REPORT

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Limestone Cliff Stability Assessment

Submitted to:
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1.0 INTRODUCTION

The Shire of Augusta and Margaret River, referred to herein as the "Shire", have engaged Golder Associates Pty Ltd (Golder) to undertake a study on limestone cliff geology and stability at four main areas in the Margaret River region. The four areas are shown on Figure 1 and include:

- Gracetown – approximately 890 m of coastal cliffs in the South Point Car Park area.
- Prevelly – approximately 1,080 m of coastal cliffs between Riflebutts Beach and Rivermouth Beach
- Gnarabup Headland – approximately 600 m of coastal cliffs at Gnarabup Headland
- Grunters Beach – approximately 190 m of coastal cliffs at the north end of Grunters Beach.

In addition to these four primarily coastal sites, it was requested that Golder Associates also complete a preliminary assessment of the rockfall hazards at the Wallcliffe Road site. The Wallcliffe Road cliff site is also shown on Figure 1 and includes approximately 280 m of vertical limestone cliff on the south side of Margaret River, immediately south of the site occupied by the former Wallcliffe House.

2.0 SCOPE OF WORK

The scope of work for the limestone cliff stability assessment includes:

- Desktop Study – review available literature and data on coastal cliff stability
- Geological Assessment –inspection of cliffs to evaluate cliff geology, potential failure mechanisms and overall slope stability to provide baseline data on cliff geology and inform a risk assessment.
- Audit of Cliff Risk Signs – check location and condition of existing cliff risk signs and provide comment on suitability and coverage.
- Risk Assessment – evaluate the risk that limestone cliff instability poses to both recreational users and Shire assets in order to inform longer term planning decisions. The risk assessment includes a risk workshop with Shire staff (undertaken 23 January 2017).
- Wallcliffe Preliminary Risk Assessment – complete a walkover assessment of the Wallcliffe site to assess its geology, geomorphology and potential risk to recreational users.
- Reporting – provide a report summarising the results of the items listed above.

3.0 DESKTOP STUDY

The desktop study involved a review of geological information available in the public domain as well as historical limestone cliff stability studies in the Margaret River area known to the Shire. The following information sources are considered the most relevant of those reviewed (full references for all relevant materials is provided in Section 14.0):

- Gordon, 2012 – Geology of the Quaternary Coastal Limestones of Western Australia
- Gordon, 2005 – Huzzas Cliffs 2005 Inspection Report
- Gordon, 2002 – Huzzas Beach Gracetown Memorial Site and Huzzas Beach Gracetown Stability of Steps
- Gordon, 1999 – The Rockfall of Huzzas Cliff, Gracetown, Western Australia.
- Landgate SLIP portal aerial photograph dating back to 1996.
- Shore Coastal, 2015 – Coastal Hazard Risk Management and Adaption Plan (CHRMAP).
- LiDAR provided by Shire of Margaret River with 0.2 m contour interval.

The desktop study provided an indication of expected geology, insight into potential rockfall failure mechanisms and guidance on key geological and geomorphological characteristics of the coastal limestone cliffs. The digital elevation model (DEM) from the LiDAR was particularly useful in clearly showing cliff morphology, slope facet changes, shelving beaches, exposed reef and the geomorphology in general. This information helped focus the mapping techniques used during the geological assessment. The LiDAR greatly assisted the mapping and enabled the position of features to be accurately located and the cliff line/slope change accurately depicted.

4.0 GEOLOGICAL ASSESSMENT

The geological assessment stage of the scope of work included detailed inspection of cliffs to evaluate cliff geology, potential failure mechanisms and overall slope stability to provide baseline data on cliff geology and inform a risk assessment.

Fieldwork for the geological assessment involved site walkover and mapping of cliff geology and rockfall hazards between 22 and 25 January 2017. A risk workshop with Shire staff also occurred on the afternoon of 23 January as part of the geological and risk assessment process.

The results of the geological assessment are presented in the subsequent sections of this report. The Wallcliffe site has a slightly different geological/geomorphological character than the other four main coastal limestone sites. Consequently we have presented the assessment of the Wallcliffe site separately in Section 11.0.

5.0 GEOLOGY AND GEOMORPHOLOGY

The following section provides an outline of the geological and geomorphological characteristics for the four main study sites.

5.1 Geology

All of the four main study sites comprise a similar geological profile. A generalised geological section is shown in Sketch 1 to illustrate this profile along with site photographs included in Appendix A.

Underlying all sites, although not always visible at surface, is the high to extremely high strength granitic-gneiss and granulite crystalline basement rock of the Leeuwin Complex (Photographs A1 and A2).

Overlying the granitic basement rock are the coastal limestone sedimentary rocks. The coastal limestone sequence present at the study sites is similar to that present along the majority of the coastline of Western Australia is described at length in Gordon (2012) and generally consists of:

- Marine Limestone Conglomerate – Conglomerate rock generally consisting of rounded granite-gneiss and granulite boulders in a matrix of medium to high strength marine limestone (Photographs A2 and A3). The boulder conglomerate rock overlies the basement rock but is not present at all localities.
- Beachrocks – Limestone rock consisting of sand and gravel lithified in place by calcium carbonate in the intertidal and spray zones of the beach (Photographs A4 and A5).
- Eolianites – Limestone rock consisting of wind-blown, lime-rich sands that have been cemented over time by calcium carbonate under subaerial conditions (Photographs A6, A7 and A8). The eolianites at the study sites are the lithified coastal sand dunes that initially formed here in the Pleistocene and Holocene and continue to form today. There have been several cycles of eolianite formation with thickness and extent varying between cycles as well as across locations.

  In most cases there are a number of cycles of sand dune and eolianite formation exposed in a coastal limestone slope. A characteristic profile for one such cycle, from the bottom up generally includes:

  - A basal paleosol (buried and fossil soil) that may or may not be cemented with calcium carbonate.

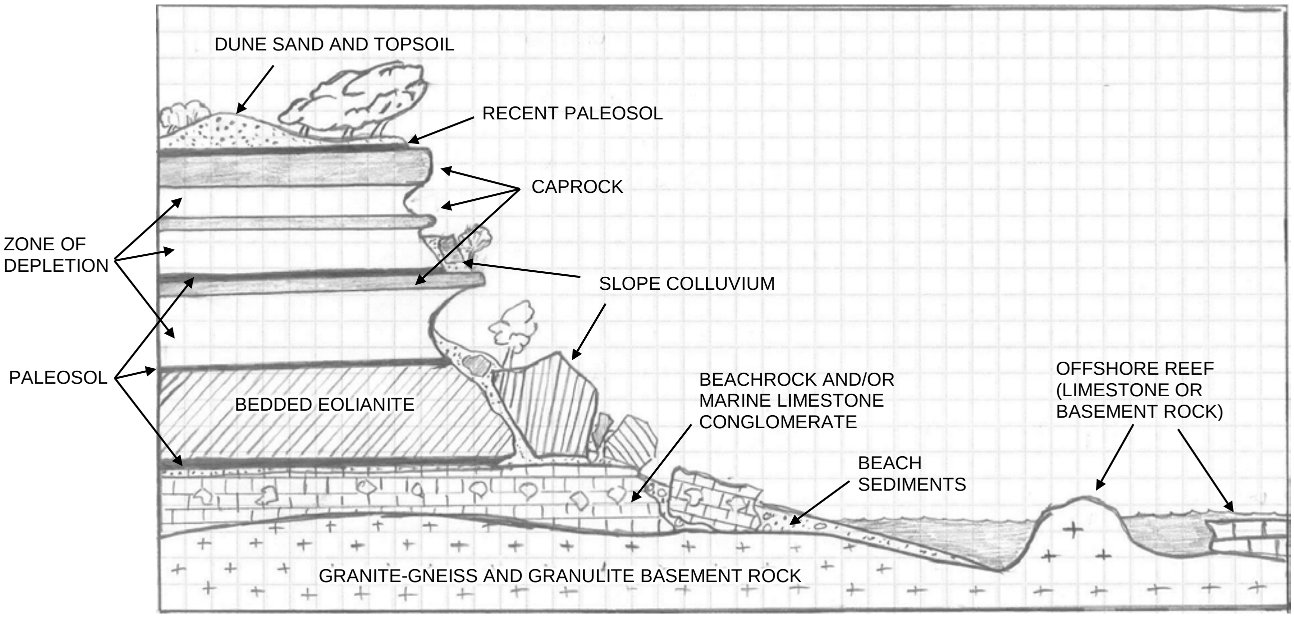
- A zone of depletion where calcium carbonate has been leached out of the rock. This leaves a highly erodible sandy material that erodes rapidly with current or former plant rootlets remaining in place due to a surrounding shell or cast of calcrete. This zone is often terms the "zone of roots" or "rhizocretion zone" (Gordon, 2012).
- A caprock layer where calcium carbonate leached out of the underlying layer accumulates and often forms a dense, high strength layer that can be up to approximately 2 m thick.

Although this profile is common across the study sites, not all of these distinct layers will be present or well developed in all eolianite cycles or at all locations. For example, some areas may have a thicker caprock layer, no paleosol or the zone of depletion may be less pronounced.

- Calcrete – Calcium carbonate cement/rock that occurs throughout the profile of most coastal limestones. Calcrete refers to hardened calcium carbonate that binds other particles such as silt, sand and gravel together. Calcrete generally forms when minerals leached from other layers in a limestone rock or soil are mobilised and precipitate elsewhere. Consequently calcrete forms a significant part of the caprock layers observed in eolianites at the study sites.

Aside from the igneous and sedimentary rocks listed above there are unconsolidated sediments at the sites that generally consist of:

- beach deposits – generally sand, gravel with some cobbles and boulders
- slope colluvium – generally cobbles and boulders from cliff collapse set in a matrix of sand with some silt
- dune sand
- thin sand-rich topsoil.



Note: Not all possible contacts and relationships are shown.

Sketch 1: Generalised geological relationship diagram showing observed and inferred contacts between main geological units

Many of the units described above can be interpreted from using the LiDAR and aerial photography supplied by the Shire and confirmed through ground-truthing.

5.2 Geomorphology

The main geomorphological processes currently forming the shoreline at the study sites and modifying the majority of the limestone cliffs are wave erosion and wind abrasion. Wave erosion causes undercutting of the limestone cliffs, which leads to instability and eventual failure of cliffs initiating cliff retreat. Wind erosion causes undercutting by sand blasting of exposed rock faces that may also leads to slope instability, eventual failure and cliff retreat.

The degree of wave and wind erosion varies along the coast and will be affected by the following in the medium to long term (decades to centuries):

Water Depth – where water depth is shallow, much of a wave's energy is dissipated offshore and does not reach the base of the cliffs except during strong storms. Deeper water depths allow more wave energy to reach the base of cliffs. Consequently the presence of reefs and exposed bedrock at shallow depths in nearshore waters will influence the amount of energy reaching the shoreline and in turn the amount of coastal erosion. Sketch 2 shows an example of how water depth may affect wave erosion rates.

- Shoreline Protection – In the context of this report shoreline protection refers to the sediments or rocks that make up the shoreline and help protect the lower edge of slopes from wave erosion. Sandy shorelines will be more prone to erosion than those with rock. For those shorelines with rock protection, the strength of the rock will also affect the rate of erosion. For example, shorelines with high strength granitic basement rock will generally be less prone to erosion than those with a weakly cemented eolianite. Sketch 3 shows an example of how the type of shoreline protection affects wave erosion rates.
- Prevailing Wind Direction – Wind data available from the Bureau of Meteorology shows that wind directions in the area varies considerably both throughout the day and the year. However, winds with southerly components often prevail and are strongest. This means that cliffs exposed to these directions will receive more wind abrasion erosion and may therefore be more prone to cliff collapse and retreat.
- Prevailing Wave Direction – Closely related to wind direction but also swell direction. Waves will also be refracted around headlands and into bays.

Notes: Point A indicates an area of extensive shallow reef where waves are breaking far offshore (~200-300 m) allowing the formation of a small promontory at B, Surfers Point beach. A smaller offshore reef is present at C and helps to reduce the wave energy delivered directly to the beach with waves breaking close to the shoreline (~30-50 m). At D the absence of shallow water and a steep beach profile allows the majority of wave energy to be transmitted directly to the shoreline. This has led to higher erosion at the shoreline and a significant indentation in the shoreline and creation of a small embayment has occurred at E (Date of Aerial Photograph: 11 November 2016, Sourced from Nearmap, 2016).

Sketch 2: Annotated aerial photograph showing effect of different water depths on long-term coastal geomorphology and cliff retreat

Notes: The lower edge of the existing slope leading up from the beach is marked by the start of vegetation. High strength granitic basement rock at A provides good shoreline protection. The presence of a small offshore reef at B, as well as beachrock and eolianite at C provide shoreline protection but both of these elements together are still not as effective as the granitic basement rock at point A. At D the only shoreline protection is beach sand and an occasional rock boulder. As a result wave erosion is greater and a small crescent shaped indentation in the shoreline has occurred. Likewise at E, the only shoreline protection present is beach sand and a smaller crescent shaped indentation in the shoreline has occurred between eolianite rock shoreline protection at C and F.

Sketch 3: Annotated aerial photograph showing effect of different types of shoreline protection on coastal geomorphology and cliff retreat

6.0 GEOLOGICAL/GEOMORPHOLOGICAL MAPPING

Based on the geological field mapping completed, the limestone cliffs in the five main study sites have been divided into a total of 22 geomorphological zones based on their geological and geomorphological characteristics. These zones were established to partition the limestone cliffs in manageable units across the length of the cliff or slope being considered at each study site. Zone divisions are based on changes in the geological and/or geomorphological characteristics of the cliff or slope in question.

The various geomorphological zones are shown on Figure 2 to Figure 5 as lines tracing the approximate interpreted top of slope and are labelled with a two letter identifier as follows:

- GC1 to GC7 – Gracetown (Figure 2)
- PR1 to PR7 – Prevelly (Figure 3)
- GN1 to GN5 – Gnarabup Headland (Figure 4)
- GR1 to GR3 – Grunters Beach (Figure 5).

Despite the high number of geomorphological zones mapped, many of the cliffs or slopes have similar characteristics. To simplify the results of the geological mapping, six broad categories of cliff or slope type have been devised that are based on a slope's geometric profile and its perceived susceptibility to erosion. These six types are the combination of geometric profiles (two sub-categories) and their susceptibility to erosion (three sub-categories. The sub-categories that comprise the six broad slope types are defined below:

Geometric Profile Sub-Categories

A slope's geometric profile has been split into two subcategories with the following general characteristics:

- Type 1 – Slopes (with substantial part) greater than 45°
  - The slope is primarily characterised by angles greater than 45° and often contains vertical or overhanging cliff faces.
  - Some slope colluvium and dune sand may have accumulated on the slope or at its base.
  - Some vegetation may be present but unlikely to be heavily vegetated.
- Type 2 – Slope less than 45° and without substantial parts of the slope greater than 45°
  - The slope is primarily characterised by angles less than 45° but may still contain small sections (generally < 3 m high) of steep, vertical or overhanging cliffs.
  - Slopes often contain large sections of slope colluvium and dune sand and may contain areas where all underlying rock is hidden from view by these materials.
  - Slopes may be heavily vegetated.

Susceptibility to Erosion Sub-Categories

All slopes are considered susceptible to erosion. However, the following sub-categories have been created to help differentiate those slopes considered more susceptible to wind and wave erosion based on the information available to date.

- Type A – Most Susceptible to Erosion
  - Slopes with no offshore reef, no shelter and no shoreline protection that allow the majority of normal wave energy to reach the base of the slope.

- Type B – Moderately Susceptible to Erosion
  - Slopes that are somewhat sheltered, have a small offshore reef, or a small area of shallow water that acts to dissipate some wave energy OR contain shoreline protection that may include slope colluvium and large boulders from historical rockfalls.
  - If shoreline protection is present it is often significantly undercut.
  - Slopes with a significant thickness of limestone or with higher strength limestone may also be included in this category. Although these cliffs will still be susceptible to wave erosion, the progression of the cliff retreat may be slowed by higher rock strength or by the creation of shoreline protection as rockfall occur and armour the base of the cliffs.
- Type C – Least Susceptible to Erosion
  - The slope is located inland of a significant offshore reef, is located in a shallow bay or is sheltered from the prevailing wave and wind directions such that the majority of wave energy, under normal conditions, is dissipated far offshore OR the slope is located a significant distance inland from the shoreline and is not currently affected by wave erosion.
  - Shoreline protection is present and consists of granitic basement rock, marine limestone conglomerate or beachrock.

Based on the above the six slope types are thus 1A, 1B, 1C, 2A, 2B and 2C.

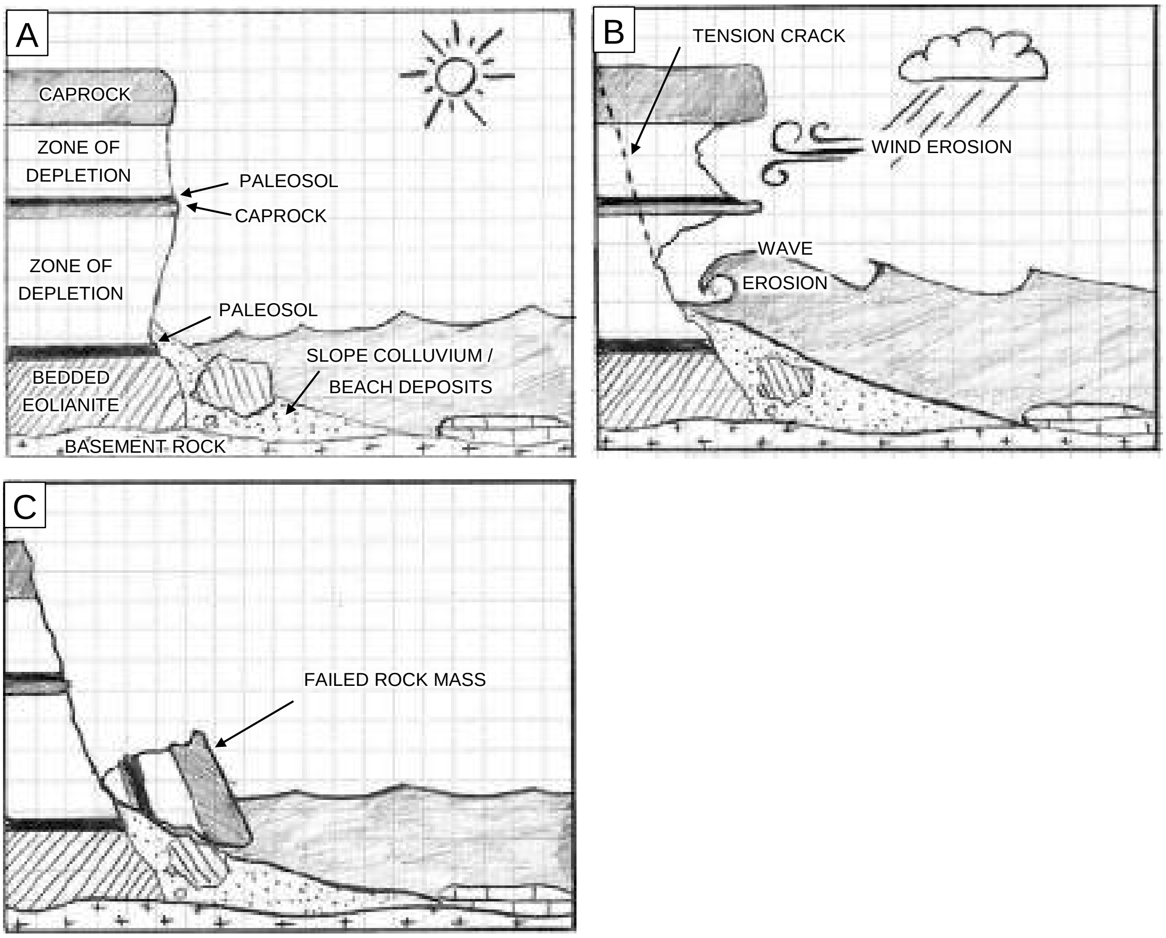
Figures 2 to 6 also shows the spatial distribution of the six broad categories of slope type (1A, 1B, 1C, 2A, 2B, 2C) along the sections of the slopes mapped. The information is also given as attributes with a supplied ArcMAP feature class (Shapefile).

7.0 ROCKFALL FAILURE MECHANISM

Despite variations in the geology and geomorphological processes acting on each section of slope, the mechanism for significant slope failure at the majority of the study sites is similar. The general slope failure mechanism is illustrated in Sketch 4 and includes the following main characteristics:

- A combination of wind and wave erosion leads to undercutting of the eolianite slopes.
- Within the eolianite profile, often the zones of depletion and paleosol layers erode at a faster rate, leaving overhanging cliffs of caprock or stronger eolianite.
- As the slope is undercut the rock becomes stressed and may begin to relax into the space created by the erosion. Relief fractures may form in the rock materials and tensions cracks in the overlying unconsolidated slope deposits.
- Rockfall in the form of minor fretting of cobble to small boulder sized material may occur prior to a larger scale failure of the undercut slope.
- Eventually undercutting occurs to such an extent that the weight of the overlying rock mass produces more downward force than the resisting forces holding it in place and failure occurs. Photograph A9 in Appendix A shows an example of a failed overhanging block near Surfers Point.
- Aside from ongoing erosion and undercutting, larger slope failures may also be triggered by heavy rainfall events, root jacking* or excessive loading from above (e.g. due to construction of infrastructure or groups of people at the cliff edge).

Notes: * This is the wedging effect of tree roots growing in joints and gaps in the rock.



Notes: A) Showing cliff face and main geological layers. B) Wind and wave erosion leads to undercutting with erosion progressing faster in some layers, as rock layers become undercut relief fractures may form. A potential trigger event of heavy rainfall is shown. C) The slope after rockfall failure has occurred and with the relief fracture being the principal plane of release. The failed material now provides some temporary protection from wave erosion to the new slope.

Sketch 4: Illustration of main rockfall mechanism

8.0 GRANITIC BASEMENT ROCK – COASTAL LIMESTONE INTERFACE

The locations of granitic basement rock outcrops observed during geological mapping are shown on Figure 2. Granitic basement rock was only observed at the Gracetown and Prevelly study sites. Using the Lidar survey information provided by the Shire, the maximum elevations of *in situ* granitic basement rock at Gracetown and Prevelly were approximately 0.4 m and 4.0 m, respectively.

The Shire has outlined that determining the interface between the granitic basement rock and the overlying coastal limestone is of significance as it will influence erosion rates. Although this is true, this is not the only factor influencing erosion rates along the coastline, as outlined above. Furthermore, predicting detailed (1 m to 5 m scale) changes to a coastline requires detailed erosion modelling and significantly more information on rock mass and soil properties, both of which are beyond the scope of this work. Given the capital value of the potential assets at risk, we do not consider that this level of analysis is warranted.

Likewise, we do not consider that further investigations aimed at determining the location of the interface between granitic basement rock and coastal limestone are warranted. However, should the Shire wish to pursue this information the following methods may be appropriate:

- Cored borehole drilling at key Shire assets. Given the observed elevation of granitic basement rock to date, boreholes may have to be up to at least 30 m deep.
- Geophysical Survey. The difference in strength and density between the granitic basement rock and the overlying coastal limestone is likely significant enough to allow approximate delineation through geophysical survey.

It should be noted that in broad terms the granitic basement has a role in controlling erosion as it is more resistant to erosion that the limestone cliffs. Its role is to be a focus for the dissipation of wave energy before waves reach cliffs but this will only occur where the granite is exposed. The elevation of granite beneath the cliff itself does not influence the degree or rate of erosion other than if it was to become exposed during a cliff retreat event, in which case the rate of cliff erosion and retreat would be greatly retarded. As such trying to delineate the elevation of the granite beneath the cliff is not expected to be particularly beneficial and would require a very large number of boreholes to map what is likely to be an undulating surface.

The nearshore reefs can clearly be seen in Figures 2A, 2B, 2C, 3A, 3B, 3C, 4A, 4B and 5. At Gracetown granitic rocks are prevalent below the low tide mark and in part form a blanket of boulders rather than a continuous rock outcrop. At Prevelly (Rivermouth area) an extensive nearshore reef of granitic rocks with a maximum elevation of about 4 m AHD exists. The extent of the granitic outcrop is indicated on Figures 3A and 3B. At Gnarabup and Grunters whilst granitic rocks can be seen in the nearshore marine environment a limestone layer is generally present with the limestone unconformably resting on an ancient wave cut platform granite surface.

The presence of granitic rocks in the foreshore or nearshore has been taken into account when considering susceptibility to erosion and assigning the geomorphological units set out in Section 6.0, recorded on Figures 2 to 6 and recorded as attributes in the ArcMAP feature class *Geomorphological Zones.*

9.0 RISK ASSESSMENT

There are two main risks associated with limestone cliff instability hazards that have been evaluated as part of this study; the risk to recreational users and the risk to Shire assets.

9.1 Locations of Hazards and Delineation of Hazard Zones

Figures are provided in this report showing the location of all hazards described. In addition *ArcMAP feature classes* (shapefiles) are provided for all mapped features and for the geological and rockfall hazards described for use in the Shire Geographical Information System. Similarly ArcMAP feature classes are provided for hazard zones namely the extent of the hazard zone for recreational users or the extent of the hazard zone for Shire assets. Geographical co-ordinates can be obtained for any feature from the supplied GIS data, alternatively the co-ordinates can be obtained by scaling off the figures provided in this report.

9.2 Risk Definitions

To ensure clarity in the discussion of risk in the subsequent sections, definitions for the risk terms used in this report are presented in Appendix B and are taken from the AGS (2007) guidelines, where applicable.

9.3 Risk to Recreational Users

9.3.1 General

The risk to recreational users has been evaluated as the annual probability of death of the individual most at risk (R_{DI}) due to either direct impact of rockfall from above, or collapse of cliff material from below.

Given the level of information available, the transient nature of rockfall (e.g. risk profile of any individual cliff could change with a heavy rainfall or following a major storm) and the relative complexity of coastline development, it is not considered reasonable to attempt to estimate risk to recreational users on predicted future slope positions coastal erosion arising from the result of sea level rise. The risk to recreational users has therefore been evaluated based on the condition of the slope at the time the geological mapping completed as at January 2017.

As part of the risk assessment, hazard zones delineating the areas that rockfall or slope collapse are most likely to impact recreational users has been estimated for each of the four main study sites and are shown on Figures 2 to 6. The hazard zone is not meant to define the only area in which rockfall or slope collapse could occur but does define areas that will be most impacted if either of these hazards were to occur.

The hazard zone has been delineated based on site observations. The lower extent has been delineated by considering the extent that an existing rockfall has reached as well as slope conditions and the likely failure mechanism. The upper limit has been defined by applying a general set-back from the existing break in slope. Where the break is a simple change in gradient, a setback of approximately 3 m from this edge has been applied. Where the break in slope is a cliff edge, a set-back of 5 m from the existing edge has been adopted.

During the geological mapping, specific rockfall/collapse hazards were identified at the various study sites and it is these specific hazards that have been assessed for risk as opposed to attempting to assign a risk level to each section of cliff. These specific hazards do not represent all the rockfall hazards present over the approximate 3 km of slope inspected. Instead, these are the hazards that were most apparent during the inspection and had, in our opinion, the highest likelihood or consequence with respect to risk to recreational users. These hazards are discussed further in Section 9.3.3, Section 9.3.4 and Appendix C.

9.3.2 Risk Criteria

Landslide, cliff collapse and rockfall risk has been evaluated using the principles outlined in the Australian Geomechanics Society Landslide Risk Management Guidelines (AGS, 2007). The AGS (2007) guidelines outline that, “there are no established individual or societal risk acceptance criteria for loss of life due to landslides in Australia or internationally.” Instead AGS (2007) uses general principles and information from other engineering industries to provide guidelines on what may be reasonably considered a tolerable risk level with risk level presented as a probability value. Nonetheless, AGS (2007) also outlines that: “the decision on risk acceptability (or tolerance) must be made by the client, owner, regulator and those at risk, where they are an identified group”.

The RfQ outlines that completion of the risk assessment should be in accordance with the AGS (2007) guidelines. AGS (2007) presents a suggested annual probability of death tolerable risk criteria for individuals of 10^{-4}. AGS (2007) also outlines that “societal risk should be evaluated for buildings having high numbers of occupants, such as schools, hospitals, hotels or motels where many lives are at risk.” The rockfall hazards identified as part of this study would generally not fall into this category and therefore not require calculation of a societal risk.

However, calculation of societal risk (R_{SOC}) is useful in providing another means of assessing the risk to recreational users and provides a good comparison with individual risk. If we use the Gracetown tragedy as an example, it is unlikely that the majority of rockfall or collapse hazards identified will result in more than 10 lives being lost for a single rockfall or collapse event. Consequently we have used ten (10) as the maximum number of lives that could potentially be lost in any single rockfall event to estimate a conservative societal risk probability for each hazard. Tolerable risk criteria for societal risk is not readily defined in AGS (2007). However, tolerable societal risk is generally at least an order of magnitude lower than individual risk as society is less accepting of multiple fatalities. We have selected a tolerable societal risk of 1.0×10^{-5} for the purposes of this report.

In addition to the calculated societal risk we have also calculated a cumulative individual risk (R_{CI}). This is not a risk outlined in the AGS (2007) guidelines but is a useful way to illustrate where higher user numbers may influence risk management. More people exposed to the same risk per day would generally warrant more attention than risk located in seldom visited places. To calculate cumulative individual risk we have multiplied the individual risk by an estimated number of recreational users. We have not suggested a tolerable risk level for the cumulative individual risk as this has been calculated for comparison purposes only.

The suggested tolerable risk levels are presented in Table 1 and we assume they are acceptable to the Shire. If, for whatever reason, the Shire have a different risk profile and wish to change the tolerable risk criteria, this risk assessment will need to be updated.

Table 1: Tolerable Risk for Loss of Life

Risk	Tolerable Annual Probability Value
Individual Risk	1.0×10^{-4}
Societal Risk	1.0×10^{-5}
Cumulative Individual Risk	NA

Lastly, we have not added together the risks from multiple rockfall hazards to provide a cumulative risk level for any given area. Instead risk is based on a single rockfall event. It is our assessment that at this stage there is not enough data to evaluate how recreational users are divided amongst the various parts of the coastline to determine if they would be subject to multiple hazards. If in the future, further data is gathered the validity of providing a cumulative risk can be further assessed.

9.3.3 Rockfall Hazards

During the geological assessment fieldwork 30 rockfall hazards were identified and a probability value has been calculated for each these hazards to evaluate the risk to recreational users. Rockfall hazards are named using the geomorphological zone that they occur in and the approximate distance from the start of that geomorphological zone. This system will easily allow for the addition of other rockfall hazards that may be identified during subsequent inspections. The approximate location of each rockfall hazard is shown on Figures 2 to 5. Photographs of each hazard, along with a brief description, and preliminary risk management options are provided in Appendix C.

Annual probability of death values have been calculated for each of the 30 rockfall hazards for the individual most at risk, as well as total societal risk using the equation and variables outlined in Table 2. The probability values, along with the values of the various risk variables used to calculate the probabilities are also presented in Appendix C. Probability values show the following:

- No rockfall or slope collapse hazard exceeds the tolerable risk criteria for the individual most at risk.
- Two collapse hazards exceed the societal tolerable risk criteria (GC6-15 and PR4-100).
- Eleven hazards exceed an arbitrary set criteria of 1.0×10^{-3} for cumulative individual risk.

Figures 2 to 5 present the annual probability results graphically and group rockfall hazards into two four coloured categories based on their probability values as follows:

- Red – Individual risk is above 1.0×10^{-4} and/or Societal Risk is above 1.0×10^{-5}
- Yellow – Individual risk is greater than 1.0×10^{-5} but less than 1.0×10^{-4}
- Green – Individual risk criteria is less than 1.0×10^{-5}.

Table 2: Risk of Loss of Life R_{DI} for Rockfall and/or Cliff Collapse

Risk Variable	Range of Annual Probability Values*	Assumptions and Comment
Risk for Person Most at Risk, $R_{(DI)} = P_H \times P_{S:H} \times P_{T:S} \times V_{D:T} \times N$		
P_H	0.2 to 0.05	***P_H describes the annual probability of a rockfall or slope collapse occurring of sufficient size to cause loss of life.*** It is conservatively assumed this kind of rockfall will occur at a frequency/likelihood of between 1 per 5 years (P_H = 0.2) to 1 per 20 years (P_H = 0.05) depending on the current condition of the specific hazard. Although it is considered improbable that all of these hazards will fail within the next 5 to 20 years, a conservative approach has been taken.
$P_{S:H}$	0.5 to 0.004	***$P_{S:H}$ describes the probability of spatial impact.*** The spatial impact area divided by the total hazard area provides the probability of spatial impact. The total hazard area is the area where it is reasonable to assume rockfall could impact if it occurs or where ground may be destabilised if slope collapse occurs. The estimated hazard area for each of the 30 rockfall hazards is shown in Figure 2 to Figure 5. In the case of rockfall, the spatial impact area describes the area that is actually impacted by a rockfall and that may be occupied by a recreational user at the same time. As not all areas of a rockfall trajectory or hazard area will be impacted by rockfall this area will be smaller than the total hazard area. In addition, recreational users are unlikely to access some parts of a rockfall trajectory (e.g. where the rockfall may end up in the water, or where part of the trajectory is a steep, relatively inaccessible slope). Golder have taken this into account during calculation of probability for each rockfall hazard. In cases where slope collapse is considered, the greatest hazard rockfall may still occur but the rockfall hazard zone has been ignored for the purposes of this calculation. Instead, a likely collapse area has been estimated and divided by an area that could potentially be affected by collapse (generally assumed to be 2 × the collapse area for the purposes of this calculation). The likely collapse divided by the potentially area affected gives the spatial impact probability.
$P_{T:S}$	2.9×10^{-5}	***$P_{T:S}$ describes the temporal spatial probability for recreational users, in other words, the probability that a person will be in the hazard zone at any given time of the year.*** There is a wide range of recreational users visiting the sections of coastline being analysed. Many users spend very little time in the rockfall or slope collapse hazard zones (e.g. sightseers, walkers) while others are present for a more significant time (e.g. beachgoers, sport spectators for surf competitions). In addition, not all users will visit all sections of the coastline assessed for the same period of time. Nonetheless, the user data available to date does not allow for differentiation amongst these different types of users and consequently some general assumptions regarding the average time spent in the hazard zone, by each user must be made. Golder have conservatively assumed that on average, each person spends a total of 60 minutes in any given rockfall hazard zone. Rockfall significant enough to cause loss of life is most likely to occur during heavy rainfall events or storms; a time when most people are unlikely to be at the study sites. Consequently we have weighted the temporal spatial probability to account for this. It is assumed than 80% of significant rockfall occurs during heavy rainfall or storms and only 20% during normal sunny conditions. It is also assumed that of the 60 minutes people spend in the hazard zone, only approximately 5 minutes (~10% of total time) of this will be in heavy rain and 55 minutes (~90% of total time) will be during dry conditions. This gives a weighted total time of approximately 15 minutes per year per person in the hazard zone when rockfall significant enough to cause loss of life could occur.
$V_{D:T}$	0.5	***$V_{D:T}$ describes the vulnerability of the individual.*** In this instance we have assumed a 1:2 chance of a fatality should the individual be struck by a falling, bouncing or rolling rock in the impact or run-out zone or should slope collapse occur. This value has been selected based on recommended values presented in AGS (2007).
N	15	***N describes the average number of times the person most at risk visits a location each year.*** It is assumed that the person most at risk is a surfer, sport spectator or beachgoer who visits a site 15 times per year (considered a conservative estimate).

Risk Variable	Range of Annual Probability Values*	Assumptions and Comment
Total Societal Risk, R_{soc} = $IR_{DI} \times N_{SOC}$		
IR_{DI}	1.4×10^{-6} to 5.2×10^{-9}	***IR_{DI} is the individual risk of death (IR_{DI}) for each person who visits a site.*** This risk is the same as the **$R_{(DI)}$** presented above except it does not account for repeat visits by the same person.
N_{SOC}	10	***N_{SOC} represents the potential number of people that could die in a single rockfall or collapse event.*** We have used the Gracetown tragedy, where 9 individuals lost their life as a case study and assumed a maximum loss of life of 10 people.
Cumulative Individual Risk, R_{CI} = $IR_{DI} \times T$		
IR_{DI}	1.4×10^{-6} to 5.2×10^{-9}	***IR_{DI} is the individual risk (IR) for each person who visits a site.*** This risk is the same as the **$R_{(DI)}$** presented above except it does not account for repeat visits by the same person.
T	2,500 to 70,000	***T represents the total number of individual visitors to a site each year.*** Statistics used for this variable have been estimated from car road count statistics provided by the Shire. It is very difficult to determine the number of individuals actually visiting a site based on car user numbers as we are not sure of such things as: ■ How many of the cars represent people driving on the road for other reasons? ■ How many people, on average are in each car? ■ How many of those cars actually visiting the site will contain people entering the hazard zone? ■ How many people will visit each of the rockfall or slope collapse areas of a given study site? In order to obtain a representative number of people potentially entering the hazard zone for each of the 30 rockfall hazard sites we have made some assumptions regarding these questions based on site observations of user numbers during geological mapping. These numbers should be reviewed by the Shire and if any additional information that can help improve the accuracy of these numbers is available, the annual probabilities should be re-calculated.

9.3.4 High Priority Rockfall Hazards

Regardless of the probabilities calculated for each of the 30 rockfall hazards, there are eight rockfall hazards that Golder consider to be of high priority because of either their position relative to recreational users, their apparent sensitivity to changes in slope conditions or their potential impact on Shire assets. All of these rockfall hazards have been coloured red in Figures 2 to 5 regardless of their calculated probabilities. Details of the eight rockfall hazards are presented in Appendix C and include (in alphanumeric order):

1) GC5-75 Gracetown – between Southpoint Carpark and Volunteers Rest (refer Figure 2B)

2) GC6-15 Gracetown – close to Southpoint Carpark (refer Figure 2B)

3) GC6-60 Gracetown – close to Southpoint Carpark (refer Figure 2B)

4) GR2-20 Grunters – 100 m west of Beach Access (refer Figure 5)

5) PR3-165 Prevelly (refer Figure 3B)

6) PR4-30 Prevelly, Surfers Point (refer Figure 3C)

7) PR4-100 Prevelly, Surfers Point (refer Figure 3C)

8) PR6-85 Prevelly, Surfers Point (refer Figure 3D)

9.4 Risk and Mitigation

Refer to Appendix C for a description of hazards, details of the calculated risk for each hazard and details of preliminary mitigation options.

Table 4 summarises the main recommendations for each rockfall hazard. Note the requirement for ongoing monitoring, additional signage, further investigation and physical risk mitigation works such as underpinning hazardous overhangs is summarised in this table together with recommended timeframes for the implementation of these recommendations.

Table 3: Summary of Rockfall Hazards and Recommended Actions

Location	Geomorphological Zone	Monitoring Requirement	Monitoring Timeframe	Signage	Timeframe for Signage	Other Recommendations (in some cases Optional or Conditional)	Timeframe for Other Recommendations
GC1-25	GC1	Yes	3 years	Additional Signage	3 months		
GC150	GC1	Yes	3 years	Additional Signage	3 months		
GC2-25	GC2	Yes	3 years	Additional Signage	3 months		
GC2-85	GC2	Yes	3 years	Additional Signage	3 months		
GC2-100	GC2	Yes	3 years	Additional Signage	3 months		
GC3-50	GC3	Yes	3 years	Additional Signage	3 months		
GC4-60	GC4	Yes	3 years	Additional Signage	3 months		
GC5-75	GC5	Yes	1 year	Additional Signage	3 months	either fencing/block stabilisation or block removal	2 years
G6-15	GC6	Yes	1 year	Additional Signage	immediate	close lookout	Immediate
						support or remove overhanging blocks	1 year
GC6-60	GC6	Yes	1 year	Additional Signage	3 months	stabilise cliff with mesh or bolts or plan for retreat into carpark	1 year
GC6-100	GC6	Yes	3 years	Additional Signage	3 months		
PR3-165	PR3	Yes	3 years	Additional Signage	3 months	support of overhang	1 year
PR4-30	PR4	Yes	1 year	Additional Signage	3 months	prevent access onto overhang, remove bench and section of viewing platform	Immediate
						Removal or support of block	1 year
PR4-40	PR4	Yes	3 years	Additional Signage	3 months	support of overhang	1 year
PR4-100	PR4	Yes	1 year	Additional Signage	3 months	support or remove overhanging blocks	1 year
PR5-50	PR5	Yes	3 years	Additional Signage	3 months		
PR5-150	PR5	Yes	3 years	Additional Signage	3 months		
PR6-85	PR6	Yes	1 year	Significant Additional Signage	3 months		
PR6-140	PR6	Yes	1 year	Significant Additional Signage	3 months		
GN1-25	GN1	Yes	3 years	Additional Signage	3 months		
GN1-50	GN1	Yes	3 years	Additional Signage	3 months		

Location	Geomorphological Zone	Monitoring Requirement	Monitoring Timeframe	Signage	Timeframe for Signage	Other Recommendations (in some cases Optional or Conditional)	Timeframe for Other Recommendations
GN3-40	GN3	Yes	3 years	Additional Signage	3 months		
GN3-90	GN3	Yes	3 years	Additional Signage	3 months		
GN3-100	GN3	Yes	3 years	Additional Signage	3 months		
GN5-5	GN5	Yes	1 year			Further investigation and stability analyses leading to possible support of overhang	1 year
GN5-30	GN5	Yes	3 years			Limit further development or remove overhang	
GN5-100	GN5	Yes	3 years	Additional Signage	3 years	Remove or support overhang	
GR1-85	GR1	Yes	3 years	Additional Signage	3 months		
GR2-10	GR2	Yes	3 years	Additional Signage	3 months		
GR2-20	GR1	Yes	3 years	Additional Signage	3 months		

This table is a summary and does not contain all information regarding options for remedial. Some timings may dependent on whether or not other recommendations have been completed. Refer to full details provided under Hazard ID in Appendix C. Locations of all hazards are shown on Figures 2 to 5. In addition provided ArcMAP feature classes for hazards contain full geographical locational data.

9.5 Risk to Shire Assets

9.5.1 General

The risk to Shire assets has been evaluated using a modified version of the risk matrix presented in the CHRMAP report (Shore Coastal, 2015). As with the risk to recreational users, the risk assessment for Shire assets has been completed based on a rockfall or slope collapse hazard impacting the Shire asset at risk.

The risk to Shire assets has been evaluated based on assessing which Shire assets may be affected by cliff retreat within a time-frame of 100 years. It assumes a sea level rise of 0.9 m over that time. The requirement of the 0.9 m sea level rise is consistent with the assessment presented in CHRMAP report (Shore Coastal, 2015) and the reader is referred to this document for additional information on establishment of this sea level rise value.

Although the risk scenario is considering changes to cliff geometry due to sea level rise, it is important to note that the hazard considered in this risk assessment is associated with impact from rockfall or collapse of cliffs materials only. This assessment does not account for damage or loss of assets due to inundation by sea water, e.g. loss of vegetation.

9.5.2 Definition of Hazard Zone

In defining a hazard zone to Shire Assets it is important to note that the landward extent of the zone described as the upper extent is the point to which changes in slope geometry might occur and there assets may be at risk. It does not represent the location of the coastline as defined by the high water mark.

The hazard zone has been delineated based on site observations.

Lower Extent

The lower extent has been delineated by considering the extent that existing rockfalls have reached, the slope conditions and the likely failure mechanism for that section of coastline. Slope geometry and observation of fallen blocks and debris on the beach help define this extent represented as a blue line on Figures 2 to 6. For example if part of the cliff collapses how far will the debris roll or slide onto the beach. Clearly any asset or person in the path of falling rocks or debris is vulnerable. This is a representation of the hazard zone and does not depict likelihood or risk. Risk is addressed separately for each observed hazard (refer Appendix C).

Upper Extents

Two lines are mapped on the landward side of cliffs and steep edges, one line (blue) on Figures 2 to 6 representing the upper extent of the hazard zone for recreational users at the time of the assessment. The other delineated extent is a line labelled “Shire Assets” and shows the landward extent of the zone considered hazardous to Shire assets due to clifftop retrogression over a 100-year period. It considers a notional 0.9 m of sea level rise over a period of 100 years as a significant trigger to initiating slope and cliff instability that ultimately results in cliff-edge retreat.

For the recreational user hazard zone, the upper limit has been defined generally as a 5 m setback from the cliff-edge based on the maximum fallen block sizes observed. Where no distinct cliff-edge was present the upper limit was defined as a notional 3 m set back from the point of change in slope facet from the coastal slope to the more level land behind. The recreational user hazard relates to the current hazard and does not consider future hazards due to increased erosion from sea level rise.

The upper (landward) extent of cliff top retreat has been delineated by applying a set-back from the existing break in slope or cliff-edge of generally between 6 and 12 m. This upper or landward extent is not meant to represent where the coastline will be in 100 years (i.e. the mean high water mark), but rather an estimate of the landward limit of coastal slope/cliff failure/collapse and rockfall over the next 100 years. As such assets landward of this line will generally not be directly impacted by cliff collapse. The line is an estimate of the likely extent of cliff top retreat.

In delineating the cliff top retreat line due to rockfall and cliff collapse the following has been considered:

- All of the study area is a rocky coastline and as such major erosion is not anticipated. It is expected however that sea level rise will locally increase the rate of cliff top regression through increasing the frequency of rockfalls and collapses.
- Major rockfalls will deposit material at the toe of the cliff, which have the effect of armouring the shoreline absorbing energy and slowing down erosion for a number of years (refer Sketch 4) until the fallen blocks break up and are dispersed.
- Sea level rise is not expected to significantly lower the seabed profiles close to the shoreline due to the large wavecut platforms of granitic rocks and limestone and the relatively shallow cover of sand over rock in the nearshore environment. Some loss of beach sand is expected in areas where the cliffs are fronted by a sandy beach where reflection of wave energy against cliffs occurs.
- It is assumed that in the short-term the toe of the cliff will erode and the cliffs become steeper as sea levels rise but without necessarily causing a cliff collapse. With time the slope profile will become sufficiently undercut for a rockfall or some other form of cliff collapse to occur. These rockfalls and collapses are expected to be similar in nature to those currently observed. This will result in a retreat of the cliff top and the rocky coastal slope but the resultant slope/cliff profile will be similar to those currently observed. Thus a parallel retreat occurs.
- The set-back (cliff-retreat) distances applied generally allow for two rockfall events of similar magnitude to those observed during the survey to occur at the same location over a 100 year period.
- Some variance in set-back distance has been applied based on the geomorphological zonation of each section of cliff using the six geomorphological zones set out in Section 6.0 as follows:

Geomorphological Zone (Cliff Type)	Nominal Set-back from current cliff edge (point of slope facet change) (m)[1]
1A	12
1B	10
1C	8
2A	10
2B	8
2C	6

9.5.2.1 Comparison of Coastal Retreat with CHRMAP Study

The mapped cliff top retreats differ significantly from those in the CHRMAP study. The CHRMAP study sets out the assumptions applied as follows (extract given below):

- Weakly Lithified Sedimentary Rocky Coast
  - S1 Erosion: Nominal planning allowance for 1 vertical: 2 horizontal for slope failure.
  - S2 Erosion: Analysis of movement from 2000 and 2013 aerial imagery.
  - S3 Erosion: Procedure as outlined in SPP2.6 (100 x 0.9m Sea Level Rise), following review of available geotechnical information at each site.

[1] Set-back may be locally modified based on local geometry of coastline/cliff line

It is noted the 'S1 Erosion' is a very conservative assumption as it is unlikely that the cliffs will degrade to a 1 vertical: 2 horizontal slope. Instead the coastal slopes will maintain similar "cliff like" profiles to those currently present albeit with some cliff top retreat in response to rockfalls and cliff collapses. Hence a parallel retreat is considered likely.

S3 is an erosion allowance of 90 m as set out in SPP2.6 (Western Australian Planning Commission 2005). However in SPP2.6 this allowance is intended to be applied only to sandy coastlines and not coastlines comprising weakly lithified rocks. The Coastal Process Allowance presented in the CHRMAP study are generally 130 m for the areas described in this report. This distance is measured from the high water mark. By comparison when account is taken of the 6 m to 12 m of cliff top retreat assessed and the limestone cliff stability assessment that is the subject of this report, the distance of the new edge from the mean high water mark is generally between about 25 and 75 m of high water mark.

It should also be noted that the Coastal Process Allowance is largely based on SPP2.6 which is a state coastal planning policy document and is intended for planning purposes with factors of safety to account for uncertainty. By contrast the delineation of cliff top retreat has been undertaken to identify those Shire assets at risk. Since it informs a risk assessment it does not contain a conservative uncertainty factor but is instead a presentation of how cliff top retreat might occur in general. Notwithstanding, it is possible that at individual locations, cliff top retreat slightly greater than depicted could occur.

9.5.3 Risk Matrix

Likelihood

Given the information available to date and the uncertainty in predicting where cliff failure may occur over the next 100 years, the likelihood for failure on different parts of the cliff line within the hazard zone is considered equal and is not analysed further in the risk matrix. The cliff line retreat delineated on Figures 2 to 5 represent the average likely position of cliff line without any safety factor.

Consequence

The consequence categories for this analysis is largely consistent with the consequences defined in Shore Coastal (2015). The previous approach however assumed that if an asset was inside the zone affected by predicted changes sea level rise, then the whole asset would be need to be replaced.

The assessment presented in this report has refined this approach by roughly estimating the cost of the damage (in 2017 Australian dollars) to repair the part of the asset affected by slope instability within the hazard zone. The bounds defining the three categories remains the same as those presented in CHRMAP report (Shore Coastal, 2015) as follows:

- Low – <$100,000 AUD
- Medium – $100,000 to $500,000 AUD
- High – >$500,000 AUD.

Since the likelihood is considered equal for all areas the risk matrix is a simple reflection of the Consequence categories as show in Table 4.

Table 4: Simple Risk Matrix for Risk to Shire Assets

	Consequence		
Likelihood (considered the same for all assets)	Low (<$100K)	Medium ($100K-$500K)	High (>$500K)

9.5.4 Results

A simple risk register showing the calculated risk to all Shire assets falling within the hazard zone is presented in Appendix D. This risk is displayed graphically on Figures 2 to 4 as coloured points (Red = High Risk, Yellow = Medium Risk, Green = Low Risk). In summary the results of the assessment of risk to Shire assets show the following:

- The risk to Shire assets is assessed to be lower than presented in the Shore Coastal (2015) report.
- 24 Shire assets fall with the hazards zones estimated for the four main study sites.
- Only four of the Shire assets have been assessed as having a medium risk, the remainder are all assessed as low risk.

10.0 AUDIT OF CLIFF RISK SIGNS

The condition of existing cliff risk signs was assessed during the geological assessment fieldwork. Photographs of each sign were taken and the condition and placement of the sign assessed. Photographs and notes from the audit are presented in Appendix E. The sign audit is also supplied as an ArcMAP feature class showing the location and with summary details as attributes. In summary, the following general observations regarding existing cliff risk signage have been made:

- Some signs were missing, defaced, faded, or not immediately visible. Some signs are placed too close to the rockfall hazard so that in order to read the sign, a recreational user may expose themselves to the rockfall hazard.
- Some signs were considered too small or did not effectively deliver a firm unambiguous warning message to recreational users.

It is our recommendation that many of the cliff safety signs need to be reinstated/updated/replaced.

If the sign is no longer visible, is missing or is too small it requires replacement.

If it is poorly sited, for instance too close to the hazard it requires relocating. It should not simply be duplicated as it is counterproductive for people to enter the hazard zone out to find out what the sign says. Therefore the old sign which is too close to the hazard must be moved.

Overall the existing signage is not considered sufficient to adequately inform beach and cliff users of the hazards and the related risks. In this context, the need for additional signs has been addressed for each of the individual rockfall hazards with specific recommendation outlined in Appendix C and with a summary presented in Table 3.

It is noted that more consistency is needed in the message presented in the signage and the following is recommended:

The words ‘Rockfall Hazard Area’ in large red letters at the top of the sign

- “Danger” in large red letters beneath a large red exclamation mark (see Sketch 5).
- An outline of the dangers to beware (as on Sign ID 22 at Gnarabup Beach) that may include:
  - Undercut cliff edges are unstable
  - Loose rockfall and unstable surfaces
  - Rockfall from above
  - Serious injury or death may result
- An outline of steps to take to avoid dangers that may include:
  - Stay on the trail or path provided

- Do not approach the cliff edge beyond this sign (signs should be placed according to the hazard but at least 5 m back from the existing cliff edge).
- Do not linger beneath cliffs

- Some signs should be larger than those observed to date to allow printing the warning message in larger font and for the addition of graphics.
- A graphic of the particular rockfall hazards. This might include either collapse from below (Sketch 5A), rockfall from above (see Sketch 5B) or both. Many of these areas are used tourists who may not have a strong command of English but a graphic of the hazard will generally be understood by all.

A

B

Sketch 5: Example graphics for; A) collapse from below, B) rockfall from above and C) Danger (copied from photo of sign 22)

It is recommended that an overall strategy for signs be developed rather than simple adding additional signs to the existing mixed collection of signage. Such a strategy may consider for instance:

- The balance between visual intrusion and the need for effective communication.
- Proximity to (or remoteness from) council provided facilities, e.g. carparks and beach access paths.
- The need for more general multi-hazard warning signs at beach or cliff access points.
- The need for signage at points of specific hazard and the need to delineate specific hazard zones, e.g. rockfall hazard for next 200 m.
- The message to be conveyed, e.g. “Rockfall hazard for next 200 m” versus “Do not go past this sign” or “Do not use beach for next 200 m”.

This study has provided the geotechnical inputs for use in such a strategy and highlighted areas of hazard where signs are needed to communicate the hazard.

11.0 WALLCLIFFE

The Wallcliffe site was added to the assessment after contract award and has a slightly different geomorphological and risk profile character to the other four main study sites. Consequently we have presented it separately from the other study sites.

11.1 Geology and Geomorphology

Gordon (2012) characterises the 20 to 30 m high vertical cliffs at Wallcliffe as a doline wall. Doline is another term for a sinkhole and is often used specifically to refer to sinkholes developed in a limestone rock sequence. Indeed; if the cliff at Wallcliffe is a doline wall, the development and eventual formation of collapsed doline would have occurred in the geological past and most remnants of the collapsed doline has been modified by the Margaret River and are no longer visible (Photograph A10).

What is distinct about the Wallcliffe site compared to other sites along the coast is that it is likely in an older eolianite that has undergone significant alteration as a result of calcrete precipitation. There is a significant amount of flowstone calcrete that has accumulated on the face of the cliff (Photograph A11). In addition, calcrete has filled in many of the holes and defects that may have previously been present in the eolianite at this site (Photograph A12). Gordon notes that calcrete formation can heal defects in an eolianite and flowstone calcrete can run overhangs into caves, as is seen at the Wallcliffe site. The formation of calcrete provides additional strength to the limestone and is one of the reasons the high, steep and overhanging cliffs are present at this site.

The site is removed from the direct effects of wave erosion and even significant wind erosion and consequently the main geomorphological processes operating at the other four study sites are essentially absent at the Wallcliffe site. Instead the main geomorphological processes altering this site are likely rainfall, vegetation growth and the slow relaxation of the doline wall by gravity. In contrast to these destructive processes, formation of additional calcrete is ongoing at Wallcliffe and may act to offset many of the destructive processes. Nonetheless, we can see evidence that occasional rockfalls do occur at the Wallcliffe site (Photograph A13, A14). Based on the debris accumulated at the site these rockfalls seem to be concentrated at the sides of the cliff and the central portion has likely not had a significant rockfall for many 10's and possibly even 100's of years.

11.2 Risk Assessment

Given that the main rock face at the Wallcliffe site is in the order of 20 to 30 m high it is difficult to assess potential rockfall hazards from the base of the cliff. Furthermore, heavy vegetation makes viewing the cliff from a distance difficult. Nonetheless, observations from the walkover inspection completed did not suggest that imminent rockfall hazards exist at the site and no specific rockfall hazard feature was noted during inspection.

Given there are no Shire assets in close proximity to Wallcliffe the only risk to assess for this location is the risk to recreational users. We have assessed the Wallcliffe site as a single site using the same methods as for the other study sites and calculated risk as an annual probably for both individual risk as well as societal risk. The breakdown of risk variables is presented with those of four other sites in Appendix C. We have calculated an individual risk of 2.2×10^{-8} and a societal risk of 2.2×10^{-6} for the Wallcliffe site. Both of these probabilities are below the tolerable risk criteria presented in Table 1. The risks relate to people being struck from a naturally occurring rockfall. These risks do not relate to artificially induced hazards, for instance a climber falling because a piton has pulled free from the rock wall or the person belaying a climber being struck by a stone dislodged by a climber.

We have delineated a notional hazard zone for both recreational users and potential Shire assets should any ever be built on top or below the cliff. These are shown on Figure 6.

11.3 Recommendations for Signage at Wallcliffe

There are current no signs warning people approaching the top or base of the cliffs of potential hazards.

The main cliff related potential hazards that need to be conveyed are as following:

At top of cliff:

- High cliff – people could walk or slip off the edge
- Unstable section of cliff that could collapse from under your feet
- People at the top of cliff could dislodge rocks that fall onto people at the base of the cliff

At the base of the cliff:

- Rockfall from above
- Small pieces of rock could be dislodged by people, rain etc. from the top

It is recommended that signage be designed to convey these hazards.

Signs should be placed strategically along approach routes to the top and bottom of the cliff. It is recommend that signage not be attached to the cliff itself as approaching the cliff to read the sign will put the person reading the sign within the hazard zone.

12.0 RECOMMENDATIONS

It is ultimately the Shire's responsibility to decide what level of risk is tolerable or acceptable to both the Shire and to the general public and what mitigation measures are warranted to reduce risk where necessary. We have provided preliminary options for the Shire to consider with regard to risk mitigation for hazards to recreational users. These preliminary recommendations are presented along with the description and photographs of the hazards in Appendix C. These risk mitigation measures are also summarised in Table 3.

It is recommended that the rockfall hazard GC6-15, South Point car park lookout receive mitigation urgently and that the lookout be closed immediately, refer to Appendix C for additional information.

Shire assets in the areas assessed are largely in place for recreational users and consequently any immediate or short-term risk to Shire assets are also a risk to recreational users. Consequently short-term mitigation of risks to Shire assets are dealt with in the risk to recreational users. On the other hand, the longer term risk to Shire assets from sea level rise and cliff retreat have been assessed as having a relatively low risk (low and medium). It should be noted that the delineation of the Shire Asset hazard zone shown in Figure 2 to 5 is a representation of the likely average cliff-top regression over a 100-year period. It is not a recommendation for planning purposes as it does not contain factors of safety. It would therefore be prudent to increase the width of the hazard zone when planning new infrastructure, especially high cost assets, to reduce the probability of new infrastructure being impacted. In this context the following is recommended:

- Any new Shire infrastructure within the hazard zone identified on Figures 2 to 6 may be at risk so needs to be designed with the understanding that coastal slope modification may occur over the next few years/decades
- Allow for coastline retreat or asset replacement strategy in long-term planning for the sites.
- Complete ongoing monitoring in areas where Shire assets are within or in close proximity (~10 m) to the hazard zones presented in Figures 2 to 6.

13.0 IMPORTANT INFORMATION

Your attention is drawn to the document titled – "Important Information Relating to this Report", which is included in Appendix F of this report. The statements presented in that document are intended to inform a reader of the report about its proper use. There are important limitations as to who can use the report and how it can be used. It is important that a reader of the report understands and has realistic expectations about those matters. The Important Information document does not alter the obligations Golder Associates has under the contract between it and its client.

14.0 REFERENCES

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Report Signature Page

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LEGEND

STUDY AREA	MINOR ROAD
FREEWAY; NATIONAL HIGHWAY	ACCESS ROAD / TRACK
MAIN ROAD	

REFERENCE

ROADS © WESTERN AUSTRALIAN LAND INFORMATION AUTHORITY TRADING AS LANDGATE (2011)
INSET BASE DATA, DRAINAGE AND RAIL SOURCED FROM STREET PRO DATA 2009.
BASE IMAGE AND TOPOGRAPHY SOURCED FROM GEOSCIENCE AUSTRALIA.

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SR
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

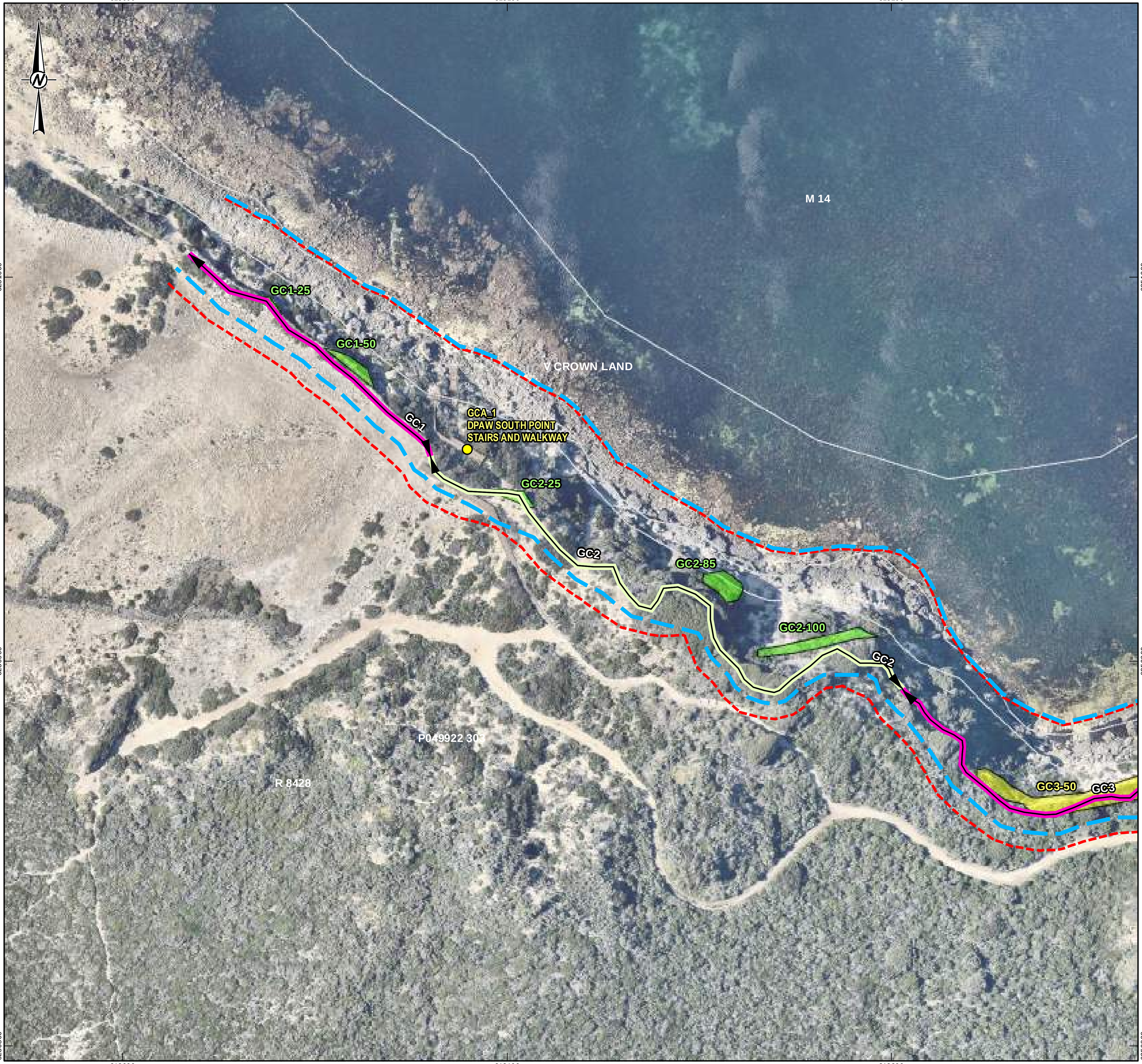
TITLE
SITE LOCATION PLAN

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	1

Path: B:\Shire_of_Augusta\Margaret_River\99_PROJECTS\1666765-Limestone_Cliff_Stability\02_PRODUCTION\MXD\001-R\Rev0\1666765-001-R-F001-Rev0.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A4

25mm



LEGEND

SHIRE ASSET RISK

- MEDIUM

GEOMORPHOLOGICAL ZONES

- 1B
- 2B

HAZARD ZONES

- SHIRE ASSETS
- RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

- MEDIUM
- LOW
- CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

AERIAL IMAGE SOURCED FROM NEARMAP (NOV.2016)

ROADS AND CADASTRE © WESTERN AUSTRALIAN LAND INFORMATION AUTHORITY TRADING AS LANDGATE (2016)

0 25 50

1:1,000 METRES

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

TITLE
GRACETOWN GEOMORPHOLOGY AND RISK MAP

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	2A

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM ISO A3

25mm

LEGEND

S	LOCATION OF EXISTING SIGN

SHIRE ASSET RISK

- MEDIUM
- LOW

GEOMORPHOLOGICAL ZONES

- 1B
- 2B
- 2C

HAZARD ZONES

- SHIRE ASSETS
- RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

- HIGH
- MEDIUM
- LOW
- CADASTRE

NOTES

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CONSULTANT

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DESIGNED	SWG
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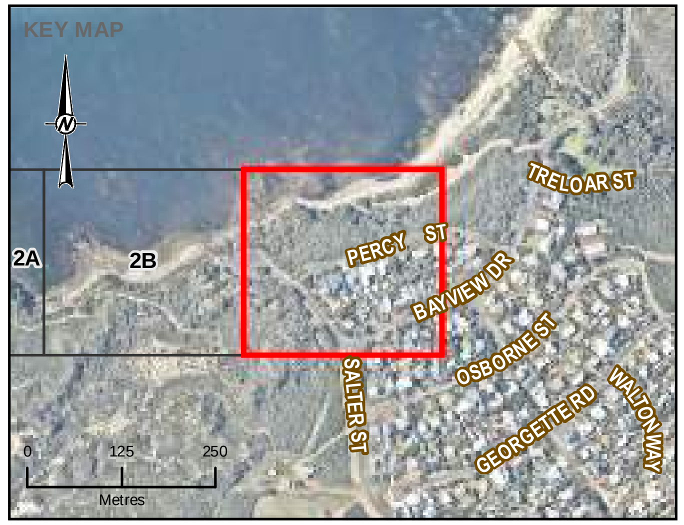
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	2B



LEGEND

LOCATION OF EXISTING SIGN

SHIRE ASSET RISK

LOW

GEOMORPHOLOGICAL ZONES

1B

2C

HAZARD ZONES

SHIRE ASSETS

RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

HIGH

LOW

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

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0 25 50

1:1,000 METRES

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TITLE
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CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	2C

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

25mm

LEGEND

SHIRE ASSET RISK

- LOW

GEOMORPHOLOGICAL ZONES

- 2B
- 2C

HAZARD ZONES

- SHIRE ASSETS
- RECREATIONAL USERS
- GRANITIC ROCK OUTCROP
- CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

AERIAL IMAGE SOURCED FROM NEARMAP (NOV.2016)

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1:1,000 METRES

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

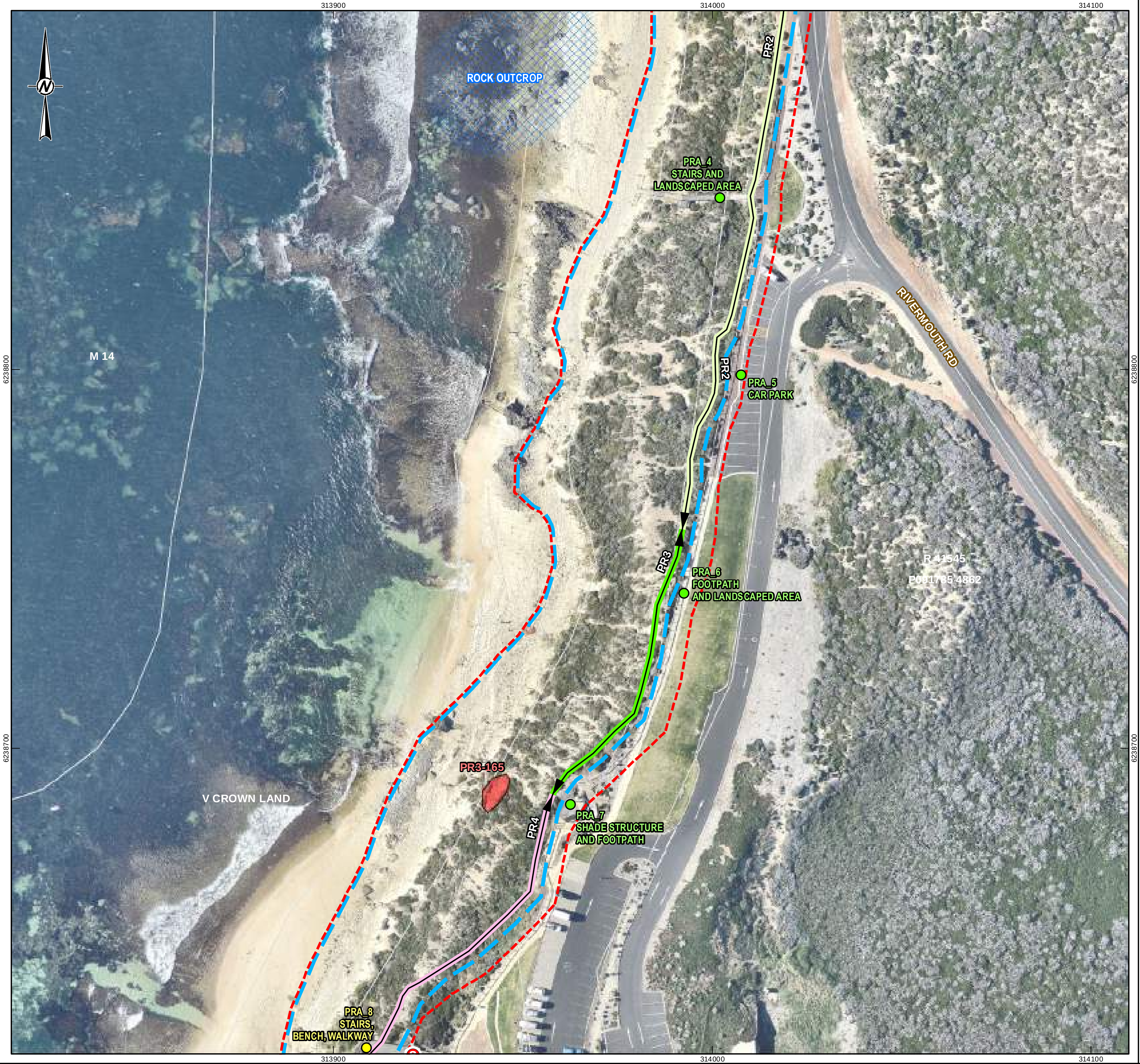
TITLE
PREVELLY GEOMORPHOLOGY AND RISK MAP

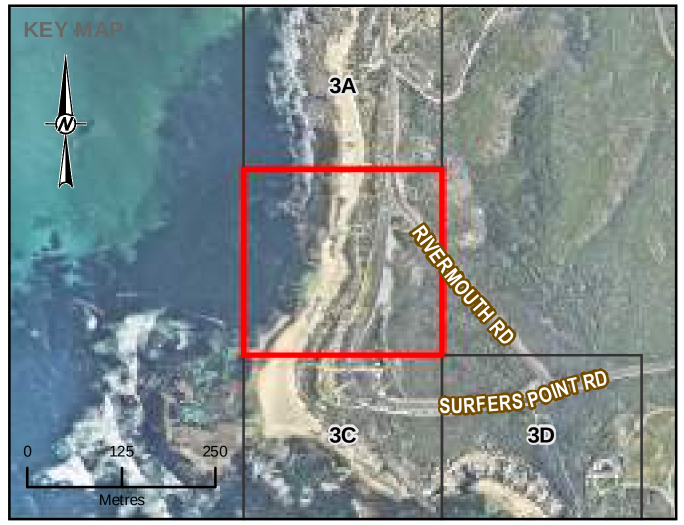
CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	3A





LEGEND

LOCATION OF EXISTING SIGN

SHIRE ASSET RISK

- MEDIUM
- LOW

GEOMORPHOLOGICAL ZONES

- 1C
- 2A
- 2B

HAZARD ZONES

- SHIRE ASSETS
- RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

- HIGH
- GRANITIC ROCK OUTCROP
- CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

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1:1,000 METRES

CLIENT
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PROJECT
CLIFF STABILITY ASSESSMENT

TITLE
PREVELLY GEOMORPHOLOGY AND RISK MAP

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
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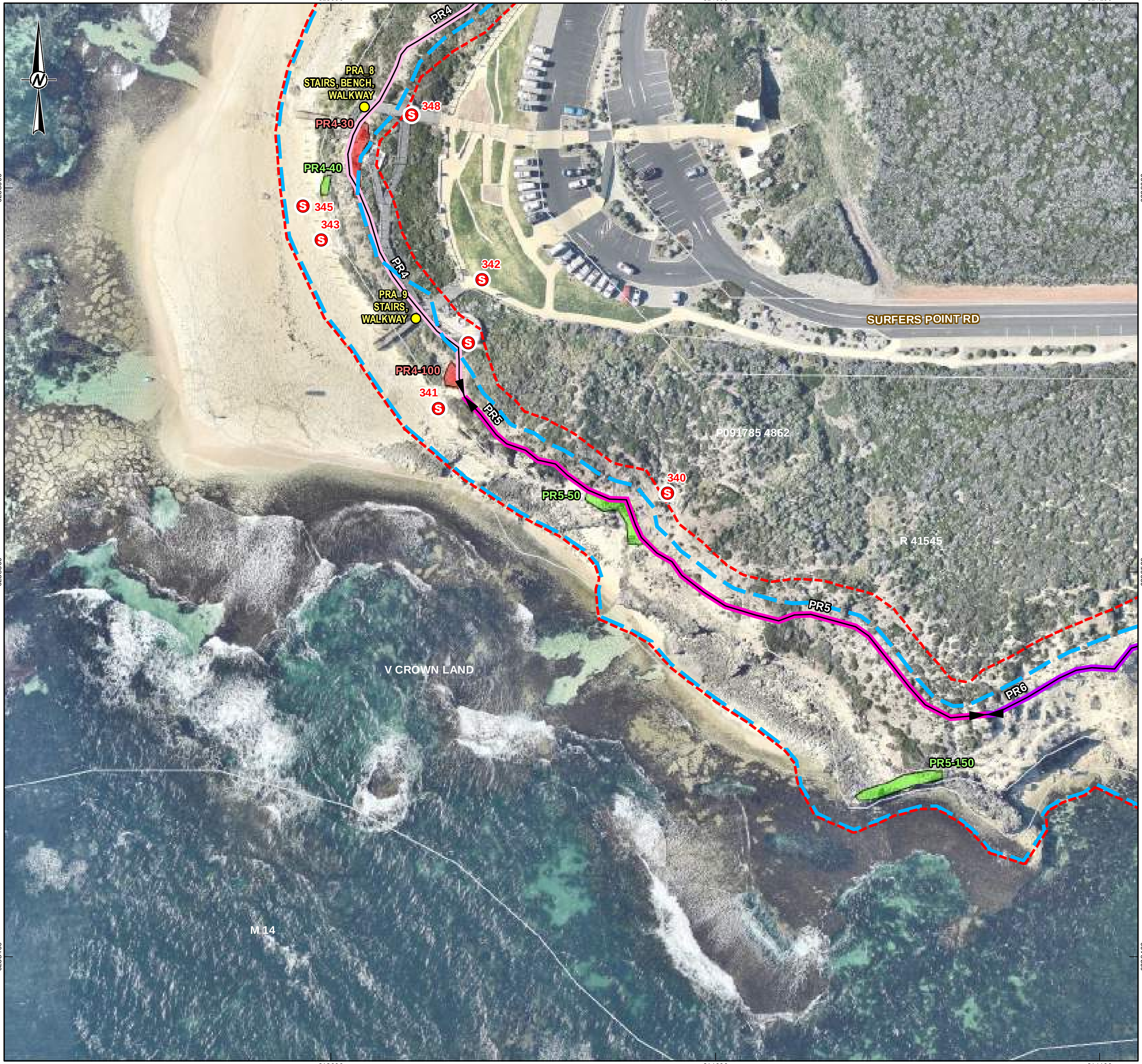
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM ISO A3



LEGEND

S LOCATION OF EXISTING SIGN

SHIRE ASSET RISK

MEDIUM

GEOMORPHOLOGICAL ZONES

1A

1B

1C

HAZARD ZONES

SHIRE ASSETS

RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

HIGH

LOW

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

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1:1,000 METRES

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

TITLE
PREVELLY GEOMORPHOLOGY AND RISK MAP

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	3C

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

LEGEND

LOCATION OF EXISTING SIGN

GEOMORPHOLOGICAL ZONES

1A

1B

HAZARD ZONES

SHIRE ASSETS

RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

HIGH

LOW

GRANITIC ROCK OUTCROP

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

AERIAL IMAGE SOURCED FROM NEARMAP (NOV.2016)

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0 25 50

1:1,000 METRES

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

TITLE
PREVELLY GEOMORPHOLOGY AND RISK MAP

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	3D

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

25mm

LEGEND

S LOCATION OF EXISTING SIGN

SHIRE ASSET RISK

LOW

GEOMORPHOLOGICAL ZONES

1B

2A

2C

HAZARD ZONES

SHIRE ASSETS

RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

LOW

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

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0 25 50

1:1,000 METRES

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

TITLE
GNARABUP GEOMORPHOLOGY AND RISK MAP

CONSULTANT	YYYY-MM-DD	2017-05-12
Golder Associates	DESIGNED	SWG
	PREPARED	SR
	REVIEWED	MAT
	APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	4A

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

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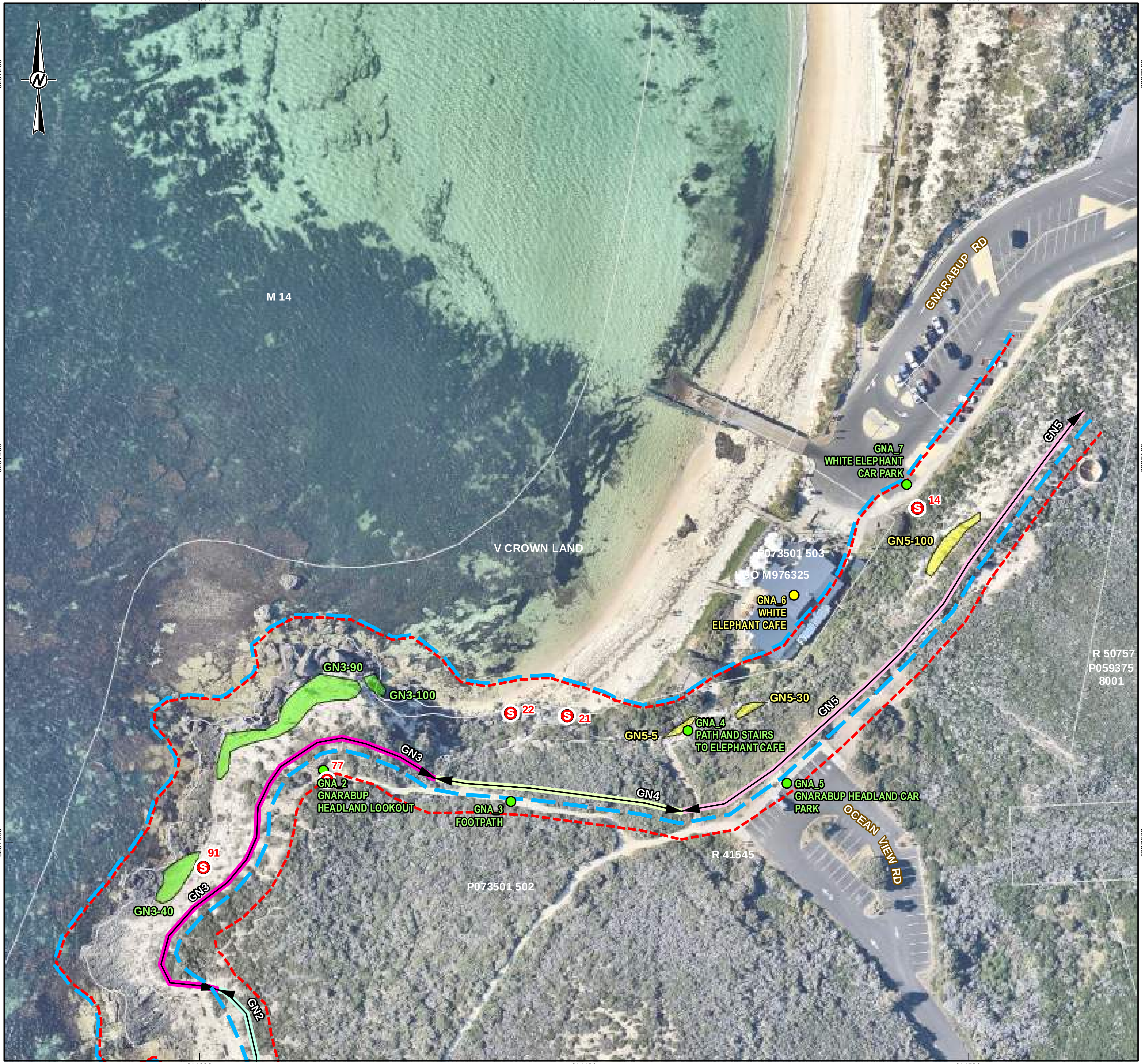

LEGEND

S LOCATION OF EXISTING SIGN

SHIRE ASSET RISK

- MEDIUM
- LOW

GEOMORPHOLOGICAL ZONES

- 1B
- 1C
- 2B
- 2C

HAZARD ZONES

- SHIRE ASSETS
- RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

- MEDIUM
- LOW

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

AERIAL IMAGE SOURCED FROM NEARMAP (NOV.2016)

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0 25 50
1:1,000 METRES

CLIENT
SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT
CLIFF STABILITY ASSESSMENT

TITLE
GNARABUP GEOMORPHOLOGY AND RISK MAP

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	4B

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LEGEND

S LOCATION OF EXISTING SIGN

GEOMORPHOLOGICAL ZONES

1B

1C

HAZARD ZONES

SHIRE ASSETS

RECREATIONAL USERS

SLOPE COLLAPSE HAZARD

HIGH

LOW

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

AERIAL IMAGE SOURCED FROM NEARMAP (NOV.2016)

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0 25 50

1:1,000 METRES

CLIENT

SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT

CLIFF STABILITY ASSESSMENT

TITLE

GRUNTERS GEOMORPHOLOGY AND RISK MAP

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
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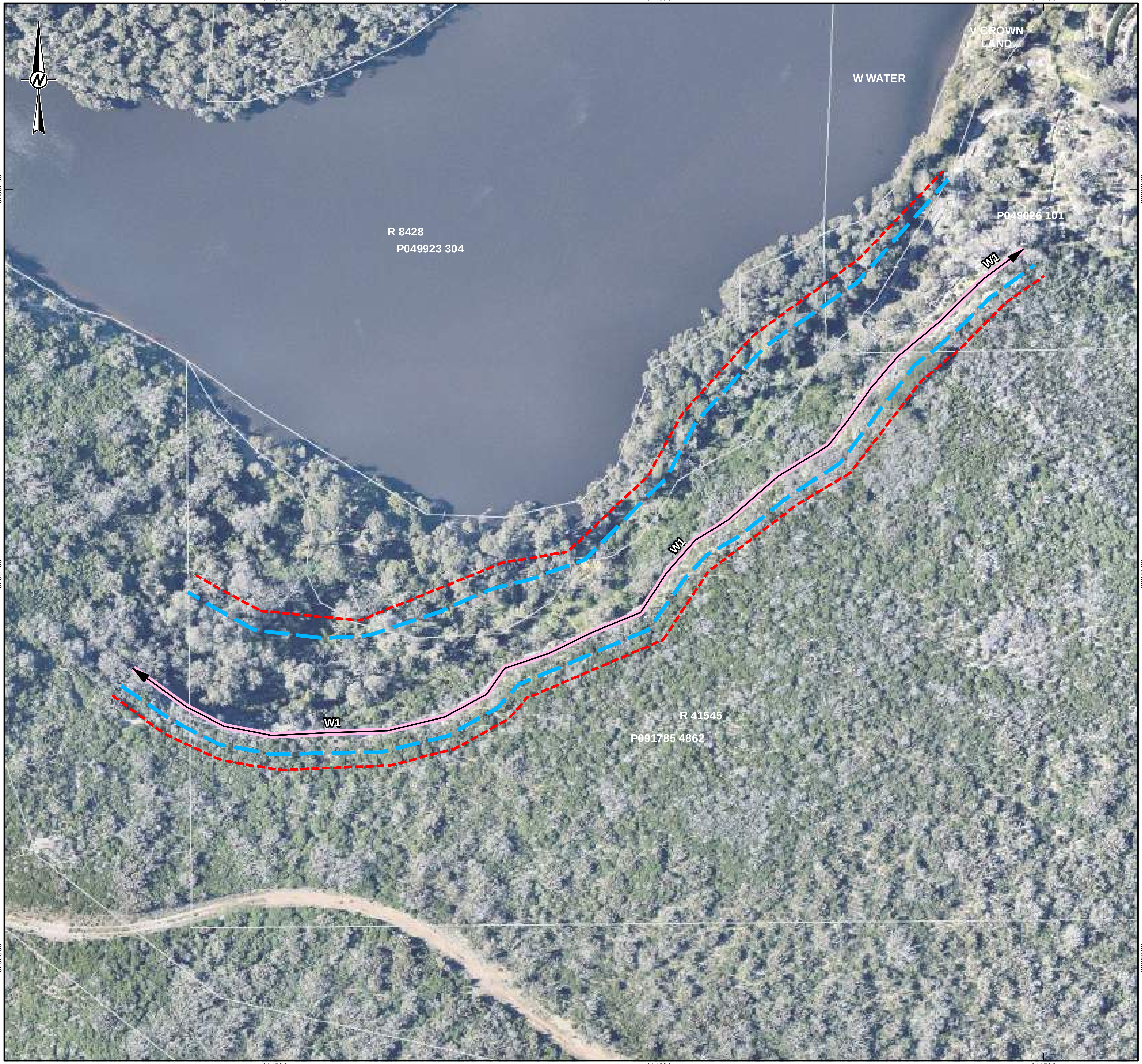

LEGEND

GEOMORPHOLOGICAL ZONES

1C

HAZARD ZONES

SHIRE ASSETS

RECREATIONAL USERS

CADASTRE

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE

AERIAL IMAGE SOURCED FROM NEARMAP (NOV.2016)

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0 25 50

1:1,000 METRES

CLIENT

SHIRE OF AUGUSTA AND MARGARET RIVER

PROJECT

CLIFF STABILITY ASSESSMENT

TITLE

WALLCLIFFE GEOMORPHOLOGY

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-12
DESIGNED	SWG
PREPARED	SR
REVIEWED	MAT
APPROVED	MAT

PROJECT NO.	CONTROL	REV.	FIGURE
1666765	001 R	0	6

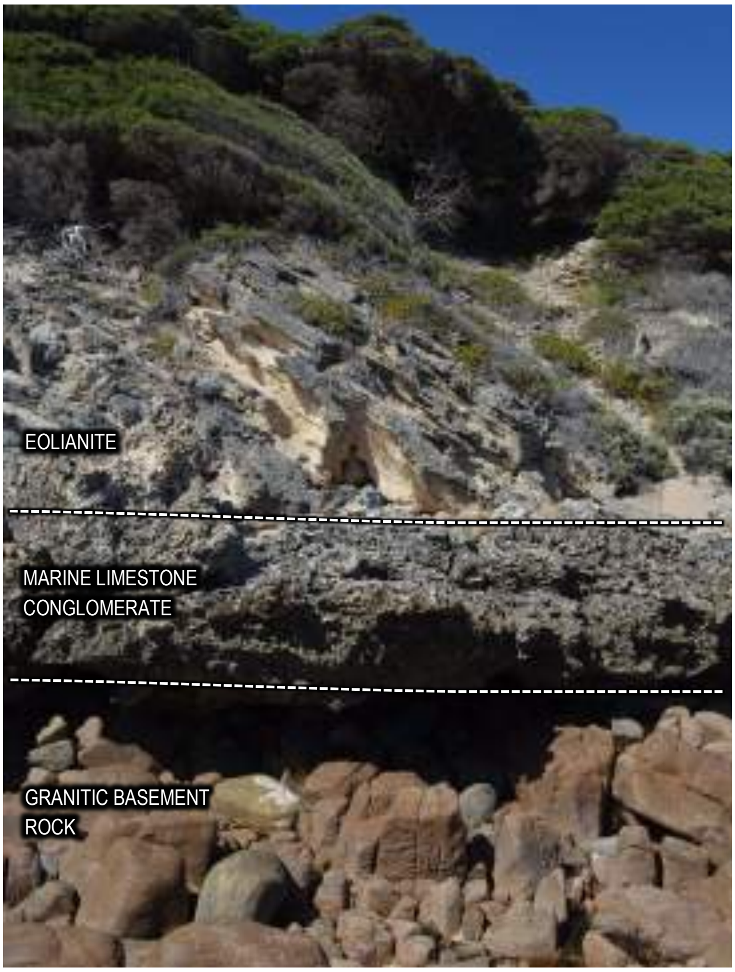
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

APPENDIX A

Site Photographs

Prevelly –Surfers Point Area

Photograph A1: Looking south towards Surfers Point with granite-gneiss basement rock of the Leeuwin Complex in foreground (Date of Photograph: 25 January 2017).



Gracetown – Huzza Cliffs Area

Photograph A2: Looking south-east at a slope profile at geomorphic zone GC2 showing granulite basement rock overlain by marine limestone conglomerate, overlain by eolianite with steeply dipping beds (Date of photograph: 24 January 2017).

Gracetown – Huzza Cliffs Area

Photograph A3: Close-up view of marine limestone conglomerate north of Huzza Cliffs, Gracetown showing granite-gneiss cobbles and boulders cemented in a matrix of marine limestone (Date of Photograph: 25 January 2017).

Gnarabup Area

Photograph A4: Looking north from the southern end of Gnarabup headland with beachrock exposed in the shoreline. A rock platform containing a mixture of marine limestone, beachrock and eolianite is visible in the background (Date of Photograph: 24 January 2017).

Prevelly – Surfers Point Area

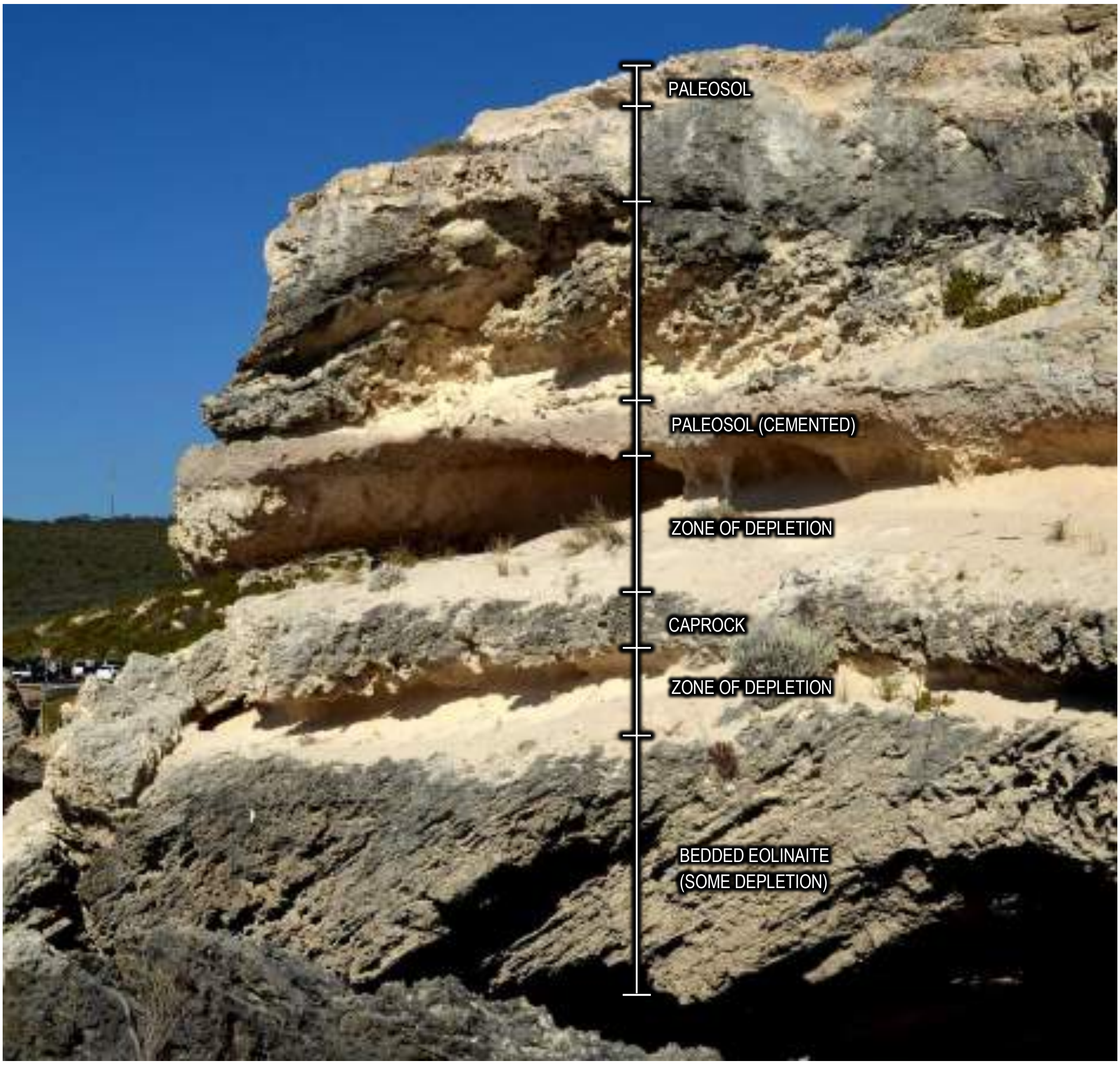
Photograph A5: Looking south-west towards Surfers Point with beachrock exposed in the shoreline, some eolianite boulders are also visible in the left of the photograph (Date of Photograph: 24 January 2017).

Gracetown – Huzza Cliffs Area

Photograph A6: Looking south at the western side of Huzza cliffs, Gracetown. The largest visible paleosols, zones of depletion and caprock layers are indicated. Gordon (1999) identifies four cycles of eolianite deposition in this cliff. Recreational users are visible sitting below cliffs on the left side of the photograph (Date of Photograph: 23 January 2017).

Prevelly – Surfers Point Area

Photograph A7: Looking east the cliffs on the north side of Prevelly Beach. The largest visible paleosols, zones of depletion and caprock layers are indicated. Beach users are visible sitting below cliffs bear the bottom centre of the photograph (Date of Photograph: 25 January 2017).



Gnarabup Area

Photograph A8: Looking north-east at the cliffs below the Gnarabup Headland lookout (cars parked at the White Elephant Café parking lot are visible in the centre left of the photograph). The largest visible paleosols, zones of depletion and caprock layers are indicated. (Date of Photograph: 24 January 2017).

Prevelly – Surfers Point Area

Photograph A9: An example of a toppled overhang south of Surfers Point (Date of Photograph: 23 January 2017).

Wallcliffe Location

Photograph A10: Looking north-east up Margaret River with the Wallcliffe site visible at the right of the photograph (Date of Photograph: 25 January 2017).

Wallcliffe Location

Photograph A11: The main wall at the Wallcliffe site showing significant accumulation of flowstone calcrete on the cliff face and formation of stalactites (Date of Photograph: 25 January 2017).

Wallcliffe Location

Photograph A12: Thin layers (lamina) of calcrete precipitated in cracks on spaces in the older eolianite at the Wallcliffe site (Date of Photograph: 25 January 2017).

Wallcliffe Location

Photograph A13: Historic rockfall on the northern side of the Wallcliffe site (Date of Photograph: 25 January 2017).

Wallcliffe Location

Photograph A14: A large (~3.5 m × 3.5 m × 7.0 m) limestone block that appears to have dropped or relaxed from the main rock face behind it near the southern end of the Wallciffe site (Date of Photograph: 25 January 2017).

APPENDIX B

Risk Definitions

APPENDIX B
Risk Definitions

To ensure clarity in the discussion of risk in the subsequent sections, a definition of the risk terms used in this report are presented below. Many of these definitions are taken directly from the AGS (2007) guidelines with minor rewording to suit the risk particular to the study sites, where applicable.

- **Risk** – A measure of the probability and severity of an adverse effect to health, property or the environment.
- **Hazard** – A condition with the potential for causing an undesirable consequence (in this case, rockfall or ground collapse).
- **Hazard Zone** – An area within which the hazard may affect elements at risk if failure were to occur.
- **Elements at Risk** – Meaning the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the hazard.
- **Probability** – The likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes. Probability is expressed as a number between 0 and 1, with 0 indicating an impossible outcome and 1 indicating that an outcome is certain.
- **Frequency** – A measure of the likelihood expressed as the number of occurrences of an event in a given time.
- **Likelihood** – Used as a qualitative description of probability or frequency.
- **Temporal Probability** – The probability that the element at risk is in the area affected by the slope failure, at the time of the slope failure.
- **Vulnerability** – The degree of loss to a given element or set of elements within the area affected by the hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.
- **Consequence** – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.
- **Individual Risk** – The risk of fatality or injury to any identifiable individual who enters the hazard zone.
- **Societal Risk** – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a slope failure causing a number of deaths, injuries, financial, environmental, and other losses.
- **Acceptable Risk** – A risk that, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.
- **Tolerable Risk** – A risk that society is willing to live with so as to secure certain net benefits in the confidence that it is being properly controlled, kept under review and further reduced as and when possible. In some situations risk may be tolerated because the individuals at risk cannot afford to reduce risk even though they recognise it is not properly controlled.

APPENDIX C

Rockfall Hazards – Risk to Recreational Users

GRACETOWN GC1 Hazard ID: GC1-25

$R_{DI} = 6.0 \times 10^{-7}$	$R_{SOC} = 4.0 \times 10^{-7}$	$R_{CI} = 2.0 \times 10^{-4}$

Description: Overhang of up to 2.5 m with caprock layer up to 2 m thick overlying friable zone of depletion. Numerous rock blocks from historic rockfall on slope below rockfall hazard indicating rockfalls likely occur when overhang reaches between 3 m and 4 m.

Preliminary Mitigation Options:

- Continue to monitor every 3 years AND;
- Install rockfall hazard signs on fencing above and on exit from stairs onto beach.

GRACETOWN GC1
Hazard ID: GC1-50

$R_{DI} = 3.4 \times 10^{-7}$	$R_{SOC} = 2.2 \times 10^{-7}$	$R_{CI} = 1.1 \times 10^{-4}$

Description: Overhang of up to 2.5 m with caprock layer up to 1 m thick overlying friable zone of depletion. Numerous rock blocks from historic rockfall on slope below rockfall hazard indicating rockfalls likely occur when overhang reaches between 3 m and 4 m.

Preliminary Mitigation Options:

- Continue to monitor every 3 years AND;
- Install large rockfall hazard signs on fencing above and on exit from stairs onto beach.

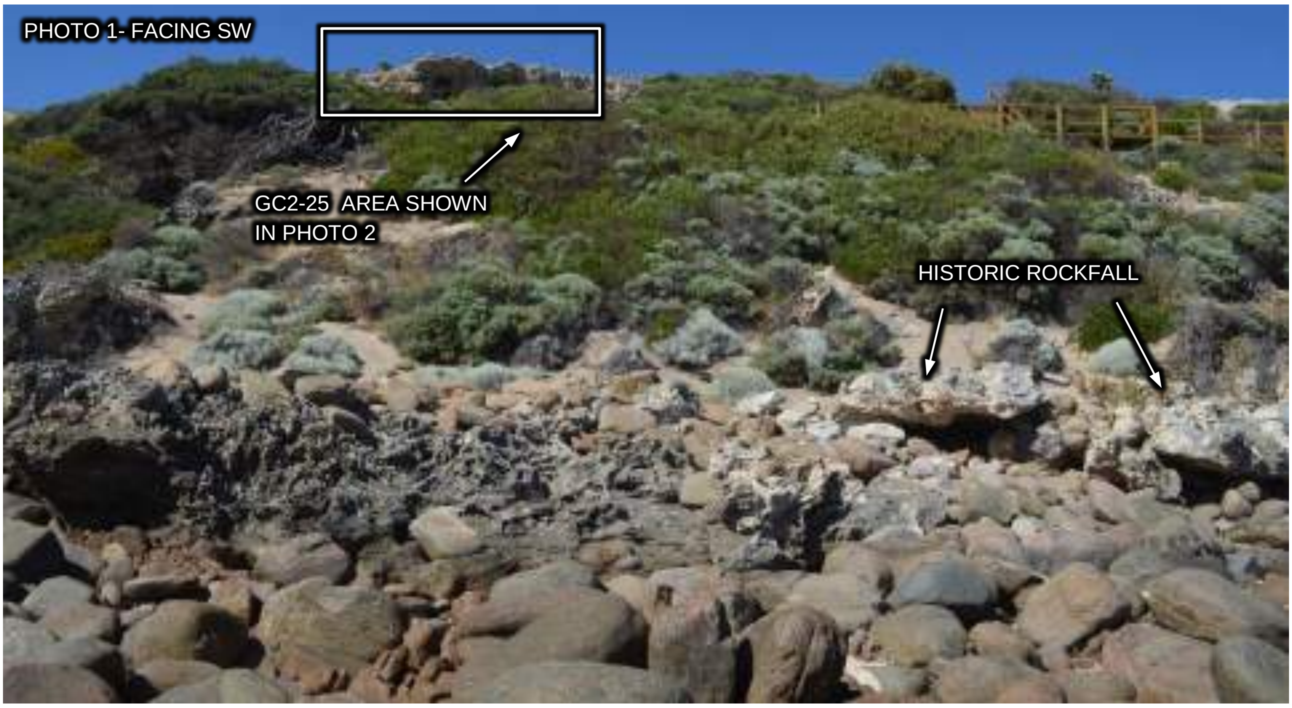
GRACETOWN GC2 Hazard ID: GC2-25

$R_{DI} = 2.4 \times 10^{-7}$	$R_{SOC} = 1.6 \times 10^{-7}$	$R_{CI} = 8.1 \times 10^{-5}$

Description: Overhang (not measured) with caprock up to ~1 m thick overlying leached and friable zone of roots

Preliminary Mitigation Options:

- Continue to monitor every 3 years AND;
- Install large rockfall hazard signs on exit from stairs onto beach.



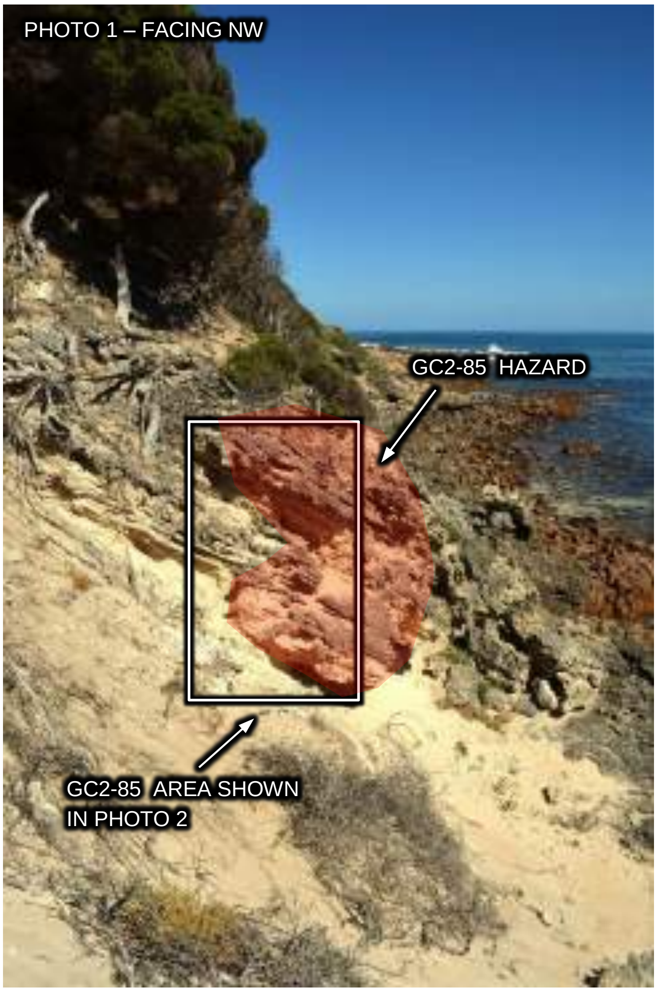
GRACETOWN GC2 Hazard ID: GC2-85

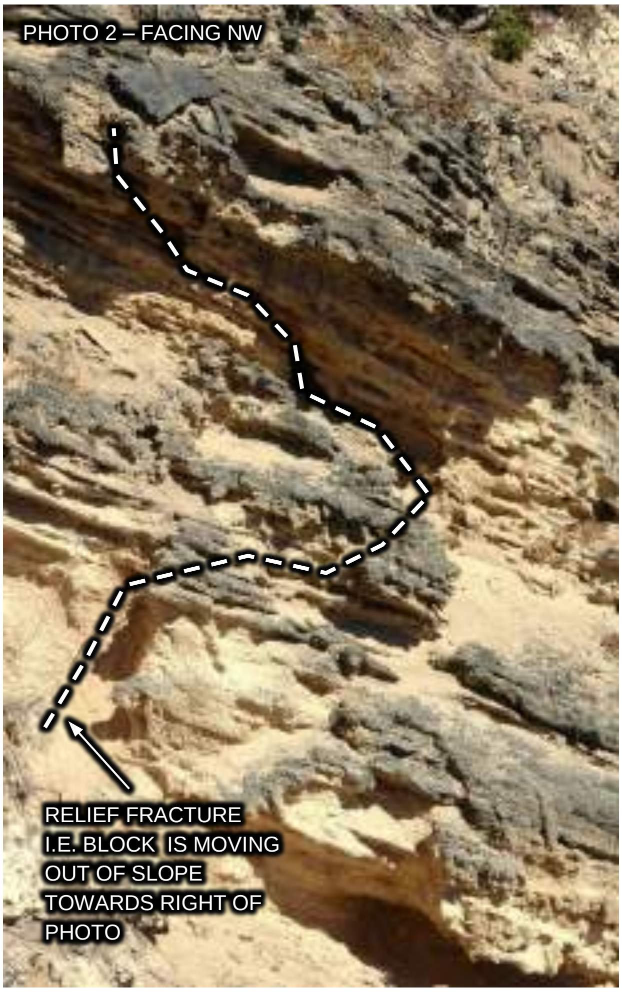
$R_{DI} = 4.6 \times 10^{-7}$	$R_{SOC} = 3.1 \times 10^{-7}$	$R_{CI} = 1.5 \times 10^{-4}$

Description: Layer of steeply dipping eolianite overlying more erodible paleosol leading to undercutting and relaxation of the layered eolianite out of the slope. Relief fractures visible due to relaxation.

Preliminary Mitigation Options:

- Continue monitoring every 3 years AND;
- Install large rockfall hazard signs on exits to the beach from access stairs.





GRACETOWN GC2   Hazard ID: GC2-100

$R_{DI} = 3.3 \times 10^{-7}$	$R_{SOC} = 2.2 \times 10^{-7}$	$R_{CI} = 1.1 \times 10^{-4}$

Description: Overhang of up to 3 m with caprock up to ~0.5 m thick overlying friable zone of depletion.

Preliminary Mitigation Options:

- Continue monitoring every 3 years AND;
- Install large rockfall hazard signs on exits to the beach from access stairs.

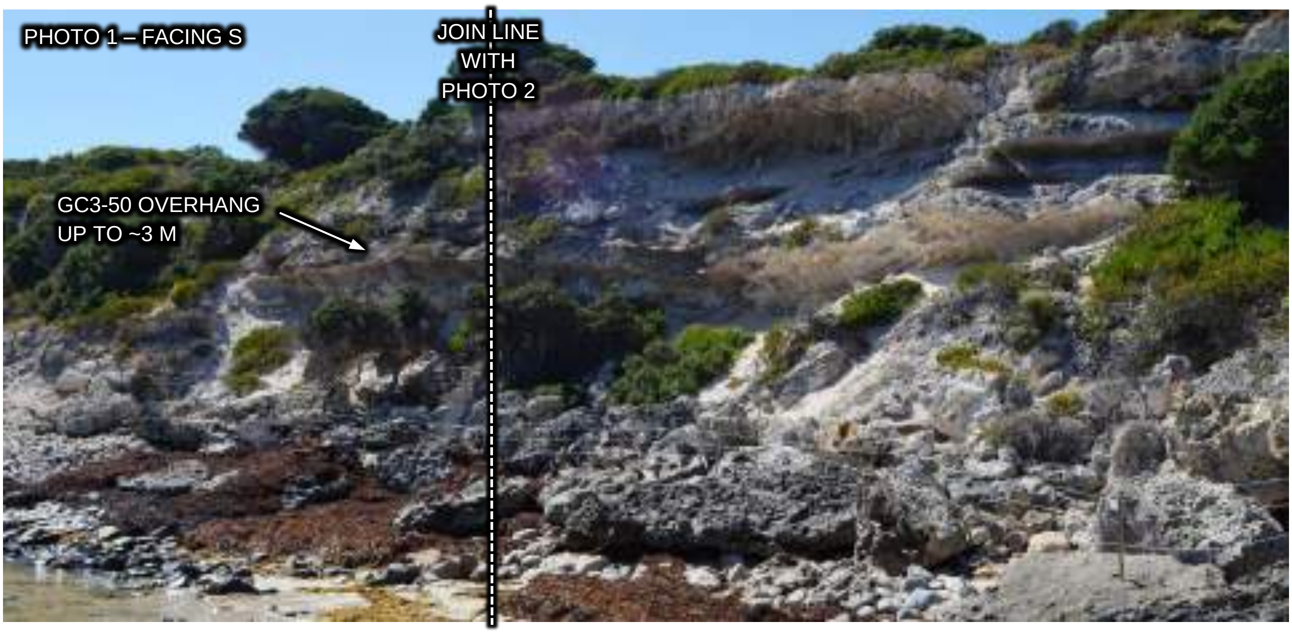
GRACETOWN GC3 Hazard ID: GC3-50

$R_{DI} = 2.3 \times 10^{-6}$	$R_{SOC} = 1.6 \times 10^{-6}$	$R_{CI} = 1.6 \times 10^{-3}$

Description: Numerous overhangs of up to ~3 m with caprock up to ~1.0 m thick overlying friable zones of depletion. Overhang at time of historic rockfall at adjacent site was estimated to be up to ~4 to 5 m.

Preliminary Mitigation Options:

- Continue monitoring every 3 years;
- Install large rockfall hazard signs on exits to the beach from access stairs; AND
- Install additional signage warning signs on the beach warning people to KEEP OUT of this area.



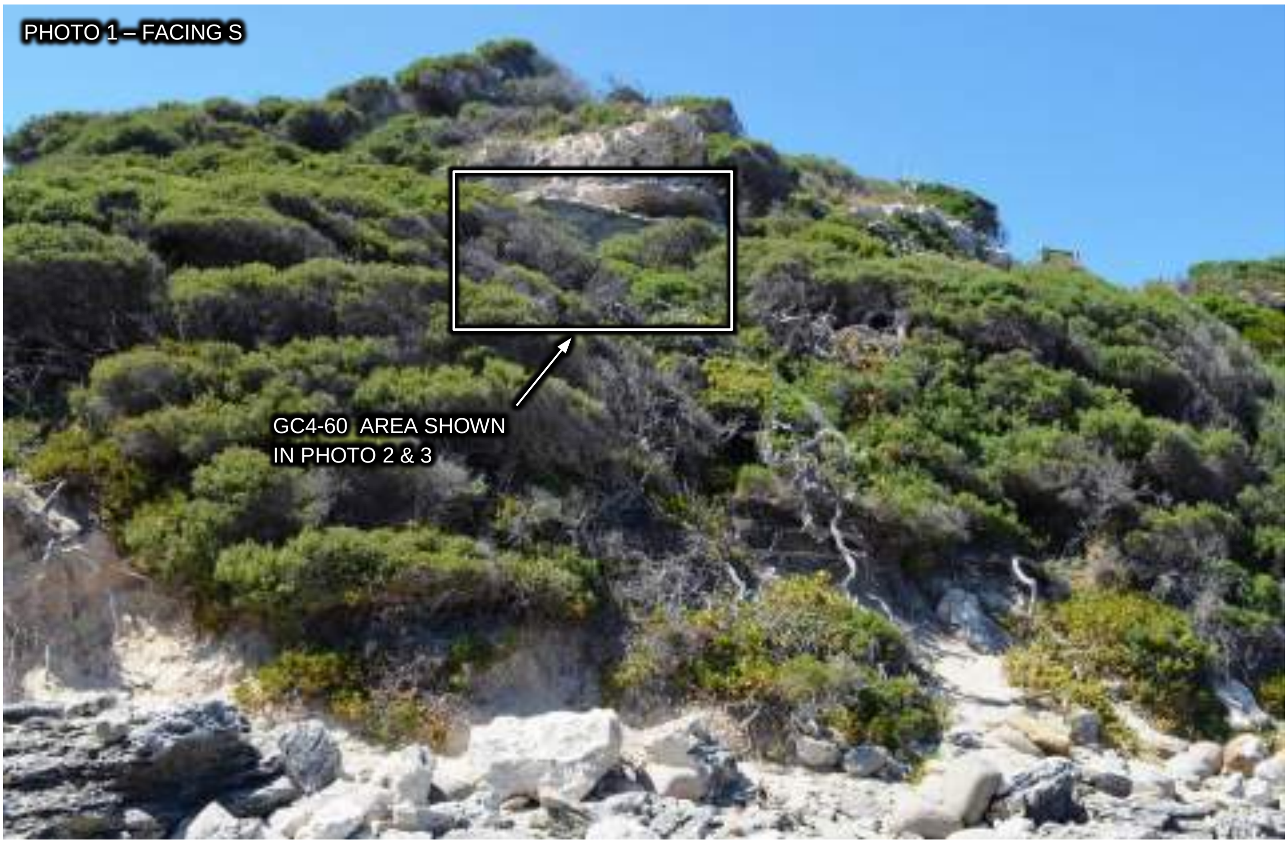
GRACETOWN GC4 Hazard ID: GC4-60

$R_{DI} = 6.1 \times 10^{-7}$	$R_{SOC} = 4.0 \times 10^{-7}$	$R_{CI} = 4.0 \times 10^{-4}$

Description: Overhang of up to ~1.5 m of caprock with relief fractures present at the back of the overhang observed (see photos).

Preliminary Mitigation Options:

- Continue monitoring every 3 years AND;
- Install large rockfall hazard signs on exits to the beach from access stairs.



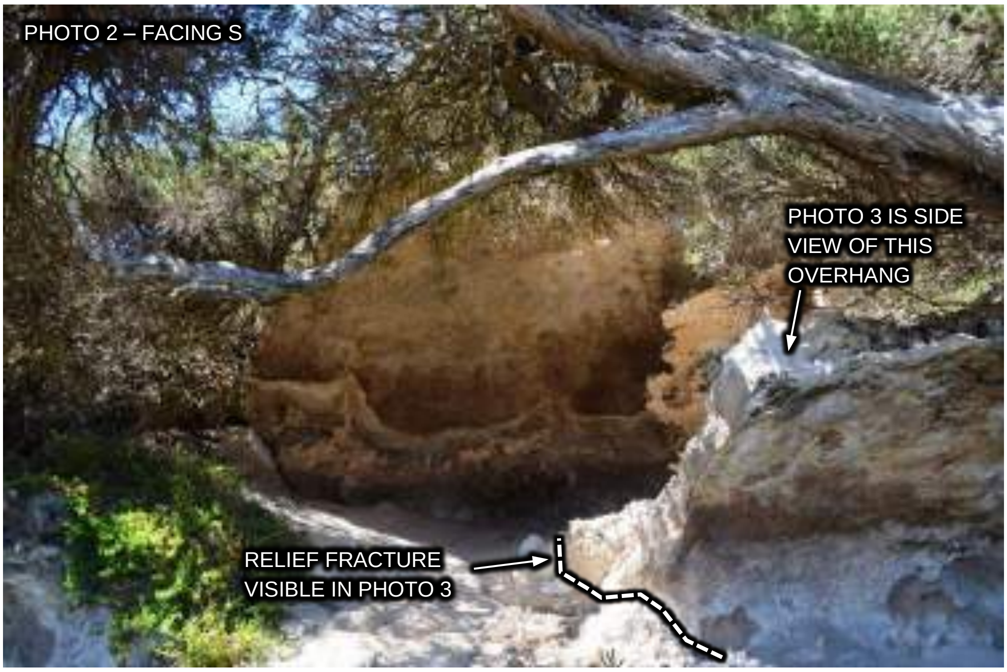


PHOTO 2 – FACING S
PHOTO 3 IS SIDE VIEW OF THIS OVERHANG
RELIEF FRACTURE VISIBLE IN PHOTO 3


PHOTO 3 – FACING W
RELIEF FRACTURE
RELIEF FRACTURE

GRACETOWN GC5 Hazard ID: GC5-75 **HIGH PRIORITY ROCKFALL HAZARD**

$R_{DI} = 5.9 \times 10^{-7}$	$R_{SOC} = 3.9 \times 10^{-7}$	$R_{CI} = 2.0 \times 10^{-3}$

Description: Overhang of up to ~1.5 m of caprock with relief fractures present at the back of the overhang observed (see photos).

Preliminary Mitigation Options:

- It is recommended that one of the mitigation options below should be implemented within 2 years of this report for this site.
- Install warning signs and fencing (offset 5 m from edge of vegetation) below hazard to keep people from entering the hazard zone and continue to monitor annually AND,
- Stabilise overhanging blocks with mesh or bolts, slope stabilisation design required, and continue monitoring annually OR,
- Remove overhanging blocks with excavator or by blasting.

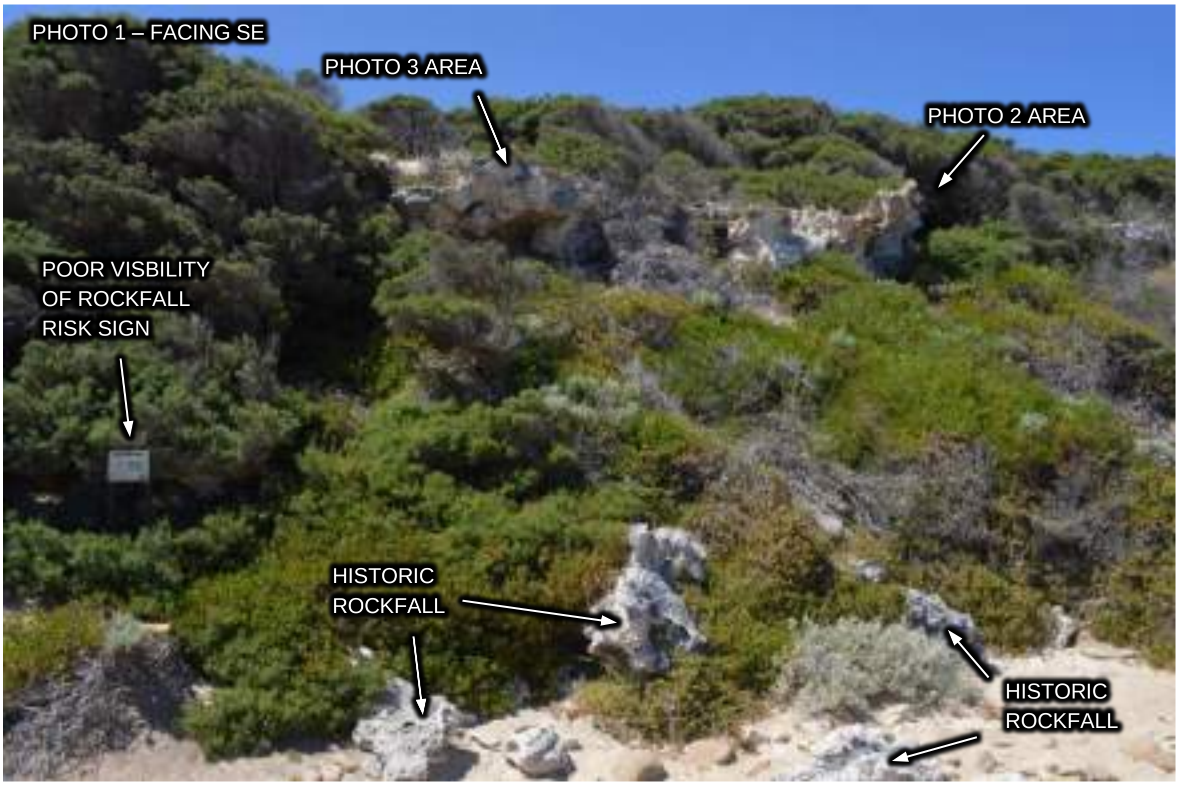



PHOTO 3 – FACING SW
RELIEF FRACTURE
SHOWN IN PHOTO 4
CALCRETIZED TREE
TRUNK OR ROOT CAST
RELIEF FRACTURES
SHOWN IN PHOTO 5

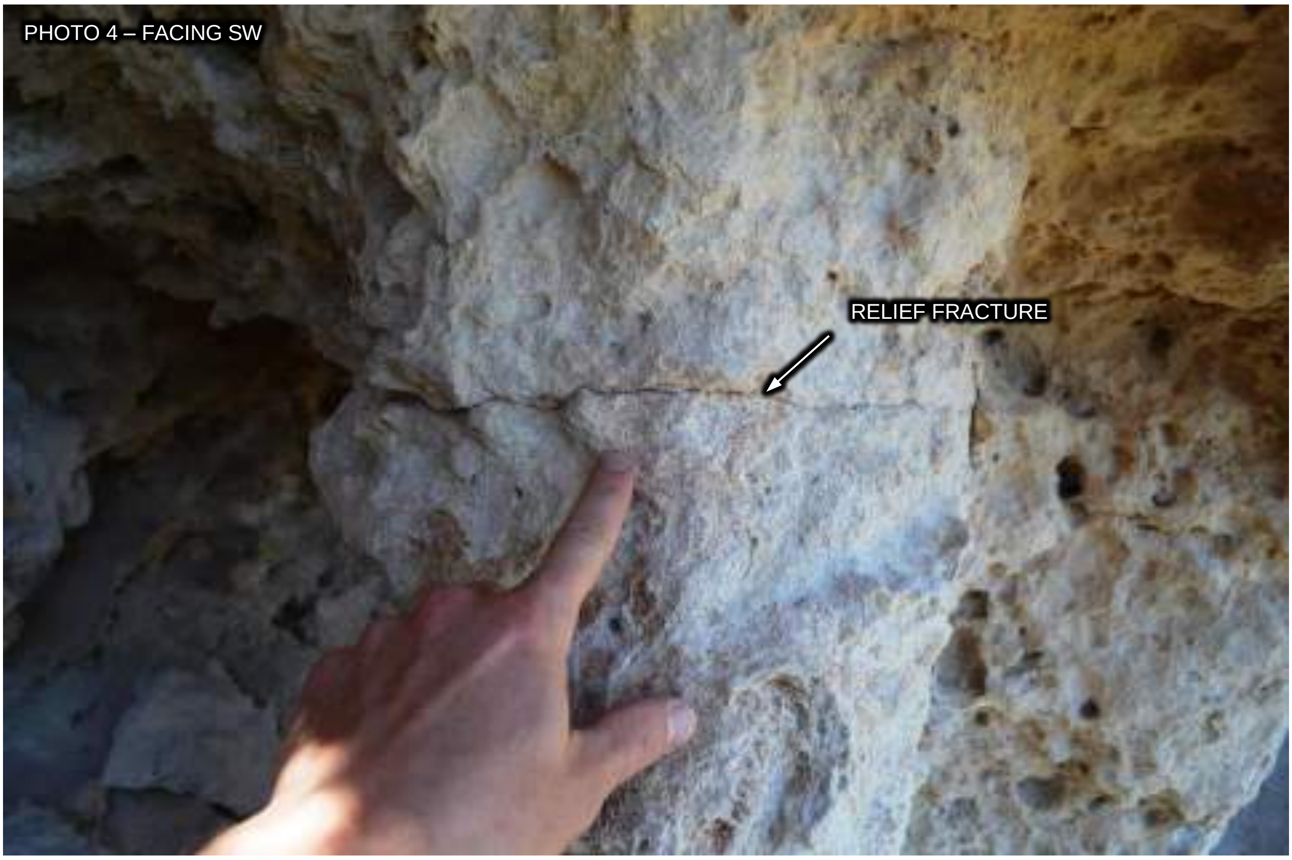


PHOTO 4 – FACING SW
RELIEF FRACTURE

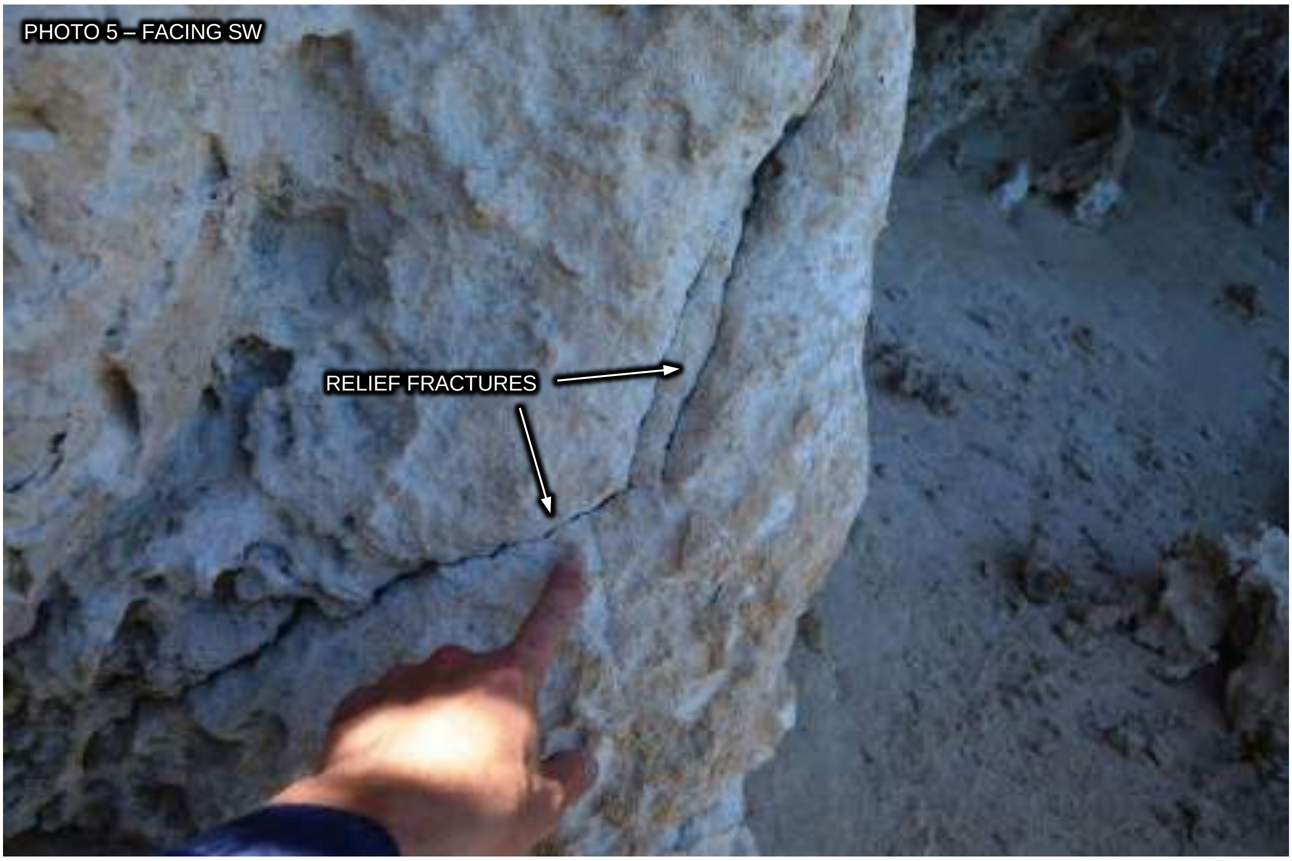


PHOTO 5 – FACING SW
RELIEF FRACTURES

GRACETOWN GC6 Hazard ID: GC6-15 HIGH PRIORITY ROCKFALL HAZARD – URGENT ATTENTION

$R_{DI} = 2.1 \times 10^{-5}$	$R_{SOC} = 1.4 \times 10^{-5}$	$R_{CI} = 7.1 \times 10^{-2}$

Description: Overhang of up to ~2.0 m of caprock with relief fractures extending behind a relaxing block on the east side of the feature and possibly through to the other side of the main outcrop supporting a pedestrian lookout (see photos). High priority rockfall hazard for both recreational users and Shire assets.

Preliminary Mitigation Options:

- Close the lookout, install warning signs below the lookout to KEEP OUT and do not linger below cliff AND apply either of the following mitigation options within 1 year.
- Support overhang and relaxing blocks, slope stabilisation design required and continue monitoring annually.
- Remove overhanging blocks and reconstruct the lookout.


PHOTO 2 – FACING W
SOUTH POINT CAR PARK LOOKOUT FOOTING
RELIEF FRACTURE EXTENDING BEHIND RELAXING BLOCK
BLOCK DROPPING OUT IN THIS DIRECTION


PHOTO 3 – FACING E
RELIEF FRACTURE POSSIBLY EXTENDING BENEATH THE ROCK OUTCROP THAT THE LOOKOUT IS CONSTRUCTED ON

GRACETOWN GC6 Hazard ID: GC6-60 **HIGH PRIORITY ROCKFALL HAZARD**

$R_{DI} = 2.4 \times 10^{-6}$	$R_{SOC} = 1.6 \times 10^{-6}$	$R_{CI} = 8.1 \times 10^{-4}$

Description: Limestone outcrop relaxing out into slope with relief fractures present and visible from above cliffs and likely extending over a length of approximately 20 m. High priority slope collapse hazard for South Point car park and recreational users. Loss of this material may move the cliff edge approximately 3 m to 5 m closer to car park area.

Preliminary Mitigation Options:

- Install large warning signs on both ends of access point to this section of coastline.
- Stabilise cliff face with mesh and/or rock bolts, slope stabilisation design required OR,
- Continue monitoring annually and plan for car park retreat if required.


PHOTO 2 – FACING E
RELIEF FRACTURES
SHOWN IN PHOTO 1
RELIEF FRACTURE


PHOTO 3 – FACING S
HISTORIC ROCKFALL
BELOW GC6-60

GRACETOWN GC6 Hazard ID: GC6-100

$R_{DI} = 8.0 \times 10^{-7}$	$R_{SOC} = 5.3 \times 10^{-7}$	$R_{CI} = 2.7 \times 10^{-4}$

Description: Overhang of up to ~3.5 m of up to ~1.5 m thick caprock layer overlying zone of depletion. Large limestone blocks from historic rockfall present in slope.

Preliminary Mitigation Options:

- Install large warning signs on both ends of access point to this section of coastline AND;
- Continue monitoring every 3 years.

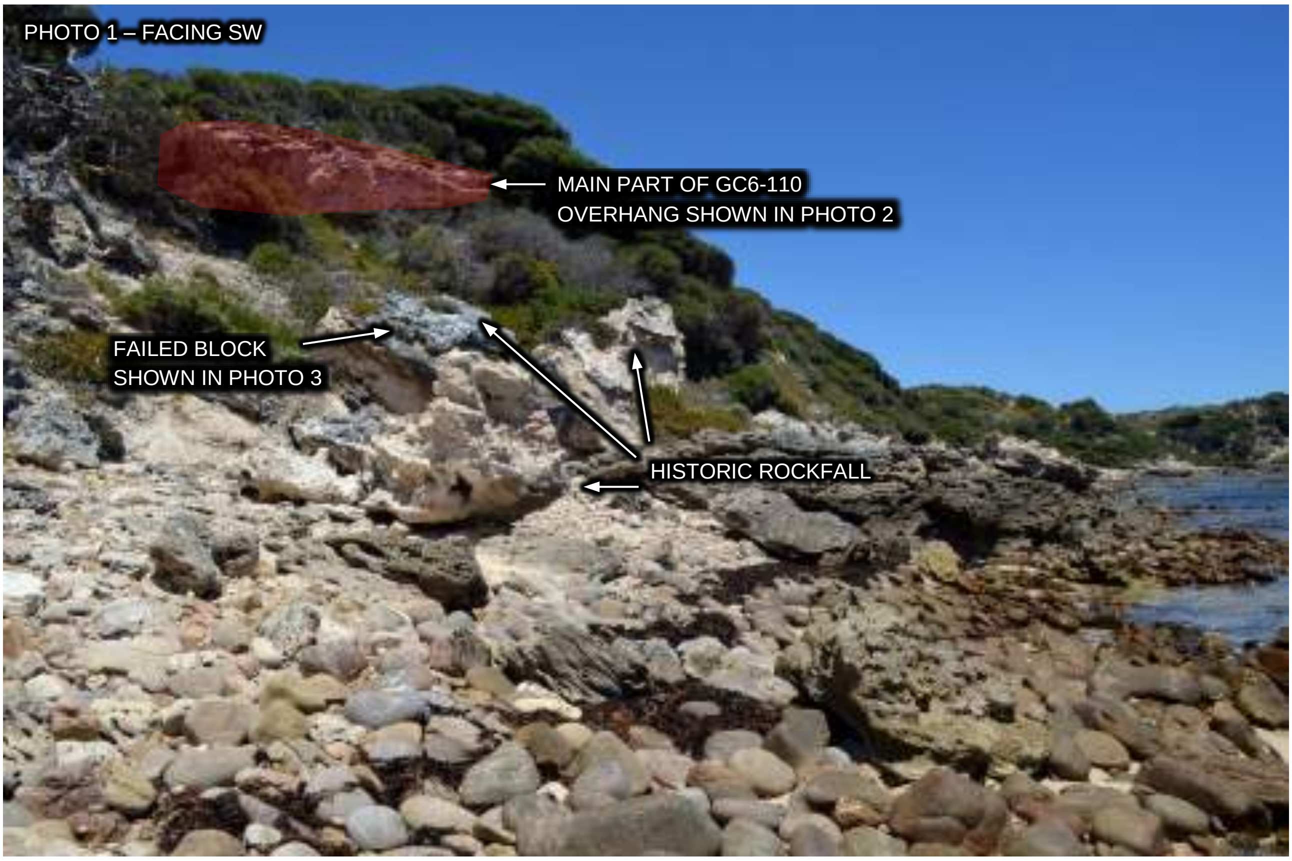



PHOTO 2 – FACING NE


PHOTO 3 – FACING S

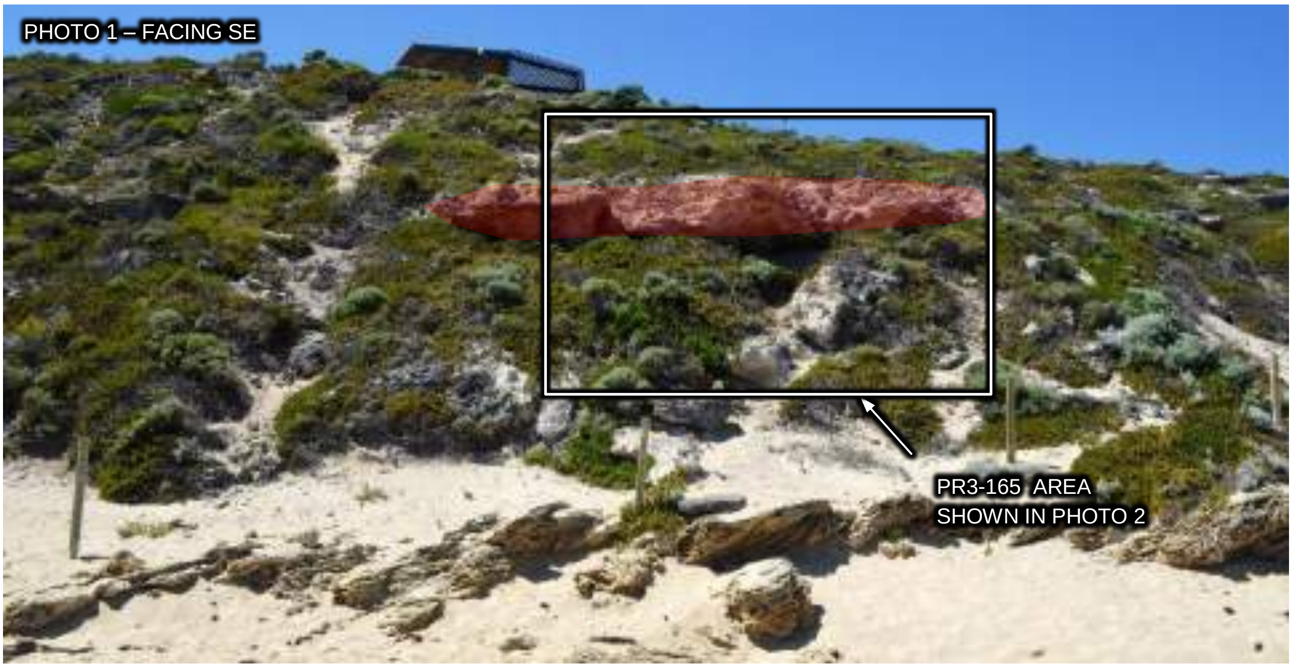
PREVELLY PR3 Hazard ID: PR3-165 HIGH PRIORITY ROCKFALL HAZARD

$R_{DI} = 1.5 \times 10^{-6}$	$R_{SOC} = 9.7 \times 10^{-7}$	$R_{CI} = 1.5 \times 10^{-3}$

Description: Overhang of up to ~2.5 m of ~0.5 m thick caprock layer overlying zone of depletion. Historic rockfall present in slope colluvium. High priority rockfall hazard for recreational users.

Preliminary Mitigation Options:

- Install large warning signs at hazard to discourage people from approaching or sitting and lying on the beach below the hazard and continue monitoring every 3 years OR;
- Block up the overhang with a cemented wall to prevent entrance beneath the overhang and provide support continue monitoring every 5 years.



PREVELLY PR4 Hazard ID: PR4-30 **HIGH PRIORITY ROCKFALL HAZARD**

$R_{DI} = 8.6 \times 10^{-7}$	$R_{SOC} = 5.7 \times 10^{-7}$	$R_{CI} = 4.0 \times 10^{-2}$

Description: Overhang of up to ~4 m of up to ~1.5 m thick caprock layer overlying zone of depletion. Failure could destroy bench and injure or kill users. Also a significant risk of injury if spectators of surfing competitions are standing on the rock mass during failure. Anecdotal evidence suggest up to ~20 people have been observed standing on this overhang during surf competitions. High priority hazard to recreational users and Shire assets.

Preliminary Mitigation Options:

- Install large cliff collapse hazard sign at the entrance to the coastal walkway warning users to stick to existing paths and complete one of the mitigation options urgently.
- Prevent access onto top of overhang
- Remove bench and section of viewing platform below overhang until one of the following is complete:
- Remove overhanging block by blasting or hydraulic breaking, design required OR;
- Attempt to support overhang with man-made structure, slope stabilisation design required for both short-term construction stability and long term slope stability and continue monitoring annually.


PHOTO 2 – FACING S
ANECDOTAL EVIDENCE SUGGESTS
LOADING ON OVERHANG BY
SPECTATORS DURING SURF EVENTS
PHOTO 3
LOOKING
STRIAGHT IN AT
THIS POINT
OVERHANG UP TO 4.0 M

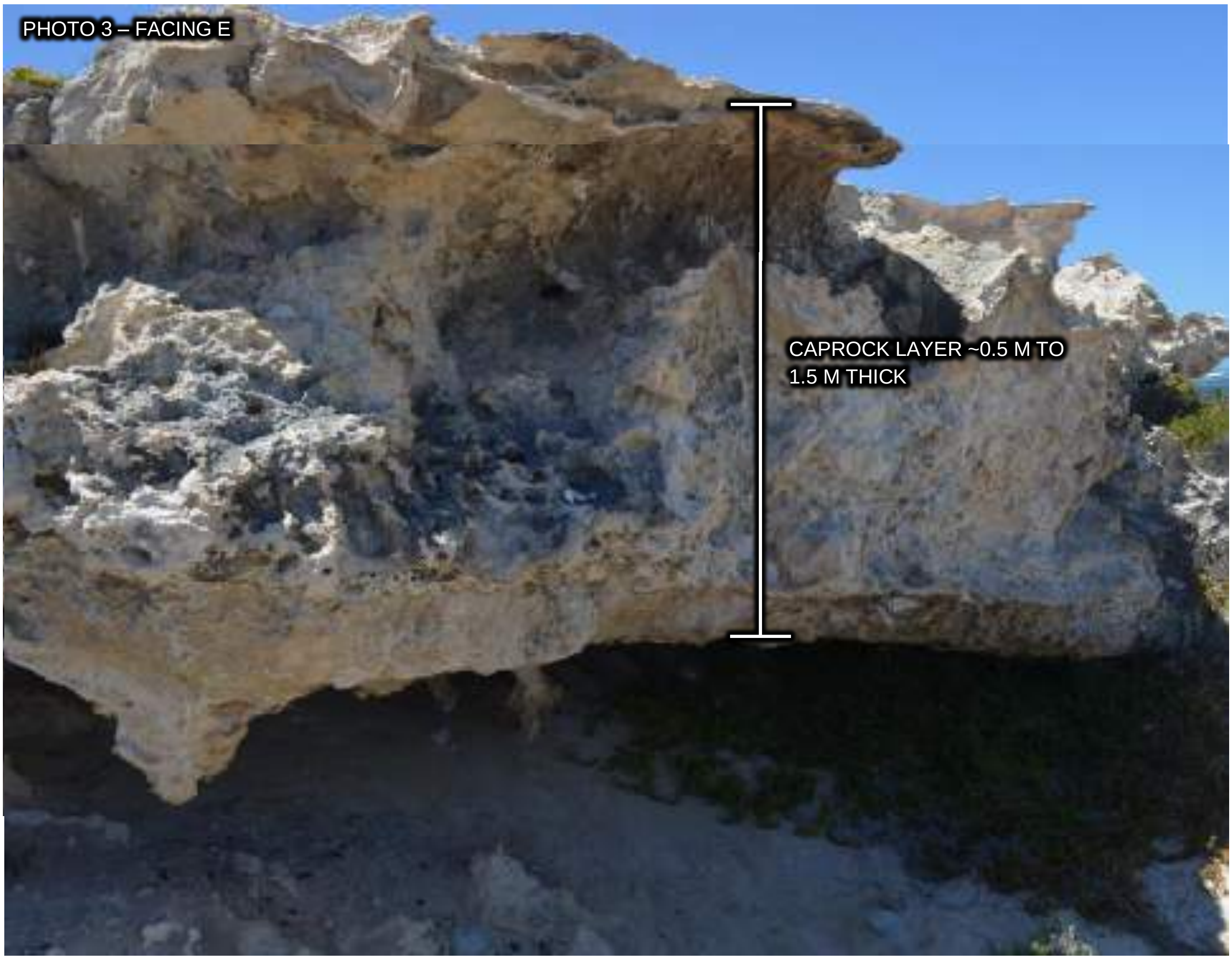


PHOTO 3 – FACING E
CAPROCK LAYER ~0.5 M TO 1.5 M THICK

PREVELLY PR4 Hazard ID: PR4-40

$R_{DI} = 1.2 \times 10^{-6}$	$R_{SOC} = 8.3 \times 10^{-7}$	$R_{CI} = 8.3 \times 10^{-4}$

Description: Overhang of up to ~1.5 m of up to ~0.5 m thick caprock layer overlying zone of depletion. The main hazard is associated with recreational users entering the cave-like formation produced by the overhang.

Preliminary Mitigation Options:

- Install a larger cliff collapse hazard sign at the entrance to the overhang and continue monitoring every 3 years OR;
- Block up the overhang with a cemented wall to prevent entrance beneath the overhang and provide support and continue monitoring every 5 years.

PREVELLY PR4 Hazard ID: PR4-100 **HIGH PRIORITY ROCKFALL HAZARD**

$R_{DI} = 2.1 \times 10^{-5}$	$R_{SOC} = 1.4 \times 10^{-5}$	$R_{CI} = 7.1 \times 10^{-3}$

Description: This hazard contains both a semi-detached block a rock overhang of up to ~4 m with a 0.5 m thick caprock layer overlying zone of depletion. The semi-detached block may be helping to support the overhang and vice versa. It is likely that if one fails they will both fail. It is considered unlikely that the semi-detached block or overhang material will reach the beach in event of failure. However, it is likely that spectators or surfing competitions or visiting recreational users may stand on top of the overhang and a collapse hazard could result in significant injury.

Preliminary Mitigation Options:

- Install large cliff collapse hazard sign at the entrance to the coastal walkway and at an offset distance of 5 m from the top of the overhang warning users to stick to existing paths, away from cliffs and out of fenced off areas and continue monitoring annually OR;
- Remove the overhang by blasting or hydraulic jacking OR;
- Attempt to support overhang with man-made structure, slope stabilisation design required for both short-term construction stability and long term slope stability.

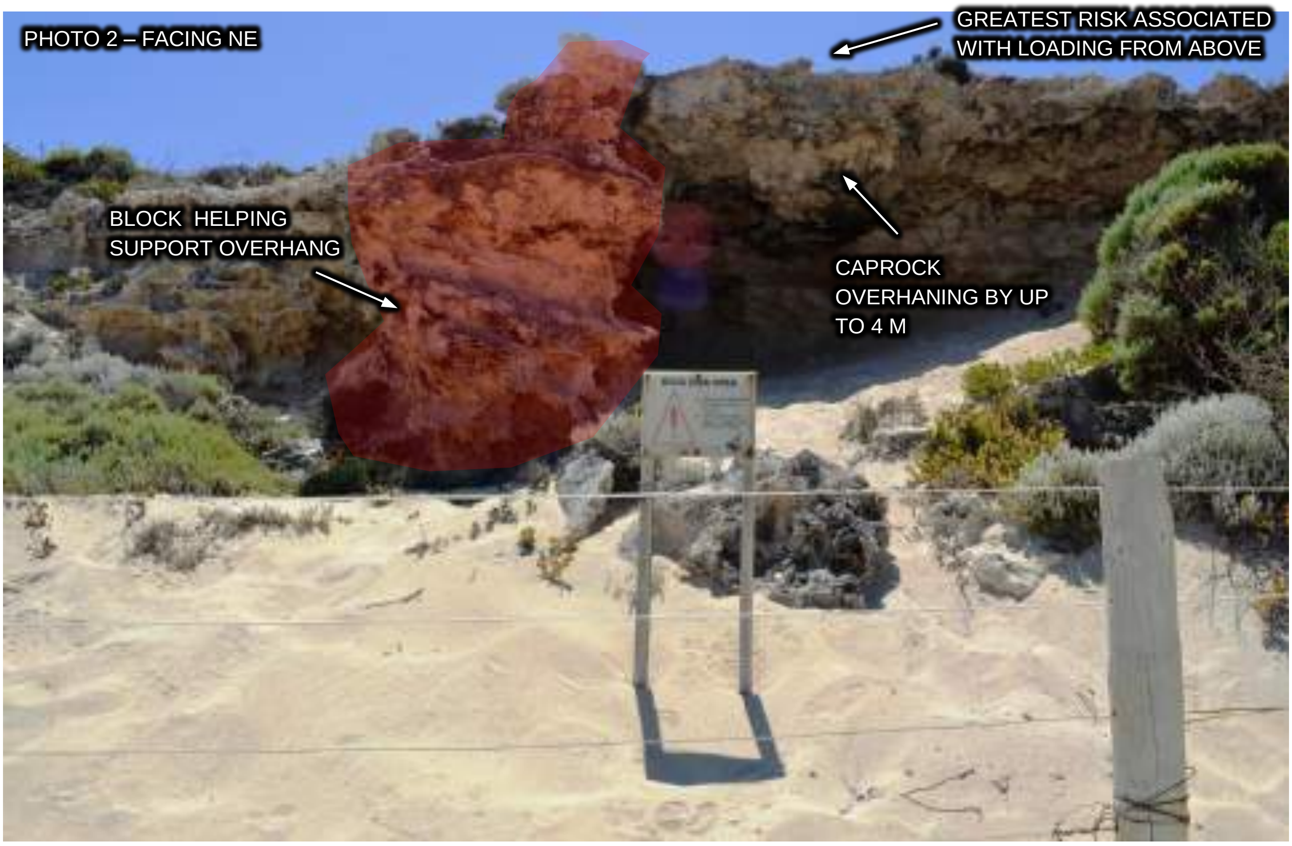


PHOTO 2 – FACING NE
GREATEST RISK ASSOCIATED WITH LOADING FROM ABOVE
BLOCK HELPING SUPPORT OVERHANG
CAPROCK OVERHANING BY UP TO 4 M


PHOTO 3 – FACING E
BLOCK HELPING SUPPORT OVERHANG COULD TOPPLE OUT TOWARD BEACH IF OVERHANG FAILS

PREVELLY PR5 Hazard ID: PR5-50

$R_{DI} = 1.8 \times 10^{-6}$	$R_{SOC} = 1.2 \times 10^{-6}$	$R_{CI} = 3.0 \times 10^{-4}$

Description: Overhang of up to ~2.5 m with a 0.5 m thick caprock layer overlying zone of depletion. The overhang is up to approximately 5 m above beach level. Collapse could seriously injure or kill recreational users who may be stood on top of the overhang or sitting below it.

Preliminary Mitigation Options:
Install large cliff collapse hazard sign at an offset distance of 5 m from the top of the overhang warning users to stick to existing paths, away from cliffs and out of fenced off areas and continue monitoring every 3 years.

PREVELLY PR5 Hazard ID: PR5-150

$R_{DI} = 1.5 \times 10^{-6}$	$R_{SOC} = 1.0 \times 10^{-6}$	$R_{CI} = 2.5 \times 10^{-4}$

Description: Overhanging rock platform that is significantly undercut in places (not measured) and may collapse. Although most recreational users for the area will never access this location, fisherman and coastal walkers are likely to pass over the area regularly.

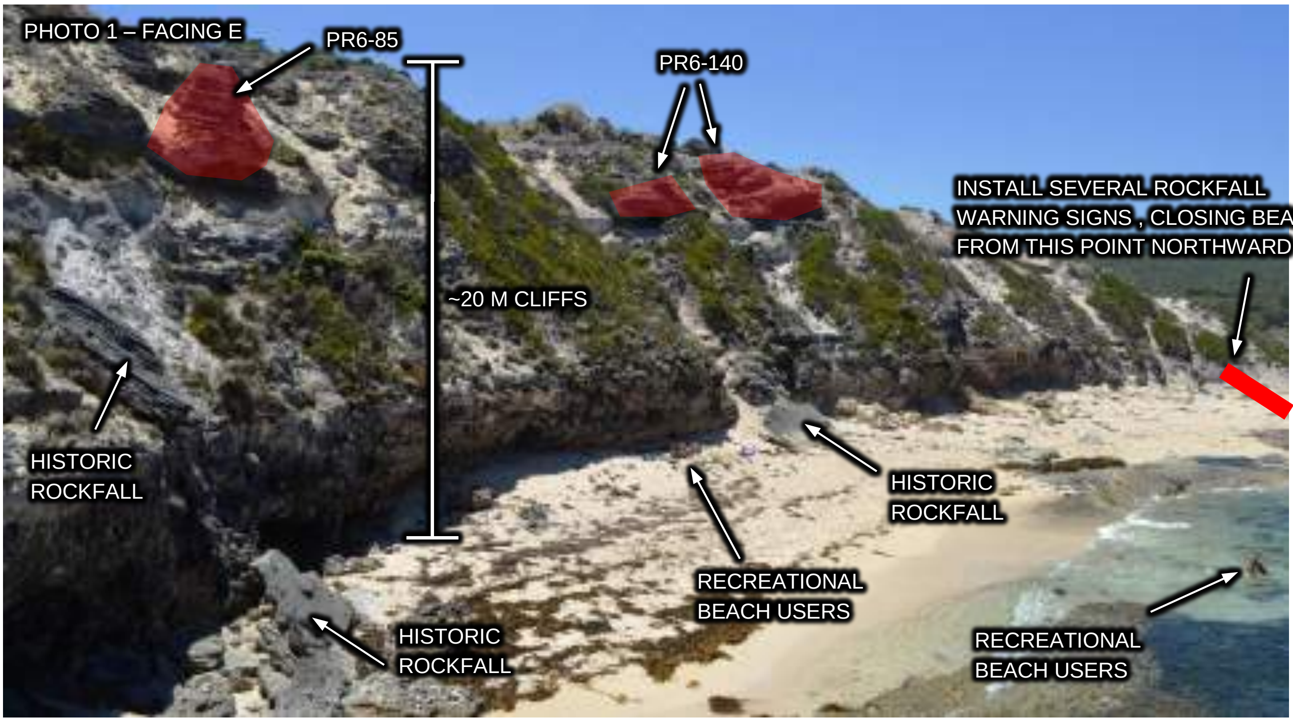
Preliminary Mitigation Options: Place rockfall warning signage on approach paths, continue monitoring every 3 years.

PREVELLY PR6 Hazard ID: PR6-85 **HIGH PRIORITY ROCKFALL HAZARD**

$R_{DI} = 6.3 \times 10^{-6}$	$R_{SOC} = 4.2 \times 10^{-6}$	$R_{CI} = 3.2 \times 10^{-3}$

Description: Large semi-detached limestone block sitting high above beach level in an area containing other historic rockfall apparently originating from the same rock level in the geological profile. Significant relief fractures extending behind the feature were noted during inspection. Rockfall is considered imminent (1 to 10 years).

Preliminary Mitigation Options: Close the beach to recreational users by way of a significant increase in rockfall signage where the footpath from Surfers Point Road and Prevelly recreational area exit onto Prevelly Beach (see picture below) and continue monitoring annually.



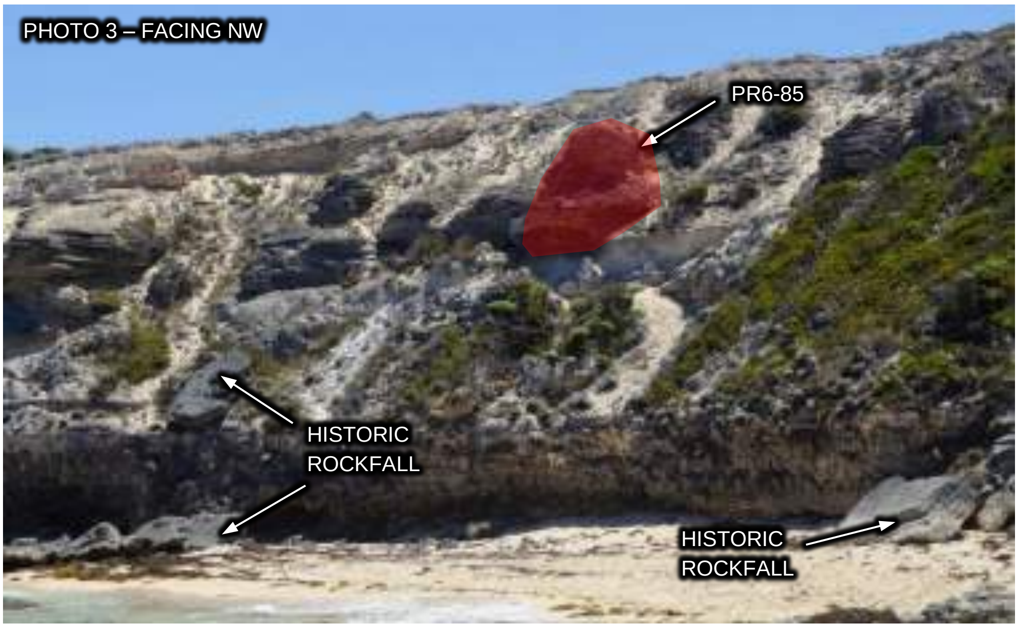



PHOTO 2 – FACING E
BLOCK OF CONCERN
POTENTIAL RELIEF
FRACTUES
UNDERCUTTING
ALONG PALEOSOL

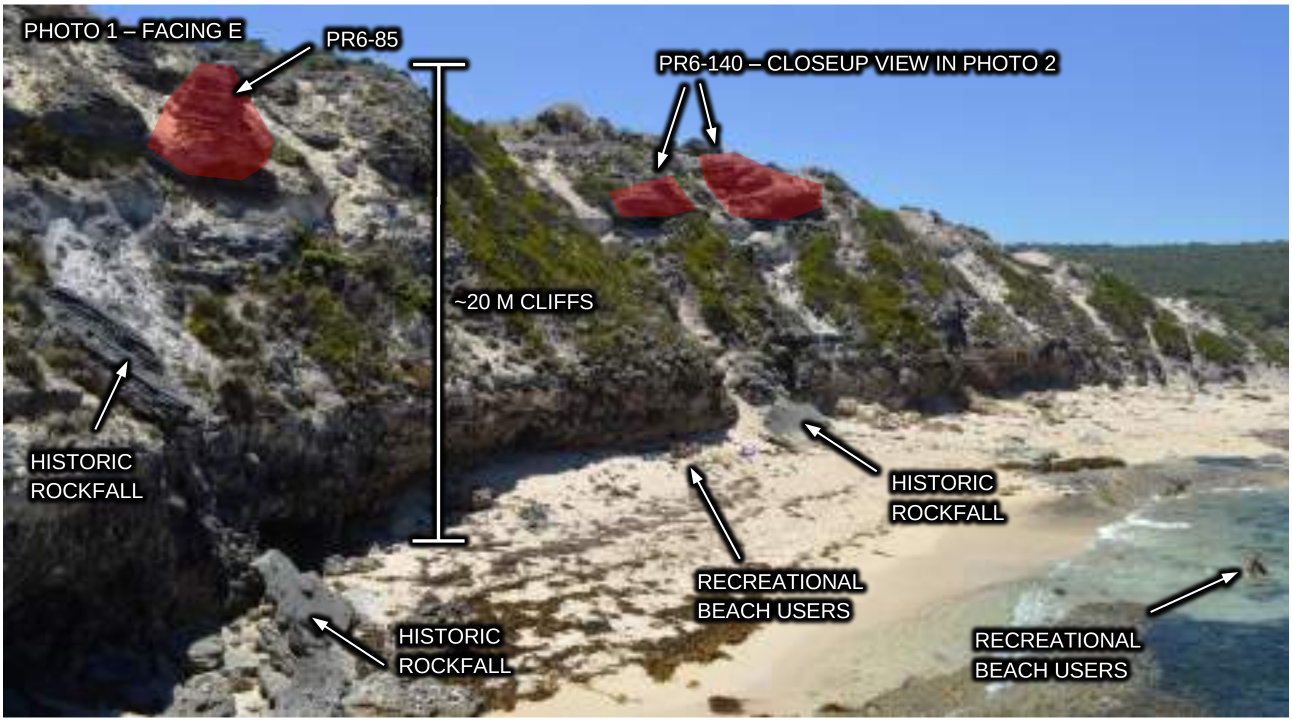

PHOTO 4 – FACING SW
SIDE VIEW OF P6-85
OPEN RELIEF
FRACTURES NOTED
DURING INSPECTION

PREVELLY PR6 Hazard ID: PR6-140

$R_{DI} = 5.8 \times 10^{-7}$	$R_{SOC} = 3.9 \times 10^{-7}$	$R_{CI} = 2.9 \times 10^{-4}$

Description: Large limestone blocks and slabs becoming undercut high above beach level in an area containing other historic rockfall apparently originating from the same rock level in the geological profile.

Preliminary Mitigation Options: Close the beach to recreational users by way of a significant increase in rockfall signage where the footpath from Surfers Point Road and Prevelly recreational area exit onto Prevelly Beach (see picture below) and continue monitoring annually.



GNARABUP GN1 Hazard ID: GN1-25

$R_{DI} = 9.6 \times 10^{-8}$	$R_{SOC} = 6.4 \times 10^{-8}$	$R_{CI} = 6.4 \times 10^{-5}$

Description: Various areas of overhanging bedded eolianite, failure could results in rockfall reaching the beach.

Preliminary Mitigation Options: Place large rockfall warning sign to keep clear and do not linger below these cliffs, continue monitoring (every 3 years).

GNARABUP GN1 Hazard ID: GN1-50

$R_{DI} = 2.0 \times 10^{-7}$	$R_{SOC} = 1.3 \times 10^{-7}$	$R_{CI} = 1.3 \times 10^{-4}$

Description: Various overlying pieces of bedded eolianite with a small debris fan and rockfall chute from historic rockfall observed during inspection.

Preliminary Mitigation Options:

- Continue to monitor every 3 years AND;
- Install rockfall hazard signs either side of hazard (on approaches) and on exit from stairs onto beach.

GNARABUP GN3 Hazard ID: GN3-40

$R_{DI} = 4.6 \times 10^{-6}$	$R_{SOC} = 3.1 \times 10^{-6}$	$R_{CI} = 7.6 \times 10^{-4}$

Description: Overhanging rock platform with significant undercut of up to ~5 m. The hazard is associated with collapse of the shelf while standing on top of it. Relief fractures were noted in the platform and historic rockfall are present adjacent to the hazard.

Preliminary Mitigation Options:

- Continue to monitor every 3 years AND;
- Install rockfall hazard signs either side of hazard (on approaches) and on exit from stairs onto beach.

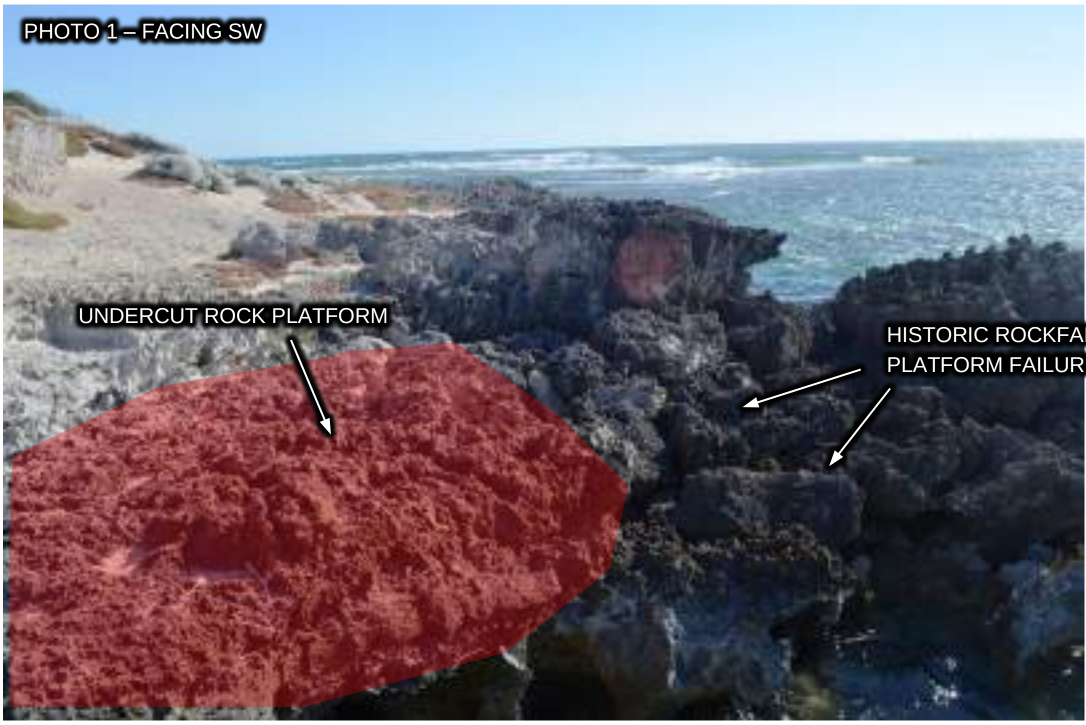



PHOTO 3 – FACING DOWN
RELIEF FRACTURE IN
UNDERCUT ROCK PLATFORM


PHOTO 4 – FACING DOWN
RELIEF FRACTURE IN
UNDERCUT ROCK PLATFORM


PHOTO 5 – FACING DOWN
RELIEF FRACTURE IN
UNDERCUT ROCK PLATFORM

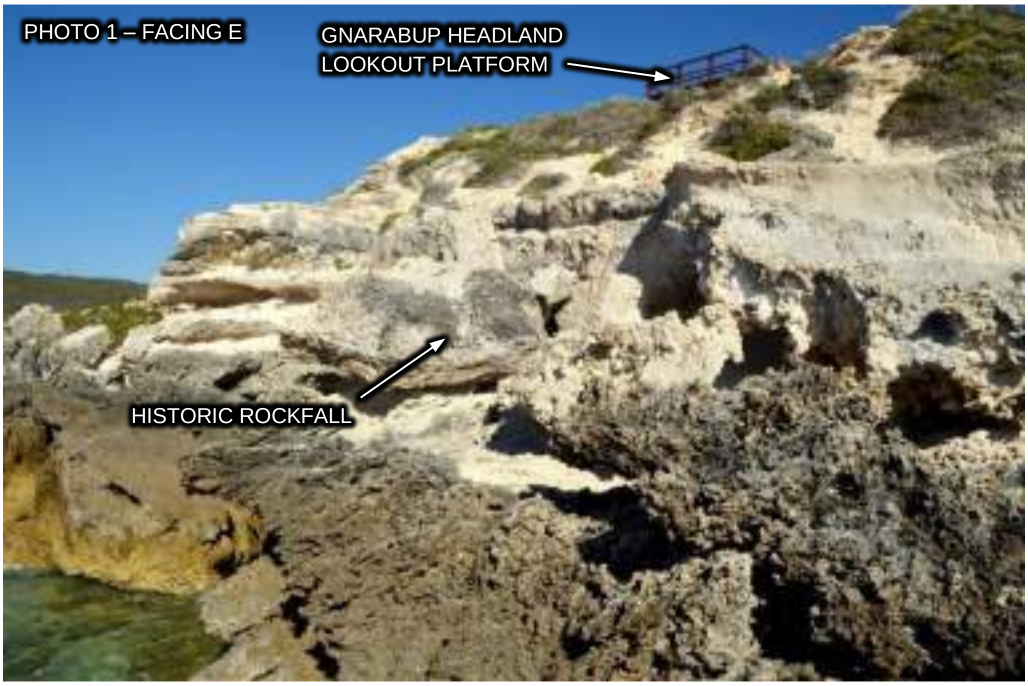
GNARABUP GN3 Hazard ID: GN3-90

$R_{DI} = 1.5 \times 10^{-6}$	$R_{SOC} = 1.0 \times 10^{-6}$	$R_{CI} = 5.1 \times 10^{-4}$

Description: Up to 5 m of undercutting in the cliffs below the Gnarabup Headland Lookout Platform. Historic rockfall was observed around the hazard. Although collapse of the undercut area may not immediately affect the lookout platform it may affect creational users walking around the headland.

Preliminary Mitigation Options:

- Install large rockfall warning sign at the lookout warning users to keep to established paths and do not approach cliff edge AND;
- Continue monitoring every 3 years.



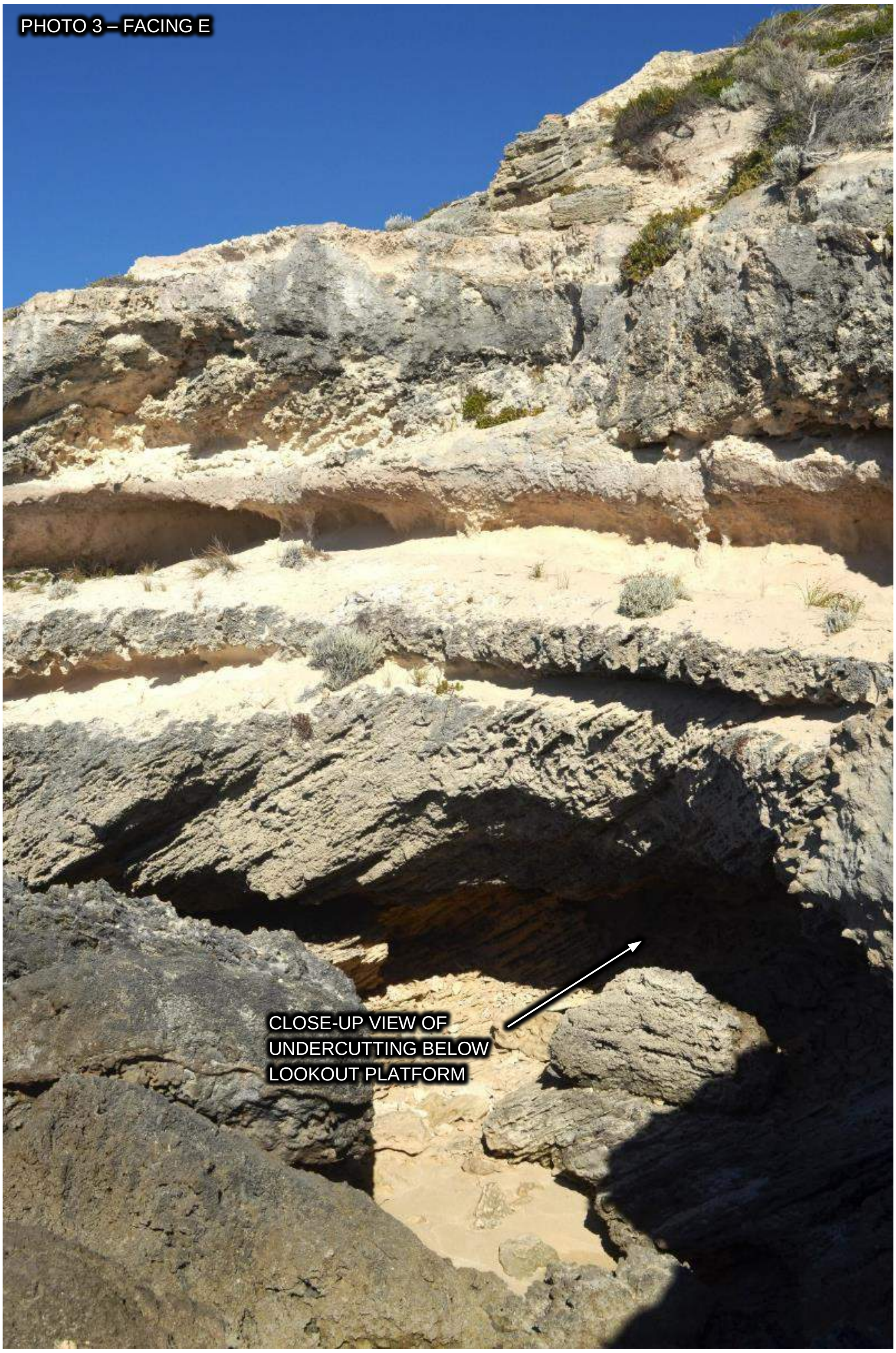


PHOTO 3 – FACING E
CLOSE-UP VIEW OF
UNDERCUTTING BELOW
LOOKOUT PLATFORM

GNARABUP GN3 Hazard ID: GN3-100

$R_{DI} = 9.7 \times 10^{-7}$	$R_{SOC} = 6.5 \times 10^{-7}$	$R_{CI} = 6.5 \times 10^{-4}$

Description: Cave present due to undercutting in steeply dipping friable bedded eolianite. Although significant sized failure may not occur until the cave is further developed, smaller rockfall from the roof during cave development may still cause injury or death to recreational users deciding to enter the cave.

Preliminary Mitigation Options:

- Install large rockfall warning sign at the end of Gnarabup beach warning users to keep away from vertical cliff faces AND;
- Continue monitoring every 3 years.

GNARABUP GN5 Hazard ID: GN5-5

$R_{DI} = 5.4 \times 10^{-6}$	$R_{SOC} = 3.6 \times 10^{-6}$	$R_{CI} = 2.5 \times 10^{-2}$

Description: Overhang of up to 2.5 m developed beneath a caprock layer up to ~1 m thick. Stairs leading down to the White Elephant Café from the upper car park area are built directly on top of the overhang. The hazard at this location is largely associated with collapse of the overhang while recreational users are using the stairs

Preliminary Mitigation Options:

- Complete further investigation and stability analysis AND;
- Continue monitoring annually AND;
- Depending on the results of the stability analysis construct additional support for the overhang sections.

Hazard ID: GN5-30

$R_{DI} = 6.9 \times 10^{-7}$	$R_{SOC} = 4.6 \times 10^{-7}$	$R_{CI} = 3.2 \times 10^{-3}$

Description: Small overhang (not measured) above the White Elephant Café and the stairs leading down from the upper car park. A large limestone block from historic rockfall is located at the base of the stairs.

Preliminary Mitigation Options:

- Continue monitoring every 3 years AND;
- Do not allow any further development from the White Elephant Café below this area OR;
- Remove the overhanging section of the rock mass.

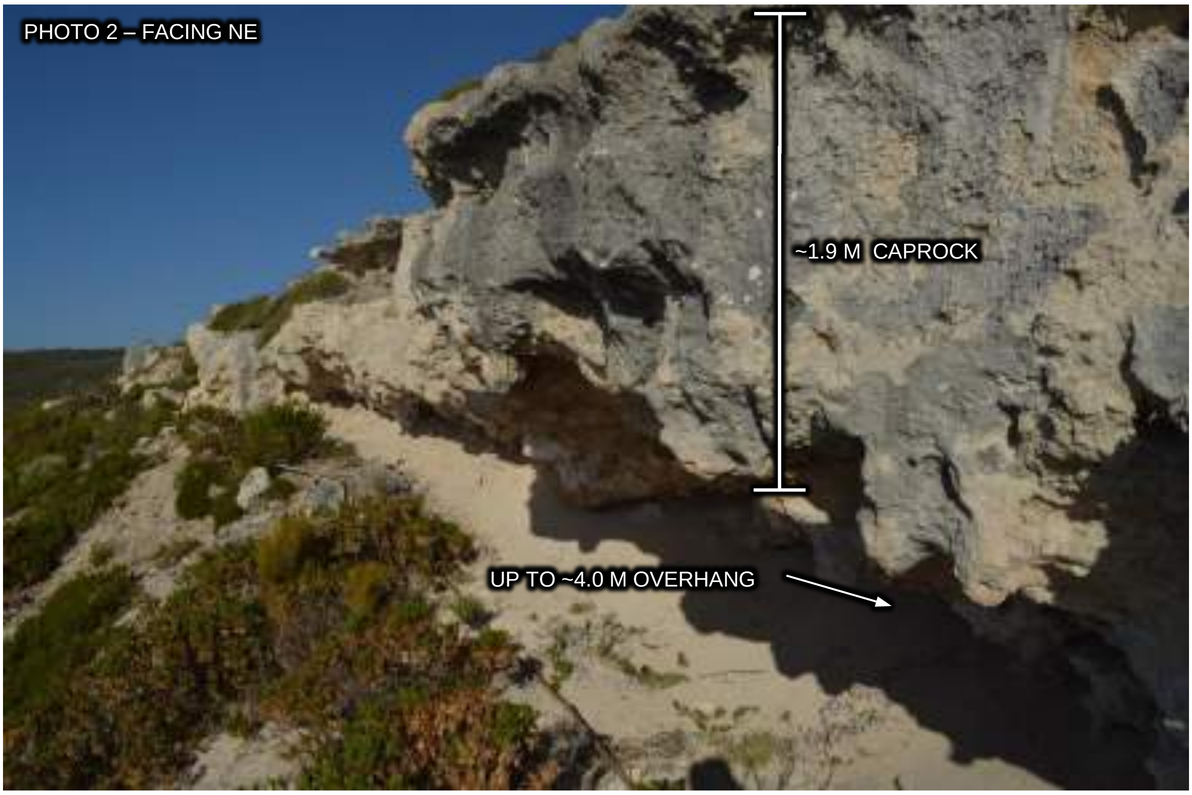
Hazard ID: GN5-100

$R_{DI} = 7.6 \times 10^{-7}$	$R_{SOC} = 5.0 \times 10^{-7}$	$R_{CI} = 3.5 \times 10^{-3}$

Description: Overhang of up to ~4 m with a 1.9 m caprock layer underlain by a zone of depletion. Although historic rockfall adjacent to the overhang do not appear to have reach the level of the car park, it is unclear if boulders may have been moved during car park construction. Significant rockfall from this area may roll down the relatively steep slope below this overhang and reach the car park.

Preliminary Mitigation Options:

- Install rockfall warning signs below the rockfall hazard cautioning people from lingering below the cliff face and continue monitoring every 3 years OR;
- Remove the overhanging section of the rock face OR;
- Attempt to support overhang with man-made structure, slope stabilisation design required for both short-term construction stability and long term slope stability.



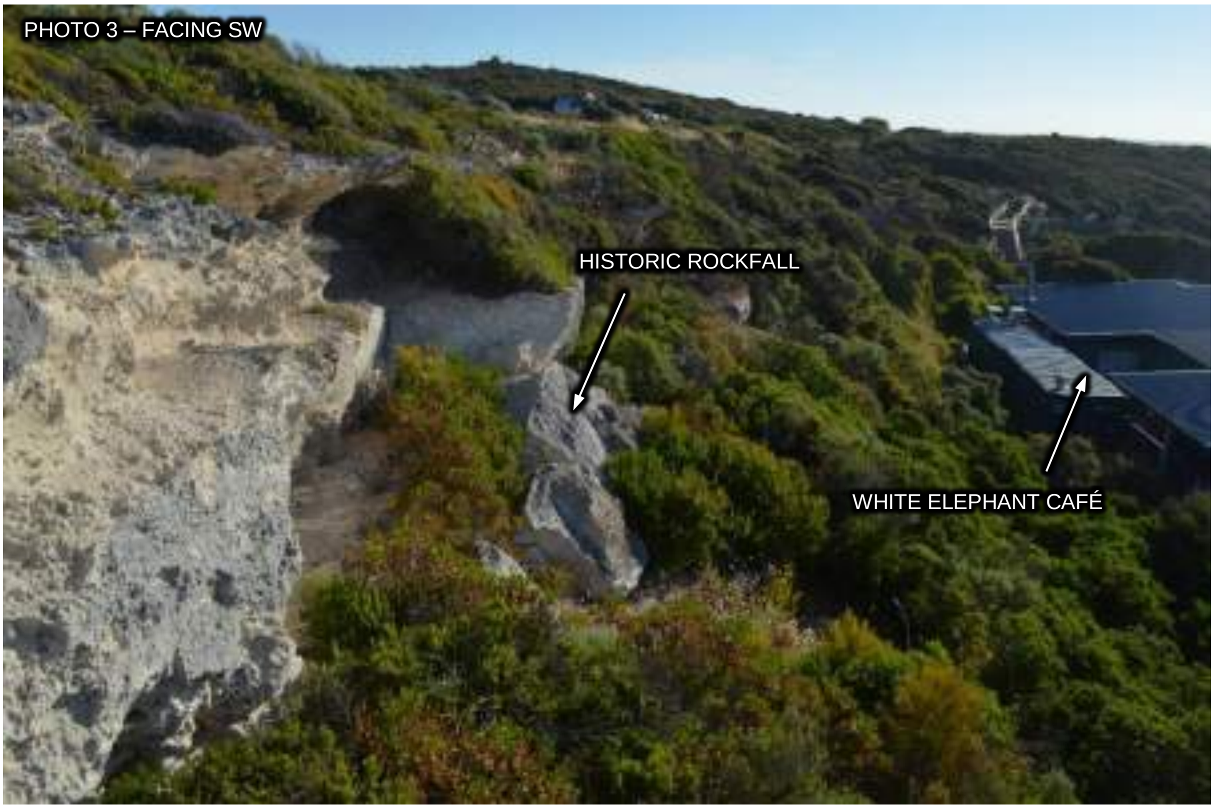


PHOTO 3 – FACING SW
HISTORIC ROCKFALL
WHITE ELEPHANT CAFÉ


PHOTO 4 – FACING SW

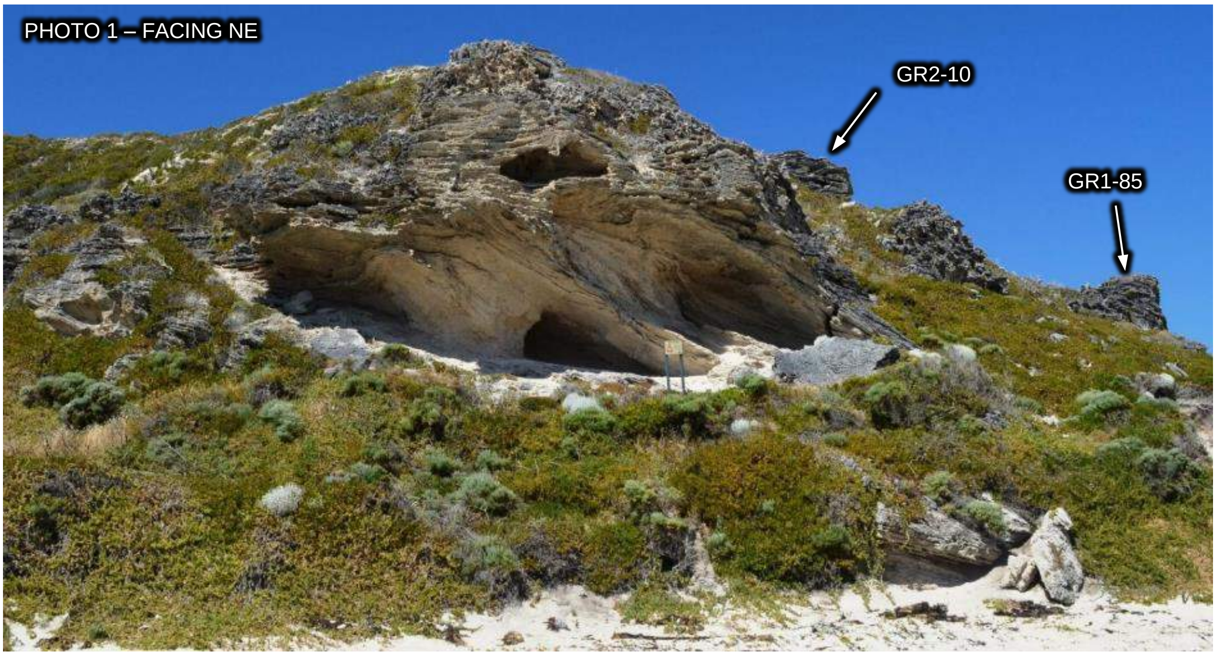
GRUNTERS GR1 Hazard ID: GR1-85

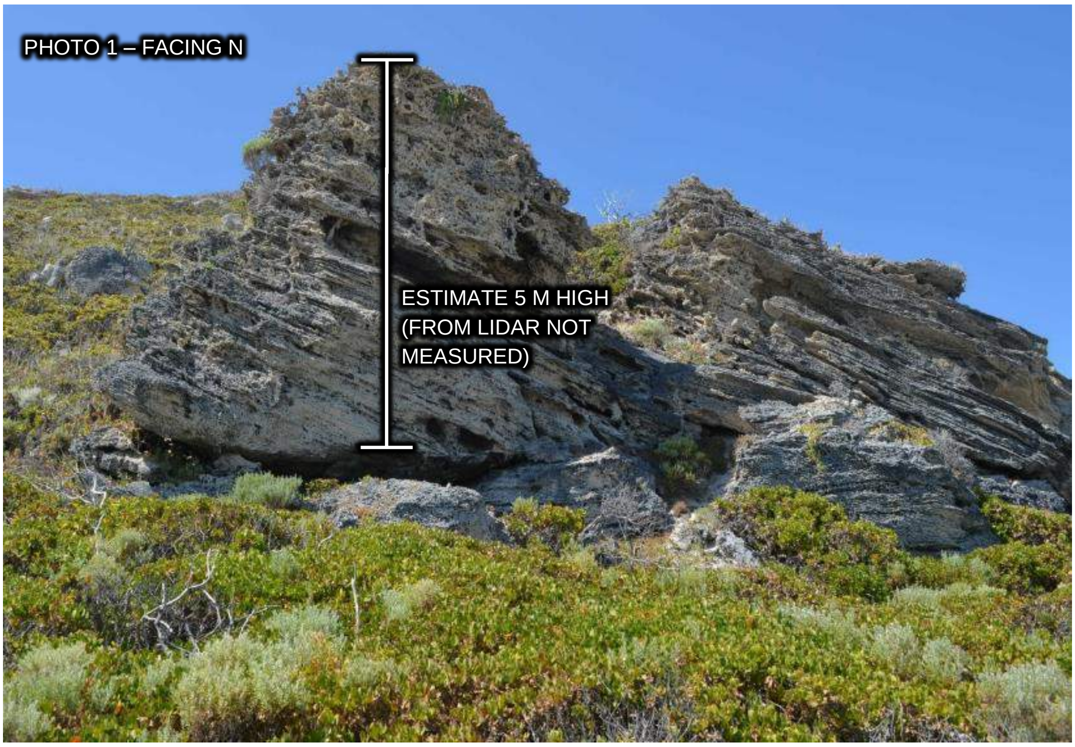
$R_{DI} = 7.8 \times 10^{-8}$	$R_{SOC} = 5.2 \times 10^{-8}$	$R_{CI} = 5.2 \times 10^{-5}$

Description: Large limestone block being undercut by wind erosion. If failure were to occur it is likely that sand dunes beneath the block would prevent impact to recreational users.

Preliminary Mitigation Options:

- Install rockfall warning sign on coastal walkway warning users to stay on established tracks AND
- Continue monitoring every 3 years.



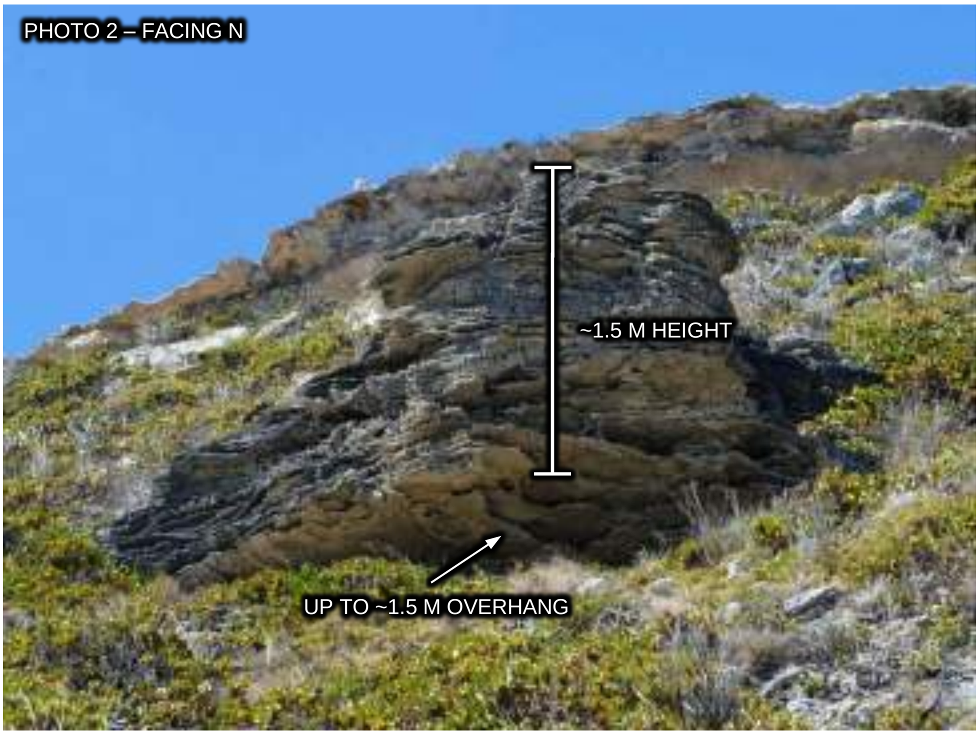


GRUNTERS GR2 Hazard ID: GR2-10

$R_{DI} = 1.3 \times 10^{-7}$	$R_{SOC} = 8.9 \times 10^{-8}$	$R_{CI} = 8.9 \times 10^{-5}$

Description: Undercut bedded eolianite sitting above a steep slope leading down to sandy beach. Significant failure here would likely reach the beach as the slope is steep (>45°) and there are no protective dunes to catch rockfall

Preliminary Mitigation Options: Install large warning signs at hazard to prevent people from approaching or sitting and lying on the beach below the hazard and continue monitoring every 3 years.



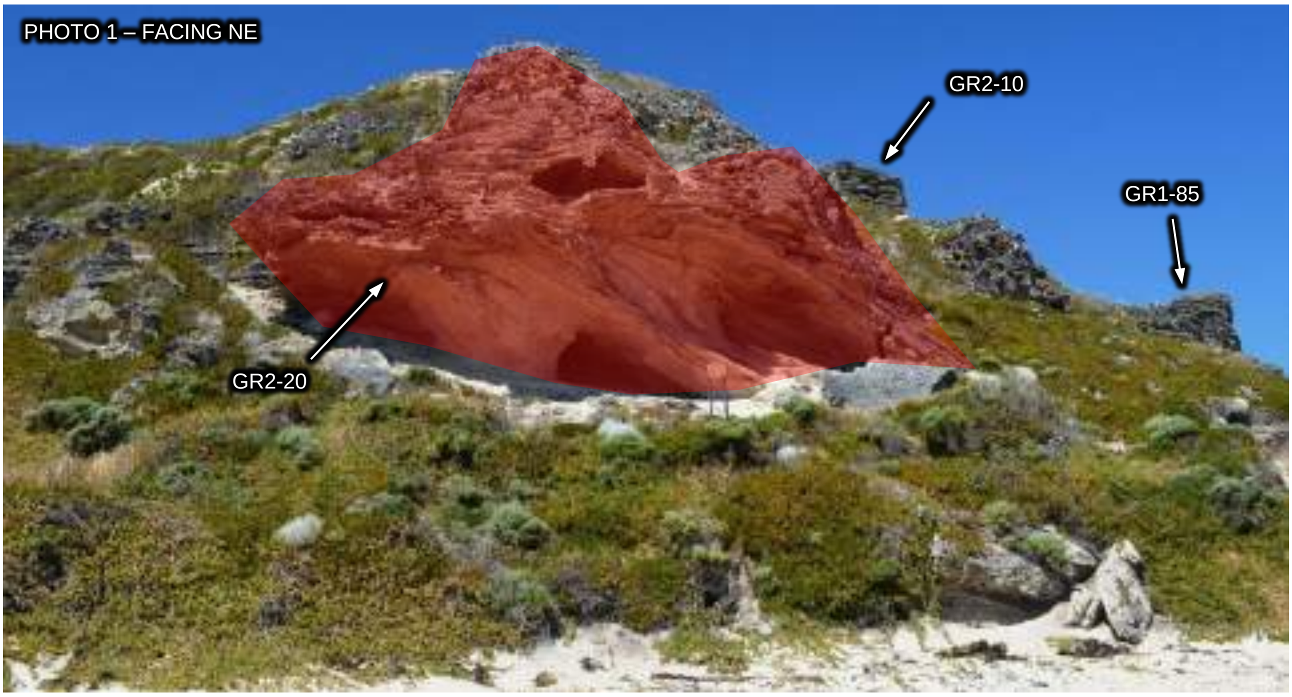
GRUNTERS GR2 Hazard ID: GR2-20 **HIGH PRIORITY ROCKFALL HAZARD**

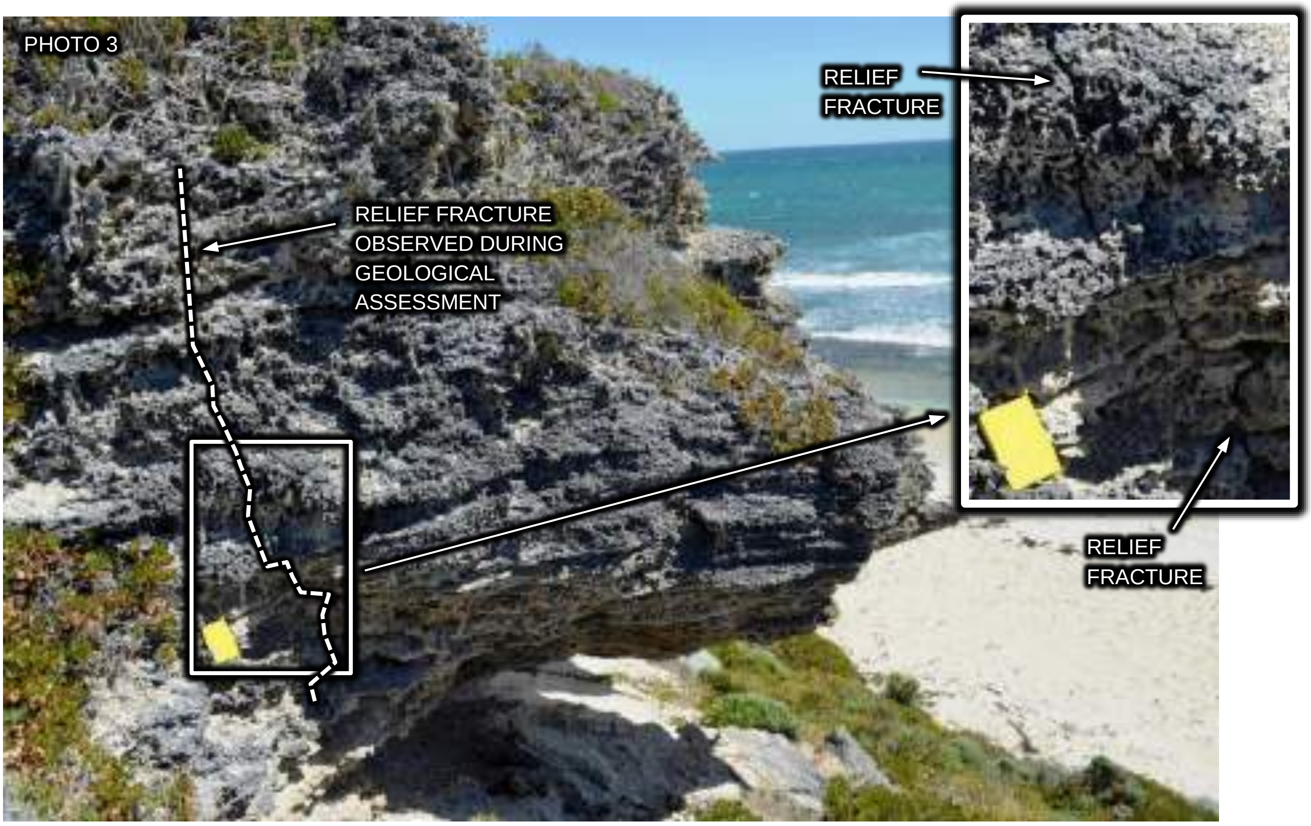
$R_{DI} = 6.2 \times 10^{-6}$	$R_{SOC} = 4.1 \times 10^{-6}$	$R_{CI} = 4.1 \times 10^{-3}$

Description: Large limestone outcrop with multiple caves developed along steeply dipping eolianite. Relief fractures noted in the North side of the outcrop may extend a significant distance behind the rock mass. Hazards associated with large slab failures from cave roofs and overall instability in the outcrop.

Preliminary Mitigation Options:

- Install large rockfall hazard warning signs on the beach below the feature indicating recreational users should keep out of caves and warn against lingering below these cliffs AND;
- Continue monitoring every 3 years.





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Location			Gracetown										
Hazard ID	Min	Max	GC1-25	GC1-50	GC2-25	GC2-85	GC2-100	GC3-50	GC4-60	GC5-75	GC6-15	GC6-60	GC6-100
Main Hazard Type Assessed			Rockfall	Rockfall	Rockfall	Rockfall	Rockfall	Rockfall	Rockfall	Rockfall	Collapse	Rockfall	Rockfall
R_{DI}	**7.8E-08**	**2.1E-05**	**6.0E-07**	**3.4E-07**	**2.4E-07**	**4.6E-07**	**3.3E-07**	**2.3E-06**	**6.1E-07**	**5.9E-07**	**2.1E-05**	**2.4E-06**	**8.0E-07**
$P_{(H)}$ =	5.0E-02	2.0E-01	5.0E-02	5.0E-02	5.0E-02	5.0E-02	1.0E-01	5.0E-02	1.0E-01	5.0E-02	2.0E-01	1.0E-01	5.0E-02
$P_{(S:H)}$ =	3.6E-03	5.0E-01	5.6E-02	3.1E-02	2.3E-02	4.3E-02	1.6E-02	2.2E-01	2.8E-02	5.5E-02	5.0E-01	1.1E-01	7.4E-02
$P_{(T:S)}$ =	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05
$V_{(D:T)}$ =	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
N	15	15	15	15	15	15	15	15	15	15	15	15	15
R_{SOC}	**5.2E-08**	**1.4E-05**	**4.0E-07**	**2.2E-07**	**1.6E-07**	**3.1E-07**	**2.2E-07**	**1.6E-06**	**4.0E-07**	**3.9E-07**	**1.4E-05**	**1.6E-06**	**5.3E-07**
Total individual visitors per day in a year =	10	10	10	10	10	10	10	10	10	10	10	10	10
R_{CI}	**5.2E-05**	**7.1E-02**	**2.0E-04**	**1.1E-04**	**8.1E-05**	**1.5E-04**	**1.1E-04**	**1.6E-03**	**4.0E-04**	**2.0E-03**	**7.1E-02**	**8.1E-04**	**2.7E-04**
N_T - total number of individuals visiting the site each year (assuming no repeat visits) =	2500	70000	5000	5000	5000	5000	5000	10000	10000	50000	50000	5000	5000
Total individual visotrs per day in a year =	7	192	14	14	14	14	14	27	27	137	137	14	14
Risk Variable Breakdown													
P_H													
Return Interval for Rockfall (once every **?** Yrs) =	5	20	20	20	20	20	10	20	10	20	5	10	20
$P_{S:H}$													
Length of Trajectory where people could be impacted (m) if rockfall is main hazard =	5	25	11	13	13	5	10	18	10	10	NA	12	12
Width of Block (m) =	0.5	20	3	3	3	5	2	20	4	5	NA	15	10
Potential Impact Area (m2) =	3	375	33	39	39	25	20	360	40	50	NA	180	120
% of Trajectory where humans could be impacted that gets hit by rockfall or affected by collapse =	0.05	1	50%	50%	50%	40%	50%	70%	50%	50%	NA	50%	50%
Assumed Spatial Impact Area (m2) =	2.2	252	16.5	19.5	19.5	10	10	252	20	25	20	90	60
Assumed Hazard Area (m2) =	30	1151	294	620	862	233	639	1151	706	457	40	790	806
$P_{T:S}$													
Minutes per year =	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600
% Significant Rockfall in Rain =	0.8	0.8	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
% Significant Rockfall in Dry =	0.2	0.2	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Average Time per spend in Rockfall Hazard Area (min) =	60	60	60	60	60	60	60	60	60	60	60	60	60
Time spent in Rockfall Hazard Zone if raining (min) =	5	5	5	5	5	5	5	5	5	5	5	5	5
Time spent in Rockfall Hazard Zone if dry (min) =	55	55	55	55	55	55	55	55	55	55	55	55	55
Weighted Time exposed in rain (min) =	4	4	4	4	4	4	4	4	4	4	4	4	4
Weighted Time exposed in dry (min) =	11	11	11	11	11	11	11	11	11	11	11	11	11
Total Weighted Time Exposed to Rockfall (min) =	15	15	15	15	15	15	15	15	15	15	15	15	15

NOTES:

- An explanation of the variables presented in this table is provided in the main text of the report.
- shows R_{SOC} values exceeding the societal tolerbale risk criteria of $1.0x10^{-3}$
- shows R_{DI} values greater than $1.0x10^{-5}$ and AND/OR R_{CI} values greater than $1.0x10^{-3}$.

Location	Prevelly							
Hazard ID	PR3-165	PR4-30	PR4-40	PR4-100	PR5-50	PR5-150	PR6-85	PR6-140
Main Hazard Type Assessed	Rockfall	Collapse	Rockfall	Collapse	Collapse	Collapse	Rockfall	Rockfall
R_{DI}	**1.5E-06**	**8.6E-06**	**1.2E-06**	**2.1E-05**	**1.8E-06**	**1.5E-06**	**6.3E-06**	**5.8E-07**
$P_{(H)}$ =	1.0E-01	1.0E-01	5.0E-02	2.0E-01	5.0E-02	5.0E-02	2.0E-01	5.0E-02
$P_{(S:H)}$ =	6.8E-02	4.0E-01	1.2E-01	5.0E-01	1.7E-01	1.4E-01	1.5E-01	5.4E-02
$P_{(T:S)}$ =	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05
$V_{(D:T)}$ =	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
N	15	15	15	15	15	15	15	15

R_{SOC}	**9.7E-07**	**5.7E-06**	**8.3E-07**	**1.4E-05**	**1.2E-06**	**1.0E-06**	**4.2E-06**	**3.9E-07**
Total individual visitors per day in a year =	10	10	10	10	10	10	10	10

R_{CI}	**1.5E-03**	**4.0E-02**	**8.3E-04**	**7.1E-03**	**3.0E-04**	**2.5E-04**	**3.2E-03**	**2.9E-04**
N_T - total number of individuals visiting the site each year (assuming no repeat visits) =	15000	70000	10000	5000	2500	2500	7500	7500
Total individual visiotrs per day in a year =	41	192	27	14	7	7	21	21

Risk Variable Breakdown								
P_H								
Return Interval for Rockfall (once every **?** Yrs) =	10	10	20	5	20	20	5	20
$P_{S:H}$								
Length of Trajectory where people could be impacted (m) if rockfall is main hazard =	16	NA	5	NA	NA	NA	12	16
Width of Block (m) =	3	NA	2	NA	NA	NA	10	4
Potential Impact Area (m2) =	48	NA	10	NA	NA	NA	120	64
% of Trajectory where humans could be impacted that gets hit by rockfall or affected by collapse =	75%	NA	100%	NA	NA	NA	60%	60%
Assumed Spatial Impact Area (m2) =	36	20	10	20	10	10	72	38.4
Assumed Hazard Area (m2) =	529	50	86	40	60	70	488	707
$P_{T:S}$								
Minutes per year =	525600	525600	525600	525600	525600	525600	525600	525600
% Significant Rockfall in Rain =	80%	80%	80%	80%	80%	80%	80%	80%
% Significant Rockfall in Dry =	20%	20%	20%	20%	20%	20%	20%	20%
Average Time per spend in Rockfall Hazard Area (min) =	60	60	60	60	60	60	60	60
Time spent in Rockfall Hazard Zone if raining (min) =	5	5	5	5	5	5	5	5
Time spent in Rockfall Hazard Zone if dry (min) =	55	55	55	55	55	55	55	55
Weighted Time exposed in rain (min) =	4	4	4	4	4	4	4	4
Weighted Time exposed in dry (min) =	11	11	11	11	11	11	11	11
Total Weighted Time Exposed to Rockfall (min) =	15	15	15	15	15	15	15	15

NOTES:

- An explanation of the variables presented in this table is provided in the main text of the report.
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- shows values exceeding $1.0x10^{-3}$ to highlight areas with particularly higher user numbers

Location	Gnarabup								Grunters			Wallcliffe
Hazard ID	**GN1-25**	**GN1-50**	**GN3-40**	**GN3-90**	**GN3-100**	**GN5-5**	**GN5-30**	**GN5-100**	**GR1-85**	**GR2-10**	**GR2-20**	
Main Hazard Type Assessed	Rockfall	Rockfall	Collapse	Collapse	Rockfall	Collapse	Rockfall	Rockfall	Rockfall	Rockfall	Rockfall	Rockfall
R_{DI}	**9.6E-08**	**2.0E-07**	**4.6E-06**	**1.5E-06**	**9.7E-07**	**5.4E-06**	**6.9E-07**	**7.6E-07**	**7.8E-08**	**1.3E-07**	**6.2E-06**	**3.3E-08**
$P_{(H)}$ =	5.0E-02	5.0E-02	1.0E-01	1.0E-01	5.0E-02	5.0E-02	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-02
$P_{(S:H)}$ =	9.0E-03	1.9E-02	2.1E-01	7.1E-02	9.1E-02	5.0E-01	3.2E-02	3.5E-02	3.6E-03	6.2E-03	2.9E-01	1.6E-02
$P_{(T:S)}$ =	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05	2.9E-05
$V_{(D:T)}$ =	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
N	15	15	15	15	15	15	15	15	15	15	15	15
R_{SOC}	**6.4E-08**	**1.3E-07**	**3.1E-06**	**1.0E-06**	**6.5E-07**	**3.6E-06**	**4.6E-07**	**5.0E-07**	**5.2E-08**	**8.9E-08**	**4.1E-06**	**2.2E-08**
Total individual visitors per day in a year =	10	10	10	10	10	10	10	10	10	10	10	10
R_{CI}	**6.4E-05**	**1.3E-04**	**7.6E-04**	**5.1E-04**	**6.5E-04**	**2.5E-02**	**3.2E-03**	**3.5E-03**	**5.2E-05**	**8.9E-05**	**4.1E-03**	**2.2E-06**
N_T - total number of individuals visiting the site each year (assuming no repeat visits) =	10000	10000	2500	5000	10000	70000	70000	70000	10000	10000	10000	1000
Total individual visotrs per day in a year =	27	27	7	14	27	192	192	192	27	27	27	3
Risk Variable Breakdown												
P_H												
Return Interval for Rockfall (once every **?** Yrs) =	20	20	10	10	20	20	10	10	10	10	10	100
$P_{S:H}$												
Length of Trajectory where people could be impacted (m) if rockfall is main hazard =	10	10	NA	NA	6	NA	10	22	11	16	25	25
Width of Block (m) =	3	1	NA	NA	0.5	NA	3	4	4	1	15	3.5
Potential Impact Area (m2) =	30	10	NA	NA	3	NA	30	88	44	16	375	87.5
% of Trajectory where humans could be impacted that gets hit by rockfall or affected by collapse =	25%	80%	NA	NA	100%	NA	20%	25%	5%	30%	50%	100%
Assumed Spatial Impact Area (m2) =	7.5	8	15	15	3	15	6	22	2.2	4.8	187.5	87.5
Assumed Hazard Area (m2) =	833	432	70	211	33	30	187	623	607	771	650	5600
$P_{T:S}$												
Minutes per year =	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600	525600
% Significant Rockfall in Rain =	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
% Significant Rockfall in Dry =	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Average Time per spend in Rockfall Hazard Area (min) =	60	60	60	60	60	60	60	60	60	60	60	60
Time spent in Rockfall Hazard Zone if raining (min) =	5	5	5	5	5	5	5	5	5	5	5	5
Time spent in Rockfall Hazard Zone if dry (min) =	55	55	55	55	55	55	55	55	55	55	55	55
Weighted Time exposed in rain (min) =	4	4	4	4	4	4	4	4	4	4	4	4
Weighted Time exposed in dry (min) =	11	11	11	11	11	11	11	11	11	11	11	11
Total Weighted Time Exposed to Rockfall (min) =	15	15	15	15	15	15	15	15	15	15	15	15

NOTES:

- An explanation of the variables presented in this table is provided in the main text of the report.
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- shows values exceeding 1.0×10^{-3} to highlight areas with particularly higher user numbers

APPENDIX D

Risk Register for Shire Assets

Asset ID	Brief Asset Description	Potential Damage[1]	Assumed Asset Damaged	Assumed Total Asset Cost ($)[2]	Assumed Cost to Repair or Replace ($)	Risk Category
GCA_1	DPAW South Point Stairs and Walkway	The vast majority of the asset may be damaged (80%) including key foundation elements, and we have assumed complete replacement would be required	100%	$250,000	$250,000	Medium
GCA_2	Huzza Cliffs Memorial	The majority of structure is within hazard zone and may be damaged. However the memorial could possibly be moved at less cost than a rebuild. We have assumed 1/2 cost of replacement for relocation.	50%	$50,000	$25,000	Low
GCA_3	Access Road to South Point	A small section of road approximately 30 m in length (<5% of road length) may be damaged. Limestone track, replacement cost is the cost of vegetation clearing and compaction assuming land purchase is not required.	5%	$20,000	$1,000	Low
GCA_4	Volunteers Rest and Access Path to South Point Car Park	A small section of a bush, sand track and all of the Volunteers Rest Area may be damaged. Assumed replacement would require vegetation clearing, minimal cost.	50%	$2,000	$1,000	Low
GCA_5	South Point Stairs	The entire asset is within the hazard zone and may be damaged. It is assumed that complete replacement would be required.	100%	$280,000	$280,000	Medium
GCA_6	South Point Car Park	The northern 2 to 3 m of car park is within the hazard zone and may be damaged. If any of the area is damaged the 12 parking spaces on the northern side of the car park may need to be abandoned due to the potential proximity to a cliff edge. 12 parking spaces represent approximately 30% of the spaces available. We have assumed land for new parking space is already available and therefore replacement of the 12 car parking spaces would be 30% of the total parking area cost.	30%	$105,000	$31,500	Low
GCA_7	Stairs to Picnic Area	A set of stone stairs leading down to a car park and picnic area. Approximately 90% of the stairs are within the hazard zone and may be damaged.	90%	$25,000	$22,500	Low
GNA_1	Stairs	The entire asset is within the hazard zone and may be damaged. It is assumed that complete replacement would be required.	100%	$75,000	$75,000	Low
GNA_2	Gnarabup Headland Lookout	The entire asset is within the hazard zone and may be damaged. It is assumed that complete replacement would be required.	100%	$35,000	$35,000	Low
GNA_3	Footpath	Approximately 60 m of sand track (~10% of Gnarabup headland track) is within the hazard zone.	10%	$40,000	$4,000	Low
GNA_4	Path and Stairs to Elephant Cafe	Pathway and stairs leading down to the White Elephant Café from the upper car park may be damaged, however given the sheltered nature of the bay and slope type is has been assumed only 50% of the asset will be damaged.	50%	$240,000	$120,000	Medium
GNA_5	Gnarabup Headland Car Park	11 to 12 parking spaces could be slightly damaged by cliff retreat, we have assumed a cost similar for replacement similar to the 12 spaces at South Point Car Park in Gracetown	NA	NA	$31,500	Low
GNA_6	White Elephant Cafe	The back of the White Elephant Café is within the hazard zone and could be damaged by rockfall from the cliffs behind the café. It is difficult to determine the level of damage and we have conservatively assumed it will be 40% even though a small area of the cafe is in the hazard zone. The area damaged would be the back of the cafe where more expensive kitchen equipment and service connections may be present.	40%	$500,000	$200,000	Medium
GNA_7	White Elephant Car Park	Damage could occur to the White Elephant Car Park if rockfall from the cliffs above the southeast side of the car park were to reach the car park. Around 6 or 7 car parks could be affected however damage would likely only include pavement damage as long as no cars were parked at those places at the time of the theoretical rockfall. The rockfall would require removal and the pavement would need to be repaired so we have assumed a similar cost as for potential damage to 12 car parks at the Gnarabup Headland Car Park.	NA	NA	$31,500	Low

Asset ID	Brief Asset Description	Potential Damage[1]	Assumed Asset Damaged	Assumed Total Asset Cost ($)[2]	Assumed Cost to Repair or Replace ($)	Risk Category
PRA_1	Rivermouth Road Nth End	Approximately 30 m of road and footpath are within the hazard zone and may be damaged. If damaged it is unlikely that the road could be replaced with like for like as some form of retaining structure would be needed or the road would need to be realigned slightly further inland. The cost estimate has therefore assumed the cost will be for a new section of road at a conservative rate of $100/m^2$	300 m^2	NA	$30,000	Low
PRA_2	Rivermouth Road Stairs and BBQ area	The entire stairs and part of the BBQ area are within the hazard zone and may be damaged. Assumed cost is similar to damage of the stairs accessing the back beach from the Gnarabup Headland car park.	NA	NA	$50,000	Low
PRA_3	Rivermouth Road	Approximately 120 m of road and footpath are within the hazard zone and may be damaged. If damaged it is unlikely that the road could be replaced with like for like as some form of retaining structure would be needed or the road would need to be realigned slightly further inland. The cost estimate has therefore assumed the cost will be for a new section of road at a conservative rate of $100/m^2$	700 m^2	NA	$70,000	Low
PRA_4	Stairs and Landscaped Area	The entire stairs and part of the landscaped area are within the hazard zone and may be damaged. Assumed cost is similar to damage of the stairs and BBQ area further north.	NA	NA	$70,000	Low
PRA_5	Car Park	An area of approximately 400 m^2 of footpath and car parks is within the hazard zone and could be damaged. We have a assumed a repair cost of $100/m^2$	400 m^2	NA	$40,000	Low
PRA_6	Footpath and landscaped area	An area of approximately 300 m^2 of footpath and landscaped area is within the hazard zone and could be damaged. We have a assumed a repair cost of $100/m^2$	400 m^2	NA	$30,000	Low
PRA_7	Shade Structure and Footpath	The shaded lookout structure and part of the footpath are within the hazard zone and could be damaged. We have assumed complete replacement is required. An estimate is based on repairing the path at $100/m^2$ and replacing the shelter at $20,000	NA	NA	$50,000	Low
PRA_8	Stairs, bench, walkway	These two assets have been combined to encompass the entire coastal platforms, stairs, walkways and access paths from the Surfers Point Car Park area. It is estimated that approximately 35% of the asset is within the hazard zone.	35%	$557,000	$194,950	Medium
PRA_9	Stairs, Walkway					

NOTES:

1 - Damage is based on damage to the area with the defined hazard zone

2 - Total cost of asset has been roughly estimated from the values presented in CHRMAP (2015) and costs provided by Shire. Where numerous assets have been grouped, an estimate of the asset's individual contribution to the total cost provided has been made.

APPENDIX E

Audit of Cliff Risk Signs

SAMR ID	Current Condition and Comments	Photograph[1]
14	Sign missing, potentially destroyed during construction of White Elephant Café Car Park?	NO PHOTO
21	■ good condition ■ good message ■ a little small ■ needs a rockfall from above graphic ■ needs to be in beach partially blocking access to risk area, or needs a second sign achieving this	
22	■ good condition ■ too small ■ no graphics of hazard	

SAMR ID	Current Condition and Comments	Photograph[1]
42	■ fair condition ■ too small ■ too close to rockfall hazard ■ no graphic of hazard	
56	Sign missing, only placard remains	
57	Sign Missing	NO PHOTO

SAMR ID	Current Condition and Comments	Photograph[1]
77	Sign and placard missing, only timber posts remain	NO PHOTO
91	Sign Missing	NO PHOTO
123	Sign missing, only placard remains ■ no hazard visible at sign or in vicinity ■ need to explain where hazard is located, e.g. rockfall hazard for next 500 m	
125	Not at provided coordinates, located at 114°59’8.67”E, 33°51’53.85”S ■ fair condition ■ not visible to public ■ no graphic of hazard ■ too small ■ no hazard visible at sign or behind it ■ need to explain where hazard is located, e.g. rockfall hazard for next 500 m	

SAMR ID	Current Condition and Comments	Photograph[1]
127	■ not visible to public ■ faded ■ no graphic of hazard ■ too small ■ no hazard visible at sign or behind it ■ need to explain where hazard is located, e.g. rockfall hazard for next 500 m	
153	■ too small ■ faded ■ no graphic of hazard ■ in close proximity to hazard, words too small to read from far	

Golder Associates

SAMR ID	Current Condition and Comments	Photograph[1]
154	■ too small ■ faded and stained ■ no graphic of hazard	
155	Sign Missing	NO PHOTO
156	■ too small ■ faded ■ no graphic of hazard ■ in close proximity to hazard, words too small to read from far ■ people standing directly in front of sign potentially at risk	

SAMR ID	Current Condition and Comments	Photograph[1]
315	Sign missing, only placard remains	
340	■ too small ■ faded ■ no graphic of hazard	

SAMR ID	Current Condition and Comments	Photograph[1]
341	■ too small ■ stained ■ no graphic of hazard ■ in close proximity to hazard, words too small to read from far	
342	Sign Missing	NO PHOTO

SAMR ID	Current Condition and Comments	Photograph[1]
343	■ good condition ■ good message ■ no graphic of hazard ■ in close proximity to hazard, words too small to read from far	
345	■ good condition ■ good message ■ no graphic of hazard ■ in close proximity to hazard, words too small to read from far	
348	Sign Missing	NO PHOTO

SAMR ID	Current Condition and Comments	Photograph[1]
353	■ good condition ■ good message ■ no graphic of hazard	
354	■ good condition ■ good message ■ no graphic of hazard	

Notes: [1] Date of photographs between 22 and 25 January 2017

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APPENDIX F

Important Information

IMPORTANT INFORMATION RELATING TO THIS REPORT

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder's Client and persons acting on the Client's behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

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Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification.

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