EVT / Kosciuszko Thredbo Pty Ltd

Sundowner Snowmaking & Associated Works Thredbo NSW

Geotechnical Investigation

Our ref: 6653-G1
6 October 2021

Your trusted engineering professionals

Document Authorization

Sundowner Snowmaking & Associated Works
Thredbo NSW
Geotechnical Investigation

Prepared for EVT / Kosciuszko Thredbo Pty Ltd

Our ref: 6653-G1
4 October 2021

For and on behalf of
AssetGeoEnviro

Mark Bartel

Mark Bartel
BE, MEngSc, GMQ, CPEng, RPEQ/NER(Civil), APEC IntPE(Aus)
Managing Director | Senior Principal Geotechnical Engineer

Document Control

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Suite 2.06 / 56 Delhi Road
North Ryde NSW 2113
02 9878 6005
assetgeoenviro.com.au

Contents

1. Introduction

1.1 General

This report presents the results of a geotechnical investigation for the above project. The investigation was commissioned on 29 September 2021 by Mr Peter Fleming of EVT / Kosciuszko Thredbo Pty Ltd, purchase order KTM038806. The work was carried out in accordance with the proposal by AssetGeoEnviro (Asset) dated 19 September 2021, reference 6553-P1.

Documents supplied to us for this investigation comprised:

- Plan of Proposed Snowmaking Pipeline – High Noon to Cat Shed – Thredbo (prepared by: Kosciuszko Thredbo Pty Ltd; undated; unreferenced).
- Plan of Proposed Isolation Valve Pit: Antons – Thredbo (prepared by: Kosciuszko Thredbo Pty Ltd; undated; unreferenced).
- Plan of Proposed Isolation Valve Pit: Gunbarrel – Thredbo (prepared by: Kosciuszko Thredbo Pty Ltd; undated; unreferenced).
- Snowmaking System Piping Plan, Valve Pit PV200 Antons (prepared by: TechnoAlpin S.p.A; project number: AU0008-20-01A; drawing numbers: AU0008-21-01A-VP200-AIR-PP-B and AU0008-21-01A-VP200-PP-C).
- Snowmaking System Piping Plan, Valve Pit PV200 Sundowner (prepared by: TechnoAlpin S.p.A; project number: AU0008-20-01A; drawing numbers: AU0008-21-01A-VP100-PP-D and AU0008-21-01A-VP100-AIR-PP-B).
- Typical cross-section steel pipe sizing, trench dimensions, and backfill (prepared by: Kosciuszko Thredbo Pty Ltd; undated; unreferenced).

We understand that the project involves replacing the snowmaking main on Sundowner ski run, following on from recent replacement work on Fridays Flat. Additional to replacing the mains there will also be:

- New isolation valve pits at Sundowner top, Antons bottom station, and Gunbarrel top station.
- Relocate five hydrants on Sundowner from skiers right to skiers left side of run.
- Two new manual hydrants on Sundowner.
- Two new snowmaking pits on Sundowner.

The new mains will connect into the existing mains for Sundance and Milkrun uphill of the isolation valve to be installed on Sundowner. The valve pits are 1.5m deep, with trenching to be approximately 1.2m to 1.5m deep. Both pits for Antons and Gunbarrel are within the access road footprint.

An electrical trench from Lovers Leap station to the top of Sundowner to power the isolation valve will be required, approximately 600 to 800mm depth. A similar trench will be required at Antons at Gunbarrel.

The work is to be conducted under a Development Application (DA), which will require geotechnical considerations for trenching for the snowmaking feed pipe (nominally 1.2 m to 1.5m deep) and the snowmaking laterals (depths from 1m to 1.2 m).

1.2 Scope of Work

The main objectives of the investigation were to assess the surface and subsurface conditions and to provide comments and recommendations relating to:

- Landslide risk assessment as per AGS 2007[1].
- Excavation requirements and batter slopes.
- Subgrade preparation.
- Groundwater levels and dewatering requirements.

The following scope of work was carried out to achieve the project objectives:

- A review of existing regional maps and reports relevant to the site held within our files.
- Clearance of underground services at proposed test locations.
- Visual observations of surface features.
- Subsurface investigation at nine locations to sample and assess the nature and consistency of subsurface soils and bedrock at accessible areas of the site.
- Engineering assessment and reporting.

This report must be read in conjunction with the attached “Important Information about your Geotechnical Report” and “Important Information about your Landslide Risk Assessment” in Appendix A. Attention is drawn to the limitations inherent in site investigations and the importance of verifying the subsurface conditions inferred herein. Landslide risk considerations presented in this report must be read in conjunction with the attached GeoGuides for Slope Management and Maintenance.

2. Compliance with Geotechnical Policy

The following table indicates how the Geotechnical Investigation Report (GIR) addresses the elements in Section 4.1 of the Department’s Geotechnical Policy (Policy):

Paragraph	Element	Addressed in GIR
4.1 (a)	An assessment of the risk posed by all reasonably identifiable geotechnical hazards which have the potential to either individually or cumulatively impact upon people or property upon the site or related land to the proposed development in accordance with the guidelines set out in ‘Landslide Risk Management Concepts and Guidelines’ first published in the Australian Geomechanics Journal, Vol. 35 No.1, March 2000 (guidelines).	Risk assessment has been carried out by a highly experienced geotechnical practitioner and outlined in Tables A and B attached to this report.
4.1 (b)	Plans and sections of the site and related land from survey and field measurements with contours and key features identified, including the locations of the proposed development, buildings/structures on both the subject site and adjoining site, stormwater drainage, sub-surface drainage, water supply and sewerage pipelines, trees, and other identifiable geotechnical hazards.	Figure 1 – Site Locality Plan Figure 2 – Site Plan Figure 3 – Test Locations Figure 4 – Interpreted Cross Sections

[1] Landslide Risk Management, Australian Geomechanics, Vol 42, No. 1, March 2007.

4.1 (c)	Details of all site inspections and site investigations and any other information used in preparation of the geotechnical report. A site inspection is required in all cases. Site investigation may require subsurface investigation; appropriate investigation may involve boreholes and/or test pit excavations or other methods necessary to adequately assess the geotechnical/geological model for the site. At Thredbo, reference may be made to the suite of existing geotechnical data and regional studies held by Kosciuszko Thredbo Pty Ltd, as part of the information to be used in assessing the site. Where similar information data exists for the other Kosciuszko Ski Resorts then this information may be similarly used in assessing the site.	Test pit logs provided in Appendix B, including Soil & Rock Explanation Sheets.
4.1 (d)	Photographs and/or drawings of the site and related land adequately illustrating all geotechnical features referred to in the geotechnical report, as well as the locations of the proposed development.	Photos included in Appendix C.
4.1 (e)	Presentation of a geological model of the site and related land showing the proposed development, including an analysis of sub-surface conditions, considering thickness of the topsoil, colluvium and residual soil layers, depth to underlying bedrock, and the location and depth of groundwater.	Refer Section 6 – Subsurface Conditions.
4.1 (f)	A conclusion as to whether the site is suitable for the development proposed to be carried out either conditionally or unconditionally.	Refer Section 8.

3. Regional Topography

The regional topography comprises moderately to steeply sloping terrain flanking the north-easterly flowing Thredbo River, with ground slopes over the land flanking the river generally ranging from 10º to 30º and some locally steeper sections, and more gentle slopes over the river shoulders. Numerous drainage depressions and watercourses flow towards the river, with some of the persistent watercourses to the north of the river carved several metres into the underlying granite bedrock. Side slopes to creeks and watercourses are typically steeper at 20 to 35º, and typically include numerous granite boulders and cobbles.

The site lies within an area designated as "G" as defined in the maps accompanying DIPNR's "Geotechnical Policy – Kosciuszko Alpine Resorts", November 2003, and therefore a geotechnical report is required to accompany the development application as per the requirements of the Geotechnical Policy.

4. Site Description

The site is located within Thredbo, north of the Alpine Way and north of the Thredbo River as shown in Figure 1. The total length of the pipeline is approximately 540m. It commences from the western end of the previous Friday Flat snowmaking (as shown in Figure 2), and follows a ski run which winds uphill in a south-westerly to north-westerly direction, terminating on a ridgeline north of a maintenance shed for caterpillar snow ploughs.

The proposed replacement pipe is located within the ski run as per the existing pipe (refer Figure 2), but to be in a separate trench some distance from the existing. It is understood that the existing pipe was constructed about 1986. The development of the ski run has disturbed the original natural ground by clearing of vegetation and some earthworks likely involving cutting and filling to even out the terrain.

The ground surface generally rises to the west and northwest at about 5 to 8º towards a creek that crosses the ski run about 1/3 along the pipeline. The creek generally flows in a southernly direction at that point and a culvert has been constructed over the creek to allow the ski run and associated snowmaking facilities to cross. The creek banks are steeper at this location, up to about 30º to 35º in parts. Filling has been placed over the culver and its approaches, visibly estimated to be up to about 1.5m to 2m thick maximum.

West of the creek, the ground surface slopes up to the west/south-west at about 15º, flattening to about 10º at the ridgeline.

The pipe will be laid along the alignment of the ski run. Ground surface slopes along the alignment are described above. Cross-slopes are generally less than about 5º, increasing over the creek banks to about 30º to 35º as described above.

5. Fieldwork

The fieldwork was undertaken on 1 October 2021 under the full-time supervision of a Senior Principal Geotechnical Engineer from Asset and included invasive investigation at nine locations.

The test locations are shown in the attached Figure 3 and were set out by our Senior Principal Geotechnical Engineer relative to existing site features.

Buried metallic services and utilities within the site boundaries near the test locations were cleared by a service locator from Kosciuszko Thredbo Pty Ltd and by referring to utility maps held by Kosciuszko Thredbo Pty Ltd.

The invasive investigation included excavation of test pits at nine locations using a Kubota U17–3 excavator. The test pits were terminated at depths ranging from 0.9 m to 1.5 m.

Engineering logs are provided in Appendix B together with their explanatory notes.

6. Subsurface Conditions

6.1 Geology

The 1:250,000 Tallangatta Geological Map indicates the site is underlain by Silurian aged intrusive granite.

6.2 Subsurface Conditions

The test pit logs indicated that the subsurface materials are quite variable, and include the following generalised geotechnical units as shown in Table 1. For a detailed description of the subsurface conditions, refer the attached engineering logs and explanatory notes. For specific design input, reference should be made to the logs and/or the specific test results, in place of the following summary.

Table 1 – Generalised Site Geotechnical Model

Unit	Origin	Description	Unit Thickness [1] (m)
1a	Topsoil Fill	Sandy SILT / Silty SAND, low plasticity silt, fine to medium grained sand, dark brown, grass roots, moist (>Wp), firm/loose. Encountered in TP 1, 3, 4, 6, 7.	0.1 – 0.25
1b	Fill	Mixture of fine to coarse grained Clayey SAND and Cobbles and boulders to 500mm size, some pieces of extremely weathered granite (remoulds to medium to coarse grained SAND), grey/brown, moist, assessed variably compacted (assessed loose to medium dense), occasional pockets of organic matter up to 100 mm thick (organic matter in sandy soil matrix), occasional small tree roots less than 25 mm diameter. Encountered in TP 1, 3, 4, 6.	0.35 – >1.2
1c	Unknown (Fill?)	Sandy SILT, low plasticity, dark grey to black, some organic matter, moist >Wp, stiff, some fine to coarse gravel. Encountered in TP 4.	>0.9
2	Topsoil	Sandy SILT, medium plasticity, dark grey, grass roots, moist, firm, occasional flat boulder up to 0.8 m size within topsoil matrix. Encountered in TP 2, 5, 7, 8, 9.	0.1 – 0.7
3	Colluvium / Slopewash	CLAY, medium plasticity, dark brown, some granite cobbles, moist = Wp, stiff. Encountered in TP 7, 8.	>0.4 – 0.8
4a	Residual	Silty CLAY, medium plasticity, orange-brown, trace fine sand, moist = Wp, stiff, occasional granite cobbles to 0.2 m size. Encountered in TP 2.	1.0
4b	Residual	Sandy SILT/Silty SAND, low plasticity, fine to medium grained sand, light brown, some granite fragments to 100 mm size, extremely weathered. Encountered in TP 5, 8, 9.	0.4 – >1.1
4c	Residual	Mixture of granite cobbles and Silty CLAY, medium plasticity, orange-brown, trace fine sand, moist = Wp, stiff. Encountered in TP 2.	> 0.1
5	Bedrock	GRANITE, extremely to highly weathered, pieces of slightly weathered rock up to 500 mm size in extremely weathered matrix. Encountered in TP 5.	> 0.4

Notes:

1. The unit thicknesses are based on the information from the test locations only and do not necessarily represent the maximum and minimum values across the site.

The various fills encountered in the test pits appear to relate to the original construction of the ski slope including the culvert crossing, and the current water supply works.

6.3 Groundwater

Groundwater was not observed in the test pits during excavation or the time they remained open.

7. Discussions & Recommendations

7.1 Key Geotechnical Site Constraints

The development will generally require trenching to a target depth of 1.2m for the pipeline replacement and trenching of up to 1.2m depth for the laterals that feed the snow guns.

The test pitting and site observations has indicated that the subsurface conditions are variable along the route including a range of soil types with large cobbles and small boulders present. Practical refusal was encountered in TP 1 in TP 2 on boulders and cobbles, and in TP 5 on granite bedrock. It is noted that the excavator used for the test pitting was of relatively small size (1.7 tonnes), whereas the excavator to be used for excavation of the trenching will likely be of the order of 15 tonnes, which is expected to be able to excavate beyond refusal of the excavator used for the investigation.

Key geotechnical constraints include excavation conditions, subgrade (foundation) conditions, and hazards related to slope instability risk. Recommendations for design and construction of the development are provided in the following sections.

7.2 Slope Instability Risk

A limited, preliminary level, risk assessment has been carried out for this site regarding slope instability, using the methods of AGS 2007[2].

The basis of the preliminary assessment undertaken for this site and important factors relating to slope conditions and the impacts of the development that commonly influence the risks of slope instability are discussed in the attached "Important Information about your Slope Instability Risk Assessment", and the attached GeoGuides.

The preliminary assessment has been carried out by:

- Consideration of the likely slope failure mechanisms and the likely initiating circumstances that could affect the elements at the site. The type and mode of landslide failure has also been classified.
- **Risk to Property.** For each case, the likely consequences with respect to future development have been considered. The current assessed probability of occurrence of each event has been estimated on a qualitative basis. The consequences and probability of occurrence have been combined for each case to provide the risk assessment.
- **Risk to Life**. For each case, the risk for the person most at risk is assessed based on multiplying the indicative annual probability of the occurrence of the hazard, the probability of spatial impact, the temporal probability, the vulnerability, and the probability of not evacuating. The risk is then compared with acceptable and tolerable risk criteria.

[2] Landslide Risk Management, Australian Geomechanics, Vol 42, No. 1, March 2007.

The following general potential hazards/events are identified for this site and relate to slope instability:

A shallow slump (cross slope)

B slump of steep creek bank

Assessment of hazards for excavation for replacement of valve pits has not been included due to the limited depth and extent of excavation.

For the hazards / events identified, the elements that are at risk are the proposed replacement water main and associated service lines, adjacent existing services, and the existing access tracks. Table A provides our preliminary risk assessment for the site with respect to risk to property, and Table B provides our preliminary risk assessment for the site with respect to risk to life.

Where development takes into consideration the possible failure mechanisms and adopts good engineering practice for hillside development, including specific risk mitigation measures recommended for **Hazard B**, it is envisaged that the outcome of such a development would be a **Low** risk assessed with respect to property and the risk with respect to life would be **Acceptable**.

The development should be carried out in accordance with good engineering practice that is described in the attached GeoGuides, and in accordance with the general recommendations in the following sections.

Based on the assessed landslide risk as per above, we conclude that the development presents only minimal geotechnical impact and therefore requires only Form 4 – Minimal Impact Certification. This certification is provided on the second page of this report.

7.3 Earthworks

7.3.1 Excavation

The excavation for the proposed development is anticipated to be predominantly within soils of variable nature and composition as indicated by the test pit logs. Completely weathered granite was encountered at some locations within the proposed trenching depth, but less weathered bedrock that would require hammering or blasting was not encountered. Some larger cobbles and small boulders and some boulders could be anticipated, which could be removed with suitably sized excavators.

Excavation for the section of pipe adjacent to the creek banks and either side of the culvert should be located at least 3 m from the edge of the creek bank to mitigate the potential landslide risk.

7.3.2 Subgrade Preparation

The following general recommendations are provided for subgrade preparation for the pipework and for the retaining section:

- Excavate to design subgrade level. Remove unsuitable materials from the site (e.g. material containing deleterious matter). Stockpile topsoil and organic matter for re-use as landscaping material or remove from site. Residual soils and completely weathered granite, and suitable fill soils could be stockpiled for re-use as engineered fill or removed to spoil.

- The subgrade should be compacted using pad wheel roller on an excavator arm for trench backfill, or a suitably sized padfoot compactor, or hand-operated compaction equipment (e.g. wacker packer).
- Areas which show visible heave under compaction equipment should be over-excavated a further 0.3m minimum (possibly deeper if soft / very soft soils are encountered) and replaced with approved fill (such as completely weathered granite) compacted to a dry density ratio not less than 100%. Where soft / very soft soils are still present in the excavation, laying of suitable geofabric and bridging with granular material (e.g. coarse gravel material or rock up to 150mm size) may be considered. Further geotechnical advice should be sought in this case.

Any waste soils being removed from the site must be classified in accordance with current regulatory authority requirements to enable appropriate disposal to an appropriately licensed landfill facility. Asset can provide further advice on this matter if required.

7.3.3 Filling

The pipe designer is to advise filling requirements for the pipeline bedding materials and filling around and immediately above the pipeline. Other filling should be placed in horizontal layers over prepared subgrade and compacted as per Table 2.

Table 2 – Compaction Specifications

Parameter	Cohesive Fill	Non Cohesive Fill
Fill layer thickness (loose measurement): • Within 1.5m of the rear of retaining walls • Elsewhere	0.2m 0.3m	0.2m 0.3m
Density: • Beneath Pavements • Beneath Structures • Upper 150mm of subgrade	≥ 95% Std ≥ 98% Std ≥ 100% Std	≥ 70% ID ≥ 80% ID ≥ 80% ID
Moisture content during compaction	± 2% of optimum	Moist but not wet

The upper part of the fill particularly within the sections adjacent to the creek bank near the culvert should comprise suitable material that reduces the risk of surface water entering the pipe trench (e.g. clayey soils). Gradients and allowance for settlement of the fill should be made to avoid the risk of ponding.

Any soils to be imported onto the site for backfilling and reinstatement of excavated areas should be free of contamination and deleterious material and should include appropriate validation documentation in accordance with current regulatory authority requirements which confirms its suitability for the proposed land use. Asset can provide further advice on this matter if required.

7.3.4 Batter Slopes

Given the shallow nature of the trenching (i.e. generally not more than 1.5m deep), practically, vertical cuts may be carried out if sidewalls remain stable during pipe construction. The test pitting confirmed that the sidewall slumping is expected to be minimal, but if this does occur, local flattening of the excavation face to no steeper than 1H:1V (horizontal to vertical) or benching in maximum 1 m vertical heights per minimum 0.5 m widths will be required. No permanent battering is proposed for this development.

Inspection of the excavation must be carried out by a suitably experienced geotechnical engineer or by suitably experienced site personnel under direction of an experienced geotechnical engineer before personnel access is allowed in the trench. Alternatively, temporary shoring may be provided either by shoring system designed by a Structural Engineer or by a proprietary shoring system certified by a Structural Engineer for the anticipated site conditions.

7.4 Groundwater Control

Limited groundwater observations made for this investigation are described in Section 6.3. The observations indicate that groundwater is unlikely to be a constraint to the proposed development. However, good practice should be followed to cater for potential groundwater, such as designing retaining walls with adequate subsoil drainage. Further geotechnical advice must be sought if significant groundwater is encountered during construction.

8. Site Suitability

We herewith conclude that the site is geotechnically suitable for the development provided that the development is carried out in accordance with the recommendations and advice in this report including the following Development Approval Conditions.

9. Recommended Development Approval Conditions

The following conditions should be included with the development approval:

(i) Conditions to be provided to establish the design parameters

The development shall be carried out in accordance with the requirements and recommendations of the preliminary geotechnical assessment by AssetGeoEnviro dated 4 October 2021 (Ref 6653-G1), and in accordance with further geotechnical assessment and advice to be provided during design development and construction.

(ii) Conditions applying to the detailed design to be undertaken for the construction certificate

Structural design and civil details (drainage, earthworks) relating to the geotechnical aspects of the proposed development shall be checked and certified by a suitably qualified and experienced Geotechnical Engineer as being in accordance with the geotechnical recommendations.

(iii) Conditions applying to the construction

During construction, inspection shall be carried out by a suitably qualified and experienced geotechnical engineer or by suitably experienced site personnel under direction of an experienced geotechnical engineer, at the following stages, to ensure that the requirements of the geotechnical report are followed:

a) Trench excavations and subgrade for filling shall be inspected after preparation.

b) All cut batters shall be inspected immediately after cutting and remedial works carried out as directed by the geotechnical engineer.

(iv) Conditions regarding ongoing management of the site/structure

No specific conditions are identified for ongoing management of the site / structure.

10. Limitations

In addition to the limitations inherent in site investigations (refer to the attached Information Sheets), it must be pointed out that the recommendations in this report are based on assessed subsurface conditions from limited investigations.

It is recommended that a qualified and experienced Geotechnical Engineer be engaged to provide further input and review during the design development; including site visits during construction (either in-person or by remote with assistance of suitably experienced site personnel) to verify the site conditions and provide advice where conditions vary from those assumed in this report.

This report may have included geotechnical recommendations for design and construction of temporary works (e.g. temporary batter slopes or temporary shoring of excavations). Such temporary works are expected to perform adequately for a relatively short period only, which could range from a few days (for temporary batter slopes) up to six months (for temporary shoring). This period depends on a range of factors including but not limited to: site geology; groundwater conditions; weather conditions; design criteria; and level of care taken during construction. If there are factors which prevent temporary works from being completed and/or which require temporary works to function for periods longer than originally designed, further advice must be sought from the Geotechnical Engineer.

This report and details for the proposed development should be submitted to relevant regulatory authorities that have an interest in the property (e.g. Department of Planning) or are responsible for services that may be within or adjacent to the site for their review.

Asset accepts no liability where our recommendations are not followed or are only partially followed. The document "Important Information about your Geotechnical Report" in Appendix A provides additional information about the uses and limitations of this report.

Landslide Risk Assessment Tables

Table A – Risk to Property

Table B – Risk to Life

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Table A – Landslide Risk Assessment (Risk to Property)
Sundowner Snowmaking Pipeline Replacement – Thredbo NSW

Possible Hazards		Consequences (Note 2)	Assessed Likelihood	Risk (Note 1)	Risk Treatment and Comments
Failure Envisaged	Failure Mode				
A - Shallow slump (cross slope)	Slide	Minor	Unlikely	Low	No specific risk treatment considered necessary. Design and construction of the development to be in accordance with recommendations in Geotechnical Report 6653-G1 dated 4 October 2021.
B - Slump of steep creek bank	Slide	Medium	Unlikely	Low	Trench compaction and grading to be carried out such that surface water ingress is minimised. Trench to be located at least 3m from the edge of the creek bank. Design and construction of the development to be in accordance with recommendations in Geotechnical Report 6653-G1 dated 4 October 2021.

Notes:

1. The risk assessment addresses only the consequences to property from potential landslide events considered relevant to the subject site. Injury to persons or potential for fatality from land sliding is not assessed in this table (refer Table B). The risk assessment is based on a preliminary appraisal only, carried out by inspection. Further assessment or quantification of the assessed geotechnical risks for the subject property would require additional data and/or investigation.
2. The consequences are for a development that is designed to accomodate the potential landslide risk or has demonstrated adequate performance over many years.
3. Refer to report and associated figures for illustration of possible hazards / slope failure mechanisms.
4. Refer to attachments for definitions and explanations of terms used in the risk assessment.

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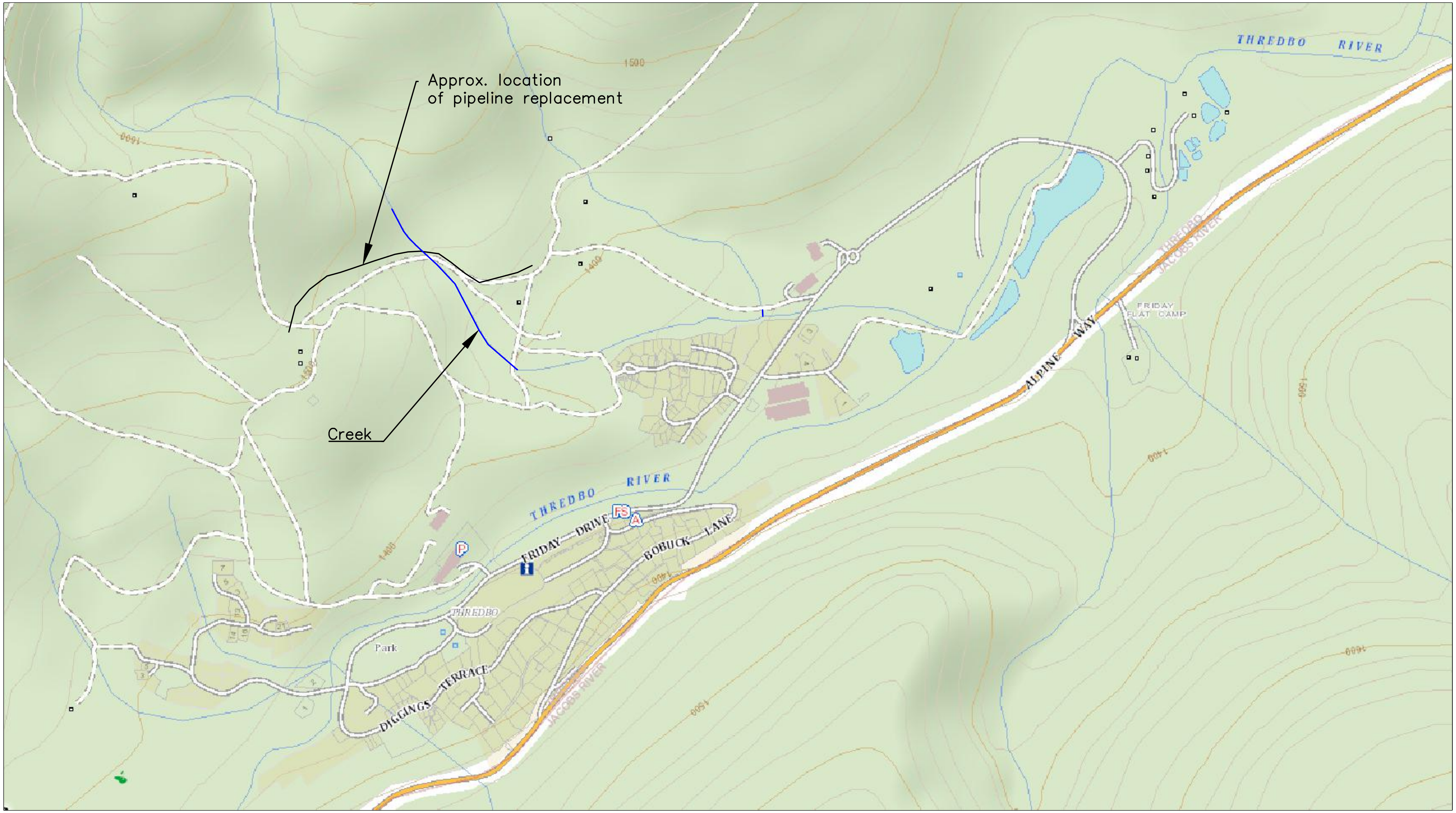
Table A – Landslide Risk Assessment (Risk to Property)
Sundowner Snowmaking Pipeline Replacement – Thredbo NSW

Possible Hazard	Use of Affected Structure & Persons at Risk	Likelihood	Indicative Annual Probability P (H)	Probability of Spatial Impact P (S:H)	Temporal Probability P (T:S)	Vulner-ability V (D:T)	Probability of becoming Trapped	Risk for Person Most at Risk [Risk Evaluation]	Risk Outcome: A = Acceptable T = Tolerable NT = Not Tolerable
A - Shallow slump (cross slope)	Maintenance workers, skiers	Unlikely	1.0E-04	1.00	0.04	0.10	0.10	4.00E-08	A
B - Slump of steep creek bank	Maintenance workers, skiers	Unlikely	1.0E-04	1.00	0.04	0.10	0.10	4.00E-08	A

Notes:

1. The appraisal of the assessed risk relative to acceptable and tolerable risks is based on Table 1 of AGS (2007) – Reference 1, for a new development.
2. Risk mitigation will be required to ensure that the assessed risk outcome during and after the proposed development is acceptable. Referred to report for further details.
3. This table must be read in conunction with Table A.
4. Risk Outcome:
   - A = Acceptable $\leq 10^{-6}$
   - T = Tolerable $\leq 10^{-5}$
   - NT = Not Tolerable - treatment options to be assessed and implemented
5. Temporal Probability based on per-person average 1 hour per day for any day of the year being in the affected area = 1 / 24 = 0.0417

Figures



Source: SixMAPS

0 1:10,000 A4 500m

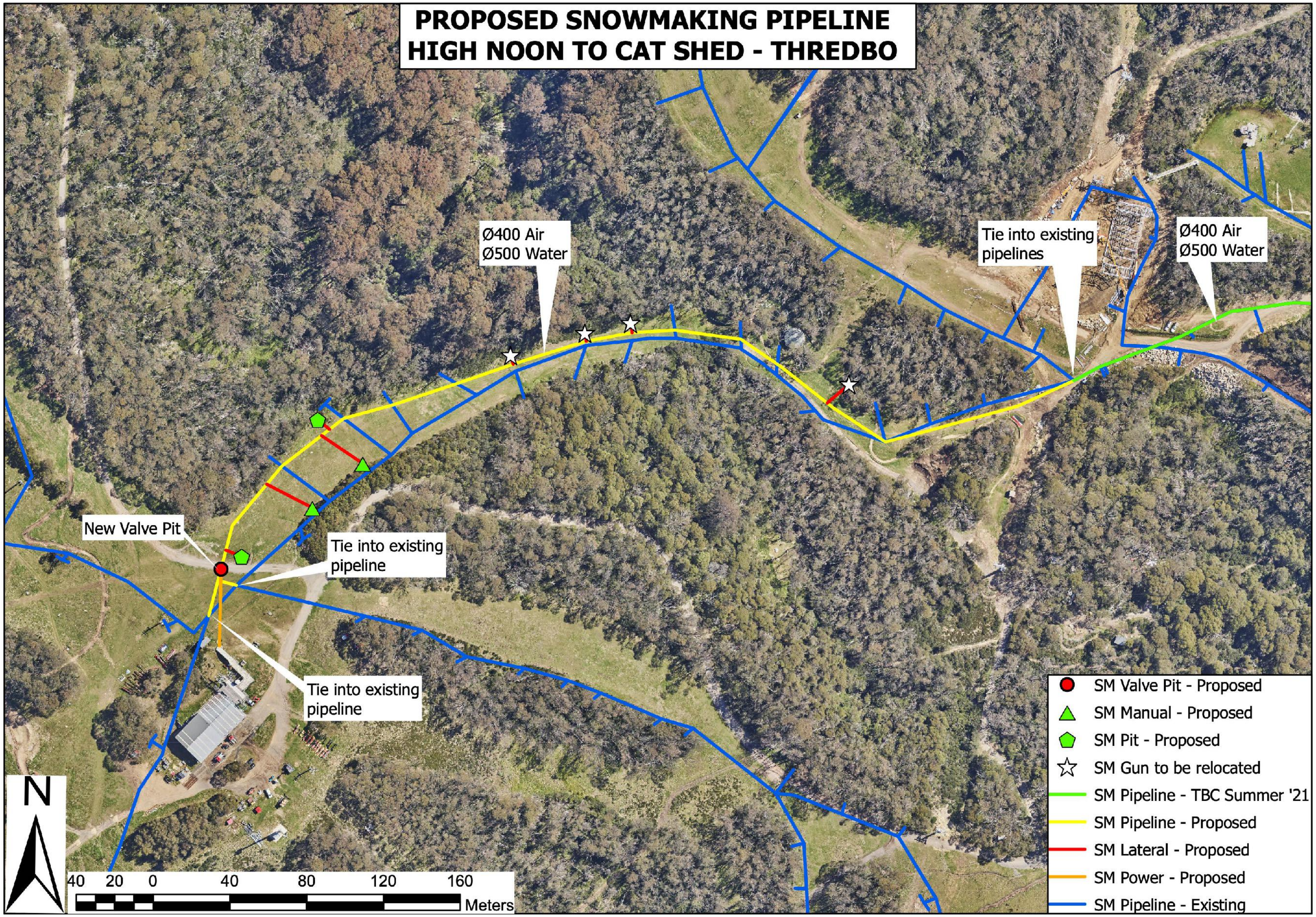
issue	date	description
A	2.10.21	Initial issue

assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Sundowner Snowmaking & Associated Works
Thredbo NSW
for
EVT / Kosciuszko Thredbo Pty Ltd

Site Locality

drawn:	MAB
date:	2.10.2021
checked:	MAB
scale:	1:10,000 A4
job no.:	6653
fig:	1
issue:	A



Source: Kosciuszko Thredbo Pty Ltd.

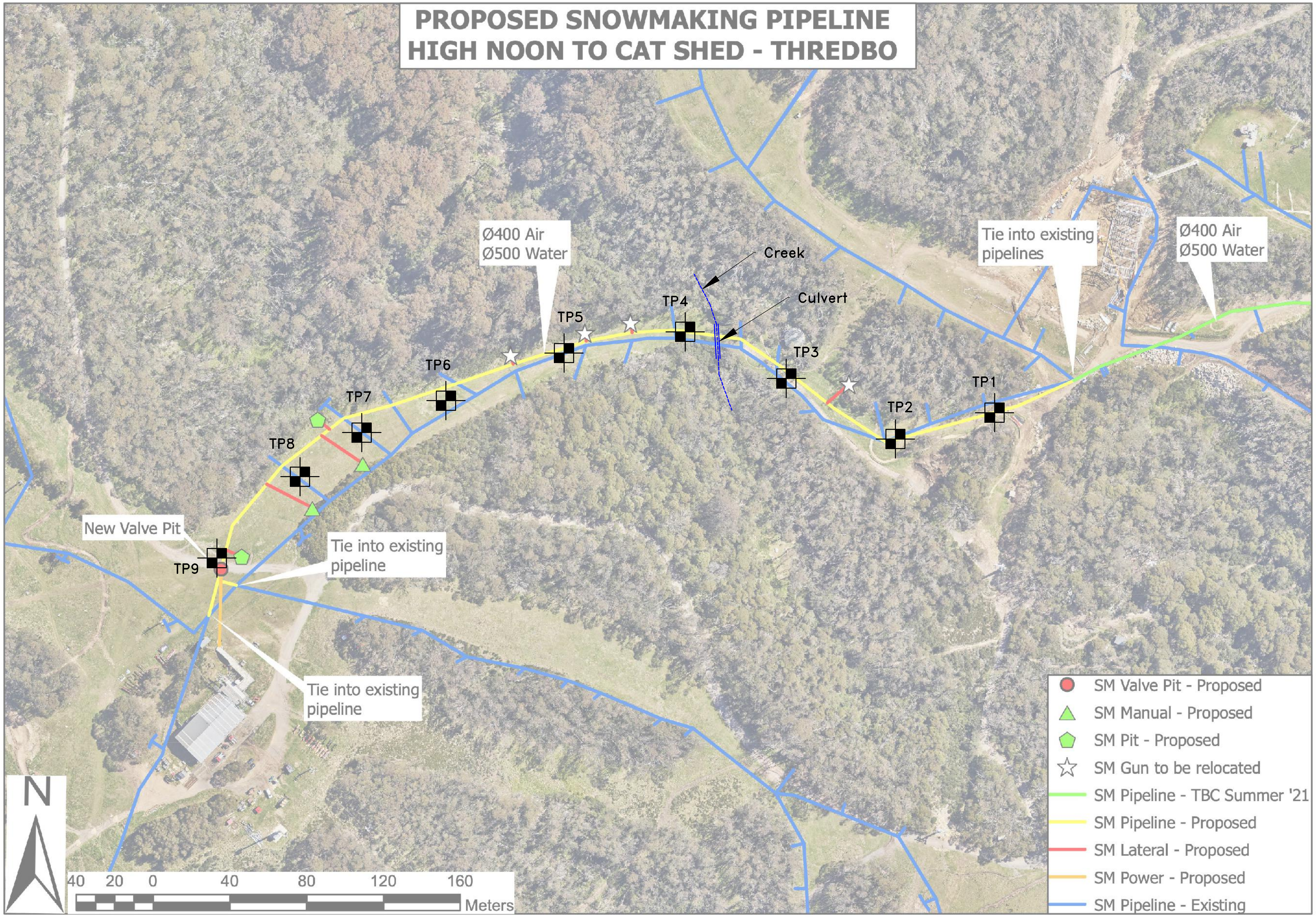
issue	date	description
A	2.10.21	Initial issue

assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Sundowner Snowmaking & Associated Works
Thredbo NSW
for
EVT / Kosciuszko Thredbo Pty Ltd

Site Plan

drawn: MAB	job no.: 6653		
date: 2.10.2021			
checked: MAB	fig: 2	issue: A	
scale: 1:2,000 A3			



Source: Kosciuszko Thredbo Pty Ltd.

Test pit locations approximate only, subject to detail survey.

issue	date	description
A	2.10.21	Initial issue

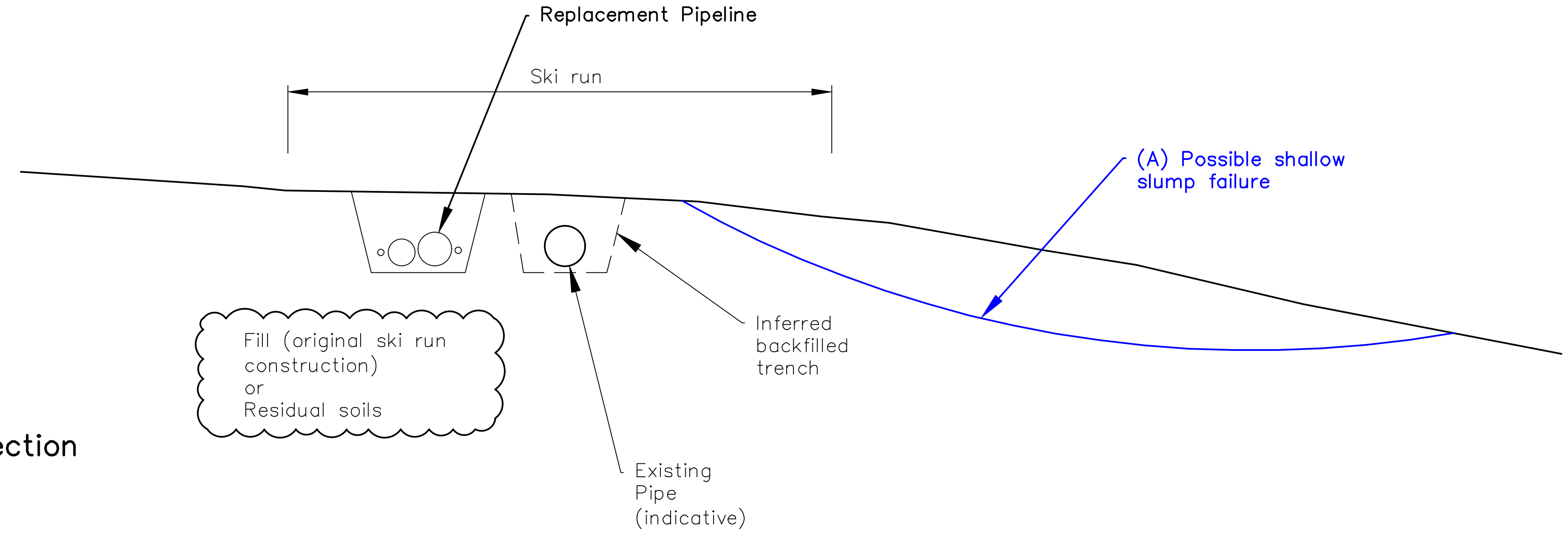
assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Sundowner Snowmaking & Associated Works
Thredbo NSW
for
EVT / Kosciuszko Thredbo Pty Ltd

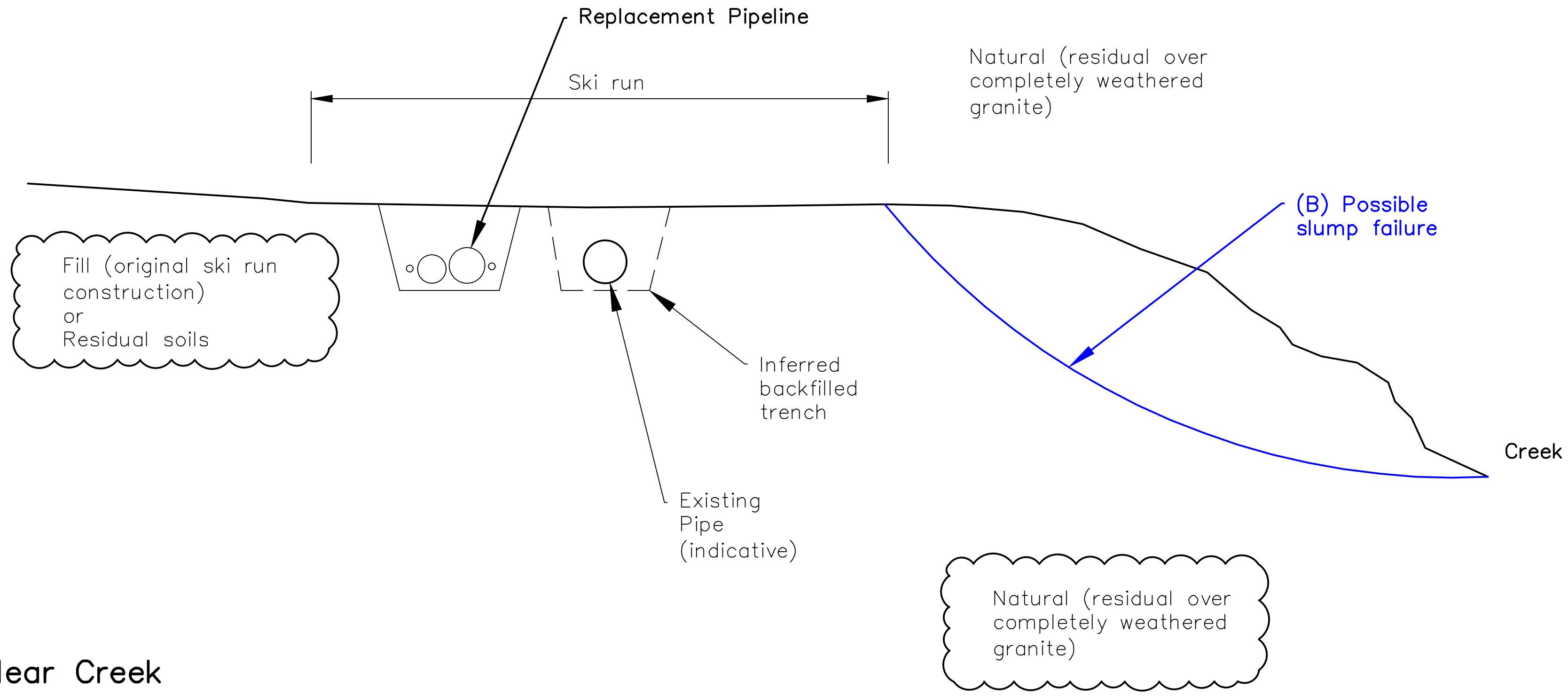
Test Locations

drawn: MAB
date: 2.10.2021
checked: MAB
scale: 1:2,000 A3

job no.: 6653
fig: 2
issue: A



Typical Section



Section Near Creek

0 1:100 A3 5m

issue	date	description
A	2.10.21	Initial issue

assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Sundowner Snowmaking & Associated Works
Thredbo NSW
for
EVT / Kosciuszko Thredbo Pty Ltd

Interpreted Cross Sections

drawn:	MAB
date:	2.10.2021
checked:	MAB
scale:	1:100 A3
job no.:	6653
fig:	4
issue:	-

Appendix A

Important Information about your Geotechnical Report
Important Information about your Landslide Risk Assessment
GeoGuides (pp1-17)

Scope of Services

The geotechnical report ("the report") has been prepared in accordance with the scope of services as set out in the contract, or as otherwise agreed, between the Client and Asset Geotechnical Engineering Pty Ltd ("Asset"), for the specific site investigated. The scope of work may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.

The report should not be used if there have been changes to the project, without first consulting with Asset to assess if the report's recommendations are still valid. Asset does not accept responsibility for problems that occur due to project changes if they are not consulted.

Reliance on Data

Asset has relied on data provided by the Client and other individuals and organizations, to prepare the report. Such data may include surveys, analyses, designs, maps and plans. Asset has not verified the accuracy or completeness of the data except as stated in the report. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations ("conclusions") are based in whole or part on the data, Asset will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to Asset.

Geotechnical Engineering

Geotechnical engineering is based extensively on judgment and opinion. It is far less exact than other engineering disciplines. Geotechnical engineering reports are prepared for a specific client, for a specific project and to meet specific needs, and may not be adequate for other clients or other purposes (e.g. a report prepared for a consulting civil engineer may not be adequate for a construction contractor). The report should not be used for other than its intended purpose without seeking additional geotechnical advice. Also, unless further geotechnical advice is obtained, the report cannot be used where the nature and/or details of the proposed development are changed.

Limitations of Site Investigation

The investigation program undertaken is a professional estimate of the scope of investigation required to provide a general profile of subsurface conditions. The data derived from the site investigation program and subsequent laboratory testing are extrapolated across the site to form an inferred geological model, and an engineering opinion is rendered about overall subsurface conditions and their likely behavior with regard to the proposed development. Despite investigation, the actual conditions at the site might differ from those inferred to exist, since no subsurface exploration program, no matter how comprehensive, can reveal all subsurface details and anomalies.

The engineering logs are the subjective interpretation of subsurface conditions at a particular location and time, made by trained personnel. The actual interface between materials may be more gradual or abrupt than a report indicates.

Therefore, the recommendations in the report can only be regarded as preliminary. Asset should be retained during the project implementation to assess if the report's recommendations are valid and whether or not changes should be considered as the project proceeds.

Subsurface Conditions are Time Dependent

Subsurface conditions can be modified by changing natural forces or man-made influences. The report is based on conditions that existed at the time of subsurface exploration. Construction operations adjacent to the site, and natural events such as floods, or ground water fluctuations, may also affect subsurface conditions, and thus the continuing adequacy of a geotechnical report. Asset should be kept appraised of any such events, and should be consulted to determine if any additional tests are necessary.

Verification of Site Conditions

Where ground conditions encountered at the site differ significantly from those anticipated in the report, either due to natural variability of subsurface conditions or construction activities, it is a condition of the report that Asset be notified of any variations and be provided with an opportunity to review the recommendations of this report. Recognition of change of soil and rock conditions requires experience and it is recommended that a suitably experienced geotechnical engineer be engaged to visit the site with sufficient frequency to detect if conditions have changed significantly.

Reproduction of Reports

This report is the subject of copyright and shall not be reproduced either totally or in part without the express permission of this Company. Where information from the accompanying report is to be included in contract documents or engineering specification for the project, the entire report should be included in order to minimize the likelihood of misinterpretation from logs.

Report for Benefit of Client

The report has been prepared for the benefit of the Client and no other party. Asset assumes no responsibility and will not be liable to any other person or organisation for or in relation to any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report (including without limitation matters arising from any negligent act or omission of Asset or for any loss or damage suffered by any other party relying upon the matters dealt with or conclusions expressed in the report). Other parties should not rely upon the report or the accuracy or completeness of any conclusions and should make their own inquiries and obtain independent advice in relation to such matters.

Data Must Not Be Separated from The Report

The report as a whole presents the site assessment, and must not be copied in part or altered in any way.

Logs, figures, drawings, test results etc. included in our reports are developed by professionals based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These data should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Partial Use of Report

Where the recommendations of the report are only partially followed, there may be significant implications for the project and could lead to problems. Consult Asset if you are not intending to follow all of the report recommendations, to assess what the implications could be. Asset does not accept responsibility for problems that develop where the report recommendations have only been partially followed if they have not been consulted.

Other Limitations

Asset will not be liable to update or revise the report to take into account any events or emergent circumstances or fact occurring or becoming apparent after the date of the report.

Important Information about your Landslide Risk Assessment

Basis of The Assessment

Our assessment of the stability of the land is presented in the framework of Landslide Risk Management (Australian Geomechanics Society, Vol 42, No 1, March 2007). The attached GeoGuides provide further information on landslide risk management and maintenance.

This assessment is based on a visual inspection of the property and also the immediate adjoining land. Limited subsurface investigation may also have been undertaken as part of this appraisal. Slope monitoring has not been carried out within or adjacent to the property for the purpose of this appraisal. The opinions expressed in this report also take into account our relevant local experience.

The property is within an area where landslip and/or subsidence have occurred, or where there is a risk of landslide. Important factors relating to slope conditions and the impact of development which commonly influence the landslide risks are discussed herein.

An owner's decision to acquire, develop or build on land within an area such as this involves the understanding and acceptance of a level of risk. It is important to recognise that soil and rock movements are an ongoing geological process, which may be affected by development and land management within the site or on ad- joining land. Soil and rock movements may cause visible damage to structures even where the risk of slope failure is considered low. This report is intended only to assess the landslide risk apparent at the time of inspection.

Our opinion is provided on the present landslide risk for the land specifically referenced in the title to this report. Foundations suitable for future building development are discussed in relation to slope stability considerations. Limited foundation advice may be provided. If so, advice is intended to guide the footing design for the proposed development. However, this report is not intended as, is not suitable for, and must not be used in lieu of a detailed foundation investigation for final design and costing of foundations, retaining walls or associated structures.

Limitations of The Assessment Procedure

The assessment procedures carried out for this appraisal are in accordance with the recommendations in Landslide Risk Management (Australian Geomechanics Society, Vol 42, No 1, March 2007), and with accepted local practice.

The following limitations must be acknowledged:

- the assessment of the stability of natural slopes requires a great degree of judgment and personal experience, even for experienced practitioners with good local knowledge;
- the assessment must be based on development of a sound geological model; slope processes and process rates influencing land sliding or landslide potential will vary according to geomorphologic influences;
- the likelihood that land sliding may occur on a given slope is generally hard to predict and is associated with significant uncertainties;
- different practitioners may produce different assessments of risk;
- actual risk of land sliding cannot be determined; risk changes with time;
- consequences of land sliding need to be considered in a rational framework of risk acceptance;
- acceptable risk in relation to damage to property from landslide activity is subjective; it remains the responsibility of the owner and/or local authority to decide whether the risk is acceptable; the geotechnical practitioner can assist with this judgment;
- the extent and methods of investigation for assessment of landslide risk will be governed by experience, by the perceived risk level, and by the degree to which the risk or consequences of land sliding are accepted for a specific project;
- the assessment may be required at a number of stages of the project or development; frequently (due to time or budget constraints imposed by the client) there will be no opportunity for long-term monitoring of the slope behaviour or groundwater conditions, or for on-going opportunity for the slope processes and performance of structures to be reviewed during and after development; such limitations should be recognised as relevant to the assessment.

Development on Slopes

Some risk of slope instability is always attached to the development of land on slopes.

Guidelines for hillside construction and examples of good practices for hillside developments are described in the attached GeoGuides.

THE AUSTRALIAN GEOGUIDES
FOR SLOPE MANAGEMENT AND MAINTENANCE

AGS Landslide Taskforce, Slope Management and Maintenance Working Group

The Australian Geomechanics Society (AGS) presents on the following pages a guideline on slope management and maintenance, as part of the landslide risk management guidelines developed under the National Disaster Funding Program (NDMP). This Guideline is aimed at home owners, developers and local councils, but also has applicability to a larger audience which includes builders and contractors, consultants, insurers, lawyers, government departments and in fact any person, or organisation, with a responsibility for the management or maintenance of a slope. The objective is to inform those with little or no knowledge of geotechnical engineering about landslides.

Each GeoGuide is a stand-alone document, which is formatted so that it can be printed on two sides of a single A4 sheet. It is expected that the set of GeoGuides will increase with time to cover a range of topics. As things stand:

- **GeoGuide LR1** is an introductory sheet that should be read by all users, since it explains what the LR (landslide risk) series is about and defines terms.
- **GeoGuides LR2, 3 and 4** explain why landslides occur and provide information on different types of landslide.
- **GeoGuide LR5** discusses the critical part that water often plays in relation to landslide occurrence and discusses measures that can be adopted to limit its effect.
- **GeoGuide LR6** refers to retaining walls and their maintenance.
- **GeoGuide LR7** puts the concept of landslide risk into an everyday context, so users can relate a particular landslide risk to other risks that they know they are prepared to take, sometimes on a daily basis.
- **GeoGuide LR8** retains the ideas of good and poor hillside construction practice originally provided by an AGS sub-committee in 1985.
- **GeoGuide LR9** concentrates specifically on effluent and surface water disposal, which is an important topic in some development areas.
- **GeoGuide LR10** is specifically aimed at those who have property on the coast and could be susceptible to coastal erosion processes.
- **GeoGuide LR11** provides information about the benefits of keeping records on inspection and maintenance activities and provides a proforma record sheet for users.

It is recognised that the GeoGuides are likely to be upgraded from time to time. Feedback on use and suggested changes should be sent to the National Chair of the Australian Geomechanics Society. The latest versions of the GeoGuides will be downloadable from the AGS website www.australiangemechanics.org

Through the NDMP, Australian governments (at Commonwealth, State and Local Government levels) are also funding the development of a Landslide Zoning Guideline (AGS 2007a), and a Practice Note Guideline (AGS 2007c) to which interested readers seeking in-depth information should refer.

ACKNOWLEDGEMENTS

These guidelines have been prepared by The Australian Geomechanics Society with funding from the National Disaster Mitigation Program, the Sydney Coastal Councils Group, and The Australian Geomechanics Society.

The Australian Geomechanics Society established a Working Group within a Landslide Taskforce to develop the guidelines. The development of the guidelines was managed by a Steering Committee. Membership of the Working Group, Taskforce and Steering Committee is listed in the Appendix.

Drafts of these GeoGuides have been subject to review by members of the AGS Landslide Taskforce, members of the geotechnical profession and local government.

REFERENCES

AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management. Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1.

AGS (2007c). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1,

AGS (2007e). The Australian GeoGuides for slope management and maintenance –. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No 1, - this paper.

AUSTRALIAN GEOGUIDE LR1 (INTRODUCTION)

INTRODUCTION TO LANDSLIDE RISK

Photographs courtesy of Greg Kotze and Tony Phillips

AUSTRALIAN GEOGUIDES

The **Australian GeoGuides (LR series)** are a set of information sheets on the subject of landslide risk management and maintenance, published by the Australian Geomechanics Society (AGS). They provide background information intended to help people without specialist technical knowledge understand the basic issues involved. Topics covered include:

LR1 - Introduction	LR2 - Landslides	LR3 - Landslides in Soil
LR4 - Landslides in Rock	LR5 - Water & Drainage	LR6 - Retaining Walls
LR7 - Landslide Risk	LR8 - Hillside Construction	LR9 - Effluent & Surface Water Disposal
LR10 - Coastal Landslides	LR11 - Record Keeping	

The GeoGuides explain why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local authority approval (if required) to remove, or reduce, the risk they represent.

Preparation of the GeoGuides has been funded by Australian governments through the National Disaster Mitigation Program (NDMP). This is a national program aimed at identifying and addressing natural disaster risk priorities across Australia. Technical input has been provided by experienced geotechnical engineers, engineering geologists and local government and government agency representatives from around Australia.

BACKGROUND

A number of landslides and cliff collapses occurred in Australia in the 1980's and 1990's in which lives were lost. Of these the Thredbo landslide probably received the most publicity, but there were several others. During this period the AGS issued a number of advisory notes to practitioners in relation to the assessment of landslide risk and its reduction. Building on these notes, and responding to changes in technology, a technical paper known as AGS2000 was prepared. It was followed in 2002 by an intensive nation-wide educational campaign attended by a large number of interested professionals from government departments and private industry. This resulted in an increased awareness of the risks associated with unstable slopes and a changed approach in many government departments responsible for regional planning, domestic development, roads, railways and the maintenance of natural features such as cliffs.

STATUS OF THE GEOGUIDES

The GeoGuides reflect the essence of good practice as perceived by a large number of geotechnical engineers, engineering geologists and other practitioners such as local government planners. **The GeoGuides are generic and do not, and cannot, constitute advice in relation to a specific situation. This must be sought from a geotechnical practitioner with first hand knowledge of the site.** It is expected that some local councils will refer to the GeoGuides and their companion publications in planning and building legislation. Check with your local council to see how it regards these documents. Companion publications to the GeoGuides are:

- AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1 and its associated commentary (AGS 2007b).
- AGS (2007c). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1 2007, and its associated "Commentary" (AGS 2007d).

Copies of the above documents are available on the AGS website www.australiangeomechanics.org

TERMINOLOGY

Terminology tends to change with time and place and with the context in which it is used. The terms listed below have the following meanings in the GeoGuides:

Consequence	the outcome, or potential outcome, arising from the occurrence of a landslide expressed quantitatively, or qualitatively, in terms of loss, disadvantage, damage, injury, or loss of life.
Discontinuity	in relation to the ground is a crack, a bedding plane (a boundary between strata) or fault (a plane along which the ground has sheared) which forms a plane of weakness and reduces the overall strength of the ground.
Equilibrium	the condition when the forces on a mass of soil or rock in the ground, or on a retaining structure, are equal and opposite.
Factor of safety (FOS)	theoretically the forces available to prevent a part of the ground, or a retaining structure, from moving divided by those trying to move it. A FOS of one or less indicates that failure is likely to occur, but not how likely it is. To allow for unknowns and to limit movements engineers always aim to achieve a FOS significantly larger than one.
Failure	when part of the ground experiences movement as a result of the out of balance forces on it. Failure of a retaining structure means it is no longer able to fulfil its intended function.
Geotechnical practitioner	when referred to in the Australian GeoGuides (LR series), is a professional geotechnical engineer, or engineering geologist, with chartered status in a recognised national professional institution and relevant training, experience and core competencies in landslide risk assessment and management. In some government departments, technical officers are specifically trained to undertake some of the functions of a geotechnical practitioner.
Hazard	a condition with the potential for causing an undesirable consequence. In relation to landslides this includes the location, size, speed, distance of travel and the likelihood of its occurrence within a given period of time.
Landslide	the movement, or the potential movement, of a mass of rock, debris, or earth down a slope.
Likelihood	a qualitative description of probability, or frequency, of occurrence.
Partial saturation	the condition in the ground above the water table where both air and water are present as well as soil, or rock.
Perched water table	a water table above the true water table supported by a low permeability stratum.
Permeability	a measure of the ability of the ground to allow water to flow through it.
Risk	a measure of the probability and severity of an adverse effect to life, health, property or the environment.
Slip failure	landslide.
Stable	the condition when failure will not occur. Over geological time no part of the ground can be considered stable. Over short periods (eg the life of a structure) stability implies a very low likelihood of failure.
Retaining structure	anything built by humans which is intended to support the ground and inhibit failure.
Structure	in relation to rock, or soil, means the spacing, extent, orientation and type of discontinuities found in the ground at a particular location.
Tension crack	a distinct open crack that normally develops in the ground around a landslide and indicates actual, or imminent , failure.
Water table	the level in the ground below which it is saturated and the voids are filled with water.

Photograph courtesy of Phil Flentje

AUSTRALIAN GEOGUIDE LR2 (LANDSLIDES)

LANDSLIDES

What is a Landslide?

Any movement of a mass of rock, debris, or earth, down a slope, constitutes a "landslide". Landslides take many forms, some of which are illustrated. More information can be obtained from Geoscience Australia, or by visiting its Australian Landslide Database at www.ga.gov.au/urban/factsheets/landslide.jsp. Aspects of the impact of landslides on buildings are dealt with in the book "Guideline Document Landslide Hazards" published by the Australian Building Codes Board and referenced in the Building Code of Australia. This document can be purchased over the internet at the Australian Building Codes Board's website www.abcb.gov.au .

Landslides vary in size. They can be small and localised or very large, sometimes extending for kilometres and involving millions of tonnes of soil or rock. It is important to realise that even a 1 cubic metre boulder of soil, or rock, weighs at least 2 tonnes. If it falls, or slides, it is large enough to kill a person, crush a car, or cause serious structural damage to a house. The material in a landslide may travel downhill well beyond the point where the failure first occurred, leaving destruction in its wake. It may also leave an unstable slope in the ground behind it, which has the potential to fail again, causing the landslide to extend (regress) uphill, or expand sideways. For all these reasons, both "potential" and "actual" landslides must be taken very seriously. They present a real threat to life and property and require proper management.

Identification of landslide risk is a complex task and must be undertaken by a geotechnical practitioner (GeoGuide LR1) with specialist experience in slope stability assessment and slope stabilisation.

What Causes a Landslide?

Landslides occur as a result of local geological and groundwater conditions, but can be exacerbated by inappropriate development (GeoGuide LR8), exceptional weather, earthquakes and other factors. Some slopes and cliffs never seem to change, but are actually on the verge of failing. Others, often moderate slopes (Table 1), move continuously, but so slowly that it is not apparent to a casual observer. In both cases, small changes in conditions can trigger a landslide with serious consequences. Wetting up of the ground (which may involve a rise in ground water table) is the single most important cause of landslides (GeoGuide LR5). This is why they often occur during, or soon after, heavy rain. Inappropriate development often results in small scale landslides which are very expensive in human terms because of the proximity of housing and people.

Does a Landslide Affect You?

Any slope, cliff, cutting, or fill embankment may be a hazard which has the potential to impact on people, property, roads and services. Some tell-tale signs that might indicate that a landslide is occurring are listed below:

- open cracks, or steps, along contours
- ground water seepage, or springs
- bulging in the lower part of the slope
- hummocky ground
- trees leaning down slope, or with exposed roots
- debris/fallen rocks at the foot of a cliff
- tilted power poles, or fences
- cracked or distorted structures

These indications of instability may be seen on almost any slope and are not necessarily confined to the steeper ones (Table 1). Advice should be sought from a geotechnical practitioner if any of them are observed. Landslides do not respect property boundaries. As mentioned above they can "run-out" from above, "regress" from below, or expand sideways, so a landslide hazard affecting your property may actually exist on someone else's land.

Local councils are usually aware of slope instability problems within their jurisdiction and often have specific development and maintenance requirements. **Your local council is the first place to make enquiries if you are responsible for any sort of development or own or occupy property on or near sloping land or a cliff.**

TABLE 1 - Slope Descriptions

Appearance	Slope Angle	Maximum Gradient	Slope Characteristics
Gentle	0°- 10°	1 on 6	Easy walking.
Moderate	10°- 18°	1 on 3	Walkable. Can drive and manoeuvre a car on driveway
Steep	18°- 27°	1 on 2	Walkable with effort. Possible to drive straight up or down roughened concrete driveway, but cannot practically manoeuvre a car.
Very Steep	27°- 45°	1 on 1	Can only climb slope by clutching at vegetation, rocks etc.
Extreme	45°- 64°	1 on 0.5	Need rope access to climb slope
Cliff	64°- 84°	1 on 0.1	Appears vertical. Can abseil down.
Vertical or Overhang	84°- 90±°	Infinite	Appears to overhang. Abseiler likely to lose contact with the face.

Some typical landslides which could affect residential housing are illustrated below:

AUSTRALIAN GEOGUIDE LR2 (LANDSLIDES)

Rotational or circular slip failures (Figure 1) - can occur on moderate to very steep soil and weathered rock slopes (Table 1). The sliding surface of the moving mass tends to be deep seated. Tension cracks may open at the top of the slope and bulging may occur at the toe. The ground may move in discrete "steps" separated by long periods without movement. More rapid movement may occur after heavy rain.

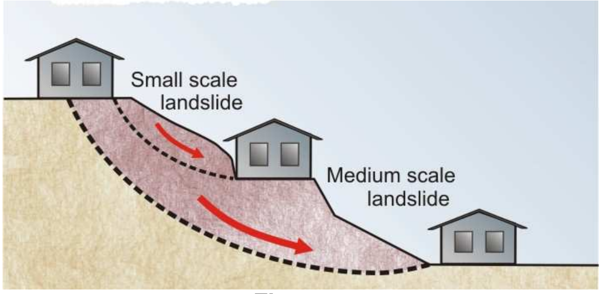


Figure 1

Translational slip failures (Figure 2) - tend to occur on moderate to very steep slopes (Table 1) where soil, or weak rock, overlies stronger strata. The sliding mass is often relatively shallow. It can move, or deform slowly (creep) over long periods of time. Extensive linear cracks and hummocks sometimes form along the contours. The sliding mass may accelerate after heavy rain.

Figure 2

Wedge failures (Figure 3) - normally only occur on extreme slopes, or cliffs (Table 1), where discontinuities in the rock are inclined steeply downwards out of the face.

Rock falls (Figure 3) - tend to occur from cliffs and overhangs (Table 1).

Cliffs may remain apparently unchanged for hundreds of years. Collections of boulders at the foot of a cliff may indicate that rock falls are ongoing. Wedge failures and rock falls do not "creep". Familiarity with a particular local situation can instil a false sense of security since failure, when it occurs, is usually sudden and catastrophic.

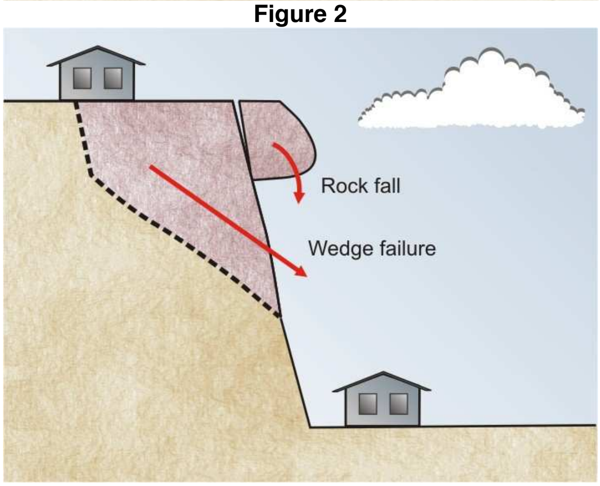


Figure 3

Debris flows and mud slides (Figure 4) - may occur in the foothills of ranges, where erosion has formed valleys which slope down to the plains below. The valley bottoms are often lined with loose eroded material (debris) which can "flow" if it becomes saturated during and after heavy rain. Debris flows are likely to occur with little warning; they travel a long way and often involve large volumes of soil. The consequences can be devastating.

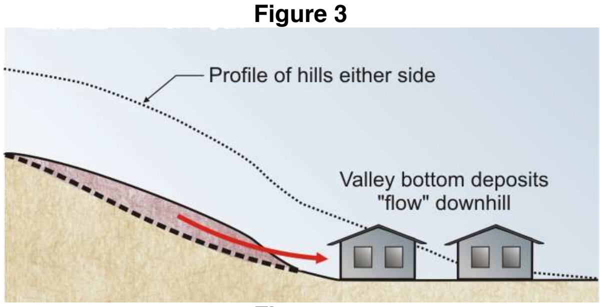


Figure 4

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR3 - Soil Slopes
- GeoGuide LR4 - Rock Slopes
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

LANDSLIDES IN SOIL

Landslides occur on soil slopes and the consequences can include damage to property and loss of life. Soil slopes exist in all parts of Australia and can even occur in places where rock outcrops can be seen on the surface. If you live on, or below, a soil slope it is important to understand why a landslide might occur and what you can do to reduce the risk it presents.

It is always worth asking the question *"why is this slope here?"*, because the answer often leads to an understanding of what might happen in the future. Slopes are usually formed by weathering (breakdown) and erosion (physical movement) of the natural ground - the "parent material". Many factors are involved including rain, wind, chemical change, temperature variation, plant growth, animal activity and our own human enthusiasm for development. The general process is outlined in Figure 1.

The upper levels of the parent material progressively weather over thousands, or millions, of years, losing strength. This can result in a surface layer which looks similar to the parent material (although its colour has probably changed) but has the strength of a soil - this is called "residual soil". At some stage the weathered surface layer is exposed to the elements and fragments are transported down the slope. In this context a fragment could be a single sand grain, a boulder, or a landslide. The time scale could be anything from a few seconds to many thousands of years. The transported fragments often collect on the lower slopes and form a new soil layer that blankets the original slope - "colluvium". If material reaches a river or the sea it is deposited as "alluvium" or as a "marine deposit". With appropriate changes in river and sea level this material can again find itself on the surface to commence another cycle of weathering and erosion. In places often, but not only, near the coast, this can include sand sized fragments which form beaches and are sometimes blown back onto the land to form dunes.

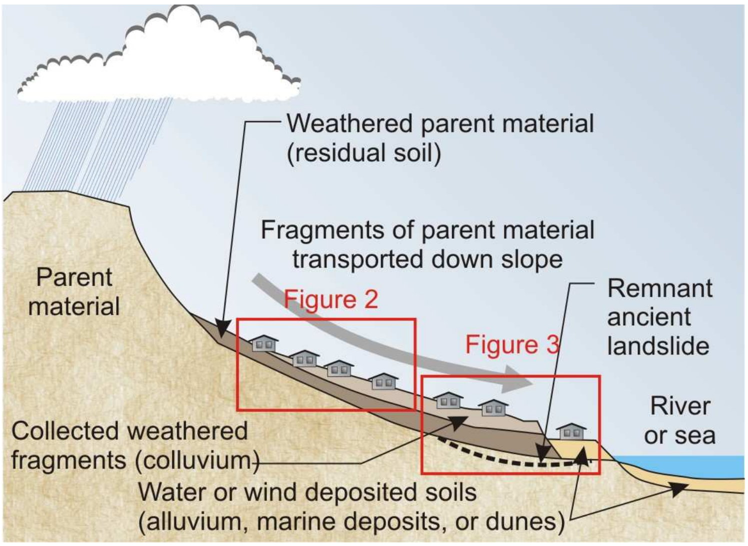


Figure 1

Landslides can occur almost anywhere on a soil slope. Slides can be rotational, translational, or debris flows (see GeoGuide LR2) and may have a number of causes.

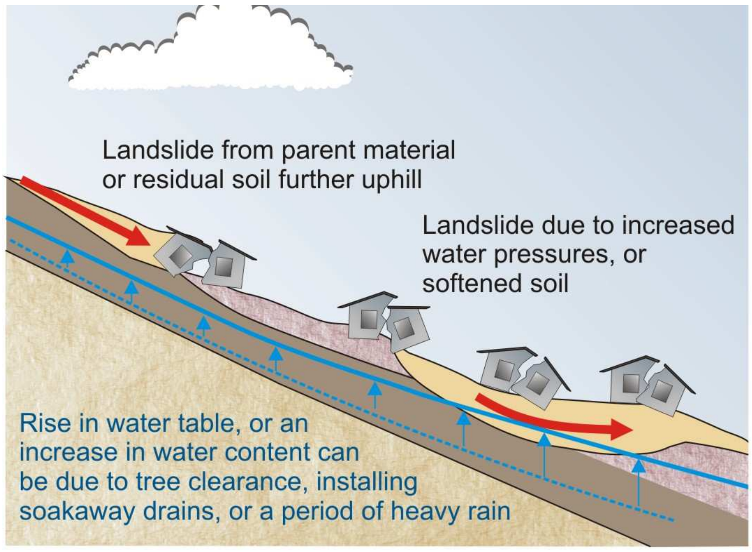


Figure 2

AUSTRALIAN GEOGUIDE LR3 (LANDSLIDES IN SOIL)

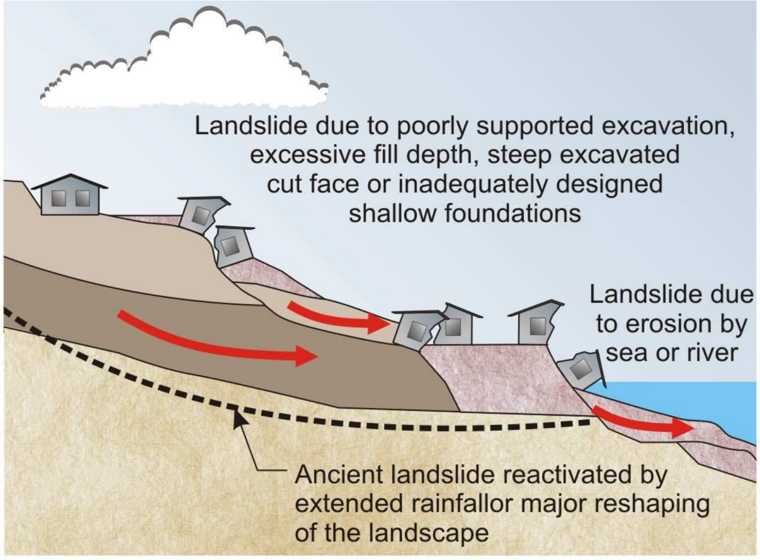


Figure 3

Some of the more common causes of landslides in soil are:

1) Falls of the parent material or residual soil from above, due to natural weathering processes (Figure 2).
2) Increased moisture content and consequent softening of the soil, or a rise in the water table. These can be due to excessive tree clearance, ill-considered soak-away drainage or septic systems, or heavy rainfall (Figure 2).
3) Excavation without adequate support, increased surface load from fill placement, or inadequately designed shallow foundations (Figure 3).
4) Natural erosion at the toe of the slope due to scour by a river or the sea (Figure 3).
5) Re-activation of an ancient landslide (Figure 3).

Most soil slopes appear stable, but they all achieved their present shape through a process of weathering and erosion and are often sensitive to minor changes in the factors that affect their stability. As a general rule, human activities only improve the situation if they have been designed to do so. Once this idea is understood, it is probably easy to see why the following basic rules are so important and should not be ignored without seeking site specific advice from a geotechnical practitioner:

- Do not clear trees unnecessarily.
- Do not cut into a slope without supporting the excavated face with an engineer designed structure.
- Do not add weight to a slope by placing earth fill or constructing buildings with inadequately designed shallow foundations (Note: in certain circumstances weight is added to the toe of a slope to inhibit landslide movement, but this must be carried out in accordance with a proper engineering design).
- Do not allow water from storm water drains, or from septic waste or effluent disposal systems to soak into the ground where it could trigger a landslide.

More information in relation to good and poor hillside construction practice is given in GeoGuide LR8. With appropriate engineering input it is often possible to reduce the likelihood, or consequences, of a landslide and so reduce the risk to property and to life. Such measures can include the construction of properly designed storm water and sub-soil drains, surface protection (GeoGuide LR5) and retaining walls (GeoGuide LR6). **Design should be undertaken by a geotechnical practitioner and will normally require local council approval.**

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
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- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
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- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

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LANDSLIDES IN ROCK

Rocks have been formed by many different geological processes and may have been subjected to intense pressure, large scale distortion, extreme temperature and chemical change. As a result there are many different rock types and their condition varies enormously. Rock strength varies and is often significantly reduced by the presence of discontinuities (GeoGuide LR1). You may think that rock lasts forever, but in reality it weathers under the combined effects of water, wind, chemical change, temperature variation, plant growth and animal activity and erodes with time. Rock is often the parent material that ends up forming soil slopes (GeoGuide LR3). Inevitably different rocks have different physical and chemical characteristics and they weather and erode to form different types of soil.

Weathering can lead to landslides (GeoGuide LR2) on rock slopes. The type of landslide depends on the nature of rock, the way it has weathered and the presence or absence of discontinuities. It is hard to generalise, though normally a specific combination of discontinuities and material types will be the determining factor and these are often underground and out of sight. Typical examples are provided in the figures 1 to 4. A geotechnical practitioner can assess the landslide risk and propose appropriate maintenance measures. This often entails making geological observations over an area significantly larger than the site and a review of available background information, including records of known landslides and aerial photographs. Depending on the amount of information available, geotechnical investigation may or may not be needed. Every site is different and every site has to be assessed individually.

<u>It is impossible to predict exactly when a landslide will occur on a rock slope, but failure is normally sudden and the consequences can be catastrophic.</u>

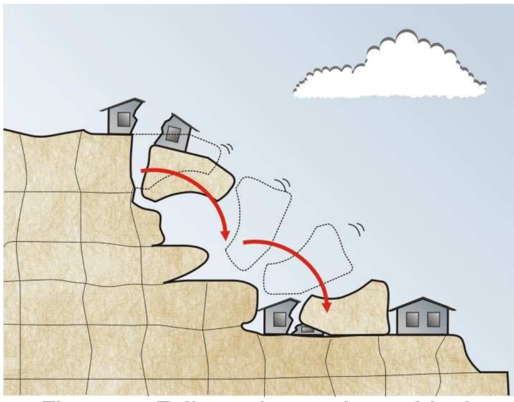

Figure 1 - Failure of an undercut block

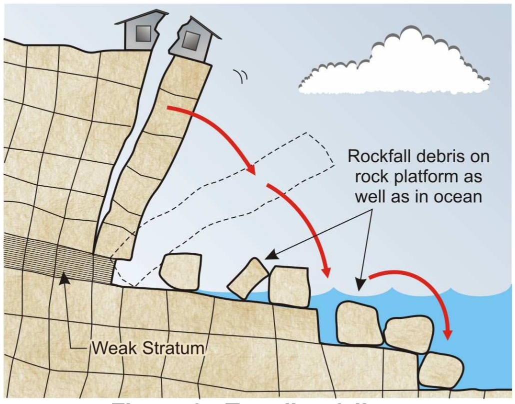

Figure 2 - Toppling failure

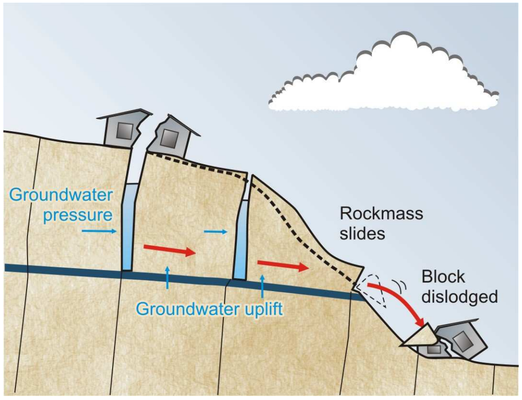

Figure 3 - Block slide on weak layer

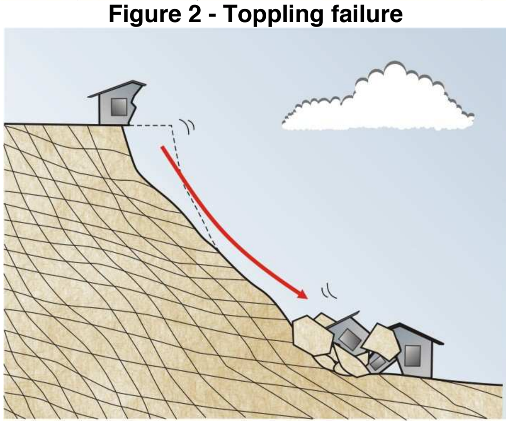

Figure 4 - Wedge failure along discontinuities

If the landslide risk is assessed as being anything other that Low, or Very Low, (GeoGuide LR7) it may be possible to carry out work aimed at reducing the level of risk.

The most common options are:

1) Trimming the slope to remove hazardous blocks of rock.
2) Bolting, or anchoring, to fix hazardous blocks in position and prevent movement.
3) Installation of catch fences and other rockfall protection measures to limit the impact of rockfalls.
4) Deep drainage designed to limit changes in the ground water table (GeoGuide LR5).

Although such measures can be effective, they need inspection and on-going maintenance (GeoGuide LR11) if they are to be effective for periods equivalent to the life of a house. **<u>Design should be undertaken by a geotechnical practitioner and will normally require local council approval.</u>** It should be appreciated that it may not be viable to carry out remedial works in all circumstances: for example where the landslide is on someone else's property, where the cost is out of proportion to the value of the property, or where the risk inherent in carrying out the work is actually greater than the risk of leaving things as they are. In situations such as these, development may be considered inappropriate.

ROCK SLOPE HAZARD REDUCTION MEASURES

Removal of loose blocks - may be effective but, depending on rock type, ongoing erosion can result in more blocks becoming unstable within a matter of years. Routine inspection, every 5 or so years, may be required to detect this.

Rock bolts and rock anchors (Figure 5) - can be installed in the ground to improve its strength and prevent individual blocks from falling. Rock bolts are usually tightened using a torque wrench, whilst rock anchors carry higher loads and require jacking. Both can be designed to be "permanent" using stainless steel, or sheathing, to inhibit corrosion, but the cost can be up to 10 times that of the "temporary" alternative. You should inspect rock bolts and rock anchors for signs of water seepage, rusting and deterioration around the heads at least once every 5 years. If you notice any of these warning signs, have them checked by a geotechnical practitioner. It is recommended that you keep copies of design drawings and maintenance records (GeoGuide LR11) for the anchors on your site and pass them on to the new owner should you sell.

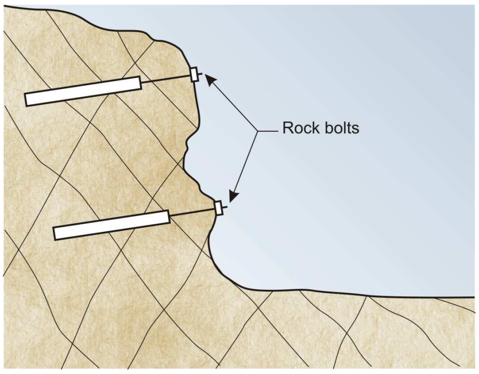

Figure 5

Rock fall netting, catch fences and catch pits (Figure 6) - are designed to catch or control falling rocks and prevent them from damaging nearby property. You should inspect them at least once every 5 years, and after major falls, and arrange for fallen and trapped rocks to be removed if they appear to be filling up. Check for signs of corrosion and replace steel elements and fixings before they lose significant strength.

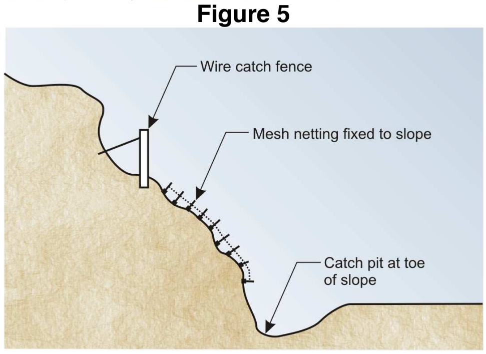

Figure 6

Cut-off drains (Figure 7) - can be used to intercept surface water run-off and reduce flows down the cliff face. Suitable drains are often excavated into the rock, or constructed from mounds of concrete, or stabilised soil, depending on conditions. Drains must be laid to a fall of at least 1% so they drain adequately. Frequent inspection is needed to ensure they are not blocked and continue to function as intended.

Clear trees and large bushes (Figure 7) - from slopes since roots can prize boulders from the face increasing the landslide hazard.

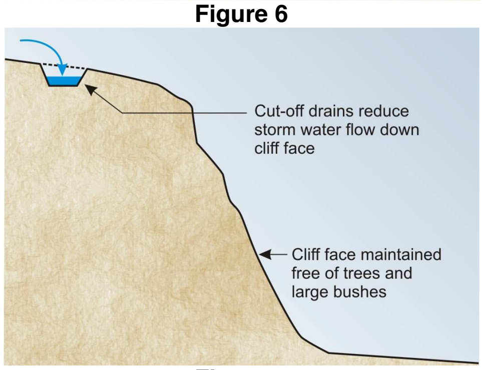

Figure 7

Natural cliffs and bluffs - often present the greatest hazard and yet are easily overlooked, because they have "been there forever". They can exist above a building, road, or beach, presenting the risk of a rock falling onto whatever is below. They also sometimes support buildings with a fine view to the horizon. Cliffs should be observed frequently to ensure that they are not deteriorating. You may find it convenient to use binoculars to look for signs of exposed "fresh" rock on the face, where a recent fall has occurred, or to go to the foot of the cliff from time to time to see if debris is collecting. A thorough inspection of a cliff face is often a major task requiring the use of rope access methods and should only be undertaken by an appropriately qualified professional. If tension cracks are observed in the ground at the top of a cliff take immediate action, since they could indicate imminent failure. **<u>If you have any concerns at all about the possibility of a rock fall seek advice from a geotechnical practitioner.</u>**

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AUSTRALIAN GEOGUIDE LR5 (WATER & DRAINAGE)

WATER, DRAINAGE & SURFACE PROTECTION

One way or another, water usually plays a critical part in initiating a landslide (GeoGuide LR2). For this reason, it is a key factor to be controlled on sites with more than a low landslide risk (GeoGuide LR7).

Groundwater and Groundwater Flow

The ground is permeable and water flows through it as illustrated in Figure 1. When rain falls on the ground, some of it runs along the surface ("surface water run-off") and some soaks in, becoming groundwater. Groundwater seeps downwards along any path it can find until it meets the water table: the local level below which the ground is saturated. If it reaches the water table, groundwater either comes to a halt in what is effectively underground storage, or it continues to flow downwards, often towards a spring where it can seep out and become surface water again. Above the water table the ground is said to be "partially saturated", because it contains both water and air. Suctions can develop in the partially saturated zone which have the effect of holding the ground together and reducing the risk of a landslide. Vegetation and trees in particular draw large quantities of water out of the ground on a daily basis from the partially saturated zone. This lowers the water table and increases suctions, both of which reduce the likelihood of a landslide occurring.

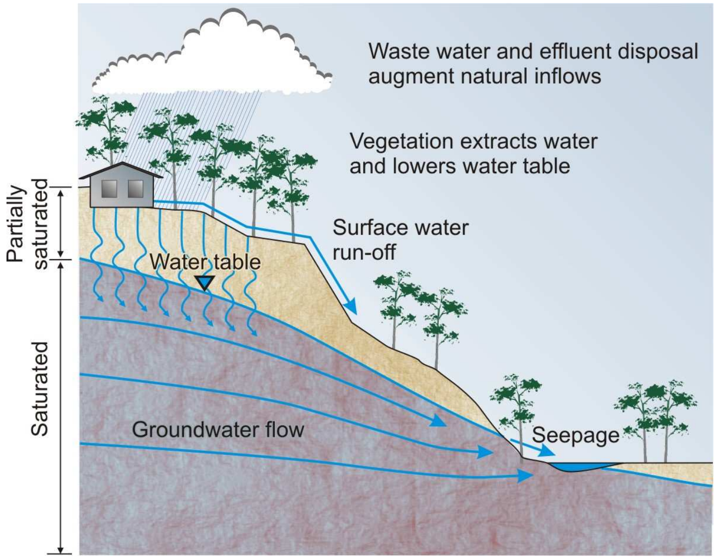

Figure 1 - Groundwater flow

Groundwater Flow and Landslides

The landslide risk in a hillside can be affected by increase in soak-away drainage or the construction of retaining walls which inhibit groundwater flow. The groundwater is likely to rise after heavy rain, but it can also rise when human interference upsets the delicate natural balance. Activities such as felling trees and earthworks can lead to:

- a reduction in the beneficial suctions in the partially saturated zone above the water table.
- increased static water pressures below the water table,
- increased hydraulic pressures due to groundwater flow,
- loss of strength, or softening, of clay rich strata,
- loss of natural cementing in some strata,
- transportation of soil particles.

Any of these effects, or a combination of them, can lead to landslides like those illustrated in GeoGuides LR2, LR3 and LR4.

Limiting the Effect of Water

Site clearance and construction must be carefully considered if changes in groundwater conditions are to be limited. GeoGuide LR8 considers good and poor development practices. Not surprisingly much of the advice relates to sensible treatment of water and is not repeated here. Adoption of appropriate techniques should make it possible to either maintain the current ground water table, or even cause it to drop, by limiting inflow to the ground.

If drainage measures and surface protection are relied on to keep the risk of a landslide to a tolerable level, it is important that they are inspected routinely and maintained (GeoGuide LR11).

The following techniques may be considered to limit the destabilising effects of rising groundwater due to development and are illustrated in Figure 2.

AUSTRALIAN GEOGUIDE LR5 (WATER & DRAINAGE)

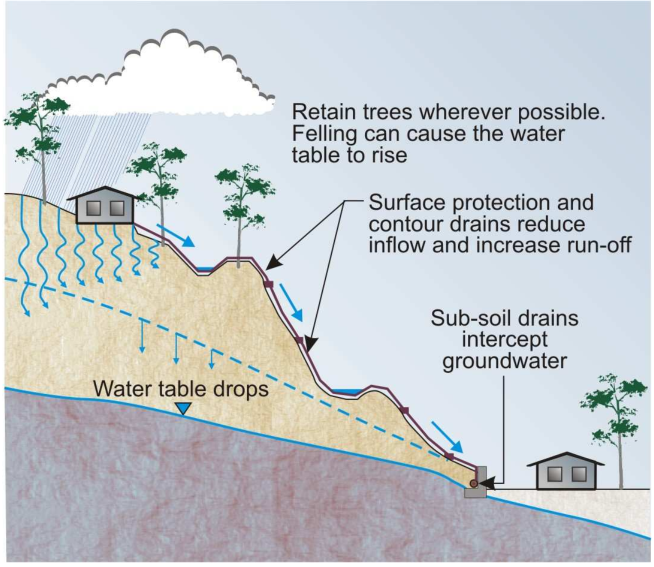

Figure 2 - Techniques used to control groundwater flow

Surface water drains (dish drains, or table drains) - are often used to prevent scour and limit inflow to a slope. Other than in rock, they are relatively ineffective unless they have an impermeable lining. You should clear them regularly, and as required, and not less than once a year. If you live in an area with seasonal rainfall, it is best to do this near the end of the dry season. If you notice that soil or rock debris is falling from the slope above, determine the source and take appropriate action. This may mean you have to seek advice from a geotechnical practitioner.

Surface protection - is sometimes used in addition to surface water drainage to prevent scour and minimise water inflow to a slope. You should inspect concrete, shotcrete or stone pitching for cracking and other signs of deterioration at least once a year. Make sure that weepholes are free of obstructions and able to drain. If the protection is deteriorating, you should seek advice from a geotechnical practitioner.

Sub-soil drains - are often constructed behind retaining walls and on hillsides to intercept groundwater. Their function is to remove water from the ground through an appropriate outlet. It is important that subsoil drains are designed to complement other measures being used. They should be laid in a sand, or gravel, bed and protected with a graded stone or geotextile filter to reduce the chance of clogging. Sub-soil drains should always be laid to a fall of at least 1 vertical on 100 horizontal. Ideally the high end should be brought to the surface, so it can be flushed with water from time to time as part of routine maintenance procedures.

Deep, underground drains - are usually only used in extreme circumstances, where the landslide risk is assessed as not being tolerable and other stabilisation measures are considered to be impractical. They work by permanently lowering the water table in a slope. They are not often used in domestic scale developments, but if you have any on your site be aware that professional maintenance is essential. If they are not maintained and stop working, the water table will rise and a landslide may even occur during normal weather conditions. Both an increase or a reduction in the normal flow from deep drains could indicate a problem if it appears to be unrelated to recent rainfall. If changes of this sort are observed, you should have the drains and your site checked by a geotechnical practitioner.

Documentation - design drawings and specifications for geotechnical measures intended to minimise landslide risk can be of great assistance to a geotechnical specialist, or structural engineer, called in to inspect and report on them. Copies of available documentation should be retained and passed to the new owner when the property is sold (GeoGuide LR11). You should also request details of an appropriate maintenance program for drainage works from the designer and keep that information with other relevant documentation and maintenance records.

More information relevant to your particular situation may be found in other Australian GeoGuides:

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RETAINING WALLS

Retaining walls are used to support cuts and fills. Some are built in the open and backfill is placed behind them (gravity walls). Others are inserted into the ground (cast *in situ* or driven piles) and the ground is subsequently excavated on one side. Retaining walls, like all man-made structures, have a finite life. Properly engineered walls should last 50 years, or more, without needing significant repairs. However, not all walls fit this category. Some, particularly those built by inexperienced tradesmen without engineering input, can deflect and even fail because they are unable to withstand the pressures that develop in the ground around them or because the materials from which they are built deteriorate with time. **Design of retaining walls more than 900mm high should be undertaken by a geotechnical practitioner or structural engineer and normally require local council approval.**

Retaining walls have to withstand the weight of the ground on the high side, any water pressure forces that develop, any additional load (surcharge) on the ground surface and sometimes swelling pressures from expansive clays. These forces are resisted by the wall itself and the ground on the low side. Engineers calculate the forces that the retained ground, the water, and the surcharge impose on a wall (the disturbing force) as well as the maximum force that the wall and ground on the low side can provide to resist them (the restoring force). The ratio of the restoring force to the disturbing force is called the "factor of safety" (GeoGuide LR1). Permanent retaining walls designed in accordance with accepted engineering standards will normally have a factor of safety in the range 1.5 to 2.

Never add surcharge to the high side of a wall (e.g. place fill, erect a structure, stockpile bulk materials, or park vehicles) unless you know the wall has been designed with that purpose in mind.

Never more than lightly water plants on the high side of a retaining wall.

Never excavate at the toe of a retaining wall.

Any of these actions will reduce the factor of safety of the wall and could lead to failure. If in doubt about any aspect of an existing retaining wall, or changes you would like to make near one, seek advice from a geotechnical practitioner, or a structural engineer. This GeoGuide sets out basic inspection requirements for retaining walls and identifies some common signs that might indicate all is not well. GeoGuide LR11 provides information about records that should be kept.

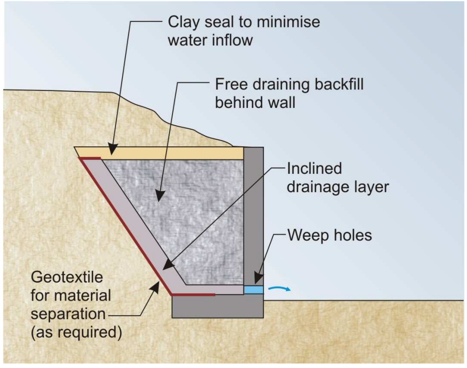

Figure 1- Typical formed concrete wall

GRAVITY WALLS

Gravity walls are so called because they rely on their own weight (the force of gravity) to hold the ground behind in place.

Formed concrete and reinforced blockwork walls (Figure 1) **-** should be built so the backfill can drain. They should be inspected at least once a year. Look for signs of tilting, bulging, cracking, or a drop in ground level on the high side, as any of these may indicate that the wall has started to fail. Look for rust staining, which may indicate that the steel reinforcement is deteriorating and the wall is losing structural strength ("concrete cancer"). Ensure that weep holes are clear and that water is able to drain at all times, as high water pressures behind the wall can lead to sudden and catastrophic failure.

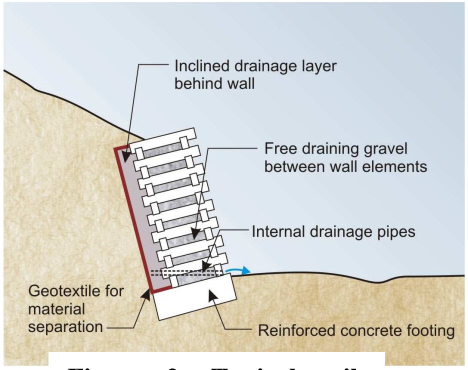

Figure 2 -Typical crib

Concrete "crib" walls (Figure 2) **-** should be filled with clean gravel, or "blue metal" with a nominated grading. Sometimes soil is used to reduce cost, but this is undesirable, from an engineering perspective, unless internal drainage is incorporated in the wall's construction. Without backfill drainage, a soil filled crib wall is likely to have a lower factor of safety than is required. Crib walls should be inspected as for formed concrete walls. In addition, you should check that material is not being lost through the structure of the wall, which has large gaps through it.

Timber "crib" walls - should be checked as for concrete crib walls. In addition, check the condition of the timber. Once individual elements show signs of rotting, it is necessary to have the wall replaced. If you are uncertain seek advice from a geotechnical practitioner, or a structural engineer.

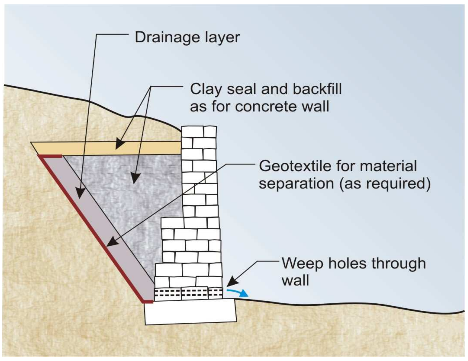

Figure 3 -Typical masonry wall

Masonry walls: natural stone, brick, or interlocking blocks (Figure 3) - more than about 1m high, should be wider at the bottom than at the top and include specific measures to permit drainage of the backfill. They should be checked as for formed concrete walls. Natural stone walls should be inspected for signs of deterioration of the individual blocks: strength loss, corners becoming rounded, cracks appearing, or debris from the blocks collecting at the foot of the wall.

Old Masonry walls (Figure 4) - Many old masonry retaining walls have not been built in accordance with modern design standards and often have a low "factor of safety" (GeoGuide LR1). They may therefore be close to failure and a minor change in their condition, or loading, could initiate collapse. You need to take particular care with such structures and seek professional advice sooner rather than later. Although masonry walls sometimes deflect significantly over long periods of time collapse, when it occurs, is usually sudden and can be catastrophic. Familiarity with a particular situation can instil a false sense of confidence.

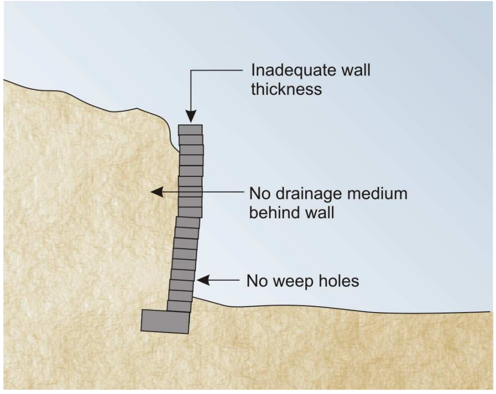

Figure 4 - Poorly built masonry wall

Reinforced soil walls (Figure 5) **-** are made of compacted select fill in which layers of reinforcement are buried to form a "reinforced soil zone". The reinforcement is all important, because it holds the soil "wall" together. Reinforcement may be steel strip, or mesh, or a variety of geosynthetic ("plastic") products. The facing panels are there to protect the soil "wall" from erosion and give it a finished appearance.

Most reinforced soil walls are proprietary products. Construction should be carried out strictly in accordance with the manufacturer's instructions. Inspection and maintenance should be the same as for formed concrete and concrete block walls. If unusual materials such as timber, or used tyres, are used as a facing it should be checked to see that it is not rotting, or perishing.

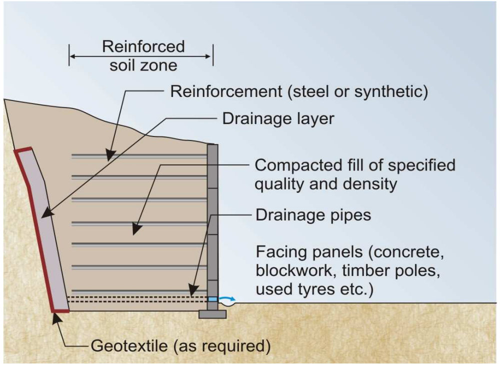

Figure 5 - Typical reinforced soil wall

OTHER WALLS

Cantilevered and anchored walls (Figure 6) **-** rely on earth pressure on the low side, rather than self-weight, to provided the restoring force and an adequate factor of safety. These walls may comprise:

- a line of touching bored piers (contiguous bored pile wall) or
- sprayed concrete panels between bored piers (shotcrete wall) or
- horizontal timber or concrete planks spanning between upright timber or steel soldier piles or
- steel sheet piles.

Depending on the form of construction and ground conditions, walls in excess of 3 m height normally require at least one row of permanent ground anchors.

INSPECTION

All walls should be inspected at least once a year, looking for tilting and other signs of deterioration. Concrete walls should be inspected for cracking and rust stains as for formed concrete gravity walls. Contiguous bored pile walls can have gaps between the piles - look for loss of soil from behind which can become a major difficulty if it is not corrected. Timber walls should be inspected for rot, as for timber crib walls. Steel sheet piles should be inspected for signs of rusting. In addition, you should make sure that ground anchors are maintained as described in GeoGuide LR4 under the heading "Rock bolts and rock anchors".

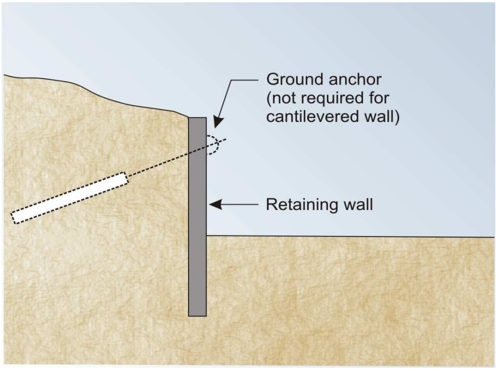

Figure 6 - Typical cantilevered or anchored wall

One of the most important issues for walls is that their internal drainage systems are operational. Frequently verify that internal drainage pipes and surface interception drains around the wall are not blocked nor have become inoperative.

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AUSTRALIAN GEOGUIDE LR7 (LANDSLIDE RISK)

LANDSLIDE RISK

Concept of Risk

Risk is a familiar term, but what does it really mean? It can be defined as *"a measure of the probability and severity of an adverse effect to health, property, or the environment."* This definition may seem a bit complicated. In relation to landslides, geotechnical practitioners (GeoGuide LR1) are required to assess risk in terms of the likelihood that a particular landslide will occur and the possible consequences. This is called landslide risk assessment. The consequences of a landslide are many and varied, but our concerns normally focus on loss of, or damage to, property and loss of life.

Landslide Risk Assessment

Some local councils in Australia are aware of the potential for landslides within their jurisdiction and have responded by designating specific "landslide hazard zones". Development in these areas is often covered by special regulations. If you are contemplating building, or buying an existing house, particularly in a hilly area, or near cliffs, go first for information to your local council.

Landslide risk assessment must be undertaken by a geotechnical practitioner. It may involve visual inspection, geological mapping, geotechnical investigation and monitoring to identify:

- potential landslides (there may be more than one that could impact on your site)
- the likelihood that they will occur
- the damage that could result
- the cost of disruption and repairs and
- the extent to which lives could be lost.

Risk assessment is a predictive exercise, but since the ground and the processes involved are complex, prediction tends to lack precision. If you commission a landslide risk assessment for a particular site you should expect to receive a report prepared in accordance with current professional guidelines and in a form that is acceptable to your local council, or planning authority.

Risk to Property

Table 1 indicates the terms used to describe risk to property. Each risk level depends on an assessment of how likely a landslide is to occur and its consequences in dollar terms. "Likelihood" is the chance of it happening in any one year, as indicated in Table 2. "Consequences" are related to the cost of repairs and temporary loss of use if a landslide occurs. These two factors are combined by the geotechnical practitioner to determine the Qualitative Risk.

TABLE 2: LIKELIHOOD

Likelihood	Annual Probability
Almost Certain	1:10
Likely	1:100
Possible	1:1,000
Unlikely	1:10,000
Rare	1:100,000
Barely credible	1:1,000,000

The terms "unacceptable", "may be tolerated", etc. in Table 1 indicate how most people react to an assessed risk level. However, some people will always be more prepared, or better able, to tolerate a higher risk level than others.

Some local councils and planning authorities stipulate a maximum tolerable level of risk to property for developments within their jurisdictions. In these situations the risk must be assessed by a geotechnical practitioner. If stabilisation works are needed to meet the stipulated requirements these will normally have to be carried out as part of the development, or consent will be withheld.

TABLE 1: RISK TO PROPERTY

Qualitative Risk		Significance - Geotechnical engineering requirements
Very high	VH	**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 the value of the property.
High	H	**Unacceptable** without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable level. Work would cost a substantial sum in relation to the value of the property.
Moderate	M	**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 possible.
Low	L	**Usually acceptable** to regulators. Where treatment has been needed to reduce the risk to this level, ongoing maintenance is required.
Very Low	VL	**Acceptable**. Manage by normal slope maintenance procedures.

Risk to Life

Most of us have some difficulty grappling with the concept of risk and deciding whether, or not, we are prepared to accept it. However, without doing any sort of analysis, or commissioning a report from an "expert", we all take risks every day. One of them is the risk of being killed in an accident. This is worth thinking about, because it tells us a lot about ourselves and can help to put an assessed risk into a meaningful context. By identifying activities that we either are, or are not, prepared to engage in we can get some indication of the maximum level of risk that we are prepared to take. This knowledge can help us to decide whether we really are able to accept a particular risk, or to tolerate a particular likelihood of loss, or damage, to our property (Table 2).

In Table 3, data from NSW for the years 1998 to 2002, and other sources, is presented. A risk of 1 in 100,000 means that, in any one year, 1 person is killed for every 100,000 people undertaking that particular activity. The NSW data assumes that the whole population undertakes the activity. That is, we are all at risk of being killed in a fire, or of choking on our food, but it is reasonable to assume that only people who go deep sea fishing run a risk of being killed while doing it.

It can be seen that the risks of dying as a result of falling, using a motor vehicle, or engaging in water-related activities (including bathing) are all greater than 1:100,000 and yet few people actively avoid situations where these risks are present. Some people are averse to flying and yet it represents a lower risk than choking to death on food. Importantly, the data also indicate that, even when the risk of dying as a consequence of a particular event is very small, it could still happen to any one of us any day. If this were not so, no one would ever be struck by lightning.

Most local councils and planning authorities that stipulate a tolerable risk to property also stipulate a tolerable risk to life. The AGS Practice Note Guideline recommends that 1:100,000 is tolerable in newly developed areas, where works can be carried out as part of the development to limit risk. The tolerable level is raised to 1:10,000 in established areas, where specific landslide hazards may have existed for many years. The distinction is deliberate and intended to prevent the concept of landslide risk management, for its own sake, becoming an unreasonable financial burden on existing communities. Acceptable risk is usually taken to be one tenth of the tolerable risk (1:1,000,000 for new developments and 1:100,000 for established areas) and efforts should be made to attain these where it is practicable and financially realistic to do so.

TABLE 3: RISK TO LIFE

Risk (deaths per participant per year)	**Activity/Event Leading to Death** (NSW data unless noted)
1:1,000	Deep sea fishing (UK)
1:1,000 to 1:10,000	Motor cycling, horse riding , ultra-light flying (Canada)
1:23,000	Motor vehicle use
1:30,000	Fall
1:70,000	Drowning
1:180,000	Fire/burn
1:660,000	Choking on food
1:1,000,000	Scheduled airlines (Canada)
1:2,300,000	Train travel
1:32,000,000	Lightning strike

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  GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

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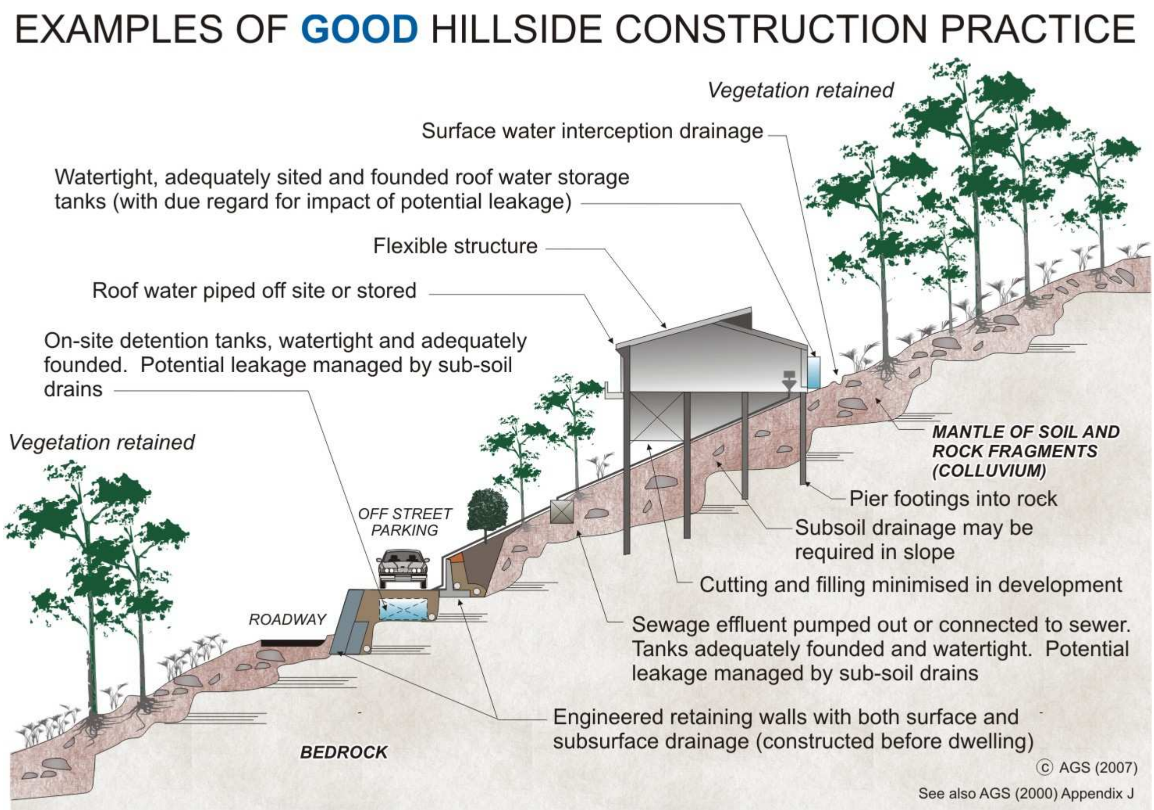
HILLSIDE CONSTRUCTION PRACTICE

Sensible development practices are required when building on hillsides, particularly if the hillside has more than a low risk of instability (GeoGuide LR7). Only building techniques intended to maintain, or reduce, the overall level of landslide risk should be considered. Examples of good hillside construction practice are illustrated below.



WHY ARE THESE PRACTICES GOOD?

Roadways and parking areas - are paved and incorporate kerbs which prevent water discharging straight into the hillside (GeoGuide LR5).

Cuttings - are supported by retaining walls (GeoGuide LR6).

Retaining walls - are engineer designed to withstand the lateral earth pressures and surcharges expected, and include drains to prevent water pressures developing in the backfill. Where the ground slopes steeply down towards the high side of a retaining wall, the disturbing force (see GeoGuide LR6) can be two or more times that in level ground. Retaining walls must be designed taking these forces into account.

Sewage - whether treated or not is either taken away in pipes or contained in properly founded tanks so it cannot soak into the ground.

Surface water - from roofs and other hard surfaces is piped away to a suitable discharge point rather than being allowed to infiltrate into the ground. Preferably, the discharge point will be in a natural creek where ground water exits, rather than enters, the ground. Shallow, lined, drains on the surface can fulfil the same purpose (GeoGuide LR5).

Surface loads - are minimised. No fill embankments have been built. The house is a lightweight structure. Foundation loads have been taken down below the level at which a landslide is likely to occur and, preferably, to rock. This sort of construction is probably not applicable to soil slopes (GeoGuide LR3). If you are uncertain whether your site has rock near the surface, or is essentially a soil slope, you should engage a geotechnical practitioner to find out.

Flexible structures - have been used because they can tolerate a certain amount of movement with minimal signs of distress and maintain their functionality.

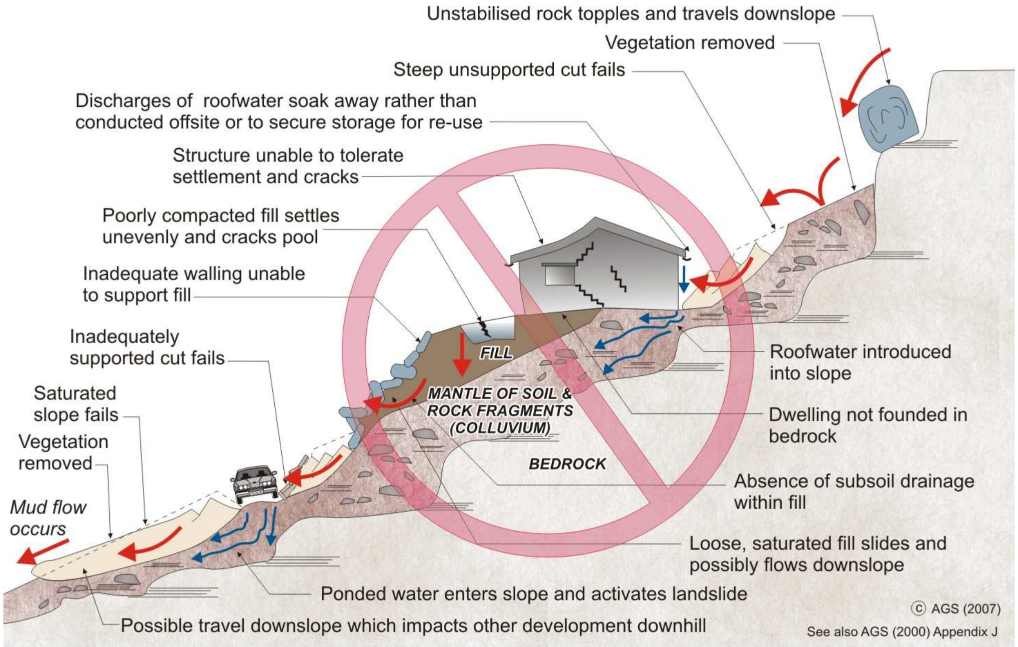
Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing can result in a rise in water table with a consequent increase in the likelihood of a landslide (GeoGuide LR5). An exception may have to be made to this rule on steep rock slopes where trees have little effect on the water table, but their roots pose a landslide hazard by dislodging boulders.

Possible effects of ignoring good construction practices are illustrated on page 2. Unfortunately, these poor construction practices are not as unusual as you might think and are often chosen because, on the face of it, they will save the developer, or owner, money. You should not lose sight of the fact that the cost and anguish associated with any one of the disasters illustrated, is likely to more than wipe out any apparent savings at the outset.

ADOPT GOOD PRACTICE ON HILLSIDE SITES

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

EXAMPLES OF POOR HILLSIDE CONSTRUCTION PRACTICE



WHY ARE THESE PRACTICES POOR?

Roadways and parking areas - are unsurfaced and lack proper table drains (gutters) causing surface water to pond and soak into the ground.

Cut and fill - has been used to balance earthworks quantities and level the site leaving unstable cut faces and added large surface loads to the ground. Failure to compact the fill properly has led to settlement, which will probably continue for several years after completion. The house and pool have been built on the fill and have settled with it and cracked. Leakage from the cracked pool and the applied surface loads from the fill have combined to cause landslides.

Retaining walls - have been avoided, to minimise cost, and hand placed rock walls used instead. Without applying engineering design principles, the walls have failed to provide the required support to the ground and have failed, creating a very dangerous situation.

A heavy, rigid, house - has been built on shallow, conventional, footings. Not only has the brickwork cracked because of the resulting ground movements, but it has also become involved in a man-made landslide.

Soak-away drainage - has been used for sewage and surface water run-off from roofs and pavements. This water soaks into the ground and raises the water table (GeoGuide LR5). Subsoil drains that run along the contours should be avoided for the same reason. If felt necessary, subsoil drains should run steeply downhill in a chevron, or herring bone, pattern. This may conflict with the requirements for effluent and surface water disposal (GeoGuide LR9) and if so, you will need to seek professional advice.

Rock debris - from landslides higher up on the slope seems likely to pass through the site. Such locations are often referred to by geotechnical practitioners as "debris flow paths". Rock is normally even denser than ordinary fill, so even quite modest boulders are likely to weigh many tonnes and do a lot of damage once they start to roll. Boulders have been known to travel hundreds of metres downhill leaving behind a trail of destruction.

Vegetation - has been completely cleared, leading to a possible rise in the water table and increased landslide risk (GeoGuide LR5).

DON'T CUT CORNERS ON HILLSIDE SITES - OBTAIN ADVICE FROM A GEOTECHNICAL PRACTITIONER

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- GeoGuide LR4 - Landslides in Rock
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EFFLUENT AND SURFACE WATER DISPOSAL

EFFLUENT AND WASTEWATER

All households generate effluent and wastewater. The disposal of these products and their impact on the environment are key considerations in the planning of safe and sustainable communities. Cities and townships generally have reticulated water, sewer and stormwater systems, which are designed to deliver water and dispose of effluent and wastewater with minimal impact on the environment. However, many smaller communities and metropolitan fringe suburbs throughout Australia are un-sewered. Some of these are located in hillside or coastal settings where landslides present a hazard.

Processes by which wastewater can affect slope stability

As explained in GeoGuides LR3 and LR5, groundwater variations have a significant impact on slope stability. Inappropriate disposal of effluent and wastewater may result in the ground becoming saturated. The result is equivalent to a localised rise of the groundwater table and may have the potential to cause a landslide (GeoGuides LR2, LR5 and LR8).

On-site effluent disposal

In un-sewered areas disposal of effluent must be achieved through suitable methods. These methods usually involve containment within the boundaries of the site ("on-site disposal"). State environment protection agencies and local government authorities can usually provide advice on suitable disposal systems for your area. Such systems may include:

- *Septic systems,* which involve a storage/digestion tank for solids, with disposal of the liquid effluent via absorption trenches and beds, leach drains, or soak wells. Such systems are best suited to areas not prone to landslides.
- *Aerobic treatment units* which incorporate an individual household treatment plant to aid breakdown of the waste into a higher quality effluent. Such effluent is further treated and disposed of by surface or sub-surface irrigation, sub-soil dripper, or shallow leach drain system.
- *Nutrient retentive leaching systems* which utilise septic tanks to process the solid and liquid wastes in conjunction with discharge of the effluent through sand filters, media filters, mound systems and nutrient retentive leaching systems, which strip the effluent of nutrients.

Toilet (and sometimes kitchen) waste is known as *black water.* Other, less contaminated, wastewater streams from showers, baths and laundries are known as *grey water*. *Grey water re-use systems* allow a household to conserve water from bathrooms, kitchens and laundries, for re-use on gardens and lawns.

Recommendations for effluent disposal

In areas prone to landslide hazard, it is recommended that whatever effluent disposal system is employed, it should be designed by a qualified professional, familiar with how such a system can impact on the local environment. Local council, and in some instances state environment protection agency, approval is usually required as well. Many local authorities require a site assessment report, which covers all relevant issues. If approved, the report's recommendations must be incorporated in the system design. Reduction in the volume of effluent is beneficial so composting toilets and highly rated (i.e. low consumption) water appliances are recommended. It should be noted that in some state and local government jurisdictions there are restrictions on the alternative measures that can be applied. Consideration should be given to applying treated wastewater to land at low rates and over as large an area as possible. Further guidance can be found in Australian Standard AS/NZS 1547:2000 On-site domestic wastewater management.

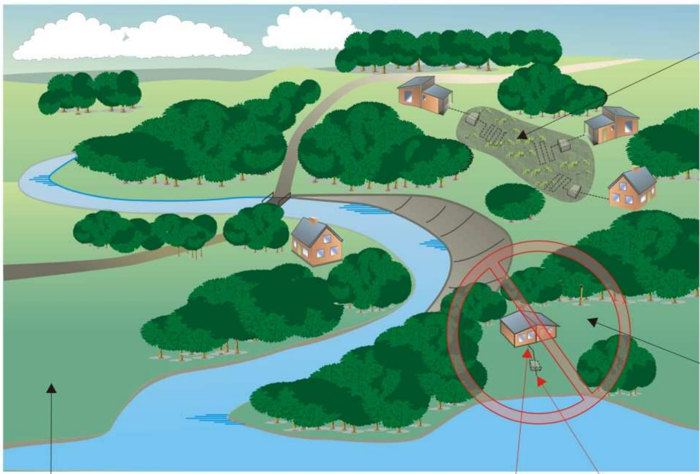
Effluent disposal fields should be sited with due consideration to the overall landscape and the individual characteristics of the property. Some guidance is provided. In particular, effluent fields should be located downslope of the building, away from stormwater, or *grey water*, discharge areas and where there is minimal potential for downstream pollution. Set backs and buffer distances vary from state to state and local requirements should be adhered to. All systems require regular maintenance and inspection. Efficient operation of the system must be a priority for property owners/occupiers to ensure safe and sustainable communities. Responsibility for maintenance rests with owners.

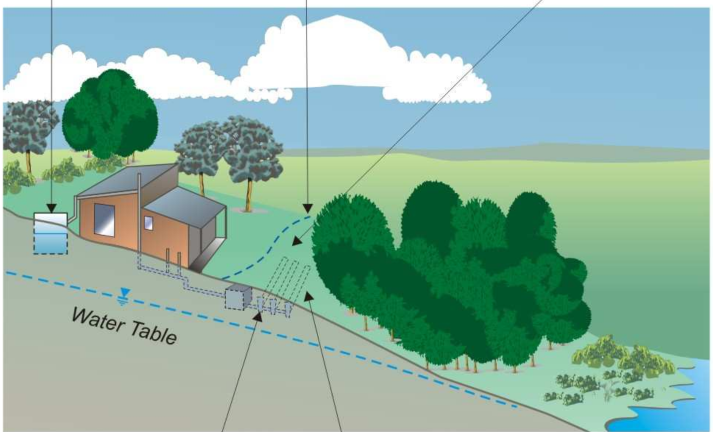
SURFACE WATER DRAINAGE

Attention to on-site surface water management is also important. Runoff from developments, including buildings, decks, access tracks and hardstand areas should be collected and discharged away from the development and other effluent disposal fields. Particular care must be given to the design of overflows on water tanks, as this is often overlooked. Discharge from any development should be spread out as much as possible, unless it can be directed to an existing natural water course. Ponding of water on hillsides and the concentration of water flows on slopes must be avoided.

It is recommended that a specific drainage plan and strategy should be developed in conjunction with the effluent disposal system for sites with a high potential for slope instability. Maintenance of the surface water drainage system is as important as maintenance of the effluent disposal system and again the responsibility rests with owners.

AUSTRALIAN GEOGUIDE LR9 (EFFLUENT DISPOSAL)





Note: Adapted from EPA Vic. Publication 451 (March 1996) "Code of Practice - Septic Tanks", which was sourced from Vic. Department of Planning and Loddon-Campaspe Regional Planning Authority.

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LANDSLIDES IN THE COASTAL ENVIRONMENT

Coastal Instability

The coast presents a particularly dynamic environment where change is often the norm. Hazards exist in relation to both cliffs and sand dunes. The coast is also the most heavily populated part of Australia and always regarded as "prime" real estate, because of the views and access to waterways and beaches.

Photo courtesy Greg Kotze

Waves, wind and salt spray play a significant part, causing dunes to move and cliff-faces to erode well above sea level. Our response is often to try to neutralise these effects by doing such things as dumping rock in the sea, building groynes, dredging, or carrying out dune stabilisation. Such works can be very effective, but ongoing maintenance is usually needed and total reconstruction may be necessary after a relatively short working life.

Of particular significance are extreme events that cause destruction on a scale that ignores our efforts at coastal protection. Records show that cliffs have collapsed, taking with them backyards which had been relied upon as a buffer between a house and the ocean. Sand dunes have also been washed away resulting in the dramatic loss of homes and infrastructure. As with most landslide issues, even though such events may be infrequent, they could happen tomorrow. It is easy to be lulled into a false sense of security on a calm day.

In coastal areas, typical landslide hazards (GeoGuides LR1 to LR4) are compounded by coastal erosion which, over time, undercuts cliffs and eventually results in failure. In the case of sand dunes, dune erosion and dune slumping have equally dramatic effects. Coastal locations are subject to particular processes relating to fluctuating water tables, inundation under storm tides and direct wave attack. Large sections of our more sandy coastline are receding under present sea conditions. The hazards are progressive and likely to be exacerbated through climate change.

Coastal Development

If you own, or are responsible for, a coastal property it is important that you understand that, where the shore line is receding, there is a greater landslide risk than would be the case on a similar site inland. The view may make the risk worthwhile, but does not reduce it.

Coastal Landslides

Coastal landslides are little different from other landslides in that the signs of failure (GeoGuides LR2) and the causes (LR3, LR4 & LR5) are largely the same. The main difference relates to the overriding influence of wave impact, tidal movement, salt spray and high winds.

Cliff failures

In addition to the processes that produce cliff instability on inland cliffs, coastal cliffs are also subjected to repeated cycles of wetting and drying which can be accompanied by the expansive effect of salt crystal growth in gaps in the rocks. These processes accelerate the deterioration of coastal cliffs. At the base of cliffs, direct wave attack and the impact of boulders moved by wave action causes undercutting and hence instability of the overall face. Figure 2 of GeoGuide LR4 provides an example. Whilst the processes leading to coastal cliff collapse may take years, failure tends to be catastrophic and with little warning. In many cases, waves produced by large oceanic storms are the trigger assisted by rainfall to produce collapse. These are also the conditions in which you are more likely to be inside your home and oblivious to unusual noises or movements associated with imminent failure.

Sand dune escarpment and slope failures

An understanding of coastal processes is essential when determining beach erosion potential. Waves produced by large oceanic storms can erode beaches and cut escarpments into dunes. These may be of relatively short duration, when beach re-building happens after the storm, but can be a permanent feature where long term beach recession is taking place. In many locations, houses and infrastructure are sited on or immediately behind coastal dunes. After an escarpment has eroded, those assets may be lost or damaged by subsequent slumping of the dune. It is important that, on erodible coastal soils, the potential for landward incursion of an erosion escarpment is determined. Having done this, the likelihood of slope instability can be established as part of the landslide risk management process. Injury, death and structural damage have occurred around the Australian coast from collapsing sand escarpments.

Photo courtesy DNR NSW

AUSTRALIAN GEOGUIDE LR10 (COASTAL LANDSLIDES)

The large scale and potentially high speed of coastal erosion processes means that major civil engineering work and large cost is normally involved in their control. The installation of rock bolts (LR4), drainage (LR5), or retaining walls (LR6) on a single house site may be necessary to provide local stability, but are unlikely to withstand the attack of a large storm on a beach or cliff-line.

BUILDING NEAR CLIFFS AND HEADLANDS

Coastal cliffs and headlands exist because the rock that they are made from is able to resist erosion. Even so, cliff-faces are not immune and will continue to collapse (Figure 1) by one or other of the mechanisms shown on GeoGuide LR4. If you live on a coastal cliff, you should undertake inspection and maintenance as recommended in LR4 and the other GeoGuides, as appropriate. The top of the cliff, its face, and its base should be inspected frequently for signs of recent rock falls, opening of cracks, and heavy seepage which might indicate imminent failure. Since the sea can remove fallen rocks rapidly, inspections should be made shortly after every major storm as a matter of course. **If collapses are occurring seek advice from an appropriately experienced geotechnical practitioner. Advise you local council if you believe erosion is rapid or accelerating.**

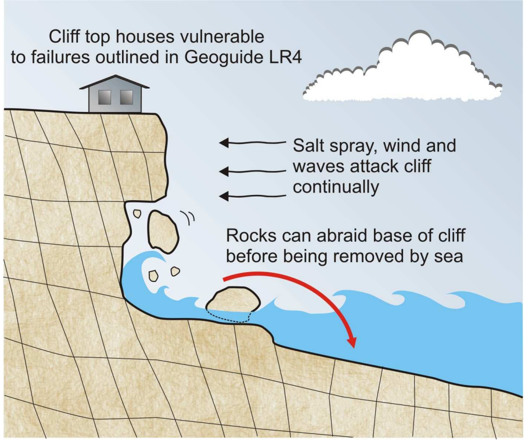

Figure 1

Building on Coastal Dunes

Any excavation in a natural dune slope is inherently unstable and must be supported and maintained (GeoGuide LR6). Dunes are particularly susceptible to ongoing erosion by wind and wave action and extreme changes can occur in a single storm. Whilst vegetation can help to stabilise dunes in the right circumstances, unfortunately a single storm has the potential to cut well into dunes and, in some cases, remove an entire low lying dune system or shift the mouth of a river. **As for cliffs, it is appropriate to observe the effects of major storms on the coastline. If erosion is causing the coastline to recede at an appreciable rate, seek advice from suitably experienced geotechnical and coastal engineering practitioners and bring it to the attention of the local council.**

Photo courtesy DNR NSW

CLIMATE CHANGE

The coastal zone will experience the most direct physical impacts of climate change. A number of reviews of global data indicate a general trend of sea level rise over the last century of 0.1 - 0.2 metres. Current rates of global average sea level rise, measured from satellite altimeter data over the last decade, exceed 3 mm/year and are accelerating. The most authoritative and recent (at the time of writing) report on climate change (IPCC, 2007) predicts a global average sea level rise of between 0.2 and 0.8 metres by 2100, compared with the 1980 - 1999 levels (the higher value includes the maximum allowance of 0.2 m to account for uncertainty associated with ice sheet dynamics).

In addition to sea level rise, climate change is also likely to result in changes in wave heights and direction, coastal wind strengths and rainfall intensity, all of which have the capacity to impact adversely on coastal dunes and cliff-faces. A Guideline for responding to the effects of climate change in coastal areas was published by Engineers Australia in 2004.

References

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IPCC (2007) *Climate Change 2007: The Physical Science Basis.* Summary for Policy Makers. Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

Nielsen, A.F., Lord D.B. and Poulos, H.G. (1992). 'Dune Stability Considerations for Building Foundations', *Aust. Civil Eng. Transactions* CE No.2, 167-174.

More information relevant to your particular situation may be found in other Australian GeoGuides:

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- GeoGuide LR2 - Landslides
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- GeoGuide LR4 - Landslides in Rock
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AUSTRALIAN GEOGUIDE LR11 (RECORD KEEPING)

RECORD KEEPING

It is strongly recommended that records be kept of all construction, inspection and maintenance activities in relation to developments on sloping blocks. In some local authority jurisdictions, maintenance requirements form part of the building consent conditions, in which case they are mandatory.

CONSTRUCTION RECORDS

If at all possible, you should keep copies of drawings, specifications and construction (i.e. "as built") records, particularly if these differ from the design drawings. The importance of these documents cannot be over-emphasised. If a geotechnical practitioner comes to a site to carry out a landslide risk assessment and is only able to see the face of a retaining wall, the heads of some ground anchors, or the outlets of a number of sub-soil drains, it may be necessary to determine how these have been built and how they are meant to work before completing the assessment. This could involve drilling through the wall to determine how thick it is, or probing the length of the drains, or even ignoring the anchors altogether, because it is uncertain how long they are. Such "investigation" of something that may only have been built a few years before is, at best, a waste of time and money and, at worst, capable of coming up with a misleading answer which could affect the outcome of the assessment. Documentary information of this sort often proves to be invaluable later on, so treat it with as much importance as the title deeds to your property.

INSPECTION AND MAINTENANCE RECORDS

If you follow the recommendations of the Australian GeoGuides it is likely that you will either carry out periodic inspections yourself, or you will engage a geotechnical practitioner to do them for you. The collected records of these inspections will provide a detailed history of changes that might be occurring and will indicate, better than your own memory, whether things are deteriorating and, if so, at what rate. Unfortunately, without some form of written record, all information is usually lost each time a property is sold. It is recommended that a prospective purchaser should have a pre-purchase landslide risk assessment carried out on a hillside site, in much the same way that they would commission a structural assessment, or a pest inspection, of the building. If the vendor has kept good records, then the assessment is likely to be quicker and cheaper, and the outcome more reliable, than if none are available. Each site is different, but noting the following would normally constitute a reasonable record of an inspection/maintenance undertaken:

- date of inspection/maintenance and the name and professional status of the person carrying it out
- description of the specific feature (eg. cliff face, temporary rock bolt, cast *in situ* retaining wall, shallow leach drain system)
- sketch plans, sketches and photographs to indicate location and condition
- activity undertaken (eg. visual inspection; cleared vegetation from drain; removed fallen rock about 500 mm diameter)
- condition of the feature and any matters of concern (e.g. weep holes damp and flowing freely; rust on anchor heads getting worse; shotcrete uncracked and no sign of rust stains; ground saturated around leach field)
- specific outcomes (eg. no action necessary; geotechnical practitioner called in to advise on the state of the anchors; cliff face to be trimmed following the most recent rock fall; leach field to be rebuilt at new location)

A proforma record is provided overleaf for convenience. Photographs and sketches of specific observations can prove to be very useful and should be included whenever possible. Geotechnical practitioners may devise their own site specific inspection/maintenance records.

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

AUSTRALIAN GEOGUIDE LR11 (RECORD KEEPING)

INSPECTION/MAINTENANCE RECORD

(Tick boxes as appropriate and add information as required) Date..

Site location (street address / lot & DP numbers / map reference / latitude and longitude)

....

FEATURE

Feature	Inspected	Maintained	Tested	By Owner	By Professional
Slopes & surface protection:					
☐ Natural slope/cliff ☐ Cut/fill slope					
☐ Surface water drains					
☐ Shotcrete ☐ Stone pitching ☐ Other					
Retaining walls:					
☐ Cast in situ concrete ☐ Concrete block					
☐ Masonry (natural stone) ☐ Masonry (brick, block)					
☐ Cribwall (concrete) ☐ Cribwall (timber)					
☐ Anchored wall ☐ Reinforced soil wall					
☐ Sub-soil drains ☐ Weep holes					
Ground improvement:					
☐ Rock bolts					
☐ Ground anchors ☐ Soil nails					
☐ Deep subsoil drains					
Effluent and storm water disposal systems:					
☐ Effluent treatment system					
☐ Effluent disposal field					
☐ Storm water disposal field					
Other:					
☐ Netting ☐ Catch fence ☐ Catch pit					
☐ --					
☐ --					
☐ --					

Observations/Notes (Add pages/details as appropriate)

....

....

....

Attachments: ☐ Sketch(es) ☐ Photograph(s) ☐ Other (eg measurements, test results)

Record prepared by .... (name): ....(signature)

Contact details: Phone:....................................... E-mail:...

Professional Status (in relation to landslide risk assessment):...

APPENDIX

AUSTRALIAN GEOMECHANICS SOCIETY

STEERING COMMITTEE

Andrew Leventhal, GHD Geotechnics, Sydney, Chair
Robin Fell, School of Civil and Environmental Engineering, UNSW, Sydney, Convenor Guidelines on Landslide Susceptibility, Hazard and Risk Working Group
Tony Phillips, Consultant, Sydney, Convenor Slope Management and Maintenance Working Group
Bruce Walker, Jeffery and Katauskas, Sydney, Convenor Practice Note Working Group
Geoff Withycombe, Sydney Coastal Councils Group, Sydney

WORKING GROUP - Guidelines on Slope Management and Maintenance
Tony Phillips, Tony Phillips Consulting, Sydney, Convenor
Henk Buys, NSW Roads and traffic Authority, Parramatta
John Braybrooke, Douglas Partners, Sydney
Tony Miner, A.G. Miner Geotechnical, Geelong

LANDSLIDE TASKFORCE
Laurie de Ambrosis, GHD Geotechnics, Sydney
Mark Eggers, Pells Sullivan Meynink, Sydney
Max Ervin, Golder Associates, Melbourne
Angus Gordon, retired, Sydney
Greg Kotze, GHD, Sydney
Arthur Love, Coffey Geotechnics, Newcastle
Alex Litwinowicz, GHD Geotechnics, Brisbane
Tony Miner, A.G. Miner Geotechnical, Geelong
Fiona MacGregor, Douglas Partners, Sydney
Garry Mostyn, Pells Sullivan Meynink, Sydney
Grant Murray, Sinclair Knight Merz, Auckland
Garth Powell, Coffey Geotechnics, Brisbane
Ralph Rallings, Pitt and Sherry, Hobart
Ian Stewart, NSW Roads and Traffic Authority, Sydney
Peter Tobin, Wollongong City Council, Wollongong
Graham Whitt, Shire of Yarra Ranges, Lillydale

Appendix B

Soil & Rock Explanation Sheets

Test Pit Logs

Soil and Rock Explanation Sheets (1 of 2)

Log Abbreviations & Notes

METHOD

borehole logs		*excavation logs*	
AS	auger screw *	NE	natural excavation
AD	auger drill *	HE	hand excavation
RR	roller / tricone	BH	backhoe bucket
W	washbore	EX	excavator bucket
CT	cable tool	DZ	dozer blade
HA	hand auger	R	ripper tooth
D	diatube		
B	blade / blank bit		
V	V-bit		
T	TC-bit		

* bit shown by suffix e.g. ADV

coring
NMLC, NQ, PQ, HQ

SUPPORT

borehole logs		*excavation logs*	
N	nil	N	nil
M	mud	S	shoring
C	casing	B	benched
NQ	NQ rods		

CORE–LIFT

|||	casing installed
├┤	barrel withdrawn

NOTES, SAMPLES, TESTS

D	disturbed
B	bulk disturbed
U50	thin-walled sample, 50mm diameter
HP	hand penetrometer (kPa)
SV	shear vane test (kPa)
DCP	dynamic cone penetrometer (blows per 100mm penetration)
SPT	standard penetration test
N*	SPT value (blows per 300mm) * denotes sample taken
Nc	SPT with solid cone
R	refusal of DCP or SPT

USCS SYMBOLS

GW	Gravel and gravel-sand mixtures, little or no fines.
GP	Gravel and gravel-sand mixtures, little or no fines, uniform gravels
GM	Gravel-silt mixtures and gravel-sand-silt mixtures.
GC	Gravel-clay mixtures and gravel-sand-clay mixtures.
SW	Sand and gravel-sand mixtures, little or no fines.
SP	Sand and gravel sand mixtures, little or no fines.
SM	Sand-silt mixtures.
SC	Sand-clay mixtures.
ML	Inorganic silt and very fine sand, rock flour, silty or clayey fine sand or silt with low plasticity.
CL, CI	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays.
OL	Organic silts
MH	Inorganic silts
CH	Inorganic clays of high plasticity.
OH	Organic clays of medium to high plasticity, organic silt
PT	Peat, highly organic soils.

MOISTURE CONDITION

D	dry
M	moist
W	wet
Wp	plastic limit
Wl	liquid limit

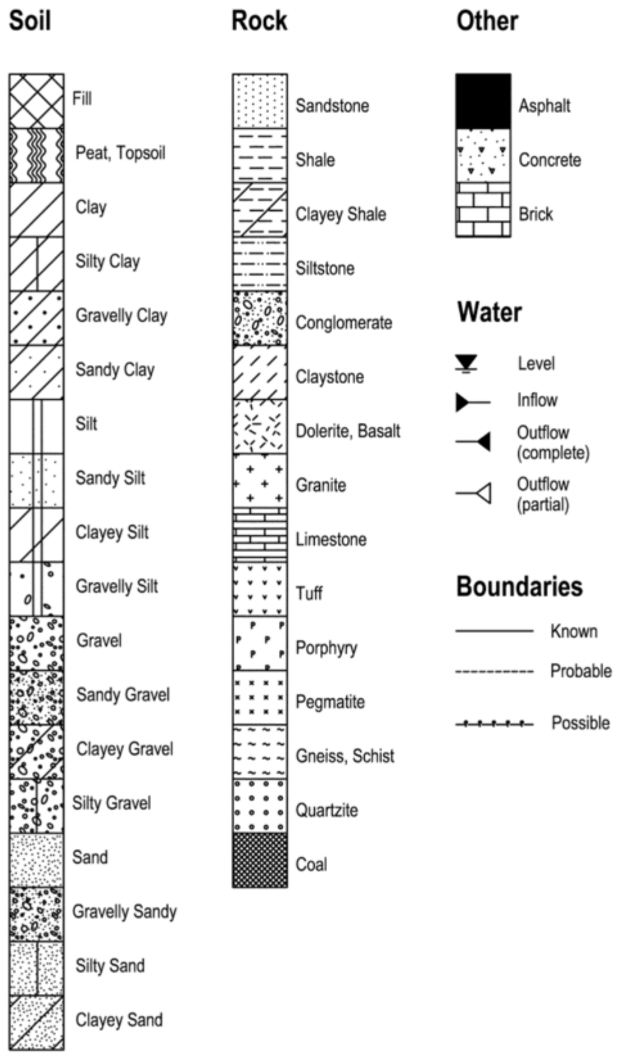
CONSISTENCY

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable

DENSITY INDEX

VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

Graphic Log



WEATHERING

XW	extremely weathered
HW	highly weathered
MW	moderately weathered
SW	slightly weathered
FR	fresh

STRENGTH

VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

RQD (%)

$$= \frac{\text{sum of intact core pieces} > 2 \times \text{diameter}}{\text{total length of core run drilled}} \times 100$$

DEFECTS:

type		*coating*	
JT	joint	cl	clean
PT	parting	st	stained
SZ	shear zone	ve	veneer
SM	seam	co	coating

shape		*roughness*	
pl	planar	po	polished
cu	curved	sl	slickensided
un	undulating	sm	smooth
st	stepped	ro	rough
ir	irregular	vr	very rough

inclination
measured above axis and perpendicular to core

AS1726-2017

Soils and rock are described in the following terms, which are broadly in accordance with AS1726-2017.

Soil

MOISTURE CONDITION

Term	Description
Dry	Looks and feels dry. Fine grained and cemented soils are hard, friable or powdery. Uncemented coarse grained soils run freely through hand.
Moist	Soil feels cool and darkened in colour. Fine grained soils can be moulded. Coarse soils tend to cohere.
Wet	As for moist, but with free water forming on hand.

Moisture content of cohesive soils may also be described in relation to plastic limit (W_P) or liquid limit (W_L) [>> much greater than, > greater than, < less than, << much less than].

CONSISTENCY OF FINE-GRAINED SOILS

Term	Su (kPa)	Term	Su (kPa)
Very soft	< 12	Very Stiff	>100 – ≤200
Soft	>12 – ≤25	Hard	> 200
Firm	>25 – ≤50	Friable	–
Stiff	>50 – ≤100		

RELATIVE DENSITY OF COARSE-GRAINED SOILS

Term	Density Index (%)	Term	Density Index (%)
Very Loose	< 15	Dense	65 – 85
Loose	15 – 35	Very Dense	>85
Medium Dense	35 – 65		

PARTICLE SIZE

Name	Subdivision	Size (mm)
Boulders		> 200
Cobbles		63 – 200
Gravel	coarse	19 – 63
	medium	6.7 – 19
	fine	2.36 – 6.7
Sand	coarse	0.6 – 2.36
	medium	0.21 – 0.6
	fine	0.075 – 0.21
Silt & Clay		< 0.075

MINOR COMPONENTS

Term	Proportion by Mass:	
	coarse grained	***fine grained***
Trace	≤ 15%	≤ 5%
With	>15% – ≤30%	>5% – ≤12%

SOIL ZONING

Layers	Continuous across exposures or sample.
Lenses	Discontinuous, lenticular shaped zones.
Pockets	Irregular shape zones of different material.

SOIL CEMENTING

Weakly	Easily broken up by hand pressure in water or air.
Moderately	Effort is required to break up by hand in water or in air.

USCS SYMBOLS

Symbol	Description
GW	Gravel and gravel-sand mixtures, little or no fines.
GP	Gravel and gravel-sand mixtures, little or no fines, uniform gravels.
GM	Gravel-silt mixtures and gravel-sand-silt mixtures.
GC	Gravel-clay mixtures and gravel-sand-clay mixtures.
SW	Sand and gravel-sand mixtures, little or no fines.
SP	Sand and gravel sand mixtures, little or no fines.
SM	Sand-silt mixtures.
SC	Sand-clay mixtures.
ML	Inorganic silt and very fine sand, rock flour, silty or clayey fine sand or silt with low plasticity.
CL, CI	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays.
OL	Organic silts
MH	Inorganic silts
CH	Inorganic clays of high plasticity.
OH	Organic clays of medium to high plasticity, organic silt
PT	Peat, highly organic soils.

Rock

SEDIMENTARY ROCK TYPE DEFINITIONS

Rock Type	Definition (more than 50% of rock consists of …..)
Conglomerate	... gravel sized (>2mm) fragments.
Sandstone	... sand sized (0.06 to 2mm) grains.
Siltstone	... silt sized (<0.06mm) particles, rock is not laminated.
Claystone	... clay, rock is not laminated.
Shale	... silt or clay sized particles, rock is laminated.

LAYERING

Term	Description
Massive	No layering apparent.
Poorly Developed	Layering just visible. Little effect on properties.
Well Developed	Layering distinct. Rock breaks more easily parallel to layering.

STRUCTURE

Term	Spacing (mm)	Term	Spacing
Thinly laminated	<6	Medium bedded	200 – 600
Laminated	6 – 20	Thickly bedded	600 – 2,000
Very thinly bedded	20 – 60	Very thickly bedded	> 2,000
Thinly bedded	60 – 200		

STRENGTH (NOTE: Is50 = Point Load Strength Index)

Term	Is50 (MPa)	Term	Is50 (MPa)
Extremely Low	<0.03	High	1.0 – 3.0
Very low	0.03 – 0.1	Very High	3.0 – 10.0
Low	0.1 – 0.3	Extremely High	>10.0
Medium	0.3 – 1.0		

WEATHERING

Term	Description
Residual Soil	Material is weathered to an extent that it has soil properties. Rock structures are no longer visible, but the soil has not been significantly transported.
Extremely …..	Material is weathered to the extent that it has soil properties. Mass structures, material texture & fabric of original rock is still visible.
Highly …..	Rock strength is significantly changed by weathering; rock is discolored, usually by iron staining or bleaching. Some primary minerals have weathered to clay minerals.
Moderately …..	Rock strength shows little or no change of strength from fresh rock; rock may be discolored.
Slightly …..	Rock is partially discolored but shows little or no change of strength from fresh rock.
Fresh	Rock shows no signs of decomposition or staining.

DEFECT DESCRIPTION

Type	
Joint	A surface or crack across which the rock has little or no tensile strength. May be open or closed.
Parting	A surface or crack across which the rock has little or no tensile strength. Parallel or sub-parallel to layering/bedding. May be open or closed.
Sheared Zone	Zone of rock substance with roughly parallel, near planar, curved or undulating boundaries cut by closely spaced joints, sheared surfaces or other defects.
Seam	Seam with deposited soil (infill), extremely weathered insitu rock (XW), or disoriented usually angular fragments of the host rock (crushed).
Shape	
Planar	Consistent orientation.
Curved	Gradual change in orientation.
Undulating	Wavy surface.
Stepped	One or more well defined steps.
Irregular	Many sharp changes in orientation.
Roughness	
Polished	Shiny smooth surface.
Slickensided	Grooved or striated surface, usually polished.
Smooth	Smooth to touch. Few or no surface irregularities.
Rough	Many small surface irregularities (amplitude generally <1mm). Feels like fine to coarse sandpaper.
Very Rough	Many large surface irregularities, amplitude generally >1mm. Feels like very coarse sandpaper.
Coating	
Clean	No visible coating or discolouring.
Stained	No visible coating but surfaces are discolored.
Veneer	A visible coating of soil or mineral, too thin to measure; may be patchy
Coating	Visible coating =1mm thick. Thicker soil material described as seam.

Excavation Log

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EX no:	TP1
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	started:	1.10.2021
principal:		finished:	1.10.2021
project:	Sundowner Snowmaking & Associated Works	logged:	MAB
location:	Thredbo NSW	checked:	AT
equipment:	Kubota U17-3 Mini Excavator	RL surface:	
dimensions:	0.6 x 1.5m E: 616810m N: 5959890m	datum:	AHD

excavation information / **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
EX	N	None observed					SM	Silty SAND, fine to medium grained, dark brown, grass roots	M	L?		TOPSOIL FILL
					0.1			Mixture of Clayey SAND, boulders, and gravel, grey brown, fine to coarse sand and gravel, boulders to 0.5m size occasional small tree roots <25mm diameter occasional pockets (<100mm thick) of organic matter and sandy soil		MD		FILL
					0.5							
					1.0							
					1.3			Excavation No: TP1 terminated at 1.3m				Practical refusal on boulders
					1.5							
					2.0							

Refer to Information Sheets for Terms and Symbols

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Excavation Log

EX no:	TP2
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	**started:**	1.10.2021
principal:		**finished:**	1.10.2021
project:	Sundowner Snowmaking & Associated Works	**logged:**	MAB
location:	Thredbo NSW	**checked:**	AT
equipment:	Kubota U17-3 Mini Excavator	**RL surface:**	
dimensions:	0.6 x 1.5m **E:** 616820m **N:** 5959860m	**datum:**	AHD

excavation information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
EX	N	None observed					ML	Sandy SILT, medium plasticity, dark grey, grass roots	M	F		TOPSOIL
								Flat boulder 0.8m size				
					0.2		CL	Silty CLAY, medium plasticity, orange-brown, trace fine sand	=Wp	St		RESIDUAL
											160	
					0.5			occasional granite cobbles to 0.2m size				
											150	
					1.0							
					1.2			Mixture of Granite cobbles and Silty CLAY				
					1.3			Excavation No: TP2 terminated at 1.3m				Practical refusal on boulders
					1.5							
					2.0							

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Excavation Log

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EX no:	TP3
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	started:	1.10.2021
principal:		finished:	1.10.2021
project:	Sundowner Snowmaking & Associated Works	logged:	MAB
location:	Thredbo NSW	checked:	AT
equipment:	Kubota U17-3 Mini Excavator	RL surface:	
dimensions:	0.6 x 1.5m — E: 616770m N: 5959890m	datum:	AHD

excavation information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
EX	N	None observed					SM	Silty SAND, fine to medium grained, dark brown, grass roots Some boulders to 0.5m size	M	L?		TOPSOIL FILL
					0.2			Mixture of Clayey SAND and Granite COBBLES and BOULDERS to 0.5m Some pockets of organic matter (roots in Silty SAND matrix), some tree roots <25mm diam		MD		FILL
					0.5							
					1.0							
					1.1			Excavation No: TP3 terminated at 1.1m				
					1.5							
					2.0							

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Excavation Log

EX no:	TP4
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	started:	1.10.2021
principal:		finished:	1.10.2021
project:	Sundowner Snowmaking & Associated Works	logged:	MAB
location:	Thredbo NSW	checked:	AT
equipment:	Kubota U17-3 Mini Excavator	RL surface:	
dimensions:	0.6 x 1.5m E: 616700m N: 5959930m	datum:	AHD

excavation information / **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetrometer kPa (100 200 300 400)	structure and additional observations
EX	N	None observed			0.0 – 0.15		ML	Sandy SILT, low plasticity, dark brown, roots	>Wp	F		TOPSOIL FILL
					0.15 – 0.5		SP	SAND, medium to coarse grained, light brown, pieces of XW GRANITE (remoulds to SAND)	M	VD		FILL
					0.5 – 1.25		ML	Sandy SILT, low plasticity, dark grey to black, some organic matter	>Wp	St		UNKNOWN ORIGIN
					1.25 – 1.4		ML	Gravelly Sandy SILT, low plasticity, dark grey, fine to coarse gravel				
					1.4			Excavation No: TP4 terminated at 1.4m				

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Excavation Log

EX no:	TP5
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	started:	1.10.2021
principal:		finished:	1.10.2021
project:	Sundowner Snowmaking & Associated Works	logged:	MAB
location:	Thredbo NSW	checked:	AT
equipment:	Kubota U17-3 Mini Excavator	RL surface:	
dimensions:	0.6 x 1.5m E: 616680m N: 5959930m	datum:	AHD

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
EX	N	None observed			0.0–0.1		SM	Silty SAND, fine to medium grained, dark brown/grey, grass roots	M	L		TOPSOIL
					0.1–0.5		SP	SAND, medium to coarse grained, light grey and orange-brown, trace fines, numerous fragments of XW GRANITE (remoulds as SAND with trace fines)		VD		RESIDUAL
					0.5–0.9			GRANITE, XW to HW, pices of SW rock in XW matrix, up to 500mm size		--		BEDROCK
					0.9			Excavation No: TP5 terminated at 0.9m				Practical refusal

Depth scale: 0.5, 1.0, 1.5, 2.0

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Excavation Log

EX no:	TP6
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	**started:**	1.10.2021
principal:		**finished:**	1.10.2021
project:	Sundowner Snowmaking & Associated Works	**logged:**	MAB
location:	Thredbo NSW	**checked:**	AT
equipment:	Kubota U17-3 Mini Excavator	**RL surface:**	
dimensions:	0.6 x 1.5m E: 616870m N: 5959890m	**datum:**	AHD

excavation information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
EX	N	None observed					ML	Sandy SILT, low plasticity, dark grey, grass roots	>Wp	F		TOPSOIL FILL
					0.25		SP	SAND, medium to coarse grained, orange-brown, granite fragments	M	MD		FILL
					0.3			Mixture of Silty SAND, Sandy SILT, granite gravel, dark grey, medium to coarse sand, low plasticity fines, medium to coarse gravel	M (=Wp)	L (St)		
					1.1			Silty SAND / Sandy SILT, fine to medium grained, low plasticity, dark grey, numerous tree roots and other organic matter	M (<Wp)			
					1.5			Excavation No: TP6 terminated at 1.5m				

Depth scale: 0.5, 1.0, 1.5, 2.0

Refer to Information Sheets for Terms and Symbols | Excavation Log - Revision 9

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Excavation Log

EX no:	**TP7**
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	**started:**	1.10.2021
principal:		**finished:**	1.10.2021
project:	Sundowner Snowmaking & Associated Works	**logged:**	MAB
location:	Thredbo NSW	**checked:**	AT
equipment:	Kubota U17-3 Mini Excavator	**RL surface:**	
dimensions:	0.6 x 1.5m **E:** 616580m **N:** 5959900m	**datum:**	AHD

excavation information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	**material** soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency/ density index	hand penetro-meter kPa 100 200 300 400	**structure and additional observations**
EX	N	None observed				▨	ML	Sandy SILT, low plasticity, dark grey / brown, grass roots	>Wp	F		TOPSOIL FILL (sawn tree branch 100mm diameter)
					0.2		ML	Sandy SILT, low plasticity, dark grey, some granite cobbles				TOPSOIL
					0.5							
					0.9	▨	CL	CLAY, medium plasticity, dark brown, some granite cobbles (angular)		St		SLOPEWASH
					1.0							
					1.3			Excavation No: TP7 terminated at 1.3m				
					1.5							
					2.0							

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Excavation Log

EX no:	TP8
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	started:	1.10.2021
principal:		finished:	1.10.2021
project:	Sundowner Snowmaking & Associated Works	logged:	MAB
location:	Thredbo NSW	checked:	AT
equipment:	Kubota U17-3 Mini Excavator	RL surface:	
dimensions:	0.6 x 1.5m E: 616530m N: 5959870m	datum:	AHD

excavation information / **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
EX	N	None observed					ML	Sandy SILT, low plasticity, dark grey to black, grass roots	>Wp	F		TOPSOIL
					0.2		CL	CLAY, medium plasticity, dark brown grading to light brown		St	160 130	SLOPEWASH
					0.5							
					1.0 / 1		ML	Sandy SILT / Silty SAND, low plasticity, fine to medium grained, light brown, some granite fragments to 100mm size, XW pieces	M (>Wp)	MD		RESIDUAL
					1.25			Excavation No: TP8 terminated at 1.25m				
					1.5							
					2.0							

Refer to Information Sheets for Terms and Symbols

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Excavation Log

EX no:	TP9
sheet:	1 of 1
job no.:	6653

client:	EVT / Kosciuszko Thredbo Pty Ltd	started:	1.10.2021
principal:		finished:	1.10.2021
project:	Sundowner Snowmaking & Associated Works	logged:	MAB
location:	Thredbo NSW	checked:	AT
equipment:	Kubota U17-3 Mini Excavator	RL surface:	
dimensions:	0.6 x 1.5m E: 616480m N: 5959800m	datum:	AHD

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material (soil type: plasticity or particle characteristics, colour, secondary and minor components)	moisture condition	consistency/ density index	hand penetrometer kPa (100 200 300 400)	structure and additional observations
EX	N	None observed			0.0–0.1		ML	Sandy SILT, low plasticity, dark brown, grass roots	M	F		TOPSOIL
					0.1–1.2		SM	Silty SAND, medium to coarse grained, light brown and brown and grey		D		RESIDUAL
					1.2			Excavation No: TP9 terminated at 1.2m				

Depth scale: 0.5, 1.0, 1.5, 2.0

A: 2.06 / 56 Delhi Road, North Ryde NSW 2113 P: 02 9878 6005 W: assetgeoenviro.com.au

Appendix C

Site Photos

Photo 1

View of connection to recent Friday Flat Snowmaking replacement looking east. Ground surface slopes up to the northwest at about 8-10º.

Photo 2

View looking west, taken from position east of TP1. Ground surface slopes up to the northwest at about 8-10º.

Photo 3

View of TP1, looking east

Photo 4

Closeup view of TP1.

Photo 5

View from near TP2 looking northwest. Ground surface slopes up to the northwest at about 5-8º.

Photo 6

View of TP2.

Photo 7

View of TP3.

Photo 8

View from near TP3 looking northwest towards culvert over creek. Ground surface slopes up to northwest at about 5-8°.

Photo 9

View from culvert looking west. Ground surface slopes down to creek at about 25-35º, culvert has been placed over creek and filled over including approaches to form ski run, locally slopes up to the west at about 5-8º.

Photo 10

View of creek under culvert, heavy flow at time of investigation.

Photo 11

View of TP4 – water in base is surface water from snow melt.

Photo 12

View of TP4.

Photo 13

View from west of TP4 looking west. Ground slopes up to west at 10-15º.

Photo 14

View of TP5.

Photo 15

View of TP5.

Photo 16

View from west of TP5 looking southwest. Ground slopes up to the west/southwest at about 15º.

Photo 17

View from proposed TP6 looking northeast to TP5. Ground surface slopes up to the west/southwest at about 15º.

Photo 18

View of TP6.

Photo 19

View of TP6.

Photo 20

View from proposed TP7 looking northeast to TP6. Ground surface slopes up to the west/southwest at about 15º.

Photo 21

View of TP7.

Photo 22

View of TP7.

Photo 23

View from TP8 looking southwest. Ground slopes up to the west at about 10–15º.

Photo 24

View of TP8

Photo 25

View of TP8

Photo 26

View of TP9

Photo 27

View from TP9 looking northwest. TP located on shoulder of northwest trending ridgeline that slopes up to the northwest at less than about 10º.

Photo 28

View from TP9 looking southwest.

Photo 29

View at TP9 looking south.