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Slope Risk Assessment Report

Patyegarang Project

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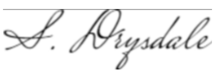
Signature:			
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EXECUTIVE SUMMARY

The Patyegarang Project is a proposed subdivision located within Belrose in the North-East Subregion of the Sydney Metropolitan Region and the Northern Beaches Council Local Government Area. The Site is approximately 72 hectares in size and was unzoned at the time of the investigation.

SMEC has undertaken a site walkover where current and potential failure mechanisms were identified. A slope risk analysis of the failure mechanisms has been carried out in line with Australian Geomechanics Society method “A National Landslide Risk Management Guideline for Australia (2007)”.

SMEC has delineated set zones within the Site area that contain slopes that may potentially pose a risk to future development. These have been grouped into nine sites.

Six main slope instability mechanisms were identified. A risk analysis was undertaken for each of the slope instability mechanisms based on three future land uses.

For the risk to property, the analysis was primarily based on a qualitative approach involving the estimation of the likelihood of a slope failure versus the consequence of the failure. SMEC also undertook an estimation of the risk to life in accordance with the AGS (2007). This approach is primarily based on a quantitative approach.

Based on the findings of the risk analysis the tolerable risk to property for the identified failure mechanisms has not been met, as the risk is classed as moderate to high.

However, the assessed risk for loss of life considering the assumed temporal probabilities are within an acceptable risk level for all six conceptualised mechanisms.

Recommendations to reduce the risk to property to tolerable levels may include; scaling the slope, removal of detached blocks/boulders, installation of rock bolts and consideration of development location.

The risk levels determined are to be considered where the instability mechanisms are present and where development occurs within the subject area.

Based on the information provided to SMEC and the findings of the slope stability assessment carried out, the area is assessed as suitable for the proposed development. It is recommended however that for the discrete locations within the proposed development area where the risk level has been classified as unacceptable or tolerable upon treatment, that implementation of treatment options to reduce this risk level to Low risk should be considered as part of any application.

These risk analyses were based on high level observations, with limited geological mapping undertaken. As such it should be noted that there may be other active or potential slope mechanisms that were not identified. On this basis, it is recommended that for any site development a specific slope stability assessment should be undertaken to assess the slope risk based on a detailed site assessment including investigation. For any development that is undertaken on slopes it is recommended that the advice presented in Appendix B “Examples of good and poor hillside construction” is followed.

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1 Introduction

1.1 Project Background

Metropolitan Local Aboriginal Land Council (referred to herein as MLALC) has requested a Preliminary Site Investigation (PSI) and soil salinity and land capability assessment to inform the planning process of the Patyegarang Project, a proposed subdivision in Belrose, NSW. It is understood that the planning process will provide a framework to support future development on the site. The proposed area is located in the greater Sydney region and occupies approximately 72 hectares of land in the suburb of Belrose.

As part of the land capability assessment slope stability assessments across the site are required; identifying areas which are, or are likely to be, prone to stability problems.

This report details the findings of SMEC's slope stability assessments undertaken for the Patyegarang Project.

1.2 Scope of Work

The scope of work for the slope stability assessments comprised visual slope observation only. It should be noted that this assessment is preliminary in nature and that further intrusive investigations may be required during future design stages.

Prior to fieldwork, the project area was delineated into set zones within the proposed Patyegarang Project which contain slopes that may potentially pose a risk to property. These set zones have been grouped into nine sites as shown on the site location plan in Figure 1.

The scope of work was to undertake a site walkover of the nine sites to identify current and potential failure slope instability mechanisms. The site observations were then used to inform a slope risk assessment of the categorised slope mechanisms in accordance with the Landslide Risk Management guidelines dated March 2007 by Australian Geomechanics Society (AGS, 2007).

Specifically, this role included:

- Observation of the slope characteristics as visible from the roadside or clearly identifiable public land;
- Risk estimation (comparative analysis of the likelihood of a slope failure versus consequence of the failure).
- Evaluation of the estimated (assessed) risk by comparing against acceptance criteria.

2 Site Description and Geology

2.1 Site Description

The Patyegarang Project is located within Belrose in the North-East Subregion of the Sydney Metropolitan Region and the Northern Beaches Council Local Government Area. The location of the site is presented in Figure 1.

The Site is approximately 72 hectares in size and was unzoned at the time of the investigation. Subsequent zoning maps provided to SMEC have the Site listed as C2, RE2 and R2. A mix of public recreational and low density residential land surrounds the Site. The area is within close proximity to a number of sensitive receivers including the Garigal and Ku-ring-gai National Parks and the residential communities of Frenchs Forest and Davidson.

The Site is broken up into two areas separated by Morgan Road which runs in a north to south direction. The western section of the site covers approximately 51 hectares of land and contains the majority of the proposed subdivision. The eastern section is approximately 21 hectares in size with approximately 1/3 of the land use proposed for the subdivision and the remaining proposed as environmental conservation area. Morgan Road also bounds the site to the north, with Kellys Way intersecting the site to the east.

The topography of the area typically consists of undulating hillsides with some steepened precipices and valleys created by Snake Creek. Snake Creek traverses through the western section of the site creating a small valley with surrounding steeper hills. The creek typically runs in a north to south direction with smaller tributaries branching from the east and west.

The typical elevation change over the site is approximately 50m to 60 m. The observed slopes fall from both the eastern and western slopes along Snake Creek. A small plateau up to 20 m high was observed along the southern boundary with a steep ridge line falling towards the south. Larger rock outcrop slopes between 15m to 20 m high sweep from the south to the west boundary with smaller outcrops following the eastern and western valley lines of the creeks. Larger rock slopes greater than 20 m high were also observed along the eastern boundary.

Based on observations from the site visit on 15 October 2020 and GIS extracted information (Figure 1) much of the area comprises terrain with a slope angle of less than 20°. There are some isolated areas where slopes have an angle of up to 30° and a very minor component with slope angles between 30° and 40°. A few vertical precipices up to 5m in height were observed over the site, some containing overhangs and cavern like voids.

Table 2-1 below provides a summary of the proposed land use within each of the nine identified sites. This is based off a proposed structure plan provided by TSA (refer to Figure 3).

Table 2-1: Summary of Proposed Land Use at Each Site

Site	Proposed Land use
1	Larger Residential Living / Proposed Road Infrastructure
2	Larger Residential Living / Proposed Road Infrastructure
3	Typical Residential Living / Environmental Conservation Area / Proposed Road Infrastructure
4	Typical and Larger Residential Living / Environmental Conservation Area / Proposed Road Infrastructure
5	Typical and Larger Residential Living / Environmental Conservation Area / Proposed Road Infrastructure / Aboriginal Cultural Centre / Open Space
6	Proposed Road Infrastructure
7	Typical and Larger Residential Living / Environmental Conservation Area / Proposed Road Infrastructure
8	Typical and Larger Residential Living / Environmental Conservation Area / Proposed Road Infrastructure
9	Typical Residential Living / Proposed Road Infrastructure

Notes: The terminology 'Typical Residential Living' and 'Larger Residential Living' is based on the descriptions outlined within the Structure Plan provided by TSA. For the purpose of this report we have assessed the terminology to refer to Low density and Medium density detached houses, respectively.

Appendix A presents a plan with comments and collation of photographs for each of the nine sites.

2.2 Regional Geology

According to the 1:100,000 Sydney Geological Map (Sheet 9130) the Patyegarang Project site is underlain entirely by Hawkesbury Sandstone of the Wianamatta group of the Triassic Age. This Hawkesbury Sandstone consists of medium to coarse grained quartz sandstone along with very minor shale and laminate lenses.

The regional geology is presented on the geological map extract included in Figure 2.

3 Inspection and Risk Assessment Methodology

3.1 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.

The methodology of assessing the risks at the site comprised the following steps:

- Site inspection involving a geological and geomorphologic appraisal;
- Hazard identification; and
- Risk Estimation.

3.2 Site Inspection

The site visit involved a walkover of the nine respective sites within the Patyegarang Project development area that had been identified by SMEC prior to fieldwork as containing slopes which may potentially pose a risk to future development. The site visit was undertaken on 15 October 2020 by a Senior Geotechnical Engineer and included a walkover survey of the areas by accessing clearly identifiable public land and road reserves. Due to the topography and vegetation cover over the site some areas present restricted access. Therefore identifiable slope features were restricted to those visible from accessible areas.

The site observations included recording of surface features including geomorphological characteristics, evident failure mechanisms, erosion and indications of slope instability.

Slope characterisation was undertaken for each precipice 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, 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 any debris flow or rock movement; and
- identify if risk from a possible slope hazards to existing or future property are acceptable.

3.3 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 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 3-1 shows the major types of landslides (AGS, 2007).

Table 3-1: Major Types of Landslides

Type of Movement	Type of Material		
	Bedrock	Engineering Soils	
		Predominantly Coarse	Predominantly Fine
Falls	Rock fall	Debris fall	Earth fall
Topples	Rock topple	Debris topple	Earth topple
Rotational slide	Rock slide	Debris slide	Earth slide
Translational slide	-	-	Earth spread
Lateral spread	Rock spread	Debris spread	Earth flow
Flows	Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
Complex	Combination of two or more principle types of movement		

The more common landslides occurring along plateaus and the surrounding slopes include falling or toppling rocks and rotational earth or debris slides.

Rock falls generally result from the under-cutting of the precipice by erosional processes, including scour from surface flows and direct rainfall. Rock topple mechanisms occur in a similar fashion to rock falls, however, the inherent jointing structure within the bedrock and root jacking may be additional factors for the instability of a precipice.

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 of weak material along a more competent planar surface.

The frequency of landslides is generally complex and typically dependent on the inter-relationship between the factors influencing the stability of the slope. Some of the common factors affecting the stability of slopes within plateau landscapes include land development, vegetation removal and changes in drainage. Some of the potential failure triggers that may affect the stability of slopes include:

- undercutting by erosion;
- prolonged rainfall with water percolating into rock mass defects causing washout of fines and reduction of rock mass strength;
- earthquakes.

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

3.4 Risk Estimation

A risk assessment was undertaken for each of the categorised slope hazards. 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 as per AGS (2007b).

3.4.1 Risk to Property

For risk to property, the assessment was primarily based on a qualitative approach. 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.

The qualitative terminology for use in assessing risk to property is presented in Appendix C.

3.4.2 Risk to 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:

$$R(LoL) = P(H) \times P(S:H) \times P(T:S) \times V(D:T)$$

Where:

- R (LoL) is the risk (annual probability of loss of life (death) of an individual).
- P (H) is the annual probability of the landslide.
- 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.
- 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.
- V (D:T) is the vulnerability of the individual (probability of loss of life of the individual given the impact).

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

4 Risk Assessment

4.1 General

The benchmark guidelines on Landslide Risk Management (LRM) are presented in the Australian Geomechanics publication, Volume 42, Number 1, dated March 2007. As noted in Section 3.1, this document presents a series of LRM guidelines and further understanding on the application of the risk assessments recommended for use by all practitioners nationwide. This investigation was undertaken in accordance with the LRM guidelines dated March 2007.

4.2 Risk Acceptance Criteria

The risk acceptance criteria consider the occurrence of the potential hazards identified and evaluate the risks against a Tolerable Risk Criteria.

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 on the community.

For property loss, the tolerable risk criterion may be determined by the importance level of infrastructure. The importance level is directly related to societal requirements during, or immediately after, extreme events. The AGS provided recommendation for tolerable risk level to property is the "low" risk level. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required. Otherwise the "very low" risk level is acceptable.

For tolerable risk related to loss of life, the following risk levels are as recommended by AGS. For the purpose of this risk assessment the site may be broadly defined as a new development. The AGS risk threshold provided in Table 4-1 for new developments suggests the 'Tolerable Loss of Life for the person most at risk' is $1x10^{-5}$ per annum.

Table 4-1: AGS Suggested Tolerable Risk (AGS, 2007)

Situation	Suggested tolerable loss of life risk for the person most at risk
Existing Slope (1) / Existing Development (2)	$1x10^{-4}$/annum or 0.01%
New Construction Slope (3) / New Development (4) / Existing Landslide (5)	$1x10^{-5}$/annum or 0.001%

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 acquire the lower risk. Even where remedial works are not required per se, it would be a reasonable expectation of the public for a known landslide to be assessed against the lower risk category as a matter of "public safety".

4.3 Risk Assessment

As noted in Section 3.2, these risk assessments were based on high level observations made during a limited site visit by a Senior Geotechnical Engineer. The assessments are considered to be preliminary because comprehensive and detailed geological mapping of the site was not possible under the prescribed scope of work and the limitations of being able to access all areas of the sites. Any future detailed evaluations of particular sites may change the quantification of the hazard risk.

The data collected for this report has enabled the definition and characterisation of slope instability hazards.

4.3.1 Failure Mechanisms

Photographs showing various site locations where representative slope mechanisms were identified are provided in Appendix A.

During the site inspection the following slope failure mechanisms were identified and conceptualised over the project area. A summary of the apparent failure mechanisms at each site are presented in Table 4-2 below. For each of these failure mechanisms a risk assessment was carried out.

4.3.1.1 Mechanism 1 (M1): Block Falls up to 1m in size from Precipices up to 5m in height

Mobilisation of block falls to 1m in size are considered to arise from the precipices with jointed sandstone units up to 2m in height and influenced by exposure conditions to wind, rain and root jacking.

4.3.1.2 Mechanism 2 (M2): Block Falls up to 2m in size from Precipices greater than 5m in height

Mobilisation of block falls to 1m in size are considered to arise from the precipices with jointed sandstone units up to 5m in height and influenced by exposure conditions to wind, rain and root jacking.

4.3.1.3 Mechanism 3 (M3): Block Falls up to 3m in size from overhangs

Mobilisation of block falls from overhangs are considered to arise from the precipices with major overhangs and influenced by exposure to wind, rain and root jacking.

4.3.1.4 Mechanism 4 (M4): Block Topples up to 2m in size from Precipices up to 5m in height

Mobilisation of block topples to 2m in size are considered to arise from the precipices with major voiding/jointing behind sandstone units up to 5m in height and influenced by exposure conditions to wind, rain and root jacking.

4.3.1.5 Mechanism 5 (M5): Boulder Rolls up to 2m in size from Slopes/Precipices greater that 5m in height

Mobilisation of boulders rolls to 2m in size are considered to arise from the slopes/precipices with detached blocks and influenced by exposure conditions to wind, rain and root jacking.

4.3.1.6 Mechanism 6 (M6): Block Slide – Translational failures up to 3m in size from precipices up to 5m in height

Mobilisation of large blocks to 3m in size are considered to arise from planes and wedge failures controlled by adverse discontinuities or material interface influenced by exposure conditions to wind, rain and root jacking.

Table 4-2: Summary of Apparent Failure Mechanisms at Each Site

Site ID	M1	M2	M3	M4	M5	M6
1	Y	Y	Y	-	Y	Y
2	Y	-	Y	-	-	-
3	Y	Y	Y	-	Y	-
4	Y	Y	Y	Y	Y	-
5	Y	-	Y	-	Y	-
6	Y	Y	Y	-	-	-
7	Y	-	Y	-	-	-
8	Y	-	Y	-	-	Y

Site ID	M1	M2	M3	M4	M5	M6
9	Y	-	Y	-	Y	-

Notes: Y – The failure mechanism was apparent at the site

4.3.2 Understanding Failure Modes and Triggering Factors

In view of the site observations, measurements and experience, a conceptual understanding of the failure mechanisms and contributing factors was developed to comprehend the site vulnerability and associated risks. The main points describing this phenomenon and triggering factors are summarised below;

- The slopes are directly exposed to weathering processes, wind, rain and atmospheric exposure. This provides the mechanism for the rock mass and joints in the rock to be weakened and blocks are loosened.
- The largely absent sub-vertical joint sets reduce the number of potential mechanisms than would be in a highly fractures and frequently jointed rock mass.
- The mature tree cover over the slopes rooting into opened joints and defects. The expansion of roots within joints causes the jacking of joints and blocks can be loosened.

4.3.3 Assets at Risk

As this risk assessment is a high level assessment for future development it is considered that the assets at risk would be newly constructed dwellings or other buildings, roads or areas of congregation of persons such as parks and other recreation areas.

4.3.4 Temporal Probability

The following assumptions have been made with respect to temporal probability. Alteration of these assumptions will inevitably alter the magnitude of risk.

Table 4-3: Adopted Temporal Probability

Aspect of Assessment	Assumed Temporal Probability P(T:S)
Residential Area	It is assumed that people would be present below the slope within residential areas on an average of 30mins/day. This would include being in an area of vulnerability to the mechanism and may include being inside the dwelling proximate to the slope.
Roads	For the suburban roads it is assumed that the temporary probability would be 0.001*.
Recreational Areas	It is assumed that people would be present below the slope within recreational areas on an average of 30mins/day.

*Notes: *Allocation of temporal probability is based on the Temporal Probability Rating Definitions adopted by RMS for Slope Risk Analysis, Table 11 RMS Guide to Slope Risk Analysis Version 4 (RMS 2011).*

With regards to the above temporal probabilities, common usage has been assumed. Allowance for more frequent presence for specific situations, such as persons seeking refuge in adverse weather conditions, has not been considered and therefore re-assessment of the specific land use at the slope is to be undertaken prior to application of these probabilities.

4.3.5 Assessed Risk

Table 4-4 and Table 4-5 below show the assessed risk to property and the risk of loss of life associated with the conceptualised failure mechanisms.

Table 4-4: Summary of Risk Assessment – Level of Risk to Property

Risk Assessment Factors		M1: Block Falls (up to 1m in size) from Precipices up to 5m in height	M2: Block Falls (up to 2m in size) from Precipices greater than 5m in height	M3: Block Falls (up to 3m in size) from overhangs	M4: Block Topples (up to 2m in size) from Precipices up to 5m in height	M5: Boulder Rolls (up to 2m in size) from Slopes/Precipices greater that 5m in height	M6: Block Slide failures (up to 3m in size) from precipices up to 5m in height
Probability P(H)	Descriptor	Likely	Possible	Unlikely	Likely	Possible	Possible
	Level	B	C	D	B	C	C
	Rate	0.01	0.001	0.0001	0.01	0.001	0.001
Consequence to Building	Level	Minor	Medium	Major	Medium	Medium	Minor
	Descriptor	4	3	2	3	3	4
Risk to Property		Moderate	Moderate	Moderate	High	Moderate	Moderate

Table 4-5: Summary of Risk Assessment – Level of Risk for Loss of Life

Risk Assessment Factors		M1: Block Falls (up to 1m in size) from Precipices up to 5m in height	M2: Block Falls (up to 2m in size) from Precipices greater than 5m in height	M3: Block Falls (up to 3m in size) from overhangs	M4: Block Topples (up to 2m in size) from Precipices up to 5m in height	M5: Boulder Rolls (up to 2m in size) from Slopes/Precipices greater that 5m in height	M6: Block Slide failures (up to 3m in size) from precipices up to 5m in height
Probability P(H)		0.01	0.01	0.01	0.01	0.001	0.001
Probability of Spatial Impact ($P_{S:H}$)		0.04 (1m length failure over 25m section of slope)	0.04 (1m length failure over 25m section of slope)	0.08 (2m length failure over 25m section of slope)	0.1 (2m length failure over 20m section of slope)	0.08 (2m length failure over 25m section of slope)	0.15 (3m length failure over 20m section of slope)
Vulnerability of an Individual ($V_{D:T}$)		1.0 (person killed) 0.1 (person injured)					
Probability of Temporal Impact ($P_{T:S}$)	Residential Areas	0.021					
	Roads	0.001					
	Recreational Areas	0.021					
Risk (loss of life)	Residential Areas	Death 8.4×10^{-6} Injury 8.4×10^{-7}	Death 8.4×10^{-6} Injury 8.4×10^{-7}	Death 1.68×10^{-5} Injury 1.68×10^{-6}	Death 2.1×10^{-5} Injury 2.1×10^{-6}	Death 1.68×10^{-6} Injury 1.68×10^{-7}	Death 3.15×10^{-6} Injury 3.15×10^{-7}
	Roads	Death 4.0×10^{-7} Injury 4.0×10^{-8}	Death 4.0×10^{-7} Injury 4.0×10^{-8}	Death 8.0×10^{-7} Injury 8.0×10^{-8}	Death 1.0×10^{-6} Injury 1.0×10^{-7}	Death 8.0×10^{-7} Injury 8.0×10^{-8}	Death 1.5×10^{-7} Injury 1.5×10^{-8}
	Recreational Areas	Death 8.4×10^{-6} Injury 8.4×10^{-7}	Death 8.4×10^{-6} Injury 8.4×10^{-7}	Death 1.68×10^{-5} Injury 1.68×10^{-6}	Death 2.1×10^{-5} Injury 2.1×10^{-6}	Death 1.68×10^{-6} Injury 1.68×10^{-7}	Death 3.15×10^{-6} Injury 3.15×10^{-7}

5 Discussion and Recommendations

The data collected during the site visit by a Senior Geotechnical Engineer has enabled the definition and characterisation of slope instability mechanisms at the nine sites. Six main mechanisms were identified. These are listed below:

- Mechanism 1: Block Falls up to 1m from Precipices up to 5m in height
- Mechanism 2: Block Falls up to 2m from Precipices greater than 5m in height
- Mechanism 3: Block Falls up to 3m from overhangs
- Mechanism 4: Block Topples up to 2m from Precipices up to 5m in height
- Mechanism 5: Boulder Rolls up to 2m from Slopes/Precipices greater that 5m in height
- Mechanism 6: Block Slide failures up to 3m from precipices up to 5m in height

SMEC considered three future uses for any land development and made assumptions with regards to the temporal probability for these uses (detailed in Section 4.3.4). The three land uses considered are:

- Residential Areas
- Roads
- Recreational Areas

A risk assessment was undertaken for each of the slope instability mechanisms. For risk to property, the assessment was primarily based on a qualitative approach involving the estimation of the likelihood of a slope failure versus the consequence of the failure.

In addition to the risk to property SMEC also undertook an estimation of the risk to life in accordance with the AGS (2007). This approach is primarily based on a quantitative approach.

5.1 Results of the Risk Assessment

Based on the findings of the risk assessment, as presented in Section 4.3.5, it has been established that the tolerable risk to future development for the identified failure mechanisms has not been met as the risk is classed as moderate to high.

The risk to loss of property has been assessed for each of the nine identified sites based on the assessed possible failure mechanisms observed during the site visit on 15 October 2020 (Table 4-2). The results of the risk assessment for each site have been summarised in Table 5-1 below.

Table 5-1: Summary of Risk Level at each of the Nine Sites

Site ID	Level of Risk to Property
1	Moderate
2	Moderate
3	Moderate
4	High
5	Moderate
6	Moderate
7	Moderate
8	Moderate
9	Moderate

According to the AGS suggested tolerable levels for loss of property for the above conceptualised mechanisms do not yield acceptable levels. As noted in the AGS Guidelines, the implications for risk to loss of property of moderate and high levels are outlined in Table 5-2 below.

Table 5-2: Risk Level Implications as per AGS Vol 42, 2007

Risk Level	Implication Guideline
High	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.
Moderate	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.

The risk for loss of life has been assessed based on the AGS suggested tolerable levels for loss of life outlined in Table 4-1 and considering the assumed temporal probabilities. The risk for loss of life is considered within an acceptable risk level for all six conceptualised mechanisms.

The assessed risk levels should be considered where the instability mechanisms are present within the subject area and implementation of treatment options should be considered as part of any application.

A summary of stabilisation recommendations for reducing the risk levels is presented in Table 5-3 below.

Table 5-3: Summary of Stabilisation Recommendations

Recommendations	Description
Scaling	Removal of rock blocks/mass can be coupled with site earthworks process
Rock Bolts	Rock bolts are frequently used for stabilisation applications of potentially unstable rock blocks due to their relative low cost and fast installation process
Appropriateness of Building	Location of proposed buildings, and suitability of building to withstand a dislodged block may be considered to accept a high level of risk or to derive a tolerable risk level
Areas of no development	Subdvision to be designed with building envelopes away from potential rock fall precipices or land slide areas.

5.2 Conclusion

Based on the information provided to SMEC and the findings of the slope stability assessment carried out, the area is assessed as suitable for the proposed development. It is recommended however that for the discrete locations within the proposed development area where the risk level has been classified as unacceptable or tolerable upon treatment, that implementation of treatment options to reduce this risk level to Low risk should be considered as part of any application.

As noted in Section 3.2, these risk analyses were based on high level observations, with limited geological mapping undertaken. As such it should be noted that there may be other active or potential slope mechanisms that were not identified. Any future detailed evaluations of particular sites may change the quantification of the hazard risk

On this basis, it is recommended that for any site development a specific slope stability assessment should be undertaken to assess the slope risk based on a detailed site assessment including investigation. For any development that is undertaken on slopes it is recommended that the advice presented in Appendix B "Examples of good and poor hillside construction" is followed.

6 References

- AGS (2007a). “Guideline for landslide susceptibility, hazard and risk zoning for land use planning”, Australian Geomechanics, Vol 42, No. 1, March 2007.
- AGS (2007b). “Commentary on guideline for landslide susceptibility, hazard and risk zoning for land use planning”, Australian Geomechanics, Vol 42, No. 1, March 2007.
- AGS (2007c). “Practice note guidelines for landslide risk management”, Australian Geomechanics, Vol 42, No. 1, March 2007.
- AGS (2007d). “Commentary on practice note guidelines for landslide risk management”, Australian Geomechanics, Vol 42, No. 1, March 2007.
- AGS (2007e). “Australian GeoGuides for slope management and maintenance”, Australian Geomechanics, Vol 42, No. 1, March 2007.
- DM (1983). "1:100,000 Geological Series Sheets 9130", Department of Mineral Resources, First Edition, 1983.
- RMS (2011). "RMS Guide to Slope Risk Analysis Version 4", 2011.

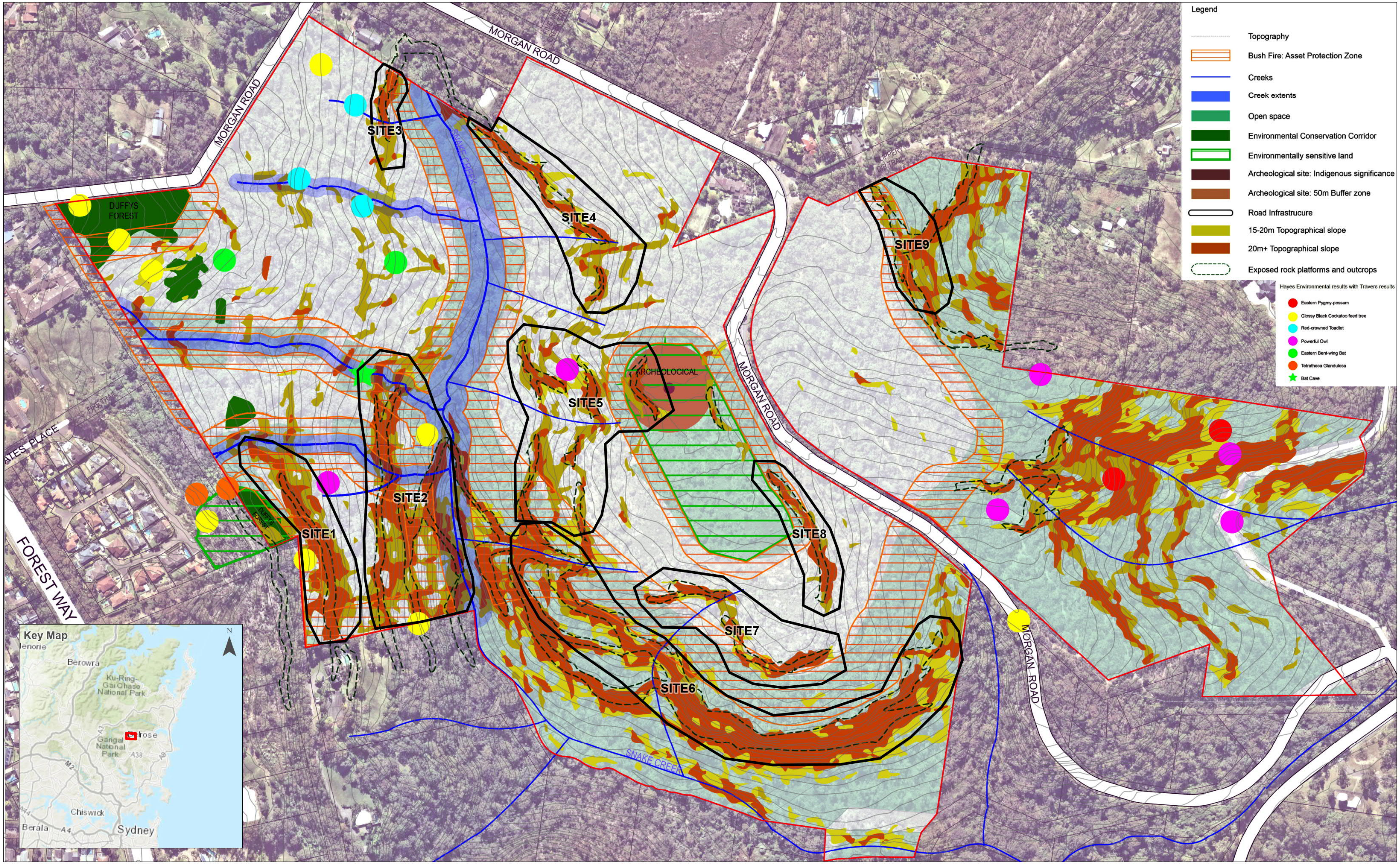
Figures

Figure 1 – Site Location Plan

Figure 2 – Regional Geology Map

Figure 3 – Proposed Structural Development Plan

Figure 1: Site Location Plan



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0 50 100 150 200
Meters
1:4,000

SOURCES:
1. Contours © Lot search 2020
2. Map provided by Top Spring
3. Basemap © World Topographic Map: Esri, HERE, Garmin, USGS, NGA

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, this map contains data from a number of sources - no warranty is given that the information contained on this is free from error or omission. Any reliance placed on such information shall be at the sole risk of the user. Please verify the accuracy of all information prior to using it. This map is not a design document.

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Figure 2: Geology

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Meters
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Geological Units

- Medium to coarse grained quartz sandstone, very minor shale and laminate lenses
- Volcanic breccia, varying amounts of sedimentary breccia, and basalt.

SOURCES:
1. Geology © NSW Government 2020
2. Basemap © World Topographic Map: Esri, HERE, Garmin, USGS, NGA
World Imagery: Maxar

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Figure 3: Structure Plan

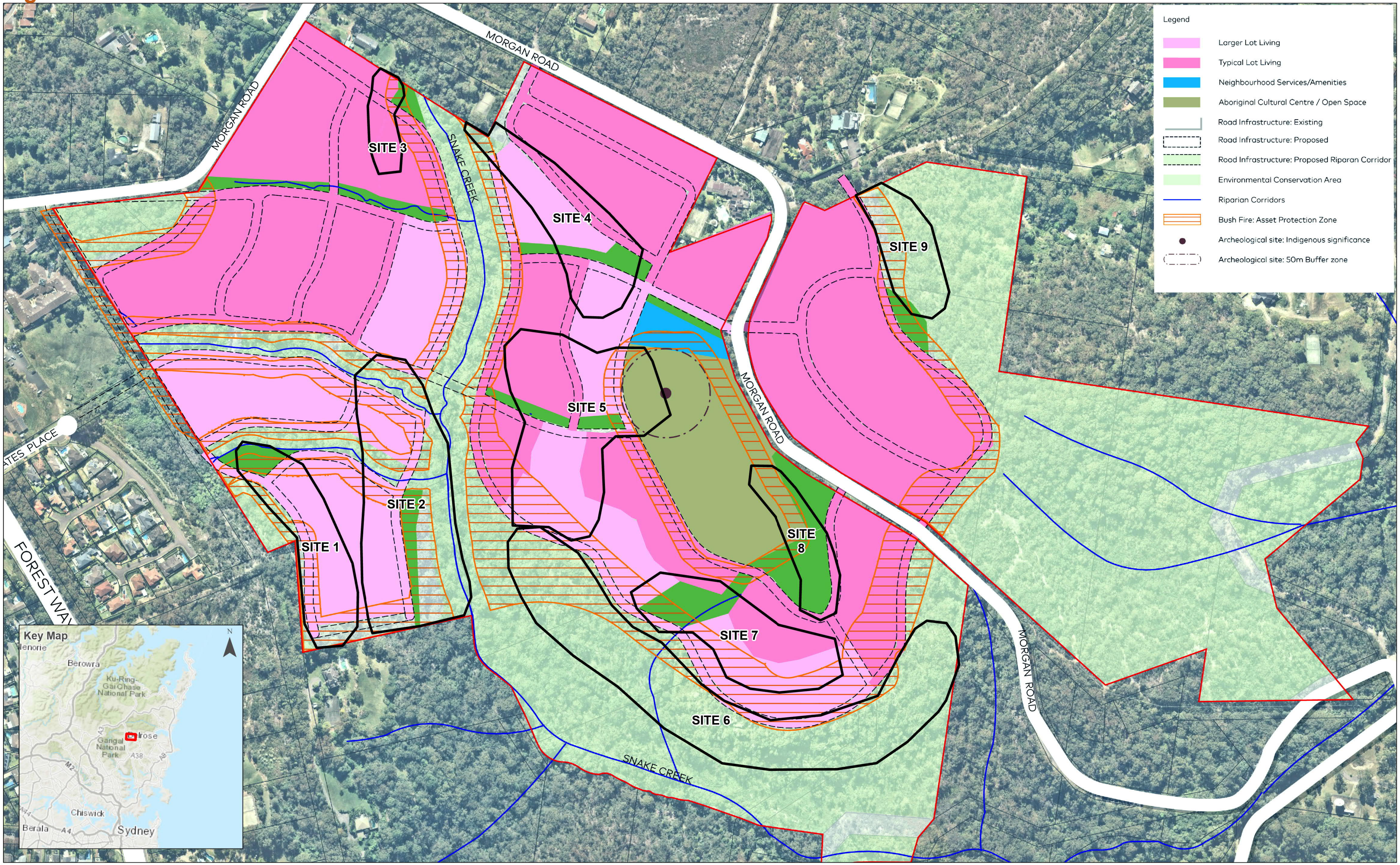

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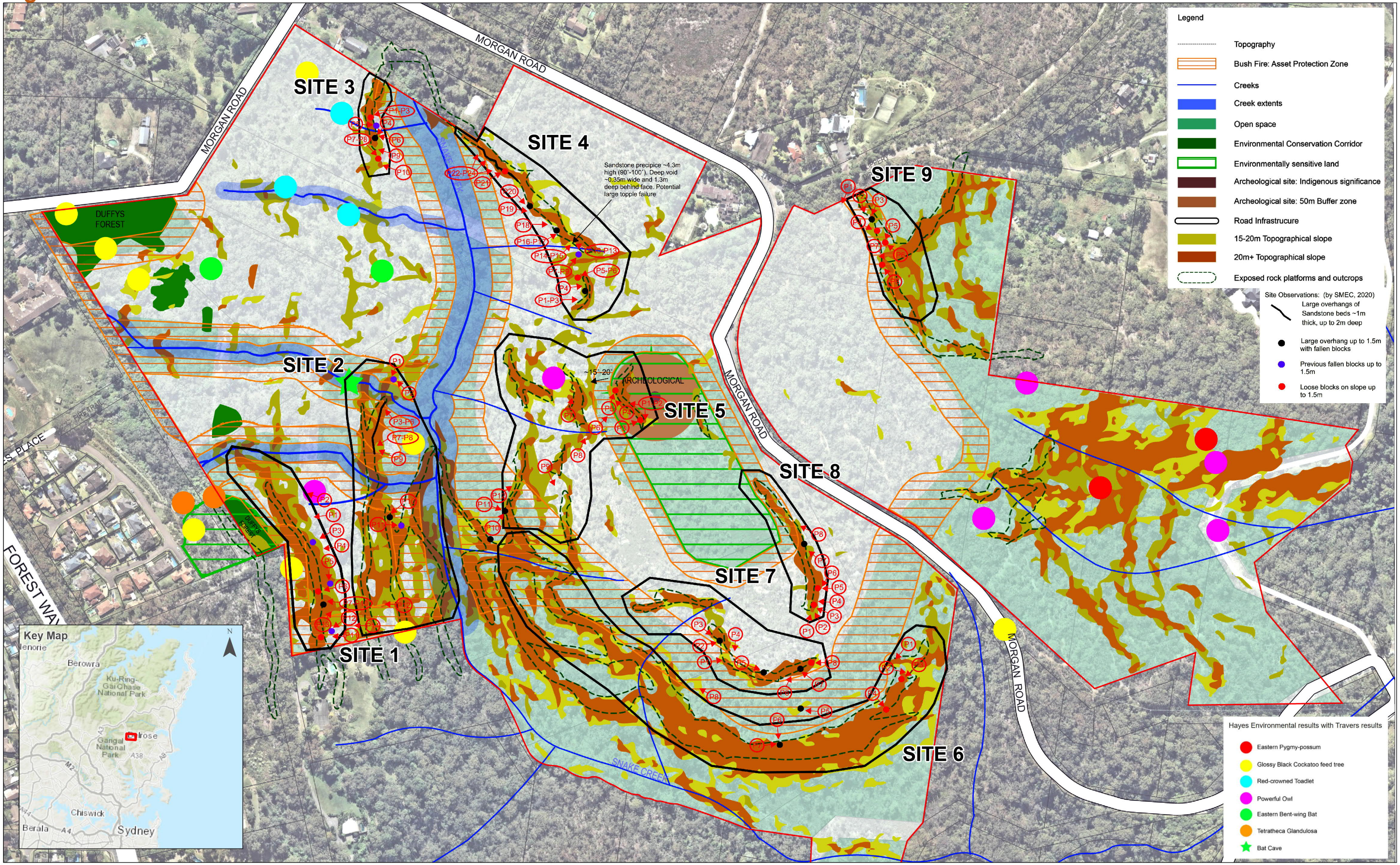
Figure 4: Photo Location Plan



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SOURCES:
1. Contours © Lot search 2020
2. Map provided by Top Spring
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Appendix A Photographs and Notes

Figure 4 – Visual Risk Analysis Photo Location Plan

Site 1 Photographs

Photograph 1: View looking west, power line and rock outcrop slopes

Photograph 2: View looking north-west, recent devegetation underneath power lines

Photograph 3: View looking south west, large blocks up to 1.5m at toe of slope

Photograph 4: View looking west, large detached block on slope suspect previous fall

Photograph 5: View looking south along crest of precipice, large fallen blocks up to 2.5m observed

Photograph 6: View looking west, loose blocks on slope crest up to 0.8m

Photograph 7: View looking west, large overhangs up to 1.5m at crest

Photograph 8: View of large overhangs at crest

Photograph 9: View of sandstone weathered at crest creating cavern like features

Photograph 10: View looking north-west, overhangs and loose blocks observed

Photograph 11: View of loose blocks up to 0.8m at crest

Photograph 12: View looking south-west, previous large failures observed suspect translational slide mechanism

Photograph 13: View looking north along crest, large loose blocks observed

Photograph 14: View looking west towards rock outcrop slopes

Site 2 Photographs

Photograph 1: Looking south, overhangs up to 0.8m observed

Photograph 2: View looking north-west, large boulder on slope with smaller loose block balancing on top

Photograph 3: View looking north-west, large sandstone bed with up to 2.5m undercut

Photograph 4: View underneath large sandstone bed, loose fallen blocks underneath

Photograph 5: View underneath undercut sandstone bed, water seepage observed

Photograph 6: View underneath undercut sandstone bed

Photograph 7: View of overhangs a lot sandstone precipice (height approximately 3-4m)

Photograph 8: View looking west at sandstone precipice, weaker eroded beds creating overhangs of larger beds

Photograph 9: View of overhangs up to 1m

Photograph 10: View looking south-west, loose undercut blocks on slope

Photograph 11: View looking east, previous fallen blocks at toe, up to 0.6m

Photograph 12: View looking west, loose sandstone blocks on slope

Site 3 Photographs

Photograph 1: View looking west, loose undercut block up to 1m

Photograph 2: View looking west, view undercut sandstone beds

Photograph 3: View of large block, potential for collapse

Photograph 4: View looking south towards slope crest, overhangs and loose blocks observed

Photograph 5: View of large fallen block on slope

Photograph 6: View looking west towards crest of precipice, overhangs and undercut blocks observed

Photograph 7: View looking south along crest, loose blocks along crest

Photograph 8: View of loose block at crest, approximately 2m x 0.5m

Photograph 9: View looking west, loose blocks and overhangs at crest

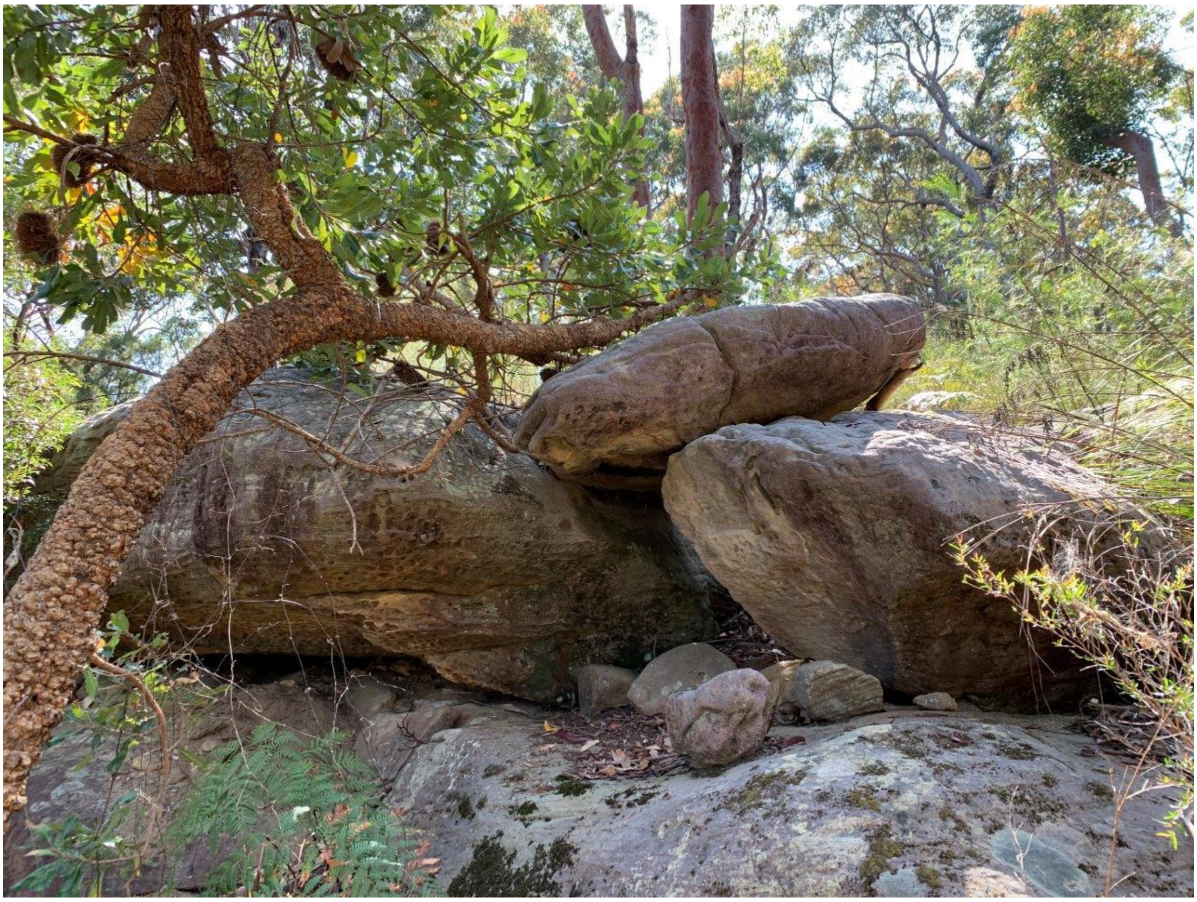
Photograph 10: View looking north, previous large fallen blocks from overhangs

Photograph 11: View looking north along crest

Site 4 Photographs

Photograph 1: View looking east towards sandstone precipice up to 4.5m height

Photograph 2: View looking east, loose boulders ad block at crest



Photograph 3: View of loose undercut blocks at crest

A

Photograph 4: View of hollow mature tree and undercut blocks at crest

Photograph 5: View looking south-east, view of large block (~0.8m x 2m) potential topple failure

Photograph 6: View of overhangs and loose blocks on slope

Photograph 7: View looking north-east, large previous falls/topple failures

Photograph 8: View of previous large fall/topple, 1.5m x 5m

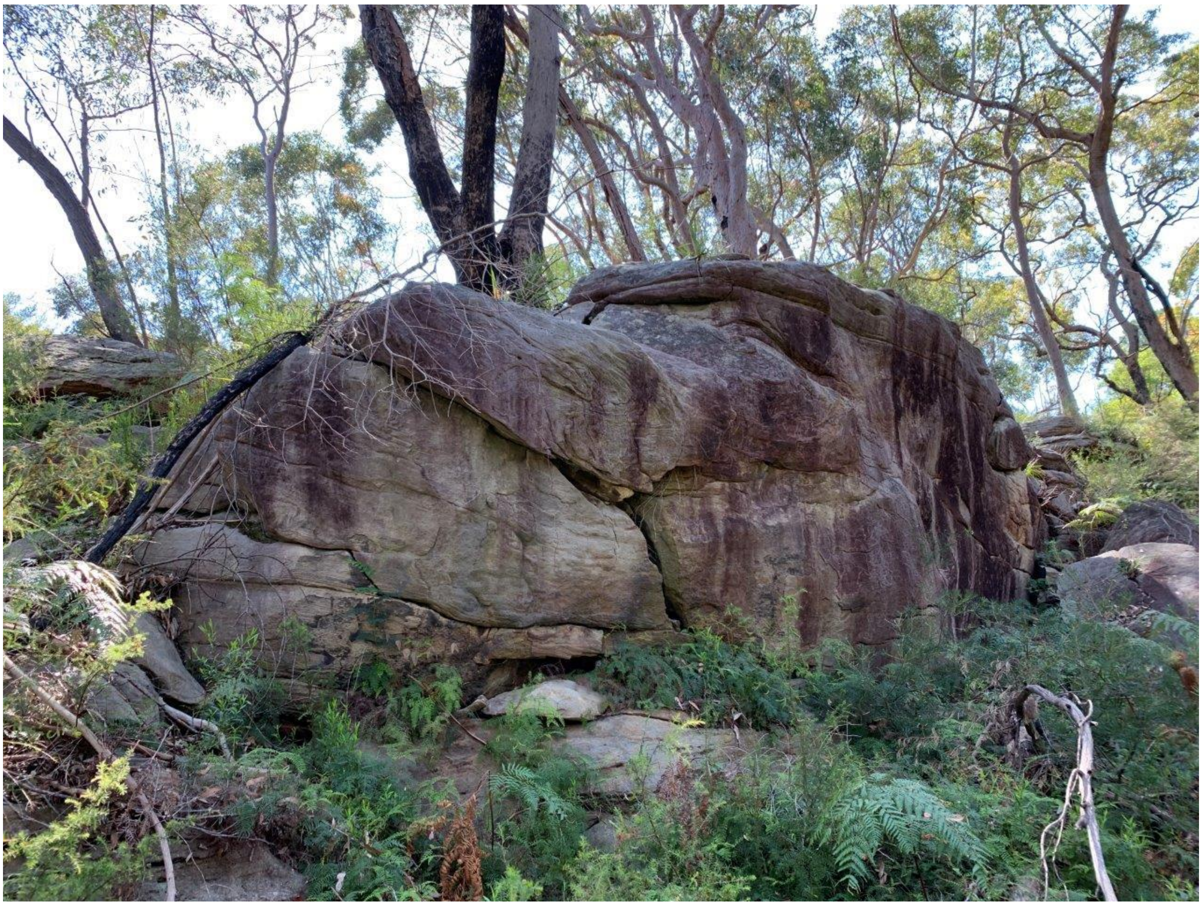
Photograph 9: View looking west of previous large failure

Photograph 10: View looking north along crest of precipice

Photograph 11: View looking north along ~4.3m high sandstone precipice, large void observed behind face

Photograph 12: View of large void approximately 0.35m wide and 1.3m deep, vegetation debris blocking truth depth

Photograph 13: View looking north-east at face of precipice, high potential of topple failure with large void behind face



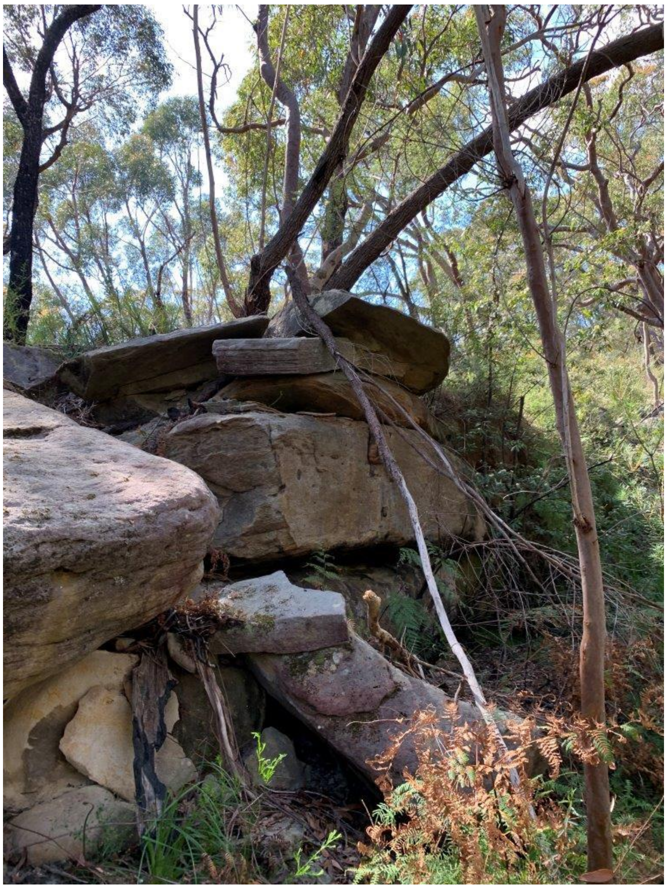
Photograph 14: View looking south-east at cracks within sandstone precipice

Photograph 15: View of open cracks within sandstone face, potential of fall/topple

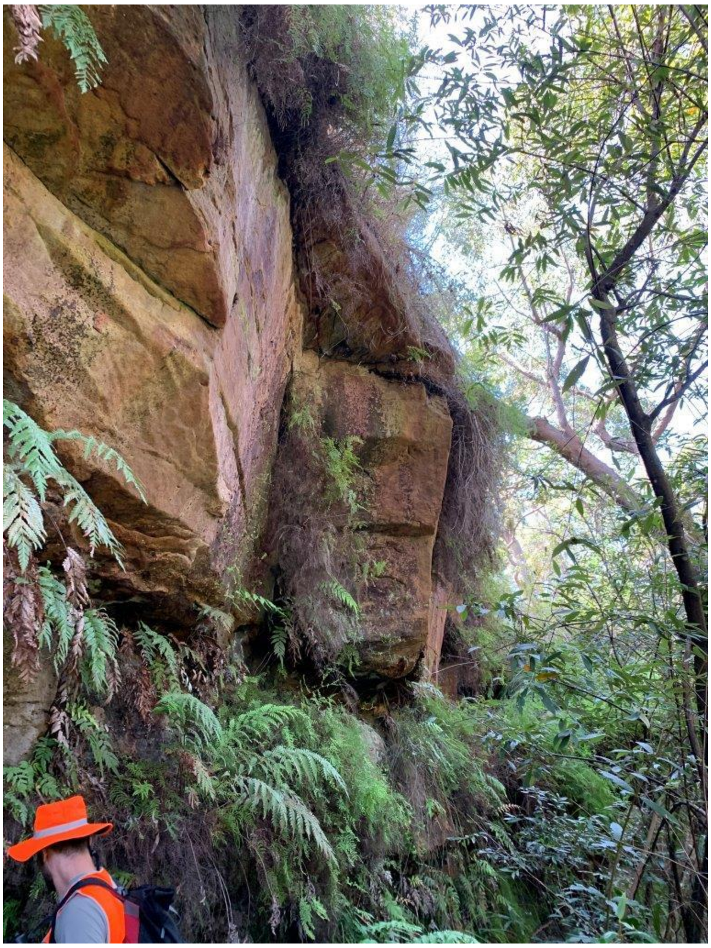
Photograph 16: View looking north, mature tree at crest, loose undercut blocks at crest

Photograph 17: View looking east, cracking observed within sandstone precipice, potential root jacking from mature tree

Photograph 18: View of large undercut sandstone beds


Photograph 19: View of large undercut sandstone bed and loose blocks at crest of precipice up to 1m


Photograph 20: View looking south-east, previous failure of large sandstone bed up to 1.5m thick



Photograph 21: View of large subvertical joint creating potential fall of large block ~1.2m x 2.5m

Photograph 22: View of sandstone precipice ~12m height, overhangs up to 2.5m observed

Photograph 23: View of high sandstone precipice with overhangs

Photograph 24: View looking south along large sandstone precipice

Site 5 Photographs

Photograph 1: View looking north along sandstone plateau

Photograph 2: View looking south along sandstone plateau

Photograph 3: View of loose blocks near crest of sandstone precipice

Photograph 4: View looking north-west downslope

Photograph 5: View of previous falls up to 2m

Photograph 6: View looking east upslope, loose boulders up to 2m on slope

Photograph 7: View looking north along sandstone precipice up to 1.5m height

Photograph 8: View of weathering in sandstone precipice creating cavern like feature

Photograph 9: View looking south towards sandstone precipice outcrop

Photograph 10: View looking east, large overhang up to 2m at crest of precipice

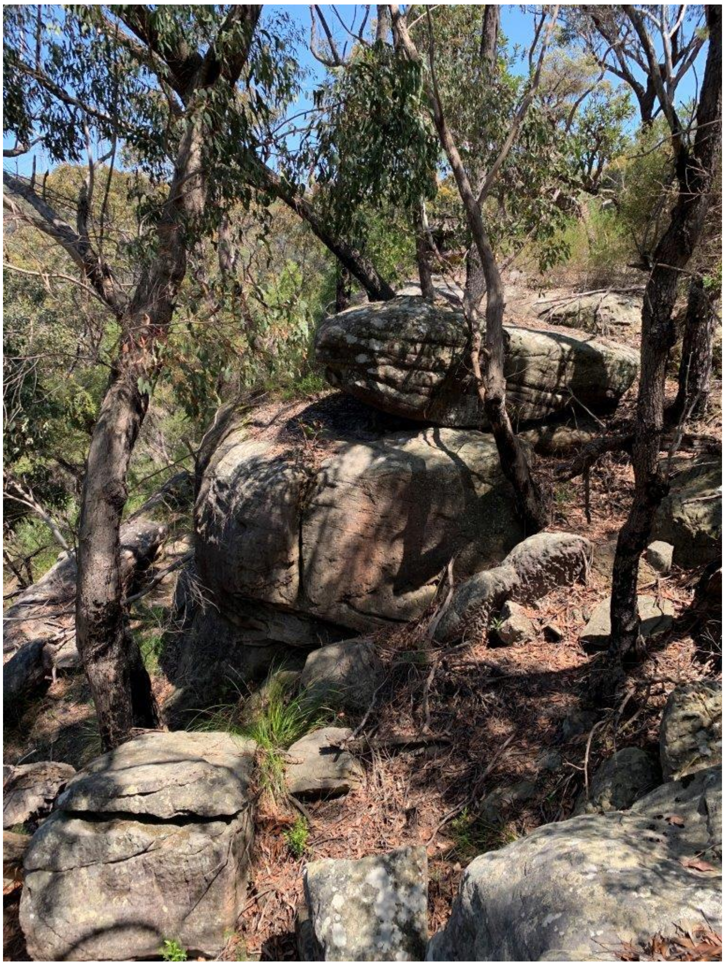
Photograph 11: View looking south, overhangs along crest

Photograph 12: View looking north, sandstone precipice up to 2m height

Site 6 Photographs

Photograph 1: View looking west, loose blocks on slope

Photograph 2: View looking south down slope



Photograph 3: View looking south-west, overhangs and undercut blocks

Photograph 4: View looking south, loose blocks along crest, Telstra satellite station noted in background

Photograph 5: View of overhangs along precipices up to 2m height

Photograph 6: View looking south at crest, open void ~0.3m with large overhanging blocks at crest

Photograph 7: View of large overhangs along crest of cliff line

Photograph 8: View of sandstone outcrop at surface

Site 7 Photographs

Photograph 1: View looking east at sandstone precipices up to 2m height

Photograph 2: View of overhangs and loose blocks at crest

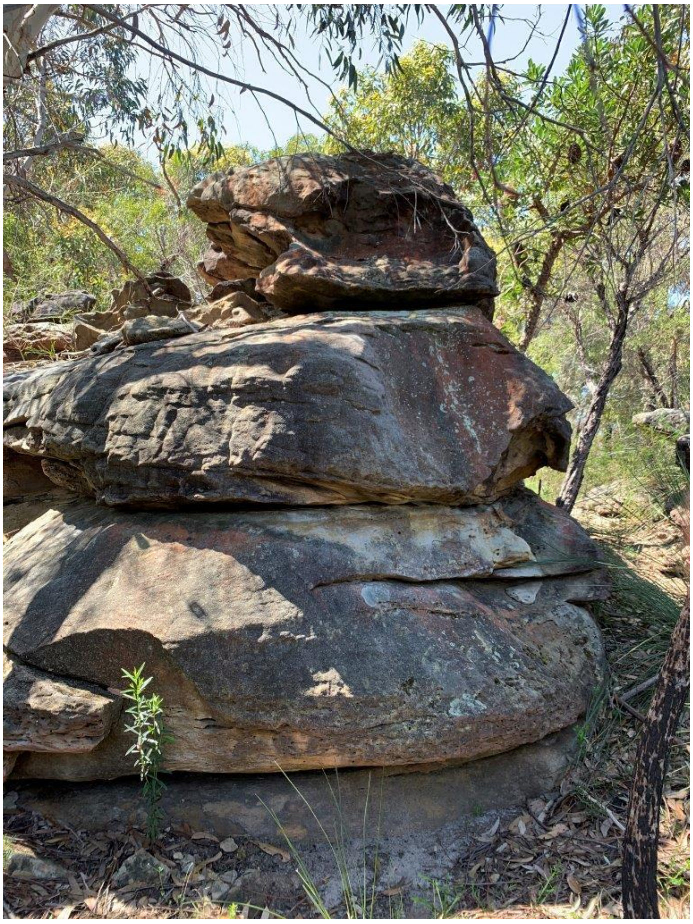
Photograph 3: View looking south, undercutting of large sandstone bed caused by erosion and weathering of weaker beds

Photograph 4: View of loose boulders on slope

Photograph 5: View looking east, overhangs up to 1m observed in precipices up to 1.5m height

Photograph 6: View looing north-east, minor overhangs up to 0.5m observed through sandstone precipice

Photograph 7: Overhangs up to 0.5m observed



Photograph 8: View of large loose block at crest of 2m high precipice

Site 8 Photographs

Photograph 1: View looking north at sandstone precipice

Photograph 2: View of weathering of sandstone boulder up to 2m, weathering creating cavern like feature

Photograph 3: View looking west, overhangs of loose blocks along crest

Photograph 4: View looking west, overhangs up to 0.8m observed

Photograph 5: View looking west, large loose block (~1m x 1.5m) at crest, potential slide failure

Photograph 6: View looking south along sandstone precipice up to 2.5m height

Photograph 7: View looking north along sandstone precipice up to 2.5m height

Photograph 8: View looking north toward sandstone precipice up to 2.5m high, overhangs up to 1m observed

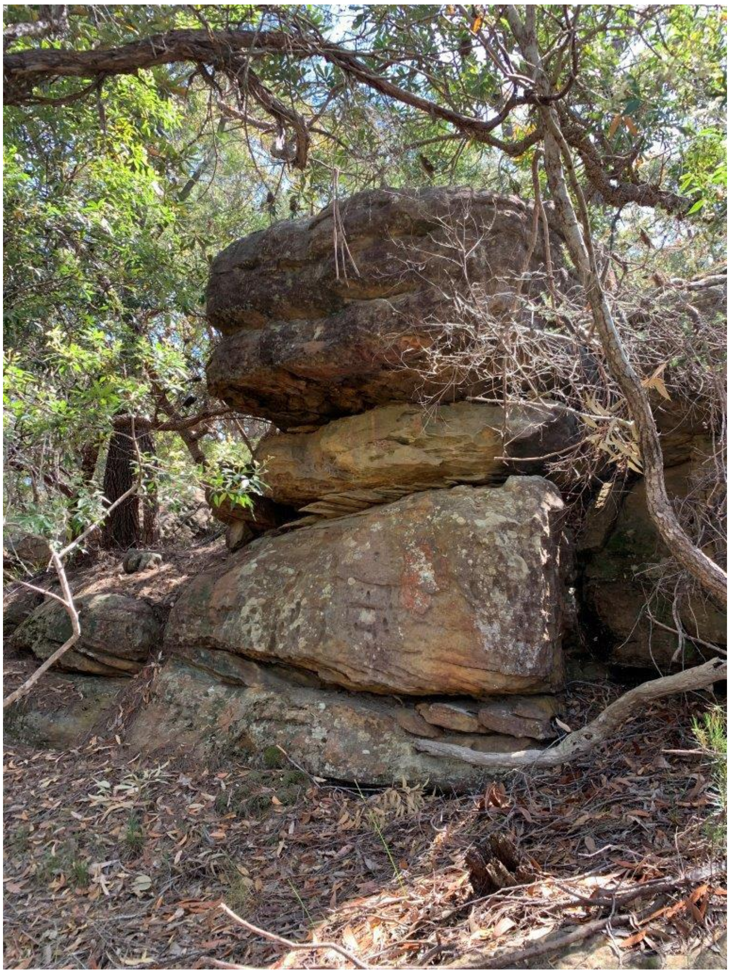
Site 9 Photographs

Photograph 1: View looking west along Slippery Dip Road, cutting up to 1.5m

Photograph 2: View looking south along sandstone outcrop

Photograph 3: View looking south, overhangs up to 1m

Photograph 4: View looking south-east, large loose blocks on slope



Photograph 5: View looking south, large loose sandstone bed with fractured weathered seam, potential of fall/topple

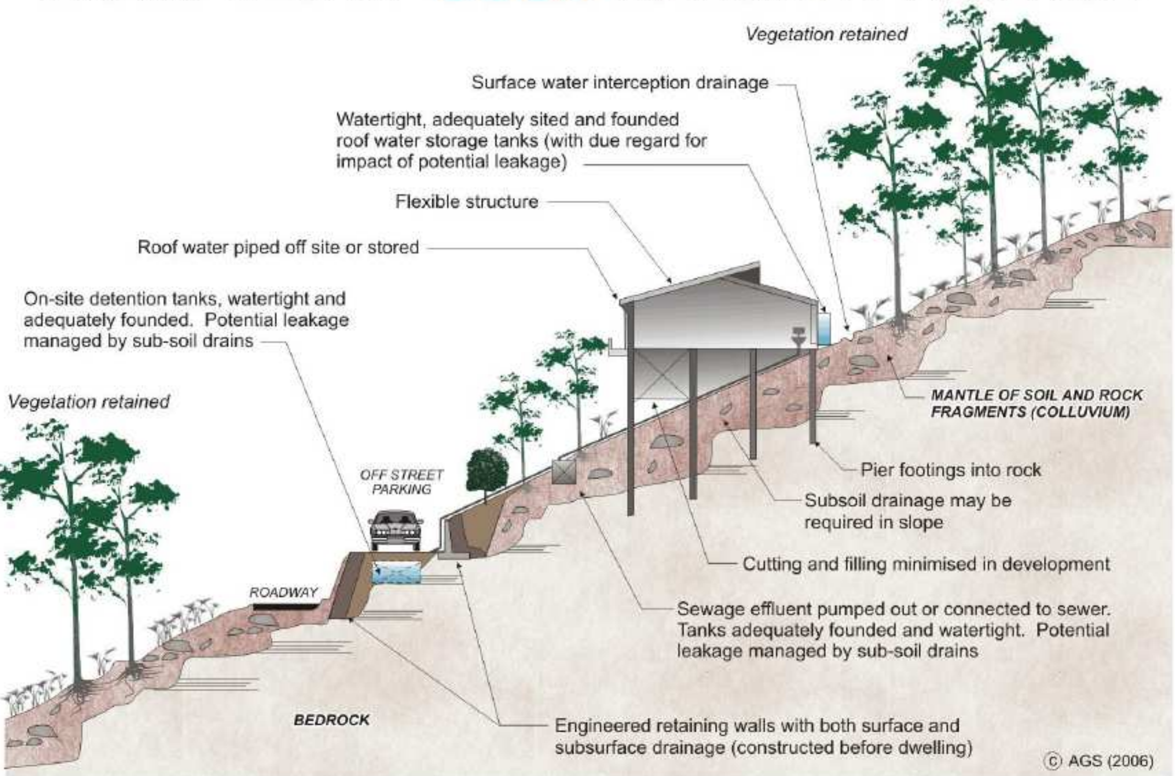
Photograph 6: Large loose sandstone bed (~2m x 4.5m), overhanging up to 1.5m

Photograph 7: View looking south along sandstone precipice up to 1.5m height

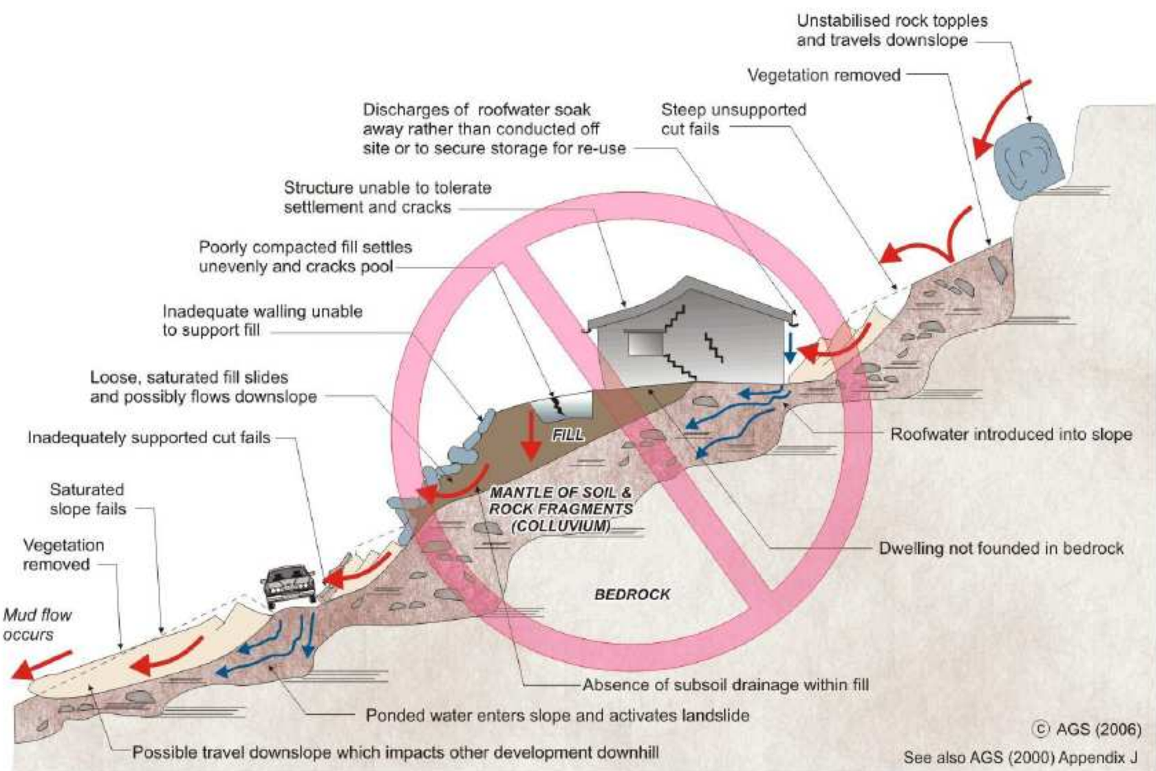
Photograph 8: View looking north, loose undercut block on slope

Appendix B Examples of Hillside Practice

EXAMPLES OF GOOD HILLSIDE PRACTICE



EXAMPLES OF POOR HILLSIDE PRACTICE



Appendix C Risk to Property Terminology

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.

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