Shoalhaven City Council
Coastal Zone Management
Study and Plan

Coastal Slope Instability Hazard Study

FINAL Report

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FOREWORD

Shoalhaven City Council is preparing a Coastal Zone Management Plan guided by the NSW Government Coastal Policy 1997. This report is part of a series of reports that document technical studies undertaken for this project.

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1 INTRODUCTION

1.1 General

The Shoalhaven City Council area comprises about 165km of the ocean shoreline extending from Shoalhaven Heads to North Durras along the South Coast of NSW. Bluffs and headlands with varying slope angles and up to approximately 50m in height from the sea level are common features along the shore. Potential slope instability in bluffs and headlands constitutes a foreshore hazard, also referred to as a slope instability hazard. Studies of foreshore hazards along the coastline and their management are required as part of the coastal hazard and management studies.

Slope instability of bluffs and headlands is a result of continuing operation of physical processes as well as anthropogenic activities within a particular geological and geomorphological setting in the coastal landscape. The physical processes could include rainfall, climate, rock weathering and disintegration, surface and ground water movement, soil erosion, sea level fluctuation, wave impact and earthquakes. On the other hand, coastal urbanisation and land use, destruction of vegetation, either intentionally or otherwise (such as by bush fire or logging activities) may be regarded as anthropogenic factors. Slope failures in bluffs and headlands (both in rock and unconsolidated sediments) are one of several coastal hazards that threaten the coastal community and values. A condition of slope instability may create public safety hazards, threaten existing infrastructure and affect sustainable development and use of coastal areas. Needs for a sensible management of slope instability hazard therefore constitute an essential objective of the coastal zone management plan.

A geotechnical study has been undertaken in the bluffs and headlands within the Shoalhaven coastal zone in accordance with the Shoalhaven City Council's requirements outlined in Section 4.4 of the contract "Coastal Hazard and Management Studies & Coastal Zone Management Plan". The intention of the study has been to establish geotechnical risks and management solutions, using a risk based framework, in coastal slope areas. The landslide risk management framework, published by the Australian Geomechanics Society (AGS) in 2007 (AGS 2007, a, b, c, d) has been used as a basis for the assessments.

1.2 Significant Headlands (Sites of Interest) Assessed

The subject sites covered by this study are located in the following coastal areas within the Shoalhaven Shire Council:

- Racecourse Headland
- Rennies Beach Bluff
- Collers Beach Headland
- Bannisters Point, Mollymook
- Inyadda Point, Manyana
- Berrara Bluff
- Hyams Point
- Plantation Point

- Penguin Head – Culburra Beach
- Culburra Beach Headland.

The sites investigated within these areas for the purpose of this study are shown in Figure 1.1.

1.3 Scope of Works

The scope of works included:

- identifying sections of the bluffs and headlands that pose slope hazards on the coastal urban areas;
- qualitative and, where possible, quantitative assessment of the impact of the hazard on coastal values and the vulnerability of an individual;
- assessing risks associated with slope hazards; and
- developing strategies to manage risks that threaten individuals, communities, existing and future development, coastal natural resources, socio-economic development and environmental sustainability.

The results of the study are presented in this report.

1.4 Document Structure

The methodology undertaken as part of this study is presented in Section 2. This includes an introduction to the AGS '*Framework for Landslide Risk Management*', a summary of the site investigations process, a review of the different modes of landslide movement followed by a summary of the components of the Landslide Risk Management framework. Section 3 describes the regional geology of the Shoalhaven, the characteristic site geology and then presents the slope instability hazards identified at each site and the estimation of the risk of slope instability. Section 4 provides details of the risk evaluation process including coastline recession estimates and discusses the risk acceptance criteria. The report concludes with Section 5 which includes recommendations on the general risk management strategies as well as site specific development options for each of the sites investigated.

2 METHODOLOGY

2.1 Introduction

The Australian Geomechanics Society sub-committee first developed and published, '*Landslide Risk Assessment Procedures*' in Australian Geomechanics, Volume 35, Number 1 dated March 2000. The intention of this system of slope risk classification was to establish terminology, define the general framework, provide guidance on risk analysis methods and provide sufficient information on tolerable and acceptable risks for loss of life. Since then, several published papers have progressed the understanding of the landslide risk framework for these assessments and the procedures have subsequently been adjusted. The updated benchmark guidelines on Landslide Risk Management (LRM) are presented in the Australian Geomechanics publication, Volume 42, Number 1, dated March 2007. This issue presents a series of LRM guidelines and further understanding on the application of the risk assessments for the recommended use by all practitioners nationwide. This investigation was undertaken in accordance with the LRM guidelines dated March 2007.

2.2 Slope Characterisation

The geotechnical study on the stability of bluffs and headlands was undertaken concurrently with studies of other forms of coastal hazards and processes during Stage 1 - Coastal Hazard Definition Study. The following activities were undertaken during this stage:

- data capture:
    - site inspection and geological/geomorphological appraisal;
    - observations of photogrammetric data at the photogrammetric facility of Department of Natural Resources, Newcastle (DNR, now DECC);
    - public consultations to identify existing concerns with headland stability.
- data analysis and review.

The collected data were processed to define and assess the slope hazards, as well as their potential impact on the Shoalhaven City coastal life and values.

A risk evaluation approach was implemented to assess the significance of the potential cliff hazards to coastal urban development and to derive:

- a fifty year fifty percent risk recession line, forward of which development would be prohibited; and

- a fifty year five percent risk recession line for the longer planning period where development will immediately require a geotechnical assessment and will be considered as a future building set back line in some locations as part of a Coastal Development Control Plan.

Assessments were made also of the risk to life. The risk assessment and management process implemented generally followed the procedure outlined in (AGS 2007). On the basis of the slope risk assessments for property and life and the evaluation of the risks, a number of possible strategies are proposed for sustainable management of the coastal zones.

2.2.1 Desk study

The desk study involved:

- reviewing available information on the geology and geomorphology, including published geological maps;
  - Wollongong 1:250,000 Geological Series Sheet SI 56-9 (Second Edition) 1966. Department of Mineral Resources, Sydney;
  - Ulladulla 1:250,000 Geological Series Sheet SI 56-13 (First Edition) 1966. Department of Mineral Resources, Sydney;
- examination of aerial photographs of the sites of interest;
- a review of existing data including photogrammetry;
- search of historical data within Geosciences Australia's database (accessible on the website) on landslides between Nowra and North Durras; and
- other information available in-house and provided by Council on the subject.

2.2.2 Field investigations

The geotechnical investigations comprised geological walkovers of the bluff and headland sites. The site visits were undertaken in April and November 2006 by senior engineering geologists and included a walkover survey of the slopes *via* accessing both above the crest and along the toe of the slope and, where possible, by accessing the slope. Access was limited to only isolated parts of the slopes due to the factors such as slope steepness, vegetation coverage, private property boundaries or a combination of these. The location plan showing the sites inspected is provided in Figure 1.1. Areas that could not be assessed due to lack of access have been annotated in Figures 4.1 to 4.9.

Geological mapping incorporated logging of rock outcrops and exposures and noting other relevant surface features including geomorphological and drainage characteristics, slope vegetation, surface and ground water conditions, erosion and indications of slope instability. Where possible, information was gathered from residents on history of slope instability in the area.

Slope characterisation was undertaken for each accessed part of the slope during the site inspection and mapping in order to:

- identify if the slope has current or potential slope instability issues;
- classify the types of slope instability, if applicable;
- assess the physical extent of the areas affected by instability being considered, including the location, areal extent and volume involved;
- assess the likely initiating event(s), the physical characteristics of the materials involved, and the failure mechanics;
- estimate the resulting anticipated travel distance and velocity of movement;
- address the possibility of fast acting processes, such as flows and falls, from which it is more difficult to escape;

- identify if existing property and/or life is at risk from a possible slope hazard; and
- collect site specific information which could assist in developing strategies to manage risks from slope hazards to existing and future development close to the slope.

2.2.3 Photogrammetric studies

The photogrammetric data of the selected slope sites were reviewed in the DNR photogrammetric facility at Newcastle by a SMEC senior engineering geologist. The purpose of this task was to identify any past, currently active or potential slip areas based on examination of both recent and historical photography.

Limited information was obtained from the aerial photographs. The photographs reviewed typically were dated later than the 1950's and due to the size and scale, shadowing due to the time of day the aerial photographs were taken, and inability to discern the crest of the headland, it was difficult to define potential or existing slip failures.

2.2.4 Coastal cliff recession assessments

Studies determining rates of cliff and bluff retreat over the last 80 to 100 years have concentrated on field measurements, historical data, field surveys and broad scale aerial photographs which have typically overestimated cliff recession rates. Cliff retreat is a slow and episodic process so all of these estimates which are based on a maximum of 100 years of data, frequently collected from sites where coastal erosion is known to be a threat to development, are likely to overestimate the overall rates of cliff and bluff recession.

However, the width of the rock platform that has developed at the foot of many coastal cliffs and bluffs provides an integrated long term average of the rate of cliff retreat. In adopting this, several key assumptions must be relied upon where using rock platform width as an indicator of long term cliff erosion. These include:

- Shore platform development and coastal cliff erosion processes expected to only occur at sites that are within the appropriate range of the mean sea level;
- Shore platform and coastal cliff development that is observed has occurred only since sea level reached its current position at the end of the last glacial episode (approximately 6500 years on the east coast of Australia) so that the morphology is not the result of cyclical sea level change; and
- The shore platform and cliffs have been developed by processes as described in the 'static model'.

The 'static' model and the 'equilibrium' model are the two principal models used to explain the development of shore platform and coastal cliff development.

The 'equilibrium' model assumes the outer margin of the shore platform retreats landward at a rate that is linked to the rate of cliff recession. In this model, wave energy is the principal driver of erosion rates and the entire platform and cliff unit migrates landward.

The ‘static’ model assumes that the outer (seaward) margin of the shore platform remains in a fixed position and the rock platform gradually widens as the cliff retreats. In this model, sub-aerial processes, both those affecting slope stability on the cliff, and various weathering processes on the surface of the shore platform, dominate. Wave energy, while still a factor, is considered to be less important.

For this study the ‘static’ model has been accepted as the preferred model to use along the Shoalhaven coastline based on the following. The toe of the Shoalhaven coastal cliffs are generally above 3m relative to the current mean sea level and typically comprise scree curtains not actively being removed by wave action. However, where the toe of the cliff is less than RL2m wave action is considered an additional, but not the primary, factor in the weathering of portions of the headlands at Inyadda Point, Berrara Bluff, Plantation Point and Culburra Beach.

The principles of the ‘static’ model, discussed above, have been assumed to establish the fifty year fifty percent risk risk recession line (i.e. the estimated average cliff recession line after fifty years) and fifty year five percent risk recession line (i.e. the estimated cliff recession line after 1000 years) for the Shoalhaven coastal bluffs and headlands. As such we have derived estimated long term rates of cliff recession which includes a combination of the weathering and erosion processes that result in kinematic instability, soil instability and larger landslide events. The long term rate of cliff retreat was assessed conservatively and simply by making the assumption that the width of the sub-tidal rock platforms represented the total amount of cliff retreat over the 6,500 year period of the current sea level “stillstand”. The estimates for landsliding events were based on observations of potential hazards and landslide failures made during the site visits.

2.3 Hazard Identification

A landslide is defined as “the movement of a mass of rock, debris or earth down a slope”. Apart from ground subsidence and collapse, this definition is open to the movement of material types including rock, earth and debris downslope. The causes of landslides can be complex. However, two common factors include the occurrence of a failure of part of the soil or rock material on a slope and the resulting movement is driven by gravity. The actual motion of a landslide is subdivided into the five kinematically distinctive types of material movement including fall, topple, slide, spread, and flow. Table 2-1 shows the major types of landslides (Australian Geomechanics, 2007).

Table 2-1: Major Types of Landslides

<table>
<tr><th colspan="2" rowspan="3">TYPE OF MOVEMENT</th><th colspan="3">TYPE OF MATERIAL</th></tr>
<tr><th rowspan="2">BEDROCK</th><th colspan="2">ENGINEERING SOILS</th></tr>
<tr><th>Predominantly Coarse</th><th>Predominantly Fine</th></tr>
<tr><td colspan="2">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">TOPPLES</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td>Rock Slide</td><td>Debris Slide</td><td>Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td><td></td><td></td><td>Earth spread</td></tr>
<tr><td colspan="2">LATERAL SPREADS</td><td>Rock Spread</td><td>Debris spread</td><td>Earth flow</td></tr>
<tr><td colspan="2">FLOWS</td><td>Rock Flow
(Deep Creep)</td><td colspan="2">Debris Flow
(Soil creep)</td></tr>
<tr><td colspan="2">COMPLEX</td><td colspan="3">Combination of two or more principle types of movement</td></tr>
</table>

The more common landslides occurring along coastal headlands and bluffs include falling or toppling rocks and rotational earth or debris slides. Figure 2.1 shows some typical scenarios experienced along coastal headlands and bluffs.

While headland faces are apparently stable, the evidence for rock falls is the pile of blocks around the base of a cliff. Rock falls generally result from the under-cutting of the cliff by wave action over time. Rock topple occurs in a similar fashion to rock falls, however, the inherent jointing structure within the bedrock may be an additional factor to the instability of a cliff face.

Rotational landslides typically develop in moderate to steep slopes where earth or debris becomes inundated by water and downward movement occurs. They are semi-circular in shape and exhibit a back tilted upper section and a disrupted toe section. Translational slides are similar to rotational slides but may feature downward movement along a more competent planar surface.

The frequency of landslides is generally complex and typically dependant on the inter-relationship between the factors influencing the stability of the slope. Some of the common factors affecting the stability of coastal bluffs and headlands include wind and wave action and sea level rise in the longer term. Other potential influences on bluff stability include land development, vegetation removal, changes in drainage. Some of the potential failure triggers that may affect the stability of coastal bluffs include:

- undercutting of slope by sea storms;
- wave action removing fallen debris, preventing the headland reaching the state of natural repose.
- periodic wetting up and salt spray by sea waves onto slope material leading to frequent repeated cycles of wet/dry conditions as well as variation in temperature;
- prolonged rainfall with water percolating into rock mass defects causing washout of fines and reduction of rock mass strength;
- high winds – effects of sand blasting, aiding the infiltration of salt spray into defects, etc.; and
- earthquakes.

One or a combination of these conditions could result in a landslide failure event.

2.4 Risk Estimation

A risk assessment was undertaken for the identified slope hazards for each site. The risk assessment and management process adopted for this study in general complies with AGS (2007a). Figure 2.2 shows the general process recommended by the AGS Guidelines in a flow chart form. Definition of the terms used in this report with respect to the slope risk assessment and management is given in Appendix A (reproduced from AGS 2007c Appendix A).

For risk to property, the assessment was primarily based on a qualitative approach. The descriptive terminology used for qualitative assessment in this report is provided in Appendix B (reproduced from AGS 2007c Appendix C, page 91 – 92). The assessment process for each hazard involved the following:

- Risk estimation (comparative analysis of likelihood of a slope failure versus consequence of the failure).

- Evaluation of the estimated (assessed) risk by comparing against acceptance criteria.

Risk management and control strategies are recommended where the estimated risk is beyond the acceptable/tolerable limit.

In accordance with the AGS 2007c Landslide Risk Management Guidelines for loss of life, the risk assessment was primarily based on a quantitative approach. The individual risk for loss of life can be calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \text{ x } \mathbf{P}_{(S:H)} \text{ x } \mathbf{P}_{(T:S)} \text{ x } \mathbf{V}_{(D:T)}$$

Where

$\mathbf{R}_{(LoL)}$ is the risk (annual probability of loss of life (death) of an individual.

$\mathbf{P}_{(H)}$ is the annual probability of the landslide.

$\mathbf{P}_{(S:H)}$ is the probability of spatial impact of the landslide impacting a building (location) taking into account the travel distance and travel direction of a given event.

$\mathbf{P}_{(T:S)}$ is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.

$\mathbf{V}_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact.

The assessment process for each hazard involved the following:

- Using the calculation, risk estimation (integration of the loss of life of an individual, frequency analysis of a slope failure, impacting a building in which a person is present, and the consequences of the failure and vulnerability of the individual/s).
- Evaluation of the estimated (assessed) risk by comparing against acceptance criteria.

Risk management and control strategies are recommended where the estimated risk is beyond the acceptable/tolerable limit.

3 RISK ASSESSMENT

3.1 Introduction

The benchmark guidelines on Landslide Risk Management (LRM) are presented in the Australian Geomechanics publication, Volume 42, Number 1, dated March 2007. This issue presents a series of LRM guidelines and further understanding on the application of the risk assessments for the recommended use by all practitioners nationwide. This investigation was undertaken in accordance with the LRM guidelines dated March 2007.

These assessments were based on observations made during short site visits at each of the selected sites by Senior Engineering Geologists and by reviewing available geotechnical data. The assessments were made conservatively because comprehensive and detailed geological mapping of all of the bluff areas was not possible within the scope of the work under this contract. Any future detailed evaluations of particular sites may change the quantification of the hazard risk.

The following subsections detail the regional geology of the Shoalhaven, typical headland geology and slope characteristics, and observations made during site visits and the risk assessments.

3.2 Shoalhaven Regional Coastal Geology and Slope

The Shoalhaven area is situated within the southern part of the Sydney Basin which extends from Batemans Bay to the Hunter Valley. The Sydney Basin is a structural trough in which sediments were deposited in a saucer-shaped configuration.

The 1:250,000 scale geological maps of Ulladulla and Wollongong indicate that the Shoalhaven area is underlain primarily by sedimentary rocks deposited as the Shoalhaven Group during the Early Permian Epoch. Two prominent sub-groups of sediments belonging to the Shoalhaven Group in the Shoalhaven area are the Conjola Formation and the younger Wandrawandian Siltstone, which underlie the coastal headlands and bluffs in the area.

The regional geology showing the approximate location of the sites along the Shoalhaven Coastline is shown in Figures 3.1 and 3.2.

The Conjola Formation comprises a sequence of siltstones, sandstones and claystones with minor conglomerate bands at the lower part of the stratigraphical sequence, which is replaced towards the upper part by, predominantly, sandstones with minor siltstones and conglomerates. This formation is overlain by fine grained mostly, quartz lithic, sandstones and siltstones, which are typical of Wandrawandian Siltstone Sub-group.

The Shoalhaven Group rock sequences are commonly overlain by undifferentiated Tertiary sediments including gravel, sand, clay, quartzite, sandstones and conglomerates. The Shoalhaven Group and/or Tertiary sediments may further be unconformably overlain by Quaternary alluvial sediments comprising alluvium gravels, swamp deposits and sand dunes.

Several igneous intrusions are evident along the Shoalhaven coastline. Small Tertiary basalt intrusions have been identified in the coastal headlands and surrounding areas near Durras, Ulladulla, Milton, Bendalong and Bhewerre. Between Bawley Point and Merry Beach at Kioloa an igneous intrusive known as Essexite (Nepheline Gabbro) dominates the coastal fringe.

Structurally, the area is located within the southern flank of the Sydney Basin. Based on the geological map of Ulladulla, a regional fault structure, named as Point Perpendicular Fault, runs parallel to and near the coast line east of Jervis Bay. Smaller faults trending normal and oblique to this fault are reported to occur across the north-eastern part of Jervis Bay and Beecroft Peninsula. No significant geological structures south of Jervis Bay are identified in the existing literature.

3.3 Typical Headland Geology and Slope Characteristics

The exposed headlands and cliffs in the Shoalhaven most commonly comprise sub-horizontally bedded sandstones, siltstones and conglomerates from the Conjola Formation and Wandrawandian Siltstone Sub-group. These units are typically distinguished by the siltstone being a fine grained grey to dark grey rock compared to the lighter grey, fine to medium grained, laminar bedded, sandstone rocks and coarse grained poorly sorted pebble conglomerates.

The rocks may differ not only as described above but also in degrees of hardness (residual strength), weathering and structural integrity including jointing. The inherent characteristics of the different rock types influence the stability of a particular cliff. Some common potential failure triggers that may affect the stability of the coastal bluffs include:

- weathering of a siltstone unit by wave impact and dynamic loading causing the undercutting of overlying sandstone units;
- periodic wetting and drying of clay-bearing siltstone units leading to the mechanical breakdown of the unit resulting in the undercutting of overlying rock units;
- prolonged rainfall with water percolating into rock mass defects and weakening of rock mass strength activating movement of rock or soil along bedding or joint planes;
- high wind buffeting the headlands with sand resulting in the abrasive physical weathering of susceptible units; and
- erosion due to creek flow and/or concentrated runoff.

The resulting instability of headlands includes rock fall and toppling failures where undercutting of structurally poor rock and weakened rock has occurred. Mass movement including slumping or block slides where water percolation has activated the gravity driven movement of a mass of rock and debris or soil along a plane.

3.4 Shoalhaven Site Investigations

The data collected during Stage 1 (hazard definition study) has enabled the definition and characterisation of slope instability hazards at each of the sites. This section details the observations, assets at risk and slope risk assessment undertaken at each of the sites.

3.4.1 Racecourse Headland

Racecourse Beach is situated approximately 1.5 to 2 kilometres south of Ulladulla. The coastline in this area is oriented to the north east. The study site comprises a slope and rock platform some 580m in length and located adjacent to 29 residential houses and a car park along Coral Crescent. At the northern end of the site, access tracks provide visitors an access to the lookout. To the south, car parking facilities, access paths and steps provide visitors an access to the rock platform and Racecourse Beach.

The area generally comprises flat to gently east to south-easterly dipping surface (generally less than 10˚) leading to the steeper slope section. In the northern part, the slope typically has dips varying between 40˚ to 60˚ and is densely vegetated. Towards the south, the slope becomes much steeper with the southern end east of the car parking facilities having a slope angle between 70˚ and 90˚ and slope height of up to 20m. The crest of the slope is generally between RL12m at the southern end and RL24m at the northern end of the site. The rock platform at the toe of the slope is approximately RL 4m and dips slightly seawards.

The geology of the area comprises Tertiary sediments overlying the Conjola Formation. The Conjola Formation includes a sub-horizontal series of weathered Permian sedimentary rocks which are part of the Shoalhaven Group and typically features sandstones, silty sandstones and conglomerates.

Site Observations

Northern end of Racecourse Beach

- The slope is approximately 10 -12m high and dips 45˚ to 55˚ to the east.
- The face of the slope is well vegetated with no obvious disturbances or areas of cleared vegetation.
- Although the toe of the slope has been undercut by wave action the rock platform is typically talus free.
- Two joint sets including one prominent northeast oriented joint set with approximately 10m true spacing and the other with a more widely spaced and orthogonal but discontinuous joint set.
- Slope and area above the crest not accessed during site visit.

Rock wall above beach near car park at southern end of rock platform:

- The car park is separated from the cliff by a fence situated 1-3m from the edge of the cliff.
- The slope varies in height up to approximately 20m and dips to the east between 60˚-90˚ (typically 70˚) and is undercut in areas below the beach access steps, see Photograph 3.1 below.

Photograph 3.1 shows an undercut cliff and shelf below car park and adjacent to beach access steps at Racecourse Beach.

- The upper slope is vegetated by grass and Bitou Bush with scarce vegetation along the sub-vertically dipping lower slope, see Photograph 3.2 below.

Photograph 3.2 is taken looking to the south along the crest of the cliff adjacent to the car park at Racecourse Beach.

- The exposed geology comprises layers of dark grey siltstones, silty sandstones and sandstones which become conglomeratic in local areas.
- Widely spaced sub-vertical jointing as described above.

- Water seepage was observed from bedding planes and jointing.
- Rock is undercut by wave action.
- Evidence of block fall up to 300 mm in size from cliff face below the car park and block fall up to 1m in size from the vertical rock face near the access stairs on the north of Racecourse Beach.

Rock above rock platform to the north of the beach access steps:

- Tidal wave erosion of the toe of the clay unit (approximately 1m thick unit) adjacent to the rock platform.
- Blocky rock mass structure of sandstones and siltstones controlled by joint patterns with block size generally <300mm.
- Seepage observed from upper bedding plane of claystone unit.
- The stratigraphy dips slightly towards the east and the primary joint orientation (dip/dip direction) is 90°/078˚ with one wide spaced orthogonal joint set.

Slope Failure Mechanisms

The following failure mechanisms appear to be typical for this slope:

- Toppling failure of <300mm blocks - The toppling failure mechanism is associated with the two joint sets and sub-horizontal bedding plane observed.
- The potential for rock fall of <1m blocks exists due to undercutting of the lower siltstone and silty sandstone units in the rock face near the steps, adjacent to the car park at Racecourse Beach.

Assets at Risk

There are over twenty houses located along the crest of the south and east faced slope on the seaward side of South Pacific Crescent which are potentially at risk in the long term.

The car park and access stairs at the south-east corner of the headland are underlain by the sub-vertical rock face that has been undercut by wind and high tide wave processes and therefore are at risk.

Risk Assessment

Table 3-1 below shows a summary of the hazards and assessed risk to property for Racecourse Beach undertaken in accordance with LRM guidelines dated March 2007 in Appendix B.

3.4.2 Rennies Beach

Rennies Beach is situated approximately 1.0km southeast of Ulladulla. The site is adjacent to a car park on Rennies Beach Close. The beach is accessed via stairs descending down a south-easterly trending steep gully formed by stormwater drainage outlet at the crest. The access path and steps are situated adjacent to the northern edge of the gully. The yard of the adjacent property bounds the crest of the southern slope of the gully.

The slope face underlying the house at the crest typically has dips varying between 40˚ to 70˚ to the east-northeast and is densely vegetated. The crest of the slope is RL 26m and the toe of the slope is at approximately RL 4m at beach level.

The geology of the area comprises Tertiary sediments overlying the Conjola Formation. The Conjola Formation includes a sub-horizontal series of weathered Permian sedimentary rocks that are part of the Shoalhaven Group and typically features sandstones, silty sandstones and conglomerates.

Site Observations

Gully/Drainage area below parking area

- Highly weathered sandstone was evident at the toe of the slope.
- The southern slope dips approximately 40˚ from the crest becoming much steeper 60˚-70˚ towards the base of the gully. This slope is sparsely vegetated with grass and shrubs and is hummocky towards the crest. Highly weathered sandstone is exposed locally on the slope face due to gully erosion, see Photograph 3.3 below:

Photograph 3.3 shows erosional rills on a steep slope adjacent to a stormwater gully at Rennies Beach. Note the retaining wall of a property above the crest of the gully.

- Small slumps ($2m^3$) and tension cracks were observed in the soil about midway down the slope on the northern side of the drainage path and adjacent to the footsteps to the beach, see Photograph 3.4 below:

Photograph 3.4 shows a <5m^3 slump failure on the southern side of a stormwater drainage gully at Rennies Beach.

- A big boulder lies at the base of the gully.

Slope Failure Mechanisms

Likely slope failure mechanisms for this site include:

- Washout erosion (<5m^3) - Washout erosion is associated with severe or prolonged rain events where overland flow of water on the slope erodes the less consolidated soil from the slope.
- Small (5-10m^3) slumps - Infiltration of water from rain events or stormwater directed towards the slope may result in the mass movement or rotational failure of a section of the slope.

Assets at Risk

There is one house and a small public car park at the mouth of the gully that may be at risk in the longer term.

Risk Assessment

Table 3-1: Racecourse Beach Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Toppling Blocks <300mm	<1000yrs	Possible	C	0.5%	Little Damage	5	VL
Rock Fall <1000mm	<100yrs	Likely	B	5%	Little Damage	5	L

The qualitative risk for rock falls and toppling blocks (<1000mm in diameter) that may affect the car parking area at Racecourse Beach is anticipated to have a recurrence interval of 100yrs to 1,000yrs (10^{-2} – 10^{-3}), that is, the failure event will probably occur under adverse conditions over the design life. However, it is anticipated that the area will not require significant stabilisation works to be undertaken to the face of the cliff adjacent to the car park area, limited damage to the car park is anticipated (Level 4). Where applied to the risk matrix, a possible occurrence of block falls where limited damage is expected to the car parking area, then the actual risk to property is determined as a moderate risk.

The quantitative risk to life assessment for the rock fall hazards <1m has been assessed using the following assumptions:

$\mathbf{P}_{(H)}$ The annual probability of the landslide – Range 10^{-2} – 10^{-3} - **Value Adopted = 10^{-2}**

$\mathbf{P}_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.2** (the rock fall event is likely to be rapid and difficult to evade for individuals within 5m of the toe of the slope).

$\mathbf{P}_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.2** (the adopted value considers 8 hours a day, 4 months in the year of high beach patronage involving high flow of people past the area. Subsequent, it was assumed there was a 0.2 probability of a person being present at the time of the failure).

$\mathbf{V}_{(D:T)}$ Vulnerability of a individual – Range 1 – 10^{-1} - **Value Adopted = 0.5** (where failure of a block <1m is more likely to cause an injury than death to a person attempting to evade the block)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall <1m has been estimated to be of the order of **4×10^{-4}**.

Table 3-2 below shows a summary of the hazards and assessed risk to property for Rennies Beach.

Table 3-2: Rennies Beach Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Washout Erosion (<5m^3)	<100yrs	Likely	B	0.5%	Insignificant	5	L
Small Slump (5-10m^3)	<100yrs	Likely	B	0.5%	Insignificant	5	L
Large Slump (20m^3)	<10,000yrs	Unlikely	D	5%	Minor	4	L

The qualitative risk assessment for washout erosion and small slumps (<10m^3 in volume) is anticipated to have a recurrence interval of 100yrs (10^{-2}), that is, the failure will probably occur over the design life, however as it is a small volume of material, the failure is anticipated to have no impact on the houses above the crest and little damage is expected (Level 5). Where applied to the risk matrix, the likely occurrence of washout erosion and slump risk where little damage is expected to property, then the actual risk to property is determined as low.

The qualitative risk for large slumps (20m^3 in volume) that may affect the property bounding the crest of the slope is anticipated to have a recurrence interval of 10,000yrs (10^{-4}), that is, the failure event, although unlikely, could occur under very adverse conditions over the design life. However, it is anticipated that the large slump will subsequently require stabilisation works to be undertaken to the face of the slope and limited damage to the property is anticipated (Level 4). Where applied to the risk matrix, the unlikely occurrence of a large slump where limited damage is expected to the property above the crest, then the actual risk to property is determined as a moderate risk.

The quantitative risk to life assessment for washout erosion and small slumps <10m^3 has not been assessed as the events are anticipated to occur within an area of the gully typically not accessed by the general public. The failure events <10m^3 are also not anticipated to impinge on property adjacent to the southern crest of the gully, or the pedestrian beach access steps adjacent to the northern edge of the gully. However, the quantitative risk to life assessment for large slumps 20m^3 has been assessed using the following assumptions:

$P_{(H)}$ The annual probability of the landslide – Range 10^{-4} – 10^{-5} - **Value Adopted = 10^{-5}**

$P_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.1** (the larger slump or debris flow is likely to impinge on the property of the house immediately adjacent to the southern crest, but probably not the house).

$P_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-1} – **Value Adopted = 0.5** (allows for persons being in the backyard of the property above the southern crest of the gully at the time of the failure).

$V_{(D:T)}$ Vulnerability of a individual – Range 10^{-1} – 1.0 - **Value Adopted = 0.3** (where the failure event is more likely to initially be slow, show tension cracks and unlikely to cause injury due to the cause an injury than death to a person attempting to evade the block)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the slumping failure of $20m^3$ has been estimated to be of the order of **1.5×10^{-7}**.

3.4.3 Collers Beach Headland

Collers Beach Headland (Nurrawallee Street) is located approximately 1km to the north of Ulladulla. The headland faces to the northeast and the site comprises a 220m length of headland with private properties facing northeast along the crest of the slope. Pedestrian access to the rock platform is primarily from Collers Beach, although at high tide during storm events access is probably limited.

The topography gently dips to the northeast with the crest of the slope at approximately RL 24m. The headland dips steeply (60-90˚) to the rock platform below (RL 2m). The rock platform is between 35m and 65m wide and features a significant build up of rock talus along the toe of the headland.

The geology of the area comprises Tertiary sediments overlying the Conjola Formation. The Conjola Formation includes a sub-horizontal series of weathered Permian sedimentary rocks that are part of the Shoalhaven Group and typically features sandstones, silty sandstones and conglomerates.

Site Observations

Inspection of the crest area of the slope

Limited inspection was undertaken along the backyard boundary of the properties located at 61 to 63 Nurrawallee Street, along the edge of the crest. The following were identified:

- Evidence of past movement along the masonry wall near the edge of the cliff
- A crack on the masonry wall (based on discussions with the owner the crack appears to have existed since 1950s and has not shown further movement)
- Existing sewer line runs parallel to the edge of the crest at a distance approx. 2 m inside from the backyard property boundary (wall).

Observation from the rock platform level:

- The slope is approximately 20m high and varies in dip from 60˚-90˚ northeast. There are houses along the crest of the slope. Several PVC poly-pipe outlets were observed along the edge of the crest to indicate stormwater drainage discharge from these properties.
- The geology comprises predominantly medium to very thinly bedded, dark grey

siltstone, and silty sandstone with some lighter grey sandstone units. The bedding has an apparent dip 2˚ to 5˚ to the north or north west. The rock mass exposed on the cliff face is generally highly to moderately weathered with the top 5m of the vertical profile which consists of extremely weathered rock to residual soil and underlies the houses at the crest. This portion of the slope has a reasonable vegetation cover except in the areas near the stormwater pipe outlets at the edge of the crest where the material is eroded by the drainage discharge. A deeply incised gully, which extends vertically from the crest to the toe, is evident below a stormwater drainage pipe discharge near the backyard of 63 Nurrawallee Street. The gully has exposed extremely weathered to highly weathered siltstone. Minor slumping was observed within the gully area, see Photograph 3.5 below:

Photograph 3.5 shows a steep gully cutting into the slope at Collers Beach Headland (Nurrawallee Street) directing stormwater from the properties above the cliff to the ocean. Slumping is apparent along the gully sides.

- Two main sub vertical joint sets were observed in the rock platform as well as along the slope. The first or primary joint set strikes sub-parallel to the cliff-line (typical dip/dip direction 85˚/240˚ and 85/060˚) with the joint spacing which varies from 0.3m to 2.0m, open to 15mm. The second joint set is orthogonal to the first joint set (with a dip/dip direction of about 90°/160˚) and has a joint spacing which ranges from 1.5m to 3m (true thickness) with the joint opening up to 15mm wide. A less frequent sub-vertical joint set oriented diagonally to the other two sets is also present in the rock platform and the slope, see Photograph 3.6 below:

Photograph 3.6 shows a loosened jointed block, a tree leaning downslope. The sandstone bedrock appears to dip down slope. Note the open (~100mm) fracture behind the block. A drainage polypipe appears to direct stormwater to the slope from the property above the crest of the cliff.

- Presence of unstable blocks of rock mass on the slope
- The moderately to highly weathered siltstone towards the toe of the slope is subject to ongoing wave erosion resulting in slow but continuous undercutting of the headland. This process is aided by the constant wetting and drying of the siltstone and silty sandstone units which results in degradation of these rock types and subsequent underpinning of the stability of the overlying sandstone units.
- Weathering of the toe of the slope is causing undercutting of the overlying jointed siltstone and sandstone units and subsequent toppling failure of the overlying jointed rock mass. As a result of this ongoing process a rock talus curtain of approximately 5m wide has formed along the toe of the slope. The talus includes the rock mass blocks of the size up to 0.5m in maximum dimension, see Photograph 3.7 below:

Photograph 3.7 shows the scree pile of blocks (~0.5m) at the toe of the cliff associated with undercutting action of tidal wave energy causing rock falls at Collers Beach Headland (Nurrawallee Street).

Slope Failure Mechanisms

- Block toppling or falling (wedge failures) to 1.5-2m^3 - The block toppling failure mechanism can occur associated with the minimum three joint sets observed. One joint set is sub-parallel to the face of the headland, one orthogonal joint set and bedding dipping out of the face.
- Rock fall may also occur associated with the undercutting of the lower siltstone and silty sandstone units in the rock face. The weathering of the toe of the slope subsequently causes the unravelling of the material from the upper cliff face.
- Slumping due to stormwater erosion - Infiltration of water from rain events or stormwater directed towards the slope (from residences above the slope) may result in the slope erosion or mass movement including rotational failure of a section of the slope.

Assets at Risk

There are three residential houses which adjoin the crest of the Collers Beach cliff along the northern side of Nurrawallee Street. These are all at risk to some degree as the coastal process on the slope appears to be reasonably active.

Risk Assessment

Table 3-3 below shows a summary of the hazards and assessed risk to property for Collers Beach Headland.

Table 3-3: Collers Beach Headland Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Blocks toppling or falling ($2m^3$)	<10yrs	Almost Certain	A	0.5%	Insignificant	5	L
Mass movement of section of headland (up to $100m^3$)	1000yrs	Possible	C	0.5%	Insignificant	5	VL
Slumping due to stormwater erosion $10m^3$	100yrs	Likely	B	0.5%	Insignificant	5	L

The qualitative risk assessment for toppling blocks (<$2m^3$) is anticipated to have a recurrence interval of less than 10yrs (10^{-1}), that is, the failure event is expected to occur over the design life, however as blocks toppling towards the toe of the slope are anticipated to have no impact on the houses above the crest, little damage is expected (Level 5). Where applied to the risk matrix, the occurrence of toppling blocks risk where little damage is expected to property, then the actual risk to property is determined as low.

The qualitative risk for mass movement of a section of the headland (<$100m^3$) that may affect the properties above the slope is anticipated to have a recurrence interval of 1000yrs (10^{-3}), that is, the failure event will possibly occur under adverse conditions over the design life. However, it is anticipated that failure of part of the headland would cause little damage to the properties above the crest (Level 5). Where applied to the risk matrix, a possible occurrence of mass movement (<$100m^3$) where little damage is expected to the properties above the cliff line, then the actual risk to property is determined as a very low risk.

The qualitative risk assessment for slumping (5-$10m^3$) is anticipated to have a recurrence interval of 100yrs (10^{-2}), that is, the failure event is expected to occur over the design life, however as slumping is anticipated to occur in a localised gully area where no residences are located, little damage is expected (Level 5). Where applied to the risk matrix, the occurrence of toppling blocks risk where little damage is expected to property, then the actual risk to property is determined as low.

The quantitative risk to life assessment for slumping has not been assessed as it was observed within gully area generally not accessible to the general public. The rock fall hazard $2m^3$ has been assessed using the following assumptions:

$\mathbf{P}_{(H)}$ The annual probability of the landslide **– Value Adopted = 10^{-1}**

P$_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.1** (the rock fall event is likely to be rapid and contained within the 5m scree pile at the base of the slope).

P$_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.05** (allows for persons being below the base of the cliff (low usage area) at the time of the failure).

V$_{(D:T)}$ Vulnerability of a individual – Range 10^{-1} – 10^{-2} - **Value Adopted = 0.5** (where failure of a block <1m is more likely to cause an injury than death to a person attempting to evade the block)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall 1.5-2m^3 has been estimated to be of the order of **2.5 x 10^{-4}** or less.

The quantitative risk to life assessment for large scale debris slide/fall event <100m^3 has been assessed using the following assumptions:

P$_{(H)}$ The annual probability of the landslide – Range 10^{-4} – 10^{-5} - **Value Adopted = 10^{-4}**

P$_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.1** (the rock fall event is likely to be slow to rapid and generally not difficult to evade).

P$_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.5 (**allows for persons being in the backyard 50% of the time or below the base of the cliff (low usage area) at the time of the failure).

V$_{(D:T)}$ Vulnerability of an individual – Range 1 x 10^{-1} – 1 x 10^{-2} - **Value Adopted = 0.5** (slow failure may be evident in the car park but not cause injury. Slow to rapid failure of debris is more likely to cause an injury than death to a person attempting to evade the debris).

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of debris slide/topple event <100m^3 has been estimated to be of the order of 2**.5 x 10^{-6}** or less.

3.4.4 Bannisters Point

Bannisters Point is located 2-2.5km to the north of Mollymook town centre. Mitchell Parade provides access to the mainly residential housing area along the bluff above Bannisters Point. Mollymook Beach and the rock platform surrounding Bannisters Point is accessed from Beach Road at the Northern end of Mollymook Beach.

The site is the south facing slope below Bellbird Close which is approximately 28m high and dips some 55˚ to 70˚ to the south. The crest of the slope is at RL 32m and the toe is located within a thickly vegetated zone above the beach level at approximately RL 4m.

The geology of the area comprises Tertiary sediments overlying the Conjola Formation. The Conjola Formation includes a sub-horizontal series of weathered Permian sedimentary rocks that are part of the Shoalhaven Group and typically features sandstone, silty sandstone and conglomerate. A Tertiary basaltic intrusive which forms part of the Meringo Creek Formation is shown to be located to the west of the Bannisters Point on the regional geological map.

Site Observations

Inspection from the beach level:

- The slope at the crest dips gently at approximately 10 -15˚ to the south and becomes steeper to about 55˚ to 70˚ lower in the cliff profile. At the inspected site, the slope is approximately 25m high.
- Generally, established vegetation cover on the slope except in localised steeper areas where sandstone is exposed on the sub-vertical face.
- At least one joint set in the sandstone rock mass is apparent sub-parallel to the slope.
- Basalt interpreted from the geological map was not observed on the exposed slope during this inspection.
- Some evidence of past toppling failures from higher parts of the slope with sandstone blocks lying at the base, typically blocks 1.0m to 1.5m in size, see Photograph 3.8 below:

Photograph 3.8 shows a thickly vegetated slope with blocks (~0.3m) at the toe of the slope and rugged blocky sandstone towards the crest of the slope.

- Lack of vegetation cover in a few areas along the upper slope which has exposed red brown HW or EW rock/soil, possibly due to the result of shallow slumping or sheet wash from stormwater runoff.

Along the crest of the slope (near intersection of Bellbird Close and Mitchell Parade):

- Surface runoff from the crest area appears to be directed to the slope and has caused minor sheet erosion of the slope.
- There are no obvious evidence of instability and disturbance of the slope at the crest.

Slope Failure Mechanism

- Toppling failure in rock mass

Assets at Risk

The slope at the eastern end of Bannisters Point, to the east of Cliff Avenue and Mitchell Parade could not be inspected due to lack of access. However, some 20 lots in this area lie close to the crest of the slope and may contain assets at risk.

Risk Assessment

Table 3-4 below shows a summary of the hazards and assessed risk to property for Bannisters Point.

Table 3-4: Bannisters Point Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Washout Erosion (<5m^3)	100 yrs	Likely	B	0.5%	Insignificant	5	L
Large Slump (20m^3)	1000 yrs	Possible	C	0.5%	Insignificant	5	VL

The qualitative risk assessment for washout erosion and small slumps (<5m^3 in volume) is anticipated to have a recurrence interval of 100yrs (10^{-2}), that is, the failure will probably occur over the design life, however as it is a small volume of material, the failure is anticipated to have no impact on the houses above the crest and little damage is expected (Level 5). Where applied to the risk matrix, the likely occurrence of washout erosion and slump risk where little damage is expected to property, then the actual risk to property is determined as low.

The qualitative risk for large slumps (20m^3 in volume) that may affect the property bounding the crest of the slope is anticipated to have a recurrence interval of 1,000yrs (10^{-3}), that is, the failure event, although unlikely, could occur under adverse conditions over the design life. However, it is anticipated that a large slump will subsequently require stabilisation works to be undertaken to the face of the slope and little damage to the property is anticipated (Level 5). Where applied to the risk matrix, the unlikely occurrence of a large slump where limited damage is expected to the property above the crest, then the actual risk to property is determined as a moderate risk.

The quantitative risk to life assessment for washout erosion has not been assessed due to the minimal consequences anticipated. The quantitative risk to life assessment for large scale debris slide/fall event <20m^3 has been assessed using the following assumptions:

$P_{(H)}$ The annual probability of the landslide – Range 5 x 10^{-2} – 5 x 10^{-3} - **Value Adopted = 10^{-3}**

$P_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.1** (the debris slide event is likely to be rapid and not extend beyond the thick vegetation and talus pile at the toe of the slope).

$P_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.1** (Due to the inaccessible nature of the toe of the slope individuals are not anticipated to be present at the time of the failure).

$V_{(D:T)}$ Vulnerability of a individual – Range 10^{-1} – 10^{-2} - **Value Adopted = 0.1** (Slow to rapid failure of debris is more likely to cause an injury than death to an individual)

The annual probability of loss of life (death) of an individual = **1×10^{-6}** or less .

3.4.5 Inyadda Point Headland, Manyana

Inyadda Point is located between Manyana and Inyadda Beaches in Manyana. The area is mostly residential with houses along the crest of the slope on the seaside of Sunset Strip road.

The 16m to 18m high slope faces to the south and south east. The crest of the slope is approximately RL18 to 20m with the toe at approximately RL 2 to 4m. A small beach and up to 20-40m wide rock platform dips gently towards the coast from the base of the slope.

The geology map of Inyadda Point shows Quaternary alluvium comprising swamp deposits, gravel and sand dunes that are underlain by undifferentiated Tertiary sediments and the Conjola Formation. The Conjola Formation includes a sub-horizontal series of weathered Permian sedimentary rocks that are part of the Shoalhaven Group and typically features sandstones, silty sandstones and conglomerates.

Site Observations

The slope was viewed and accessed from vacant blocks on the headland. The access to the slope from Sunset Strip Road was limited due to residential houses along the crest.

- On one vacant block, the ground above the slope was disturbed. However, due to the build up of mulch/vegetation clippings dumped along the crest of the slope, it was difficult to determine if the disturbance was caused by human activities.
- On the backyard, which borders the steep slope to the east, of one of the houses along the street, tension cracks were noted in the fill layer below the timber deck extension. It appears that some regrading and construction of berm on the slope was carried out by placement of some fill on the slope as part of levelling of the backyard.
- The slope is well vegetated with shrubs and trees with some trees leaning down the slope.
- Some wash-out structures were observed in the upper soil layer located immediately below the crest.
- The soil is a red clayey soil (Quaternary Alluvial sediments).
- Although slightly hummocky, the surface above the crest of the slope was grass covered with no obvious signs of disturbance.

- Overland runoff has caused erosion of the unconsolidated soil in the upper slope and water infiltration has resulted in soil creep, see Photograph 3.9 below:

Photograph 3.9 shows a destabilised section of soil towards the crest of the slope resulting in soil creep. Trees in this area were also observed to be leaning downslope.

Slope Failure Mechanisms

- Washout erosion and soil creep (<20m^3) **–** It is associated with severe or prolonged rain events where overland flow of water on the slope result in erosion of the less consolidated soil from the slope.
- Slump failure (<20m^3) **–** Significant infiltration of water from a large rain event may result in the mass movement or rotational failure of a section of the slope.

Assets at Risk

Over thirty houses along the south facing slope may be potentially at risk. The slope to the east of Sunset Strip Road was unable to be inspected due to lack of access. However, several lots in this area are located at the crest of the slope and may contain assets at risk.

Risk Assessment

Table 3-5 below shows a summary of the hazards and assessed risk to property for Inyadda Point Headland.

Table 3-5: Inyadda Point Headland Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Soil Creep (<5m^3)	1-10yrs	Almost Certain	A	0.5%	Insignificant	5	L
Large Slump (<200m^3)	500yrs	Likely to Possible	B-C	40%	Medium to Major	3	H

The qualitative risk assessment for soil creep (<5m^3 in volume) is anticipated to have a recurrence interval of 1-10yrs (10^{-1}), that is, the failure is expected to occur over the design life, however as it is a small volume of material, the failure is anticipated to have little impact on the residences nearby and little damage is expected (Level 5). Where applied to the risk matrix, the likely occurrence of soil creep where little damage is expected to property, then the actual risk to property is determined as low.

The qualitative risk for large slumps (<200m^3 in volume) that may affect the property bounding the crest of the slope is anticipated to have a recurrence interval of 500yrs ($5x10^{-3}$), that is, the failure event will probably occur under adverse conditions over the design life. However, it is anticipated that a large slump could possibly significantly damage at least one property and possibly adjoining properties (Level 3). Where applied to the risk matrix, the likely occurrence of a large slump where medium damage is expected, then the actual risk level to property is determined as high.

The quantitative risk to life assessment for soil creep has not been assessed due to the minimal consequences. The quantitative risk to life assessment for large slump event <200m^3 has been assessed using the following assumptions:

P$_{(H)}$ The annual probability of the landslide – Range 10^{-3} – 10^{-4} - **Value Adopted = 5 x 10^{-3}**

P$_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.2** (the landslide event is likely to occur between the seaward side of the dwellings and the toe of the slope).

P$_{(T:S)}$ Probability of persons present during event – Range 1 – 10 – **Value Adopted = 4** (allows for 4 individuals from 2 properties to be present in their dwelling at the time of the failure).

V$_{(D:T)}$ Vulnerability of an individual – Range 1 - 10^{-1} - **Value Adopted = 1** (slow failure may be able to avoid, however a rapid landslide during a storm is likely to leave individuals vulnerable.)

The annual probability of loss of life (death) of an individual = **4 x 10^{-3}** or less.

3.4.6 Berrara Bluff

Berrara bluff is located approximately 1.5km to the south of Sussex Inlet, between Berrara Beach and Monument Beach. The headland is occupied, essentially, by individual residential properties. The houses along the eastern side of Myrniong Grove are closest to the slope and are most exposed to coastal processes.

The 10m to 12m slope adjacent to the beach and rock platform at the sea level faces to the east. The crest of the slope is approximately RL15m and dips to the east with the toe at approximately RL 3m. A 20m-50m wide rock platform at the sea level dips gently towards the coast from the base of the slope.

The geology of the headland comprises Quaternary alluvial sediments that are underlain by the Wandrawandian Siltstone of the upper Shoalhaven Group. The Wandrawandian Siltstone sequence comprises siltstones and silty sandstones that are pebbly in part.

Site Observations

Inspection of the headland was made from the wave cut platform.

- Siltstone headland 10m to 12m high, typically 50˚-60˚ but near vertical where undercut, see Photograph 3.10 below:

Photograph 3.10 shows a house with a retaining wall adjacent to the crest of a steep slope at Berrara Headland.

- Jointing appears to be sub-parallel to the headland with an orthogonal joint set.
- The headland is actively being eroded by the wave action at high tide causing undercutting and block failure from the overlying units, see Photograph 3.11 below:

Photograph 3.11 shows a steep slope underlain by hard rock. Note the undercutting of the siltstone at the toe of the slope in the distance at Berrara Headland.

- Sandstone units located above the typically siltstone slope and wave platform are undercut.
- In areas the build up of talus at the toe of the slope is up to 2m thick comprising blocks up to, but typically less than, 1.5m in diameter, see Photograph 3.12 below:

Photograph 3.12 shows blocks to 300mm and blocks to 1.0m and 1.5m in the talus pile at the toe of the cliff at Berrara Headland.

Slope Failure Mechanisms

Typical slope failure mechanisms observed includes:

- Siltstone Block Topple <300mm - The block toppling failure mechanism is typically associated with the three joint sets observed. One joint set is sub-parallel to the face of the headland, one orthogonal joint set and bedding planes and partings.
- Sandstone Block Falls of 1m to 1.5m - The rock fall occurs due to unravelling of sandstone blocks from the headland resulting from the undercutting of the lower siltstone units in the rock face.

Assets at Risk

There is a possibility that up to 8 houses along the eastern side of Myrniong Grove could be at some degree of risk from coastal slope instability hazards over the longer term.

Risk Assessment

Table 3-6 below shows a summary of the hazards and assessed risk to property for Racecourse Beach.

Table 3-6: Berrara Bluff Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Toppling Blocks <300mm	<10yrs	Almost Certain	A	0.5%	Insignificant	5	VL
Rock Fall <1.5m	<100yrs	Likely	B	0.5%	Insignificant	5	L

The qualitative risk assessment for toppling blocks (<300mm in diameter) is anticipated to have a recurrence interval of 10yrs (10^{-1}), that is, the failure is almost certain to occur over the design life, however as blocks toppling towards the toe of the slope are anticipated to have no impact on the houses above the crest, little damage is expected (Level 5). Where the possible occurrence of toppling blocks causing little damage is applied to the risk matrix, the actual risk to property is determined as very low.

The qualitative risk for rock falls and toppling blocks (<1500mm in diameter) that may affect the foundations of houses at Berrara Headland is anticipated to have a recurrence interval of less than 100yrs (10^{-2}), that is, the failure event will probably occur under adverse conditions over the design life. However as blocks falling or toppling towards the toe of the slope are anticipated to have no impact on the houses above the crest, little damage is expected (Level 5). Where applied to the risk matrix, a likely occurrence of block falls where limited damage is expected to the properties above, then the actual risk to property is determined as a low risk.

The quantitative risk to life assessment for the rock fall hazard <1.5m has been assessed using the following assumptions:

$P_{(H)}$ The annual probability of the landslide **– Value Adopted = 10^{-2}**

$P_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.2** (the rock fall event is likely to be rapid and may fall and bounce up to 5m away from the toe of the cliff.

$P_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.1** (Although accessible, it is anticipated that this area would not be highly frequented).

$V_{(D:T)}$ Vulnerability of a individual – Range 10^{-1} – 1 - **Value Adopted = 0.5** (where failure of a block <1.5m is more likely to cause an injury than death to a person attempting to evade the block)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall <1.5m has been estimated to be of the order of 1 x 10^{-4},.

3.4.7 Hyams Point

Hyams Point is a residential area which is surrounded by the Jervis Bay National Park and located between Chinamans and Hyams Beaches approximately 2.5km to the south of Vincentia.

The 5m high slope faces to the north east. The crest of the slope is approximately RL10m and dips up to 60˚ to the north east with the toe at approximately RL 5m. The beach and rock platform is generally up to 25m wide and dips gently towards the coast from the base of the slope.

The geology at Hyams Point comprises Quaternary alluvium comprising swamp deposits, gravel and sand dunes that are underlain by the Conjola Formation. The Conjola Formation includes a sub-horizontal series of weathered Permian sedimentary rocks that are part of the Shoalhaven Group and typically features sandstones, silty sandstones and conglomerates.

Site Observations

- Slope dips 30-60˚ to north east and appears stable.
- Houses well back from the crest of the slope.
- Rock fall observed around Hyams Point headland, see Photograph 3.13 below:

Photograph 3.13 shows an unravelled sandstone blocks at the toe of the slope at Hyams Point.

Slope Failure Mechanisms

- Toppling failure (typical block size <300mm) - The rock fall can occur associated with the undercutting of the lower siltstone and silty sandstone units in the rock face.
- Toppling failure with block size of 1m to 1.5m in upper sandstone unit.

Assets at Risk

There are five houses along the Hyams Point bluff that are at risk from coastal impact in the long term.

Risk Assessment

Table 3-7 below shows a summary of the hazards and assessed risk to property for Hyams Point.

Table 3-7: Hyams Point Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Siltstone Block Topple (<300mm)	<10yr	Almost Certain	A	0.5%	Insignificant	5	L

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Block Fall/Topple (1.5m)	10-30yrs	Likely	B	0.5%	Insignificant	5	L

The qualitative risk assessment for toppling blocks (<300mm in diameter) is anticipated to have a recurrence interval of <10 years (10^{-1}), that is, the failure event is expected to occur over the design life, however as blocks toppling towards the toe of the slope are anticipated to have no impact on the properties above the crest, little damage is expected (Level 5). Where applied to the risk matrix, the occurrence of toppling blocks risk where little damage is expected to property, then the actual risk to property is determined as low.

The qualitative risk for rock falls and toppling blocks (<1.5m in diameter) that is anticipated to have a recurrence interval of 10-30 years, that is, the failure event will probably occur under adverse conditions over the design life. However, it is anticipated that rock falls will do little damage to the properties above the crest (Level 5). Where applied to the risk matrix, a possible occurrence of block falls where little damage is expected, then the actual risk to property is determined as a low.

The quantitative risk to life assessment for the rock fall/topple hazard <1.5m has been assessed using the following assumptions:

$P_{(H)}$ The annual probability of the landslide - Range 1 - 10^{-1} – **Value Adopted = 0.2**

$P_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-2} - **Value Adopted = 0.05** (the rock fall event is likely to be medium to rapid but not reach more than 2m beyond the toe of the slope).

$P_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.1 (**Although accessible, it is anticipated that this area would not be highly frequented**)**.

$V_{(D:T)}$ Vulnerability of a individual – Range 1 - 10^{-1} - **Value Adopted = 0.1** (where failure of a block <1m is more likely to cause an injury than death to a person attempting to evade the block)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall 1.5m has been estimated to be of the order of 1 x 10^{-4}.

3.4.8 Plantation Point

Plantation Point is the most north eastern point of Vincentia. It is situated between Orion and Nelsons Beaches. The area of land above the crest of Plantation Point is currently used as a picnic area/parkland. Plantation Point is the most north eastern point of Vincentia. It is situated between Orion and Nelsons Beaches. To the south, Plantation

Point Parade is a road that runs adjacent to the crest of Nelsons Beach to the east and with residential housing to the west.

The four metre high slope faces to the northwest at Plantation Point. The crest of the slope is approximately five metres (RL) and dips at an angle of up to 70 degrees with the toe at approximately RL 1m to 1.5m. The beach and rock platform are generally greater than 20m wide and dip gently towards the coast from the base of the slope.

Along Nelsons Beach, the crest of the bluff is approximately eight to ten metres above beach level. The crest of the slope is approximately eight metres (RL) and dips at an angle of 70 degrees to vertical. The beach and rock platform are generally greater than 25m wide and dip gently towards the coast from the base of the slope.

The geology at Plantation Point and along the exposed crest of Nelsons Beach comprises moderately weathered sandstone belonging to the Conjola Formation which includes a sub-horizontal series of Permian sedimentary rocks that are part of the Shoalhaven Group and typically features sandstones, silty sandstones and conglomerates.

The geology along Nelsons Beach from beach level comprises some 3.5 metres of iron stained pebbly, highly weathered to moderately weathered sandstone/conglomerate overlain by a two metre thick light grey pebbly sandstone/conglomerate and around 300mm of topsoil.

Site Observations at Plantation Point

- Wave action at high tide is actively undercutting the headland.
- The slope is formed in the moderately weathered grey silty sandstone and siltstone.
- Numerous rotational failures were noted along the headland 3-4m high with notable tree instability from the crest, see Photograph 3.14 below:

Photograph 3:14 shows that coastal processes have weathered the toe of the bluff and toppling failure of the overlying weathered rock, soils and trees has resulted.

Site Observations along Nelsons Beach

- Storm scour has eroded the extremely to highly weathered pebbly sandstone at the toe of the bluff and undercut the top two metres under the crest.
- The beach at low tide is typically >30m from the toe of the bluff.
- Failures including blocks to 0.5 metres and approximately five cubic metre debris slides were observed.
- Water seepage was observed from bedding planes at the toe of the bluff.
- Sections of the bluff have been eroded to within five metre of the road (Nelsons Beach Parade).
- Nature walk path appears to be some ten metres from the crest of the bluff to the south of Nelson Beach Parade.
- Vegetation located in front of residential properties along Nelsons Beach adjacent to the crest of the bluff has been removed or perished.

Photograph 3:14a shows that coastal processes have weathered the toe of the bluff and toppling failure of the overlying weathered rock, soils and trees has resulted.

Slope Failure Mechanisms

Undercutting of the extremely to highly weathered siltstone by coastal processes at high tide and subsequent toppling failure (<$5m^3$) and debris slide of sections of the 4-6m high cliff including 0.5 metre sized blocks.

Assets at Risk

There are no houses or developments at risk at Plantation point. The picnic area is gradually being removed by coastal processes.

The Nelson Beach Parade road reserve located adjacent to Nelsons Beach is at risk during large storm events.

Risk Assessment

Table 3-8 below shows a summary of the hazards and assessed risk to property for Plantation Point. The comprehensive assessment is provided in Appendix B.

Table 3-8: Plantation Point Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Debris Slide ($5m^3$)	1 yr	Almost Certain	A	0.5%	Insignificant	5	L

The qualitative risk assessment for debris slide (<$5m^3$ in volume) is anticipated to have a recurrence interval of 1yr, that is, the failure event is expected to occur over the design life, however as trees topple and debris slides towards the toe of the slope and there are no properties in the near vicinity, little damage to property is expected (Level 5). Where applied to the risk matrix, the occurrence of debris slides where little damage is expected to property, then the actual risk to property is determined as low.

The quantitative risk to life assessment for the debris slides (<$5m^3$) has been assessed using the following assumptions:

$\mathbf{P}_{(H)}$ The annual probability of the landslide, 1 to 2 events following heavy storm activity per annum **– Value Adopted = 0.5**

$\mathbf{P}_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.5** (the rock fall event is likely to be rapid and difficult to evade for individuals within 5m of the toe of the slope).

$\mathbf{P}_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.2** (the adopted value considers 8 hours a day, 4 months in the year of high beach patronage involving high flow of people past the area. Subsequent, it was assumed there was a 0.2 probability of a person being present at the time of the failure).

$\mathbf{V}_{(D:T)}$ Vulnerability of a individual – Range 1 – 10^{-1} - **Value Adopted = 0.5** (where failure of a block <1m is more likely to cause an injury than death to a person attempting to evade the block)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall <1m has been estimated to be of the order of $\mathbf{4 \times 10^{-4}}$.

3.4.9 Penguin Head – Culburra Beach

Penguin Headland is situated at the southern end of Culburra Beach. The flat surface at the crest of the headland comprises a residential area that is accessible from Penguin Head Road. Penguin Head Road runs from west to east bisecting the headland and residential properties are situated on both sides of the road.

The 8-15m high headland faces roughly south. The adjacent rock platform is generally greater than 20m wide and dips gently towards the coast from the base of the slope. In some areas the platform is less then 10m from the toe of the slope.

The geology of the headland comprises Wandrawandian Siltstone of the upper Shoalhaven Group. The Wandrawandian Siltstone sequence comprises siltstones, silty sandstones that are pebbly in part.

Site Observations

- Headland comprises typically dark grey shale, siltstone overlain towards the crest by a silty sandstone unit.
- The headland is approximately 8m to 15m high with slopes averaging 60˚ to 90˚ for the upper slopes.
- Coastal processes at high tide appears to be undercutting more friable shale and siltstone headland causing the competent sandstone blocks to unravel and fall from the upper slope.
- Jointing sub-parallel and sub-perpendicular to the headland

  Jol – 90˚/000˚ : 1-3m spaced

  Jo2 - 90˚/109˚: 0.15m-2.0m spacing

  F1- 37˚/089˚: up to 1m displacement.

- Water flows from bedding planes and jointing in the face of the headland.
- Blocky jointed material. Pedestrians along the rock platform may be in risk of blocks falling from the headland

  F2 – 53˚050˚: 200mm displacement.

- Bedding dips approximately 3˚/135˚, open sub-vertical joints may result in toppling failure of headland rocks.
- Sandstone blocks to 1.2m in size toppling from the jointed cliff line, see Photograph 3.15 below:

Photograph 3.15 shows blocks (1.5m) accumulated at the toe of the bluff.

- Stormwater drainage directed towards slope via poly-pipes from residences above the crest.

- Sections of the northern slope appear to be unravelling however the vegetation is quite thick and trees are not leaning down slope.
- 200m from the headlands eastern tip comprises jointed siltstone undercutting along the cliff-line.
- Debris slide/topple (5-20m^3) due to water infiltration into soil at the crest and coastal processes eroding the siltstone towards the toe of the slope, see Photograph 3.16 below:

Photograph 3.16 shows a recent debris topple (<5m^3) event at Penguin Headland.

- The houses around the headland are typically greater than 10m away from the crest of the slope, however, a few residences are approximately 5m from the slope crest, see Photograph 3.17 below:

Photograph 3.17 shows a property fence adjacent to the crest of the bluff.

Slope Failure Mechanisms

- Rock Topple up to 1.5m in size - The block toppling failure mechanism can occur associated with the three joint sets observed. One joint set is sub-parallel to the face of the headland, one orthogonal joint set and a bedding joint set.
- Rock Fall up to 1.5m in size - The rock fall may be associated with the unravelling of sandstone blocks from the headland resulting from the undercutting of the lower siltstone units in the rock face.
- Debris slide/topple <20m^3 associated with both infiltration of water from rain events or stormwater above the cliff and undercutting of the toe of the slope by coastal processes.

Assets at Risk

Over 35 houses around the headland may be at risk at some time in the future.

Risk Assessment

Table 3-9 below shows a summary of the hazards and assessed risk to property for Penguin Headland – Culburra Beach.

Table 3-9: Penguin Headland - Culburra Beach Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Rock Fall/Topple (1.5m)	10 yrs	Almost Certain	A	0.5%	Insignificant	5	L
Debris Slide/Topple (<20m^3)	100yrs	Likely to possible	B-C	0.5%	Insignificant	5	L-VL

The qualitative risk assessment for toppling blocks (<1.5m in diameter) is anticipated to have a recurrence interval of 10yrs (10^{-2}), that is, the failure event will probably occur under adverse conditions over the design life, however as blocks toppling towards the toe of the slope are anticipated to have no impact on the houses above the crest, little damage is expected (Level 5). Where the occurrence of toppling blocks is expected (anticipating little damage to property) then the actual risk to property is determined as low.

The qualitative risk for debris slides (<20m^3 in volume) is anticipated to have a recurrence interval of 100yrs and will probably occur under adverse conditions over the design life. However, it is anticipated that debris slides will cause little damage to the properties nearby (Level 5). Where applied to the risk matrix, a possible occurrence of debris slides where little damage is expected then the actual risk to property is determined as low to very low.

The quantitative risk to life assessment for the rock fall hazard <1.5m has been assessed using the following assumptions:

$P_{(H)}$ The annual probability of the landslide **– Value Adopted = <10^{-1}**

$P_{(S:H)}$ Probability of spatial impact of hazard – Range 0.1 to 1 - **Value Adopted = 0.1** (the rock fall event is likely to be very rapid but has a limited travel distance (<5m of toe).

$P_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-2} – **Value Adopted = 0.1** (assuming the headland would be mostly frequented in the warmer months, during the day).

$V_{(D:T)}$ Vulnerability of a individual – Range 0.1 – 1 - **Value Adopted = 0.5** (where failure of a block <1.5m occurs in an open space)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall 1.5m has been estimated to be of the order of **5 x 10^{-4}**.

The quantitative risk to life assessment for large scale debris slide/topple event <20m^3 has been assessed using the following assumptions:

P$_{(H)}$ The annual probability of the landslide – Range 10^{-1} – 10^{-3} - **Value Adopted = 10^{-2}**

P$_{(S:H)}$ Probability of spatial impact of hazard – Range 1 – 10^{-1} - **Value Adopted = 0.1** (the rock fall event is likely to be slow to rapid and generally not difficult to evade).

P$_{(T:S)}$ Probability of persons present during event – Range 0 – 1 – **Value Adopted = 0.5** (assuming the backyard usage of a property above the cliff and/or rock platform would be mostly frequented in the warmer months, during the day).

V$_{(D:T)}$ Vulnerability of a individual – Range 10^{-1} – 1 - **Value Adopted = 0.1** (Slow to medium failure of debris is more likely to cause an injury than death to a person attempting to evading the debris)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of a debris slide/topple failure event <20m^3 has been estimated to be of the order of **5 x 10^{-5}**.

3.4.10 Culburra Beach

The slope is located towards the southern end of Culburra Beach. The area above the crest of the slope comprises predominantly a residential area and a car park area that is accessible from Allerton Avenue.

The 10 m to 15m high headland faces north west roughly north to north-west. The adjacent rock platform is generally greater than 20m wide and dips gently towards the coast from the base of the slope. In some areas the platform is less then 10m from the toe of the slope.

The geology of the headland comprises Wandrawandian Siltstone of the upper Shoalhaven Group. The Wandrawandian Siltstone sequence comprises siltstones and silty sandstones that are pebbly in part.

Site Observations

- Headland comprises typically dark grey shale and siltstone overlain towards the crest by a silty sandstone unit.
- The headland is approximately 10-15m high with slopes averaging 60˚ for the upper slopes and 30˚ towards the toe.
- The slope area affected is approximately 140m long.
- Difficult to observe the geological profile due to the thick vegetation.
- Siltstone is HW-EW, orthogonal joint sets observed in the sandstone.
- Wave action at high tide appears to be undercutting the more friable siltstone headland causing the competent sandstone blocks to unravel and fall from the upper slope.
- Trees to 8m high were observed leaning down slope.
- Erosion from around the base of some trees is indicative of poor drainage and erosive nature of overland flow on slope.

- Stormwater drainage directed towards slope from residences above the crest. Appears to have developed a drainage gully in the highly weathered to extremely weathered siltstone slope. Further, minor slumping was observed from the EW siltstone around the gully sides.
- One property has an existing development (shed) on the lower dune that might be at risk in the case of a severe storm.
- Slope is being eroded back through the dune into the HW-EW siltstone beyond.
- Tension cracking observed along the slopes indicative of the ongoing instability and the possibility exists for future slumps in the area.
- The joints are typically open and the slope is gradually unravelling.
- Typical joint Sets 85˚/265˚ with an orthogonal joint set 90˚/187˚ that is evident sub-parallel to the headland.
- In the area of the rock platform, the headland has a set of stairs for beach access to properties above the headland, the property boundaries may be less than 10m from the crest of the slope in this area.
- Significant sandstone boulders observed at the point below the constructed steps.

Slope Failure Mechanisms

- Rock Topple up to 1.5m in size - The block toppling failure mechanism can occur associated with the three joint sets observed from the 10-15m cliff. One joint set is sub-parallel to the face of the headland, one orthogonal joint set and a bedding joint set.
- Slumping 10x8x2=160m^3 and Tree Fall - up to 10m high - Infiltration of water from rain events or stormwater directed towards the slope may result in the mass movement or rotational failure of a section of the slope.

Assets at Risk

There may be five houses at risk in the future. The slope below the car park at the southern end of Culburra Beach may also be at risk at some time in the future.

Risk Assessment

Table 3-10 below shows a summary of the hazards and assessed risk to property for Culburra Beach.

Table 3-10: Culburra Beach Qualitative Risk Assessment

Hazard Size	Likelihood			Consequences			Risk to Property
	Recurrence Interval	Descriptor	Level	Approximate Cost	Descriptor	Level	
Rock Fall/Topple (1.5m)	10 yrs	Almost Certain	A	0.5%	Insignificant	5	L
Slumping/Debris Slide (<200m^3)	10 yrs	Almost Certain	A	5%	Minor	4	H

The qualitative risk assessment for toppling blocks (<1.5m in diameter) is anticipated to have a recurrence interval of 10yrs, that is, the failure event could possibly occur under adverse conditions over the design life, however as blocks toppling towards the toe of the slope are anticipated to have no impact on the houses above the crest, little damage is expected (Level 5). Where applied to the risk matrix, a possible occurrence of toppling blocks risk where little damage is expected to property, then the actual risk to property is determined as low to very low.

The qualitative risk for large slumps or debris slides (<200m^3 in volume) that may affect the car park above the crest of the slope at the southern end of Culburra Beach is anticipated to have a recurrence interval of 10yrs, that is, the failure event is expected to occur over the design life. However, it is anticipated that a large slump may partially damage the car parking facilities (Level 4). Where applied to the risk matrix, the likely occurrence of a large slump where limited damage is expected, then the actual risk level to property is determined as high.

The quantitative risk to life assessment for the rock fall hazard <1.5m has been assessed using the following assumptions:

P$_{(H)}$ The annual probability of the landslide **– Value Adopted = 0.1**

P$_{(S:H)}$ Probability of spatial impact of hazard **–** Range 0.1 to 1 - **Value Adopted = 0.1** (the rock fall event is likely to be very rapid but has a limited travel distance (<5m of toe).

P$_{(T:S)}$ Probability of persons present during event – Range 1 – **10^{-2} – Value Adopted = 0.1** (assuming the headland would be most traffic in the warmer months, during the day on a weekend where 1 person may be present at the time of the failure with no warning).

V$_{(D:T)}$ Vulnerability of a individual – Range 0.1 – 1 - **Value Adopted = 0.5** (where failure of a block <1.5m occurs in an open space)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of the failure of block fall 1.5m has been estimated to be of the order of **5×10^{-4}**.

The quantitative risk to life assessment for large scale debris slide/fall event 200m^3 has been assessed using the following assumptions:

P$_{(H)}$ The annual probability of the landslide – Range 10^{-1} – 10^{-2} - **Value Adopted = 10^{-1}**

P$_{(S:H)}$ Probability of spatial impact of hazard – Range 10^{-1} to 1 - **Value Adopted = 0.1** (the rock fall event is likely to be slow to medium and generally not extend more than 5m beyond the toe of the slope).

P$_{(T:S)}$ Probability of persons present during event – Range 1 – 10^{-1} – **Value Adopted = 0.3** (allows for individuals to be present on the beach or in the car park at the time of the failure).

V$_{(D:T)}$ Vulnerability of an individual – Range 1 – 10^{-1} - **Value Adopted = 0.2** (slow failure may be evident in the car park but not cause injury. Slow to rapid failure of debris is more likely to cause an injury than death to an individual attempting to evade the debris)

On the basis of the assumptions determined above, the annual probability for loss of life in the event of large scale debris slide/fall event 200m^3 has been estimated to be of the order of = **6 x 10^{-4}**.