REPORT TO

PRIMO DESIGN PTY LTD

ON

SLOPE STABILITY RISK ASSESSMENT

FOR

PROPOSED TOWNHOUSES

AT

3 BROOKVALE AVENUE, BROOKVALE, NSW

Date: 12 May 2021
Ref: 33999SFrpt

JKGeotechnics
www.jkgeotechnics.com.au

T: +61 2 9888 5000
JK Geotechnics Pty Ltd
ABN 17 003 550 801

Report prepared by:

Owen Fraser
Associate | Geotechnical Engineer MIEAust

Report reviewed by:

Paul Stubbs
Principal | Geotechnical Engineer MIEAust CPEng

For and on behalf of
JK GEOTECHNICS
PO BOX 976
NORTH RYDE BC NSW 1670

DOCUMENT REVISION RECORD

Report Reference	Report Status	Report Date
33999SFrpt	Final Report	12 May 2021

Table of Contents

ATTACHMENTS

1 INTRODUCTION

This report presents the results of a slope stability assessment for the proposed townhouses at 3 Brookvale Avenue, Brookvale, NSW. The location of the site is shown in Figure 1. The assessment was commissioned by Mariam Hashemizadeh of Primo Design Pty Ltd by signed Acceptance of Proposal form dated 14 April 2021. The assessment was carried out in accordance with our fee proposal dated 8 March 2021, Ref: P53705YF.

We understand from the supplied architectural drawings prepared by Barry Rush & Associates (Job No. 2005, Version DA dated 2 March 2021) that it is proposed to demolish the existing site structures and construct three storey townhouses over one basement level. The proposed basement level will have Finished Floor Level (FFL) of RL20.8, resulting in excavations about 1.7m to 4.1m deep to achieve the Bulk Excavation Level (BEL). Localised deeper excavations will be required for the lift pit and services. The basement will generally be set back 2m or greater from the site boundaries, except where the driveway ramp on the eastern boundary and the basement stair access on the western boundary are present.

The purpose of the assessment was to carry out a slope stability assessment to satisfy Council DA requirements, and to also provide preliminary comments and recommendations on excavation conditions, hydrogeological considerations, retention systems, footings and basement slabs.

2 ASSESSMENT PROCEDURE

The assessment procedure comprised:

- A site walkover on 19 April 2021.
- A search of the JK Geotechnics project database to identify relevant geotechnical investigations completed within close proximity to the site.
- A review of aerial photography (NearMap and Google Earth).
- A review of the regional geology map of Sydney.

3 RESULTS OF ASSESSMENT

3.1 Site Description

The site lies at the boundary of hilly topography to the north and relatively low lying topography to the south with a gentle slope down to the north and north-west. Slopes at the northern end of the site initially fall at approximately 10° but then flatten to about 3° to 4° for the majority of the site. The site is bounded by Brookvale Avenue to the north.

The site contains a single storey weatherboard building that generally appears in good condition based on a cursory external inspection. Towards the north-western corner of the site, a single storey timber building was also present that appeared in good external condition. The external areas of the site mostly comprised of grassed and garden areas with concrete and paved areas surrounding the existing site structures. Small to large trees were present around the site perimeter.

The neighbouring eastern property contains a single storey brick house that appears in good condition based upon a cursory inspection from the street frontage. The house is set back approximately 4.2m from the site boundary at its closest point. The property maintains similar site levels as the subject site.

The neighbouring southern property contains a two storey brick building that appears in good condition based upon a cursory inspection from the subject site. The building is set back about 6m from the site boundary at its closest point and maintains similar site levels as the subject site. Observations were limited by a boundary fence, but there appears to be a concrete dish drain running along the common boundary, as shown on the survey plan.

The neighbouring western property contains a one to two storey brick house that appears in good condition based upon a cursory inspection from the street frontage and subject site. The house is set back approximately 1.3m from the site boundary and maintains similar site levels as the subject site.

3.2 General Geology and Inferred Subsurface Conditions

The 1:100,000 Geological Map of Sydney indicates that the site is mapped to be underlain by Hawkesbury Sandstone of the Wianamatta Group comprising medium to coarse-grained quartz sandstone, very minor shale and laminite lenses.

Based on our assessment and experience in the area, we expect to encounter fill and residual soils overlying relatively shallow sandstone bedrock. The depth to bedrock is likely to be less than 1m, although may deepen slightly towards the southern end of the site. The bedrock is likely to initially be extremely weathered but will quickly improve to good quality bedrock of low strength or better. The groundwater table is not expected to be encountered.

4 COMMENTS AND RECOMMENDATIONS

4.1 Slope Stability Risk Assessment

The site falls within 'Zone B' of the Warringah Council's Landslide Risk Zoning Map. Given that excavations of 2m are expected for the proposed basement, a geotechnical assessment is required to satisfy Council.

Our slope stability risk assessment is based on our walkover inspection and our experience in the local area in regard to slope instability. 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 Australian Geomechnics Society 2007c (Reference 1).

Based on our assessment, we consider the potential slope instability hazards associated with the site and the proposed development are as follows:

A. Instability of the proposed excavation;

B. Instability of the proposed retaining walls;

C. Instability of the natural hillside slope.

   a. Upslope of the proposed development
   b. Beside the proposed development
   c. Downslope of the proposed development

The attached Table A summarises our qualitative assessment of each potential landslide hazard and of the consequences to property should the landslide hazard occur. 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 to be "Very Low" or "Low" which would be considered 'Acceptable' in accordance with the criteria given in Reference 1.

We have also used the indicative probabilities associated with the assessed likelihood of instability to calculate the risk to life. The temporal and vulnerability factors that have been adopted are given in the attached Table B together with the resulting risk calculation. Our assessed risk to life for the person most at risk is about 10^{-7}. This would be considered to be 'Acceptable' in relation to the criteria given in Reference 1.

Based on our slope stability risk assessment, we consider that the risk of the proposed development poses an acceptable risk to both property and life, provide the preliminary advice in the following sections are adhered to and further detailed site investigations are carried out prior to construction.

4.2 Excavation

We understand that excavations between 1.5m and 3.9m deep will be required for the proposed basement. Based on our assessment, the proposed excavation will likely encounter fill, natural soils and predominantly sandstone bedrock. The bedrock is likely to be of at least low strength or better but will likely increase in strength to medium to high strength with depth. Detailed geotechnical investigations prior to construction are recommended to determine the subsurface profile to confirm the excavation conditions, in the form of a minimum two cored boreholes extending about 3m below BEL.

Excavation of the soils and any extremely weathered sandstone bedrock up to very low strength will be able to be completed using the bucket of a hydraulic excavator. Excavation of the sandstone bedrock of low strength or better will result in "hard rock" excavation conditions. "Hard rock" excavation techniques may consist of percussive or non-percussive techniques. Percussive techniques comprise the use of rock hammers while non-percussive techniques comprise rotary grinders, rock saws, etc. In addition, rock hammers may be required for the demolition of existing footings and floor slabs. Where percussive excavation techniques are adopted there is the risk that transmitted vibrations may damage the existing building on site or nearby movement sensitive structures. Consequently, we recommend that measures be taken as detailed below. If rotary grinders or rock saws attached to the excavator are used then we do not consider that vibrations pose a risk.

Care should be taken when using rock hammers so that ground vibrations do not adversely affect neighbouring structures. Consequently, we recommend that periodic vibration monitoring of the neighbouring buildings and structures to the east and west be undertaken while the rock hammer is being used to confirm that peak particle velocities fall within acceptable limits. We recommend that the peak particle velocities along the site boundaries do not exceed 5mm/sec. We note that this vibration limit will reduce the risk of vibration damage to the neighbouring building and structures. However, these vibrations may still result in discomfort to occupants of the neighbouring buildings. If excessive vibrations are occurring, it will be necessary to use lower energy equipment such as grinder attachments on hydraulic excavators or hand tools.

4.3 Hydrogeological Considerations

There may be some groundwater seepage flows within the basement excavation faces, particularly after periods of heavy and/or prolonged rainfall. However, groundwater is not expected to be a significant issue for this development and therefore we consider a drained basement is likely suitable for this site.

Seepage, if any, during excavation is expected to infiltrate through the natural sand and flow downslope (to the south) across the stepped bedrock surface. Any groundwater inflows within the excavations should be able to be controlled by conventional sump and pump drainage techniques and discharged into the stormwater system. Inspection and monitoring of groundwater seepage during any excavations is recommended, so that appropriate drainage may be detailed. Some instability of temporary excavation batters (where they can be accommodated) may occur towards the base of soil batter slopes, especially after rain periods and sand bagging may be required to stabilise the toe of batter slopes through the soils.

As part of the detailed investigation, an assessment of the groundwater conditions across the site should also be carried out. This should include, but not be limited, installation of at least two groundwater monitoring wells and longer term groundwater monitoring, although we note that most authorities require at least three groundwater monitoring wells. This additional investigation will likely be required to satisfy Council and the relevant authority that a drained basement is feasible, in lieu of a tanked basement.

4.4 Retention Systems

Based on the inferred subsurface conditions and the proposed basement excavation, we consider that a combination of temporary batter slopes and retaining walls will be required to support the excavation sides. Temporary excavation batters through the clayey soil profile and extremely weathered bedrock should be no steeper than 1 Vertical (V) in 1 Horizontal (H). No surcharge loads, such as from plant or equipment, may be placed at the crest of such batters and should be behind a line drawn upward at 1V in 2H from the toe of the batter.

The bedrock, once encountered, is likely to be suitable to be excavated vertically unsupported provided it is of at least low strength or better. However, the excavation cut faces must be inspected by a geotechnical engineer to assess the bedrock quality and the presence of adverse defects that require additional support. Additional support may comprise flattening of the cut faces or the use of rock bolts or shotcrete and will need to be determined by the geotechnical engineer at the time of the inspection.

Therefore, based on the above and given the bedrock is inferred to be at relatively shallow depths, the northern, southern and the majority of the western sides of the excavation, will likely be able to accommodate temporary batters through the soils and weathered bedrock. The good quality bedrock may then be excavated vertically below the toe of the temporary batters.

If the above batters cannot be accommodated within the site boundaries, such as for portions of the eastern and western boundaries, then shoring systems would need to be installed prior to the start of excavation, such as soldier pile walls. We recommend that a detailed geotechnical investigation be carried out to assess the depth to good quality rock and whether temporary batters can be accommodated.

Based on the expected excavation depths, we expect that a soldier pile cantilever wall socketed below BEL will likely be the most economical solution, even if it requires drilling through good quality bedrock. Alternatively, the pile wall could be terminated above BEL and the bedrock excavated vertically below the pile toes, however temporary anchors will be required to provide the necessary lateral support to the pile wall.

For cantilevered retaining walls supporting soil materials and sandstone bedrock, we recommend that walls can be designed on the basis of an active earth pressure co-efficient (K_a) of 0.35 where some wall movements are tolerable and assuming a horizontal backfill surface. A bulk unit weight of 20kN/m^3 should be adopted for the soil profile and 22kN/m^3 for the weathered sandstone profile. Where walls are laterally restrained or movements are to be reduced then we recommend the walls be designed on the basis of an 'at rest' earth pressure coefficient (K_o) of 0.6. Propped or anchored soldier pile walls may be designed based on a trapezoidal earth pressure distribution of 6H kPa, where H is the retained height of soils and sandstone bedrock up to very low strength. Whilst the good quality bedrock of low strength or better is self-supporting, there may be defects within the bedrock that may results in surcharge to be rear of the wall and therefore we recommend adopting 10Kpa surcharge for the good quality bedrock to take into account the potential presence of adverse defects.

All surcharge loads, i.e. adjoining buildings, traffic, sloping backfill, etc., should be allowed for in the design, plus full hydrostatic pressures unless measures are undertaken to provide complete and permanent drainage behind the walls.

Anchors should have their bond formed within sandstone of at least low strength and may be provisionally designed based on an allowable bond stress of 200kPa. The anchor bond should be formed outside a line drawn up at 45° from the bulk excavation level, with a minimum free length of 3m and a minimum bond length of 3m. All anchors should be proof loaded to at least 1.3 times their design working load before locking off at about 80% of the working load. Lift-off tests should be carried out on at least 10% of the anchors 24 to 48 hours following locking off to confirm that the anchors are holding their load. Generally, anchors are installed on a design and construct contract so that optimisation of bond stresses does not become a contractual issue in the event of an anchor failing the test load.

Passive toe resistance of the retention system below the base of the bulk excavation, where piles extend below the base of the excavation, may be estimated based on a preliminary allowable lateral resistance of 300kPa for sandstone of medium or higher strength. The passive resistance should be ignored to at least 0.3m below the base of the excavation, including footing and service excavations. Where the retention piles are to accommodate building loads, we recommend that these piles be founded below the basement the bulk excavation.

If temporary anchors are to run below neighbouring properties, then permission from the owners must be obtained prior to installation. We recommend that requests for permission commence early in the construction process as our experience has shown that it can take significant time for such permission to be granted. If permission is not forthcoming, then the alternative is to provide lateral support by internal bracing or propping. We assume that permanent support of the shoring system will be provided by bracing from the proposed building.

From review of the DBYD drawings, it appears that there is a Council stormwater asset that partially runs along the eastern boundary. The DBYD drawings do not provide details of the stormwater asset, however given the proposed basement excavation, Council might require an analysis to assess the potential impact of the development on their asset. The presence of the drainage easement suggests that disposal of stormwater directly to the existing drain should be feasible. Similarly, a Sydney Water asset (sewer) extends across the southern end of the site, which may also require analysis for further assessment.

4.5 Footings

It is anticipated that following excavation for the proposed basement that sandstone bedrock will be uniformly exposed across the bulk excavation. Consequently, we recommend that the proposed structures be uniformly supported on footings founded on the sandstone bedrock to provide uniform support and reduce the risk of differential settlements. Pad or strip footings may be used where rock is exposed or is at depth of less than about 1m. For any parts of the structure outside the basement footprint, then bored piles will likely be required where bedrock is greater than 1m deep.

Footings founded on sandstone bedrock of at least very low strength may be designed for a preliminary Allowable Bearing Pressure (ABP) of 1,000kPa. It is likely that higher bearing pressures may be achieved however details investigations in the form of cored boreholes will be required to prove the quality of the bedrock present at founding level.

At least the initial stages of footing excavation or drilling should also be inspected by a geotechnical engineer to confirm that a suitable founding stratum is being achieved. Where water ponds in the base of the footing prior to pouring concrete, they should first be pumped dry and then re-excavated to remove all loose and softened materials.

4.6 Basement Slab

Based on the assessment, the proposed basement floor slab will likely directly overlie sandstone bedrock. We therefore recommend that underfloor drainage blanket be provided. The underfloor drainage should comprise a strong, durable, single-sized washed aggregate such as 'blue metal' gravel. The underfloor drainage should connect with the perimeter drains and lead groundwater seepage to a sump for pumped disposal to the stormwater system.

Joints in the basement concrete on-grade floor slabs should be designed to accommodate shear forces but not bending moments by using dowelled or keyed joints.

5 GENERAL COMMENTS

The preliminary recommendations presented in this report include specific issues to be addressed during the construction phase of the project. In the event that any of the construction phase recommendations presented in this report are not implemented, the general recommendations may become inapplicable and JK Geotechnics accept no responsibility whatsoever for the performance of the structure where recommendations are not implemented in full and properly tested, inspected and documented.

This report provides advice on geotechnical aspects for the proposed civil and structural design. As part of the documentation stage of this project, Contract Documents and Specifications may be prepared based on our report. However, there may be design features we are not aware of or have not commented on for a variety of reasons. The designers should satisfy themselves that all the necessary advice has been obtained. If required, we could be commissioned to review the geotechnical aspects of contract documents to confirm the intent of our recommendations has been correctly implemented.

A waste classification is required for any soil and/or bedrock excavated from the site prior to offsite disposal. Subject to the appropriate testing, material can be classified as Virgin Excavated Natural Material (VENM), Excavated Natural Material (ENM), General Solid, Restricted Solid or Hazardous Waste. Analysis can take up to seven to ten working days to complete, therefore, an adequate allowance should be included in the construction program unless testing is completed prior to construction. If contamination is encountered, then substantial further testing (and associated delays) could be expected. We strongly recommend that this requirement is addressed prior to the commencement of excavation on site.

This report has been prepared for the particular project described and no responsibility is accepted for the use of any part of this report in any other context or for any other purpose. If there is any change in the proposed development described in this report then all recommendations should be reviewed. Copyright in this report is the property of JK Geotechnics. We have used a degree of care, skill and diligence normally exercised by consulting engineers in similar circumstances and locality. No other warranty expressed or implied is made or intended. Subject to payment of all fees due for the investigation, the client alone shall have a licence to use this report. The report shall not be reproduced except in full.

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

TABLE A

SUMMARY OF RISK ASSESSMENT TO PROPERTY

POTENTIAL LANDSLIDE HAZARD	A Instability of the proposed excavation	B Instability of the proposed retaining walls	C Instability of the natural hillside slope		
			Upslope of the proposed development	Beside the proposed development	Downslope of the proposed development
Assessed Likelihood	Unlikely	Rare	Rare	Barely Credible	Barely Credible
Assessed Consequence	Minor	Minor	Minor	Insignificant	Insignificant
Risk	Low	Very Low	Very Low	Very Low	Very Low
Comments	Comments and recommendations contained in this report are adopted in full	Comments and recommendations contained in this report are adopted in full			

TABLE B

SUMMARY OF RISK ASSESSMENT TO LIFE

POTENTIAL LANDSLIDE HAZARD	A Instability of the proposed excavation	B Instability of the proposed retaining walls	C Instability of Natural Hillside Slope		
			Upslope of the proposed development	Beside the proposed development	Downslope of the proposed development
Assessed Likelihood	Unlikely	Rare	Rare	Barely Credible	Barely Credible
Indicative Annual Probability	10^{-4}	10^{-5}	10^{-5}	10^{-6}	10^{-6}
Persons at risk	Persons at crest or toe of excavation	Persons at crest of toe or wall	Persons within grass verge	Persons beside house	Persons within northern garden
Number of Persons Considered	8	4	2	4	4
Duration of Use of area Affected (Temporal Probability)	6 hours/day (0.25)	2 hours/day (0.08)	0.25 hours/day (0.01)	0.25 hours/day (0.01)	1 hour/day (0.04)
Probability of not Evacuating Area Affected	0.4	0.1	0.3	0.3	0.3
Spatial Probability	0.2	0.2	0.2	0.5	0.2
Vulnerability to Life if Failure Occurs Whilst Person Present	0.1	0.5	0.1	0.3	0.1
Risk for Person most at Risk	$2x10^{-7}$	$8x10^{-9}$	$6x10^{-10}$	$4.5x10^{-10}$	$2.4x10^{-10}$
Total Risk	$1.6x10^{-6}$	$3.2x10^{-8}$	$1.2x10^{-9}$	$1.8x10^{-9}$	$9.6x10^{-10}$

Note: From the summation of risk for person most at risk, the total risk for the person most at risk is $2.1x10^{-7}$

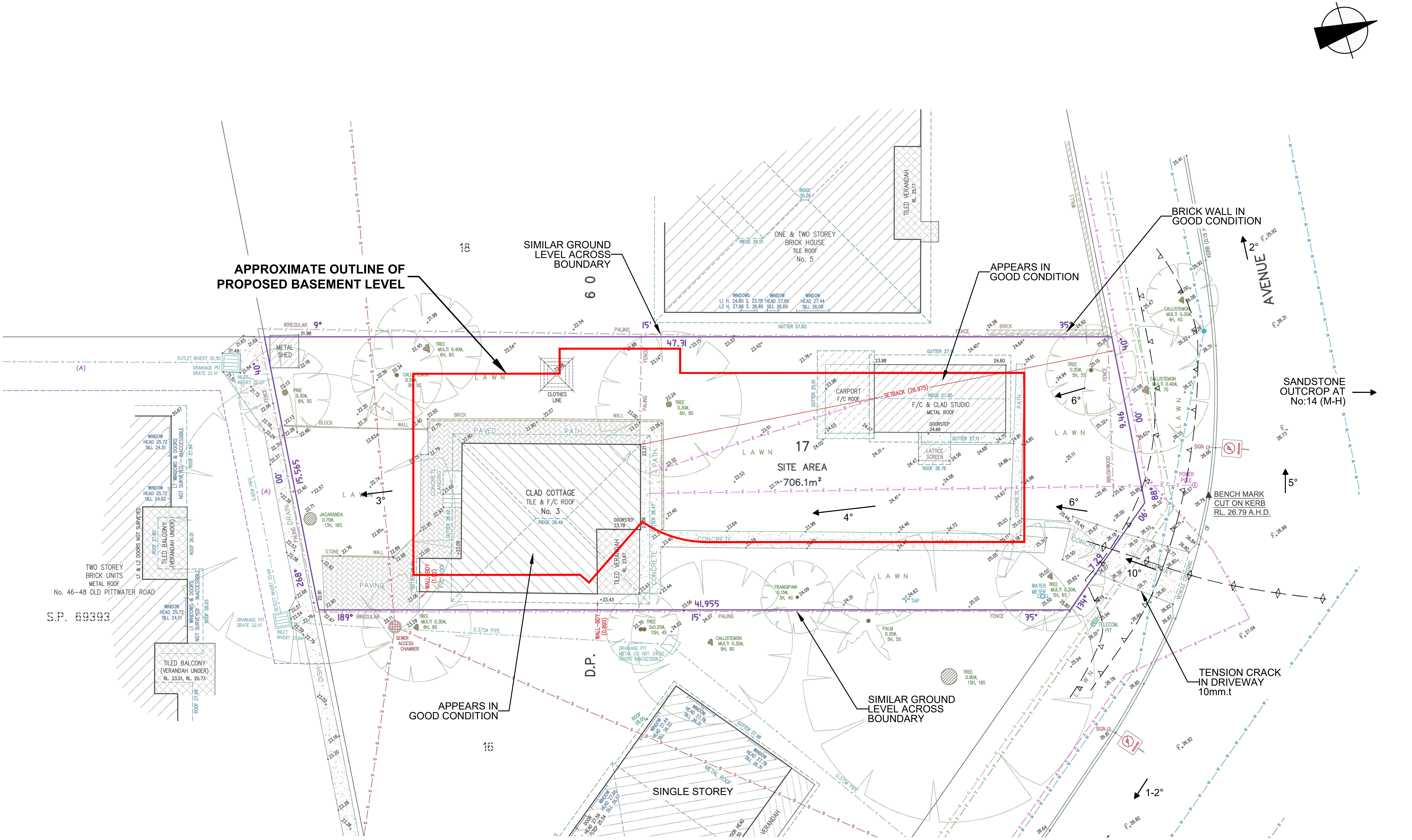
AERIAL IMAGE SOURCE: MAPS.AU.NEARMAP.COM

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

Title:	**SITE LOCATION PLAN**
Location:	3 BROOKVALE AVENUE, BROOKVALE, NSW
Report No:	33999YF
Figure No:	1

JKGeotechnics

PLOT DATE: 22/04/2021 3:07:17 PM DWG FILE: Y:\33000'S\33999YF BROOKVALE\CAD\33999YF.DWG



0 2 4 6 8 10 SCALE 1:200 @A3 METRES	Title: **GEOTECHNICAL SITE PLAN**	
	Location: 3 BROOKVALE AVENUE, BROOKVALE, NSW	
	Report No: 33999YF	Figure No: 2

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

JKGeotechnics

PLOT DATE: 12/05/2021 12:54:39 PM DWG FILE: Y:\33000's\33999YF BROOKVALE\CAD\33999YF.DWG

TOPOGRAPHY

Symbol *Ground Profile*

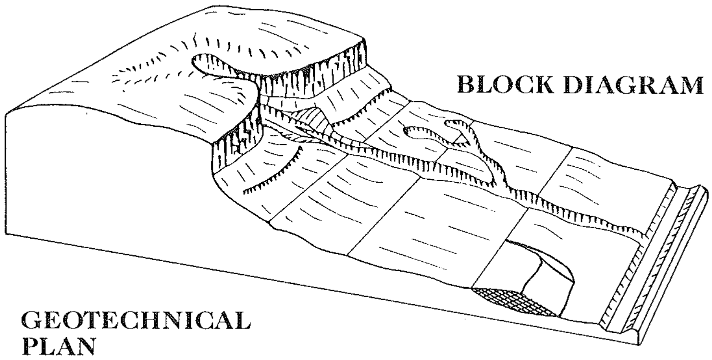
- convex / concave — well defined or angular break of slope
- convex / concave — poorly defined or smooth change of slope
- breaks of slope / changes of slope — convex and concave too close together to allow the use of separate symbols
- sharp / rounded — ridge crest
- 3 — Cliff or escarpment or sharp break 40° or more (estimated height in metres)
- 15 Uniform Slope / 10 Concave Slope / 8 Convex Slope — Slope direction and angle (Degrees)
- Top / Bottom — Cut or fill slope, arrows pointing down slope
- Hummocky or irregular ground

OTHER FEATURES

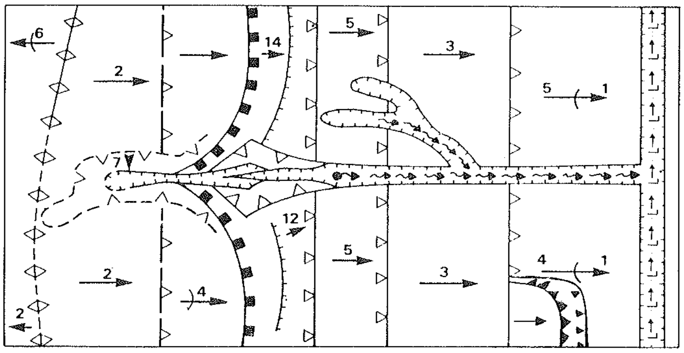
- Boulder
- Seepage/spring
- Swallow hole for runoff
- Natural water course
- Open drain, unlined
- Open drain, lined
- Fenceline
- Property boundary
- Dry Stone Wall
- J —— J 200 — Major joint in rock face (opening in millimetres)
- – T – T – 10 — Tension crack (opening in millimetres)
- Masonry or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

GEOTECHNICAL MAPPING SYMBOLS

JKGeotechnics

Report No. 33999SF Figure No. 3

APPENDIX A

LANDSLIDE RISK

MANAGEMENT

TERMINOLOGY

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.

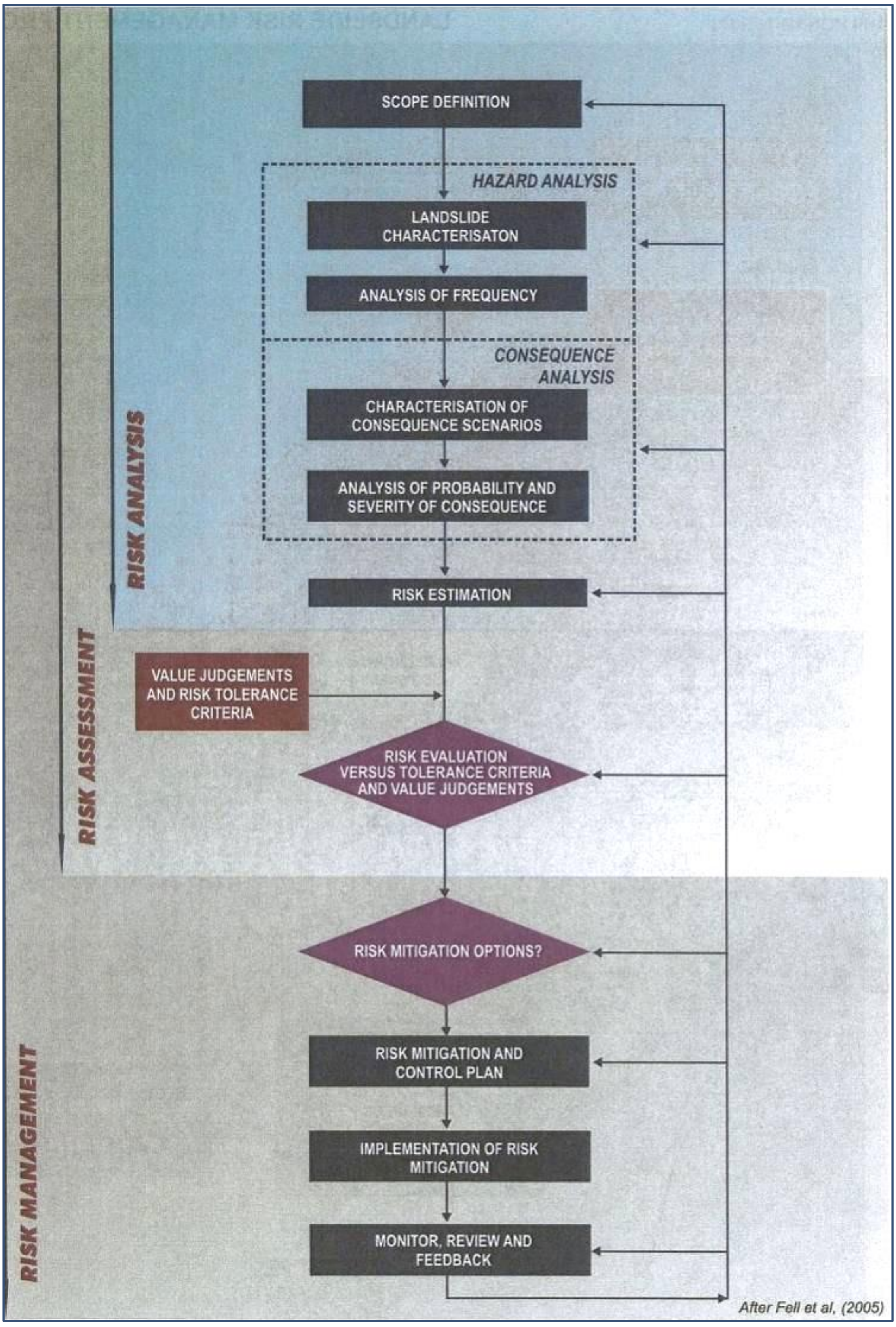


FIGURE A1: Flowchart for Landslide Risk Management.

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}	5×10^{-2}	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	5×10^{-3}	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	5×10^{-4}	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	5×10^{-5}	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	5×10^{-2}	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.

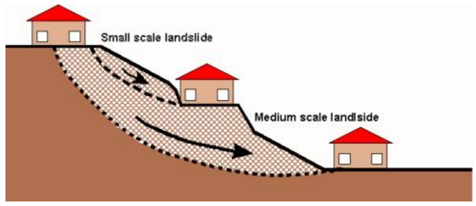


Figure 1

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.

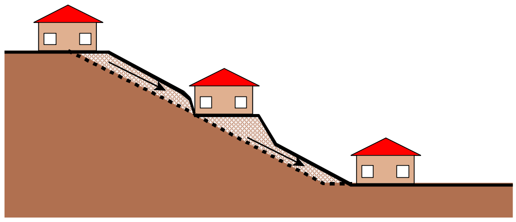


Figure 2

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.

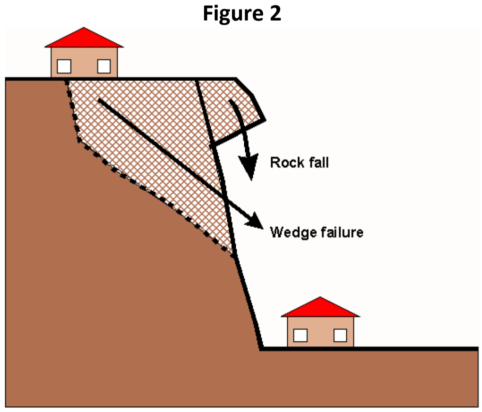


Figure 3

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.

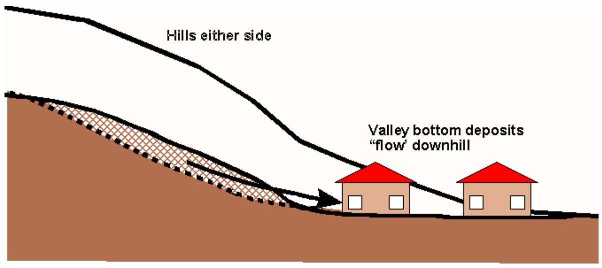


Figure 4

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.

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 the repairs and temporary loss of use if the 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 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 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. 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

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.