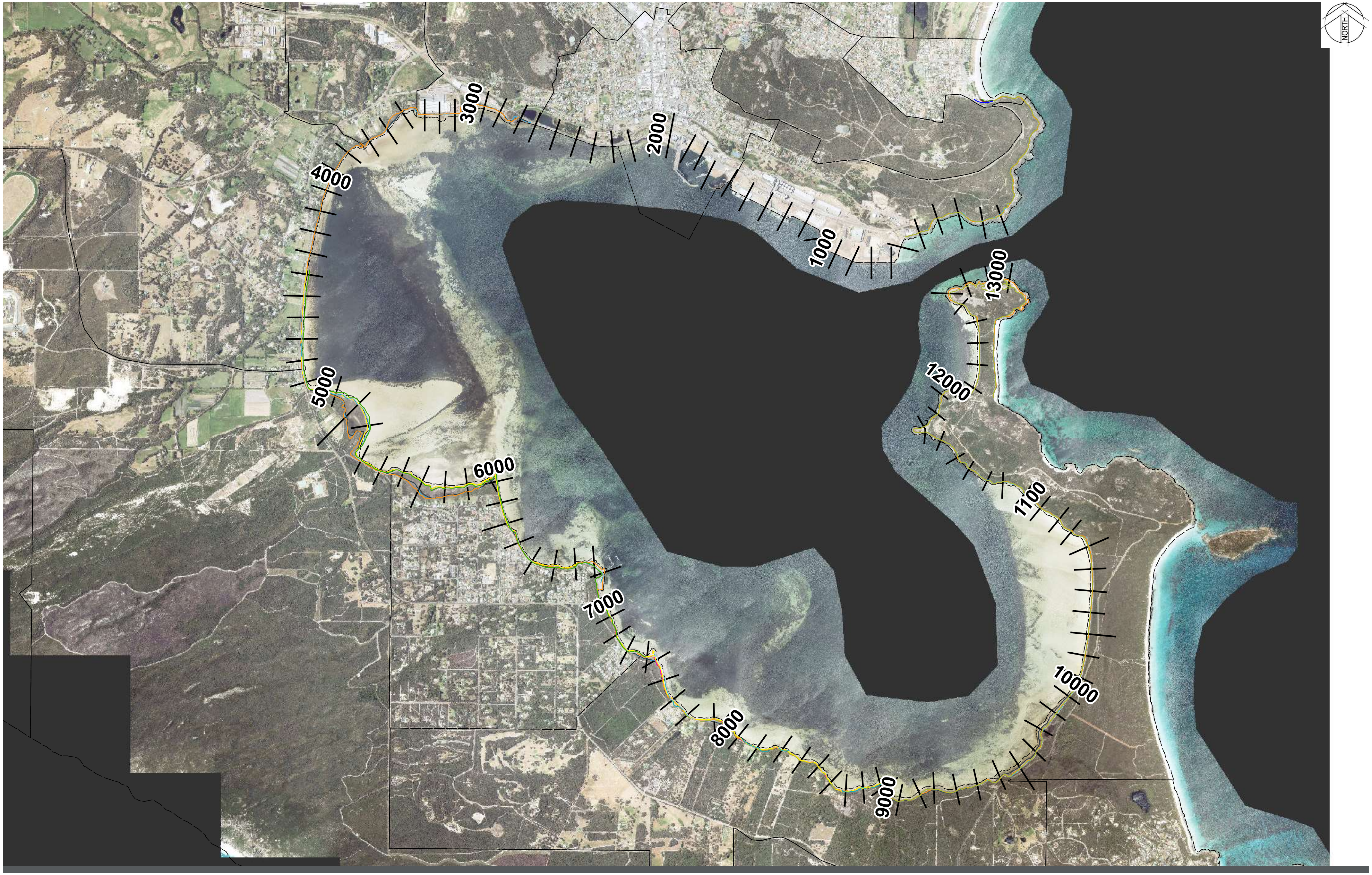
In order to estimate the long-term average shoreline movement rate, the change in shoreline position was analysed between each of the selected years and a baseline time period, depending on the location. The historical shoreline movement distances are presented in **Figure 4-14**. Based on analysis of the average rates of shoreline change across the study area, an S2 rate of annual shoreline movement was derived. The selection of this rate has considered the various coastal controls along the length of the PRH coastline. As a conservative approach and in line with the recommendations of SPP2.6, the S2 erosion allowance was selected as zero for all areas where long-term accretion has been observed.

Due to the presence of shoreline protection structures such as seawalls and revetments, vegetation lines are unable to be analysed for some sections of coastline. As such, an estimate of the likely long-term stability of the coastline has been undertaken based on the sections of shoreline immediately adjacent to these structures. It has been assumed that these protection structures are adequately maintained until the end of their estimated remaining serviceable life.

The results from the historical shoreline movement analysis indicate PRH has remained relatively stable since 1943. The most notable changes in the position of the shoreline include erosion along the Torndirrup and Little Grove foreshores (Ch. 4,900 to 6,000), however these observations appear to be attributed to discrepancies in interpretating the vegetation line. Other noteworthy areas of shoreline instability have been identified anecdotally and reinforced through the historical shoreline movement analysis. Such areas include the foreshore along Frenchman Bay Road (Ch. 4,000 to 5,000), Rushy Point (Ch. 6,000, to 6,4000), the foreshore along Harbour Esplanade Road (Ch. 7,000 to 7,300), and the Panorama Caravan Park foreshore (Ch. 7,600 to 7,700).

A comparison of recent aerial imagery and historical chart data dated 1814 (**Figure 4-15**), indicates that some changes in the position of the shoreline have occurred, without necessarily being reflected in the vegetation line mapping. These changes include accretion of land in the lee of the active sand feed at Torndirrup, and accretion of the sand spit at Rushy Point. Some erosion can also be observed along the eastern shoreline of Rushy Point. There also appears to have been some reclamation of land at and immediately south of the Woolstores. The recent erosion observed in this area may be attributed to the shoreline adjusting to a new state of equilibrium. Other areas of the PRH, such as the undulating shoreline along Big Grove appear to have remained relatively stable over the last approximately 200 years.

The comparison of recent and historical chart data also indicates changes in the local bathymetry. Such changes include shallowing of the nearshore seabed between Ch. 2,000 and 4,000, Ch. 5,000 and 6,000, and Ch. 9,000 and 1,100. These changes could be attributed to the development along the northern shoreline of PRH.




**Legend**

Vegetation lines

| | | | |
|---|---|---|---|
| 1904 | 1965 | 2004 | 2014 |
| 1943 | 1976 | 2007 | 2016 |
| 1957 | 1986 | 2008 | 2021 |
| | 1997 | 2011 | Chainage lines |

Date
5/12/2022

Size
A4

Scale
1:45,000

0 250 500 750 1,000 Meters

# PRINCESS ROYAL HARBOUR

## FIGURE 4-13: SHORELINE MOVEMENT PLAN

CW1200123-GS-007-SHORELINEMOVEMENTPLAN_A4

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Web: www.cardno.com.au

Aerial Imagery supplied by MetroMap (19/12/2021)




DATE PLOTTED:5/12/2022 5:39:15 PM BY: CORY.SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-007-ShorelineMovementPlan_A4.mxd

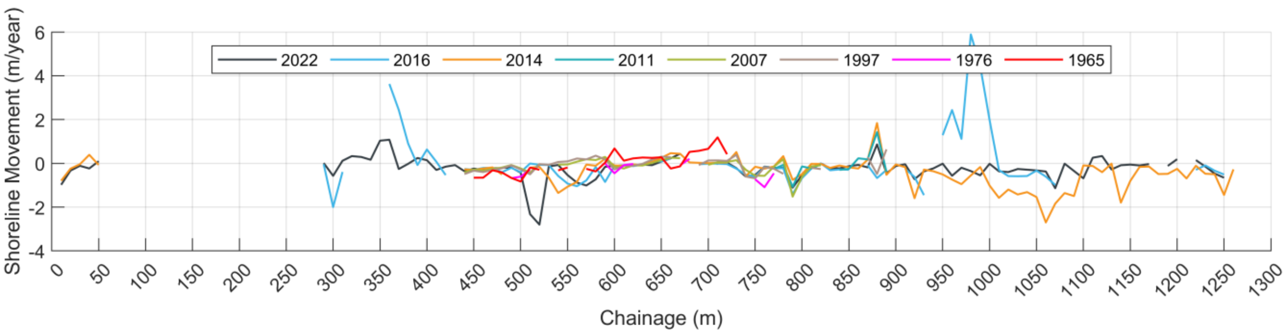



Figure 4-14 Shoreline movement plot relative to baseline imagery

Figure 4-15 Comparisons in recent aerial imagery (2022) and historical chart data (1814)

## 4.4 S3 Erosion Allowance

In line with the requirements of SPP2.6, for the 2120 planning timeframe, an S3 erosion allowance for projected future sea level rise of 94 m (100 times the adopted sea level rise value of 0.94m) was adopted across the study area. For the intermediate planning timeframes of 2047 and 2072, values of 15 and 35 m, respectively, were adopted (100 times the adopted sea level rise value at each timeframe).

## 4.5 Coastal Erosion Allowances Summary and Mapping

The coastal foreshore reserve allowances for coastal erosion have been calculated at present day, 2047, 2072 and 2122. The total allowances were calculated for two scenarios; controlled and uncontrolled, as the sum of the S1, S2 and S3 components plus the uncertainty allowance of 0.2 m/year, as per SPP2.6. The controlled scenario assumes that existing physical controls detailed in **Table 3-1** are adequately maintained until the end of their remaining serviceable life. The uncontrolled scenario assumes the existing physical controls are removed immediately. The rate of shoreline change following removal of the existing physical controls has been estimated based on the sections of shoreline immediately adjacent to the control. The total coastal foreshore reserve allowances with and without coastal controls, are summarised in **Table 4-5** and **Table 4-6**, respectively. The full results with each component value are presented in **Appendix B**. The significant range in the total allowance across profiles is mainly attributed to differences in the S2 component that can, in places, vary significantly over relatively short distances along the coast.

The coastal erosion allowance at present day (2022), 2047, 2072 and 2122, with, and without coastal controls, was spatially mapped in order to demonstrate the areas that are potentially at risk from coastal erosion over the planning timeframes (**Appendix C**). The allowances were applied perpendicular (inland) to the HSD, which was determined from the results of SBEACH modelling (peak steady water level under storm conditions).

### 4.5.1 Isthmus Stability

The coastal erosion allowances indicate that the isthmus within MU5 could potentially be breached by the 2072 planning horizon. This outcome arises due to the assumption that the feature is entirely sandy above the HSD level. This assumption has been made given the absence of local geotechnical information and the lack of visible bedrock at the surface in available aerial imagery. Geological Surveys of Western Australia (2001) have also characterised the isthmus under geological unit S2, which is defined as sand – white, medium to coarse-grained, moderately well sorted, quartz and shell debris. (see also **Figure 2-2**).

Given the feature's long-term stability however, as evident in the historical chart dated 1814 (**Figure 4-15**), it is considered likely that the isthmus is underlain by stabilising geological features. Furthermore, calculated erosion setbacks are applied horizontally, but do not consider the volume of dune (or, in this case, isthmus) to be eroded to allow them to eventuate. Coastal erosion hazards have been assessed within PRH assuming that the isthmus remains in place as a barrier to the ocean throughout the 100-year planning time frame. If the isthmus was breached and a second entrance to PRH created, implications for coastal hazard risk within the harbour would be significant and, in general, be much higher for assets than those evaluated in this CHRMAP.

Given the potential for much higher future risk and the lack of information available to assess this risk at present, further investigation and ongoing monitoring of the feature will be recommended by the CHRMAP.

Table 4-5 Total coastal erosion allowance summary – Controlled

| Profile | Present day (2022) | 2047 | 2072 | 2122 |
|---|---|---|---|---|
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 0.0 | 0.0 | 0.0 | 150.5 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 33.8 | 66.5 | 180.0 |
| 3,100 - 3,500 | 0.0 | 0.0 | 46.8 | 160.3 |
| 3,500 - 3,900 | 3.0 | 18.3 | 43.5 | 142.0 |
| 3,900 - 4,200 | 3.0 | 19.5 | 46.0 | 147.0 |
| 4,200 - 4,400 | 10.0 | 22.8 | 45.5 | 139.0 |
| 4,400 - 4,800 | 10.0 | 27.8 | 55.5 | 159.0 |
| 4,800 - 5,000 | 0.0 | 0.0 | 46.8 | 150.3 |
| 5,000 - 5,300 | 0.0 | 9.0 | 28.0 | 114.0 |
| 5,300 - 5,500 | 0.0 | 12.8 | 35.5 | 129.0 |
| 5,500 - 6,100 | 0.0 | 9.0 | 28.0 | 114.0 |
| 6,100 - 6,200 | 4.0 | 15.5 | 37.0 | 128.0 |
| 6,200 - 6,600 | 4.0 | 15.5 | 37.0 | 128.0 |
| 6,600 - 6,700 | 0.0 | 9.0 | 28.0 | 114.0 |
| 6,700 - 6,900 | 0.0 | 0.0 | 0.0 | 128.5 |
| 6,900 - 7,100 | 6.0 | 16.3 | 36.5 | 125.0 |
| 7,100 - 7,300 | 6.0 | 16.3 | 36.5 | 125.0 |
| 7,300 - 8,000 | 0.0 | 22.8 | 55.5 | 169.0 |
| 8,000 - 8,600 | 6.0 | 28.8 | 61.5 | 175.0 |
| 8,600 - 8,900 | 7.0 | 21.0 | 45.0 | 141.0 |
| 8,900 - 9,500 | 1.0 | 28.8 | 66.5 | 190.0 |
| 9,500 - 9,800 | 5.0 | 29.0 | 63.0 | 179.0 |
| 9,800 -10,100 | 1.0 | 23.8 | 56.5 | 170.0 |
| 10,100 - 10,800 | 12.0 | 49.8 | 97.5 | 241.0 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 0.0 | 0.0 | 0.0 | 177.5 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 31.3 | 66.5 | 185.0 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 30.0 | 69.0 | 118.0 | 264.0 |

Table 4-6 Total coastal erosion allowance summary – Uncontrolled

| Profile | Present day (2022) | 2047 | 2072 | 2122 |
|---|---|---|---|---|
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 9.0 | 31.8 | 64.5 | 178.0 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 33.8 | 66.5 | 180.0 |
| 3,100 - 3,500 | 5.0 | 27.8 | 60.5 | 174.0 |
| 3,500 - 3,900 | 3.0 | 18.3 | 43.5 | 142.0 |
| 3,900 - 4,200 | 3.0 | 19.5 | 46.0 | 147.0 |
| 4,200 - 4,400 | 10.0 | 22.8 | 45.5 | 139.0 |
| 4,400 - 4,800 | 10.0 | 27.8 | 55.5 | 159.0 |
| 4,800 - 5,000 | 10.0 | 27.8 | 55.5 | 159.0 |
| 5,000 - 5,300 | 0.0 | 9.0 | 28.0 | 114.0 |
| 5,300 - 5,500 | 0.0 | 12.8 | 35.5 | 129.0 |
| 5,500 - 6,100 | 0.0 | 9.0 | 28.0 | 114.0 |
| 6,100 - 6,200 | 4.0 | 15.5 | 37.0 | 128.0 |
| 6,200 - 6,600 | 4.0 | 15.5 | 37.0 | 128.0 |
| 6,600 - 6,700 | 0.0 | 9.0 | 28.0 | 114.0 |
| 6,700 - 6,900 | 12.0 | 22.3 | 42.5 | 131.0 |
| 6,900 - 7,100 | 6.0 | 16.3 | 36.5 | 125.0 |
| 7,100 - 7,300 | 6.0 | 16.3 | 36.5 | 125.0 |
| 7,300 - 8,000 | 0.0 | 22.8 | 55.5 | 169.0 |
| 8,000 - 8,600 | 6.0 | 28.8 | 61.5 | 175.0 |
| 8,600 - 8,900 | 7.0 | 21.0 | 45.0 | 141.0 |
| 8,900 - 9,500 | 1.0 | 28.8 | 66.5 | 190.0 |
| 9,500 - 9,800 | 5.0 | 29.0 | 63.0 | 179.0 |
| 9,800 -10,100 | 1.0 | 23.8 | 56.5 | 170.0 |
| 10,100 - 10,800 | 12.0 | 49.8 | 97.5 | 241.0 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 6.0 | 43.8 | 91.5 | 235.0 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 31.3 | 66.5 | 185.0 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 30.0 | 69.0 | 118.0 | 264.0 |

## 4.6 S4 Coastal Inundation Allowance

### 4.6.1 Design Storm Event

Schedule One of SPP2.6 describes four different geographical areas for the definition of the design storm event for the assessment of coastal inundation. Princess Royal Harbour lies in area four, which requires the application of a mid-latitude depression or extra-tropical low storm event for coastal erosion. Policy guidance for coastal inundation is that an event corresponding to the 500-year ARI ocean forces and coastal processes should be selected.

### 4.6.2 Allowance for Coastal Inundation

Water levels within PRH are primarily determined by the combination of the astronomical tide (predominantly), inverse barometer effects, wind and wave set-up, and freshwater runoff from adjacent coastal catchments.

An extreme value analysis was undertaken to provide an estimate of extreme water levels within PRH (see **Section 4.2.6**). The tide gauge used to estimate extreme water levels is located within PRH, in a water depth of approximately 12m. As such, the extent of wind and wave set-up that would occur in shallower sections of PRH would not have entirely been accounted for. Thus, it is appropriate and conservative to include an additional allowance for nearshore set-up on top of the peak steady water level.

Wave setup is the increase in ocean water level near to the coast due to wave breaking and the onshore conservation of momentum flux. The extent of wave set-up can be substantial depending on the incident wave conditions and local bathymetry. The results of the SBEACH modelling undertaken as part of the storm erosion modelling (**Section 4.2.7**) were analysed to determine an estimate for nearshore wave setup at each profile location. Nearshore wave setup at the entrance to PRH has been estimated based on the results of the SBEACH modelling on the eastern side of the isthmus. These conditions represent the nearshore wave setup during the 100-year ARI event.

In addition to wave setup, SPP2.6 stipulates that the allowance for coastal inundation is to include consideration for wave runup. Wave run-up refers to the vertical distance that a wave will run up a beach or coastal structure after it breaks. It is generally governed by the incident wave conditions and the slope and form of the nearshore seabed and shoreline. Inundation due to wave runup is therefore transient and irregular in nature and will vary on a wave-by-wave basis. Analogously to wave set-up, estimates of the extent/level of nearshore wave runup were extracted from the results of the SBEACH modelling.

The combined allowances for wave setup and wave runup were averaged across each of the 5 MUs. The adopted allowances are detailed in **Table 4-7**. Values for wave setup and wave runup have been presented separately to account for the uneven temporal and spatial distribution of wave runup.

Table 4-7 Wave setup values adopted in inundation assessment

| Management Unit | Wave setup (m) | Wave runup (m) |
|---|---|---|
| MU1 - Sheltered | 0.20 | 1.8 |
| MU1 - Entrance | 0.70 | 3.0 |
| MU2 | 0.10 | 0.6 |
| MU3 | 0.10 | 0.6 |
| MU4 | 0.10 | 0.6 |
| MU5 – Sheltered | 0.20 | 0.6 |
| MU5 – Eastern Shoreline | 0.70 | 3.0 |

### 4.6.3 Allowance for Catchment Inundation

PRH is not connected to any rivers but receives freshwater inflow from rainfall runoff, groundwater seepage and drainage discharge from adjacent land catchments. Consideration has been given to the statistical dependence between extreme rainfall and extreme coastal water levels, given that both variables can be driven by common meteorological forcings. Low-pressure systems, for example, may produce strong onshore winds and an inverse barometric effect, leading to extreme nearshore water levels, while simultaneously generating large quantities of rainfall on the adjacent catchments.

Engineers Australia (2014) undertook an investigation into the statistical dependence of runoff generated by extreme rainfall and elevated sea levels due to storm surge. The investigation indicates that the dependence between rainfall and tidal events in the Albany region is relatively weak. Nonetheless, the local topography surrounding PRH is relatively steep, resulting in a time of concertation in the order of 2 hours. The time of concentration is an estimate of the time required for runoff to travel between the upstream and downstream bounds of the catchment. The low time of concentration is expected to increase the dependence between the two inundation mechanisms.

For conservatism, an allowance for surface water runoff has been included in the calculation of S4 coastal inundation allowance for PRH. The allowance has been estimated using hydrological and hydraulic modelling, based on the localised increase in the hydraulic gradient at the discharge locations. A common approach to assessing joint probability between catchment and coastal inundation is provided in NSW Department of Environment (2010). The approach adopts a probability ratio of 1:5 between the two mechanisms, i.e., assuming 100-year ARI catchment inundation and 500-year ARI coastal inundation occur concurrently. This approach has been adopted for this study.

It should be noted that elevated tailwater within PRH can have significant impact on upstream flood levels. The assessment of which is outside of this coastal hazard assessment.

*Intensity Frequency Duration*

Intensity-frequency-duration (IFD) data was required to characterise the storm intensity within the study area. This is generally provided by techniques in ARR (Australian Rainfall and Runoff), a national guideline for the estimation of design flood characteristics in Australia. The IFD data for PRH is presented in **Table 4-8**.

Table 4-8 Intensity frequency duration data (rainfall in mm)

| Duration | ARI | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 Year | 2 Year | 5 Year | 10 Year | 20 Year | 50 Year | 100 Year |
| 1 hour | 13.7 | 15.3 | 20.7 | 24.9 | 29.5 | 36 | 41.5 |
| 2 hours | 17.9 | 20 | 26.9 | 32.2 | 37.8 | 45.8 | 52.4 |
| 6 hours | 27.7 | 30.8 | 41.2 | 48.9 | 57 | 68.8 | 78.8 |
| 12 hours | 35.8 | 39.9 | 53.6 | 63.9 | 74.7 | 91.1 | 105 |
| 24 hours | 44.7 | 50 | 68.2 | 82.3 | 97.6 | 121 | 141 |
| 72 hours | 60 | 67.4 | 94.1 | 116 | 140 | 178 | 210 |

*Catchment Delineation*

The major surface water catchments within the study area discharge into PRH via open channels adjacent Robinson Road and Princess Avenue (**Figure 4-16**). These catchments collect runoff from agricultural land in the Robinson Estate and Marbellup-Elleker region, and effluent from local industry. The catchments have been delineated using a combination of LiDAR data collected in 2021, and Shuttle Radar Topography Mission (SRTM) data collected in 2011. Collectively, the total catchment area is approximately 35 $km^2$. A description of the key catchment parameters adopted in the hydrological model is provided in **Table 4-9**.

Table 4-9 Catchment Parameters

| Catchment | Area (km$^2$) | Primary Stream Length (km) | Slope (%) | Impervious % | Initial Loss (mm) | Continual Loss (mm/hr) |
|---|---|---|---|---|---|---|
| Robinson Road | 23.0 | 7.5 | 1.5 | 30 | 20 | 2 |
| Princess Avenue | 12.0 | 4.0 | 3.0 | 30 | 20 | 2 |

*Hydrological Model*

A hydrological model was developed to estimate surface water runoff from the two primary land catchments. The model was developed using XP Solution's Stormwater & Wastewater Management Model (XPSWMM). XPSWMM is a dynamic modelling tool that is the combination of one-dimensional calculations for the channel flow and two-dimensional calculations for the surface runoff modelling.

Using the IFD data for PRH, the 100-year ARI design flood extents within the Robinson Road and Princess Avenue catchments were simulated. In order to identify the critical storm for each catchment, the 1, 2, 6, 12, 24, and 72-hour storm durations were simulated. The critical storm duration was defined as the 6-hour storm event for both catchments, based on the modelled peak discharge into PRH.

*Hydraulic Model*

A two-dimensional hydraulic model was developed to estimate the localised increase in the hydraulic gradient at the Robinson Road and Princess Avenue discharge location. The hydraulic model was developed using the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) numerical model from the US Army Corp of Engineers. HEC-RAS helps to simulate water surface profiles for steady and unsteady flow, water quality analysis, and sediment transport computation.

The model extent was localised to the downstream extents of the Robinson Road and Princess Avenue catchments, using topography from LiDAR data collected in 2021. The 100-year ARI hydrograph was applied to the upstream boundary, and a constant downstream boundary level was applied equivalent to the 500-year ARI coastal inundation level.

The results from the hydraulic modelling indicate that the increase in water level within PRH, due to runoff from adjacent surface water catchments, is relatively minor and highly localised to the discharge locations. The maximum increase in water level was found to be in the order of 0.02 m. As such, this additional allowance of for catchment inundation was adopted within MU2. An increase in SLR may reduce the hydraulic gradient of the adjacent catchment, slightly backing up flows through the catchment and potentially reducing the localised increase in water level. This effect is however expected to be minimal for the projected increase in SLR across the planning horizon, given the much higher elevation of the catchment compared to the sea level.

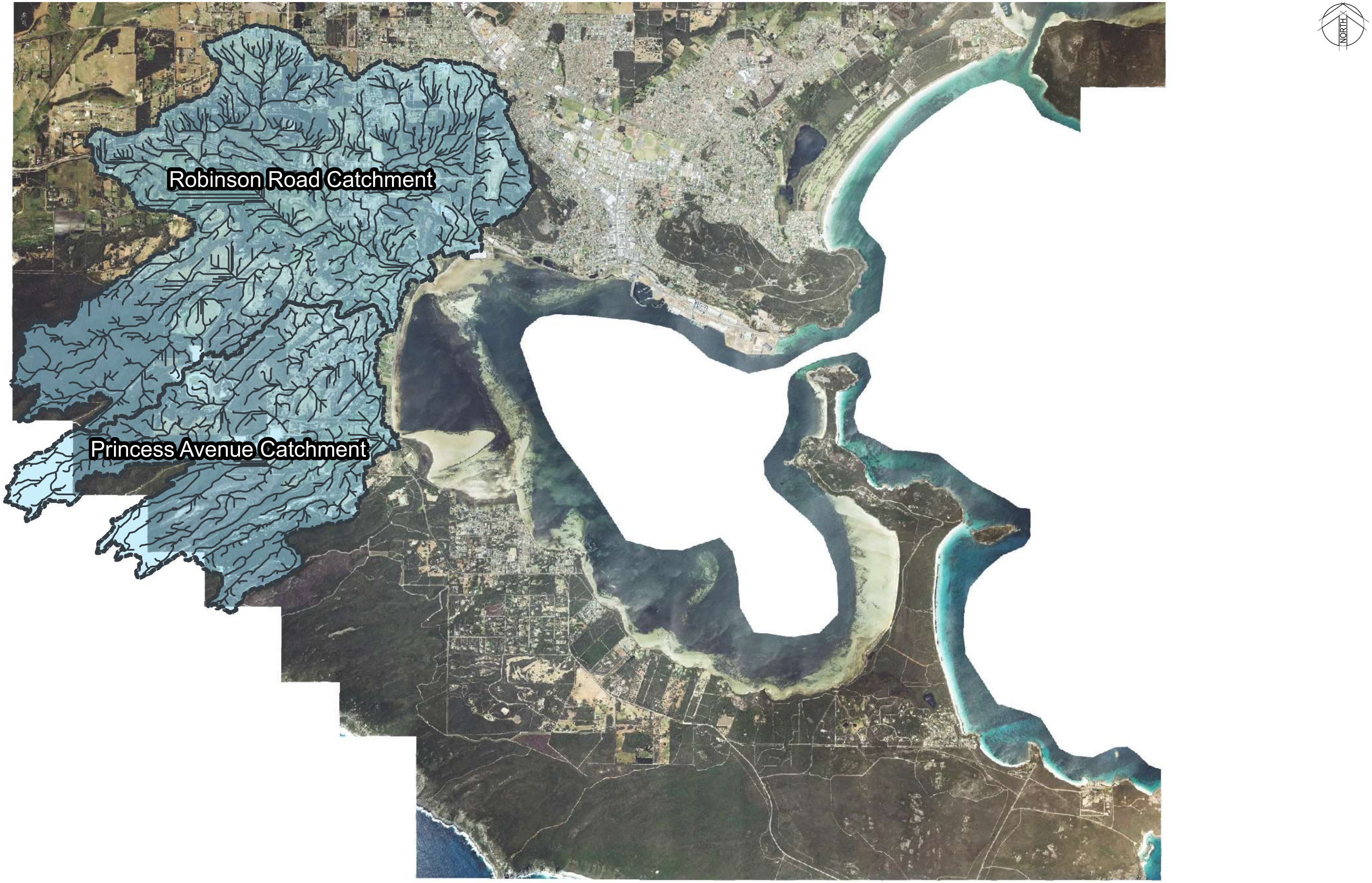
## 4.7 Coastal Inundation Allowances Summary Mapping

The total water levels for storm surge (S4) inundation adopted for this study, which combine extreme water level, nearshore wave setup, wave run-up, an allowance for future sea level rise, and an allowance for catchment inundation, and are presented in **Table 4-10**. Wave run-up is defined in SPP2.6 as being the rush of water up a shoreline (or structure) on the breaking of a wave. It is thus only relevant on or immediately behind a beach (or structure) face upon which waves break, where wave run-up might cause water to rush up far enough to inundate an asset or infrastructure located close to the beach (or structure) face.

The extent of inundation for the present day, 2047, 2072, and 2122 planning timeframe was approximated and mapped for the Study Area (**Appendix D**). The extent was estimated using LiDAR data collected in 2021. The study area comprises several areas of low-lying topography which are subject to flooding during the present-day planning horizon. Such areas include the Mount Elphinstone, Robinson, Little Grove, and Big Grove foreshores.

Table 4-10 S4 storm surge inundation levels

| Management Unit | Present Day (2022) | 2047 | 2072 | 2122 | Wave runup (m) |
|---|---|---|---|---|---|
| MU1 - Sheltered | 1.34 | 1.49 | 1.69 | 2.28 | 1.8 |
| MU1 - Entrance | 1.84 | 1.99 | 2.19 | 2.78 | 3.0 |
| MU2 | 1.24 | 1.39 | 1.59 | 2.18 | 0.6 |
| MU3 | 1.24 | 1.39 | 1.59 | 2.18 | 0.6 |
| MU4 | 1.24 | 1.39 | 1.59 | 2.18 | 0.6 |
| MU5 – Sheltered | 1.34 | 1.49 | 1.69 | 2.28 | 0.6 |
| MU5 – Eastern Shoreline | 1.84 | 1.99 | 2.19 | 2.78 | 3.0 |




DATE PLOTTED:5/12/2022 5:39:50 PM BY: CORY.SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-008-Catchment.mxd

Cardno now Stantec

Map produced by Cardno WA Pty Ltd
11 Harvest Terrace, West Perth WA 6005, Australia
Phone: +61 8 9273 3888
Web: www.cardno.com.au
Aerial Imagery supplied by MetroMap (19/12/2021)



**Legend**

Major Catchments
Streams

Date
5/12/2022

Size
A4

Scale
1:75,000

0 425 850 1,275 1,700Meters

# PRINCESS ROYAL HARBOUR

FIGURE 4-16: CATCHMENT PLAN

CW1200123-GS-008-CATCHMENT

## 4.8 Wave Attack

As stipulated in AS 4997-2005, coastal and maritime structures are designed to tolerate metocean forcing, based on specified design events and in some instances a tolerable allowance for damage (**Table 4-11**). However, projected climate change effects, most notably a rise in mean sea level, have the potential to shift the context of the structures underlying design basis.

For example, a 100-year ARI event at the end of the century may be projected to be more severe than what is considered a 500-year ARI event at present day. In accordance with AS 4991-2005, this would result in a shift in the underlying design basis from what would be applied for a 'normal structure', to what would be applied for a 'temporary structure' (see **Table 4-11**). This shift in the underlying design basis has been considered in the severity of wave attack across the planning timeframes, demonstrating at what timeframe an asset might be considered 'under-designed'.

In addition to projected changes in the underlying design basis, the structures identified within the study area may also be susceptible to additional risk from wave attack for the following reasons:

- The structures have deteriorated since their construction and no longer have the same integrity as at their original design and construction (e.g., revetments have slumped and experienced displacement of rocks, wharf elements have corroded or been damaged by storm events).
- The structures have not been designed to properly incorporate SLR across their working life. **Figure 4-17** provides a historical timeline of Australian maritime design standards with respect to climate change considerations. The figure also shows the evolution of mean SLR predictions by the IPCC over the period.
- Additionally, assets may be located inland where wave attack was not a design consideration, but where they may be prone to the impact of waves at future timeframes due to higher water levels and an evolved coastline.

Table 4-11 ARI design wave events corresponding to maritime structure importance level and design life (AS 4991-2005)

| Function Category | Category Description | Design Working Life (years) | | | |
|---|---|---|---|---|---|
| | | 5 or less (temporary) | 25 (small craft facilities) | 50 (normal maritime structures) | 100 or more (special structures/ residential developments) |
| 1 | Structures presenting a low degree of hazard to life of property | 1/20 | 1/50 | 1/200 | 1/500 |
| 2 | Normal structures | 1/50 | 1/200 | 1/500 | 1/1000 |
| 3 | High property value or high risk to people | 1/100 | 1/500 | 1/1000 | 1/2000 |

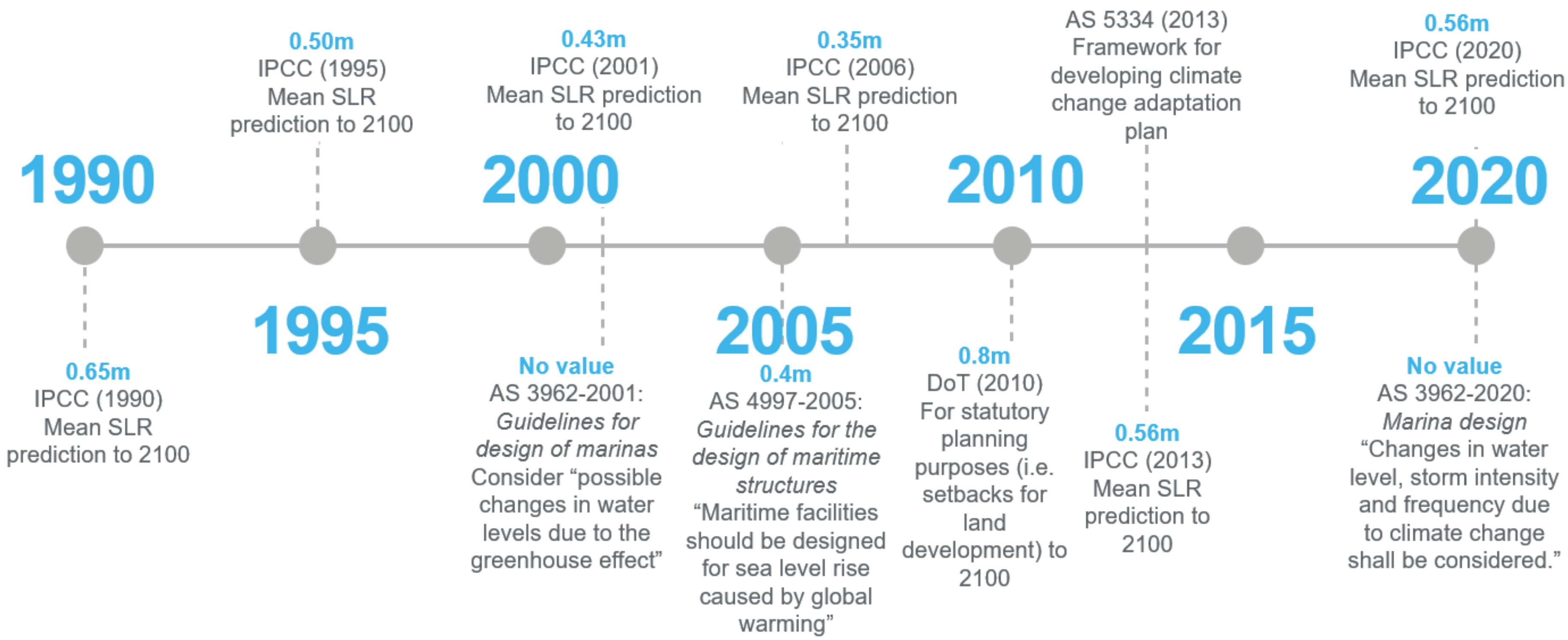



Figure 4-17 History of relevant design guidelines and standards with respect to sea level rise allowance, as well as IPCC mean SLR projections

### 4.8.2 Approach

Wave attack hazards have been calculated based on an assessment of projected changes to wave height, water level, and the likely inter-dependence of the two.

The SWAN wave-modelling system described in **Section 4.2.3** was applied to investigate the transformation of offshore swell waves into the entrance of PRH. The transformation modelling was undertaken based on a hindcast period of approximately 34-years (1981 through 2021), using modelled wave data from CSIRO CAWCR WaveWatch III at a location within King George Sound (CSIRO 1 in **Figure 4-3**). The hindcast period was controlled by the local water level record within PRH.

The contribution of local seas to the total wave climate was assessed by undertaking an additional wind-wave hindcast modelling study, based on approximately 34-years (1981 through 2021) of modelled wind data from CSIRO CAWCR WaveWatch III at a second location within King George Sound (CSIRO 2 in **Figure 4-3**). The total wave energy at the output locations has been determined as a summation of the spectral energy associated with the swell propagating from the offshore boundary, and the sea generated locally within the model domain.

The combined spectral wave parameters have been used to describe the wave climate at two locations within PRH (**Figure 4-18)**. The output locations have been selected to represent depth limited (Location A in **Figure 4-18**) and non-depth limited (Location B in **Figure 4-18**) waves impinging on Port's infrastructure. The approximate seabed level at the output locations are -0.9 m AHD and -13.4 m AHD for Location A and Location B, respectively.

Depth limited breaking occurs when waves propagate into shallow areas, and the wave height can no longer be sustained. Projected increases in mean sea level will allow waves heights that would currently break offshore, to impinge on coastal and maritime assets.


Figure 4-18 Output locations for wave attack assessment

*Offshore Waves*

The propagation of Southern Ocean swell waves into King George's Sound was investigated by implementing the SWAN wave model, to prepare wave transfer coefficients for a comprehensive suite of relevant offshore wave heights, periods and directions. Specifically:

- − Significant wave heights ($H_{m0}$) of 0.2 and 1 to 9 m - at 1.0 m intervals.
- − Peak wave periods ($T_p$) ranging from 2.5 s to 25.5 s - at 2.5 s intervals.
- − Wave directions ranging from 0 °TN to 360 °TN - at 11.25-degrees intervals.
- − Water level conditions of -1 to 2.4 m MSL – at 0.85 m intervals.

The results of this SWAN wave modelling provided matrices of wave coefficients and nearshore wave directions at the model output locations.

*Local Sea Waves*

The local sea wave climate was investigated by implementing the SWAN wave model to prepare wave transfer coefficients for a full suite of local wind speeds and wind directions, namely:

- − Wind speeds ranging from 0 to 25 m/s - at 5 m/s intervals.
- − Wind directions from 0° to 360° – at 11.25°intervals.
- − Water level conditions of -1 to 2.4 m MSL – at 0.85 m intervals.

The results of this SWAN wave modelling provided matrices of wave coefficients and nearshore wave directions at the model output locations.

*Combined Swell and Local Sea Waves*

The wave climate at the output locations typically comprises a combination of swell waves, that are generated by winds blowing across the open ocean offshore, and local seas, that are generated by winds blowing across the local ocean surface. Consequently, the nearshore wave conditions must consider the relative contribution of both processes. Combined 2D spectral wave parameters at the site ($H_{m0}$, $T_p$, $T_{m01}$ and mean wave direction) have been determined based on weighted spectral energy algorithms, as follow:

- Significant Wave Height, $H_{m0}$

$$H_{m0,total} = \sqrt{H_{m0,swell}^2 + H_{m0,sea}^2}$$

- Peak Wave Period, Tp

$$T_{p,total} = T_{p,swell} \text{ for } H_{m0,swell} > H_{m0,sea}$$

$$T_{p,total} = T_{p,sea} \text{ for } H_{m0,swell} < H_{m0,sea}$$

- Mean Wave Period, $T_{m01}$

$$T_{m01,total} = \frac{\left(H_{m0,swell}^2 \times T_{m01,swell}\right) + \left(H_{m0,sea}^2 \times T_{m01,sea}\right)}{\left(H_{m0,swell}^2\right) + \left(H_{m0,sea}^2\right)}$$

- Mean Wave Direction, MWD

$$U_{Total} = \frac{\left(U_{swell} \times H_{m0,swell}^2 \times T_{m02,swell}\right) + \left(U_{sea} \times H_{m0,sea}^2 \times T_{m02,sea}\right)}{\left(H_{m02,swell}^2 \times T_{m02,swell}\right) + \left(H_{m0,sea}^2 \times T_{m02,sea}\right)}$$

$$V_{Total} = \frac{\left(V_{swell} \times H_{m0,swell}^2 \times T_{m02,swell}\right) + \left(V_{sea} \times H_{m0,sea}^2 \times T_{m02,sea}\right)}{\left(H_{m0,swell}^2 \times T_{m02,swell}\right) + \left(H_{m0,sea}^2 \times T_{m02,sea}\right)}$$

Where:

$H_{m0}$ spectrally derived significant wave height (m)

$T_p$ spectral peak wave period (s)

$T_{m01}$ mean absolute wave period (s), $T_{m01} = m_0 / m_1$

$T_{m02}$ mean absolute zero-crossing wave period (s),

$T_{m02} = \text{sqrt}(m_0 / m_2)$ and approximately equivalent to $T_z$ (or $\bar{T}$ or $T_m$),

mean wave period from the statistical analysis ($T_{m02} \approx T_z = 0.9317 \times T_{m01}$)

U the east-west component of the mean wave direction

V the north-south component of the mean wave direction

The combined time-series have been used as the basis for all analyses of wave conditions at the output locations).

### 4.8.3 Joint Frequency of Occurrence

The average joint-frequency of occurrence intervals for significant wave height and water level were determined using the JOIN-SEA software, developed by HR Wallingford (1999).

The significant wave height, peak wave period and water level were extracted at each high water during the 34-year overlapping period. This data was then processed to determine an appropriate joint probability distribution.

### 4.8.4 Contextual Design Basis

Changes to the contextual design basis for the Port's coastal and maritime infrastructure have been estimated based on the joint probably analysis and projected climate change effects relevant to the study area. With reference to the climate change projections discussed in **Section 2.7**, the following assumptions have been made to translate the joint frequency of occurrence results to the future planning timeframes considered in this study.

- A sea level rise allowance adhering to the upper bound of the SSP predictions (SSP5-8.5), specifically, the medium confidence and 50th percentile of the SSP5-8.5 predictions has been adopted (**see Table 2-1).**
- Projected increases in mean and extreme wind speeds in the Southern Ocean by 3.0% to 2122. This projection has been assumed to increase offshore swell heights generated in the Southern Ocean (**see Table 2-2**).
- Projected reduction in local mean and extreme wind speeds during the winter months and a projected increase in local mean and extreme wind speeds during the summer months. These projections have been assumed to counteract each other and therefore, have no effect on the local sea climate within PRH (**see Table 2-2**).
- A wave breaking parameter (wave height to depth ratio) of 0.75, to predict changes in depth limit wave heights.

An example of the projected shift in the underlying design basis at the entrance of PRH is presented in **Figure 4-19** . The figure shows contours of equal joint exceedance probability for depth limited environments at presented day and at the 2047 planning timeframe. The figure demonstrates that, for depth limited environments, the 500-year ARI design event would be less severe than what is projected to be a 5-year ARI event at the end of the planning timeframe. As such, the contextual design standard of a normal structure designed at present day, in accordance with AS4997-5, is projected to be comparable to that of a temporary structure by 2047. Comparatively, for non-depth limited environments (**Figure 4-20**), the 500-year ARI design event would be similar to what is projected to be a 100-year ARI event by 2047. It is important to note that the wave attack hazards assumes that the current level of risk is maintained across the planning period, with respect to present day conditions (like-for-like replacement/refurbishment of assets).

Figures showing the projected shift in the underlying design basis for the 2047, 2072, and 2122 planning timeframes are provided in **Appendix E**.

The results of the wave attack assessment indicate that projected climate change effects, including an increase in MSL, and minor increases in Southern Ocean swell, are more likely to affect assets in depth limited environments. Such assets include the revetment at Berth 6 and adjacent the Grain Facility. Assets located in deeper water and outside of the impact of swell propagation into PRH were found to be more resilient to the climate change effects included in this study.

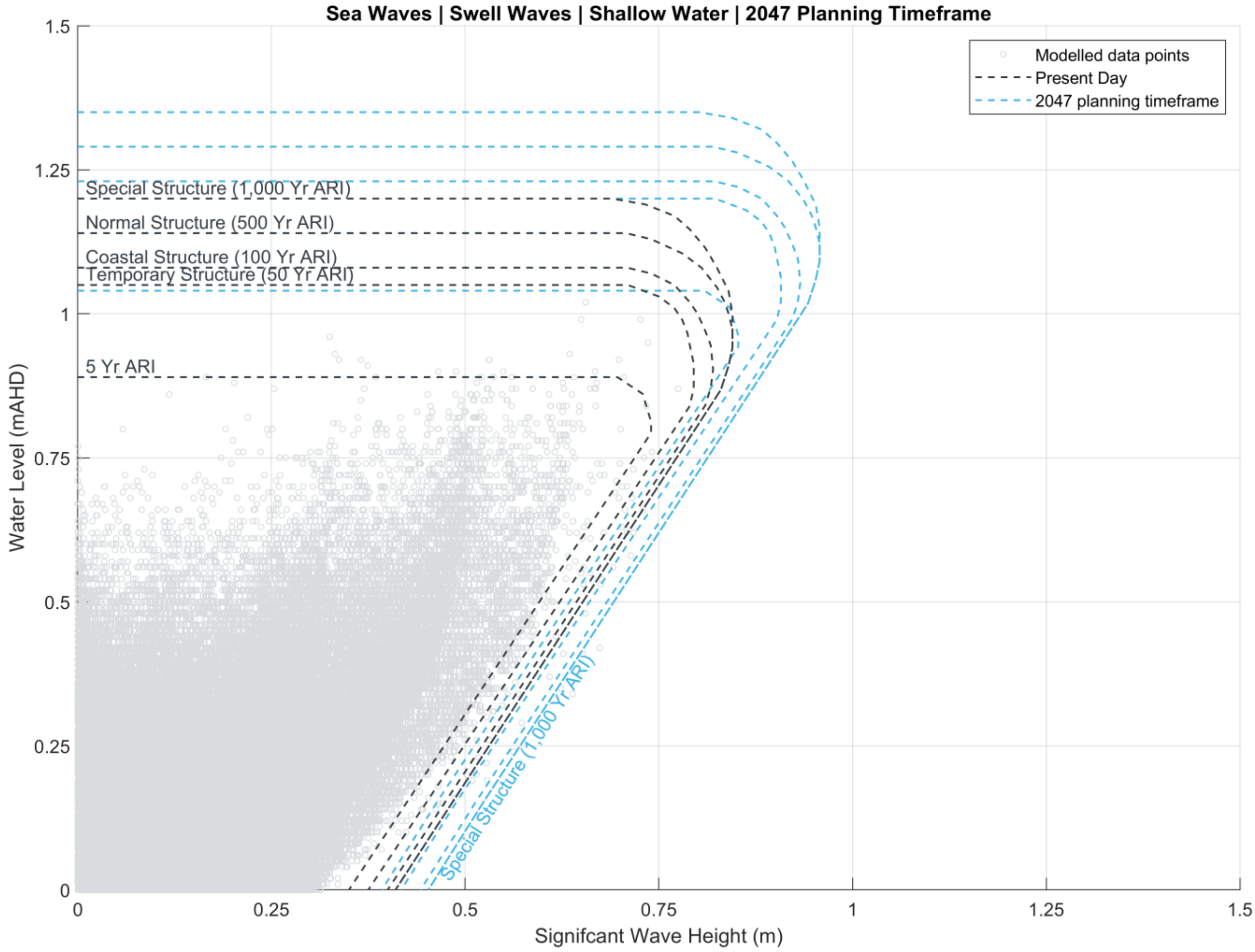



Figure 4-19 Contours of equal joint exceedance probability Joint probability for depth limited environments (Approximate seabed level: -0.9 m AHD)

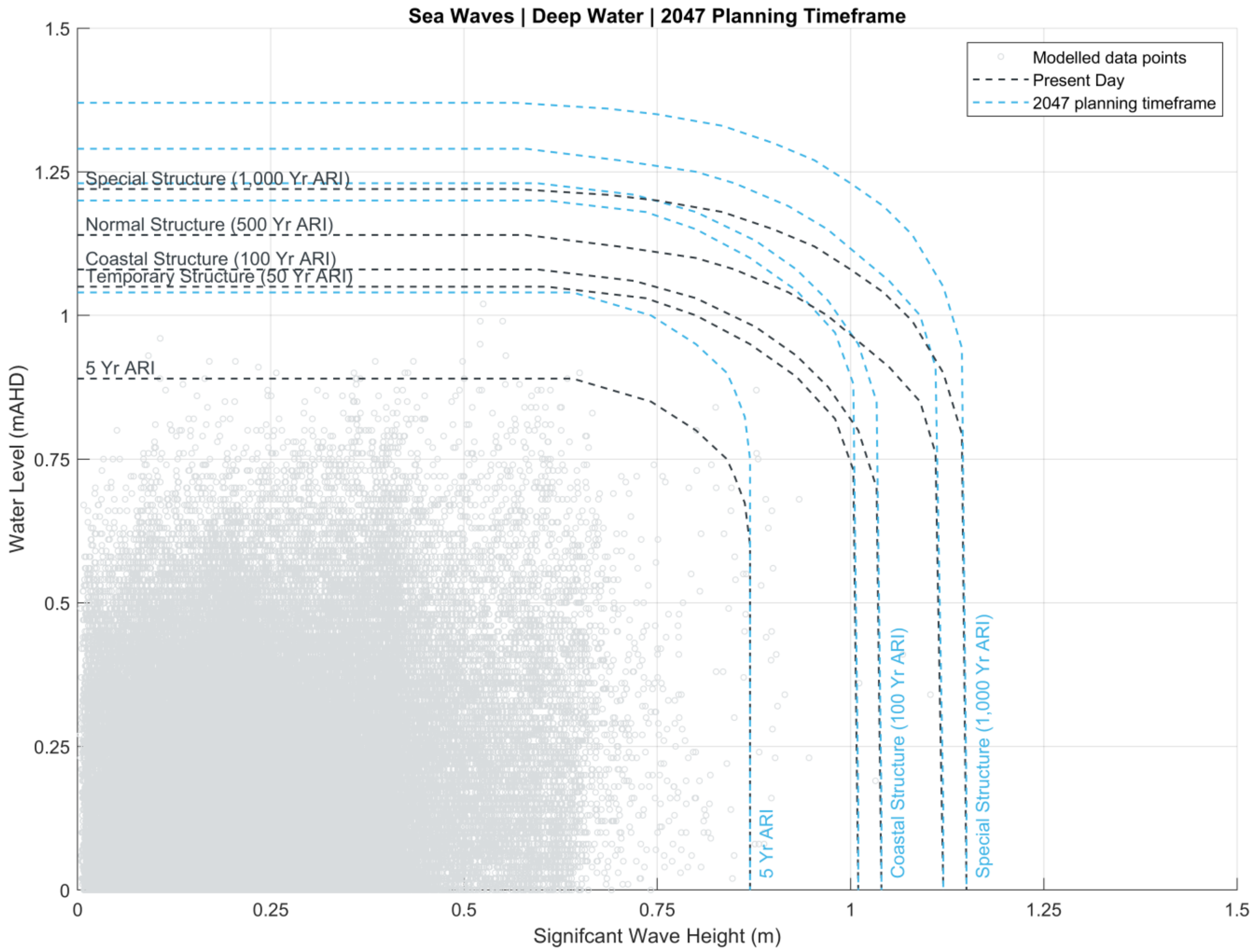



Figure 4-20 Contours of equal joint exceedance probability Joint probability for non-depth limited environments (Approximate seabed level: 13.3 m AHD)

## 4.9 Wave Attack Summary and Mapping

Wave attack hazard levels have been depicted in hazard mapping presented in **Appendix F**. The wave attack hazard lines represent the shift in the underlying design basis relative to a normal structure (500-year ARI event, in accordance with AS4997-2005) at present day. For example, an asset depicted as the 100-year ARI event in the hazard mapping indicates that the 500-year ARI event at the present day is projected to be comparable to what is projected to be a 100-year ARI event by the stipulated planning timeframe. The purpose of the hazard lines is to demonstrate at what timeframe an asset might be considered ‘under-designed’.

# 5 Asset Identification

Assets at risk of coastal erosion and inundation have been identified by overlaying the hazard extents over recent aerial imagery of the Town's coastline. The assets have been grouped into seven categories, in accordance with the City of Albany Local Planning Scheme: Residential, commercial, developed foreshore, public and community, roads, environment, and heritage.

The assets identified as being at risk of coastal erosion and inundation are summarised in **Table 5-1**. The location of each asset, and an overlay of the asset categories is provided in **Appendix G**.

Table 5-1 Asset classification by number

| Location | Asset Number | Asset |
|---|---|---|
| Port Albany | PA01 | Southern Ports Berth 1 Revetment |
| | PA02 | Southern Ports Berth 2 Revetment |
| | PA03 | Southern Ports Berth 3 Revetment |
| | PA04 | Southern Ports Berth 6 Revetment |
| | PA05 | Southern Ports Berth 1 Maritime Infrastructure |
| | PA06 | Southern Ports Berth 2 Maritime Infrastructure |
| | PA07 | Southern Ports Berth 3 Maritime Infrastructure |
| | PA08 | Southern Ports Berth 6 Maritime Infrastructure |
| Albany | A01 | Albany Waterfront Marina Eastern Breakwater |
| | A02 | Albany Waterfront Marina Western Breakwater |
| | A03 | Albany Boatshed Markets |
| | A04 | Albany Waterfront Marina Carpark 2 |
| | A05 | Albany Waterfront Marina Carpark 3 |
| | A06 | Lawley Park |
| | A07 | Railway |
| | A08 | Due South |
| | A09 | Haz Beanz |
| | A10 | Albany Entertainment Centre |
| | A11 | RSL Memorial Gardens Queens Park |
| | A12 | Albany Commercial Precinct |
| | A13 | Anzac Park |
| | A14 | Albany Waterfront Marina Western Breakwater |
| | A15 | Hanover Bay Jetty |
| | A16 | Peace Park |
| | A17 | Old Gaol Museum |
| | A18 | Anzac Park Revetment |
| | A19 | Museum of the Great Southern |
| | A20 | Brig Amity |
| | A21 | Fish Garden |
| Mount Melville | MM01 | Mount Melville Residential and Commercial Properties |
| | MM02 | Museum of the Great Southern |
| | MM03 | Princess Royal Drive |

| | | |
|---|---|---|
| | MM04 | Festing Street |
| | MM05 | Vancouver Street Social Precinct |
| | MM06 | Drainage Basins |
| | MM07 | Point Melville Campsite |
| | MM08 | Mount Melville Residential and Commercial Properties |
| | MM09 | Albany Wool stores |
| Mount Elphinstone | ME01 | Mount Elphinstone Residential and Commercial Properties |
| | ME02 | Mount Elphinstone Natural Foreshore Area |
| | ME03 | Drainage Outlet |
| Robinson | R01 | Robinson Residential and Commercial Properties |
| | R02 | Robinson Natural Foreshore Area |
| | R03 | Frenchy's Restaurant and Tea Rooms |
| | R04 | Robinson Road |
| | R05 | Frenchman Bay Road |
| | R06 | Frenchman Bay Road Access Path |
| | R07 | Drainage Channels |
| | R08 | Seawolf Road |
| | R09 | Harding Road |
| | R10 | Limeburners Distillery |
| | R11 | Great Southern Distilling Company |
| | R12 | Bramwell Road |
| | R13 | Princess Avenue |
| | R14 | Scrub Bird Road |
| Torndirrup | T01 | Public Toilet |
| | T02 | Torndirrup Access Path |
| | T03 | Torndirrup Residential and Commercial Properties |
| | T04 | Torndirrup Natural Foreshore Areas |
| | T05 | South Coast Progress Association |
| | T06 | Bay View Drive |
| | T07 | Torndirrup Tennis Courts |
| | T08 | Bay View Drive |
| Little Grove | LG01 | Little Grove Natural Foreshore Areas |
| | LG02 | Bay View Drive |
| | LG03 | Little Grove Residential and Commercial Properties |
| | LG04 | Marine Terrace |
| | LG05 | Rusty Lane |
| | LG06 | Stubbs Road |
| | LG07 | Mill Park |
| | LG08 | Chipana Drive |
| | LG09 | Grove Street |
| | LG10 | Gordon Street |

| | | |
|---|---|---|
| | LG11 | Spring Street |
| | LG12 | Princess Royal Sailing Club |
| | LG13 | Paulas Way |
| | LG14 | Gull Park |
| | LG15 | Maitland Avenue |
| | LG16 | Princess Royal Sailing Club Carpark |
| | LG17 | Harbour Esplanade |
| | LG18 | Panorama Caravan Park |
| | LG19 | Panorama Caravan Park Jetty |
| Big Grove | BG01 | Big Grove Natural Foreshore Areas |
| | BG02 | Big Grove Residential and Commercial Properties |
| | BG03 | Limeburner Point |
| | BG04 | Limekilns Point |
| | BG05 | Shoal Bay Retreat |
| | BG06 | Quaranup Road |
| | BG07 | Vancouver Peninsula Natural Foreshore Areas |
| Vancouver Peninsula | VP01 | Jessica's Beach |
| | VP02 | Vancouver Beach |
| | VP03 | Lake Vancouver |
| | VP04 | Vancouver Peninsula |
| | VP05 | Camp Quaranup Jetty 1 |
| | VP06 | Camp Quaranup |
| | VP07 | Camp Quaranup Jetty 2 |
| | VP08 | Quaranup Heritage Complex |
| | VP09 | Vancouver Peninsula |
| | VP10 | Quaranup Gate |

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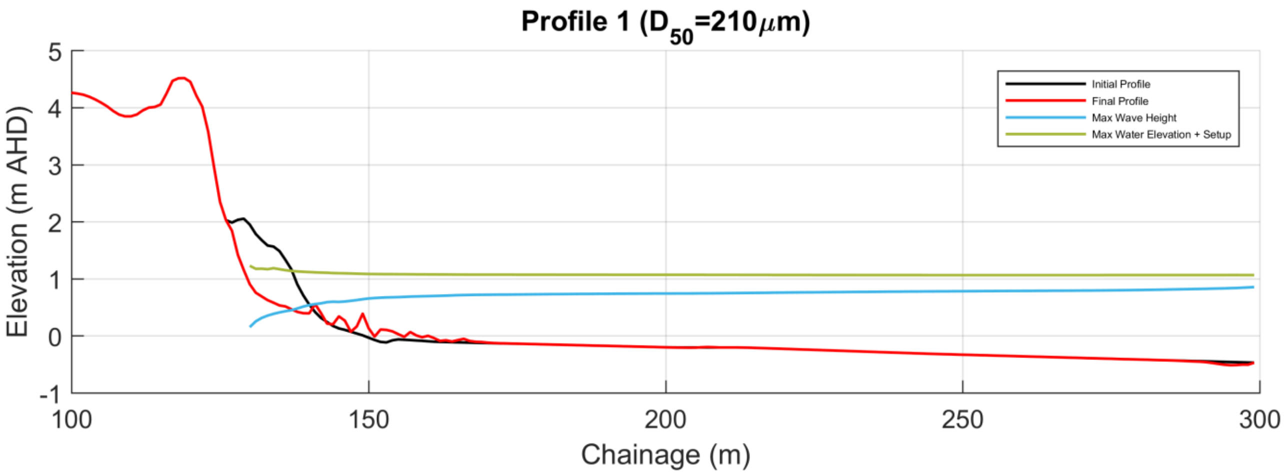
# APPENDIX

# A

## SBEACH RESULTS


Profile 1 (D50=210μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup
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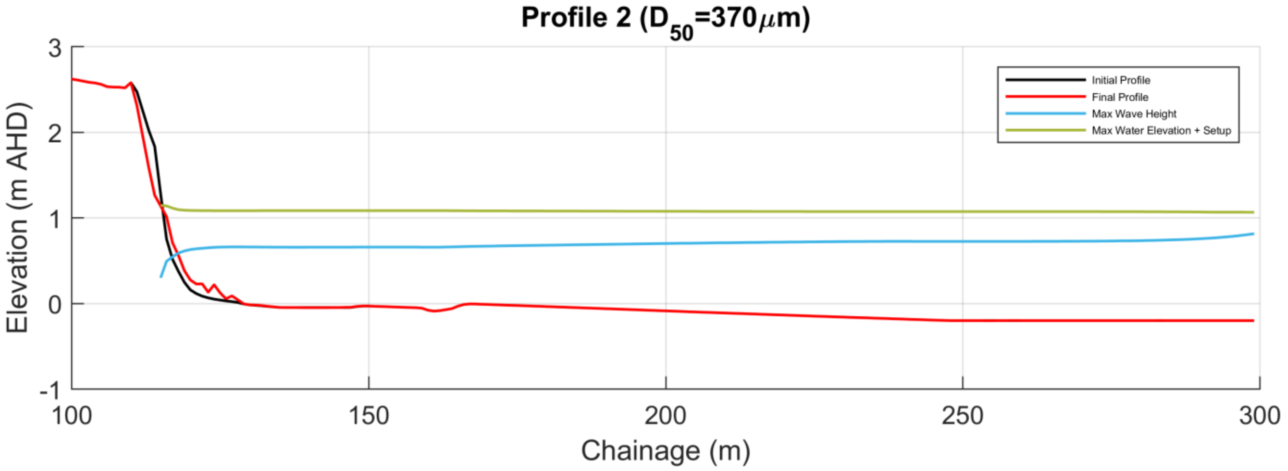
3
2
1
0
-1
100
150
200
250
300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Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup
3
2
1
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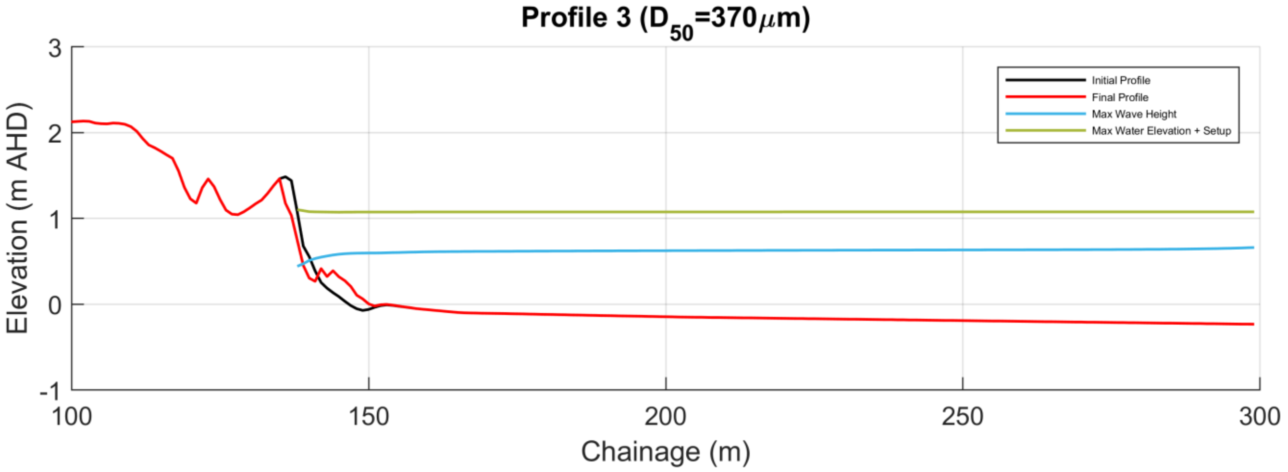
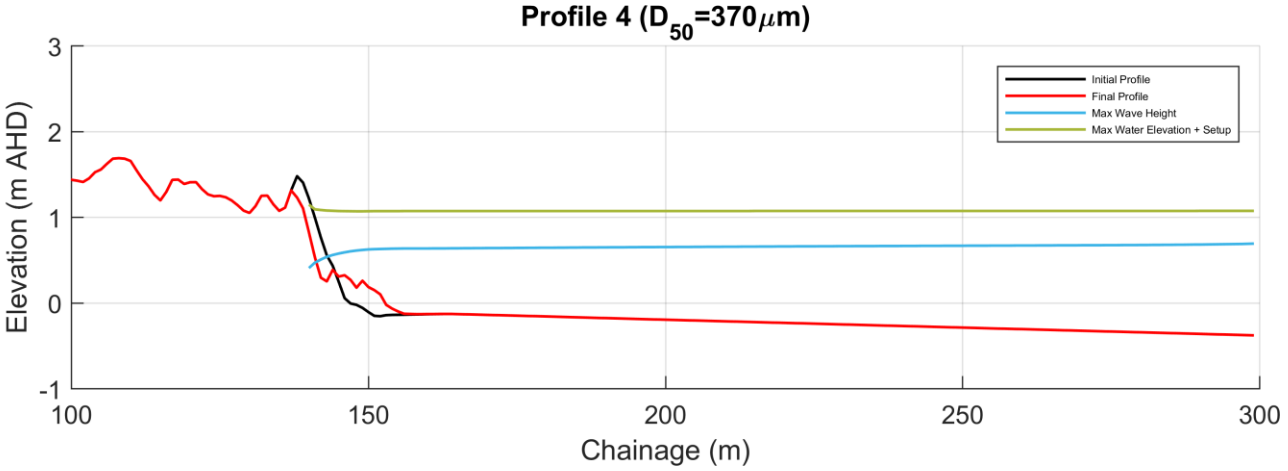
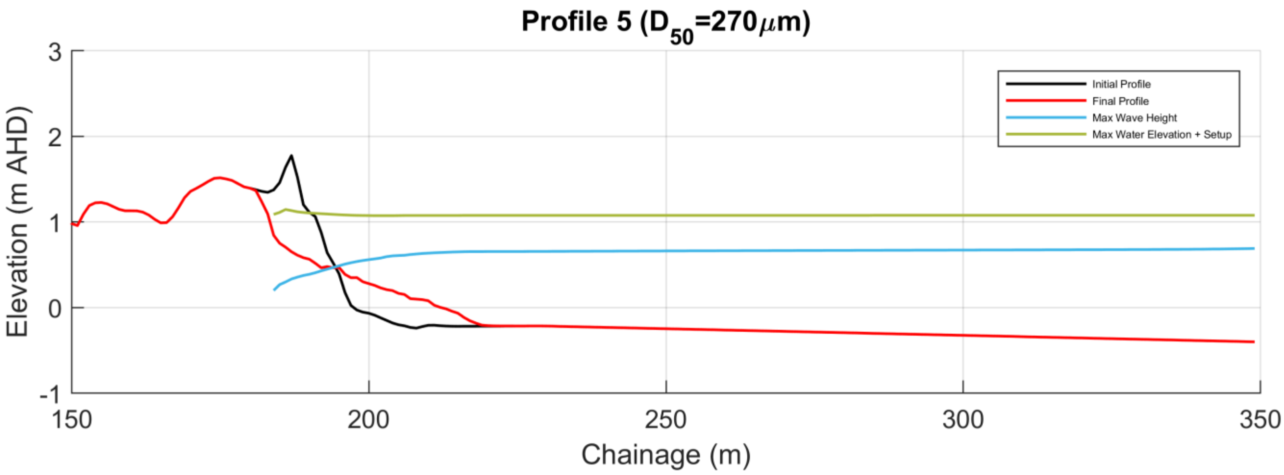
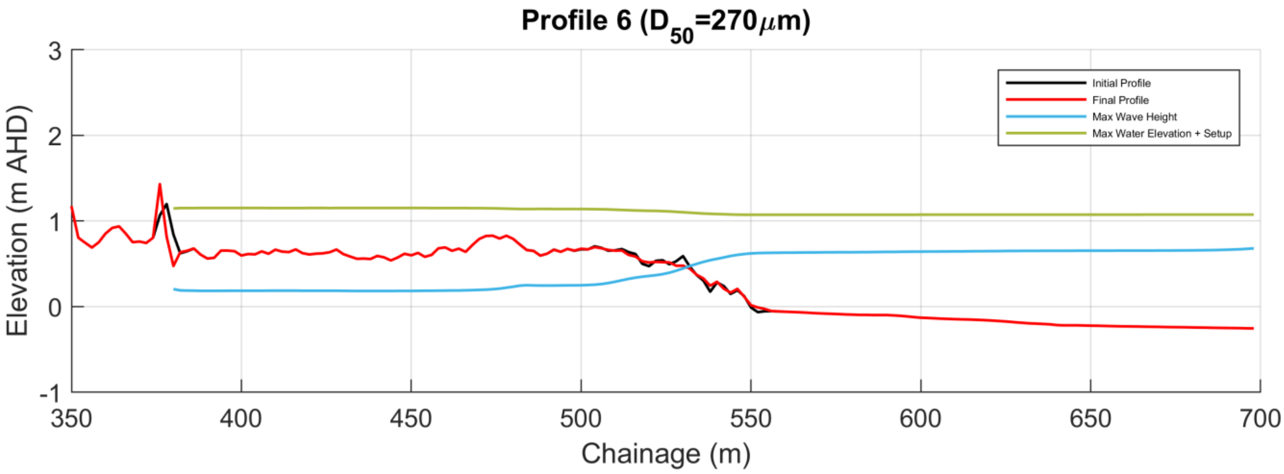
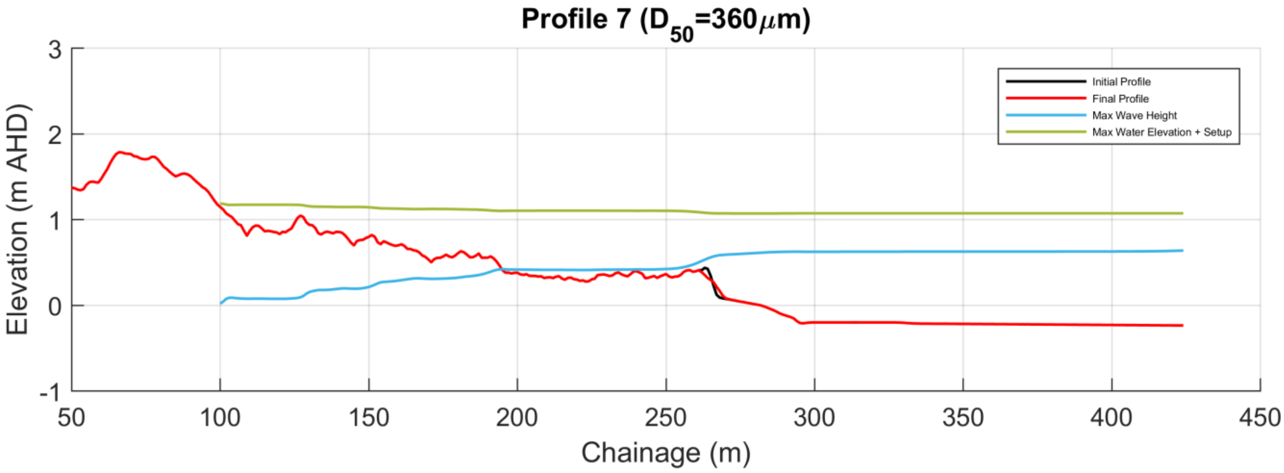
-1
100
150
200
250
300

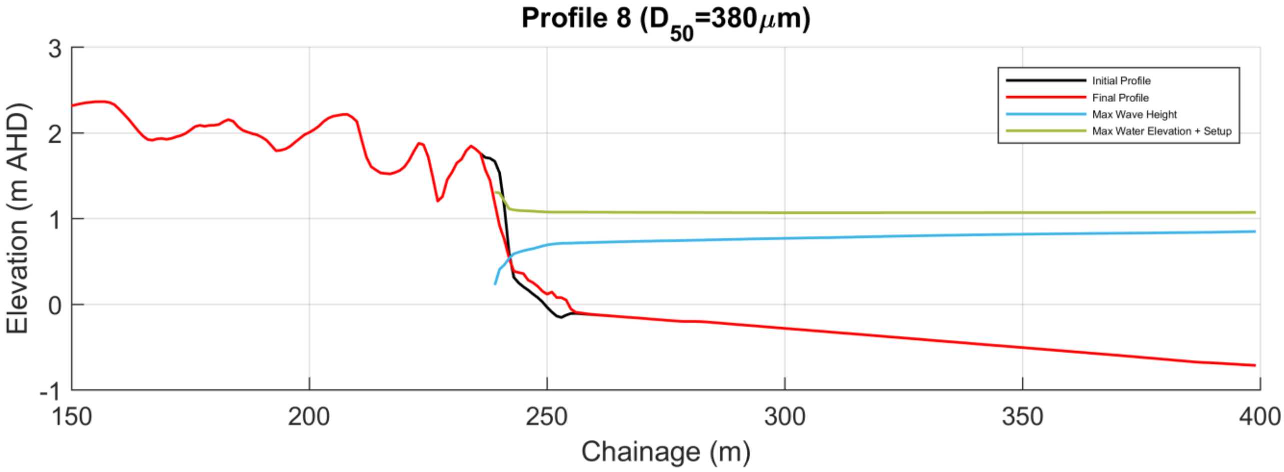

Profile 3 (D50=370μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup
3
2
1
0
-1
100
150
200
250
300


Profile 4 (D50=370μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup
3
2
1
0
-1
100
150
200
250
300

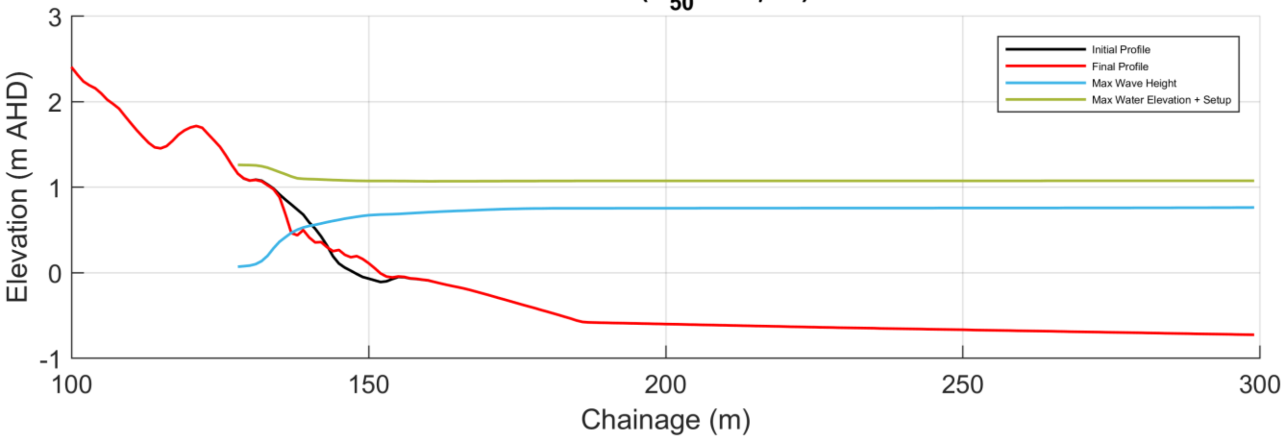

Profile 5 (D50=270μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup


Profile 6 (D50=270μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup

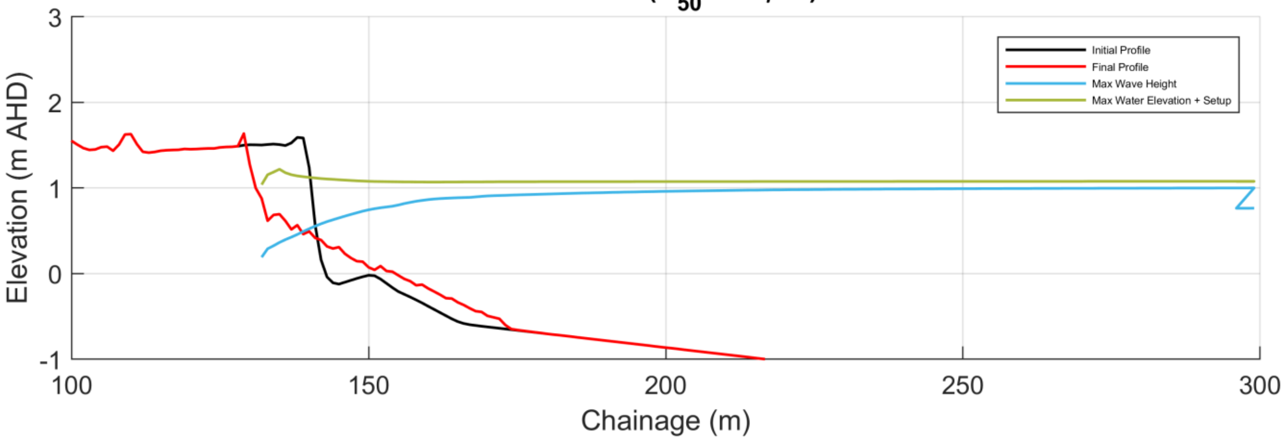

Profile 7 (D50=360μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup


Profile 8 (D50=380μm)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup

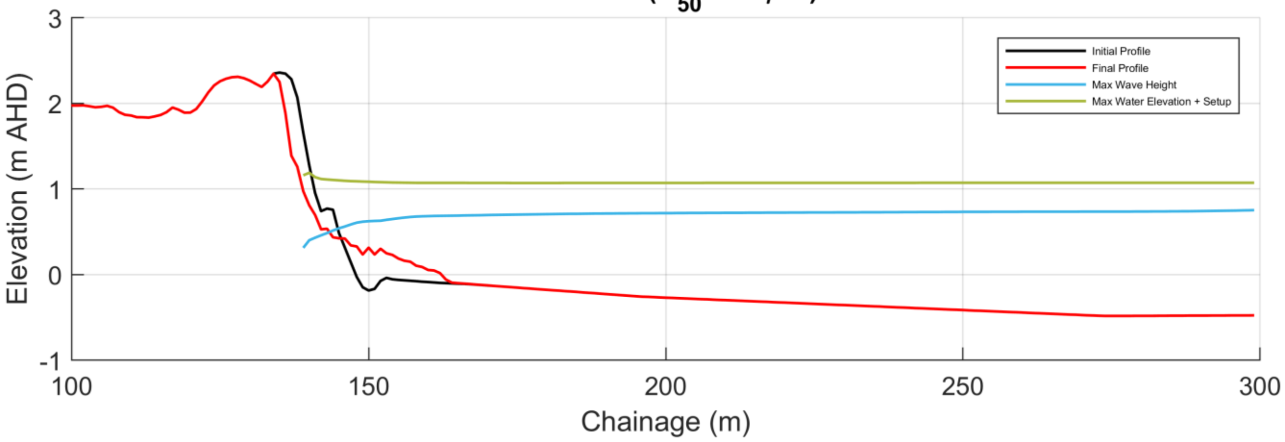
**Profile 9 ($D_{50}$=360$\mu$m)**



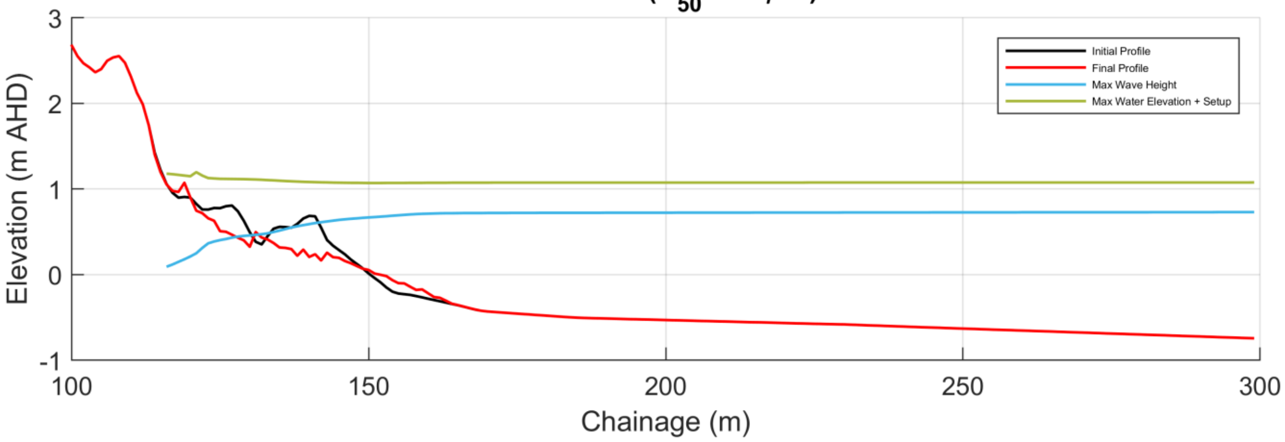

**Profile 10 ($D_{50}$=360$\mu$m)**

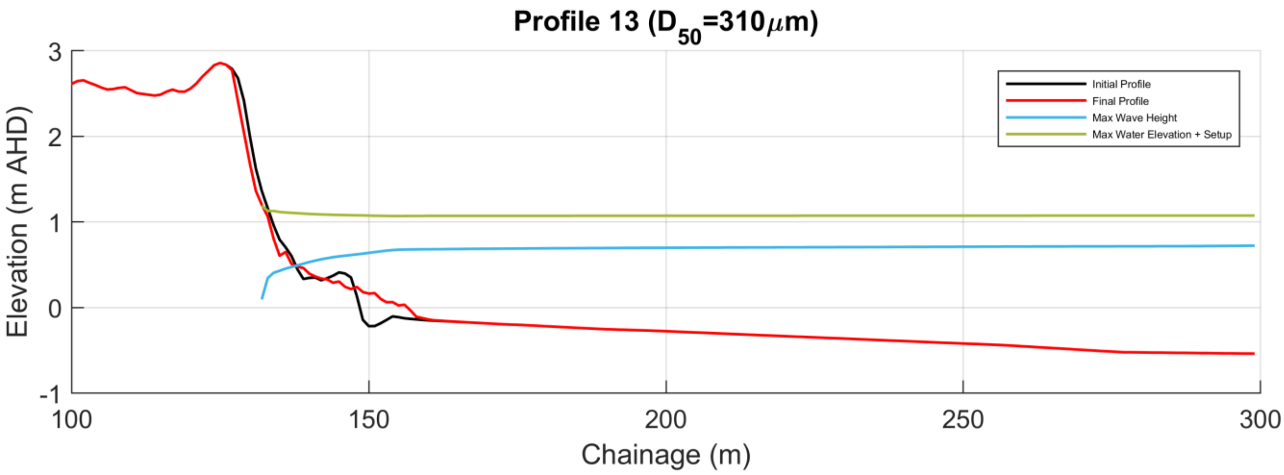


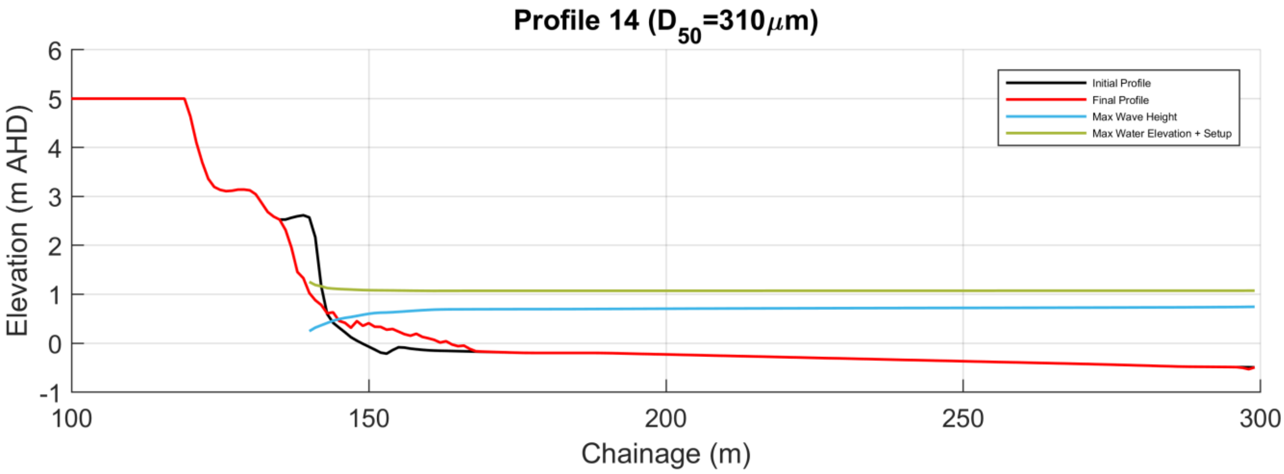

**Profile 11 ($D_{50}$=310$\mu$m)**

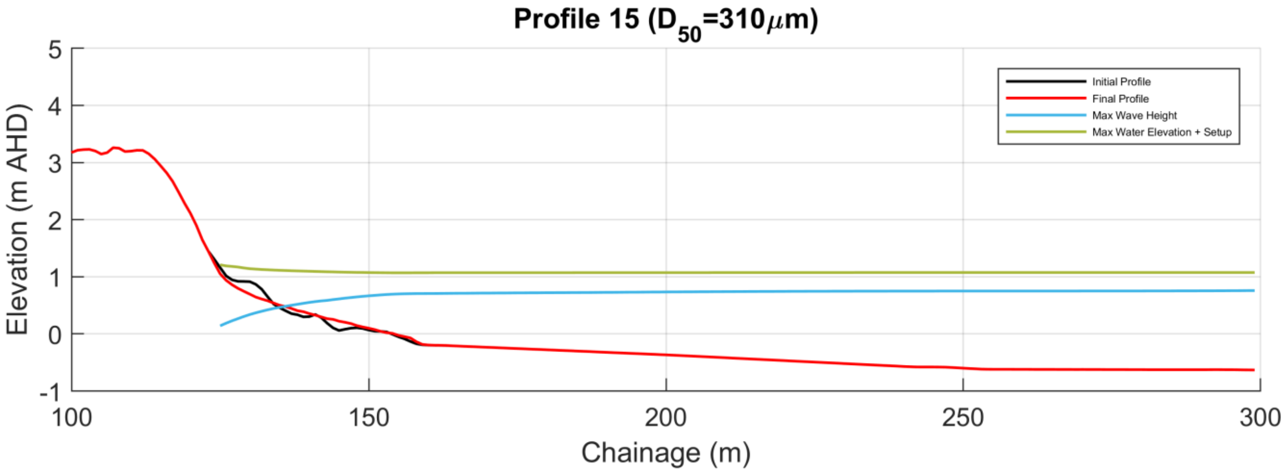


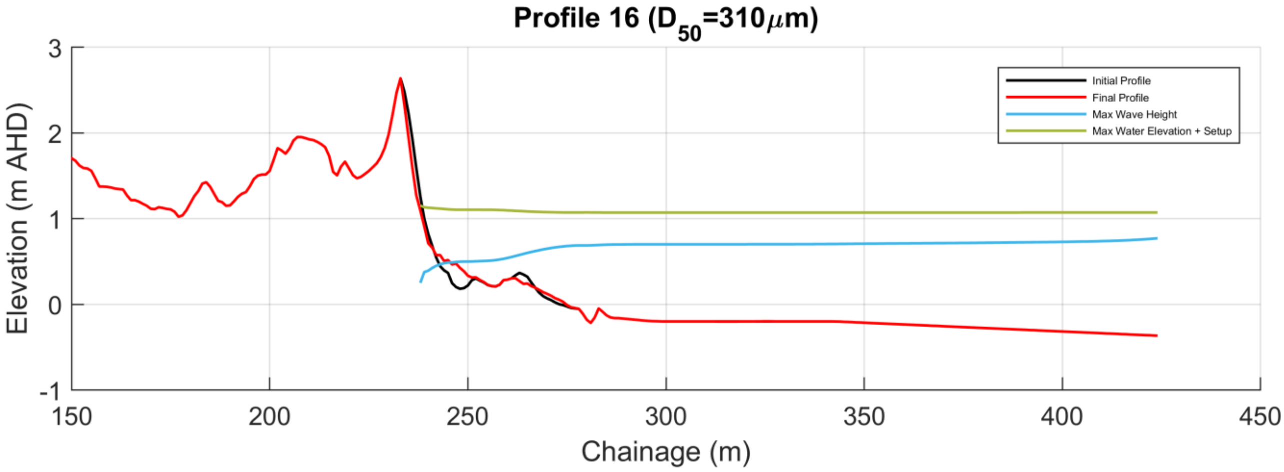

**Profile 12 ($D_{50}$=310$\mu$m)**



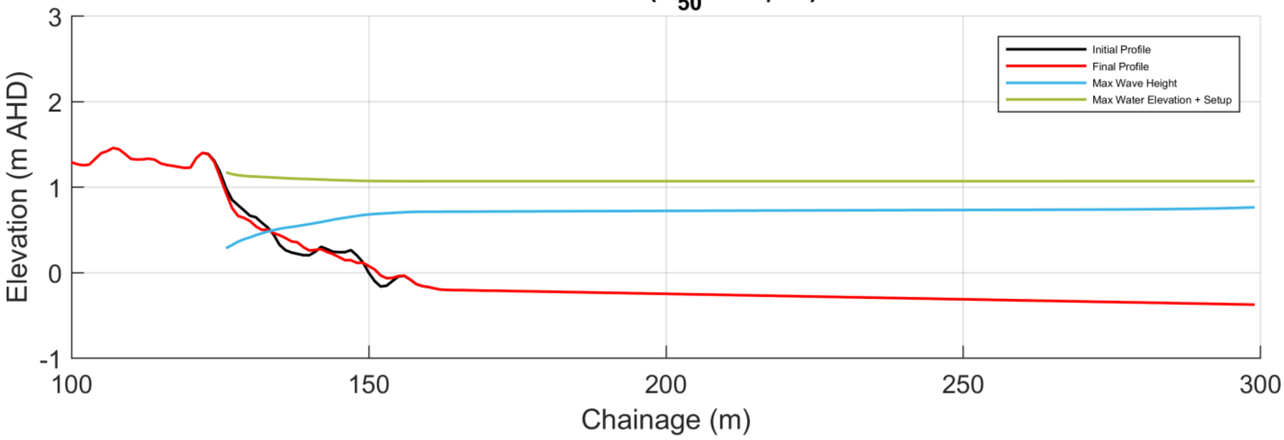

Profile 13 ($D_{50}$=310$\mu$m)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup


Profile 14 ($D_{50}$=310$\mu$m)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup

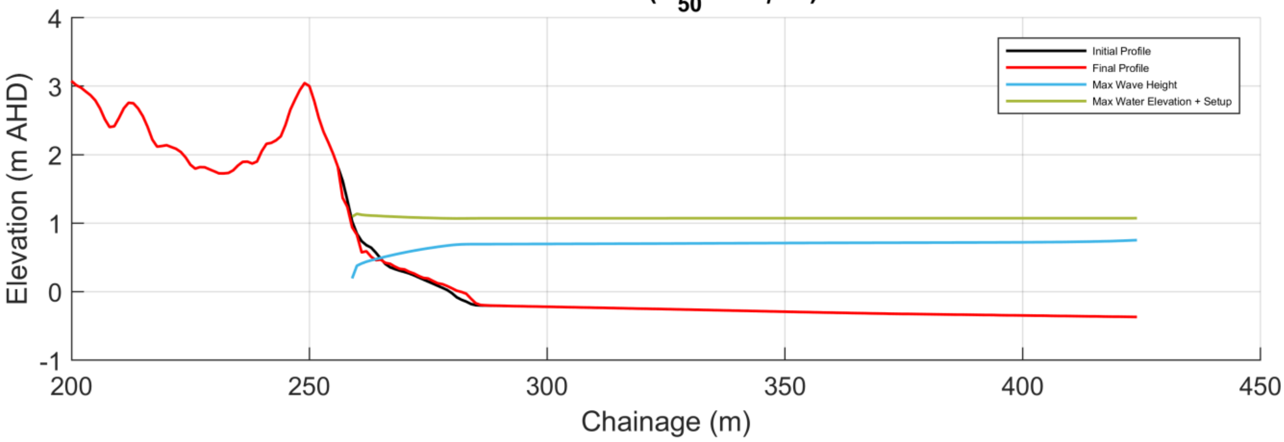

Profile 15 ($D_{50}$=310$\mu$m)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup


Profile 16 ($D_{50}$=310$\mu$m)
Elevation (m AHD)
Chainage (m)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup

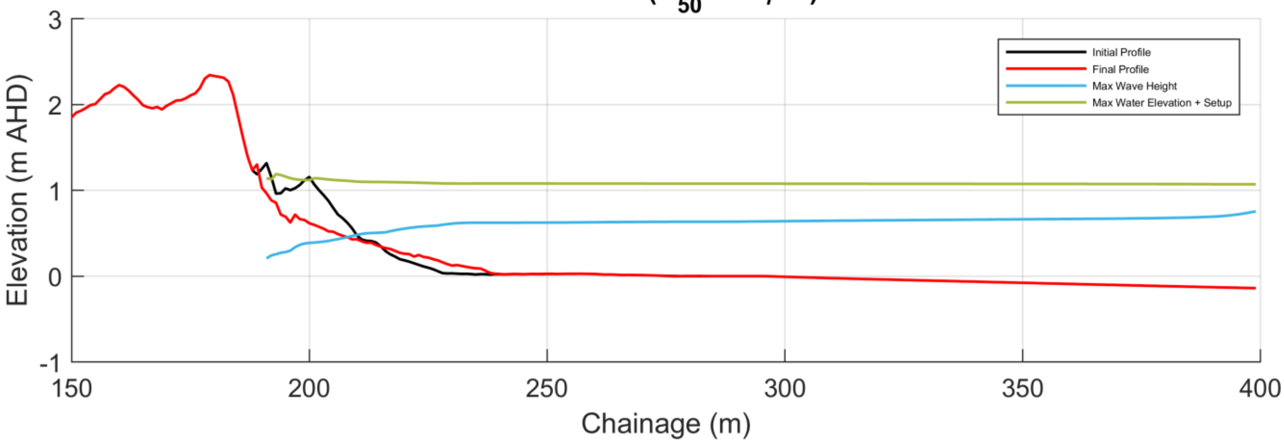
**Profile 17 ($D_{50}$=320$\mu$m)**

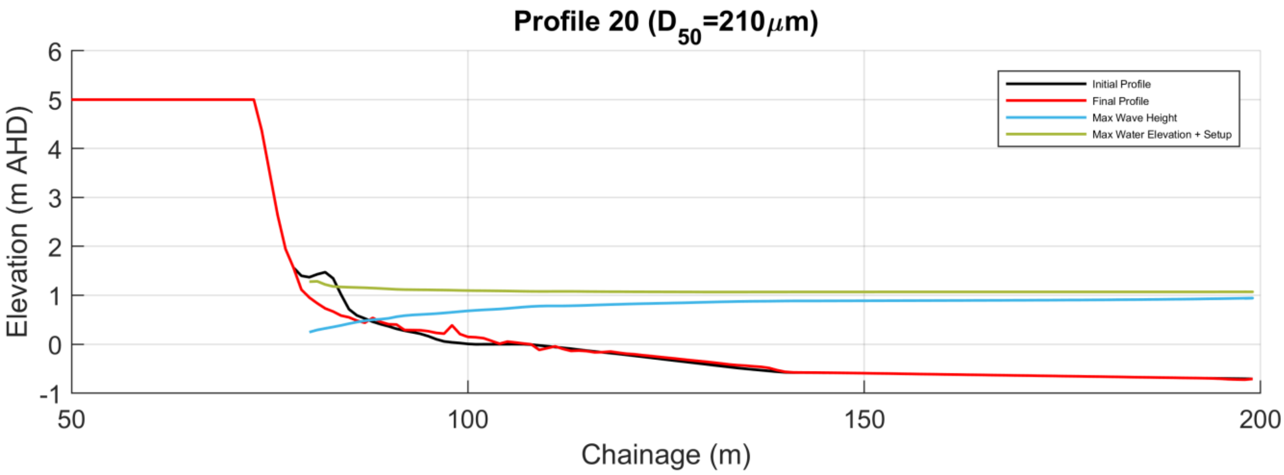


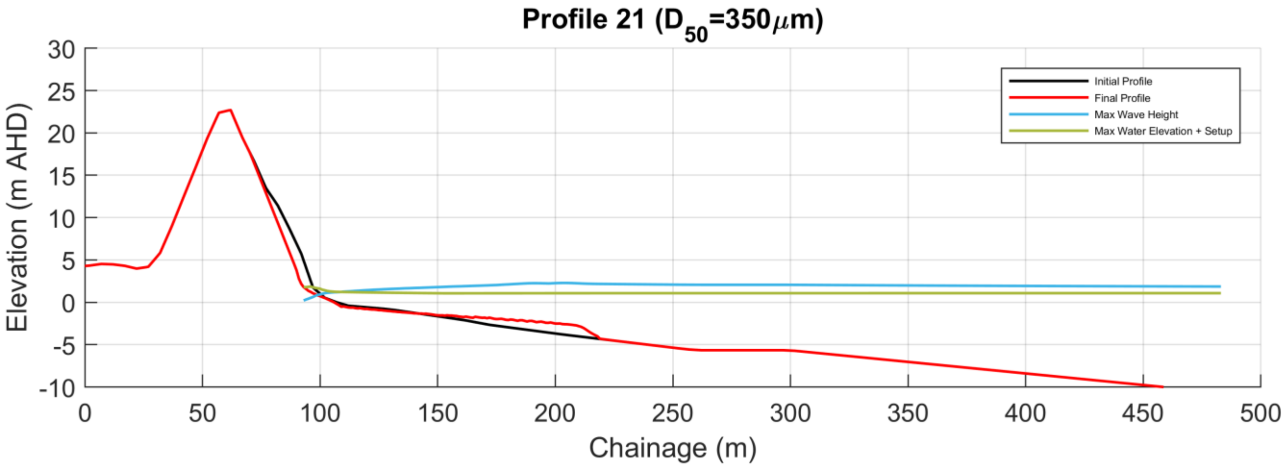

**Profile 18 ($D_{50}$=320$\mu$m)**




**Profile 19 ($D_{50}$=210$\mu$m)**




Profile 20 (D50=210μm)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup
Elevation (m AHD)
Chainage (m)
6
5
4
3
2
1
0
-1
50
100
150
200


Profile 21 (D50=350μm)
Initial Profile
Final Profile
Max Wave Height
Max Water Elevation + Setup
Elevation (m AHD)
Chainage (m)
30
25
20
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500

APPENDIX

# B

EROSION ALLOWANCE SUMMARY

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Stantec

| Present Day - Controlled | | | | | |
|---|---|---|---|---|---|
| Chainage (m) | S1 | S2 | S3 | SU | Total |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 0.0 | 0.0 | 0.0 | 11.0 |
| 3,100 - 3,500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3,500 - 3,900 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 3,900 - 4,200 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 4,200 - 4,400 | 10.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| 4,400 - 4,800 | 10.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| 4,800 - 5,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5,000 - 5,300 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5,300 - 5,500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5,500 - 6,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6,100 - 6,200 | 4.0 | 0.0 | 0.0 | 0.0 | 4.0 |
| 6,200 - 6,600 | 4.0 | 0.0 | 0.0 | 0.0 | 4.0 |
| 6,600 - 6,700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6,700 - 6,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6,900 - 7,100 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 7,100 - 7,300 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 7,300 - 8,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8,000 - 8,600 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 8,600 - 8,900 | 7.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| 8,900 - 9,500 | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| 9,500 - 9,800 | 5.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| 9,800 -10,100 | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| 10,100 - 10,800 | 12.0 | 0.0 | 0.0 | 0.0 | 12.0 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 0.0 | 0.0 | 0.0 | 25.0 |

| 2047 - Controlled | | | | | |
|---|---|---|---|---|---|
| **Chainage (m)** | **S1** | **S2** | **S3** | **SU** | **Total** |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 13.8 | 4.0 | 5.0 | 33.8 |
| 3,100 - 3,500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3,500 - 3,900 | 3.0 | 6.3 | 4.0 | 5.0 | 18.3 |
| 3,900 - 4,200 | 3.0 | 7.5 | 4.0 | 5.0 | 19.5 |
| 4,200 - 4,400 | 10.0 | 3.8 | 4.0 | 5.0 | 22.8 |
| 4,400 - 4,800 | 10.0 | 8.8 | 4.0 | 5.0 | 27.8 |
| 4,800 - 5,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5,000 - 5,300 | 0.0 | 0.0 | 4.0 | 5.0 | 9.0 |
| 5,300 - 5,500 | 0.0 | 3.8 | 4.0 | 5.0 | 12.8 |
| 5,500 - 6,100 | 0.0 | 0.0 | 4.0 | 5.0 | 9.0 |
| 6,100 - 6,200 | 4.0 | 2.5 | 4.0 | 5.0 | 15.5 |
| 6,200 - 6,600 | 4.0 | 2.5 | 4.0 | 5.0 | 15.5 |
| 6,600 - 6,700 | 0.0 | 0.0 | 4.0 | 5.0 | 9.0 |
| 6,700 - 6,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6,900 - 7,100 | 6.0 | 1.3 | 4.0 | 5.0 | 16.3 |
| 7,100 - 7,300 | 6.0 | 1.3 | 4.0 | 5.0 | 16.3 |
| 7,300 - 8,000 | 0.0 | 13.8 | 4.0 | 5.0 | 22.8 |
| 8,000 - 8,600 | 6.0 | 13.8 | 4.0 | 5.0 | 28.8 |
| 8,600 - 8,900 | 7.0 | 5.0 | 4.0 | 5.0 | 21.0 |
| 8,900 - 9,500 | 1.0 | 18.8 | 4.0 | 5.0 | 28.8 |
| 9,500 - 9,800 | 5.0 | 15.0 | 4.0 | 5.0 | 29.0 |
| 9,800 -10,100 | 1.0 | 13.8 | 4.0 | 5.0 | 23.8 |
| 10,100 - 10,800 | 12.0 | 28.8 | 4.0 | 5.0 | 49.8 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 16.3 | 4.0 | 5.0 | 31.3 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 30.0 | 4.0 | 5.0 | 64.0 |

| 2072 - Controlled | | | | | |
|---|---|---|---|---|---|
| **Chainage (m)** | **S1** | **S2** | **S3** | **SU** | **Total** |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 0.0 | 0.0 | 18.0 | 0.0 | 0.0 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 27.5 | 18.0 | 10.0 | 66.5 |
| 3,100 - 3,500 | 0.0 | 13.8 | 18.0 | 10.0 | 46.8 |
| 3,500 - 3,900 | 3.0 | 12.5 | 18.0 | 10.0 | 43.5 |
| 3,900 - 4,200 | 3.0 | 15.0 | 18.0 | 10.0 | 46.0 |
| 4,200 - 4,400 | 10.0 | 7.5 | 18.0 | 10.0 | 45.5 |
| 4,400 - 4,800 | 10.0 | 17.5 | 18.0 | 10.0 | 55.5 |
| 4,800 - 5,000 | 0.0 | 8.8 | 18.0 | 10.0 | 46.8 |
| 5,000 - 5,300 | 0.0 | 0.0 | 18.0 | 10.0 | 28.0 |
| 5,300 - 5,500 | 0.0 | 7.5 | 18.0 | 10.0 | 35.5 |
| 5,500 - 6,100 | 0.0 | 0.0 | 18.0 | 10.0 | 28.0 |
| 6,100 - 6,200 | 4.0 | 5.0 | 18.0 | 10.0 | 37.0 |
| 6,200 - 6,600 | 4.0 | 5.0 | 18.0 | 10.0 | 37.0 |
| 6,600 - 6,700 | 0.0 | 0.0 | 18.0 | 10.0 | 28.0 |
| 6,700 - 6,900 | 0.0 | 0.0 | 18.0 | 0.0 | 0.0 |
| 6,900 - 7,100 | 6.0 | 2.5 | 18.0 | 10.0 | 36.5 |
| 7,100 - 7,300 | 6.0 | 2.5 | 18.0 | 10.0 | 36.5 |
| 7,300 - 8,000 | 0.0 | 27.5 | 18.0 | 10.0 | 55.5 |
| 8,000 - 8,600 | 6.0 | 27.5 | 18.0 | 10.0 | 61.5 |
| 8,600 - 8,900 | 7.0 | 10.0 | 18.0 | 10.0 | 45.0 |
| 8,900 - 9,500 | 1.0 | 37.5 | 18.0 | 10.0 | 66.5 |
| 9,500 - 9,800 | 5.0 | 30.0 | 18.0 | 10.0 | 63.0 |
| 9,800 -10,100 | 1.0 | 27.5 | 18.0 | 10.0 | 56.5 |
| 10,100 - 10,800 | 12.0 | 57.5 | 18.0 | 10.0 | 97.5 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 0.0 | 0.0 | 18.0 | 0.0 | 0.0 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 32.5 | 18.0 | 10.0 | 66.5 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 60.0 | 18.0 | 10.0 | 113.0 |

| 2122 - Controlled | | | | | |
|---|---|---|---|---|---|
| **Chainage (m)** | **S1** | **S2** | **S3** | **SU** | **Total** |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 0.0 | 27.5 | 94.0 | 20.0 | 150.5 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 55.0 | 94.0 | 20.0 | 180.0 |
| 3,100 - 3,500 | 0.0 | 41.3 | 94.0 | 20.0 | 160.3 |
| 3,500 - 3,900 | 3.0 | 25.0 | 94.0 | 20.0 | 142.0 |
| 3,900 - 4,200 | 3.0 | 30.0 | 94.0 | 20.0 | 147.0 |
| 4,200 - 4,400 | 10.0 | 15.0 | 94.0 | 20.0 | 139.0 |
| 4,400 - 4,800 | 10.0 | 35.0 | 94.0 | 20.0 | 159.0 |
| 4,800 - 5,000 | 0.0 | 26.3 | 94.0 | 20.0 | 150.3 |
| 5,000 - 5,300 | 0.0 | 0.0 | 94.0 | 20.0 | 114.0 |
| 5,300 - 5,500 | 0.0 | 15.0 | 94.0 | 20.0 | 129.0 |
| 5,500 - 6,100 | 0.0 | 0.0 | 94.0 | 20.0 | 114.0 |
| 6,100 - 6,200 | 4.0 | 10.0 | 94.0 | 20.0 | 128.0 |
| 6,200 - 6,600 | 4.0 | 10.0 | 94.0 | 20.0 | 128.0 |
| 6,600 - 6,700 | 0.0 | 0.0 | 94.0 | 20.0 | 114.0 |
| 6,700 - 6,900 | 0.0 | 2.5 | 94.0 | 20.0 | 128.5 |
| 6,900 - 7,100 | 6.0 | 5.0 | 94.0 | 20.0 | 125.0 |
| 7,100 - 7,300 | 6.0 | 5.0 | 94.0 | 20.0 | 125.0 |
| 7,300 - 8,000 | 0.0 | 55.0 | 94.0 | 20.0 | 169.0 |
| 8,000 - 8,600 | 6.0 | 55.0 | 94.0 | 20.0 | 175.0 |
| 8,600 - 8,900 | 7.0 | 20.0 | 94.0 | 20.0 | 141.0 |
| 8,900 - 9,500 | 1.0 | 75.0 | 94.0 | 20.0 | 190.0 |
| 9,500 - 9,800 | 5.0 | 60.0 | 94.0 | 20.0 | 179.0 |
| 9,800 -10,100 | 1.0 | 55.0 | 94.0 | 20.0 | 170.0 |
| 10,100 - 10,800 | 12.0 | 115.0 | 94.0 | 20.0 | 241.0 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 0.0 | 57.5 | 94.0 | 20.0 | 177.5 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 65.0 | 94.0 | 20.0 | 185.0 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 120.0 | 94.0 | 20.0 | 259.0 |

| Present Day - Uncontrolled | | | | | |
|---|---|---|---|---|---|
| **Chainage (m)** | **S1** | **S2** | **S3** | **SU** | **Total** |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 9.0 | 0.0 | 0.0 | 0.0 | 9.0 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 0.0 | 0.0 | 0.0 | 11.0 |
| 3,100 - 3,500 | 5.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| 3,500 - 3,900 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 3,900 - 4,200 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 4,200 - 4,400 | 10.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| 4,400 - 4,800 | 10.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| 4,800 - 5,000 | 10.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| 5,000 - 5,300 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5,300 - 5,500 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5,500 - 6,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6,100 - 6,200 | 4.0 | 0.0 | 0.0 | 0.0 | 4.0 |
| 6,200 - 6,600 | 4.0 | 0.0 | 0.0 | 0.0 | 4.0 |
| 6,600 - 6,700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6,700 - 6,900 | 12.0 | 0.0 | 0.0 | 0.0 | 12.0 |
| 6,900 - 7,100 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 7,100 - 7,300 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 7,300 - 8,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8,000 - 8,600 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 8,600 - 8,900 | 7.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| 8,900 - 9,500 | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| 9,500 - 9,800 | 5.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| 9,800 -10,100 | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| 10,100 - 10,800 | 12.0 | 0.0 | 0.0 | 0.0 | 12.0 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 0.0 | 0.0 | 0.0 | 6.0 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 0.0 | 0.0 | 0.0 | 25.0 |

| 2047 - Uncontrolled | | | | | |
|---|---|---|---|---|---|
| **Chainage (m)** | **S1** | **S2** | **S3** | **SU** | **Total** |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 9.0 | 13.8 | 4.0 | 5.0 | 31.8 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 13.8 | 4.0 | 5.0 | 33.8 |
| 3,100 - 3,500 | 5.0 | 13.8 | 4.0 | 5.0 | 27.8 |
| 3,500 - 3,900 | 3.0 | 6.3 | 4.0 | 5.0 | 18.3 |
| 3,900 - 4,200 | 3.0 | 7.5 | 4.0 | 5.0 | 19.5 |
| 4,200 - 4,400 | 10.0 | 3.8 | 4.0 | 5.0 | 22.8 |
| 4,400 - 4,800 | 10.0 | 8.8 | 4.0 | 5.0 | 27.8 |
| 4,800 - 5,000 | 10.0 | 8.8 | 4.0 | 5.0 | 27.8 |
| 5,000 - 5,300 | 0.0 | 0.0 | 4.0 | 5.0 | 9.0 |
| 5,300 - 5,500 | 0.0 | 3.8 | 4.0 | 5.0 | 12.8 |
| 5,500 - 6,100 | 0.0 | 0.0 | 4.0 | 5.0 | 9.0 |
| 6,100 - 6,200 | 4.0 | 2.5 | 4.0 | 5.0 | 15.5 |
| 6,200 - 6,600 | 4.0 | 2.5 | 4.0 | 5.0 | 15.5 |
| 6,600 - 6,700 | 0.0 | 0.0 | 4.0 | 5.0 | 9.0 |
| 6,700 - 6,900 | 12.0 | 1.3 | 4.0 | 5.0 | 22.3 |
| 6,900 - 7,100 | 6.0 | 1.3 | 4.0 | 5.0 | 16.3 |
| 7,100 - 7,300 | 6.0 | 1.3 | 4.0 | 5.0 | 16.3 |
| 7,300 - 8,000 | 0.0 | 13.8 | 4.0 | 5.0 | 22.8 |
| 8,000 - 8,600 | 6.0 | 13.8 | 4.0 | 5.0 | 28.8 |
| 8,600 - 8,900 | 7.0 | 5.0 | 4.0 | 5.0 | 21.0 |
| 8,900 - 9,500 | 1.0 | 18.8 | 4.0 | 5.0 | 28.8 |
| 9,500 - 9,800 | 5.0 | 15.0 | 4.0 | 5.0 | 29.0 |
| 9,800 -10,100 | 1.0 | 13.8 | 4.0 | 5.0 | 23.8 |
| 10,100 - 10,800 | 12.0 | 28.8 | 4.0 | 5.0 | 49.8 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 6.0 | 28.8 | 4.0 | 5.0 | 43.8 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 16.3 | 4.0 | 5.0 | 31.3 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 30.0 | 4.0 | 5.0 | 64.0 |

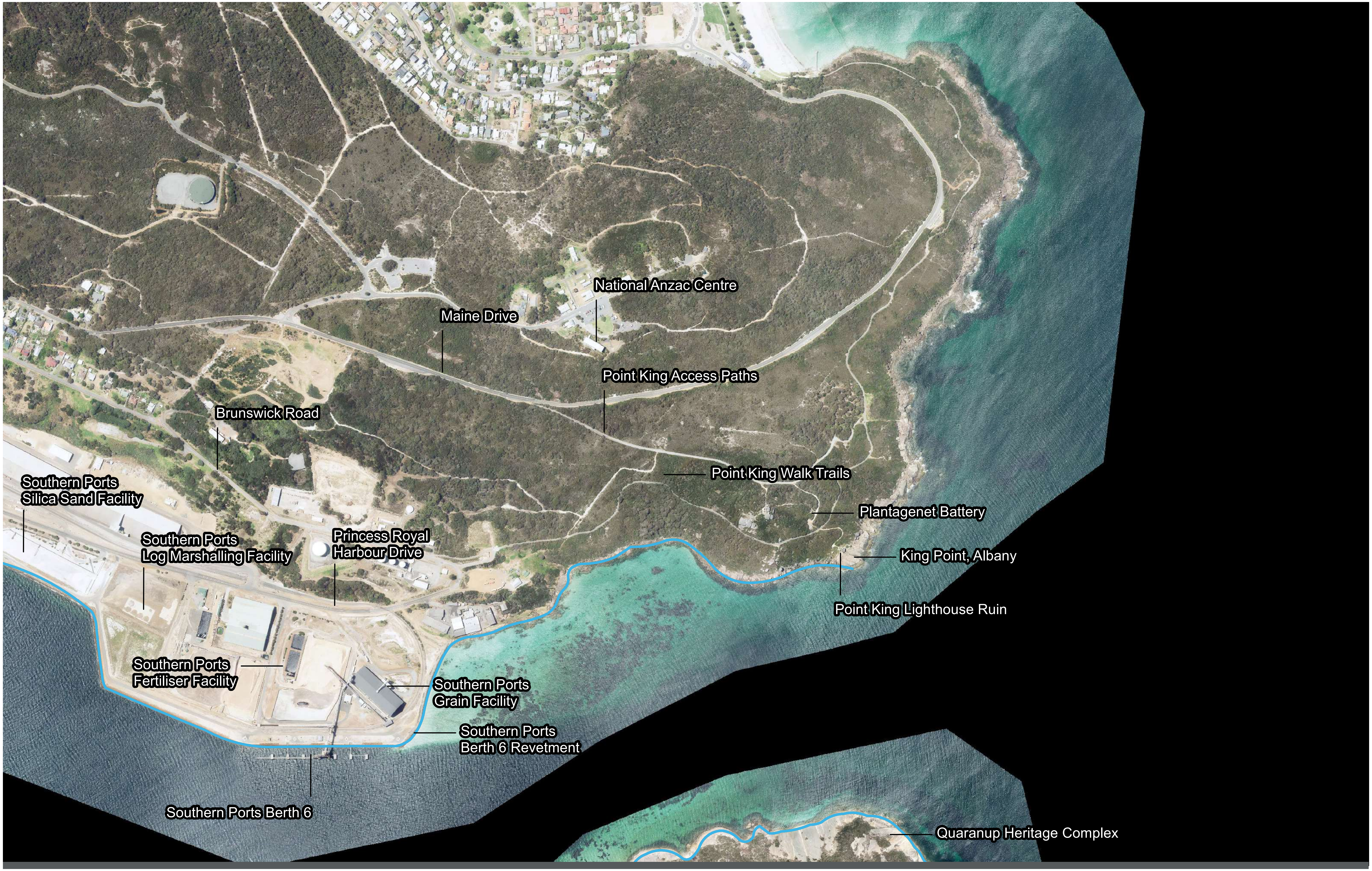
| 2072 - Uncontrolled | | | | | |
|---|---|---|---|---|---|
| **Chainage (m)** | **S1** | **S2** | **S3** | **SU** | **Total** |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 9.0 | 27.5 | 18.0 | 10.0 | 64.5 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 27.5 | 18.0 | 10.0 | 66.5 |
| 3,100 - 3,500 | 5.0 | 27.5 | 18.0 | 10.0 | 60.5 |
| 3,500 - 3,900 | 3.0 | 12.5 | 18.0 | 10.0 | 43.5 |
| 3,900 - 4,200 | 3.0 | 15.0 | 18.0 | 10.0 | 46.0 |
| 4,200 - 4,400 | 10.0 | 7.5 | 18.0 | 10.0 | 45.5 |
| 4,400 - 4,800 | 10.0 | 17.5 | 18.0 | 10.0 | 55.5 |
| 4,800 - 5,000 | 10.0 | 17.5 | 18.0 | 10.0 | 55.5 |
| 5,000 - 5,300 | 0.0 | 0.0 | 18.0 | 10.0 | 28.0 |
| 5,300 - 5,500 | 0.0 | 7.5 | 18.0 | 10.0 | 35.5 |
| 5,500 - 6,100 | 0.0 | 0.0 | 18.0 | 10.0 | 28.0 |
| 6,100 - 6,200 | 4.0 | 5.0 | 18.0 | 10.0 | 37.0 |
| 6,200 - 6,600 | 4.0 | 5.0 | 18.0 | 10.0 | 37.0 |
| 6,600 - 6,700 | 0.0 | 0.0 | 18.0 | 10.0 | 28.0 |
| 6,700 - 6,900 | 12.0 | 2.5 | 18.0 | 10.0 | 42.5 |
| 6,900 - 7,100 | 6.0 | 2.5 | 18.0 | 10.0 | 36.5 |
| 7,100 - 7,300 | 6.0 | 2.5 | 18.0 | 10.0 | 36.5 |
| 7,300 - 8,000 | 0.0 | 27.5 | 18.0 | 10.0 | 55.5 |
| 8,000 - 8,600 | 6.0 | 27.5 | 18.0 | 10.0 | 61.5 |
| 8,600 - 8,900 | 7.0 | 10.0 | 18.0 | 10.0 | 45.0 |
| 8,900 - 9,500 | 1.0 | 37.5 | 18.0 | 10.0 | 66.5 |
| 9,500 - 9,800 | 5.0 | 30.0 | 18.0 | 10.0 | 63.0 |
| 9,800 -10,100 | 1.0 | 27.5 | 18.0 | 10.0 | 56.5 |
| 10,100 - 10,800 | 12.0 | 57.5 | 18.0 | 10.0 | 97.5 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 6.0 | 57.5 | 18.0 | 10.0 | 91.5 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 32.5 | 18.0 | 10.0 | 66.5 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 60.0 | 18.0 | 10.0 | 113.0 |

| 2122 - Uncontrolled | | | | | |
|---|---|---|---|---|---|
| Chainage (m) | S1 | S2 | S3 | SU | Total |
| 0 - 550 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 550 - 700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700 - 1,600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1,600 - 2,800 | 9.0 | 55.0 | 94.0 | 20.0 | 178.0 |
| 2,800 - 2,900 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2,900 - 3,100 | 11.0 | 55.0 | 94.0 | 20.0 | 180.0 |
| 3,100 - 3,500 | 5.0 | 55.0 | 94.0 | 20.0 | 174.0 |
| 3,500 - 3,900 | 3.0 | 25.0 | 94.0 | 20.0 | 142.0 |
| 3,900 - 4,200 | 3.0 | 30.0 | 94.0 | 20.0 | 147.0 |
| 4,200 - 4,400 | 10.0 | 15.0 | 94.0 | 20.0 | 139.0 |
| 4,400 - 4,800 | 10.0 | 35.0 | 94.0 | 20.0 | 159.0 |
| 4,800 - 5,000 | 10.0 | 35.0 | 94.0 | 20.0 | 159.0 |
| 5,000 - 5,300 | 0.0 | 0.0 | 94.0 | 20.0 | 114.0 |
| 5,300 - 5,500 | 0.0 | 15.0 | 94.0 | 20.0 | 129.0 |
| 5,500 - 6,100 | 0.0 | 0.0 | 94.0 | 20.0 | 114.0 |
| 6,100 - 6,200 | 4.0 | 10.0 | 94.0 | 20.0 | 128.0 |
| 6,200 - 6,600 | 4.0 | 10.0 | 94.0 | 20.0 | 128.0 |
| 6,600 - 6,700 | 0.0 | 0.0 | 94.0 | 20.0 | 114.0 |
| 6,700 - 6,900 | 12.0 | 5.0 | 94.0 | 20.0 | 131.0 |
| 6,900 - 7,100 | 6.0 | 5.0 | 94.0 | 20.0 | 125.0 |
| 7,100 - 7,300 | 6.0 | 5.0 | 94.0 | 20.0 | 125.0 |
| 7,300 - 8,000 | 0.0 | 55.0 | 94.0 | 20.0 | 169.0 |
| 8,000 - 8,600 | 6.0 | 55.0 | 94.0 | 20.0 | 175.0 |
| 8,600 - 8,900 | 7.0 | 20.0 | 94.0 | 20.0 | 141.0 |
| 8,900 - 9,500 | 1.0 | 75.0 | 94.0 | 20.0 | 190.0 |
| 9,500 - 9,800 | 5.0 | 60.0 | 94.0 | 20.0 | 179.0 |
| 9,800 -10,100 | 1.0 | 55.0 | 94.0 | 20.0 | 170.0 |
| 10,100 - 10,800 | 12.0 | 115.0 | 94.0 | 20.0 | 241.0 |
| 10,800 - 11,800 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11,800 - 12,000 | 6.0 | 115.0 | 94.0 | 20.0 | 235.0 |
| 12,000 - 12,200 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12,200 - 12,600 | 6.0 | 65.0 | 94.0 | 20.0 | 185.0 |
| 12,600 - 13,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13,100 - 13,800 | 25.0 | 120.0 | 94.0 | 20.0 | 259.0 |

APPENDIX

# C

EROSION HAZARD MAPPING




# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 1 )

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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION


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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 2 )

CW1200123-GS-005-EROSION


# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 3 )

5/12/2022

Size

A3

Scale

1:7,500

0 50 100 150 200 Meters

CW1200123-GS-005-EROSION

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

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# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 4 )

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION

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# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 5 )

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION

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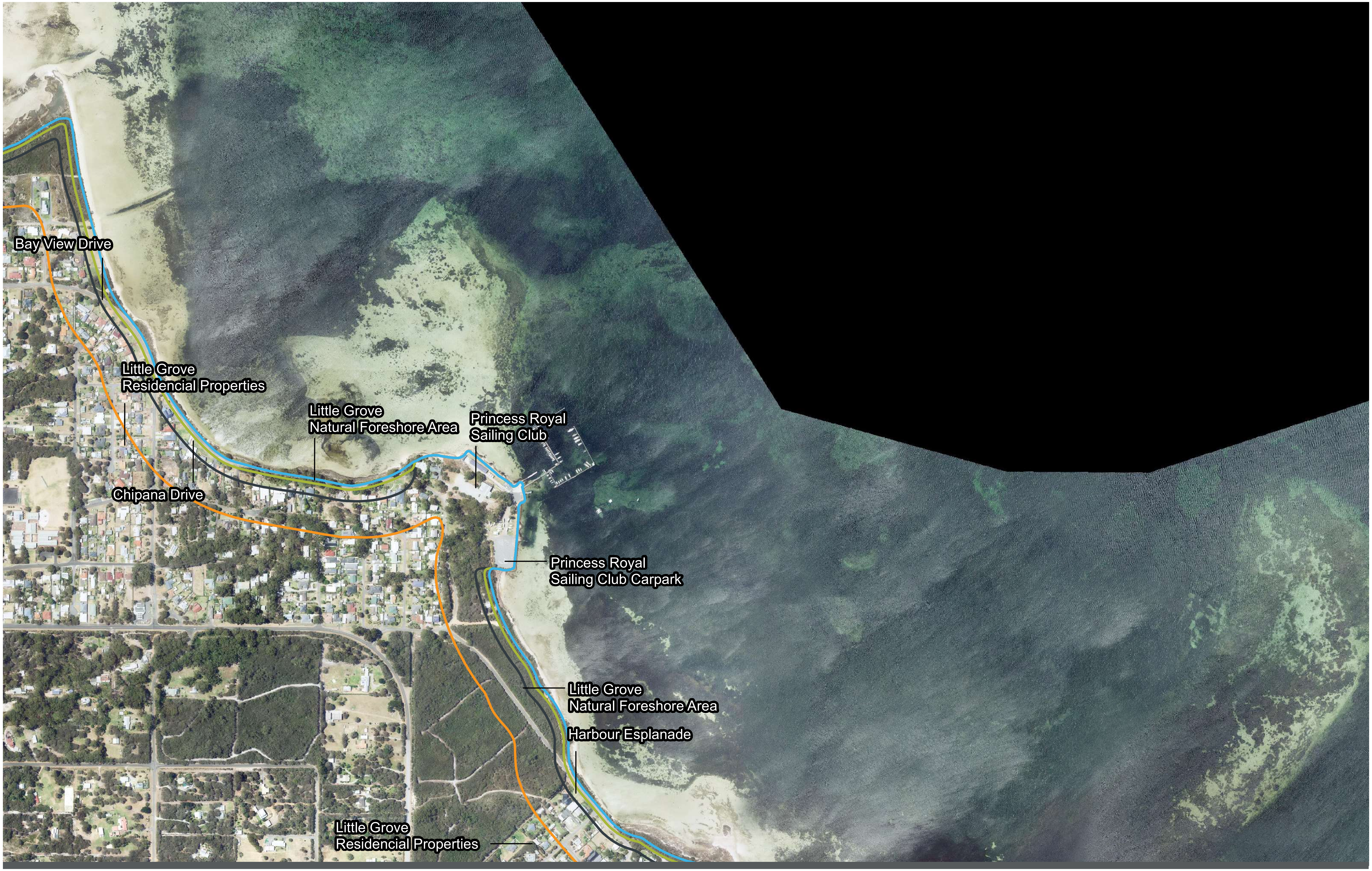


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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 6 )

CW1200123-GS-005-EROSION


# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 7 )

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION

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# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 8 )

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

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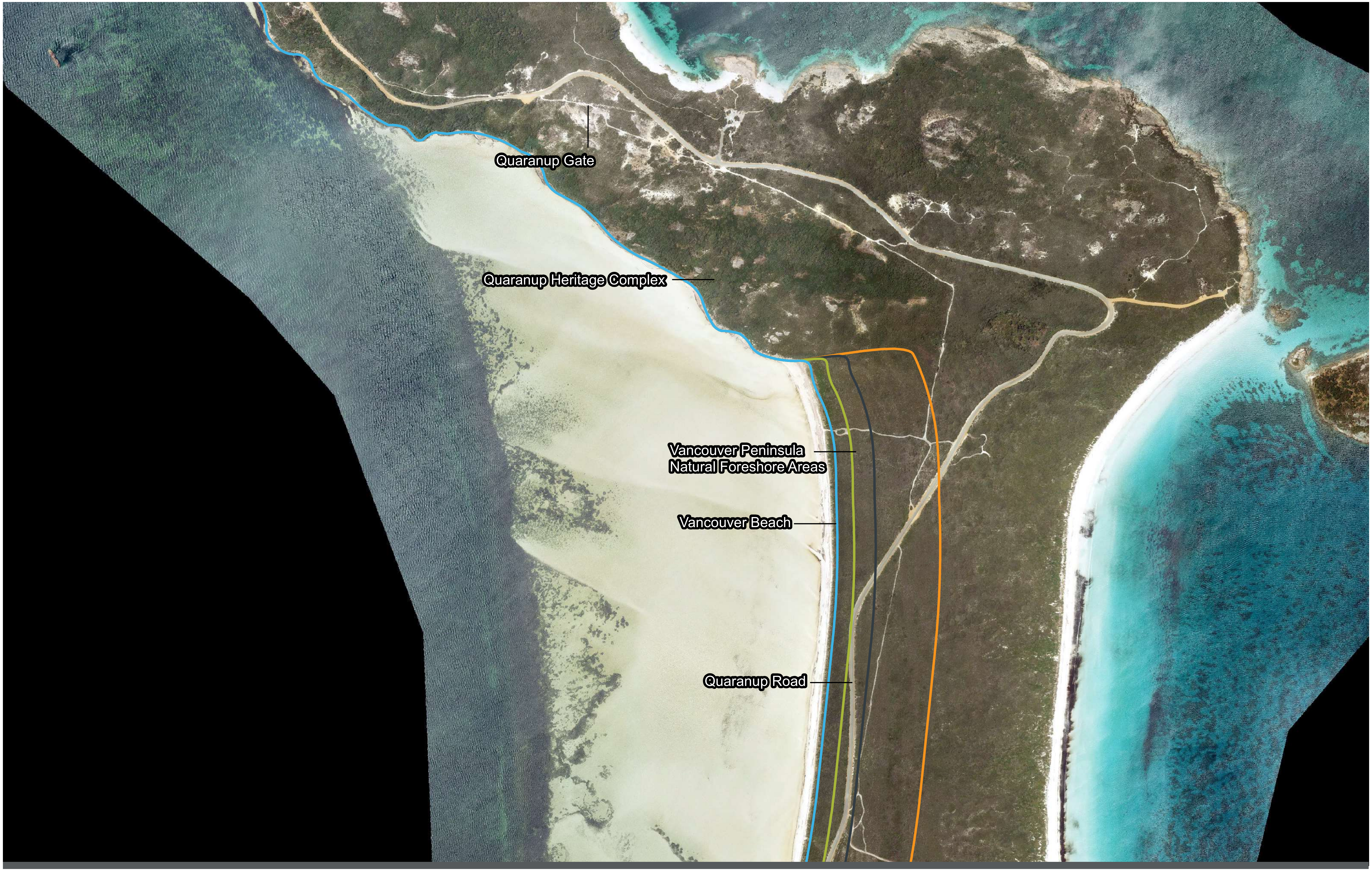


# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 9 )

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

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# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - CONTROLLED ( MAP SECTOR 10)

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION

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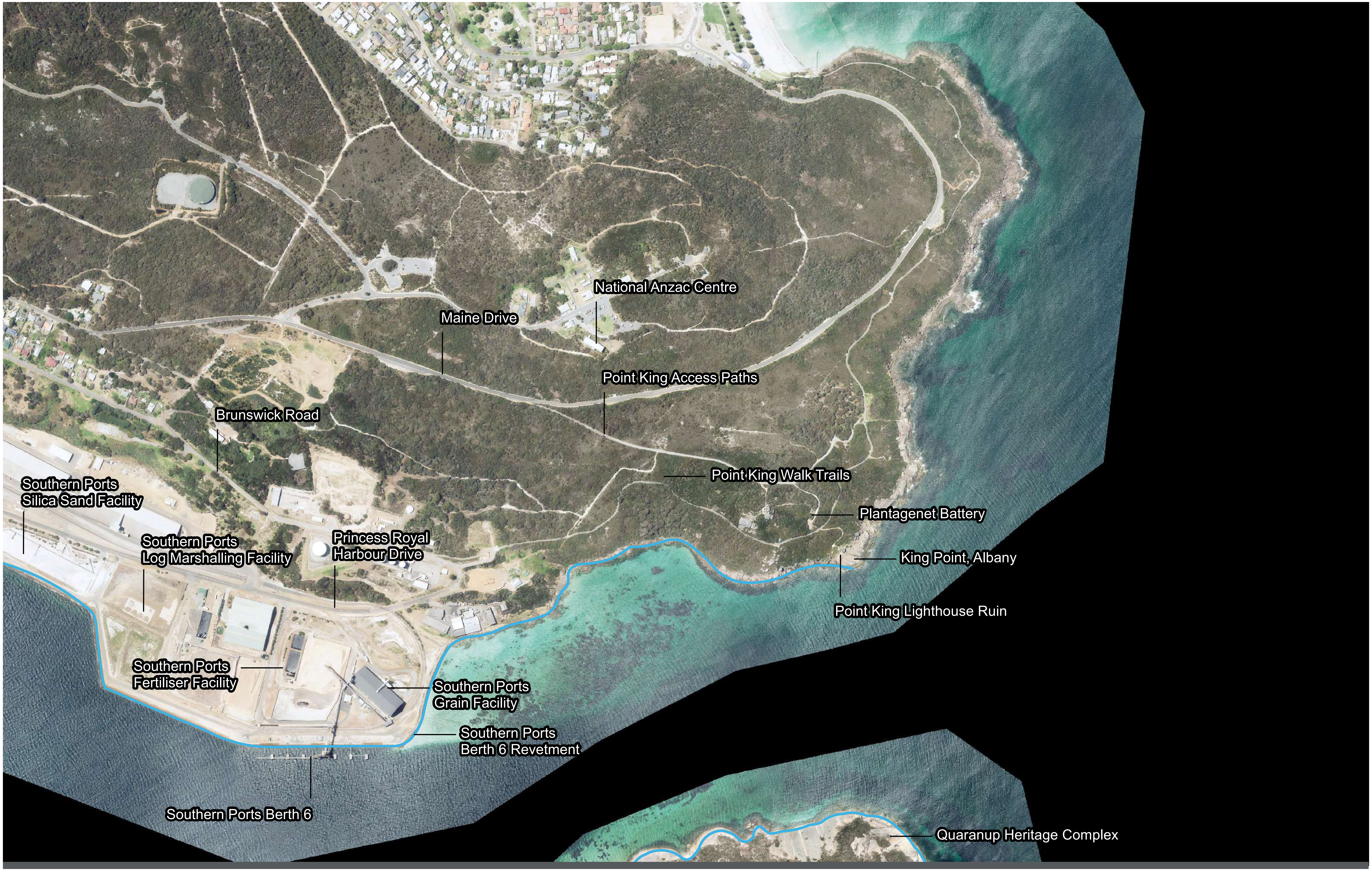


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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 1 )

CW1200123-GS-005-EROSION_UNCONTROLLED


# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 2 )

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

CW1200123-GS-005-EROSION_UNCONTROLLED

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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 3 )

CW1200123-GS-005-EROSION_UNCONTROLLED


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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 4 )

CW1200123-GS-005-EROSION_UNCONTROLLED


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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

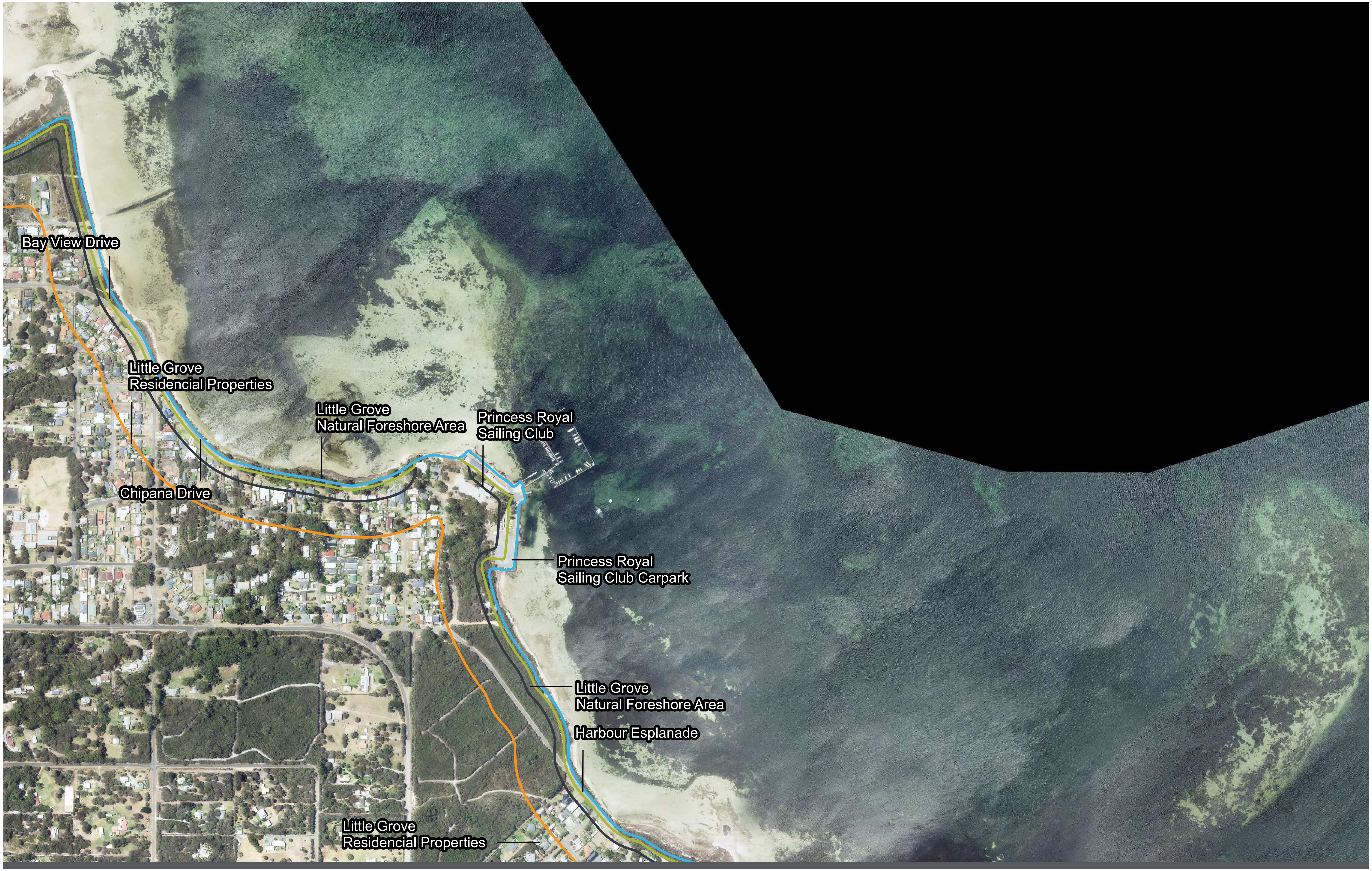
Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 5 )

CW1200123-GS-005-EROSION_UNCONTROLLED

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# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 6 )

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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION_UNCONTROLLED


# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 7 )

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION_UNCONTROLLED

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents


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**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

5/12/2022

Size
A3

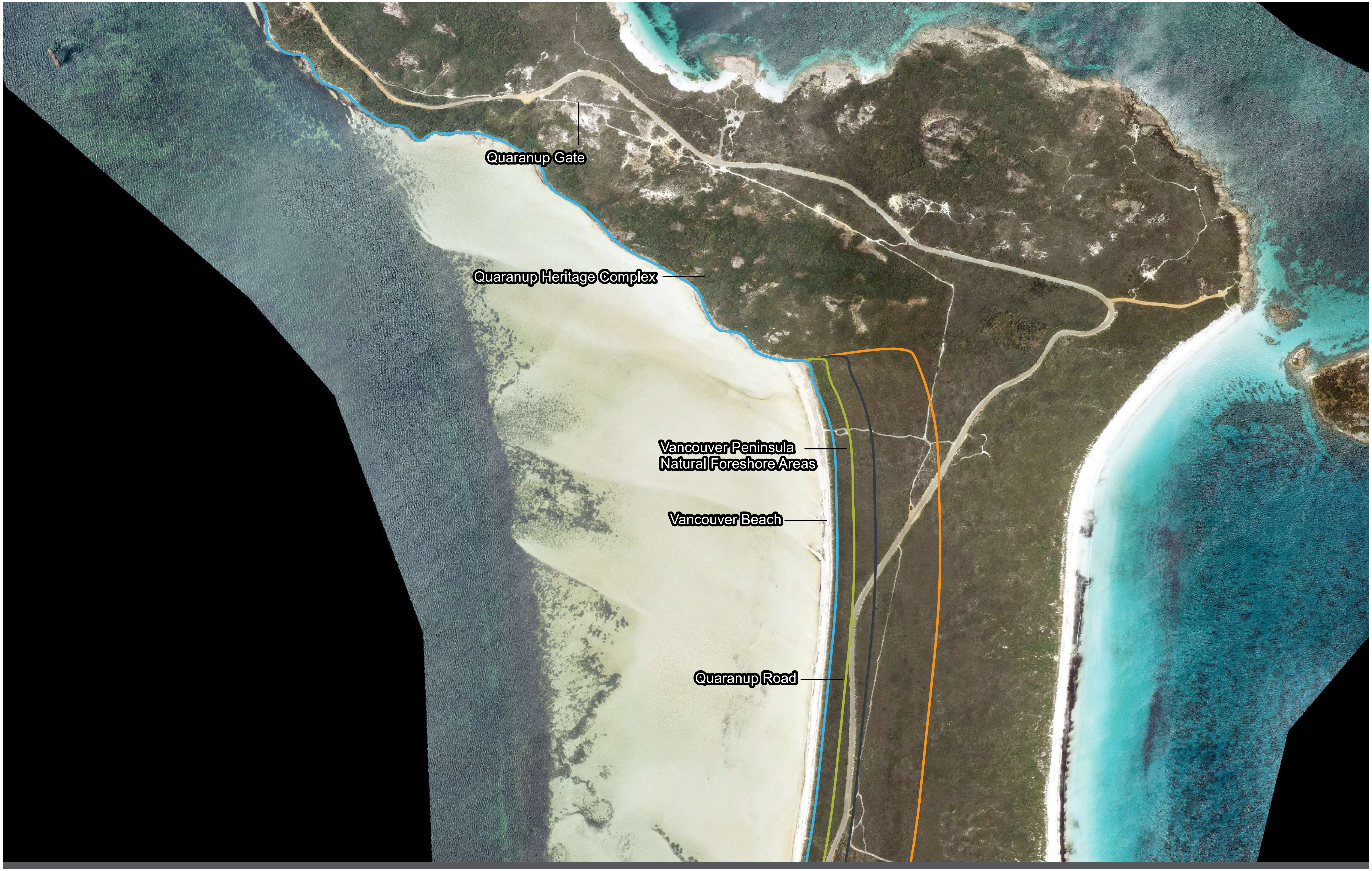
Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 8 )

CW1200123-GS-005-EROSION_UNCONTROLLED




# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 9 )

CW1200123-GS-005-EROSION_UNCONTROLLED

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

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# PRINCESS ROYAL HARBOUR CHRMAP

EROSION - UNCONTROLLED ( MAP SECTOR 10)

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-005-EROSION_UNCONTROLLED

**Legend**

- PRH 2022 Erosion Extents
- PRH 2047 Erosion Extents
- PRH 2072 Erosion Extents
- PRH 2122 Erosion Extents

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APPENDIX

# D

INNUNDATION HAZARD MAPPING


# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 1 )

CW1200123-GS-004-INUNDATION

**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

2/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

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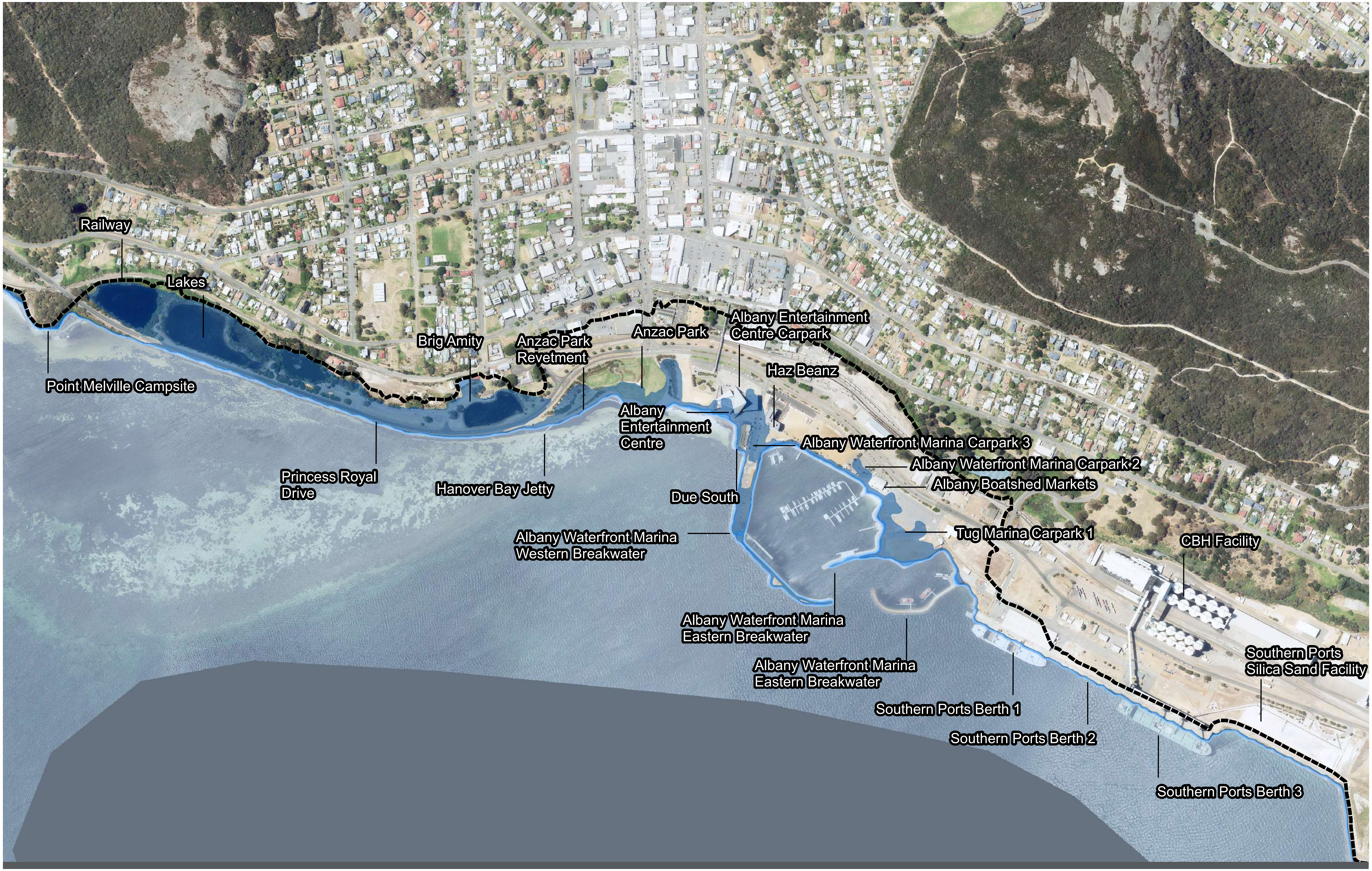


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**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

2/12/2022

Size
A3

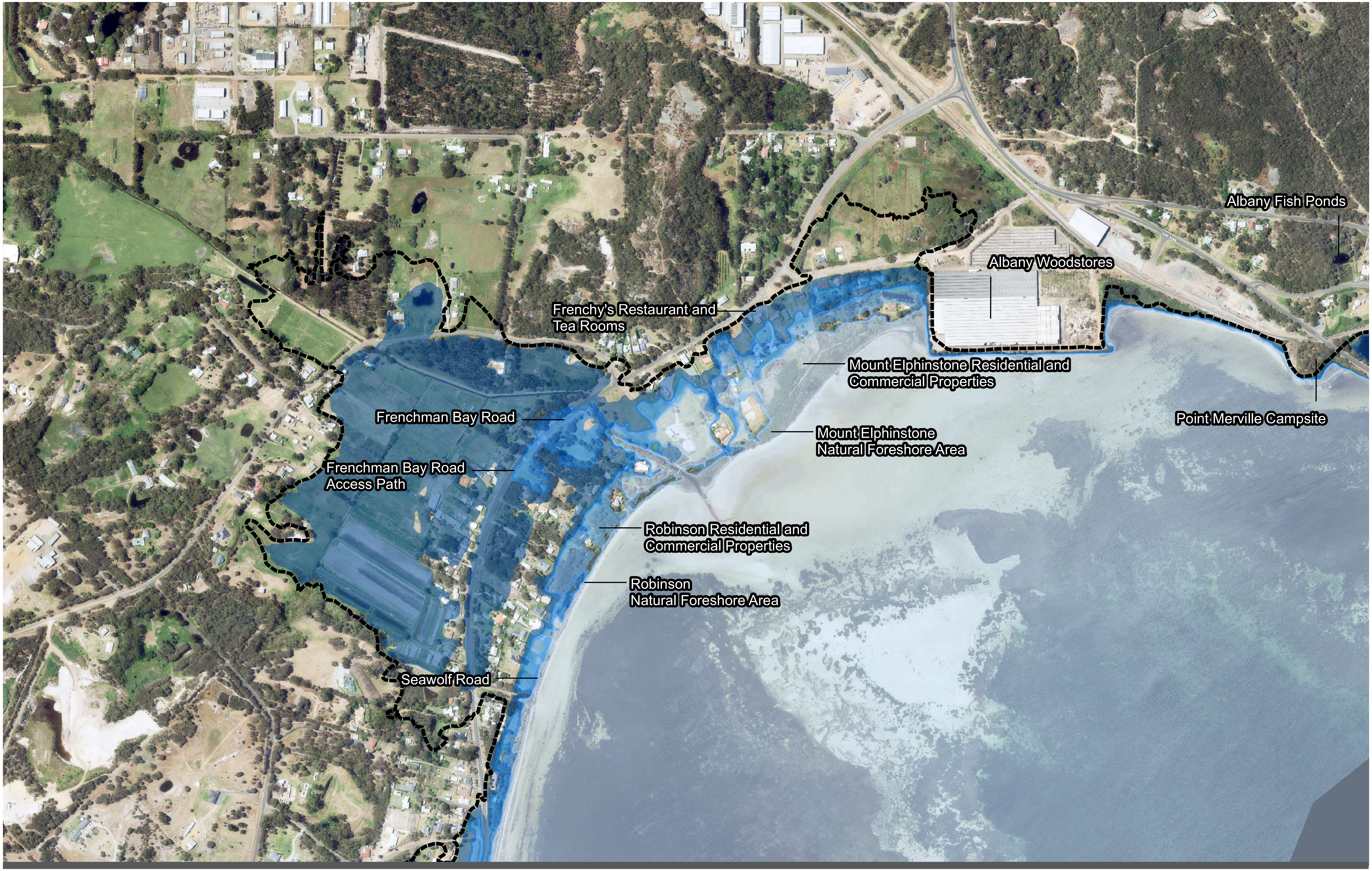
Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 2 )

CW1200123-GS-004-INUNDATION

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**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 3 )

CW1200123-GS-004-INUNDATION

DATE PLOTTED:1/12/2022 1:38:51 PM BY: CORY.SMITH
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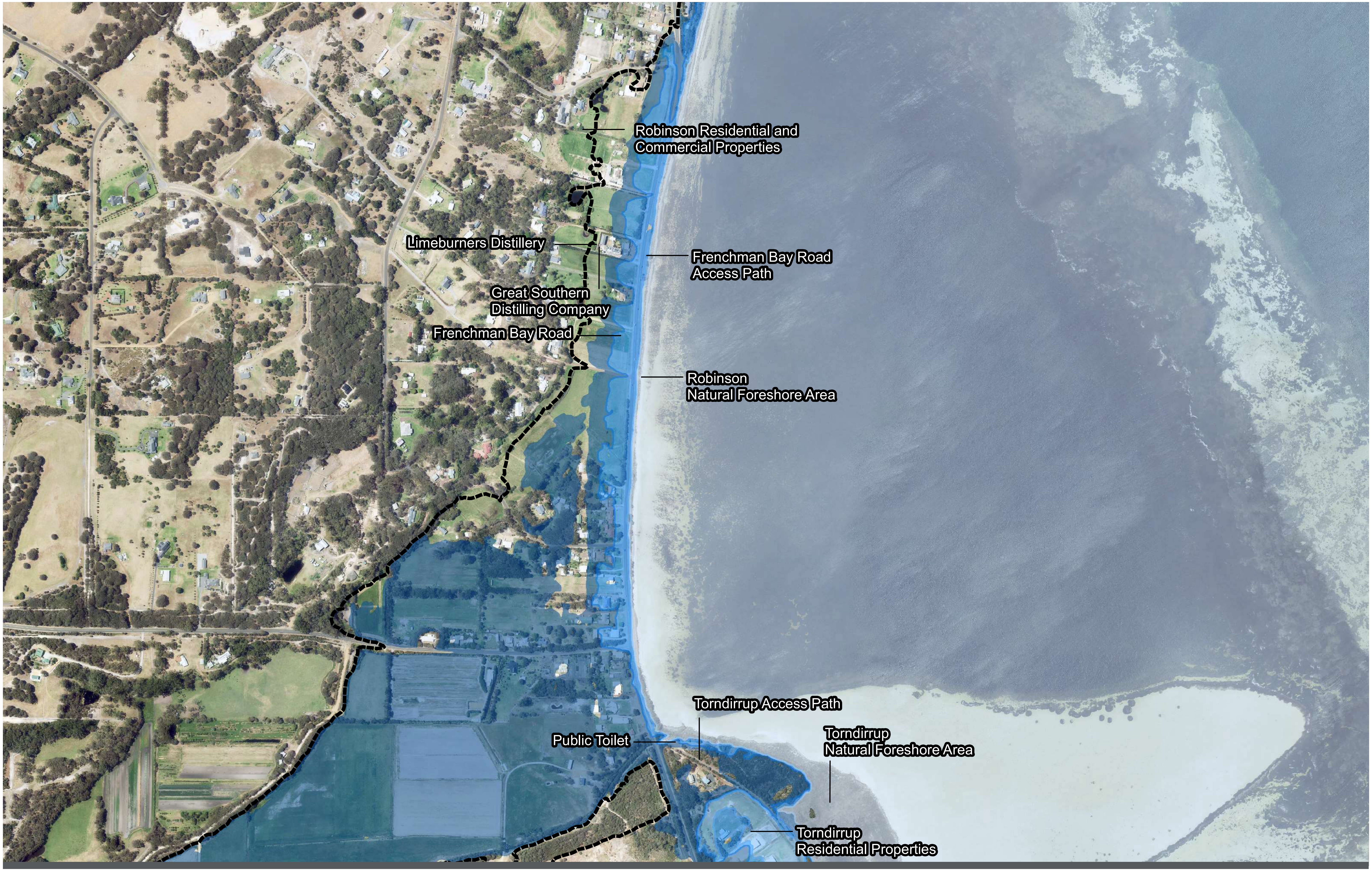


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**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 4 )

CW1200123-GS-004-INUNDATION


DATE PLOTTED: 1/12/2022 1:42:45 PM BY: CORY.SMITH
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**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

1/12/2022

Size
A3

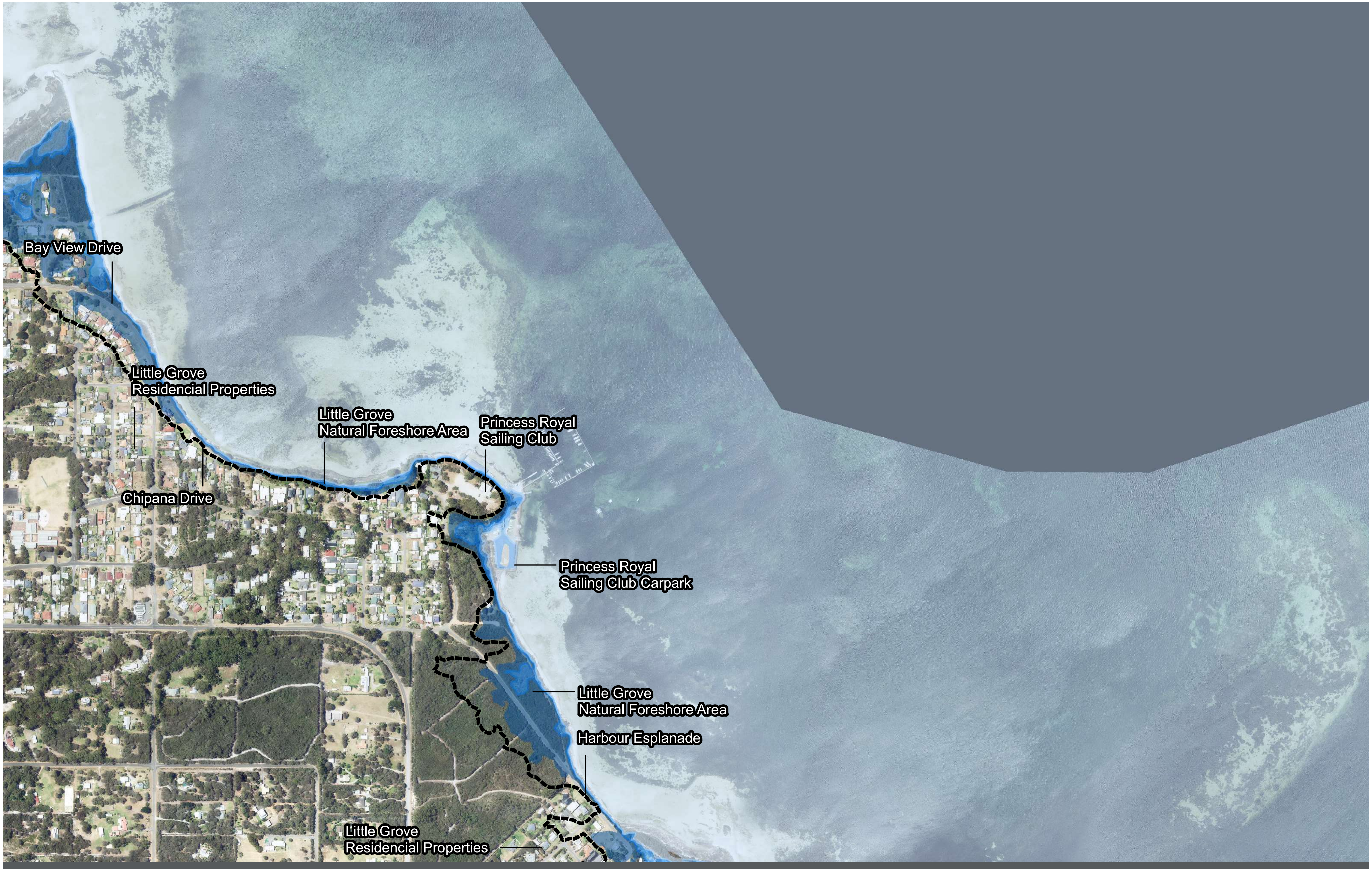
Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 5 )

CW1200123-GS-004-INUNDATION




# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 6 )

**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-004-INUNDATION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# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 7 )

CW1200123-GS-004-INUNDATION

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

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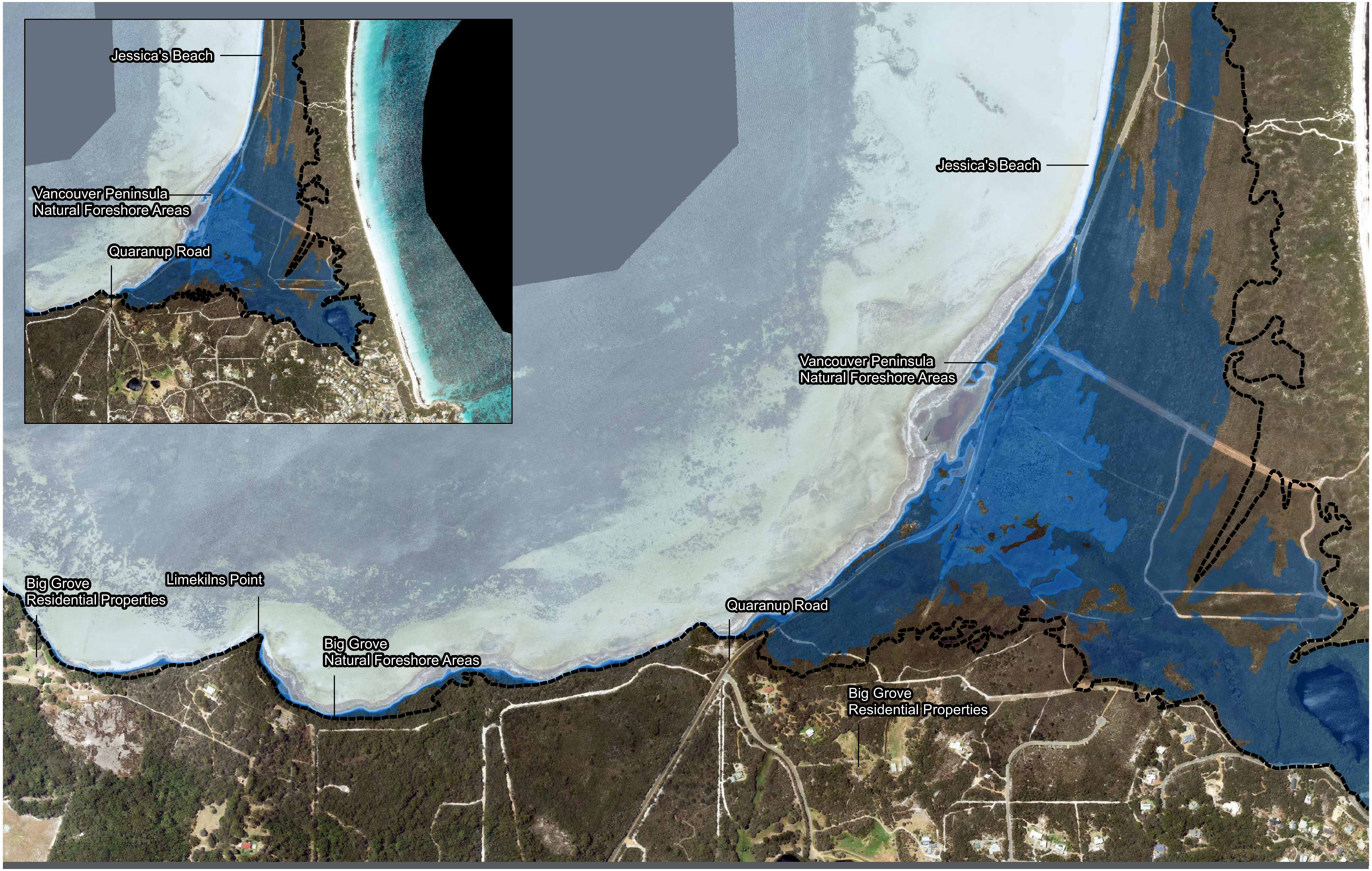


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**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

1/12/2022

Size
A3

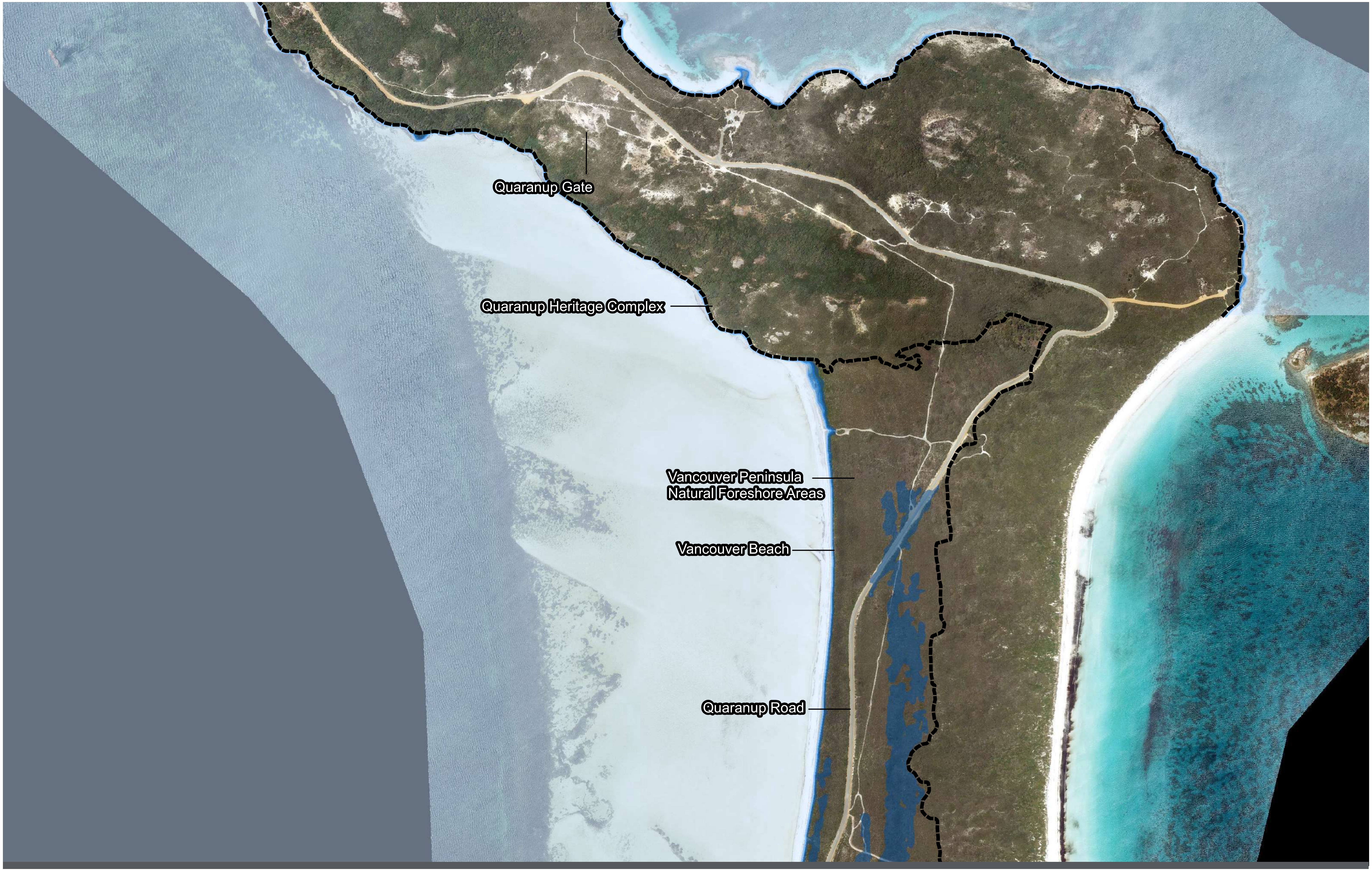
Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 8 )

CW1200123-GS-004-INUNDATION

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**Legend**

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 9 )

CW1200123-GS-004-INUNDATION

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# PRINCESS ROYAL HARBOUR CHRMAP

INUNDATION ( MAP SECTOR 10)

CW1200123-GS-004-INUNDATION

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

## Legend

- 2122 Wave Runup Level
- 2022 Inundation Extent
- 2047 Inundation Extent
- 2072 Inundation Extent
- 2122 Inundation Extent

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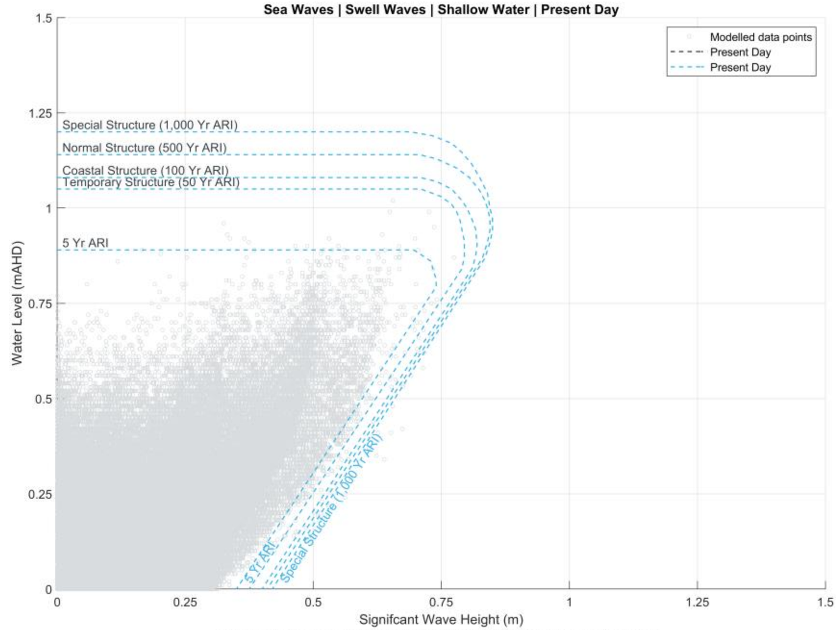
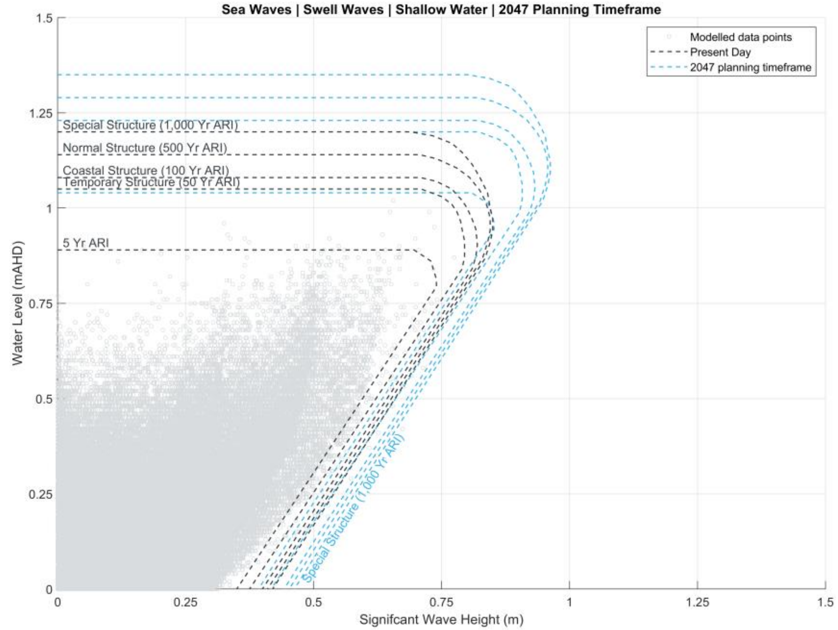
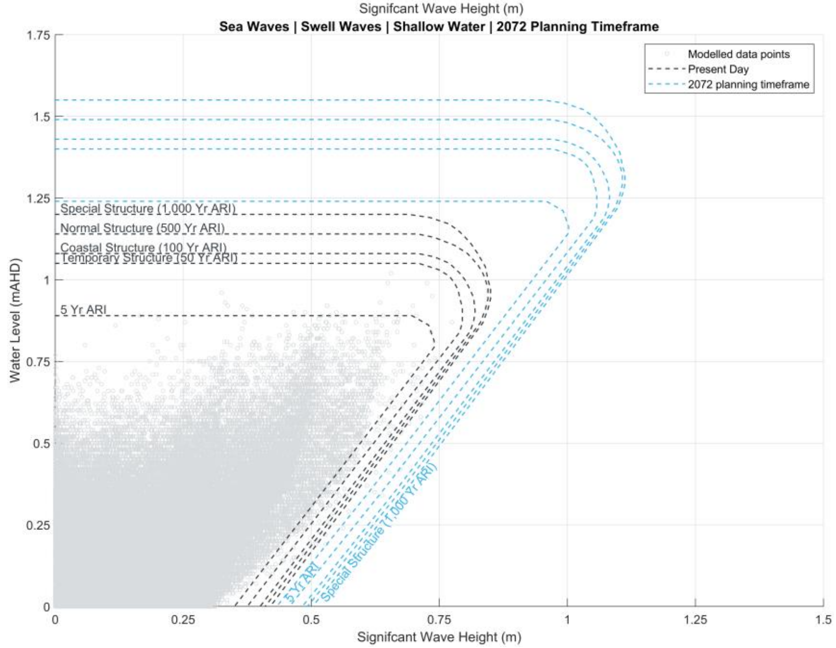
# APPENDIX

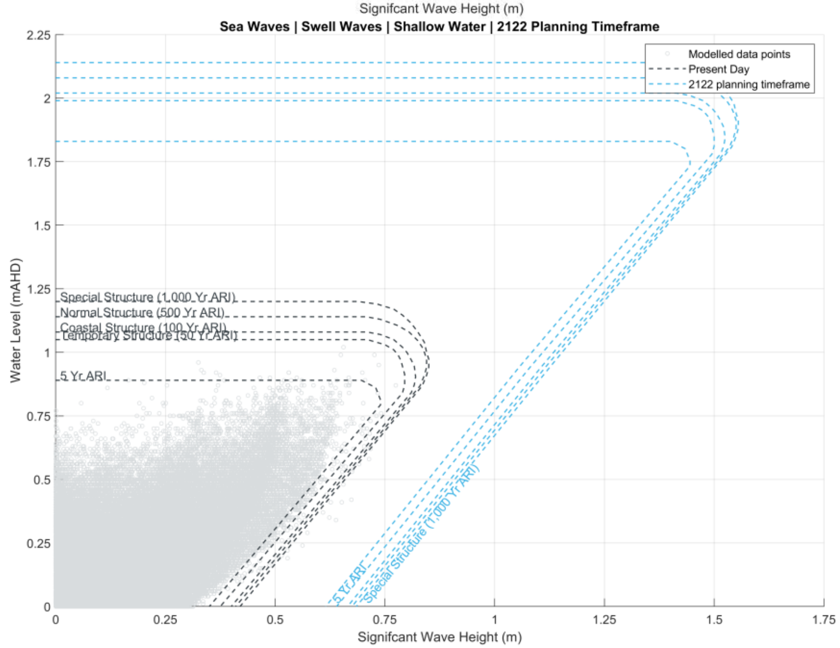
# E

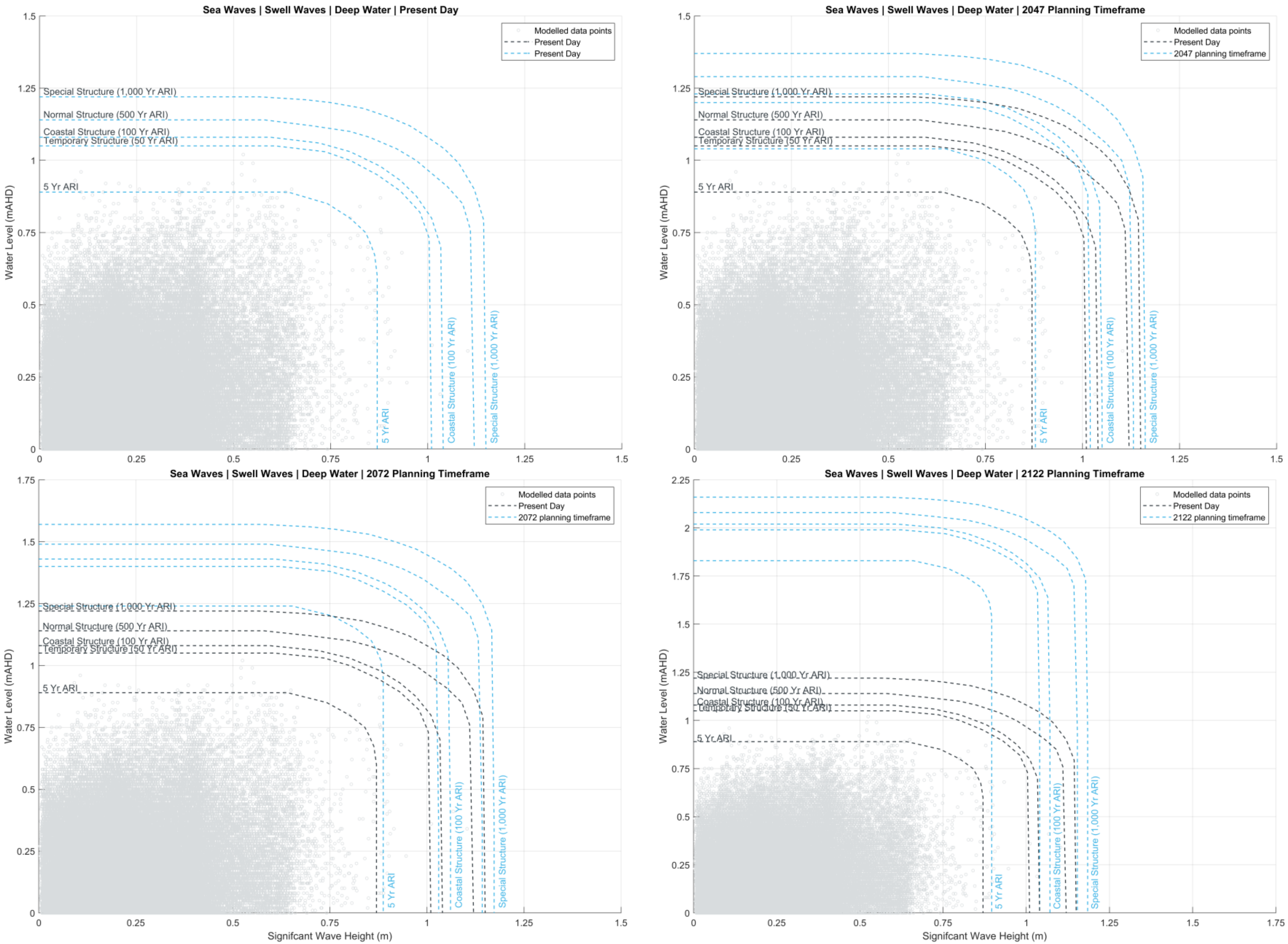
WAVE ATTACK JOINT PROBABILITY

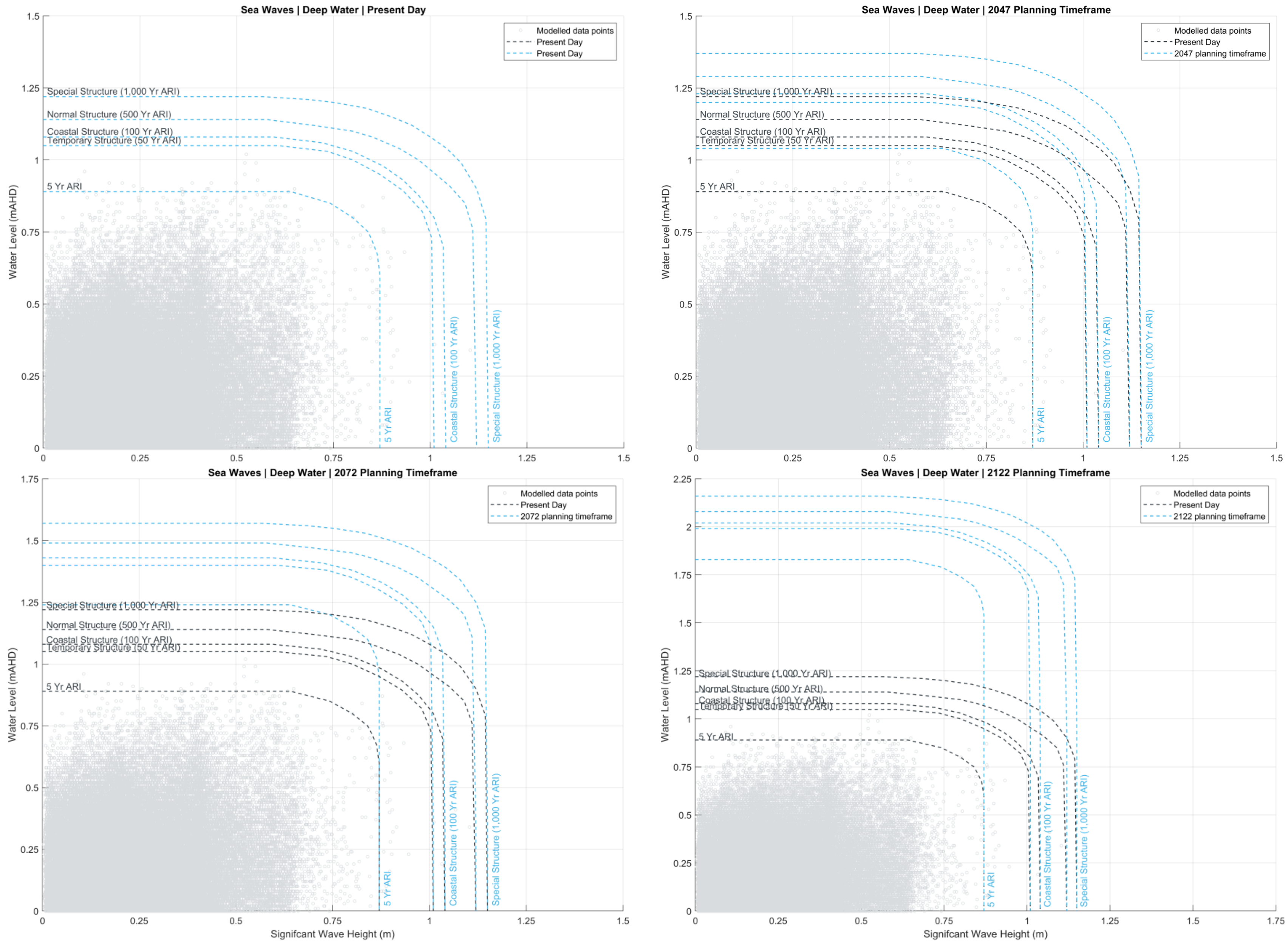

Sea Waves | Swell Waves | Shallow Water | Present Day
Modelled data points
Present Day
Present Day
Special Structure (1,000 Yr ARI)
Normal Structure (500 Yr ARI)
Coastal Structure (100 Yr ARI)
Temporary Structure (50 Yr ARI)
5 Yr ARI
Special Structure (1,000 Yr ARI)
5 Yr ARI
Water Level (mAHD)
Signifcant Wave Height (m)
0
0.25
0.5
0.75
1
1.25
1.5


Sea Waves | Swell Waves | Shallow Water | 2047 Planning Timeframe
Modelled data points
Present Day
2047 planning timeframe
Special Structure (1,000 Yr ARI)
Normal Structure (500 Yr ARI)
Coastal Structure (100 Yr ARI)
Temporary Structure (50 Yr ARI)
5 Yr ARI
Special Structure (1,000 Yr ARI)
Water Level (mAHD)
Signifcant Wave Height (m)
0
0.25
0.5
0.75
1
1.25
1.5


Sea Waves | Swell Waves | Shallow Water | 2072 Planning Timeframe
Modelled data points
Present Day
2072 planning timeframe
Special Structure (1,000 Yr ARI)
Normal Structure (500 Yr ARI)
Coastal Structure (100 Yr ARI)
Temporary Structure (50 Yr ARI)
5 Yr ARI
Special Structure (1,000 Yr ARI)
5 Yr ARI
Water Level (mAHD)
Signifcant Wave Height (m)
0
0.25
0.5
0.75
1
1.25
1.5
1.75


Sea Waves | Swell Waves | Shallow Water | 2122 Planning Timeframe
Modelled data points
Present Day
2122 planning timeframe
Special Structure (1,000 Yr ARI)
Normal Structure (500 Yr ARI)
Coastal Structure (100 Yr ARI)
Temporary Structure (50 Yr ARI)
5 Yr ARI
Special Structure (1,000 Yr ARI)
5 Yr ARI
Water Level (mAHD)
Signifcant Wave Height (m)
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25

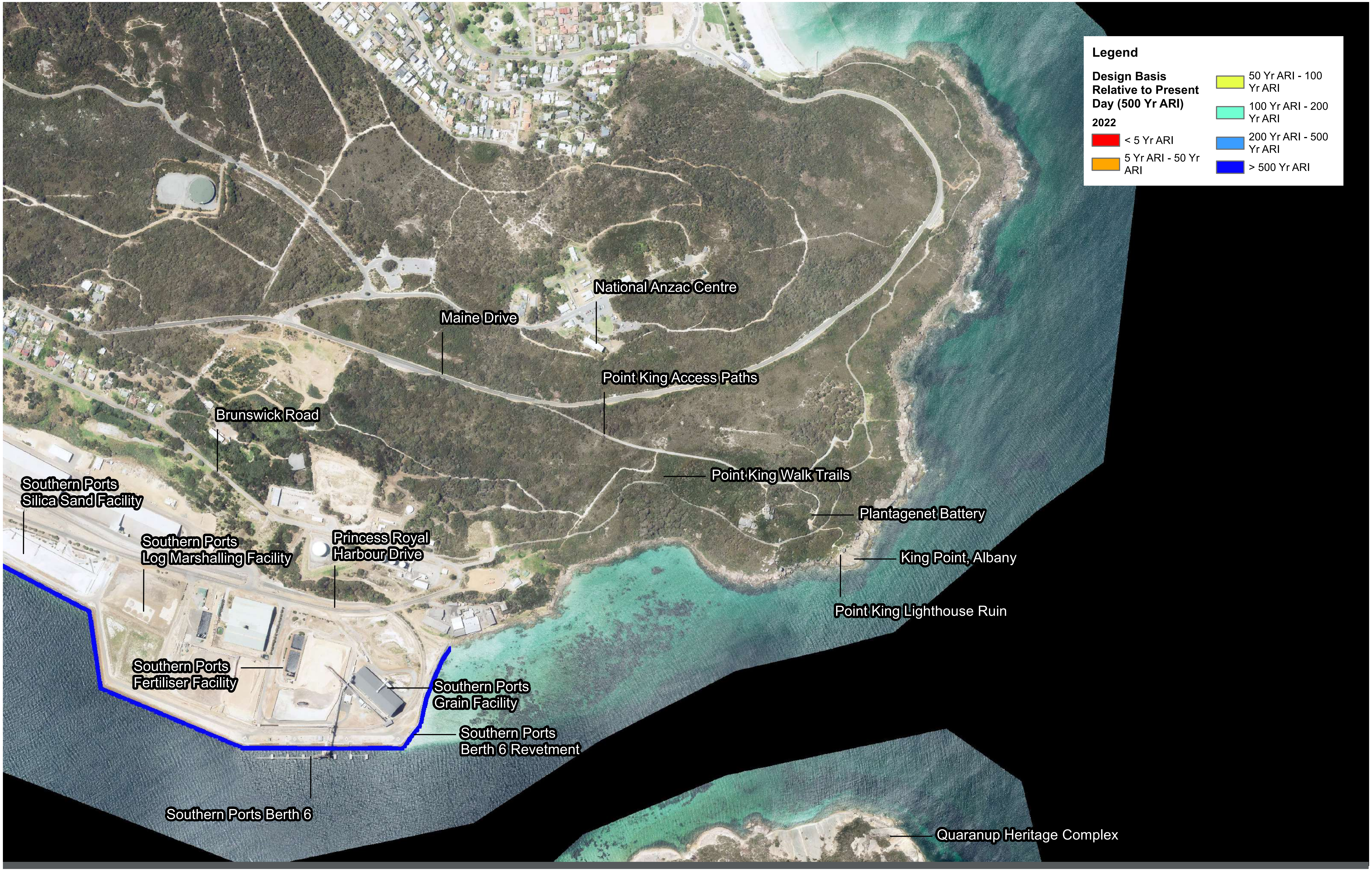

Sea Waves | Swell Waves | Deep Water | Present Day
Modelled data points
Present Day
Present Day
Special Structure (1,000 Yr ARI)
Normal Structure (500 Yr ARI)
Coastal Structure (100 Yr ARI)
Temporary Structure (50 Yr ARI)
5 Yr ARI
Water Level (mAHD)
Sea Waves | Swell Waves | Deep Water | 2047 Planning Timeframe
Modelled data points
Present Day
2047 planning timeframe
Sea Waves | Swell Waves | Deep Water | 2072 Planning Timeframe
Modelled data points
Present Day
2072 planning timeframe
Sea Waves | Swell Waves | Deep Water | 2122 Planning Timeframe
Modelled data points
Present Day
2122 planning timeframe
Signifcant Wave Height (m)


Sea Waves | Deep Water | Present Day
Modelled data points
Present Day
Present Day
Special Structure (1,000 Yr ARI)
Normal Structure (500 Yr ARI)
Coastal Structure (100 Yr ARI)
Temporary Structure (50 Yr ARI)
5 Yr ARI
Water Level (mAHD)
Sea Waves | Deep Water | 2047 Planning Timeframe
Modelled data points
Present Day
2047 planning timeframe
Sea Waves | Deep Water | 2072 Planning Timeframe
Modelled data points
Present Day
2072 planning timeframe
Sea Waves | Deep Water | 2122 Planning Timeframe
Modelled data points
Present Day
2122 planning timeframe
Signifcant Wave Height (m)

# APPENDIX

# F

## WAVE ATTACK HAZARD MAPPING




DATE PLOTTED:5/12/2022 3:25:20 PM BY: CORY.SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-009_Wave_Attack.mxd

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5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 1 )

CW1200123-GS-009_WAVE_ATTACK


DATE PLOTTED:5/12/2022 3:22:36 PM BY: CORY.SMITH
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5/12/2022

Size
A3

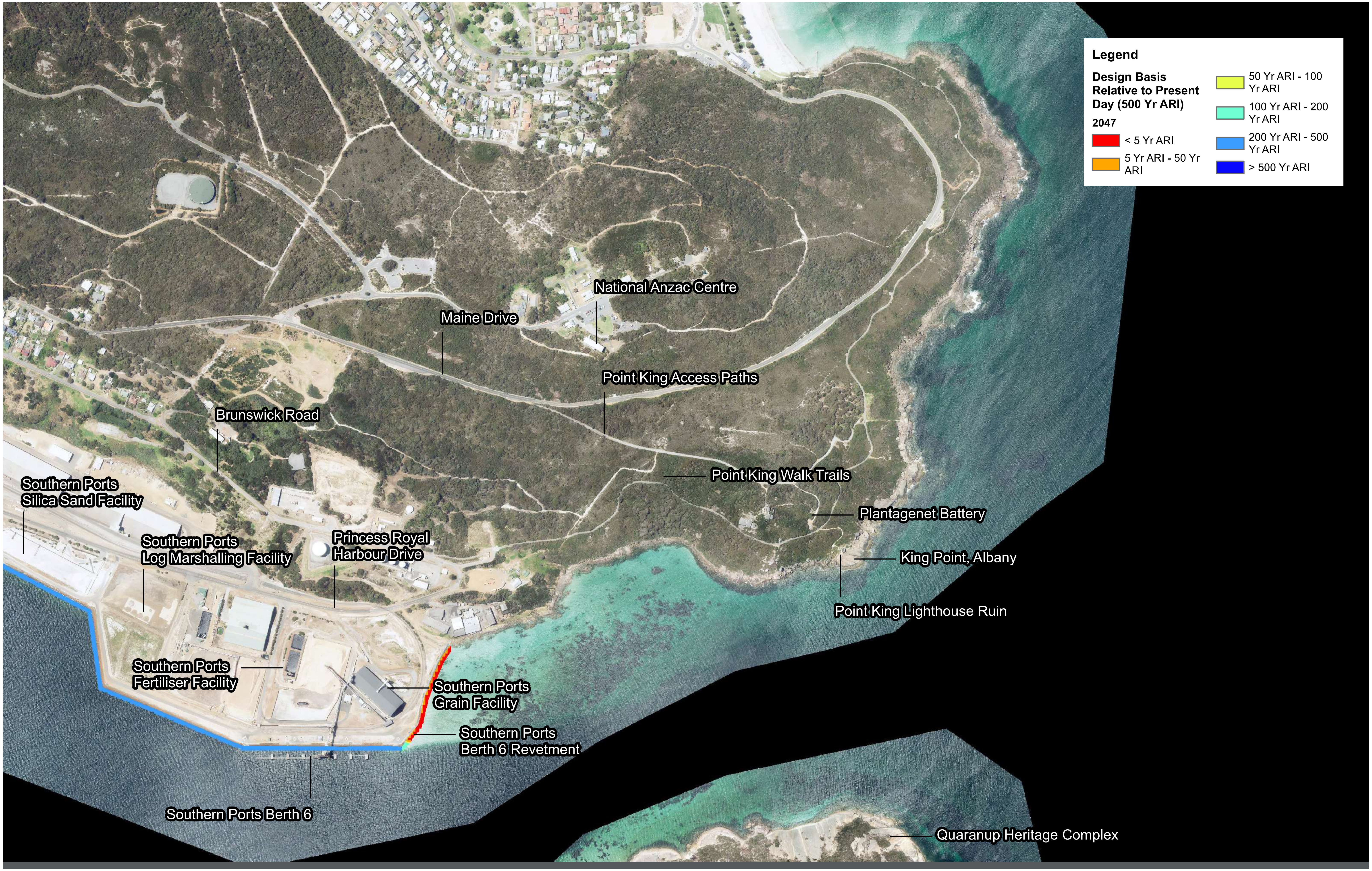
Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 2 )

CW1200123-GS-009_WAVE_ATTACK

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5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 1 )

CW1200123-GS-009_WAVE_ATTACK


DATE PLOTTED:5/12/2022 3:23:27 PM BY: CORY.SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-009_Wave_Attack.mxd

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5/12/2022

Size
A3

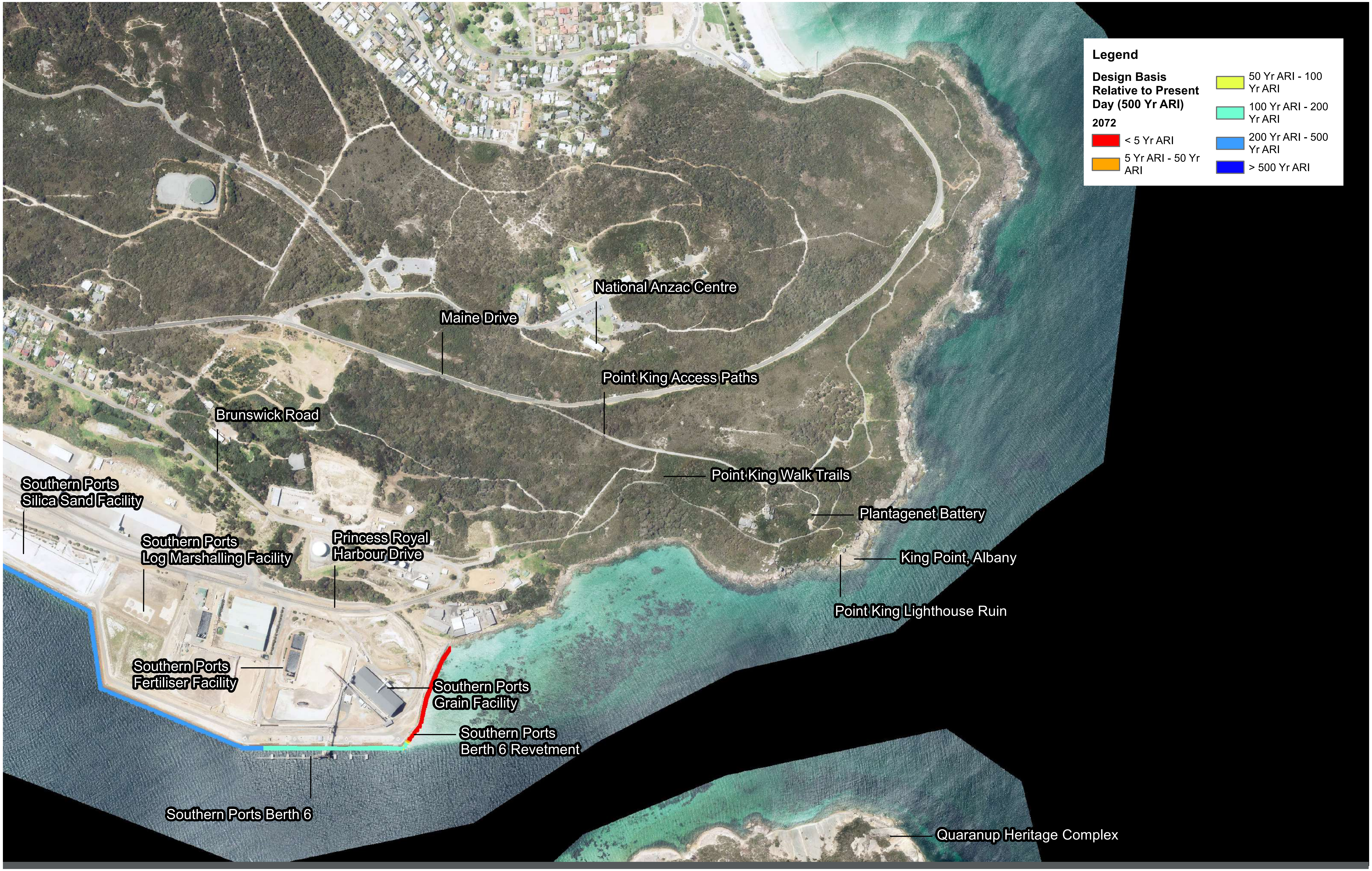
Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 2 )

CW1200123-GS-009_WAVE_ATTACK

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5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 1 )

CW1200123-GS-009_WAVE_ATTACK


DATE PLOTTED: 5/12/2022 3:23:59 PM BY: CORY.SMITH
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5/12/2022

Size
A3

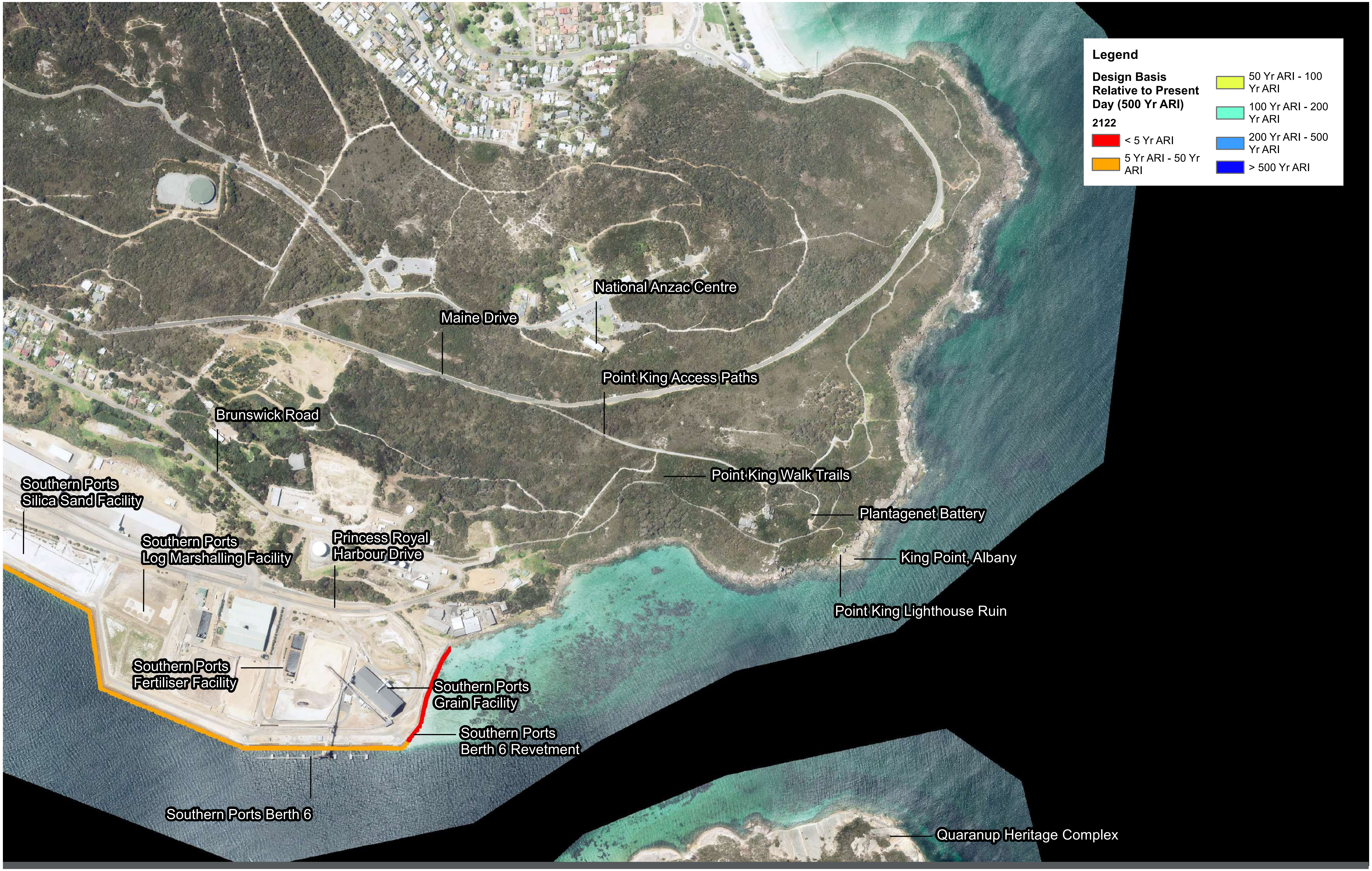
Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 2 )

CW1200123-GS-009_WAVE_ATTACK




# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 1 )

5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

CW1200123-GS-009_WAVE_ATTACK

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5/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

WAVE ATTACK ( MAP SECTOR 2 )

CW1200123-GS-009_WAVE_ATTACK

APPENDIX

# G

ASSET LOCAILITY MAPS

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DATE PLOTTED:2/12/2022 8:48:52 AM BY: CORY.SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-003-AssetLocality_v2.mxd

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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

2/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 1 )

CW1200123-GS-003-ASSETLOCALITY_V2


DATE PLOTTED:1/12/2022 3:24:14 PM BY: CORY.SMITH
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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 2 )

CW1200123-GS-003-ASSETLOCALITY_V2


# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 3 )

**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-003-ASSETLOCALITY

Cardno now Stantec

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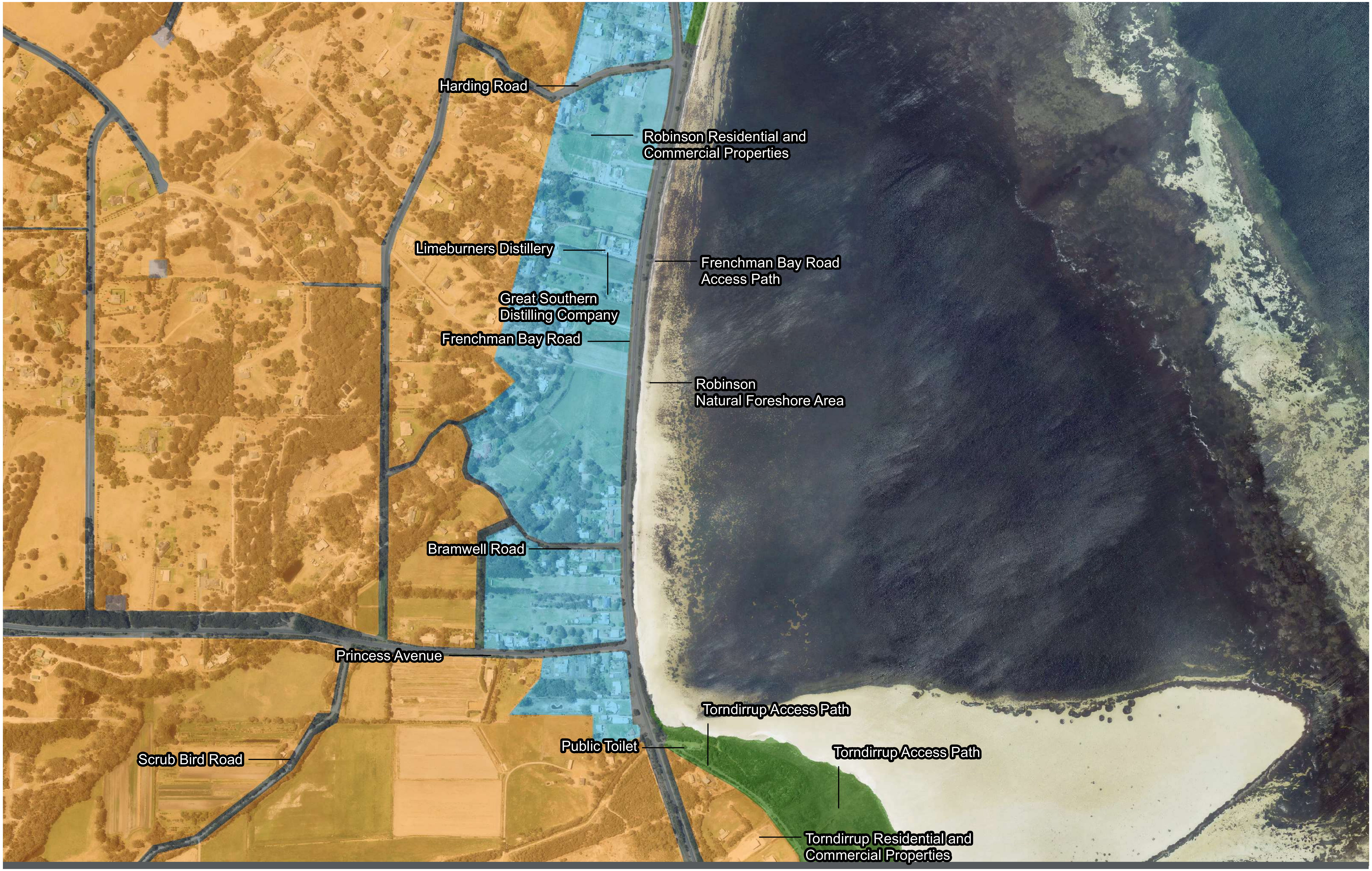


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# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 4 )

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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

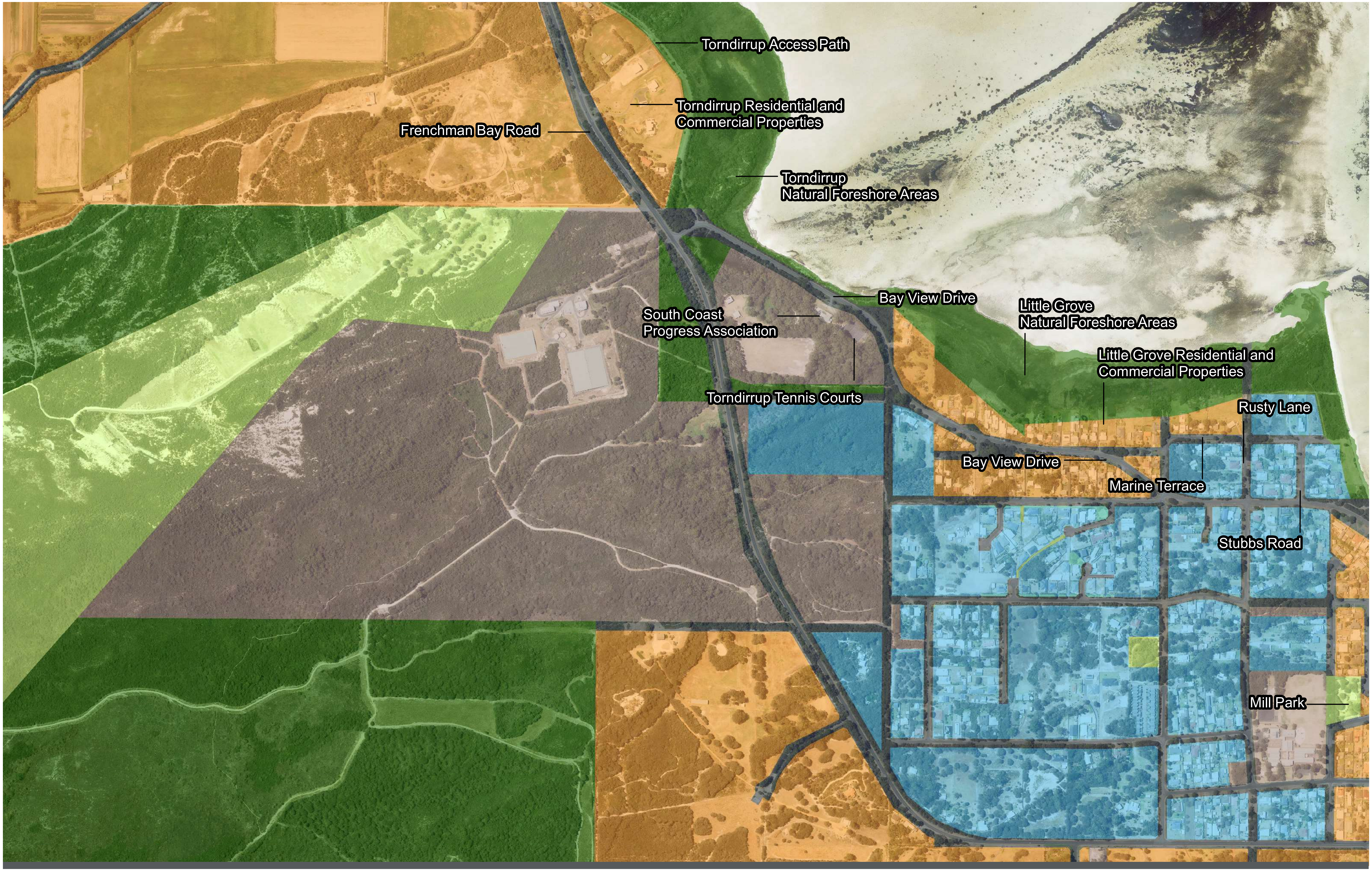
1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-003-ASSETLOCALITY

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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

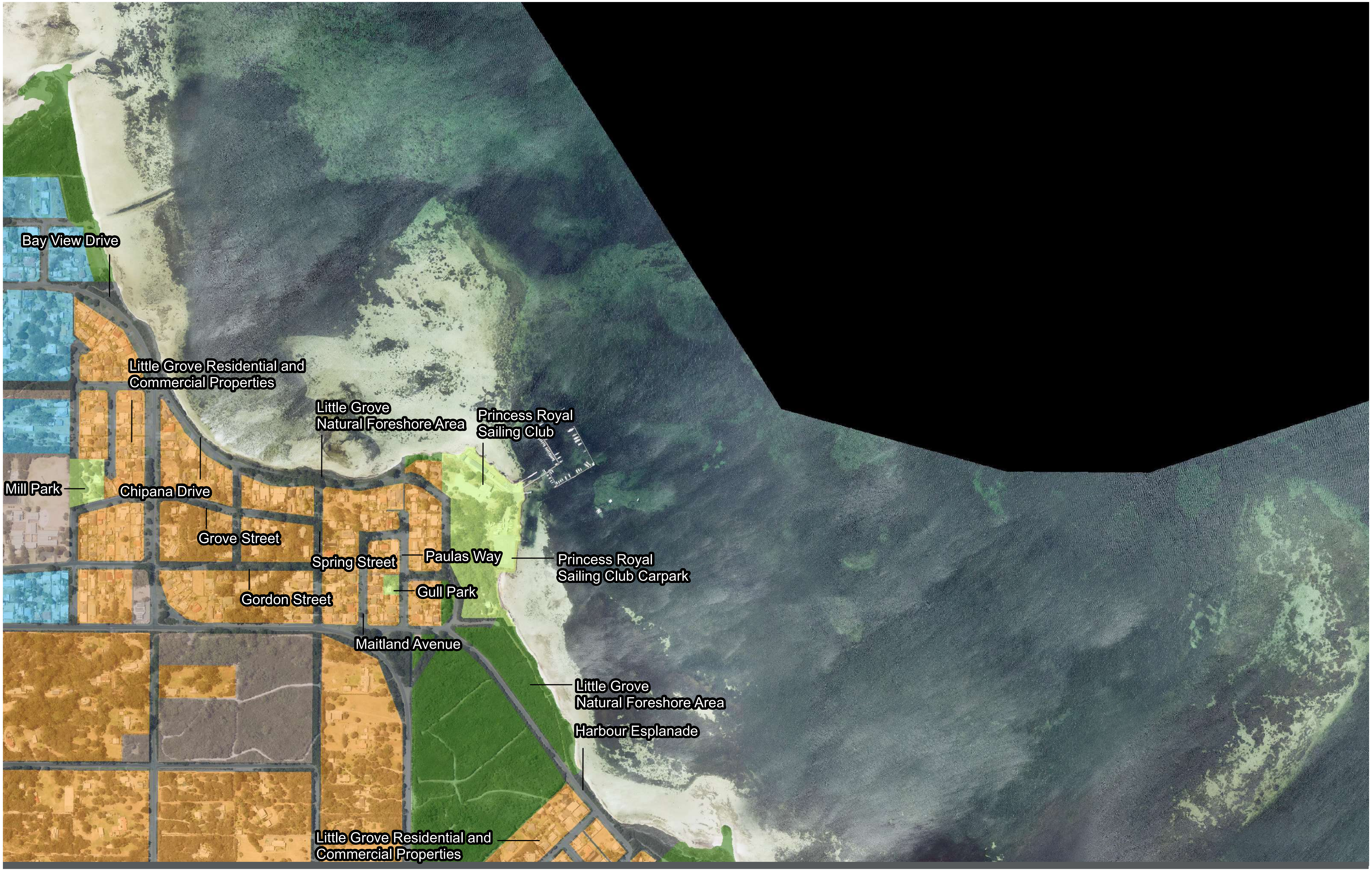
0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 5 )

CW1200123-GS-003-ASSETLOCALITY

DATE PLOTTED:1/12/2022 2:44:36 PM BY: CORY.SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-003-AssetLocality.mxd




# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 6 )

**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-003-ASSETLOCALITY_V2

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# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 7 )

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

CW1200123-GS-003-ASSETLOCALITY

**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

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DATE PLOTTED:1/12/2022 2:47:57 PM BY: CORY.SMITH
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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 8 )

CW1200123-GS-003-ASSETLOCALITY_V2


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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

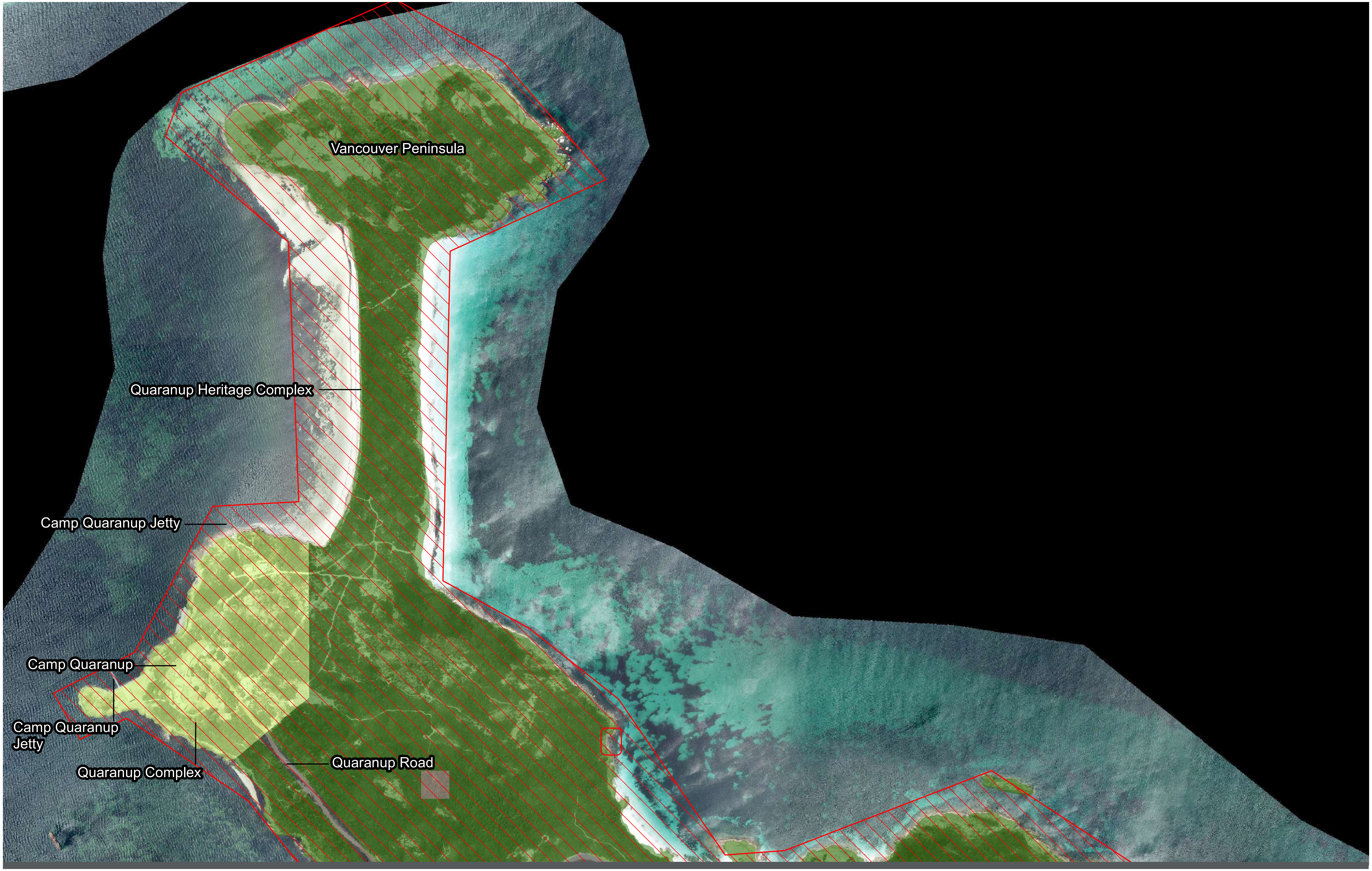
0 50 100 150 200 Meters

# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 9 )

CW1200123-GS-003-ASSETLOCALITY_V2

DATE PLOTTED:1/12/2022 3:32:01 PM BY: CORY SMITH
FILE: K:\Projects\CW1200123_Water Technology_Princess Royal Harbour CHRMAP\5_Technical\Water and Environment\Comps_Drawings_File_Notes\arcGIS\Build\CW1200123-GS-003-AssetLocality_v2.mxd




DATE PLOTTED:1/12/2022 2:36:13 PM BY: CORY.SMITH
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**Legend**

- Commercial
- Developed Foreshore
- Environmental
- Heritage
- Public and Community
- Residential
- Roads

1/12/2022

Size
A3

Scale
1:7,500

0 50 100 150 200Meters

# PRINCESS ROYAL HARBOUR CHRMAP

ASSET LOCALITY ( MAP SECTOR 10)

CW1200123-GS-003-ASSETLOCALITY_V2

## About Cardno

Cardno is a professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

## Contact


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