REPORT

TO
MEGAN O'LEARY

ON
GEOTECHNICAL ASSESSMENT
(In Accordance with Geotechnical Risk Management Policy for Northern Beaches Council)

FOR
PROPOSED ALTERATIONS AND ADDITIONS

AT
7 PAVILION STREET, QUEENSCLIFF, NSW

17 April 2019
Ref: 30038SYrpt

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1 INTRODUCTION

This report presents the results of our geotechnical assessment of the site at 7 Pavilion Street, Queenscliff, NSW. The assessment was commissioned by Mrs Megan O'Leary and was completed in accordance with our standard rates. The site was inspected by the undersigned on 16 April 2019, in order to assess the existing stability of the site and the effect on stability of the proposed development. An assessment of the cliff line was completed in 2010 (Ref: 23810SYrptrev, dated 22 July 2010). This report incorporates the findings of this earlier work and considers the site as a whole in accordance with Council's policy.

Reference to the drawings prepared by Corban Architects (Job No: OPQ, Drawing No's: DA03 to DA14, Dated 11 April 2019) indicates that it is proposed to:

- Extend the existing kitchen and dining room approximately 1m to 1.65m further to the east,
- Move the northern rumpus room wall to the west and back into the house by approximately 1m and push the southern wall further to the south by about 1.3m,
- Extend the existing lounge further to the west such that it occupies the whole space between the house and garage where the courtyard was previously located, and
- Make internal changes to both the ground and first level with the addition of a third floor parents retreat over the southern portion of the house.

This report has been prepared in accordance with the requirements of the Geotechnical Risk Management Policy for Northern Beaches Council (Warringah). It is understood that the report will be submitted to Council as part of the DA documentation.

2 ASSESSMENT METHODOLOGY

This stability assessment is based upon a detailed inspection of the topographic, surface drainage and geological conditions of the site and its immediate environs. These features were compared to those of other similar lots in neighbouring locations to provide a comparative basis for assessing the risk of instability affecting the proposed development. The attached Appendix A defines the terminology adopted for the risk assessment together with a flowchart illustrating the Risk Management Process based on the guidelines given in AGS 2007c (Reference 1).

Due to the presence of the cliff line, which potentially poses a significant risk of instability, our earlier investigation defined the cliff line geometry at a number of locations to develop sections through the cliffline. This was achieved by abseiling down the cliff face to measure both the location and depth of undercuts in the cliffline. A 30m tape attached at the top and running to the base of the cliff allowed the height at which horizontal changes in the cliff face geometry occurred to be mapped. The presence of bedding partings and other geological and rock mass features were also noted. The prepared sections through the cliff line (Figures 2, 3, 4 and 5) are attached to the rear of this report and their locations shown on Figure 1.

During our earlier investigation a plan view of the cliffline geometry was developed. This was then checked against the results of a later survey incorporated in the plans prepared by Corban Architects (Job No: OPQ). The strike of jointing observed in the exposed cliff face and exposed during construction of the pool was recorded and plotted on the proposed development plan. We have also annotated this plan to indicate the features present across the site as a whole. This plan is presented as Figure 1 and attached to the rear of this report.

A summary of our observations is presented in Section 3 below. Our risk assessment and specific comments and recommendations regarding the proposed alterations and additions and proposed landslide risk management are discussed in Section 4.

3 SUMMARY OF OBSERVATIONS

The site is located on the headland that runs between Freshwater and Queenscliff beaches. It extends from Pavilion Street at the crest of the headland to the mean high water mark on the Freshwater side of the headland; a change in elevation of about 37m.

The house is located over the central portion of the site and is a two-storey building of masonry construction. To create a level building platform it has been cut slightly into the hillside with cuts to maximum depths of about 1.5m. From Pavilion Street the driveway sweeps down from the southern side of the property boundary to the front of the house and the double garage positioned over the northern side of the front of the site. The garage extends to the front boundary, is approximately 3m lower than street level and has been cut into the hillside. Sandstone bedrock was exposed in the western wall of the garage excavation. A garden and recreation area extends from the road out over the roof of the garage, which occupies the northern portion of the front yard.

The house is set down approximately 1.5m lower than the drive and garage and has been cut into the hillside. Masonry retaining walls are located on the high side of the drive and garage and on the high side of the house. Both the house and the walls appear in good condition and show no signs of distress in the form of cracking, bulging or outward rotation.

Extending from the rear of the house to the cliffline is a tiled terrace and pool. The pool is located over the southern end of this portion of the site and extends to and is partially cantilevered out over the cliffline with a wet edge and balance tank forming the eastern extremity of the built structure. Where the pool is not present it appears that a retaining wall has been constructed along the full length of the eastern side of the terrace, which has reportedly been backfilled between the house and retaining wall, however it is unclear whether the slab extending from the retaining wall back to the house has been constructed as a suspended slab or slab on grade. While the majority of the terrace is located between the retaining wall and the house, over the northern portion of the property the terrace cantilevers out over the cliff. The terrace appeared in a good condition and showed few signs of distress.

The cliffline is roughly 30m high and predominantly comprises sandstone bedrock, although some shale inclusions were noted. The bedrock was generally assessed to be of medium strength, although bands of both lower and higher strength rock were noted with some clay bands present. The cliffline in plan view has a saw toothed appearance. This appearance has been controlled by the orientation of the near vertical orthogonal jointing present within the rock mass with jointing predominantly running north-north-east and east-south-east (strikes of between about 10^o to 15^o and 100^o to 120^o).

Due to the weathering and erosion processes, which have occurred more rapidly along bedding partings and the poorer quality less well cemented and/or durable bands within the bedrock, the cliff line is, in places, undercut. The lateral extent of undercutting varies but typically ranges from 1.5m to 3.5m. The thickness of the overhangs similarly varies but is typically in the range of 1m to 3m. However, extending from Section 2 to Section 4, a very thin band of sandstone, approximately 0.4m thick has been undercut to a maximum depth of about 1.95m and is present at the crest of the cliff. This undercut appears to have been formed by the loss of a large block of rock below it that had been undercut and fallen out of the face. In places material that has fallen out of the cliff face, including some quite large blocks, has landed on shelves in the cliff face rather than falling to the base of the cliff. This material is perched at varying heights above the base of the cliff. The wave cut rock platform at the base of the cliff is strewn with large blocks of rock that have fallen out of the face.

The adjoining property to the south has a similar landform to that of the site and is occupied by a seven storey building that appears in good structural condition. Sandstone bedrock is exposed at the surface in some areas. To the north is a three storey house that is set back about 1m from the common boundary and extends to Pavilion Street, at which point it steps up approximately 4m to the road. A concrete framed structure has been constructed along this boundary and supports a carport constructed at street level. The neighbouring property is about 0.6m higher than the subject site and is supported by a masonry retaining wall. The adjoining house and wall appear to be in good condition. To the west is Pavilion Street while to the east is Queenscliff Bay.

4 GEOTECHNICAL ASSESSMENT

By far the greatest risk to the stability of the site is the cliff line. The hazards posed by the site are described below.

4.1 Natural Processes Affecting the Stability of the Cliff

The cliff faces have revealed Hawkesbury Sandstone bedrock assessed to be typically distinctly to slightly weathered and generally of medium strength. It is evident that the topography of the majority of the cliff face has been influenced by the orthogonal joint sets identified during our inspection. At the base of the cliff was a sandstone wave cut platform, generally covered by an abundance of detached blocks from previous rock falls. The blocks were either elongated or "cubic" and suggest that they were derived from collapse of cliff face overhangs and wedges of sandstone bedrock within the cliff face. The detached sandstone blocks ranged in size from less than about $1m^3$ to in excess of about $20m^3$ and their shape and size appeared to be controlled by the two principal orthogonal joint sets and bedding partings.

The predominant mechanism of collapse of the cliff line is differential weathering and erosion (by wave and wind action) of weaker seams that results in undercutting of the more competent sandstone above. This is then followed by toppling of blocks isolated by orthogonal jointing and bedding partings/weaker seams. Collapse of these overhangs then appears to migrate up the cliff face in a similar manner as described above with sub-horizontal bedding partings and orthogonal joint sets controlling each successive block collapse. This process can occur at any point in the cliff face.

As material weathers and falls out of the cliff face it does not in all cases fall to the base of the cliff. In some instances the material (colluvium) collects on ledges midway down the cliff and can be remobilised at a later date to fall further down the cliff. Remobilisation generally triggered by water flowing down the cliff but may also be driven by wind.

The presence of detached blocks along the wave cut platform is considered to be the product of erosional processes. The potential geotechnical hazards 1(i), 1(ii) and 1(iii) (as discussed in Section 4.2 Risk Assessment of Cliff Line) are associated with continuation of these natural processes.

Crucial to the erosional processes is the rate at which they are occurring. Little evidence is available on the overall rates of occurrence of these forms of instability and the resultant rate of recession of the cliff face. Nonetheless, it is clear that rock falls do occur. There is some evidence on the rates of erosion in the paper by Young & Wray (2000), Reference 2. Rates of erosion, which may be summarised from observations given in this paper, are:

- For recession of the coastal escarpment south of Nowra, the "maximum possible rate of 170m/Ma" has been determined. This corresponds to 0.17mm per year.
- The most rapid rates of recession occur in gorges (usually where undercutting occurs on weaker bands due to waterfall erosion effects) being about 2km to 3km/Ma. This corresponds to a rate of 2mm to 3mm per year.
- There is no data given for the Hawkesbury Sandstone clifflines in the Sydney area.
- Dragovich (Reference 3) refers to weathering of softer beds causing undercutting of cliff lines. Dragovich quotes Roy as determining an average rate of undercutting of 2mm to 5mm per year, but that the overall rate would be slower due to rock falls protecting the softer bed.
- It is clear from the discussion in Young & Wray, that there will be significant variations in the rates of weathering and that extreme events, such as tsunamis or higher past sea levels during interglacial periods can also be relevant to the rates of recession and cliff line formation.

Based on the above, we could expect the Hawkesbury Sandstone cliff face to erode at less than 1mm per year. As an example, we have taken a 2m x 2m x 2m size block on the side of the cliff face. We have assumed that the block will remain 'stable' provided the horizontal extent of undercutting is less than 1m in from the outer face. Adopting a relatively high (or conservative) rate of erosion of 1mm per year, it would take at least 1000 years before the block would fall from the cliff face. However, these figures are very much averages for the cliff face as a whole and take no account of localised issues such as channelling of water.

Additional triggers to collapse of blocks and wedges over the cliff faces are:

- Water pressure developed in the sub-vertical joints behind potentially unstable blocks or wedges during and following rainfall events.
- Localised tree root jacking where tree roots penetrate joints at the rear of blocks and wedges over the cliff faces.
- Earthquakes and Tsunamis.

It is important to be mindful that rock falls, soil slumps etc can occur at any time and it would be difficult to impossible to predict when the identified potential hazards will occur. Also, we cannot predict when an extreme or unusual event may occur (such as an earthquake or 1 in 100 year rainfall event etc) and what impact it may have on the stability of the cliff face.

4.2 Risk Assessment

4.2.1 Methodology

The assessment of site stability has been made using the guidelines presented in the Landslide Risk Management Concepts and Guidelines prepared by the Australian Geomechanics Society, Sub-Committee on Landslide Risk Management (Reference 1). In this regard acceptable risks for loss of life of $1x10^{-5}$ and $1x10^{-6}$ have been adopted for existing slopes/structures and new developments respectively (for the person most at risk). For loss to property the acceptable risk should be determined by the owner, provided loss to property only affects the owners' property and does not impact on the property of others. Where risks posed by slope instability are considered unacceptable, remedial measures should be adopted to reduce the risk posed to an acceptable level.

The risk to life assessment has been made on a semi-quantitative basis with quantitative values assigned to qualitative assessments. The risk to property assessment has been carried out in qualitative terms. The qualitative assessments are based on judgements made in the field by the geotechnical engineer and in this regard are subjective and formed in part by the engineers' previous experiences. The range of annual probabilities assigned to the likelihood of events occurring, the recommended vulnerability values and the qualitative risk analysis matrix are presented in Appendix A.

4.2.2 Identified Hazards

The potential geotechnical hazards for the site can broadly be grouped as outlined below.

1. Instability of overhang features, wedges or blocks within the sandstone bedrock of the cliff face either:
   (i) at the crest,
   (ii) mid-height or
   (iii) towards the base of the cliff face
2. Instability of colluvial features either
   (i) at the crest,
   (ii) mid-height or
   (iii) towards the base of the cliff face
3. Failure of any of the retaining walls
   (i) at the crest or
   (ii) at the base of the wall

The hazards identified for this site are shown on Figures 1, 2, 3, 4 and 5 and are as described below:

Hazard A: Instability of Overhang Feature

Hazard B: Instability of Overhang Features

(i) Crest of Cliff (Terrace)

(ii) Crest of Cliff (Pool)

(iii) Base of Cliff

Hazard C: Instability of Overhang Features

Hazard D – Instability of Colluvium

Hazard E – Instability of Driveway and Garage Retaining Wall

(i) Crest of Wall

(ii) Base of Wall

Hazard F – Instability of Retaining Wall behind the House

(i) Crest of Wall

(ii) Base of Wall

Hazard G – Instability of Retaining Wall along Northern Property Boundary

(i) Crest of Wall

(ii) Base of Wall

4.2.3 Risk to Property

The risk to property is dependent on two factors, the likelihood of the hazard or event occurring and the consequence to property of this occurrence. In this regard the consequence of the damage suffered is expressed as a percentage of the total improved land value prior to the event occurring. Whilst we do not consider that the failure of the overhangs at the crest of the cliff line will result in the loss and destruction of the balcony, we do consider that it may become structurally compromised should any of the overhangs fail on which support for the balcony relies. Should this occur it is our opinion that access constraints and the occupational risks associated with working at the crest of a cliff line will increase the cost of the remedial works required to restore the structural integrity of the balcony to an acceptable level. In this regard we have assumed that the cost of works will be less than $94,000 (based on an assumed property value of $9.4M). If this is not the case the assessed damage will increase from insignificant to minor which will similarly increase the assessed level of risk to property.

The attached Table A summarises our qualitative assessment of each potential landslide hazard and of the consequences to property should the landslide hazard occur, under existing conditions. Based on the above, the qualitative risks to property have been determined. The terminology adopted for this qualitative assessment is in accordance with Table A1 given in Appendix A.

Table A indicates that the assessed risk to property is Very Low to Low, which would be considered to be ‘acceptable, in accordance with the criteria given in Reference 1. However, where the cost of remediating damage to the balcony is greater than $94,000 then the risk posed to property will increase to moderate which would only be considered tolerable. Where this is the case this risk can be reduced if desired by strengthening or providing alternative support to the terrace such that it will not be damaged if the overhangs collapse. Alternatively, the risk could be managed by periodic inspections conducted on say a 10 yearly basis both of the structural integrity of the balcony and the condition of the cliff line.

4.2.4 Risk to Life

The assessed likelihood of failure of a hazard, temporal, vulnerability and evacuation factors that have been adopted in the assessment of the risk to life for this property are given in the attached Table B together with the resulting risk calculation.

The assessment of risk to life completed in our report to Warringah Council assessing the risk posed by Queenscliff Headland indicated that the risk to life for persons present in the rear yard was in the order of 3.2×10^{-5}, which is acceptable for an existing development. This assessment was based on an assessed likelihood of failure of the overhang occurring as likely. Whilst this is the case for Hazard A, the footings for the terrace do not extend over Hazard A and thus this hazard has no impact on the risk to life for persons on the terrace above.

However, footings for the terrace do extend over Hazard B. The likelihood of Hazard B occurring is possible rather than likely (ie one order of magnitude less) and as a result the risk to the person most at risk for the site reduces by one order of magnitude to 3.48×10^{-6} which is considered acceptable for new developments. If the structural engineer considers that the terrace will not deflect excessively or fail entirely if the overhang supporting the column below the balcony fails, then Hazard B will no longer affect the terrace and the risk to person most at risk will reduce to 2.8×10^{-7}. If the structural engineer considers that the terrace may be at risk of failure if Hazard B occurs, the risk to the person most at risk can similarly be reduce to 2.8×10^{-7} if the cantilevered section of the terrace currently supported by the terrace is strengthened or alternatively supported by the construction of a prop supported on the existing retaining wall. In this regard we recommend that the structural engineer provides some assessment of the susceptibility of the terrace to failure if Hazard B occurs and support is lost below the column.

Note that although risks are shown as calculated to two decimal places this does not imply that level of accuracy and is done to allow effect of relative varying contributing factors to be assessed.

4.2.5 Additional Comments

It is recognised that due to the many complex factors that can affect a site, the subjective nature of a risk analysis, and the imprecise nature of the science of geotechnical engineering, the risk of instability for a site cannot be completely removed. It is, however, essential that risk be reduced to at least that which could be reasonably anticipated by the community in everyday life and that landowners are made aware of reasonable and practical measures available to reduce risk as far as possible. Hence, risk cannot be completely removed, only reduced, as removing risk is not currently scientifically achievable.

In preparing our recommendations given below we have assumed that no activities on surrounding land which may affect the risk on the subject site would be carried out. We have further assumed that all buried services are, and will be regularly maintained to remain, in good condition.

5 COMMENTS AND RECOMMENDATION

5.2.1 Excavation and Retention

The proposed alterations and additions are anticipated to result in some excavation, although these depths are anticipated to be limited to about 1.5m. Although no subsurface investigation has been completed we understand that the fill was placed below the terrace and as a result we anticipate that excavation will result in the removal of a sandy fill material and sandstone bedrock. Access to the site is restricted and consequently we anticipate that all excavation will be undertaken using hand operated equipment. Only contractors experienced with difficult access sites located at the crest of clifflines should be considered for this work.

Where encountered the soils are anticipated to be easily removed using hand excavation methods. The sandstone bedrock is expected to be removed by jack hammer or other appropriate hand operated rock breaking techniques. Previous works have exposed the existing footing system which consists of high level footings founded on the underlying sandstone bedrock. Notwithstanding this, we recommend that in the initial stages of excavation an exploratory test pit be excavated at the proposed northern end of the pool to confirm that the existing house is founded on the underlying sandstone bedrock and that the proposed pool excavation will not undermine the house.

Excavation is not anticipated to result in the removal of any of the existing overhangs or significant amounts of sandstone bedrock that may result in a lessening of the thickness of the overhangs. If this is not the case further advice should be sought from this office. Where excavation extends to the cliffline care will be required to control any spoil that may fall over the cliff during the construction period. To control the risk posed to people present at the base of the cliff, excavation material must either be prevented from falling over the cliff or alternatively, people must be prevented from accessing any part of the base of the cliff where material may land (either directly or following ricocheting, bouncing or exploding upon impact) during the period materials are allowed to fall over the cliff face.

Where percussive excavation techniques (ie jack hammers) are used ground borne vibrations will be generated. Whilst we do not anticipate that the magnitude of vibrations generated by jack hammers will be such that they will cause damage to the house or adjoining structures there is the risk that they may cause the failure of nearby overhangs. Hazard A appears to be the most sensitive to transmitted vibration. It is never clear how sensitive overhangs are to vibration as the rock itself may contain micro-fractures that are not visible to the eye and are easily propagated by vibration. In this regard we recommend that where percussive excavations are adopted that people be prevented from accessing the base of the cliffline during the percussive excavation period.

Where soils are required to be retained we recommend that a triangular pressure distribution be adopted together with a coefficient of active earth pressure ,k_a, of 0.35 and a bulk unit weight of

20kN/m^3. All appropriate hydrostatic pressures and surcharge loads must be added to the above pressures.

5.2.2 Footing Design

Where new footings are required they should be uniformly founded on the underlying sandstone bedrock. For preliminary design, footings founded on sandstone bedrock of at least low strength may be designed for an ABP of 600kPa. All footings must be located back behind the extent of the undercut and potentially adversely orientated jointing, as shown on the attached Figure 1, and the surface of the bedrock cleaned and washed down so that it may be inspected for the presence of potentially adverse defects. If all footings are not located behind the undercuts and adversely orientated joints the overhangs on which the footings are located must be underpinned to competent bedrock below. Where this is proposed further advice must be sought from this office. Only contractors with the appropriate experience and insurance should be considered for the above work.

Prior to pouring concrete, all footings should be free from all loose and softened materials. Where water ponds in the base of footings prior to pouring, the footing should first be pumped dry and then re-excavated to remove all loose and softened materials. We recommend that all footings be inspected by a geotechnical engineer to confirm that the design allowable bearing pressures (ABP) have been achieved.

5.2.3 Stormwater Management

Where new gutters are installed they should be connected into the existing stormwater system which should discharge to Council's stormwater system. Where discharge is over the cliff, devices should be installed to manage any erosion that may occur such that erosion rates of the cliff are not accelerated as a result of stormwater disposal.

5.2.4 Ongoing Risk Management

The site in its current state poses an acceptable risk to life to persons most at risk and a low risk to property based on our assessment of the costs for repairing the terrace should Hazards A or B occur. As detailed above the natural processes affecting the cliffline will continue to occur which will, overtime result in regression of the cliffline. This regression is anticipated to occur slowly over a long period of time. Management of the risk posed by this cliffline may be address by either monitoring or remediation/circumvention of hazards.

If the monitoring approach were adopted we recommend that on a periodic basis (say every 10 years) that a structural engineer prepare a report on the structural soundness of the terrace and its ability to continue to cantilever, even after the loss of support below the column. In addition, a geotechnical engineer should inspect the cliffline on a similar time basis to assess whether the likelihood of hazards has increased or remains the same.

Management of the risk posed by either remediation or circumvention would consist of the removal of the identified risks or alternatively by the implementation of engineered solutions such that the hazard no longer impacts on structures or people ie strengthening of the terrace such that it can continue to perform adequately even following loss of support below the column.

6 OVERVIEW

Provided the comments and recommendations provided above are followed we consider that the proposed alterations and additions provide an acceptable risk in terms of both risk to property and life.

It is possible that the subsurface soil, rock or groundwater conditions encountered during construction may be found to be different (or may be interpreted to be different) from those inferred from our surface observations in preparing this report. Also, we have not had the opportunity to observe surface run-off patterns during heavy rainfall and cannot comment directly on this aspect. If conditions appear to be at variance or cause concern for any reason, then we recommend that you immediately contact this office.

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Reference 1: Australian Geomechanics Society (2007c) *'Practice Note Guidelines for Landslide Risk Management'*, Australian Geomechanics, Vol 42, No 1, March 2007, pp63-114.

Reference 2: Young, R W & Wray, R A L (2000). "The Geomorphology of Sandstone in the Sydney Region", published in "Sandstone City", ed. McNally, G H & Franklin, B J, Monograph No 5, Geological Society of Australia, pp.55-73.

Reference 3: Dragovich, D (2000). "Weathering Mechanisms and Rates of Decay of Sydney Dimension Sandstone", published in "Sandstone City", ed. McNally, G H & Franklin, B J, Monograph No 5, Geological Society of Australia, pp.74-82.

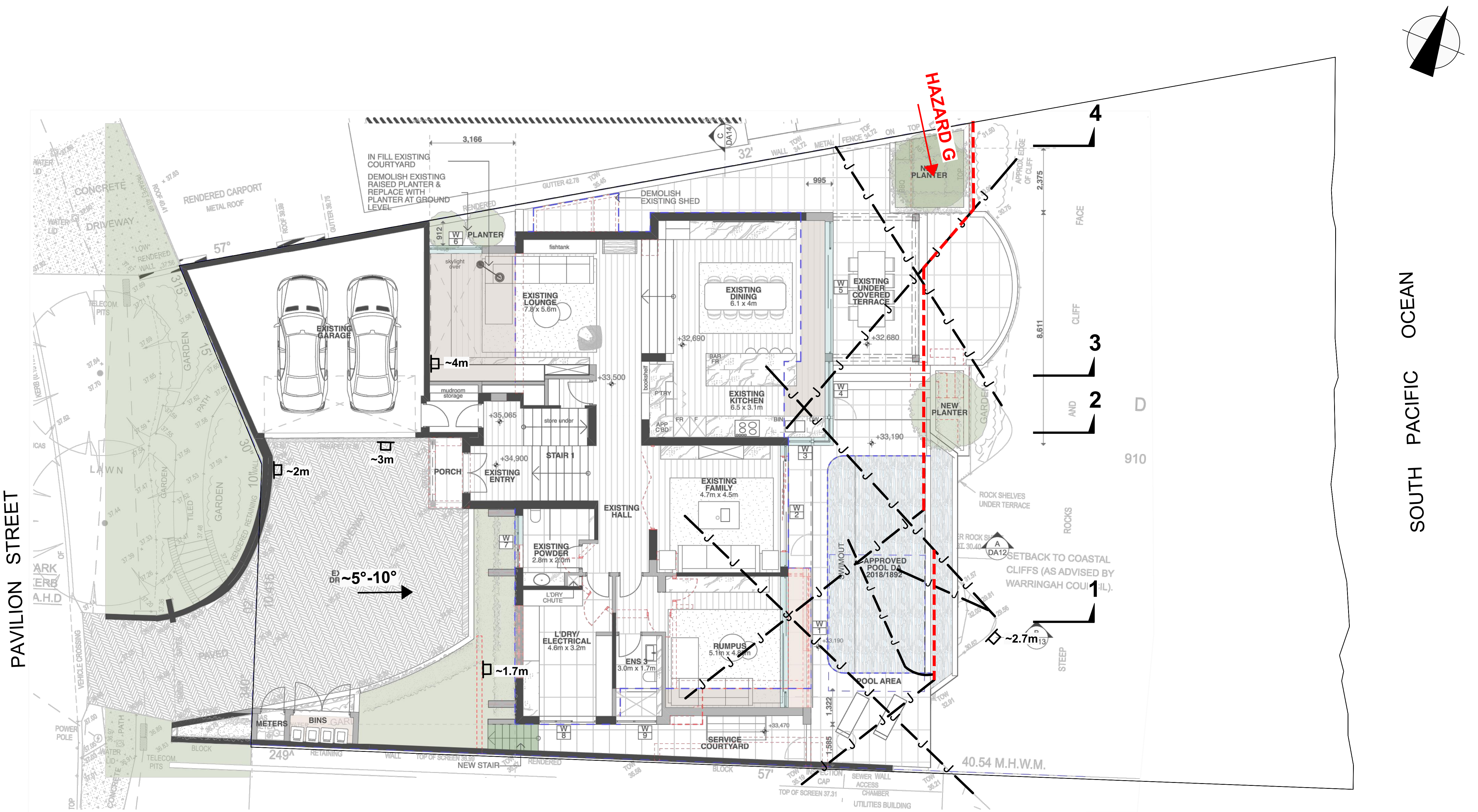
TABLE A

SUMMARY OF RISK ASSESSMENT TO PROPERTY UNDER EXISTING CONDITIONS

Potential Landslide Hazard	A - Instability of Overhang Feature	B - Instability of Overhang Feature (where present at crest of cliff line)	E – Instability of Driveway and Garage Retaining Wall	F – Instability of Retaining Wall behind the House	G – Instability of Retaining Wall along Northern Property Boundary
Assessed Likelihood	Likely	Possible	Barely Credible	Barely Credible	Barely Credible
Assessed Consequences	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Risk	Low	Very Low	Very Low	Very Low	Very Low
Comments	Risk to property involves a judgement to be made on the potential value of the damage done as a percentage of the improved value of the property. While we do not consider that failure of the overhangs will result in the loss or failure of the balcony, we consider that the structural integrity of the balcony may be comprised as a result of the overhangs collapsing. In this regard we have assumed that due to the restricted access the potential cost of remediating the balcony after such a failure will be $94,000 or less. If this is not the case, and the cost of repair is greater than $94,000 the assessed consequence of the failure of the overhangs will increase to minor and the Risk posed by Hazards A and B will increase to moderate.				

TABLE B
SUMMARY OF RISK ASSESSMENT TO LIFE UNDER EXISTING CONDITIONS

Potential Landslide Hazard	A - Instability of Overhang Feature to Persons at Base of Cliff	B- Instability of Overhang Features	C – Instability of Overhang Features to Persons at Base of Cliff	D – Instability of Colluvium	Hazard E – Instability of Driveway and Garage Retaining Wall	Hazard F – Instability of Retaining Wall behind the House	Hazard G – Instability of Retaining Wall along Northern Property Boundary
Assessed Likelihood	Likely	Possible	Unlikely	Possible	Barely Credible	Barely Credible	Barely Credible
Indicative Annual Probability	10^{-2}	10^{-3}	10^{-4}	10^{-3}	10^{-6}	10^{-6}	10^{-6}
Number of Hazards Present	1	(i) 1 (ii) 1 (iii) 5	6	2	1	1	1
Duration of Use of Area Affected (Temporal Probability)	4×10^{-5} Occupancy based on average walking rate of 4 seconds per 5m length per day for 9 months of year	(i) 0.02 Occupancy based on 0.5 hour per day (ii) 0.02 Occupancy based on 0.5 hour per day (iii) 4×10^{-5} Occupancy based on average walking rate of 4 seconds per 5m length per day for 9 months of year	4×10^{-5} Occupancy based on average walking rate of 4 seconds per 5m length per day for 9 months of year	4×10^{-5} Occupancy based on average walking rate of 4 seconds per 5m length per day for 9 months of year	(i) 4.96×10^{-4} 5 minutes per week (ii) 9.92×10^{-4} 10 minutes/week	(i) 4.96×10^{-4} 5 minutes per week (ii) 0.02 30 minutes/day	(i) 1.98×10^{-4} 2 minutes per week (ii) 1.98×10^{-4} 2 minutes/week
Probability of Not Evacuating Area Affected	0.4 Noise likely both as overhang fails and as it falls down the cliff	(i) 0.4 Terrace will begin to deflect giving people present warning and some time to evacuate (ii) 0.8 Pool may crack and deflect giving some warning (iii) 0.4 Noise likely both as overhang fails and as it falls down the cliff	0.4 Noise likely both as overhang fails and as it falls down the cliff	0.4 Noise likely both as colluvium falls down the cliff	(i) 1 Likely no warning (ii) 0.5 Cracking and bulging of wall likely to give some warning	(i) 1 Likely no warning (ii) 0.5 Cracking and bulging of wall likely to give some warning	(i) 1 Likely no warning (ii) 0.5 Cracking and bulging of wall likely to give some warning
Vulnerability to Life if Failure Occurs Whilst Person Present	1	(i) 0.4 (ii) 1×10^{-6} Structure constructed independently of overhang and it is barely credible that the structure will fail if the overhang does (ii) 1	1	1	(i) 0.01 Likely to ride failure down (ii) 1 Likely to be buried	(i) 0.01 Likely to ride failure down (ii) 0.7 Possibly buried	(i) 0.01 Likely to ride failure down (ii) 0.01 Unlikely to be buried
Cumulative Risk for each Hazard	1.6×10^{-7}	(i) 3.2×10^{-6} (ii) 1.6×10^{-11} (iii) 8×10^{-8}	9.6×10^{-9}	3.2×10^{-8}	(i) 4.96×10^{-12} (ii) 4.96×10^{-10}	(i) 4.96×10^{-12} (ii) 7×10^{-9}	(i) 1.98×10^{-12} (ii) 9.9×10^{-13}
Risk for Person Most at Risk	**3.48×10^{-6}**						



LEGEND

—J—J— JOINTS

- - - - - EXTENT OF UNDERCUT

0 1.5 3 4.5 6 7.5

SCALE 1:150 @A3 METRES

This plan should be read in conjunction with the JK Geotechnics report.

Title: **SITE PLAN**

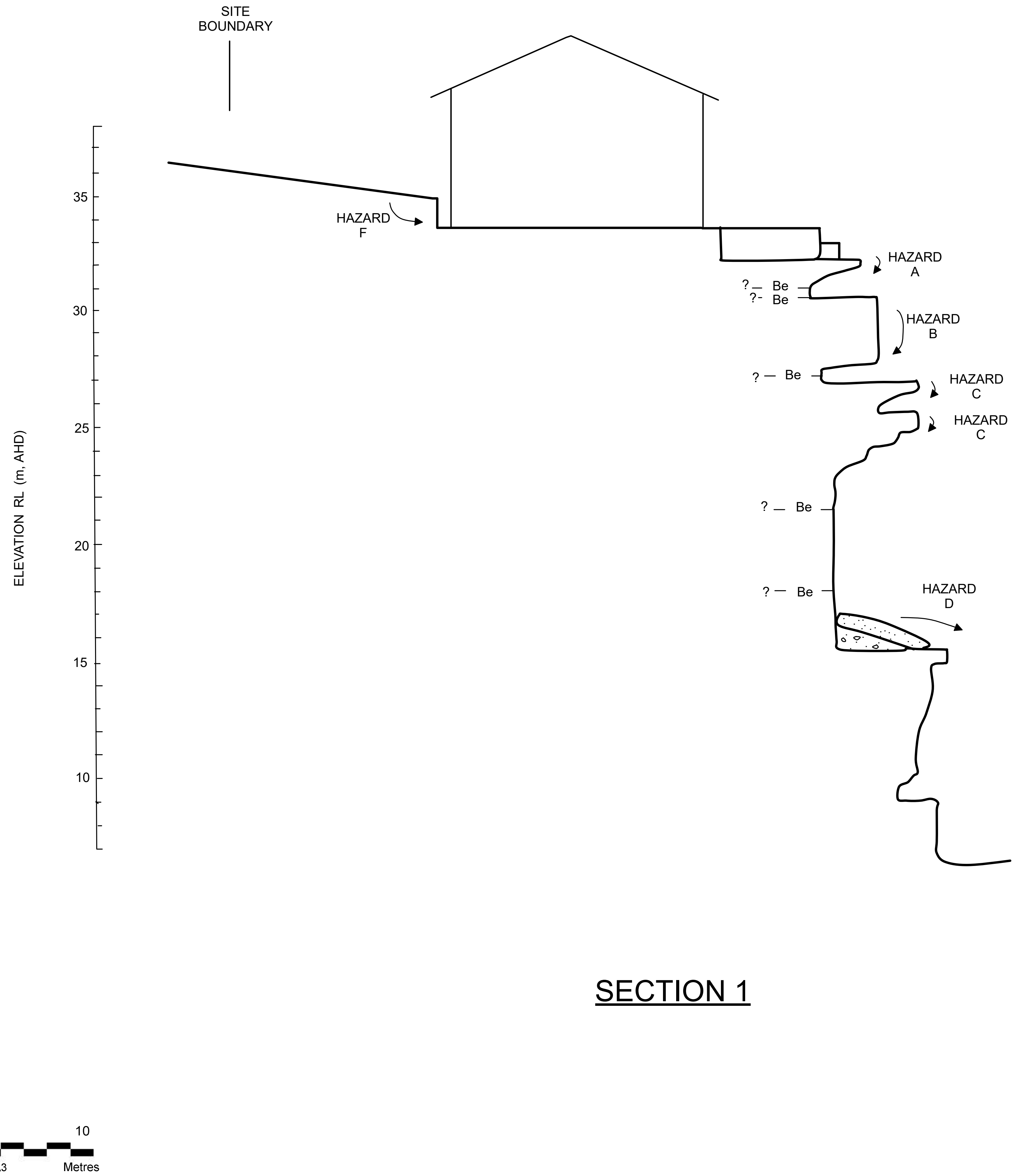
Location: 7 PAVILION STREET QUEENSCLIFF, NSW

Report No: 30038SY

Figure No: 1

JK Geotechnics

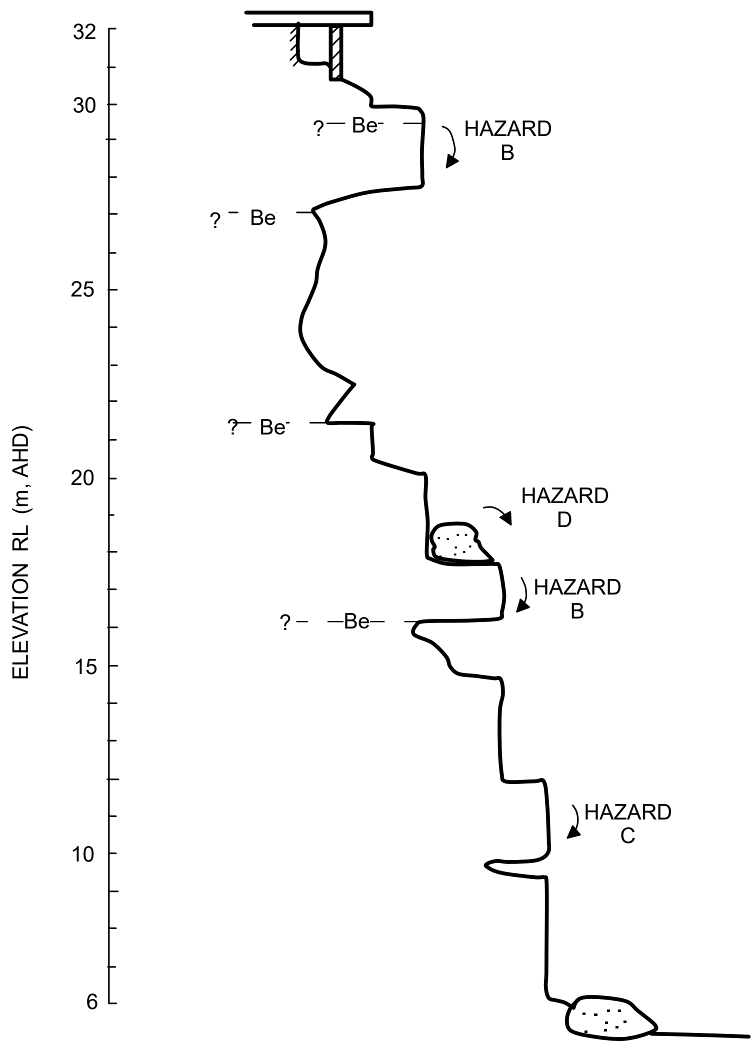
PLOT DATE: 16/04/2019 4:37:51 PM DWG FILE: S:\6 GEOTECHNICAL\6F GEOTECHNICAL JOBS\30000'S\30038SY QUEENSCLIFF\CAD\30038SY.DWG



SECTION 1

JK Geotechnics
GEOTECHNICAL & ENVIRONMENTAL ENGINEERS

Report No. 30038SY Figure No. 2

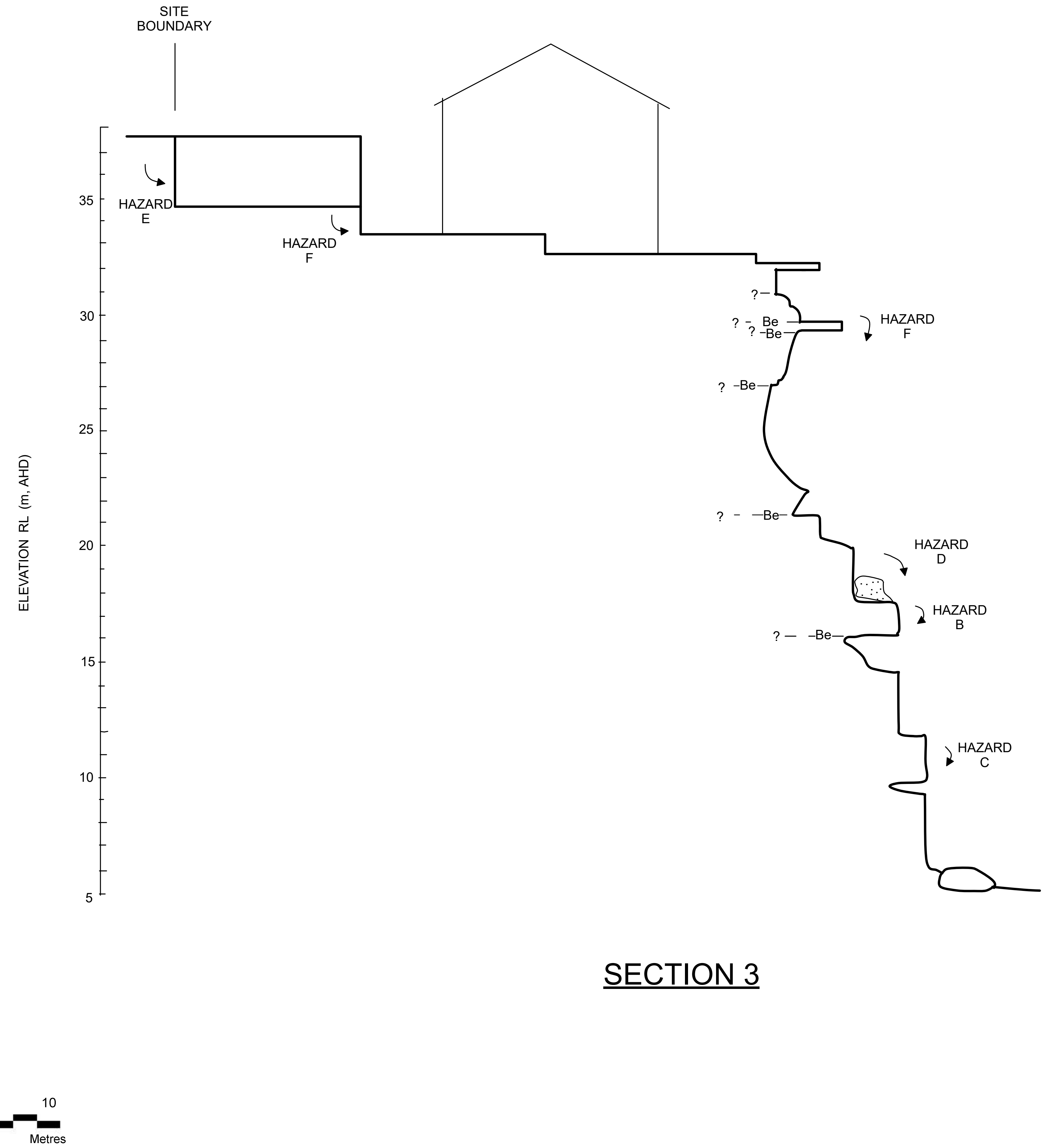


SECTION 2

0 0.5
Scale 1:10 @A4 Metres

JK Geotechnics
GEOTECHNICAL & ENVIRONMENTAL ENGINEERS

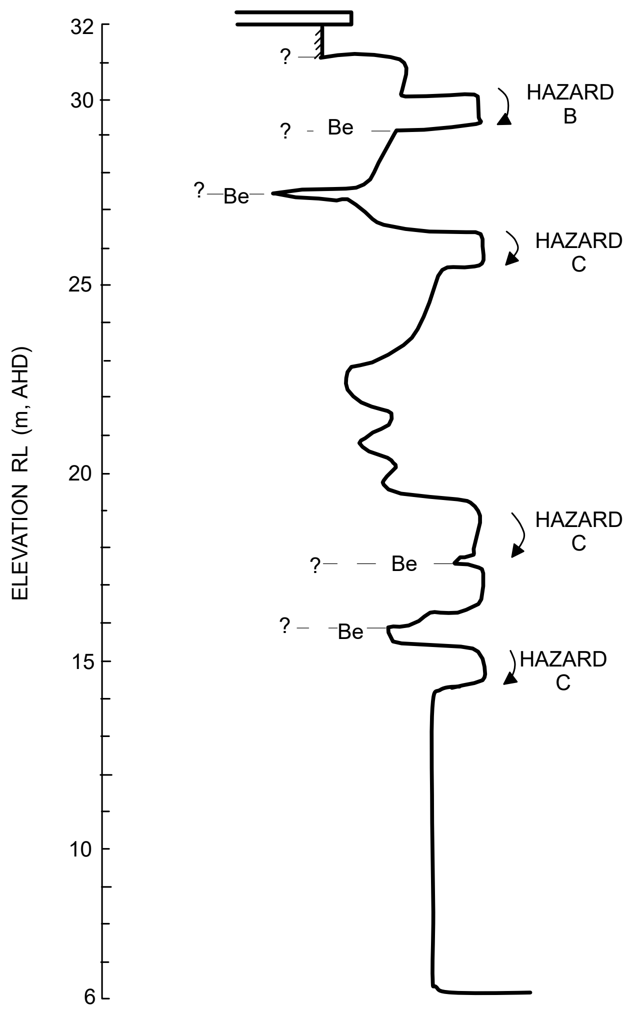
Report No. 30038SY Figure No. 3



SECTION 3

JK Geotechnics
GEOTECHNICAL & ENVIRONMENTAL ENGINEERS

Report No. 30038SY Figure No. 4



SECTION 4

0 10
Scale 1:200 @A4 Metres

JK Geotechnics
GEOTECHNICAL & ENVIRONMENTAL ENGINEERS

Report No. 30038SY

Figure No. 5

GEOTECHNICAL MAPPING SYMBOLS

TOPOGRAPHY

Symbol / *Ground Profile*		
convex	concave	well defined or angular break of slope
convex	concave	poorly defined or smooth change of slope
breaks of slope	changes of slope	convex and concave too close together to allow the use of separate symbols
sharp	rounded	ridge crest

Cliff or escarpment or sharp break 40° or more (estimated height in metres) — 3

15 → Uniform Slope	Slope direction and angle (Degrees)
10 → Concave Slope	
8 → Convex Slope	
Top	Cut or fill slope, arrows pointing down slope
Bottom	

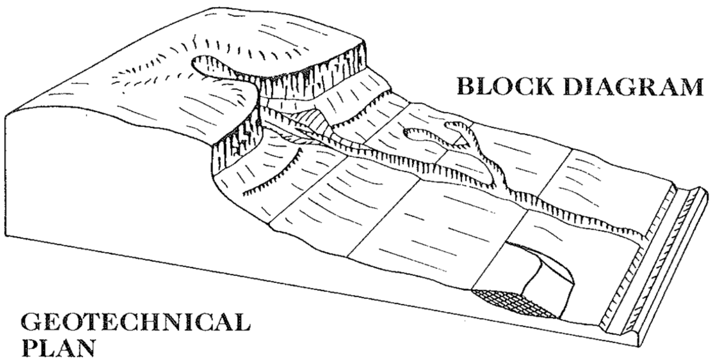
Hummocky or irregular ground

OTHER FEATURES

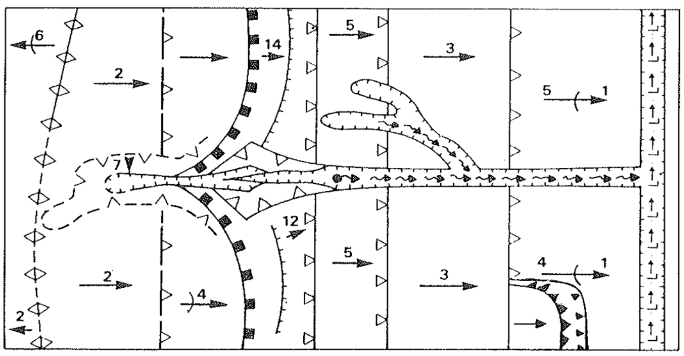
- Boulder
- Seepage/spring
- Swallow hole for runoff
- Natural water course
- Open drain, unlined
- Open drain, lined
- Fenceline
- Property boundary
- Dry Stone Wall
- J —— J 200 Major joint in rock face (opening in millimetres)
- – T – T – 10 Tension crack (opening in millimetres)
- Masonry or concrete wall
- Ponding water
- Boggy or swampy area

EXAMPLE OF USE OF TOPOGRAPHIC SYMBOLS:

BLOCK DIAGRAM



GEOTECHNICAL PLAN



(After Gardiner, V & Dackombe, R.V. (1983), Geomorphological Field Manual; George Allen & Unwin).

APPENDIX A

LANDSLIDE RISK

MANAGEMENT

TERMINOLOGY

APPENDIX A
LANDSLIDE RISK MANAGEMENT

Definition of Terms and Landslide Risk

Risk Terminology	Description
Acceptable Risk	A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.
Annual Exceedance Probability (AEP)	The estimated probability that an event of specified magnitude will be exceeded in any year.
Consequence	The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.
Elements at Risk	The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.
Frequency	A measure of likelihood expressed as the number of occurrences of an event in a given time. See also 'Likelihood' and 'Probability'.
Hazard	A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.
Individual Risk to Life	The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.
Landslide Activity	The stage of development of a landslide; pre failure when the slope is strained throughout but is essentially intact; failure characterised by the formation of a continuous surface of rupture; post failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (eg. seasonal) or continuous (in which case the slide is 'active').
Landslide Intensity	A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, or kinetic energy per unit area.
Landslide Risk	The AGS Australian GeoGuide LR7 (AGS, 2007e) should be referred to for an explanation of Landslide Risk.
Landslide Susceptibility	The classification, and volume (or area) of landslides which exist or potentially may occur in an area or may travel or retrogress onto it. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.
Likelihood	Used as a qualitative description of probability or frequency.
Probability	A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event. These are two main interpretations: (i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an 'objective' or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

Risk Terminology	Description
Probability *(continued)*	(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.
Qualitative Risk Analysis	An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.
Quantitative Risk Analysis	An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.
Risk	A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
Risk Analysis	The use of available information to estimate the risk to individual, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.
Risk Assessment	The process of risk analysis and risk evaluation.
Risk Control or Risk Treatment	The process of decision-making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.
Risk Estimation	The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.
Risk Evaluation	The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.
Risk Management	The complete process of risk assessment and risk control (or risk treatment).
Societal Risk	The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.
Susceptibility	See 'Landslide Susceptibility'.
Temporal Spatial Probability	The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.
Tolerable Risk	A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
Vulnerability	The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

NOTE: Reference should be made to Figure A1 which shows the inter-relationship of many of these terms and the relevant portion of Landslide Risk Management.

Reference should also be made to the paper referenced below for Landslide Terminology and more detailed discussion of the above terminology.

This appendix is an extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in Australian Geomechanics, Vol 42, No 1, March 2007, which discusses the matter more fully.

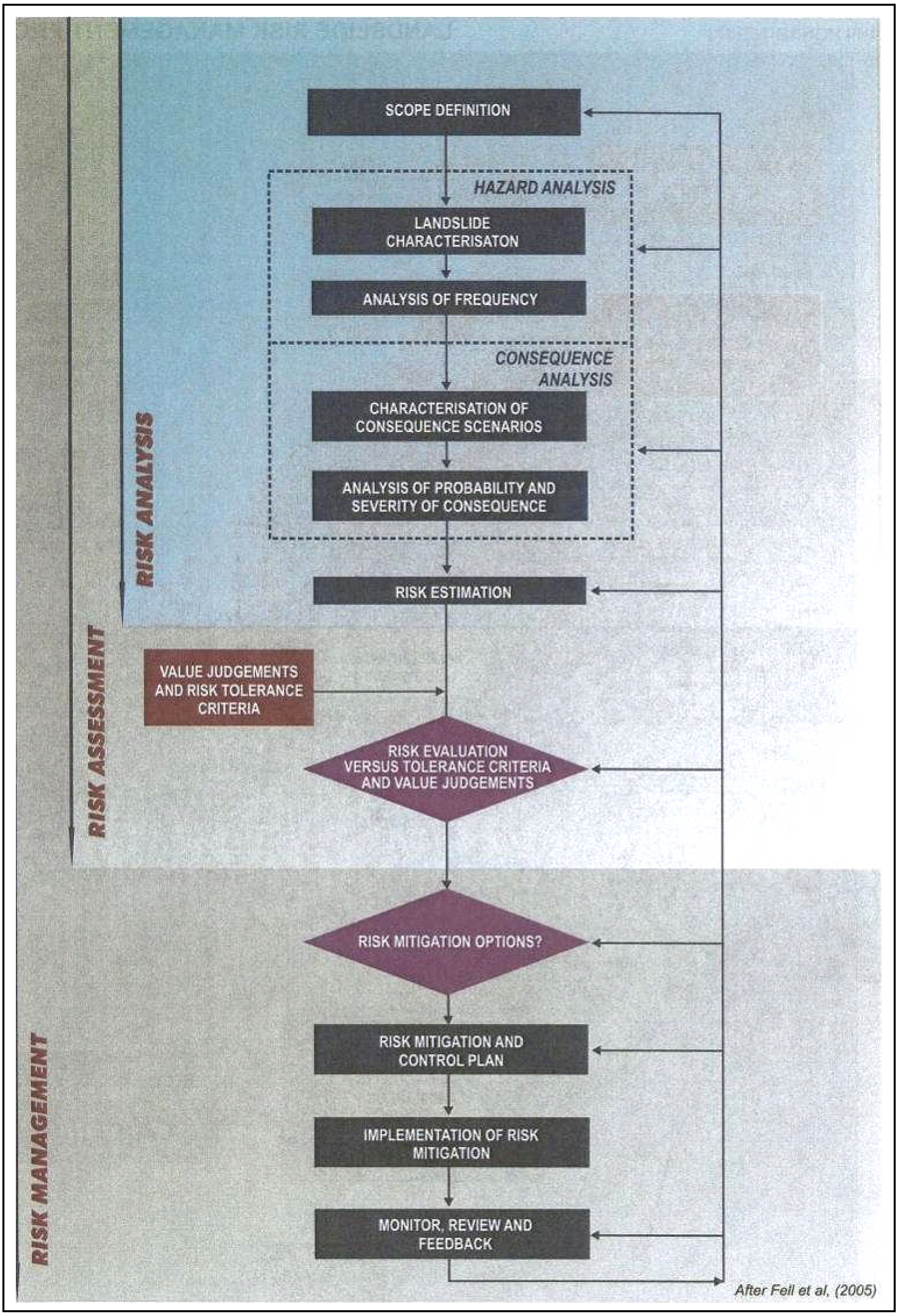


FIGURE A1: Flowchart for Landslide Risk Management.

This figure is an extract from GUIDELINE FOR LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING, as presented in Australian Geomechanics Vol 42, No 1, March 2007, which discusses the matter more fully.

TABLE A1: LANDSLIDE RISK ASSESSMENT
QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	**Notional Boundary**					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

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

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

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

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

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

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

Extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in Australian Geomechanics, Vol 42, No 1, March 2007, which discusses the matter more fully.

TABLE A1: LANDSLIDE RISK ASSESSMENT
QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (continued)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

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

Notes: (5) Cell A5 may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

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

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

Extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in Australian Geomechanics, Vol 42, No 1, March 2007, which discusses the matter more fully.

AUSTRALIAN GEOGUIDE LR2 (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 fall 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. The 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 series consequences. Wetting up of the ground (which may involve a rise in groundwater 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
- Groundwater 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:

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.

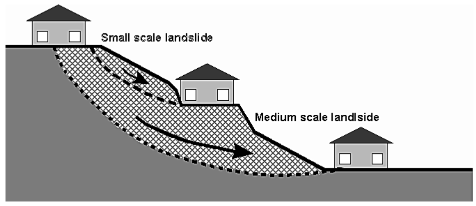


Figure 1

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.

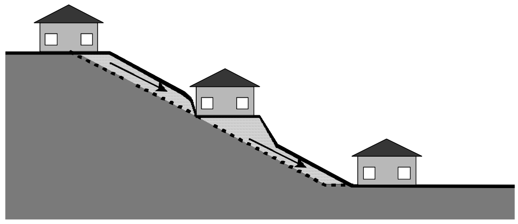


Figure 2

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.

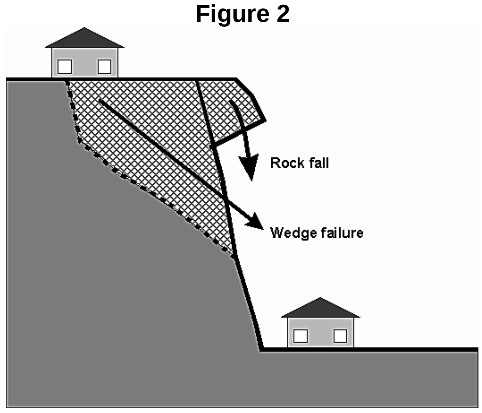


Figure 3

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.

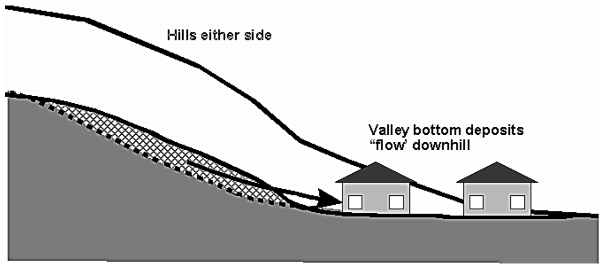


Figure 4

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.

AUSTRALIAN GEOGUIDE LR7 (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 (see 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 normally covered by special regulations. If you are contemplating building, or buying an existing house, particularly in a hilly area, or near cliffs, then go first for information to your local council. If you have any concern that you could be dealing with a landslide hazard that your local council is not aware of you should seek advice from a geotechnical practitioner.

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 inevitably lacks 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 the repairs and perhaps temporary loss of use. These two factors are combined by the geotechnical practitioner to determine the Qualitative Risk.

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.

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", "tolerable" 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 risk level. This may be lower than you feel is reasonable for your block but it is, nonetheless, a pre-requisite for development. Reasons for this include the fact that a landslide on your block may pose a risk to neighbours and passers-by and that , should you sell, subsequent owners of the block may be more risk averse than you.

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. 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 today. If this were not so, there would be no risk at all and clearly that is not the case.

In NSW, the planning authorities consider that 1:1,000,000 is the maximum tolerable risk for domestic housing built near an obvious hazard, such as a chemical factory. Although not specifically considered in the NSW guidelines there is little difference between the hazard presented by a neighbouring factory and a landslide: both have the capacity to destroy life and property and both are always present.

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

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APPENDIX B

SOME GUIDELINES

FOR

HILLSIDE CONSTRUCTION

APPENDIX B – SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

	GOOD ENGINEERING PRACTICE	POOR ENGINEERING PRACTICE
ADVICE		
GEOTECHNICAL ASSESSMENT	Obtain advice from a qualified, experienced geotechnical consultant at early stage of planning and before site works.	Prepare detailed plan and start site works before geotechnical advice.
PLANNING		
SITE PLANNING	Having obtained geotechnical advice, plan the development with the risk arising from the identified hazards and consequences in mind.	Plan development without regard for the Risk.
DESIGN AND CONSTRUCTION		
HOUSE DESIGN	Use flexible structures which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	Floor plans which require extensive cutting and filling. Movement intolerant structures.
SITE CLEARING	Retain natural vegetation wherever practicable.	Indiscriminately clear the site.
ACCESS & DRIVEWAYS	Satisfy requirements below for cuts, fills, retaining walls and drainage. Council specifications for grades may need to be modified. Driveways and parking areas may need to be fully supported on piers.	Excavate and fill for site access before geotechnical advice.
EARTHWORKS	Retain natural contours wherever possible.	Indiscriminant bulk earthworks.
CUTS	Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and erosion control.	Large scale cuts and benching. Unsupported cuts. Ignore drainage requirements.
FILLS	Minimise height. Strip vegetation and topsoil and key into natural slopes prior to filling. Use clean fill materials and compact to engineering standards. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.	Loose or poorly compacted fill, which if it fails, may flow a considerable distance (including onto properties below). Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc. in fill.
ROCK OUTCROPS & BOULDERS	Remove or stabilise boulders which may have unacceptable risk. Support rock faces where necessary.	Disturb or undercut detached blocks or boulders.
RETAINING WALLS	Engineer design to resist applied soil and water forces. Found on bedrock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.
FOOTINGS	Found within bedrock where practicable. Use rows of piers or strip footings oriented up and down slope. Design for lateral creep pressures if necessary. Backfill footing excavations to exclude ingress of surface water.	Found on topsoil, loose fill, detached boulders or undercut cliffs.
SWIMMING POOLS	Engineer designed. Support on piers to rock where practicable. Provide with under-drainage and gravity drain outlet where practicable. Design for high soil pressures which may develop on uphill side whilst there may be little or no lateral support on downhill side.	
DRAINAGE SURFACE	Provide at tops of cut and fill slopes. Discharge to street drainage or natural water courses. Provide generous falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.	Discharge at top of fills and cuts. Allow water to pond bench areas.
SUBSURFACE	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.	Discharge of roof run-off into absorption trenches.
SEPTIC & SULLAGE	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some areas if risk is acceptable. Storage tanks should be water-tight and adequately founded.	Discharge sullage directly onto and into slopes. Use of absorption trenches without consideration of landslide risk.
EROSION CONTROL & LANDSCAPING	Control erosion as this may lead to instability. Revegetate cleared area.	Failure to observe earthworks and drainage recommendations when landscaping.
DRAWINGS AND SITE VISITS DURING CONSTRUCTION		
DRAWINGS	Building Application drawings should be viewed by a geotechnical consultant.	
SITE VISITS	Site visits by consultant may be appropriate during construction.	
INSPECTION AND MAINTENANCE BY OWNER		
OWNER'S RESPONSIBILITY	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident seek advice. If seepage observed, determine cause or seek advice on consequences.	

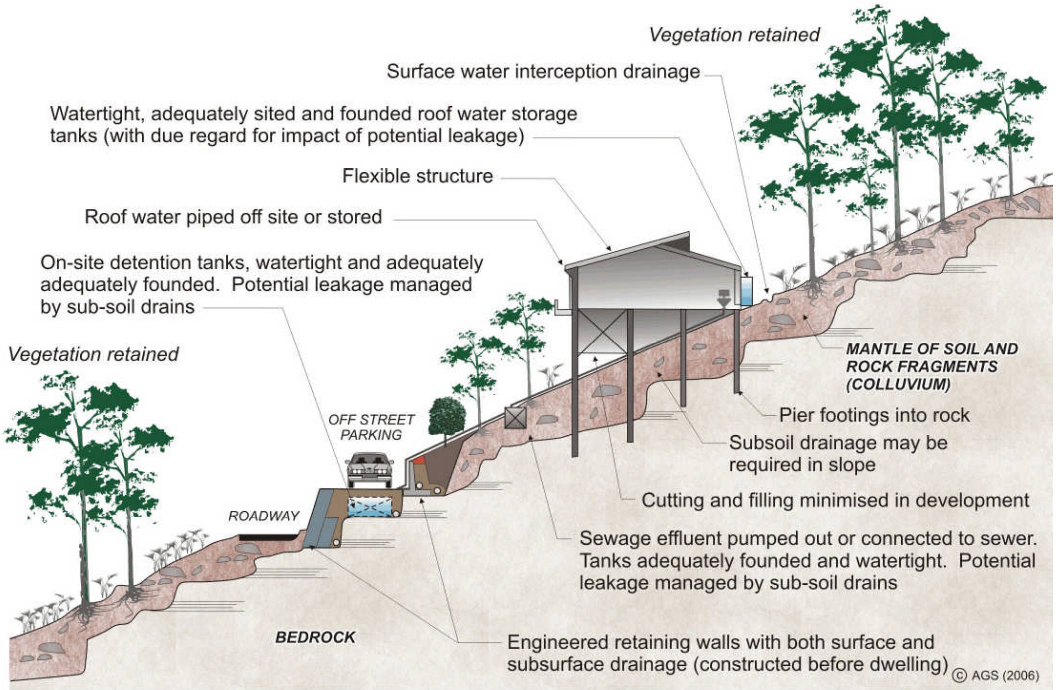
This table is an extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in *Australian Geomechanics*, Vol 42, No 1, March 2007 which discusses the matter more fully.

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

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.

EXAMPLES FOR **GOOD** HILLSIDE CONSTRUCTION PRACTICE



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 due to 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 fulfill 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.

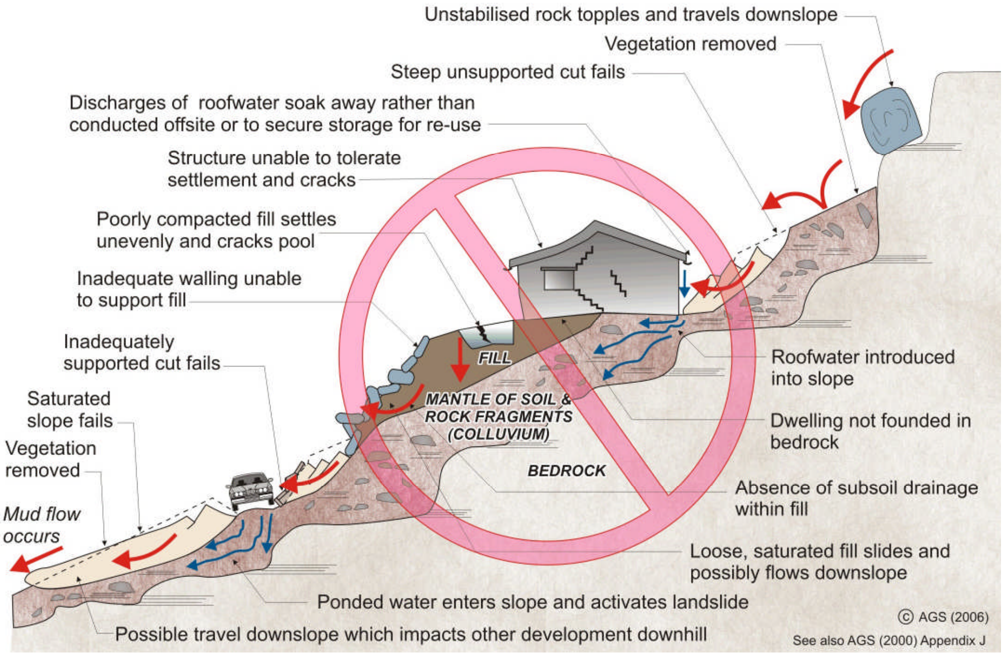
Flexible structures - have been used because they can tolerate a certain amount of movement with minimal signs of distress and maintain their functionality.

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
Extract from Geoguide LR8 – Hillside Construction Practice

EXAMPLES FOR 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 soaks 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 herringbone, 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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Extract from Geoguide LR8 – Hillside Construction Practice.