Great Lakes Coastal Hazard Study

Appendix F – Coastal Slope Risk Assessment, Seal Rocks

Project Name:	Great Lakes Coastal Slope Risk Assessment
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PREPARATION, REVIEW AND AUTHORISATION

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1 INTRODUCTION

1.1 General

The Great Lakes Local Government Area is located on the NSW mid north coast approximately 300km north of Sydney.

In recognition of the growing pressures and complex interactions between coastal processes that operate within the coastal zone, the Great Lakes Council has resolved to undertake a comprehensive Coastal Process and Hazard Definition Study, to take account of contemporary scenarios for long term sea level rise and climate change. The findings of the Study will allow a Coastline Management Study and Coastline Management Plan to be developed, in accordance with the Coastline Management Process as described in the NSW Coastline Management Manual (1990).

Bluffs and headlands with varying slope angles and heights are common features along the shore line. 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 Process and Hazard Definition Study.

Slope instability of bluffs and headlands is a result of the continuing operation of physical processes as well as human 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 human 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 the coastal areas. Needs for sensible management of slope instability hazards therefore constitute an essential objective of the coastal zone management plan.

As part of this Coastal Process and Hazard Definition Study two sites have been identified within the locality of Seal Rocks that require a slope risk assessment to be undertaken.

The intention of this report is to determine the geotechnical risks and management solutions for the two identified sites using a risk based framework. 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 Sites of Interest

The two sites identified as requiring slope risk assessments are detailed below. Location plans are presented in Appendix A.

- The cliff line at the western end of Boat Beach
- The cliff line supporting the access road into Seal Rocks adjacent to Number One Beach

1.3 Scope of Works

The scope of works for the slope risk assessment includes:

- Description of the two sites within Seal Rocks including the potential slope stability hazards present at the sites;
- Qualitative and, where possible, quantitative assessment of the impact of the hazards 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 assessment are presented in this report.

1.4 Document Structure

The document is set out in the following structure:

- Section 2 presents the methodology used to carry out the slope risk assessments. This includes an introduction to the AGS '*Framework for Landslide Risk Management'*;
- Section 3 presents the site descriptions for the two sites at Seal Rocks and the identified slope stability hazards;
- Section 4 presents the slope risk assessment for risk to property and risk of loss of life; and
- Section 5 presents conclusions and recommendations for the two sites.

2 METHODOLOGY

2.1 General

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 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 down slope. 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 1 below shows the major types of landslides (Australian Geomechanics, 2007).

Table 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 rowspan="2">Rock Slide</td><td rowspan="2">Debris Slide</td><td rowspan="2">Earth Slide</td></tr>
<tr><td>Translational</td></tr>
<tr><td colspan="2">Lateral spreads</td><td>Rock Spread</td><td>Debris spread</td><td>Earth Spread</td></tr>
<tr><td colspan="2" rowspan="2">Flows</td><td rowspan="2">Rock Flow
(Deep Creep)</td><td>Debris Flow</td><td>Earth Flow</td></tr>
<tr><td colspan="2">(Soil Creep)</td></tr>
<tr><td colspan="5">Complex – 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. Typical scenarios experienced along coastal headlands and bluffs are presented in Appendix D.

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.

2.3 Risk Assessment: General

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). Definition of the terms used in this report with respect to the slope risk assessment and management is given in Appendix B (reproduced from AGS 2007c Appendix A).

2.4 Risk Assessment: Risk to Property

For risk to property, the risk assessment was primarily based on a qualitative approach. The descriptive terminology used for qualitative assessment in this report is provided in Appendix C (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.

2.5 Risk Assessment: Risk to Loss of Life

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:

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

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.

2.6 Risk Acceptance Criteria

The risk acceptance criteria consider the occurrence of the potential geotechnical hazards identified for the site and evaluate the risk against a Tolerable Risk Criteria for loss of life. In this instance, the individual risk is accepted due to being tolerable or risk mitigation measures are undertaken to reduce the risk to more tolerable levels.

The AGS 2007 guidelines indicate that the regulator, with assistance from the practitioner where required, is the appropriate authority to set the standards for tolerable risks relating to perceived safety in relation to other risks and government policy. The importance of the implementation of levels of the tolerable risk should not be understated due to the wide ranging implications, both in terms of the relative risks or safety to the community and the potential economic impact to the community. The AGS provide recommendations in relation to tolerable risk for loss of life as shown below in Table 2.

The AGS risk threshold provided in Table 2 for existing developments on slopes suggests the 'Tolerable Loss of Life for the person most at risk' is 10^{-5} per annum as existing landslides exist at both sites.

Table 2: AGS suggested Tolerable loss of life individual risk. (AGS, 2007)

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4}/annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5}/annum

Notes:

1. "Existing Slopes" in this context are slopes that are not part of a recognisable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
2. "Existing Development" includes existing structures, and slopes that have been modified by cut and fill, that are not located on or part of a recognisable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
3. "New Constructed Slope" includes any change to existing slopes by cut or fill or changes to existing slopes by new stabilisation works (including replacement of existing retaining walls or replacement of existing stabilisation measures, such as rock bolts or catch fences).
4. "New Development" includes any new structure or change to an existing slope or structure. Where changes to an existing structure or slope result in any cut or fill of less than 1.0m vertical height from the toe to the crest and this change does not increase the risk, then the Existing Slope/Existing Structure criterion may be adopted. Where changes to an existing structure do not increase the building footprint or do not result in an overall change in footing loads, then the Existing Development criterion may be adopted.
5. "Existing Landslides" have been considered likely to require remedial works and hence would become a New Constructed Slope and require the lower risk. Even where remedial works are not required per se, it would be reasonable expectation of the public for a known landslide to be assessed to the lower risk category as a matter of "public safety".

3 SITE INSPECTIONS

3.1 General

Two sites were identified in the Seal Rocks area that required slope risk assessments to be undertaken.

The site inspections comprised geological walkovers of the two sites. The site visits were undertaken in March 2011 by two Experienced 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 plans showing the sites inspected are provided in Appendix A.

The site inspections identified the relevant surface features including geomorphological and drainage characteristics, slope vegetation, surface and ground water conditions, erosion and indications of slope instability.

Slope characterisation was undertaken for each accessed part of the slope during the site inspection 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.

3.2 Boat Beach

3.2.1 Site Description

The Boat Beach slope that was investigated is located between Kinka Road to the west, at the crest of the slope, and Boat Beach to the east, at the toe of the slope. The site comprises a coastal bluff approximately 17m in height with a slope angle varying between 45° to 60°. The slope dips to the east. The section of slope considered is approximately 210 m in length and is shown on the location plan presented in Appendix A.

About eighty percent of the slope is heavily vegetated with bitou bush, shrubs approximately 1m in height and a few trees. There are some visible rock outcrops at the northern and southern end of the site. As such most of the slope area was inaccessible to a walkover survey; however a visual assessment was undertaken from both the toe and the crest of the slope.

Evidence of a previous debris slide was observed in the slope face in the centre of the site. Even though the slope is heavily vegetated it is possible to see that the slope is concave in shape indicating the presence of a failure scar. A gabion wall is located at the top of the failure scar at the same level as Kinka Road. Approximately 140 m^3 and 25 m in length of old debris slide material can be observed at the toe of the slope. This is heavily vegetated, but the uneven appearance indicated that it is not in situ material.

The gabion wall is formed from three levels of gabion baskets each 1m in height and 2m in width. The gabion wall is approximately 16 m in length. The edge of the gabion wall is approximately 1.7 m from road edge. It is understood that the gabion wall is approximately two years old and appears to be in good condition.

Visual evidence indicates that water runoff from Kinka Road is flowing over the centre of the gabion wall and on to the slope below. This could potentially be eroding soil from the slope and undermining the gabion wall.

At the southern end of the gabion wall the crest of the slope is affected by gully erosion and the crest of the slope is soft under foot. This is probably due to runoff from the road and potentially accentuated by a speed hump, located on Kinka Road approximately 5m from the southern end of the gabion wall that also directs water on to the slope. Anecdotal evidence provided by local residents indicates that the slope has failed three times in the last thirty years.

It is noted that the exposed rock comprises grey to dark grey, fresh to slightly weathered, strong to very strong, well bedded siltstone. There is little evidence of rock falls occurring with no boulders or cobble sized rocks visible on the beach. A few areas, at the northern end of the slope, were identified where there is potential for rock fall to occur

Photo 1: View of the area inspected on Boat Beach including the gabion wall at the crest of the slope.

3.2.2 Hazard Identification

Based on the walkover the following hazards have been identified at the Boat Beach site.

- Debris slide from the crest of the slope, this could be to either side of the existing gabion wall and could also potentially include the gabion wall and the area below the gabion wall, especially if the area has been undermined by soil erosion. The magnitude of the debris slides could vary in size from 75 m^3 to 350 m^3.
- There is potential for rock falls to occur. The maximum size of the rock fall material would be boulders up to 1 m in length. The length of slope where rock falls could occur is approximately 145 m in length.

3.2.3 Assets at Risk

Assets at risk from slope failure in the area of Boat Beach are listed below:

- The gabion basket wall located at the crest of the slope
- Kinka Road located at the crest of the slope
- Boat Beach at the toe of the slope

Photo 2: View of the gabion wall at the crest of the slope and alongside Kinka Road.

3.3 Number One Beach

3.3.1 Site Description

The slope investigated at Boat Beach is located between Seal Rocks Road to the south, at the crest of the slope, and Number One Beach to the north, at the toe of the slope. The site comprises a coastal bluff approximately 5m in height with a slope angle varying between 45° to 50°. The slope dips to the north. The section of slope considered is approximately 200m in length and is presented on the site location in Appendix A

The surface of the slope is heavily vegetated with scrub. A visual assessment was undertaken from both the toe and the crest of the slope.

Evidence of previous debris slide at three locations was observed in the slope from the beach. Slip scars were visible with exposed soil and rock. The slip scars were between 3.5 m and 8 m wide and encompassed the total height of the slope. The crest of the slope is approximately 1.2 m to 1.4 m from the edge of the road.

Visual evidence indicates the water runoff from Seal Rocks Road is causing gully erosion in the exposed soil of the slip scars. This could potentially lead to further failures in these areas. During the site visit it was noted that vehicles park along the crest of the slope and people regularly use the slope to access the beach.

Photo 3: View of the slope failures along Number One Beach.

3.3.2 Hazard Identification

Based on the walkover the following hazards have been identified at the Number One Beach site.

- Debris slide from the crest of the slope, this could be either at the site of the existing slip scars or potentially to either side at an area that is currently unaffected. Based on the size of the existing slips the debris slide would be of the order of 25 m^3 to 50 m^3.
- There is the potential for soil creep to occur at the areas of exposed soils. Continued erosion by surface water runoff and potentially by wave action and or the effects of sea level rise can lead to the bluff retreating back leading to the eventual undermining of Seal Rocks Road.

3.3.3 Assets at Risk

The assets at risk from slope failure in the area of Number One Beach are listed below:

- Seal Rocks Road located at the crest of the slope
- Vehicles parked at the crest of the slope along Seal Rocks Road
- Number One Beach at the toe of the slope

4 RISK ASSESSMENT

4.1 Boat Beach Risk Assessment

4.1.1 Risk Estimation

Table 3 below shows the assessed risk to property and the risk of loss of life associated with the hazards for the Boat Beach site.

Table 3: Risk Assessment for Boat Beach

Hazard		Rock Fall (1m long boulder)	Debris Slide (15m in length & 75m³)	Debris Slide (25m in length & 370m³)
Probability	Descriptor	Possible	Likely	Possible
	Level	C	B	C
	Rate	0.001	0.01	0.001
Consequence	Descriptor	Insignificant	Insignificant	Minor
	Level	5	5	4
Property at Risk		Boat Beach	Slope, Road Edge	Road Edge, Gabion Wall
Risk To Property		**Very Low**	**Low**	**Moderate**
Annual Probability of Landslide		0.001	0.01	0.001
Probability of Spatial Impact ($P_{S:H}$)		0.007	0.07	0.12
Probability of Temporal Impact ($P_{T:S}$)		0.18	0.18	0.18
Vulnerability of an Individual ($P_{D:T}$)		0.5	0.1	0.5
Risk (loss of life)		**6.3×10^{-7}**	**1.26×10^{-5}**	**1.1×10^{-5}**

Notes:

1. The annual probability of a rock fall occurring has been calculated based on engineering judgement and observations made during the site visit.
2. The probability of spatial impact of rock falls is calculated by dividing the size of the estimated rock fall by the length (145 m) of bluff where that rock fall type has been identified.
3. The probability of spatial impact of debris slide is calculated by dividing the estimated length of the debris slide by the length (210 m) of bluff where that failure type has been identified.
4. The temporal spatial probability has been calculated based on the assumption that most people will visit during the summer months and public holidays (15 weeks a year). During this time it has been assumed that someone will be present at the toe or crest of the slope for half the day (12 hours). This gives a total occupancy of 1260 hours. For the

remainder of the year it is assumed that someone will present for 5% of the time, 310.8 hours. These occupancy hours are then divided by the number of hours in a year.

5. The vulnerability of an individual is based on values from Australian Geomechanics Vol 42.
6. If visitor numbers to the site were to increase then this would change the risk to loss of life. This could affect whether the risk is considered tolerable or intolerable.
7. Any changes to the site will affect the risk assessment outcome, making it necessary to carry out the risk assessment again.

4.1.2 Risk Evaluation

The risk to property, in this case the gabion wall and Kinka Road varies from very low to moderate risk. A debris slide on the slope of below Kinka Road could possibly cause the failure of the gabion wall and possibly undermine the pavement. A debris slide may potentially cause damage to the road and pavement and could also potentially affect any buried services in the roadway.

Based on the information provided by the AGS, and presented in Appendix C, the implications for a moderate risk level is that it may be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce potential failures to a Low risk should be implemented as soon as practicable.

From the quantitative risk to life assessment it can be seen that the annual probability of risk to life is estimated to range from 1.1×10^{-5} to 6.3×10^{-6}. It can be seen that the greatest risk to loss of life comes from a 350 m^3 debris slide. These values would be deemed tolerable under the AGS risk acceptance criteria.

4.2 Number One Beach Risk Assessment

4.2.1 Risk Estimation

Table 4 below shows the assessed risk to property and the risk of loss of life associated with the hazards for the Number One Beach site.

Table 4: Risk Assessment for Number One Beach

Hazard		Soil Creep	Debris Slide ($50m^3$)
Probability	Descriptor	Likely	Likely
	Level	B	B
	Rate	0.01	0.01
Consequence	Descriptor	Minor	Minor
	Level	4	4
Property at Risk		Seal Rocks Road	Seal Rocks Road
Risk To Property		**Moderate**	**Moderate**
Annual Probability of Landslide		0.01	0.01

Hazard	Soil Creep	Debris Slide ($50m^3$)
Probability of Spatial Impact ($P_{S:H}$)	0.025	0.025
Probability of Temporal Impact ($P_{T:S}$)	0.18	0.18
Vulnerability of an Individual ($P_{D:T}$)	0.01	0.1
Risk (loss of life)	**4.5×10^{-7}**	**4.5×10^{-6}**

Notes:

1. The annual probability of a rock fall occurring has been calculated based on engineering judgement and observations made during the site visit.
2. The probability of spatial impact is calculated by dividing the size of the estimated rock fall by the length (200m) of bluff where that rock fall type has been identified.
3. The temporal spatial probability has been calculated based on the assumption that most people will visit during the summer months and public holidays (15 weeks a year). During this time it has been assumed that someone will be present at the toe or crest of the slope for half the day (12 hours). This gives a total occupancy of 1260 hours. For the remainder of the year it is assumed that someone will present for 5% of the time, 310.8 hours. These occupancy hours are then divided by the number of hours in a year.
4. The vulnerability of an individual is based on values from Australian Geomechanics Vol 42.
5. If visitor numbers to the site were to increase then this would change the risk to loss of life. This could affect whether the risk is considered tolerable or intolerable.
6. Any changes to the site will affect the risk assessment outcome, making it necessary to carry out the risk assessment again.

4.2.2 Risk Evaluation

The risk to property, in this case Seal Rocks Road is a moderate risk. A debris slide on the slope below Seal Rocks Road could possibly cause the undermining of the road. As well the potential to cause damage to the road this will potentially affect any buried services in the roadway. The continued soil creep will not cause a catastrophic slope failure but unless treated and the soil is left exposed it will continue to erode back from a combination of rainfall, stormwater runoff, wave action and sea level and eventually undermine the road.

Based on the information provided by the AGS, and presented in Appendix C, The implications for a moderate risk level is that it may be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to low.

From the quantitative risk to life assessment it can be seen that the annual probability of risk to life is estimated to be 4.5×10^{-6} to 4.5×10^{-7}. This value would be deemed tolerable under the AGS risk acceptance criteria.

5 SUMMARY

5.1 Summary And Conclusion

Slope risk assessments at the two Seal Rocks sites have defined potential slope failure mechanisms presenting a risk to property and/or individuals susceptibility to landslides. Qualitative assessments have been used to define the risk to property at each of the sites visited. Quantitative assessments have been used to define the risk to life at each of the sites visited.

The failure mechanism identified as most commonly occurring at these sites were debris slides ranging from 25 m^3 to 350 m^3. In addition there was some potential for rock falls at Boat Beach. Risk assessments were undertaken on those potential failures deemed significant in terms of potential to cause property damage or risk to life.

The qualitative risk assessments undertaken for property, predominantly public infrastructure such as roads varies from very low to moderate.

Quantitative risk to life assessments of individual susceptibility during the occurrence of failure events also showed that the debris slides resulting in loss of life had a risk varying between 1.1 x 10^{-5} and 4.5 x 10^{-7}. The risk of loss of life from rock falls was 6.3 x 10^{-7}.

The AGS guidelines show an example of evaluating the risks in terms of a tolerable acceptance criteria property loss and loss of life. In this instance, the individual or property risks are accepted due to being tolerable or risk mitigation measures are undertaken to reduce the risk to more tolerable levels.

The AGS 2007 guidelines indicate that the regulator is the appropriate authority to set the standards for tolerable risks relating to perceived safety in relation to other risks and government policy. However, the AGS recommendation of tolerable risk to life on existing developed slopes is 10^{-4} and 10^{-5} on slopes where existing landslides exist. For both the two sites a value of are 10^{-5} has been used as the tolerable level. For both sites the risk to loss of life is tolerable.

In terms of property, the AGS recommends the importance level of the property or structure be rated in terms the societal requirements particularly during or after extreme events. In this case Seal Rocks Road is the only access road into Seal Rocks and therefore would be considered an important structure. A risk to property of moderate has been determined at both sites. The implications for a moderate risk level is that it may be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to low.

5.2 Site Specific Development Recommendations

The site observations and assessments made at each site have been discussed in Section 3 and the risk evaluation has been discussed in Section 4. These assessments have concluded that geotechnical risks identified at a number of the study areas are marginally tolerable for risk to property and as such management and remediation of the sites should be implemented. In addition, specific sites should adopt additional mitigation measures to alleviate the assessed risks including those defined below:

5.2.1 Boat Beach

- Protective measure either side of the gabion wall to prevent the erosion of the slope crest. This could possibly comprise an extension of the gabion wall itself. In addition to the protective measures control of surface water flow should be considered. This is of particular concern where water can overflow the gabion wall and potentially erode the slope below and undermining the gabion wall. Consideration should be given to the placement of a geotextile to prevent surface erosion. It is recommended that the flow of surface water is controlled so that it does not impact on the slope.

- Further inspections should be carried out at regular yearly intervals regarding the stability of the slope and to determine whether any deterioration has increased the risk to loss of life or property.

5.2.2 Number One Beach

- Protective measures need to be implemented at the locations of the existing failure scars. These should at a minimum comprise a geotextile to prevent further erosion of the slope. This should be overlain by rip rap, boulder sized rocks, to further protect the slope.
- Control of surface water runoff on to the slope should be considered. This may require additional drainage along the road.
- Consider putting up signs and barriers to stop the general public parking above the slope and accessing the slope and thereby eroding the slope surface.
- Further inspections are required in future years regarding the stability of the headland and to determine whether any deterioration has increased the risk to loss of life or impacted on the coastal road.

6 REFERENCES

AGS (2007a). “Guideline for landslide susceptibility, hazard and risk zoning for land use planning”, Australian Geomechanics, Vol 42, No. 1, March 2007.

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APPENDIX A – SITE LOCATION PLANS

DATE 23/05/2011

0 25 50 100
1:3,000 Meters

PAGE SIZE A4

COORDINATE SYSTEM GDA94 MGA56

FIG NO. 1

FIGURE TITLE Site Location Plan - Boat Beach

PROJECT NO. 3001829

PROJECT TITLE Great Lakes Coastal Hazard Study

CREATED BY PR11334

SOURCES Vector Backdrop - Roadnet, Copyright Map Data Sciences 2011

SMEC

Celebrating 40 years 1970 - 2010

Location: I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS\Figure 1 - Site Location Plan - Boat Beach.mxd

DATE 23/05/2011	0 50 100 200 Meters 1:4,000	PAGE SIZE A4	COORDINATE SYSTEM GDA94 MGA56
FIG NO. 2	FIGURE TITLE Site Location Plan - Number One Beach		
PROJECT NO. 3001829	PROJECT TITLE Great Lakes Coastal Hazard Study		
CREATED BY PR11334	SOURCES Vector Backdrop - Roadnet, Copyright Map Data Sciences 2011		

SMEC Celebrating 40 years 1970 - 2010

Location: I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS\Figure 2 - Site Location Plan - Number One Beach.mxd

APPENDIX B – DEFINITIONS OF TERMS

APPENDIX B – DEFINITION OF TERMS AND LANDSLIDE RISK

(Australian Geomechanics Vol 42 No 1 March 2007)

Acceptable Risk – A risk for which, 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.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

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.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard – A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide Activity – The stage of development of a landslide; pre failure when the slope is strained throughout but is essentially intact; failure characterised by the formation of a continuous surface of rupture; post failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (e.g. seasonal) or continuous (in which case the slide is “active”).

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Risk – The AGS Australian GeoGuide LR7 (AGS, 2007e) should be referred to for an explanation of Landslide Risk.

Landslide Susceptibility – The classification, and volume (or area) of landslides which exist or potentially may occur in an area or may travel or retrogress onto it. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an “objective” or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment

ii) Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis – An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individual, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: Scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (or risk treatment).

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 landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility – see Landslide Susceptibility

Temporal Spatial Probability – The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide 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.

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APPENDIX C – QUALITATIVE RISK ASSESSMENT

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	**Notional Boundary**					
10^{-1}	5×10^{-2}	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	5×10^{-3}	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	5×10^{-4}	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	5×10^{-5}	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	5×10^{-6}	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	**Notional Boundary**			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (5)
B - LIKELY	10^{-2}	VH	VH	H	M	**L**
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E - RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.

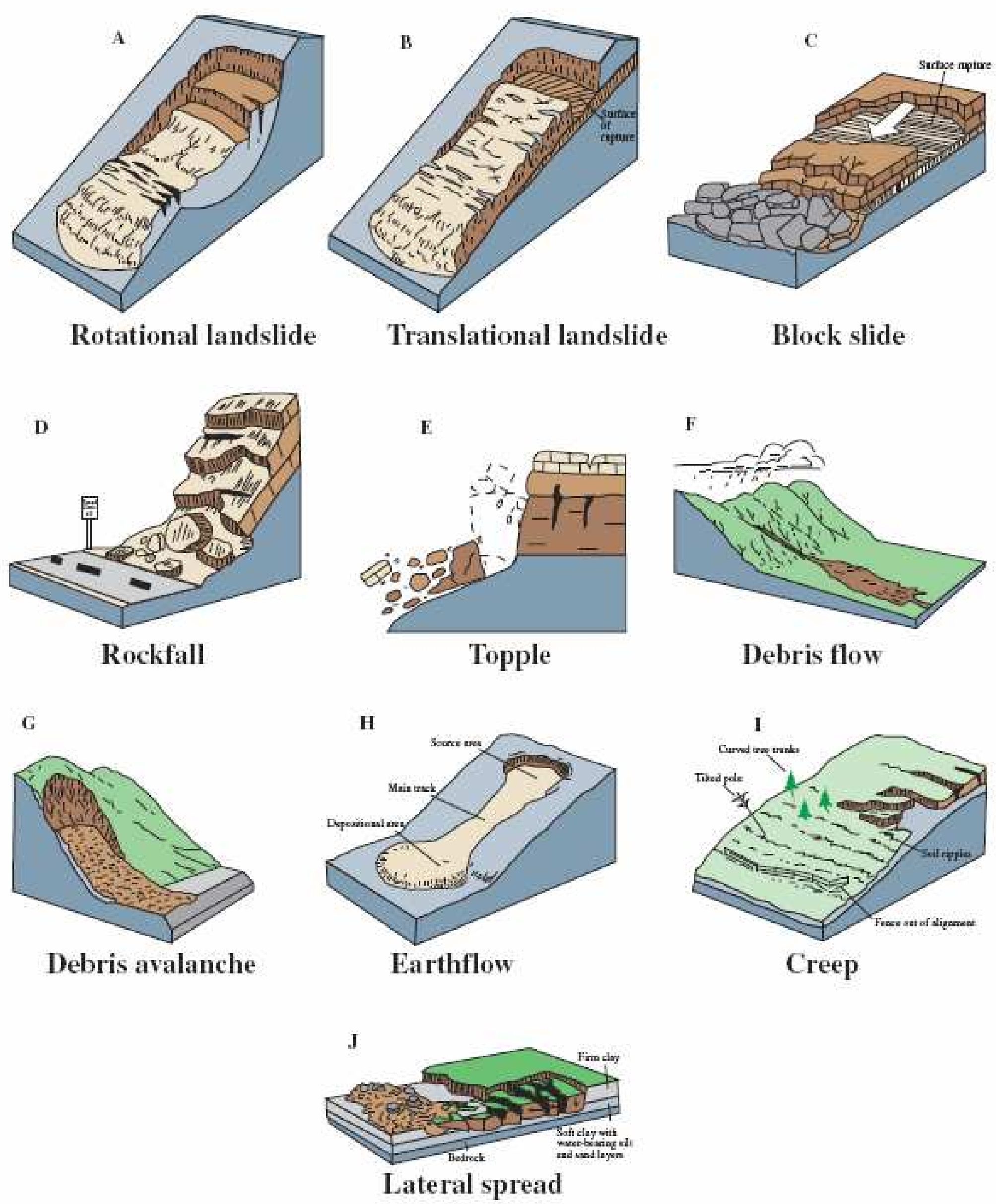
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		Example Implications (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

APPENDIX D – MAJOR TYPES OF LANDSLIDES



ATTACHMENT 3 MAJOR TYPES OF LANDSLIDES