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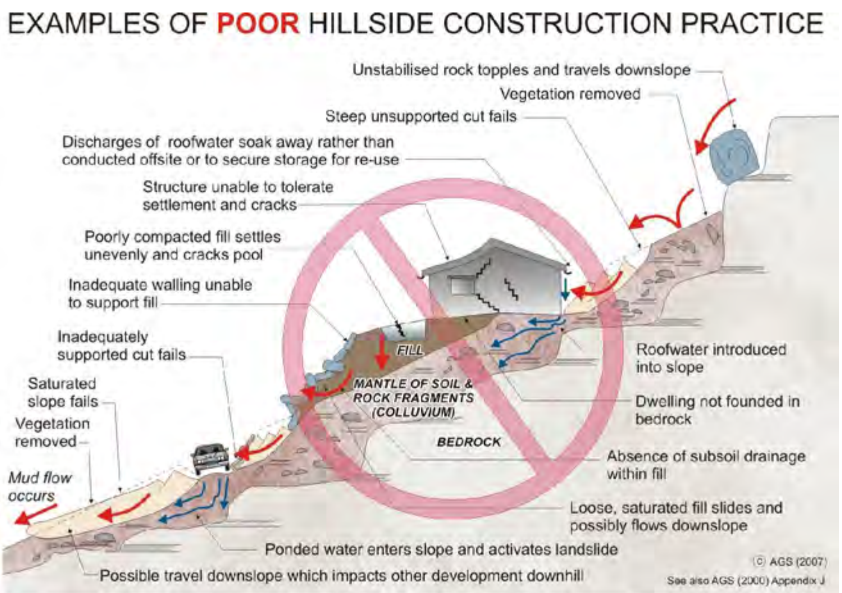

Landslide Risk Management

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COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Australian Geomechanics Society Landslide Taskforce,

Landslide Practice Note Working Group

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COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

PART A BACKGROUND

C1 INTRODUCTION

C1.1 PREAMBLE

In 2000 the Australian Geomechanics Society (AGS) published "Landslide Risk Management Concepts and Guidelines" (AGS 2000). In 2002 the content and application of AGS (2000) were demonstrated around Australia by "the Risky Roadshow" which was sponsored by Emergency Management Australia and AGS. Papers for the "Roadshow" were published in Australian Geomechanics Vol 37 No 2 May 2002. Since then there have been many published papers and an extensive body of discussion which has progressed the use of Landslide Risk Management (LRM) as discussed further below.

C1.2 PURPOSE

In preparing the Practice Note Guidelines for Landslide Risk Management (AGS 2007c) ('the Practice Note') , the intention has been to limit the document in so far as is possible to a clear and concise set of recommended requirements and principles. The purpose of this Commentary is to provide additional background, relevant references, comments and guidance relevant to the Practice Note.

C1.3 SCOPE

Since publication of AGS (2000) there have been many published papers and discussion which have progressed Landslide Risk Management (LRM) in particular and risk management in general. It would be an almost impossible task to distil all the thoughts and useful developments that are contained in the publications listed below and others. Nonetheless, the interested reader should refer to some, or all, of these to gain a greater understanding.

For example:

- Bowden, Lane and Martin (2001) "Triple Bottom Line Risk Management" which considers risk management in a broader business management context with aims to achieve benefits to the social, environmental and financial accountability of a business.
- Vick (2002) "Degrees of Belief, Subjective Probability and Engineering Judgment" which has extensive discussion of the basis behind LRM and examples. In particular it discusses subjective probability in some detail.
- AGS (2002) "Risky Roadshow" which provides some examples of qualitative and quantitative LRM.
- RTA NSW "Guide to Slope Risk Analysis Version 3.1" (Stewart *et al.*, 2002) which provides a specific LRM methodology for roads.
- ANCOLD (2003) "Guidelines on Risk Assessment" which provides useful guidelines and commentary in relation to dams. As part of the consideration for dams (that is stability of embankment dams) is similar to landslides, this document forms a very useful companion reference and is recommended reading for examples of the detailed assessment process.
- Lee & Jones (2004) "Landslide Risk Assessment" which examines the issues and literature in considerable detail, with numerous examples from various published papers. These examples can provide guidance on how to tackle particular problems and is a valuable reference.
- Standards Australia HB436:2004 "Handbook; Risk Management Guidelines Companion to AS/NZ 4360:2004" which discusses risk management in general terms, including consideration of the elements involved.
- "Landslide Risk Management" (2005) Proc Intl Conference on Landslide Risk Management June 2005 in Vancouver. This volume provides a wealth of up to date information and examples in relation to LRM. It includes six state of the art papers. Picarelli *et al.* (2005) provides a comprehensive discussion of hazard characterization and quantification. Leroi *et al.* (2005) which provides a comprehensive discussion on Acceptable Risk and tolerable loss of life criteria. Knowledge of the contents of this volume is a useful background for an experienced practitioner in LRM. This volume also provides a number of case history type papers and an extensive list of references for the interested reader or practitioner seeking examples or further guidance on specific issues.
- Glade *et al.* Eds (2005) "Landslide Hazard and Risk" which provides further discussion and examples.

In view of the developments included in the above, and as a number of Australian Government bodies have existing geotechnical policies or have developed draft policies which are based on the principles of AGS (2000), it was considered appropriate to develop updated guidelines and commentary for the use of both regulators and practitioners. In particular, the Practice Note should provide a reference document for legislative purposes. The Practice Note was initially developed as an update of AGS (2000). However, during development it became clear that it would be unworkable to merely update parts of AGS (2000) and leave other parts unaltered. Therefore, the Practice Note supersedes AGS (2000). Consequently, it is anticipated that legislation will refer to and/or be based on the Practice Note.

The Practice Note has been formulated to be prescriptive in content. This has the advantage to the regulator that the scope of LRM reports is better defined and to the practitioner that, in general, the required quality of LRM reports is known. Some practitioners perceive that prescriptive requirements will stifle innovation and ingenuity. The Working Group considers that innovation and ingenuity are an essential part of applying the principles given in the Practice Note. The important message is to document the LRM assessment process including definition of terminology used.

The Practice Note has specifically excluded detailed consideration of roads and railways (or similar). The state–of-the-art paper by Picarelli *et al.* (2005) provides detailed advice on how these should be considered for LRM.

C1.4 CONVENTIONS USED

The Practice Note has been kept to a format similar to that adopted in the ANCOLD (2003). The paragraphs in bold type represent recommendations from AGS. This Commentary has section numbers that correspond directly to those used in the Practice Note.

Further discussion of the issues and considerations relevant to the guidance given in the Practice Note are provided in this Commentary where appropriate. The Commentary may also provide comment on whether the relevant practice is well accepted by experienced practitioners or under discussion with contending points of view.

Throughout the Practice Note and this Commentary, reference to “landslide” includes both existing (or known landslides) and potential landslides, which a practitioner might reasonably predict based on the relevant geometry, geology and slope forming processes and experience.

C1.5 STAKEHOLDERS

No additional comment.

C2 RISK TERMINOLOGY

The technical jargon associated with risk terminology can be confusing initially to the lay person or inexperienced practitioner. However, it is necessary to use such terminology to convey succinct ideas or facts. The main terms can be expressed in simple plain English terms as follows:

What might happen?	What are the landslide types?
How big might they be?	What are the landslide characteristics?
How often do they occur?	What is the Frequency (LIKELIHOOD)?
What damage or injury might result?	What are the CONSEQUENCES?
How important is it?	What is the RISK?
What can be done about it?	What are the RISK TREATMENT options?
Has everyone understood the above?	Has the treatment plan been properly communicated?

A generalised discussion of terminology and concepts is given in “HB 436:2004 Risk Management Guidelines, Companion to AS/NZS 4360:2004” (Standards Australia 2004). The principles of AS/NZS 4360 have been embodied in the Practice Note. However, the terminology has evolved for LRM and Practice Note Appendix A presents the current internationally agreed terminology for landslides.

Usage of the terminology since AGS (2000) was published has shown that the term “hazard” has frequently been used incorrectly to encompass the landslide characteristics but not the likelihood of occurrence (frequency). The definition of hazard in AGS (2000) and in the Practice Note includes the likelihood of the landslide and is consistent with the internationally adopted definition.

The flow chart in Figure 1 of the Practice Note demonstrates how the various terms interrelate. This flowchart is similar to Figure 1 in AGS (2000) but is in a simplified form. Also the Practice Note Figure 1 correctly shows the relationship for Hazard Analysis, which must include the frequency analysis as a result of the formal definition. Landslide Characterisation was previously inferred, incorrectly, to be the Hazard Identification.

The practitioner must be careful to use the terms given in Appendix A of the Practice Note consistently and correctly in relation to their defined meaning. Rigour in their use reduces possible misunderstanding. In this context, it is noted that frequently the public, the media and published papers colloquially use “risk” when they really mean frequency or probability (likelihood).

Further, the Practitioner should be aware that the literature may be confusing as terms used may not be defined or may have changed their meaning with time.

PART B GUIDELINES FOR REGULATORS

C3 GUIDELINES FOR REGULATORS

C3.1 BACKGROUND

The regulator is the regulatory authority (at Federal Government / State Government / Instrumentality / Regional / Local Authority or Council level) having statutory responsibility for community activities, community safety and development approval or management of development within its defined area / region. (Practice Note, Appendix A).

Where landsliding is a possible threat to development, either planned or existing, then the regulator has a duty of care, if not a statutory requirement, to consider LRM as part of its planning process. The companion AGS Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning (AGS 2007a) provides detailed guidance in relation to this aspect.

The results of zoning studies will be considered by the regulator and implemented as appropriate controls and regulations to cover approvals for subsequent specific development applications.

It is not the intention of the Practice Note and Commentary to provide regulators with all the detail required for establishment and administering of a planning or control scheme, due to the possible variations from state to state and local considerations. It is, however, expected that the LRM principles will be appropriately considered and implemented.

C3.2 RELEVANCE TO APPROVAL PROCESS

Once planning controls are in place and general constraints are established (based on studies in accordance with AGS 2007a), then, where required by the planning controls, each individual development proposal will require specific consideration by the regulator. The planning controls may require a LRM assessment as part of the proposal application documentation for consideration as part of an approvals process. If so, the LRM assessment will need to consider the specific development proposals in relation to the geotechnical model for the site and its surrounding area to determine appropriate risk reduction and maintenance strategies. The extent of the surrounding area considered must be sufficient to identify those landslides that may impact on or be impacted by the site.

The requirement for an LRM assessment may still be imposed by the regulator where landslide risk is identified as an issue even if there are no broad planning studies to initiate it. The basis for such implementation may be local knowledge and experience or the nature of the proposed development.

The regulator will consider the LRM assessment submission together with other application documentation and will determine whether (having regard to the outcomes of the LRM assessment) the development should proceed and if any consent conditions should be applied to the proposal. Risk control measures will form an essential and integral component of the conditions. The regulator will take into account the subsequent process of documentation and inspection during detailed design and construction. Often these subsequent phases are not under the direct control of the regulator and this lack of control must be reflected in the consent conditions.

Where appropriate, the regulator may engage its own practitioner to provide independent advice on LRM reports submitted before any decision on the use and/or development proposal is finalised and consent conditions are stipulated. Alternatively, the regulator could employ its own practitioner for “in-house review” or require submission of a “peer review” report in addition to the LRM report.

Clients and builders must be aware of the implications of consent conditions in relation to the requirements for inspections, testing and confirmation during construction. The required inspections and testing should be carried out during construction, so that compliance with consent conditions can be demonstrated. Without this inspection and testing, compliance can be very difficult and/or costly, if not impossible, to achieve. This predicament can be problematic for the client and may also cause the practitioner difficulties and unwarranted liability exposure. In accordance with good practice, the practitioner can not approve or “certify” work completed if it was not inspected by the practitioner in accordance with consent conditions, unless additional investigations have been completed to satisfy the practitioner as to the extent and quality of the work completed. The regulator should not give the final completion certificates if the required work, including inspection and testing, has not been completed in accordance with the consent conditions.

Ongoing maintenance may be a requirement of the risk mitigation strategy. This aspect is discussed in Section 9 of the Practice Note and makes reference to the Geoguides (AGS 2007e). Regulators may require annotation on the land title to draw the attention of future land owners to the need for maintenance and the existence of a risk mitigation strategy.

Existing development may still be subject to LRM assessment by imposition of Orders (or similar statutory instrument) to investigate and rectify situations which may appear, or are known, to be unsatisfactory.

C3.3 POLICY REQUIREMENTS

Policy Requirements are intended to be prescriptive so that the principal elements are covered by each policy. Individual regulators may have specific additional considerations or requirements relevant to specific hazards or planning requirements within their jurisdiction. A policy should advise if one particular qualitative terminology (such as the Practice Note Appendix C) is preferred and whether other terminologies will be accepted and under what circumstances.

In addition, the resulting requirements for the practitioner are also intended to be prescriptive. Such prescription is considered to be appropriate as experience has shown that a number of practitioners do not fully comply with the procedures nor do they justify such non compliance. This is to the detriment of the community.

Such prescription is not to prevent some flexibility or innovation in application of policy requirements where the practitioner provides an appropriate documented justification. Such justification must be technically sound.

Early completion of planning studies in accordance with AGS (2007a) will assist with determining appropriate detail and specific mandatory requirements for individual policies.

The regulators should seek review by and input from local practitioners before final publication of a policy to confirm that particular local needs and conditions have been adequately addressed.

C3.4 PROCESSING REQUIREMENTS

Local government and other regulators must establish strong internal procedures for dealing with land use and development proposals on land situated within a landslide susceptibility zone which requires LRM under legislation / regulation. Staff will require training, not only in the procedures themselves, but also in regards to the basis of landslide mechanisms, LRM and dealing with geotechnical reports and practitioners. Such procedures may include the adoption of peer review or independent advice by appropriately experienced practitioners should sufficient knowledge not be available “in house” or in the event of contentious situations.

The use of recommended processing forms (such as the example forms in the Practice Note Appendix D or similar tailored to suit local specific requirements) should simplify the approval by non technical staff of the regulator by acting as a checking template. (The Working Group notes that similar forms have been successfully used by Pittwater, Gosford and Wollongong Councils and for Kosicuisko area in NSW.) Staff may not be required to understand the technical content of the LRM reports submitted since “self-certification” by the practitioner, via the completed forms, provides a basis, both technically and legally, for the regulator to accept the content. Nonetheless, the regulator should confirm compliance of LRM submissions with the policy requirements. Where the practitioner has to complete declarations, the regulator should confirm that the declaration is appropriately completed and not omitted. For both parties, the forms will assist with quality control and liability issues.

In view of the specialized nature of some LRM aspects, the verification process may rely on confirmation by the practitioner that the design drawings have appropriately incorporated the landslide risk control measures identified in the LRM assessment. The verification process would usually not be a review or check of the structural or civil design and should clearly state this unless commissioned otherwise. The verification process may be documented by control forms covering the scope of design needed to cover the risk control measures, such as Form B in Appendix D of the Practice Note, to cover each design professional’s documents.

Processing of approvals may have costs which regulators may wish to include within the application fee.

Adoption of a NPER (LRM) category will provide a bench mark for regulators to determine the competency of practitioners for submission of LRM assessments. The Regulator may include a requirement for the Practitioner to submit documentary evidence of registration and/or qualifications with the completed forms. Similarly, a client may request such documents.

C3.5 ESTABLISHMENT OF TOLERABLE RISK CRITERIA

The regulator is responsible for setting the Tolerable Risk Criteria within their policy. Consideration has to be given to uniformity of approach and the risk values adopted. The discussion in Section C8.2 is provided to give as much technical guidance as is considered to be currently available from practice and literature. The regulator may wish to seek its own technical advice in relation to adoption of specific Tolerable Risk Criteria and details of the policy.

C3.6 LANDSLIDE INVENTORY

Refer to AGS (2007a) for recommendations in relation to the content of the inventory. Compilation of an inventory will become a valuable tool for both the regulator and the practitioners.

Such an inventory may also refer to LRM reports prepared for development applications, though if there is no known landslide this should be documented to avoid confusion. Although LRM reports may be restricted in use under intellectual property rights (copyright), such documents are in the public domain once included with a formal application and may be referred to.

C3.7 ROLE AND RESPONSIBILITY OF THE PRACTITIONER

The practitioner has the role and responsibility of providing the technical advice to the client, as well as to the regulator. Although the practitioner is responsible to his client, there is an overarching responsibility associated with the Code of Ethics to the public at large. This overarching responsibility is not insignificant. The practitioner must provide his advice in an unbiased manner and with the duty to the public at large in mind in accordance with the Code of Ethics of a professional association.

Compliance by the practitioner with the regulator’s policy requirements would be expected unless departures can be justified on sound technical grounds.

Practitioners should be aware of the liability issues associated with signing the declarations on the Forms (Appendix D, Practice Note) submitted with the LRM reports and at subsequent stages. As part of the “in house” risk management procedures, the practitioner should only sign off what is reasonably known by observation and/or testing to be adequate or appropriate to the intent of the design requirements. This would also be in accordance with most Professional Indemnity insurance limitations.

PART C GUIDELINES FOR PRACTITIONERS

C4 SCOPE DEFINITION

Implicit in the scope will be compliance with the requirements of the regulator’s policy. Such requirements are likely to be derived from studies in accordance with the AGS (2007a).

Such studies, and resulting policy, may determine a particular minimum scope or level of study, as discussed in Section C5.2. If the minimum scope is not completed, then the reasons for departure from such a scope should be documented by the practitioner.

In more complex studies, staged study may be appropriate, so that increasing complexity of study is only adopted if the results obtained from the initial studies show it to be warranted. It may be appropriate to discuss with the client the alternative levels of study and implications arising therefrom.

Frequently a lay client will not have sufficient knowledge to question whether the scope is appropriate. If there may be a need to extend the scope of the assessment, based on the results of the initial assessment or response from the regulator, then it would be “good practice” to advise the client at the earliest opportunity of the possibility of such an extension

Communication of the scope adopted and inherent limitations arising therefrom becomes “good practice” for the practitioner as a liability risk management issue. It is essential that the client be informed of the limitations of the particular risk assessment and inherent uncertainty.

C5 HAZARD ANALYSIS

C5.1 DATA GATHERING / DESK STUDY

Proper recording of data, including sources, is an aid to subsequent review and possible revision as additional data comes to light.

A useful data source should be the local council (or regulator) who may have a "database" of experience, though it may be somewhat informal. Councils (regulators) are encouraged to set up a landslide inventory in accordance with AGS (2007a) which should be updated with reports of landslides and the damage resulting. Where information becomes available to Council through reports that may have intellectual property rights limitations (copyright), then a summary of salient data and reference to the holder of the copyright would be appropriate. The Council has an obligation to make such data readily available to practitioners working in the area to enable them to be fully informed. Provision of such data enables the practitioner to better understand the local conditions and performance history and will enable the regulator to reduce potential exposure to liability issues. Appropriate disclaimers or privacy considerations may also have to be observed.

Relevant maps and aerial photographs may be available from other government departments/ agencies. Images available on the web, such as from "google earth", may assist.

For studies of larger areas (rather than individual lots), aerial photographs may form a useful data source. Air photo interpretation using stereo pairs can assist with slope morphology and identification of geological features. Examination of aerial photographs, if available, taken over a number of years may assist in determining site and landuse changes that may have occurred with time at the site or surrounding area. Evidence of past instability may be available from such photographs. Often the small scale of available aerial photographs will limit detail, particularly at the level of individual residential lots.

C5.2 FIELD INVESTIGATION REQUIREMENTS

The investigations completed need to be sufficient to provide confidence in the geotechnical model, notwithstanding the uncertainties inherent. Table C1 lists the questions to be addressed in landslide investigations (Fell *et al.*, 2000).

Table C1: Questions to be addressed in slope stability and landslide investigations (Fell *et al*., 2000)

1	Topography?	1.1	In the landslide source and potential travel path.
		1.2	Effect and timing of natural and human activity on the topography.
2	Geological setting?	2.1	Regional stratigraphy, structure, history (eg. glaciation, sea level submergence and emergence).
		2.2	Local stratigraphy, slope processes, structure, history.
		2.3	Geomorphology of slope and adjacent areas.
3	Hydrogeology?	3.1	Regional and local groundwater model?
		3.2	Piezometric pressures within and around the slide?
		3.3	Relationship of piezometric pressures to rainfall, snowfall and snowmelt, temperature, streamflows, reservoir levels, both seasonally and annually?
		3.4	Effect of natural or human activity?
		3.5	Groundwater chemistry and sources.
		3.6	Annual exceedance probability (AEP) of groundwater pressures.
4	History of movement?	4.1	Velocity, total displacement, and vectors of surface movement?
		4.2	Any current movements and relation to hydrogeology and other natural or human activity?
		4.3	Evidence of historic movement and incidence of sliding (eg. lacustrine deposits formed behind a landslide dam, shallow natural slides, or failures of cuts and fills).
		4.4	Geomorphic or historic evidence of movement of slope or adjacent slopes.
5	Geotechnical characterisation of the slide or potential slide?	5.1	Stage of movement (pre failure, post failure, reactivated, active).
		5.2	Classification of movement (eg. slide, flow).
		5.3	Materials factors (classification, fabric, volume change, degree of saturation).
6	Mechanisms and dimensions of the slide or potential slide?	6.1	Configuration of basal, other bounding, and internal rupture surfaces?
		6.2	Is the slide part of an existing or larger slide?
		6.3	Slide dimensions, volume?
		6.4	Is a slide mechanism feasible?
7	Mechanics of shearing and strength of the rupture surface?	7.1	Relationship to stratigraphy, fabric, pre existing rupture surfaces.
		7.2	Drained or undrained shear?
		7.3	First time or reactivated shear?
		7.4	Contractant or dilatant?
		7.5	Saturated or partially saturated?
		7.6	Strength pre and post failure, and stress-strain characteristics.
8	Assessment of stability?	8.1	Current, and likely factors of safety allowing for hydrological, seismic and human influences?
		8.2	AEP of failure (factor of safety $\leq$1)?
9	Assessment of deformations and travel distance?	9.1	Likely pre failure deformations?
		9.2	Post failure travel distance and velocity?
		9.3	Likelihood of rapid sliding?

Whilst such questions are aimed at the investigation of specific existing landslides of a moderate to large size, they are also useful to keep in mind for an assessment at a walk-over level such as for an individual residential block.

The applicability of various investigation methods is ranked in Table C2 (Fell *et al.*, 2000) for different types of slopes.

Table C2: Application of site investigation methods to slope classes (Fell *et al.*, 2000)

SITE INVESTIGATION METHOD	NATURAL SLOPES			CONSTRUCTED SLOPES				
	Small/ Shallow	Medium	Large	Existing Cut	Existing Fill	New Cut	New Fill	Soft Clay
Topographic mapping and survey	A	A	A	A	A	A	A	A
Regional geology	A	A	A	A	A	A	A	A
Geological mapping of project area	B	B	A	A	B	A	B	C
Geomorphological mapping	A	A	A	B	B	B	B	D
Satellite imagery interpretation	D	D	C	D	D	D	D	D
Air photograph interpretation	A	B	A	C	C	C	C	C
Historic record	A	B	B	A	B	B(2)	B(2)	B(2)
Dating past movements	B	C	B	D	D	D	D	D
Geophysical methods	C	C	B	C	C	C	D	C
Trenches and pits	B	A	B	B	B	B	B	C
Drilling/boring	C	A	A	C	B	B	B	A
Downhole inspection	C	B	B	C	D	C	D	D
Shafts and tunnels	D	C	B	D	D	D	D	D
Insitu testing of strength and permeability	C(3)	C(3)	C(4)	D	B(3)	C	C	A(3)
Strength and permeability monitoring pore pressures, rainfall, etc	C	A	A	A	A	C	C	A(5)
Monitoring of displacements	C	B	A	B	B	B(5)	C(5)	A(5)
Laboratory testing	C	A	B	B	B	B	C	A
Back analysis of stability	C	B	A	C	B	B(2)	C(2)	C(2)

NOTES: (1) A – Strongly applicable, B – Applicable, C – May be applicable, D – Seldom applicable.
(2) In similar areas.
(3) SPT, CPT, CPTU.
(4) Permeability.
(5) During construction.

The driver / purpose of the field investigations is to understand the geotechnical model, possible landslide causes and triggers. Field investigations should start with a walk-over survey, including diligent field mapping to record the geomorphic features. These should be drawn to scale on plans and sections to provide a sound methodology of observation which can then lead to a preliminary geotechnical model and an understanding of the slope forming processes applicable. Subsequent subsurface investigations help refine the preliminary geotechnical model.

Moon and Wilson (2004) advise “particular skills and knowledge bases relevant to developing slope models include understanding of:

- Slope failure mechanisms.
- Landslide travel distances and speeds.
- The relationship between landslides and the intensity and duration of rainfall.
- Landslide hydrogeology.
- Landslide formation process rates.”

References are given by Moon and Wilson (ibid) for examples of the above.

The scope of work may vary depending on the level of the study completed, even within the complying scope. Indicative levels of study would be:-

- **Reconnaissance:** to establish the broad topography, evidence of past instability and geology on a regional scale or as a screening process to aid determination of scope of subsequent studies.
- **Walk-over:** to establish site (or area) specific topography and detailed observation of relevant features such as outcrops, topographic form and evidence of past instability. Some initial subsurface investigation may also be completed.

- **Preliminary design:** to provide sufficient data to enable the concept designs to be selected from possible alternatives based on the risk management requirements.
- **Detailed design:** to enable design of risk control measures to be optimised and to remove sufficient uncertainty such that the design will be satisfactory.
- **Construction:** to confirm the design assumptions and allow modification to the design sufficient to address departures from the assumed geotechnical model.

Not all levels of study will be applicable for every project. For example, for some cases completion of a walk-over investigation may be sufficient to allow detailed design to be completed satisfactorily. For more complex projects, the investigations may be completed in stages (for different levels) to enable the geotechnical model to be progressively refined and uncertainties reduced. The levels of study form a continuum and furthermore the scope will vary from project to project.

The appropriate level for residential LRM should be set out in the regulator's policy and should be at least to a walk-over level but with subsurface investigation as needed to establish the subsurface profile. Preliminary and/or detailed design level investigations may only be warranted once the consent conditions have been set. Such consent conditions may include the requirement to complete the more detailed investigations so that the risk control measures may be properly designed and constructed.

The prescriptive requirements given in the Practice Note are considered to be "best practice" for LRM of individual lots or possibly for subdivision assessments. They would also be applicable for investigation of a particular landslide or area, but should be completed to a more comprehensive level.

Monitoring of ground water levels and responses to rainfall events would be ideal. However, practical limitations (including cost and time) limit how often such monitoring is likely to be completed. Frequently a qualitative assessment is likely to be sufficient. For stabilisation by subsurface drainage some monitoring before and after installation of the drainage measures will be required to enable the effectiveness of such drainage to be assessed.

If a practitioner does not comply with the requirements of a policy, then it should be fully documented in the report as to why not.

C5.3 LANDSLIDE CHARACTERISATION

No further comment.

C5.4 FREQUENCY ANALYSIS

5.4.1 Techniques for Frequency Analysis

i) *Main Techniques*

The Practice Note outlines the main techniques which are routinely adopted. AGS (2000) Appendix C provides further discussion. Lee and Jones (2004) and Picarelli *et al.* (2005) provide more detailed discussion and examples from published papers.

ii) *Limitations for Historical Analysis*

The Working Group notes that, in Australia, gathering of historical knowledge is not usually as easy or fruitful as it should be. Experience shows that local government seldom has a complete listing and records become difficult to retrieve, whilst local papers tend to concentrate on "the human aspect" with little factual documentation, not even of date and time of a landslide event, nor the extent and nature of the landslide. Notwithstanding this, a listing of landslide events (as a basic inventory) is of relevance and aids in assessment of likelihood. Much of the data on the incidence of landslides is held by consultants who work in the area. There would be considerable benefits if local government authorities gathered the data held by all the consultants who work in their area and established an inventory which could be accessed by all.

Within Australia an inherent limitation is likely to be the relatively short time period that development has been exposed to landslides. Historically, original development tended to avoid problem areas based on common sense and possibly trial–and-error. If historical records are limited to say 30 years, then the frequency of single events will be limited to a basic 1 in 30 probability (about 0.03), though this may be modified by the probability of trigger events during that period, and response within a population of similar landslides in similar geology and geomorphology. Table C3 shows the length of historical record required to estimate return periods with selected reliability.

Table C3: The length of historical record required to estimate return period events with 95% and 80% reliability.

Return Period (Years)	Length of record in years required to deliver reliability of return period estimate	
	95% reliable	80% reliable
2.33	40	25
10	90	38
25	105	75
50	110	90
100	115	100

From Lee and Jones (2004) after Benson (1960).

With sufficient data it may be possible to formulate Frequency vs Magnitude curves to summarise the data and gain a better understanding of the overall process and associated frequencies. (For example, refer Moon, Wilson & Flentje 2004, and MacGregor *et al.,* 2007).

iii) Evaluation of Rainfall

Statistical evaluation of rainfall data is relatively easy to perform using computer spreadsheets. These statistics can be related to the incidence of landslides. An example is given in MacGregor *et al.* (2007).

Consideration has to be given to possible trigger thresholds which may relate to rainfall, either in the short term (minutes to hours) or the long term, such as antecedent rainfall over weeks to months. Usually, antecedent rainfall will be relevant where rising groundwater levels are seen as the main trigger, and this is frequently applicable for the larger landslides

In addition, there may be a conditional probability of the landslide event occurring during a given rainfall event, or the conditional probability related to the proportion of similar slopes that might be affected by a rainfall event. Such conditional probabilities may be evaluated by considering the proportion of slopes that have failed in a given rainfall event (based on the landslide inventory in conjunction with the rainfall analysis).

Use of simulation models which predict piezometric responses to rainfall events may assist with calibration and extrapolation to extreme rainfall events. However, these require long periods of records of rainfall and piezometric data, and even when this is available simulation is difficult. Fell *et al.* (1991) gives an example. Table C4 indicates the probability of different return period events occurring over different periods of time. It can be seen that the probability of having a low return period event (for example a 1 in 100 year event) over a relatively short monitoring period such as 5 years is quite low (4%). Thus such models and extrapolation will have obvious limitations but may still be a useful tool for understanding a particular scenario.

Table C4: Percentage probability of the N-Year event occurring in a particular period.

Number of years in period	N = Average return period in years							
	5	10	20	50	100	200	500	1000
1	20	10	5	2	1	0.5	0.2	0.1
5	67	41	23	10	4	2	1	0.5
10	89	65	40	18	10	5	2	1
30	99	95	79	45	26	14	6	3
60	>99.9	98	95	70	31	26	11	6
100	>99.9	99.9	99.4	87	65	39	18	9
300	>99.9	>99.9	>99.9	99.8	95	78	45	26
600	>99.9	>99.9	>99.9	>99.9	99.8	95	70	45
1000	>99.9	>99.9	>99.9	>99.9	>99.9	99.3	87	64

After Lee and Jones (2004).

The effects of ‘climate change’ may show that use of historical rainfall records has an implied limitation. However, at this stage the effect of climate change cannot be predicted. Some predict longer dry periods, whilst others are predicting higher intensity rainfalls. Since it may be that a changed rainfall pattern may in many cases increase the probability of landsliding, whilst dryer periods may decrease the probability for others, it is considered appropriate at this time not to attempt to adjust the assessed frequency for such changes.

iv) “Degree of Belief” or Subjective Probability

For many cases, the practitioner will have to rely on the “degree–of-belief” method or subjective probability. This will be necessary due to the lack of relevant information such as historical records and/or quantitative analysis of trigger events which would enable an objective assessment of event probabilities. The practitioner will have to make best estimates of frequency/likelihood from limited site data, using experience and broad knowledge of an area or other areas of similar slope form and geology.

Moon and Wilson (2004) provide a useful over-view to developing judgments on landslide likelihood. *"The necessary evidence on which judgments of landslide likelihood are based has to be assembled, understood and interpreted. This process involves developing a slope model that reflects a sound knowledge of how the slope was formed, how it behaved in the past and how it might behave in the future. The ability to build up such a model comes from knowledge of the slope and its surrounds, knowledge of similar slopes in similar environments, and a range of skills and knowledge bases that result from training and experience."* Many useful references are cited.

Vick (2002) discusses the role of evidence and logical inference to subjective probability and engineering judgment. Although the assessed likelihood will be a subjective judgment, it should, like a bookmakers odds, be based on evidence (Moon and Wilson, 2004).

There are undoubted problems associated with use of "degree–of-belief" methods. The following presents a summary of the discussion in Lee and Jones (2004).

The main potential problems identified by Roberds (1990) are, in summary:

- *Poor quantification of uncertainty*, which may result in significant over estimates of likelihood where the slope forming process is ignored or misunderstood.
- *Poor problem definition*, as a result of the practitioner's experience and background, resulting in emphasis on one area or element of the slope at the expense of another.
- *Motivational bias* which may result in over optimistic or overly conservative assessments depending on the purpose of the assessment.
- *Cognitive bias* where the practitioner's judgment does not match the available facts.

The effects of these potential problems can be reduced or eliminated by techniques such as those of Lee and Jones (2004):

- "*Self assessment* where the rationale behind every judgment has to be well documented as required by the Practice Note. The same operator bias is likely to apply, but the documentation process clarifies the logic and results in a more defensible judgment.
- *Independent review or second opinion* which also should be well documented. This may still suffer from bias.
- *Calibrated assessment* where the practitioner's biases are identified and calibrated, and the assessment adjusted accordingly. The biases may be identified by peer group review or objectively by a set of experiments or questionnaires.
- *Probability encoding*, which involves the training of practitioners to produce reliable assessments of the probability of various events in a formal manner. This involves six stages:
    1. Training the practitioner to properly quantify uncertainty.
    2. Identifying and minimizing the practitioner's bias tendencies.
    3. Defining and documenting the item to be assessed in an unambiguous manner.
    4. Eliciting and documenting the practitioner's rationale for the assessment.
    5. Eliciting, directly or indirectly, the practitioner's quantitative assessment of uncertainty and checking for self-consistency. The practitioner's uncertainty can be established by determining the probability of various states through comparison with reference situations, such as poker hands, or by choosing between two lotteries (e.g. probability wheels or intervals) until indifference is achieved.
    6. Verifying the assessment with the practitioner and repeating the process if necessary."

Group consensus about a judgment is desirable but is achieved at increased cost and may not be economic. There may be significant differences of opinion between different practitioners. Where such differences of opinion are identified then they should be attempted to be resolved preferably in an open forum. The outcomes from this resolution process can be:

- *Convergence* to a common belief or assessment agreed to by all practitioners in the group.
- *Consensus*, where a single assessment can be determined but the assessment may not be the exact view of each individual. The consensus assessment may be a compromise derived from the individual assessments of group members but without the express agreement of the individuals concerned (forced), or the group may expressly agree to it for a particular purpose (agreed).
- *Disagreement.* Where convergence or consensus to a single assessment is not possible from the multiple assessments due to the major differences of opinion.

More detailed discussion of the above is presented in Lee and Jones (2004).

The Working Group considers that the Practice Note outlines "best practice" for self assessment where a "degree–of-belief" method is frequently adopted. However, it is anticipated that documentation of the assessment will include reference to known history and trigger events to help calibrate the judgment and provide defensibility.

The assessment of frequency should adopt the best means available given the nature of the landslides, circumstances of the geotechnical model, nature of triggering events and requirements of the risk assessment. Where few data are available, then estimates erring on the conservative side should be adopted to cover inherent uncertainty. More detailed studies may then be required to provide more reliable risk estimates.

In considering the circumstances of the particular assessment, the practitioner has to use best estimates from the available data when assigning likelihood (and consequences) values, but will inevitably be based on a subjective assessment of the practitioner's "belief" of the assessment. The assessment needs to consider range/uncertainty/sensitivity of the assessed values to establish confidence. The practitioner has to apply judgment, but must provide an explicit trail, or explanation, of logic applied to derive the best estimates adopted.

Stewart *et al.* (2002) discuss the RTA Guide to Slope Risk Analysis which provides a systematic procedure for LRM for roads based on defined ratings to derive an Assessed Risk Level. The companion paper (Baynes *et al.*, 2002) discusses the issues of accuracy and precision in use of the procedure by many practitioners on a large number of slopes. The methodology of the procedure is based on principles outlined above. Training in use of the system is required to help calibrate each practitioner and reduce bias. Audit procedures are used to derive consensus where necessary.

The state-of-the-art paper by Picarelli *et al.*, (2005) also provides a further overview and examples.

v) Event trees

Event trees enable the logical sequence of events to be considered in a structured manner. A suitable structured approach might, for example, consider for each scenario sequences such as likely trigger event, slope response, and consequence. An event tree can be used for complex scenarios.

The method has the advantage of enabling the logic adopted to be clearly shown together with each estimate of conditional probability, thereby providing clear documentation for review and appraisal.

This matter is discussed further in Lee and Jones (2004), and provides some examples where the method has been used. Hsi and Fell (2005) give an example where triggering by rainfall, over-taxing of a culvert and earthquake is modelled. Mostyn and Sullivan (2002) provides examples in relation to failure of fill embankments along a road. Hill *et al.* (2002) provides further discussion of issues associated with the principles of event trees.

5.4.2 Estimation of Annual Probability (Frequency) ($P_{(H)}$) of Each Landslide

a) Use best estimates for frequency estimates but consider range/ uncertainty/ sensitivity.

AGS (2000) acknowledged that assessment of frequency, or likelihood, is the most difficult part of the risk assessment process.

Assessment is particularly difficult at the medium to low frequency end (say 10^{-4} pa to 10^{-6} pa) because historic data based methods are not applicable. However, such values may still be appropriate by a combination of understanding the slope forming processes and logical elimination of other values. For some cases, such low frequency values may obviously be appropriate to hazards which could only occur over periods of geological time.

Experience has shown there is an inherent danger with Appendix G of AGS (2000), in that some practitioners assessed the likelihood solely based on the Descriptor. The Indicative Likelihood would then be adopted without due consideration. This procedure is incorrect as described below. An estimate of the probability should be made based on the best estimate of performance, trigger probabilities etc. and then the descriptor may be assigned accordingly.

Words such as "likely" can mean many different things to different people and in various contexts. The likelihood descriptors vary enormously in probability value between different publications as shown in the attached Table C5.

The qualitative terminology for Likelihood adopted for the Practice Note Appendix C is essentially the same as Appendix G, AGS (2000). The lowest category of likelihood has been revised to Barely Credible (from Not Credible).

The Descriptors are given to provide a consistent set of terms to assist the non-practitioner to interpret the assessed annual probability. In addition, the Descriptors provide a useful summary term for discussion purposes with due recognition of the inherent limitation of accuracy that is involved.

Table C5: Some published relationships between verbal descriptor and probabilities.

Verbal Descriptor	Conditional Probability				Annual Probability		
	USBR (2003)	Vick (1992)	Bowden *et al.* (2003)	Reagan *et al.* (1989)	AGS (2000) Appendix G	De Ambrosis & Mostyn (2004)	Moon & Wilson (2004)
Virtually certain	0.999	0.99	0.999	0.9	Approx 0.1 *	>=0.1*	>0.2*
Very likely	0.99	0.9		0.85			0.2 to 0.02
Likely	0.9			0.7	Approx 0.01	>=0.01	0.02 to 0..002
Neutral (even chance)	0.5	0.5		0.5			
Unlikely	0.1		0.001	0.15	Approx 0.0001	>=0.0001	<0.0002
Very unlikely	0.01	0.1	0.0001	0.1			<<0.0002
Virtually impossible	0.001	0.01	0.000001	0.02	<0.000001*	<0.000001*	

Note: * Verbal descriptor similar

Consideration has been given to the cumulative probability associated with each Descriptor and the expectation for the probability of occurrence of the lay user for those terms. For example, on first sight the use of the term ALMOST CERTAIN for an annual probability of greater than 0.05 seems inappropriate. However, examination of the Practice Note Figure 2 shows that within a design life of 60 years the cumulative probability of occurrence is about 0.95, and about 0.99 for 100 years. The apparent anomaly is explained by consideration of performance over the design life (as discussed in Section C9.3 below), and it is considered acceptable The indicative probability of occurrence over various design lives is given for each Descriptor in Tables CC1 and CC2 in Appendix CC attached.

Where knowledge based expert judgment or 'degree of belief' method of assessment of frequency is used, the resulting assessment could only be expected to have a precision within about one order of magnitude as discussed by Baynes *et al.* (2002). A consensus assessment by two or more practitioners can improve the precision to a reasonable level.

Although descriptors may have different meanings in other systems or publications, they are well defined in the Practice Note Appendix C. If an alternative system is to be adopted then the alternative should be similarly well defined and include an explanation as to why the preferred scheme was not adopted for the LRM assessment.

b) Estimates of frequency may be derived by partitioning the problem to (Annual probability of trigger event) x (Probability of sliding given the trigger event) over the range of trigger events.

It is sometimes useful to consider the likely response of a slope to given rainfall events (or other trigger events, such as earthquakes) when assessing frequency. Hence:

Frequency = (Annual probability of trigger event) x (Probability of sliding given the event)

$$= P_T \times P_{S:T}$$

assessed over the range of trigger events.

The probabilities of sliding are assessed judgementally from historic data and the experience of the practitioner. Table C6 provides an example of employment of partitioning to produce an estimate of annual probability over a range of trigger events.

Table C6: Example of the assessment of the annual probability (frequency) of landsliding employing the annual probability of rainfall and the response of the slope to the rainfall.

Annual probability of the rainfall	Annual probability rainfall is exceeded	Probability/annum rainfall is in this range (P_T)	Estimated conditional probability of landsliding given the rainfall is in this range ($P_{S:T}$)	Annual probability (Frequency) of landsliding
1 in 1	1.0			
		0.9	0.001	0.0009
1 in 10	0.1			
		0.095	0.1	0.0095
1 in 200	0.005			
		0.0049	0.9	0.0044
1 in 10,000	0.0001			
		0.0001	0.99	0.0001
			Total	0.0149

Where there is little historic data on which to assess the conditional probabilities ($P_{S:T}$) it is useful to use inferred relationships known as mapping schemes. These link qualitative and quantitative terms for probability. Table C7 shows a scheme which has been used widely in dams risk assessment in Australia.

Table C7 was developed for use in dams risk assessment, by Barneich *et al.* (1996) from Military Standard (1993), using Baysian theory to assess historical data. This was done by a group of dams and geotechnical experts, and reviewed by Professor A. Cornell. It has been used and validated in other areas such as pavement management systems, environmental risks at mine sites and seismic risk analysis projects. Experience shows the table helps in obtaining consistent estimates of conditional probabilities within event trees.

Table C7: Mapping scheme linking description of likelihood to quantitative probability (Barneich *et al.*, 1996)

Description of Condition or Event	**Order of Magnitude of Probability Assigned**
Occurrence is virtually certain	1
Occurrences of the condition or event are observed in the available database	10^{-1}
The occurrence of the condition or event is not observed, or is observed in one isolated instance, in the available database; several potential failure scenarios can be identified.	10^{-2}
The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort.	10^{-3}
The condition or event has not been observed, and no plausible scenario could be identified, even after considerable effort.	10^{-4}

c) Complete a review of the assessed frequency in relation to the implied cumulative frequency of the event occurring within the design life and known performance within the area.

Practice Note Appendix C Likelihood table has included the "Implied Indicative Landslide Recurrence Interval". The correspondence to the Approximate Annual Probability is not strictly correct, especially at low probability values. As discussed by Moon and Wilson (2004) the recurrence interval has a connotation about long periods of time based on long periods of evidence. The reality is that data in relation to the annual probability values of about 10^{-4} or less will be limited. "However, because likelihood evidence relates to years not abstract numbers (e.g. year of last slope movement, return period of landslide inducing rainstorms), many practitioners find it easier to think in terms of 'landslide recurrence intervals' and then convert the judgments to annual probabilities" (Moon and Wilson, 2004).

The inclusion of likelihood terms for annual probability values of less than 10^{-4} is considered to be appropriate to allow for differentiation, particularly where the probability of spatial impact may be quite different for different hazards. This also offers easy differentiation for hazards where the probability of landsliding is barely credible, for example on a plateau area remote from any escarpment or possible regression (except over geological time) and having relatively gentle slopes underlain by competent strata the probability is likely to be less than 10^{-6}pa.

5.4.3 Assessment of Travel Distance and the probability of spatial impact ($P_{(S:H)}$) of the elements at risk

For most risk assessments it will be adequate to estimate travel distance using empirical or simplified methods. Only in very detailed studies of large and important landslides would it be necessary or useful to use methods such as finite element or distinct element analyses to estimate deformations of individual slides, or to use numerical methods to model debris flows or rock avalanches. Hungr *et al.* (2005) provides an overview of methods for estimating travel distance.

For rotational landslides which remain essentially intact, the method proposed by Khalili *et al.* (1996) or experience with landslides in similar geological, topographic and climatic conditions can be used to estimate the displacement. This method is based on the principle of conservation of energy assuming the factor of safety at failure is unity, adopting the residual strength and the slope geometry to estimate the displacement. The results compare reasonably with case studies. The displacements are greatest for "brittle" failures i.e. where there is a large loss of strength on shearing. The strength loss may be best measured in undrained strength terms, e.g. for soft clays peak and remoulded strengths should be used and for saturated loose (collapsing) granular fills where liquefaction may occur, post liquefaction strengths should be used. For non-circular surfaces, the method may overestimate displacements. Deformation may be modelled for more important projects using finite element, finite difference or distinct element programs.

There is a degree of uncertainty in the methods available for estimating travel distance. Judgment will also have to be applied when consideration of travel direction is relevant in relation to the landslide impacting a particular element at risk. (Such consideration is most likely to be relevant for boulder falls or similar.) For individual allotment assessments, a best estimate or slightly conservative approach may be used, though for more detailed risk assessments, the uncertainty in travel distance and /or travel direction should be modelled as shown in the example presented in Table C8.

Table C8: Example of modelling uncertainty in travel distance and the probability of spatial impact ($P_{(S:H)}$).

Travel Distance Range metres	Estimated Probability the Travel Distance will be in this Range	Probability of spatial impact ($P_{(S:H)}$) assuming the element at risk is 32 metres below the landslide
<20	0.2	0
20 to 30	0.6	0
30 to 40	0.2	0.2
	Total 1.0	Total 0.2

The probability values could be further modified by the conditional probability associated with travel direction, where this is appropriate. For example, if a rockfall is assessed to have a variety of possible trajectories, only some of which will result in spatial impact on the element at risk, then application of the conditional probability for the trajectory would be applied to the travel distance probability.

C6 CONSEQUENCE ANALYSIS

C6.1 ELEMENTS AT RISK

No further comment.

C6.2 TEMPORAL SPATIAL PROBABILITY ($P_{(T:S)}$)

Roberds (2005) gives a detailed account of how to estimate temporal spatial probability where the elements at risk are mobile. AGS (2000, 2002) Appendix E gives details for the case of traffic travelling on a road.

For most assessments involving persons at risk in a building, the practitioner should make an estimate of temporal spatial probability based on the use of the building. This should include assessment of the probability of non-evacuation which may be used as a conditional probability. The landslide velocity and possibility of forewarning of the landslide failure will be relevant considerations.

The assessment may need to be based on a regulator’s notional occupancy for a dwelling, not necessarily the client’s proposed occupancy. For example, a client may wish to build a holiday house with relatively low occupancy factors (particularly for the time of year most likely to have a landslide event). However, a subsequent owner may be occupying with an average family on a fulltime residential basis. The later occupancy would be more critical and should be adopted for assessment purposes for the development.

C6.3 EVALUATION OF CONSEQUENCE TO PROPERTY

C6.3.1 Estimate the extent of damage likely to property arising from each of the landslides

The assessment of vulnerability and damage to property is subjective, and there is little published information. The Practice Note Appendix F has some data but note that for property this represents the judgements of those doing the study and is not a record of actual vulnerability. There are some general points which should be considered:

- Landslides which move slowly (particularly those with a near planar, horizontal surface of rupture) may cause little damage to structures on the landslide, though those structures which are on the boundaries of the landslide will experience differential displacement.
- For stuctures on the landslide, the rate of movement is less important for damage to the structures, except insofar as it affects the time rate of damage, than it is for loss of life.
- For stuctures below the landslide, the velocity of the landslide has a major effect on the damage and hence vulnerability. Hence structures which are near the toe of a landslide which will travel a long distance are likely to experience a high velocity impact and will suffer extensive damage (high vulnerability), and structures which are near the limit of the travel (or run-out) of the landslide will experience low velocity impact by only part of the landslide mass and will probably suffer “minor” damage (low vulnerability).

- It will sometimes be appropriate to consider vulnerability of a small part of the element at risk. For example, a room in a house which may be affected by a small landslide such as rock fall, may have a vulnerability of 1.0, whereas this may represent only a proportion of the value of the house as a whole.
- The proportion of a structure damaged is unlikely to represent the same proportion of the value of the structure. For example, damage to 10% of structure may represent 50% of the value of the structure.

C6.3.2 Estimate the indicative cost of the damage

The direct cost of damage to the structure is not the Total Cost to the owner if a landslide occurs. The Practice Note details the costs to be considered to derive an estimate of the Total Cost.

For many risk assessments it will be sufficient to estimate the costs approximately for example by using published construction cost guides which are relatively inexpensive (such as Rawlinson's, Cordell's, Reed's or similar). However, the practitioner is not a quantity surveyor and caution should be used in providing broad brush guesstimates on which legal decisions may be made and enforced. All cost estimates should be well documented and referenced using up to date industry sources appropriate to the location and types of costs involved.

Experience using the qualitative terminology in AGS (2000) Appendix G indicated that evaluation of the meaning of the description of the consequences to property can be subject to wide interpretation. In an effort to narrow the interpretation, de Ambrosis and Mostyn (2004) suggested use of estimates of the cost of damage as a more objective measure so as to limit disputes of interpretation of the description. The Practice Note definition builds on that proposal. Assessment of the consequences to property has been normalised as the Total Cost relative to the Market Value of the property under consideration. AGS recommends adoption of this updated approach using a semi-quantitative method as presented in Appendix C of the Practice Note.

There may be some situations where the regulator will require the risk from all landslide hazards to be brought to tolerable risk levels as part of the remedial works in the event of a landslide on a property. Regulators who will take this approach should make it clear to Practitioners doing risk assessments in their area.

For Practice Note Appendix C, the consequences scale has been adjusted in conjunction with appraisal of the risk categories as discussed in Appendix CC. It is considered that the adopted consequence scale is preferable to the order of magnitude scale in de Ambrosis and Mostyn (2004) as the Appendix C scale enables a more workable subdivision of risk in the Medium and Major categories (10% to 100% consequences) and shifts the descriptors towards the higher consequences, which is more realistic.

There is an obvious limitation in application of the method if the practitioner is not experienced enough to appreciate the civil engineering and structural engineering implications of particular landslide events. However, as consequences are an essential input to risk evaluation, this limitation has to be addressed and may require assistance ffom other experts, such as civil or structural engineers (as appropriate) or quantity surveyors for refinement of cost estimates.

C6.3.3 Estimate the market value

No additional comments.

C6.3.4 Consider the resulting Consequence classification, such as using Practice Note Appendix C, and implied accuracy of the above estimates.

No additional comments.

C6.4 EVALUATION OF CONSEQUENCES TO PERSONS

The assessment of vulnerability to persons is subjective and there is little published information. The Practice Note Appendix F has some data but note that except for the data in Finlay et al (1999) this represents the judgements of those doing the study and is not a record of actual vulnerability. There are some general points which should be considered:-

- For persons below the landslide, the velocity of the landslide has a major effect on the vulnerability. Persons who are near the toe of a landslide which will travel a long distance are likely to experience a high velocity impact and will have a high vulnerability and persons who are near the limit of the travel (or run-out) of the landslide will experience low velocity impact by only part of the landslide mass and will have a lower vulnerability.
- Persons who are in buildings which collapse totally have high vulnerability.
- Persons who are in buildings are less vulnerable than those in the open unless the building collapses.

- Persons in vehicles are less vulnerable than those in the open. Their vulnerability depends on the volume and velocity of the landslide. Experience in Hong Kong (Finlay *et al.,* 1999) indicates that rapid landslides of only a few hundred cubic metres are likely to result in death of the occupants of the vehicle.

It should be noted that whether a person will evacuate from the path of the landslide is covered in temporal spatial probability, not in vulnerability.

C7 RISK ESTIMATION

Standards Australia (2004) HB436:2004 discusses the types of risk analysis which may be summarized as:

- *Qualitative analysis*: "uses words to describe the magnitude of potential consequences and the likelihood that those consequences will occur. These scales can be adapted or adjusted to suit the circumstances, and different descriptions may be used for different risks"
- *Semi-quantitative analysis*: "qualitative scales, such as those described above are given values. The objective is to produce a more expanded ranking scale than is usually achieved in qualitative analysis, not to suggest realistic values for risk such as is attempted in quantitative analysis."
- *Quantitative analysis*: "uses numerical values (rather than descriptive scales used in qualitative and semi-quantitative analysis) for both consequences and likelihood using data from a variety of sources. The quality of the analysis depends on the accuracy and completeness of the numerical values and the validity of the models used."

Appendix G of AGS (2000) presented an example of qualitative terminology and risk matrix that was considered to be suitable for use in landslide risk assessment for property. AGS (2000) recognized that alternative schemes may be used, provided they are defined. As previously noted, AGS (2000) has now been superseded by the Practice Note.

C7.1 QUANTITATIVE RISK ESTIMATION

Reference should be made to Lee and Jones (2004) for a number of examples of risk calculations for a variety of scenarios. Some examples are also given in Roberds (2005) and other invited papers in the same volume. Such examples may be useful for deriving an appropriate model to enable suitable risk estimates.

C7.2 SEMI-QUANTITATIVE AND QUALITATIVE RISK ESTIMATION FOR RISK TO PROPERTY

In the context of risk assessments for residential development with submission to a regulator, adoption of a common preferred qualitative terminology should be mandatory as stipulated in the regulator's policy. If the practitioner considers an alternative scheme to be preferable for a particular hazard/situation, then adoption of this alternative must be justified by detailed documentation of the reasons.

There is considerable benefit to the regulator and the practitioner to use a common terminology. Comparison between different sites and between different practitioners is facilitated. Whilst there may be an inherent difference in assessment between practitioners (for example as shown by Baynes *et al.*, 2002), adoption of a common terminology will facilitate understanding and calibration between practitioners. Use of a scheme developed for a specific site or case makes cross comparisons difficult or confusing.

Although the Practice Note Appendix C scheme uses qualitative terminology to communicate and/or summarise the assessment of risk to property, it is in essence a quantitative scheme since it relies on the best estimates of the likelihood and consequence for the analysis. Risk to life should only be considered quantitatively and the adoption of semi-quantitative methods is considered to be inappropriate.

C7.3 RISK MATRIX FOR PROPERTY LOSS

The preferred Risk Matrix for Property presented in the Practice Note Appendix C has been derived primarily for residential development. It may also be appropriate to apply the scheme to other development,or situations/consequences. If the scheme is modified, or an alternative adopted, then full discussion of the justification and basis for the alternative scheme should be given.

A number of alternative qualitative scales for Likelihood, Consequences and resulting risk matrices and assigned risk levels were examined before deriving the final scheme in the Practice Note. Further discussion is given in Appendix CC of the considerations involved.

The main considerations were:

- The use of the annualised cost of damage to help allocate the risk categories.

- The risk values have been skewed down in favour of consequence (as discussed by de Ambrosis and Mostyn 2004) for the lower value consequences. It is judged that higher consequences are more readily accepted or tolerated at the lower likelihood values.
- Cell A5 (Almost Certain / Insignificant) has been subdivided in recognition of the practicality of hazards that result in very low value consequences and are readily accepted by most owners.
- The recommendation to the regulator that MODERATE risk is tolerable and that LOW (and Very Low) Risk is acceptable for Importance Level 2 and 3 structures (Appendix A, Practice Note) based on the assessment of implied cost impact of damage on most home owners and the fact that most home owners will be risk averse in the light of lack of insurance availability. If insurance was available then an annualised dollar value equivalent to an insurance policy cost would be a reasonable and rational benchmark for acceptability. (Refer to Section C8.2b below).

Alternative qualitative schemas for measures of likelihood and/or consequences may be used but the onus is on the practitioner to fully document the methodology and definitions for the terminology adopted. The documentation should include an explanation as to why the AGS preferred scheme is not appropriate. To avoid confusion, different descriptor terms (words) should be used wherever possible. In addition, the components of any alternative system must be compatible and form a consistent and logical process to allow LRM. It is considered likely that the piecemeal substitution of only one element of the preferred AGS terminology is unlikely to produce a consistent system.

C7.4 ESTIMATION OF RISK OF LOSS OF LIFE

It is widely accepted that Risk to life can only be evaluated quantitatively and this enables direct comparison with tolerable risk criteria. For this reason, AGS (2000, 2002) required life loss risk to be estimated quantitatively as does the Practice Note. Refer also to discussion in Lee and Jones (2004) and Leroi *et al*. (2005).

De Ambrosis and Mostyn (2004) have proposed some qualitative terms for risk to life. This proposal has not been adopted by the Working Group because their table can only be realistically used from right to left. That is, the assessor has to evaluate the conditional probabilities of vulnerability, non-evacuation, temporal probability and spatial probability in order to determine the required value of "Indicative Vulnerability". Since the conditional probabilities are required anyway, it makes more sense to continue to use them for evaluation of the risk to life quantitatively, using the assessed best guess likelihood value applicable to the hazard.

C8 RISK ASSESSMENT

C8.1 RISK EVALUATION

The final step in the Risk Assessment is the Risk Evaluation. The Practitioner has to relate the estimated risks to the risk tolerability criteria and then, if required, determine the appropriate and necessary risk mitigation options to reduce risks to within tolerable limits. The owner and regulator have to decide if risks are tolerable, though pragmatically the ultimate decision resides with the regulator.

If the risk cannot be reliably reduced by mitigation measures to satisfy the tolerable risk criteria, then either the development should not occur or the scope of the development should be modified accordingly.

Individual risk will usually be the governing consideration for most residential developments and should relate to the "individual most at risk". The risk from all landslide hazards which may affect that person should be considered and summed to give the individual risk and this should satisfy the tolerable risk criteria.

In cases where occupancies are likely to include many individuals (such as for schools, hospitals, shopping centres, boarding houses, motels, clubs etc, i.e. Importance Level 3 and Importance Level 4 structures) rather than a family unit in a single residential dwelling, Societal Risk should also be considered. For a family unit in a residential dwelling it is considered to be impractical to consider societal risk for every case and the risk assessment outcome is unlikely to be significantly different.

The example in Appendix CB demonstrates how Societal Risk can be evaluated. More details are given in ANCOLD (2003) and Leroi *et al.* (2005).

Additional considerations by the owner and regulator for determination of whether risks are tolerable may include political issues, social and community considerations, business confidence, environmental impacts and post-disaster uses.

C8.2 TOLERABLE RISK CRITERIA

a) Loss of Life criteria

As discussed in Section C3.5, the regulator is the appropriate authority to set standards for tolerable risk which may relate not only to perceived safety in relation to other risks, but also to government policy. Implementation of a tolerable risk level has implications to the community at large, both in terms of relative risks or safety, but also in terms of economic impact.

Table C9: Individual Loss of Life Risk Criteria. (Leroi *et al.*, 2005)

Organisation	Industry	Description	Risk/annum	Reference
Health and Safety Executive, United Kingdom	Land use planning around industries	Broadly acceptable risk. Tolerable limit	10^{-6}/annum, public and workers 10^{-4}/annum public[(1)] 10^{-3}/annum workers	HSE (2001)
Netherlands Ministry of Housing	Land use planning for industries	Tolerable limit [(2)]	10^{-5}/annum, existing installation 10^{-6}/annum, proposed installation	Netherlands Ministry of housing (1989), Ale (2001), Vrijling *et a*l. (1998)
Department of Urban Affairs and Planning, NSW, Australia	Land use planning for hazardous industries	"acceptable" (tolerable) limits [(2)]	$5x10^{-7}$/annum hospitals, schools, childcare facilities, old age housing 10^{-6}/annum residential, hotels, motels $5x10^{-6}$/annum commercial developments 10^{-5}/annum sporting complexes	
Australian National Committee on Large Dams	Dams	Tolerable limit	10^{-4}/annum existing dam, public most at risk subject to ALARP 10^{-5}/annum new dam or major augmentation, public most at risk, subject to ALARP.	ANCOLD (2003)
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum, public most at risk, new slope	AGS (2000)
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	10^{-4}/annum public most at risk, existing slope. 10^{-5}/annum public most at risk, new slope	Ho et al. (2000), ERM (1998), Reeves *et al.* (1999)
Iceland ministry for the environment hazard zoning	Avalanches and landslides	"acceptable" (tolerable) limit	$3x10^{-5}$/annum residential, schools, day care centres, hospitals, community centres. 10^{-4}/annum commercial buildings $5x10^{-5}$ recreational homes[(3)]	Iceland Ministry for the environment (2000), Arnalds *et al.* (2002)
Roads and Traffic Authority, NSW Australia	Highway landslide risk	Implied tolerable risk	10^{-3}/annum[(4)]	Stewart *et al*. (2002), RTA (2001)

Notes:

(1) But for new developments HSE (2004) "advises against giving planning permission where individual risks are > 10^{-5}/annum".

(2) Based on a temporal spatial probability of 1.0.

(3) Assumes temporal spatial probability of 0.75 for residential, 0.4 commercial, 0.05 recreational.

(4) Best estimate of societal risk for one person killed, top risk ranking. If slope ranks in this range action is taken to reduce risks within a short period. For the second ranking, societal risk is 10^{-4}/annum, and slope is put on priority remediation list.

Table C9 summarises published individual loss of life risk criteria. An overview of the issues in relation to Loss of Life criteria are discussed in Leroi *et al.* (2005).

It is important to distinguish between "acceptable risks" and "tolerable risks".

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

Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

Most organisations listed in Table C9 have adopted Tolerable Risk as the measure to gauge risk. This is because there is a trade-off between the benefits and cost of risk mitigation, and the costs to achieve acceptable risk levels are often high. The Australian National Committee on Large Dams (ANCOLD) has adopted tolerable risk criteria for assessing risks posed by dams. This decision was reached after extensive consultation locally and internationally and after seeking legal opinion.

After due consideration of these factors and taking account of the criteria which were included in AGS (2000, 2002) AGS suggests that **for most development in existing urban areas criteria based on Tolerable Risks levels are applicable because of the trade-off between the risks, the benefits of development and the cost of risk mitigation. The recommended Tolerable loss of life risk values for the person most at risk for different situations are shown in Table 1 of the Practice Note.**

It is recommended that risks be assessed only for the person most at risk, and not for the average person as suggested in AGS (2000, 2002). ANCOLD (2003) reported that the person most at risk always controlled, and that average risks were difficult to define and determine.

The recommended values are higher for existing slopes than for new slopes. This is in keeping with ANCOLD (2003) and general literature on risk tolerability which indicates that persons tolerate risks from existing hazards more than for newly constructed ones. Where development modifies an existing slope, the "new slope" criteria should be applied in accordance with the definitions given for the situation in Table 1 of the Practice Note.

Regulators may decide to apply "acceptable risk" criteria for high consequence cases, such as schools, hospitals and emergency services in recognition of the importance of these structures and as a way of covering societal risk concerns. This is also reflected in the recommended criteria for property loss for different Importance Levels of structures below.

The community may tolerate higher risks from natural hazards than man made hazards (IUGS 1997). Such a consideration by the regulator may result in some natural hazards being tolerated in the face of exceptional expenditure to reduce the risk to tolerable levels. An example of this may be the risks associated with boulder falls from natural cliff lines in a bush reserve adjacent to existing residential development. If the regulator and potentially affected owners were not aware of the circumstances then prior to the LRA they would have been "uninformed". Adoption of such tolerable risks should be made on the basis of an appropriate LRA and assessment of the risk mitigation options.

It is recognised that the recommended criteria are higher than required by NSW Department of Planning (2002) However, their criteria are applied to development such as chemical plants which can be sited in areas where the low risks can be achieved. Urban development is within designated areas, the land owner has no option but to develop (if practical) so the trade-off between risk levels, cost of development and risk mitigation have to be considered. This is a similar situation to dams and is part of the reason ANCOLD have adopted tolerable risk criteria.

Societal Risk may be measured against the ANCOLD (2003) recommended values as given in Figure 4 of Leroi *et al.* (2005). Reference should be made to ANCOLD (2003) when carrying out such assessments.

For special cases of work place related risks, such as in mining and tunnelling, and/or for short term stability in construction sites, then work-place safety requirements will control and those criteria might govern.

b) Loss of Property Criteria

Acceptable (or tolerable) values for Risk to Property are rarely quoted in literature.

Lee and Jones (2004) considers evaluation of such risk in economic terms by evaluating economic indicators such as the Benefit-to-Cost Ratio, Net Present Value and Incremental Benefit-to-Cost Ratio. This allows comparison of alternative risk management strategies. Application of a decision rule allows selection of the most cost effective management option. Various methodologies for evaluation are detailed in Lee and Jones (2004) and are too lengthy to repeat here. Such methods should be investigated for larger projects or where a variety of stabilisation options are possible.

The issue of what might be an acceptable value for risk to property has been subject to considerable discussion following publication of the Pittwater Council Draft policy in 2003. This policy required a Low Risk to property using the qualitative terminology given in Appendix G of AGS (2000).

Discussion of whether this risk criterion should be modified and whether it is in accordance with community expectations was progressed by consideration of the annualised cost of damage to property as discussed in Appendix CC.

Annualised cost of property damage is a useful benchmark for comparison of different hazards. However, adoption of a dollar value based on a cost equivalent to an insurance policy premium is only considered to be appropriate where such policies can be obtained. Where insurance cannot be obtained (which unfortunately is currently the case across Australia), then experience shows that most informed home owners are likely to be risk averse as a result of appreciation of the consequences at a family or personal level, almost regardless of the likelihood of the event. This risk aversion suggests that Low Risk to Property is an appropriate recommendation for acceptable risk to the regulator for domestic dwellings which are of Importance Level 2 (as defined in the BCA, refer to Practice Note Appendix A). Alternative levels are risk are considered reasonable for structures of other Importance Levels as shown in Table C10

Table C10: AGS suggested Acceptable qualitative risk to property criteria.

Importance Level of Structure (1)	Suggested Upper Limit of Acceptable Qualitative Risk Property (2)	
	Existing Slope (3) / Existing Development (4)	New Constructed Slope (5) / New Development (6) / Existing Landslide (7)
1	Moderate	Moderate
2	Low	Low
3	Low	Low
4	Very Low	Very Low

Notes:

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

Tolerable risk levels would be one class higher (for example Moderate where Low is acceptable). Consideration should be given by regulators to adopting Tolerable risk to property for Existing Slope and Existing Development situations in a similar vein to the recommended differentiation for risk to life.

C9 RISK MANAGEMENT

C9.1 RISK MITIGATION PRINCIPLES

The principal aim of the risk mitigation measures should be to reduce risk, to engineer out uncertainty in the risk and to provide a level of risk satisfying community expectations through the regulator's criteria once properly implemented.

Not all options for risk control methods will be feasible or appropriate for each project/ circumstance.

The issue of whether residual risk (after implementation of risk mitigation measures) is tolerable or acceptable (as appropriate) should take into account the ALARP principle. ANCOLD (2003) defines ALARP (As Low As Reasonably Practicable) principle as "that principle which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on level of risk) to the improvement gained." Note that ANCOLD (2003) adopts tolerable risk criteria; where an acceptable risk criterion is adopted, then "acceptable" would replace "tolerable" in that definition. Putting this principle in another way, if risk can be reasonably and cost effectively reduced further than the acceptability criterion, then the additional risk mitigation measures should be adopted also.

Risk control measures are likely to require on-going maintenance in most, if not all, instances.

Detailed specification of the design, construction and maintenance criteria for each risk treatment measure should be appropriately specified or addressed. Feedback is essential throughout the design and construction process to enable re-evaluation of the assessment as appropriate.

C9.2 SITE SPECIFIC DEVELOPMENT CONDITIONS

Site specific development conditions need to be determined such that risk levels are reduced to satisfy the regulator's criteria. They need to take into account uncertainties and limitations of design and construction.

The development conditions may be thought of as recommendations. Recommendations are usually considered to be optional for the client to accept or reject if other factors weigh more heavily. However, the development conditions may not be an option for the owner if they form an essential component of the risk management strategy.

The practitioner should be mindful of the need to sign documentation upon completion of construction of the approved works, such as by submission to the regulator of a completion form (such as the Practice Note, Appendix D, Form G).The experienced practitioner will be aware of the implied liability associated with such forms. Therefore, as a matter of good practice for liability risk management, the practitioner needs to specify appropriate inspection and testing throughout the detailed design and construction phases so that he can sign-off on completion without unnecessary liability exposure.

AS2870 (Standards Australia, 1996) requires sites where the "foundation condition on a sloping site where downhill foundation movement or failure is a design consideration" (clause 1.7.29, AS2870) to be classified as Class P (clauses 2.1.2 and 2.4.4, AS2870). Such sites require design of footings from engineering principles. The design and construction aspects of such footings may form an integral part of the risk mitigation measures. Some general guidance is given in Appendix G of the Practice Note.

C9.3 DESIGN LIFE

The premise behind adoption of a design life may be the community expectation that a residential dwelling frequently, with appropriate maintenance, will have a functional life well in excess of 50 to 60 years. The community can reasonably expect this performance for a well designed and constructed building. Such a design life is consistent with that nominated by relevant Australian Standards and other design guides as summarised in Table C11.

Table C11: Summary of Design Life Requirements.

<table>
<tr><th>Standard or Design Guide</th><th>Title</th><th>Clause/Section</th><th colspan="3">Design Life</th></tr>
<tr><td>AS 2870–1996</td><td>Residential Slabs and Footings - Construction</td><td>1.4.2</td><td colspan="3">50 years</td></tr>
<tr><td>AS 3600–2001</td><td>Concrete Structures</td><td>4.1</td><td colspan="3">40 – 60 years</td></tr>
<tr><td>AS 3700–2001</td><td>Masonry Structures</td><td rowspan="3">Refer to
AS 1170.0 and
AS 1170.4-</td><td rowspan="3" colspan="3">[AS 1170.4 – Appendix F, Table 3.3]

<6 months ranging to >= 100 years for varying Importance Levels and varying Annual Probability of Exceedance</td></tr>
<tr><td>AS 4100–1998</td><td>Steel Structures</td></tr>
<tr><td>AS 1720.1–1997</td><td>Timber Structures</td></tr>
<tr><td>AS/NZ 4676–2000</td><td>Structural Design Requirements for Utility Services Poles</td><td>Appendix D, Table D2</td><td colspan="3">Varying according to pole construction material and exposure.
<u>Galvanised Steel</u>: up to 60 – 100 years and >100 years, down to 3 – 12 years
<u>Concrete</u>: 50 – 100 years and >100 years</td></tr>
<tr><td rowspan="6">AS 4678–2002</td><td rowspan="6">Earth Retaining Structures</td><td rowspan="6">3.4.1 and Table 3.1</td><td>Short</td><td>5 years</td><td>Temporary site works</td></tr>
<tr><td rowspan="2">Medium</td><td>10 years</td><td>Mine structures</td></tr>
<tr><td>30 years</td><td>Industrial structures</td></tr>
<tr><td rowspan="3">Long</td><td>60 years</td><td>River and marine structures, residential dwellings</td></tr>
<tr><td>90 years</td><td>Minor public works</td></tr>
<tr><td>120 years</td><td>Major public works</td></tr>
<tr><td>Concrete Masonry Association of Australia 2003/04</td><td>Design and Construction Guides:
▪ Reinforced Concrete Masonry Cantilever retaining Walls
▪ Segmental Concrete Reinforced Soil Retaining Walls
▪ Segmental Concrete Gravity Retaining Walls</td><td>Appendix C</td><td colspan="3">As above for AS 4678</td></tr>
<tr><td>Building Code of Australia</td><td>Importance Level</td><td>Table B1.2a</td><td colspan="3">Read in conjunction with AS 1170.0 and AS 1170.4</td></tr>
</table>

Usually the time-frame for the life of the structure or development, and hence the period over which the landslide risk assessment is relevant, will be based on that specified by relevant design codes or the regulator. For example, Sydney's

Pittwater Council requires a baseline period of 100 years as the context within which the geotechnical risk assessment should be made, broadly reflecting the expectations of the community for the anticipated life of a residential structure.

The practitioner should identify the maintenance required to achieve the required design life in relation to the landslide hazards. The design life should also be nominated, particularly if it is not in accordance with a specific requirement.

On-going maintenance is essential for the effectiveness of the risk control measures. Without such maintenance, the risk may change from acceptable to unacceptable with time.

C9.4 MAINTENANCE REQUIREMENTS

It is essential that the owner (and occupier) be made aware of the necessity of maintenance to provide effective and sufficient risk control over the design life. The Practitioner should advise on appropriate inspection and maintenance to control the risk. Some guidance is given in the GeoGuides (AGS 2007e)

Future owners need to be made aware of the same requirements. One method available to inform future owners is to have annotation on the Land Title so that the details referred to in the annotation become readily known to new owners. Such details should include the reference details of the risk management report and relevant design and construction records, as well as maintenance records.

C10 REPORTING STANDARDS

The report has the overriding function to document the data, assumptions and thought process used for the assessment. Such documentation facilitates subsequent review and revision. The report should be technically rigorous but must also be understood by non-technical people who are required to make decisions based on it.

The report should fully document sources of data, extent of investigations completed, assumptions made and associated limitations. The report is to be clear, unambiguous, stating outcomes from the investigations and assessment, and to make clear recommendations. If there is uncertainty, then such doubt needs to be stated in the report together with what can be done to clear up the doubt. A good principle to adopt for such documentation is to assume that the report may be tendered as an expert report to a subsequent court case. Such documentation is necessary to justify the expert's conclusions if it is not to be rejected on the basis of the "Makita Principle" which, broadly speaking, requires reasons based on facts or calculations or precedents, not simply an unsubstantiated opinion.

The report should document the best estimate results for the risk analysis, based on data available at that stage.

Table C12 presents an example checklist of issues to be addressed / considered by LRM reports. The checklist should also assist the practitioner when preparing reports to confirm that all relevant aspects have been addressed, and the regulator when evaluating reports for compliance with policy requirements.

C11 SPECIAL CHALLENGES

C11.1 MINOR WORKS

No further comment.

C11.2 PART OF THE SITE NOT ACCEPTABLE

The requirement to address other parts of the site is derived from the community expectation that unacceptable risks will be identified and addressed as part of a broad duty of care.

C11.3 ADJOINING AREAS NOT UNDER THE RESPONSIBILITY OF THE SITE OWNER

Again the broad duty of care requires these other such areas to be addressed. Adjoining areas may be under the regulator's control and require direct input.

C11.4 COASTAL CLIFFS

Stability of coastal cliffs (and bluffs) is often not associated with a rainfall trigger (as is usually the case with soil and colluvial slopes). Cliff stability is often triggered by sea conditions, such as undercutting in storms, wetting by run up and spray leading to frequent wetting and drying cycles and possibly temperature.

Access to coastal cliffs is often difficult due to the physical constraints. Nonetheless, where there are elements at risk (being either property or people, above or below the cliff) then the situation needs to be examined from both above and below to confirm the appropriate site details / features since the likelihood and consequences will be highly dependent on those features.

Table C12: Example Checklist for LRM Reports

Items	Check	Response: Yes, No, NA, NK	Comments/ Description (If used by the Regulator, then all except No answers require comment)
Site	Report Reference and date		
	Client's name		
	Site address		
	Date of site visit. Site visit by (name)		
	Weather conditions on date of visit		
Development	Will the proposed development have a degree of use or occupation by humans?		
	Does the development involve significant modification to the landscape, including cut and fill?		
	What is the landslide susceptibility classification for this slope/site? (Assuming the regulator has completed such zoning studies in accordance with AGS 2007a)		
	What is the landslide hazard or risk classification for this? (as above)		
Geology	What is the regional geology according to published maps?		
	Is the site located on surface fill or colluvium?		
	Has the geology been confirmed by inspection or investigation? If not – why not. If Yes – provide basis for confirmation.		
Geomorphology	Are there any indications of possible instability on the site or adjacent to it?		
	Does the site have distinct breaks in slope or benches?		
	Are there terracettes or other signs of creep on the site?		
	Are there signs of tunnel erosion, such as sinkholes or collapse of soils on the site?		
	Are there any tension cracks in the ground surface of the site?		
Adjacent Sites	Do adjacent sites show signs of slope instability as described above?		
	Do adjacent sites have non-retained cuts or fills close to boundaries?		
	Are there steep slopes, different geology or landforms on adjacent sites that may pose a threat to this site?		
	Will the proposed development threaten the stability of adjacent developments via cuts, fill or drainage?		
Slope	What is the overall (natural) slope of the site?		
	Are there changes (breaks) in the slope? Are these man made or natural?		
	What is the maximum slope of the site?		
	Is the slope in an area of development different to elsewhere (large sites)?		
Drainage	Does the site have deeply dissected drainage courses?		
	Is the site likely to receive significant surface water runoff from other sites upslope?		
	Does the site have dams, lakes, ponds, swamps, bogs, seeps or soaks?		
	Does the site receive drainage from road culverts or spoon drains?		
	Will any aspect of the development significantly modify the existing site drainage?		

Items	Check	Response: Yes, No, NA, NK	Comments/ Description (If used by the Regulator, then all except No answers require comment)
Erosion	Are there any severe forms of erosion including tunnels or gullies on the site?		
	Do any existing cuts and fills show signs of erosion including loss of vegetative cover?		
	Do access tracks show erosion, scouring or signs of uncontrolled runoff?		
	Will the development have the potential to change the current conditions?		
Site Cuts and Fills	Are there existing cuts and/or fill areas on the site?		*(If Yes, attach site sketch showing location, extent, height and batter angles)*
	Are there any existing unsupported cuts or fills that exceed 1.0m in vertical height from toe to crest?		
	Are batter angles steeper than 1V:2H (or 26 degrees or 50%) for any existing cut or fill in soil materials?		
	Are batter angles steeper than 1V:1H (or 45 degrees or 100%) for any existing cut in rock?		
	Do existing cuts and fills have adequate surface or subsurface drainage? Provide details.		
	Were vegetation and topsoil removed prior to filling? If No, provide details.		
	Have suitable fill materials been used and have they been properly compacted (with evidence thereof)?		
	Do any existing cuts and fills show seepage? If Yes, show details on site plan.		
Retaining Walls	Are there any existing retaining walls on the site?		*(If Yes, attach site sketch showing location, extent, height, type, condition and slope of batter above)*
	Are timber or dry rock retaining walls used for any purpose other than minor landscaping of vertical height less than 1.0m?		
	Do existing retaining walls supporting major cuts and fills appear to be unengineered?		
	Do existing retaining walls show signs of distress or movement? If Yes, provide details.		
	Do existing retaining walls have adequate drainage above and below the wall? If No, provide details.		
Groundwater	Are there discharge areas such as springs, seeps, bogs, swamps or constantly wet areas on the site or adjacent to the site?		*(If Yes, provide site sketch showing location and extent)*
	Are there bores intersecting a shallow watertable on the site?		
	Any other evidence of high groundwater levels?		
Rock	Is rock exposed on the site?		
	Do any exposed cuts have rock strata that are dipping out of the slope?		
	Do any exposed rock faces show open joints or loose boulders? If yes, provide site sketch plan and details.		
Soil Profile	Do exposed faces or existing excavations show soil profiles exceeding 1.5m vertical height?		
	Do exposed faces or existing excavations show a mixture of soil and rock, which may be landslide debris or colluvium?		
	Does the soil profile show inconsistent colouring or interbedded layers of differing materials?		

Items	Check	Response: Yes, No, NA, NK	Comments/ Description (If used by the Regulator, then all except No answers require comment)
	Does the exposed profile show imported materials or fill?		
	Is there significant evidence of yabby holes or other burrowings?		
Vegetation	Has the natural vegetation been substantially cleared from the site?		
	Does the proposed development involve significant clearing of the site?		
	Are any of the plants species on site indicators of waterlogging (eg. spiny rush, swamp gums)?		
	Is revegetation work required?		
	Do existing trees and shrubs show signs of slope instability, such as tilting or bent trunks?		
	Does any existing vegetation show signs of isolated dieback or distress?		
	Will the removal of any vegetation cause increased erosion and degradation to the adjacent area?		
Effluent and Stormwater Disposal	What type of effluent disposal system is currently used? If on site disposal, show discharge area on site plan.		
	Provide details of current discharge point for stormwater. Show location on site plan.		
	Does the geology or stability of the site suggest that septic system absorption trenches are unsuitable?		
	Are there any signs of increased waterlogging or impact from effluent of adjacent sites?		
	Is a new point/area for stormwater discharge proposed? If so, give details and show location (and extent if dispersed on site) on site plan.		
	Is a new on site effluent disposal system proposed? If Yes, give details and show proposed disposal area on site plan.		
Slope Classification	Have landslide hazards been identified and shown on relevant plan or section?		
	Has the risk to property been assessed and is the result in accordance with the acceptance criterion?		
	Has the risk to life been assessed and is the result in accordance with the acceptance criterion?		
	What is recommended to maintain or reduce the landslide risk at this site? Are detailed requirements given?		
OTHER COMMENTS			

Assessed by: ………………………………………………………… **Date:** ………………………………………………..
Company: ………

Note (1) Assessment must be completed by a suitably qualified geotechnical practitioner.

Note (2) Every clear box must be filled in with either Yes (Y), No (N), Not Applicable (NA) or Not Known (NK). Comments could cross reference to specific sections or page of the report.

Note (3) This checklist is intended to document the basic date to facilitate a landslide risk assessment in accordance with the requirements of a regulator's specific policy. The above table may require edits to be suited to local conditions and the requirements of the policy.

Note (4) A comment or full description is required for all Yes responses. Applicant should submit detailed responses in the attached report.

Acknowledgement: This table has been based on the checklist from Yarra Ranges Shire with their kind permission.

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The preparation of the Practice Note and Commentary has been carried out under the auspices of the AGS by a Practice Note Working Group comprising:

Bruce Walker, Working Group Convenor, Jeffery and Katauskas Pty Ltd
Grahame Wilson, Douglas Partners Pty Ltd
Warwick Davies, Davies Geotechnical Pty Ltd
with assistance from Robin Fell and Andrew Leventhal.

The documents prepared by the Working Group have been subject to peer review and discussion by the AGS Landslides Taskforce who have been listed in the Practice Note

The Working Group considers the Practice Note and Commentary represents a reasonable state-of-the-art at the time of preparation. Future revisions may become appropriate in the light of experience gained in application and other research/publications. Better qualitative schemes may be devised to overcome specific difficulties that come to light in due course; for example, an alternative scheme for assessment of Consequences to Property.

It is recognised that inspiration for the presentation format of the Practice Note and Commentary has been gained from ANCOLD (2003) and has resulted in adoption of a similar methodology and convention.

C13 REFERENCES

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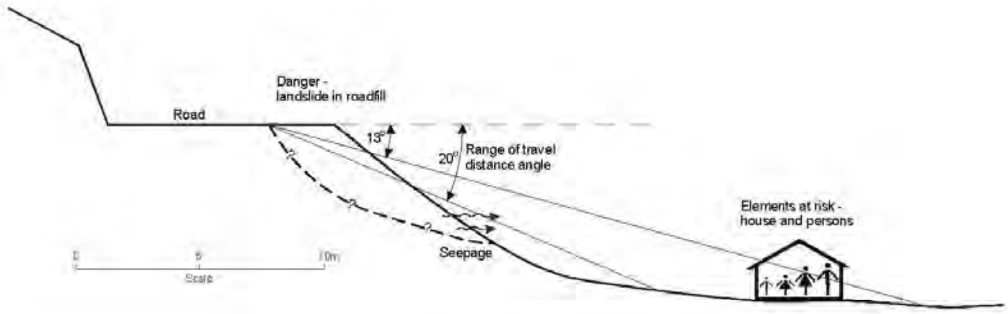
APPENDIX CA: EXAMPLES OF RISK CALCULATIONS

The following examples of risk calculations are reproduced from Fell *et al.* (2005) with kind permission from the publisher, Balkema.

Other examples are given in Lee and Jones (2004), in Roberds (2005) and in other invited papers in the Proceedings of the Vancouver 2005 Landslide Risk Management conference (Balkema).



1. SCOPE DEFINITION

Calculate the risk to persons living in the house below a road as shown in the figure. Assess the tolerability of this risk against the tolerable risk criteria shown in Table 1 and Figure 4.

2. RISK ANALYSIS

(i) Danger (Landslide) characterisation

The road was built 50 years ago, by cut and fill with a bulldozer. There was no proper compaction of the fill. The site is underlain by granitic rocks, and the fill is derived from residual soils and completely weathered granite which classifies as a silty sand. A thorough search of records has indicated that over the length of this road, which is all in similar topography, geology and climatic conditions to this fill, there have been 4 landslides in a total of 60 fills.

Based on the geometry of the fill, and the landslides which have occurred, it is assessed that the likely volume of the slide is about 1000m^3. Because of the loose, saturated nature of the fill it is anticipated that there may be a large loss of undrained shear strength on sliding ("static liquefaction") and the movement after failure is likely to be rapid.

Using empirical methods, it is estimated that the travel distance angle will be between 13° and 20°. Based on this estimate, and the geometry of the slope, it is estimated that the probability of the landslide reaching the element at risk (the house and its occupants) $P_{T:L} = 0.4$.

(ii) Frequency analysis

Assuming this fill is similar to the other 60 fills on the road and that the 50 years of the road's performance road is representative of the future, the frequency of sliding of the fill is:

$$P_L = \frac{4}{60 \times 50} = 1.33 \times 10^{-3} \text{ / annum}$$

(iii) Consequence analysis

(a) Temporal spatial probability ($P_{(S:T)}$) of the persons

Four persons live in the house. One of those persons is in the house 20 hours per day, 7 days per week; while the other three are in the house 12 hours per day, 2 days per week.

For the person most at risk:

$$P_{(S:T)} = \frac{20}{24} = 0.83$$

For the other three persons:

$$P_{(S:T)} = \frac{12}{24} \times \frac{2}{7} = 0.14$$

$$P_{(S:T)} = \frac{12}{24} \times \frac{2}{7} = 0.14 \text{ assuming no warning.}$$

(b) Vulnerability (of the persons ($V_{(D:T)}$)

Based on the volume of landsliding, its likely velocity when it hits the house, it is estimated that the vulnerability of the persons to being killed if they are in the house when the landslides hits is 0.4.

Figure 5. Example I – landsliding in road fill

(iv) Risk estimation

The annual probability of the person most at risk losing his/her life is

$$P_{(LOL)} = P_{(L)} \times P_{(T:L)} \times P_{(S:T)} \times V_{(D:T)}$$

$$= (1.33 \times 10^{-3}) \times (0.4) \times (0.83) \times (0.4) / \text{annum}$$

$$= 1.7 \times 10^{-4} / \text{annum}$$

The annual probability of four persons being in the house when it is hit by the slide (assuming the time they spend in the house overlap)

$$= (1.33 \times 10^{-3}) \times (0.4) \times (0.14)$$

$$= 0.74 \times 10^{-4} / \text{annum}$$

Since their vulnerability is 0.4, so 1.6 persons (say 1 to 2) would be killed.

3. RISK ASSESSMENT

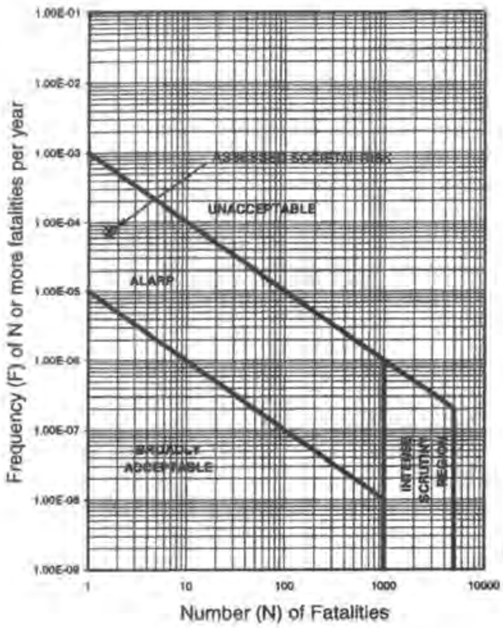
(i) Risk evaluation

(a) Individual Risk

From Table 2, the tolerable individual risk for an existing slope is 1×10^{-4}/annum; so for the individual most at risk, with $P_{(LOL)} = 1.7 \times 10^{-4}$, the risk is just in the intolerable range.

(b) Societal Risk

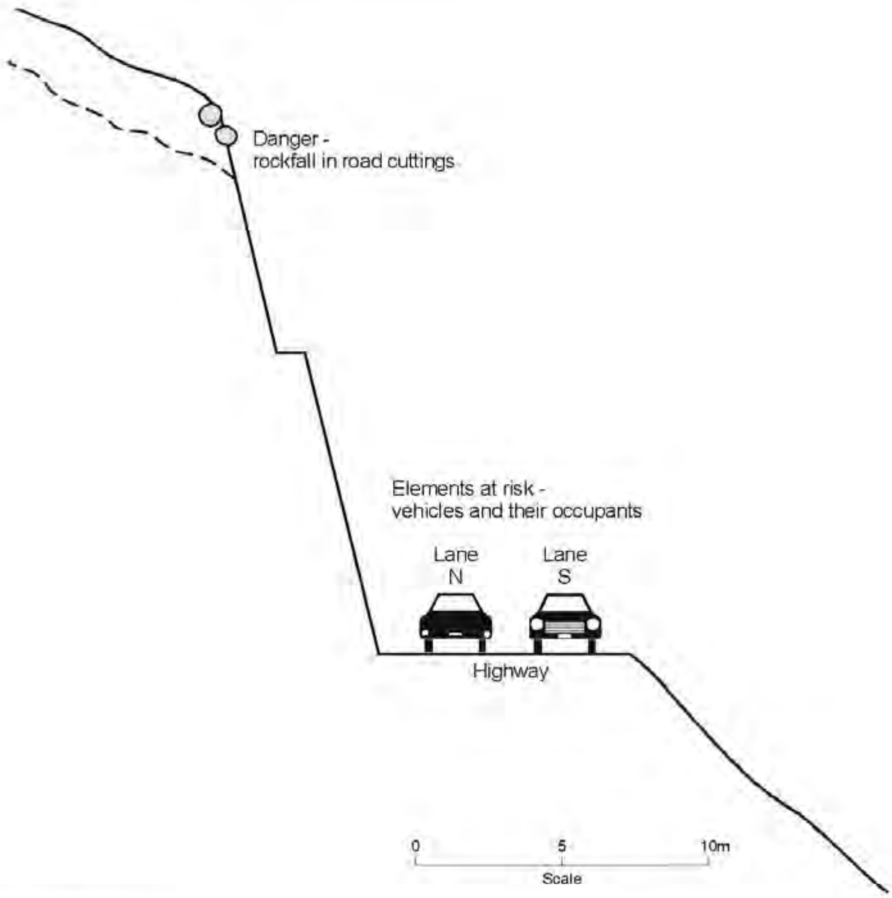
From Figure 4 reproduced below, the societal risk is below the limit of tolerability line, but in the ALARP region.



(ii) Comment

At this time, possible risk mitigation options would be considered, and the risks re-calculated. The ALARP principle might be used along with values judgements to determine a risk mitigation and/or monitoring plan, or to consider doing more geotechnical investigations to get an improved more accurate assessment of the risk.

Figure 5. *(Continued)*



1. SCOPE DEFINITION

Calculate the risk to persons travelling on the highway as shown in the figure. Assess the tolerability of this risk against the tolerable risk criteria shown in Table 1 and Figure 4. Only consider direct impact falls.

2. RISK ANALYSIS

(i) Danger (landslide) characterisation

The road to a ski resort is privately owned and was built 10 years ago. The 50 cuts in the road were constructed at relatively steep slopes, and without treatment to control weathering, erosion and shallow instability leading to rockfalls.

A thorough search of the maintenance records and observations of boulder impacts on the road surface indicated that for the average cutting on the road, there have been 2 rockfalls per annum, with boulders ranging in size from 0.5m dia to 1m dia. The cuttings are in similar topography, geology and climatic conditions. Based on the recorded boulder impacts on the road surface, and the use of rockfall simulation programs, it is assessed that 60% of rocks falling from the slope will impact on Lane N which is closest to the cut, and 10% on Lane S.

(ii) Frequency analysis

The average frequency of rockfalls for each cutting is 2 per annum. There are a total of 50 cuts along the road, giving a total of 100 rockfalls per annum or 0.27/day, the average frequency of rockfalls (N_R) onto lane, N = 0.6 x 0.27 = 0.16/day, and on Lane S, = 0.1 x 0.27 = 0.027/day.

Figure 6. Example II – rockfalls from cuttings on a highway

(iii) Consequence analysis

(a) Temporal spatial probability ($P_{(S:T)}$) of vehicles

The probability of a vehicle occupying the length of road onto which the rock falls is given by

$$P_{(S:T)} = \frac{N_V}{24} \bullet \frac{L}{1000} \bullet \frac{1}{V_V}$$

where N_V = average number of vehicles/day
L = average length of vehicle (metres)
V_V = velocity of vehicle (km/hour)

For each lane, the average number of vehicles per day over the year is 2000, the average length of the vehicles is 6 metres, and they are travelling at 60 km/hr, ignoring the width of the boulder:

For each lane

$$P_{(S:T)} = \frac{2000}{24} \bullet \frac{6}{1000} \bullet \frac{1}{60} = 0.0083$$

For a particular vehicle travelling once each day in one direction

$$P_{(S:T)} = \frac{1}{24} \bullet \frac{6}{1000} \bullet \frac{1}{60} = 0.0000042$$

(b) Vulnerability of the persons in the vehicles $V_{(D:T)}$

Based on published information and judgement, it is estimated that the vulnerability of persons in vehicles in lane N is 0.3 and in lane S, 0.15.

(iv) Risk estimation

The annual probability of the person most at risk losing his/her life by driving along the road is:

(a) For lane N

$$P_{(LOL)} = P_{(S)} \; x \; V_{D:T} = (1 - (1 - P_{(S:T)})^{N_R}) \; x \; V_{D:T}$$
$$= (1 - (1 - 0.0000042)^{0.16}) \; x \; 0.3$$
$$= 2.0 \; x \; 10^{-7} \; / \; annum$$

(b) For lane S

$$P_{(LOL)} = (1 - (1 - 0.0000042)^{0.027}) \; x \; 0.15$$
$$= 0.17 x \; 10^{-7} \; / \; annum$$

The total probability of death for the person most at risk is 2.17 x 10^{-7}/annum. For a person who only travels on the road once per year in each direction, $P_{(LOL)}$ = 5.9 x 10^{-10}/annum (2.17 x 10^{-7}/365). The total annual risk assuming each of the 2000 vehicles/day carries an average of 3 persons is 2000 x 365 x 3 x 5.9 x 10^{-10}/annum = 0.0013 persons/annum. The F-N plot has not been determined in this case.

3. RISK ASSESSMENT

(i) Risk evaluation

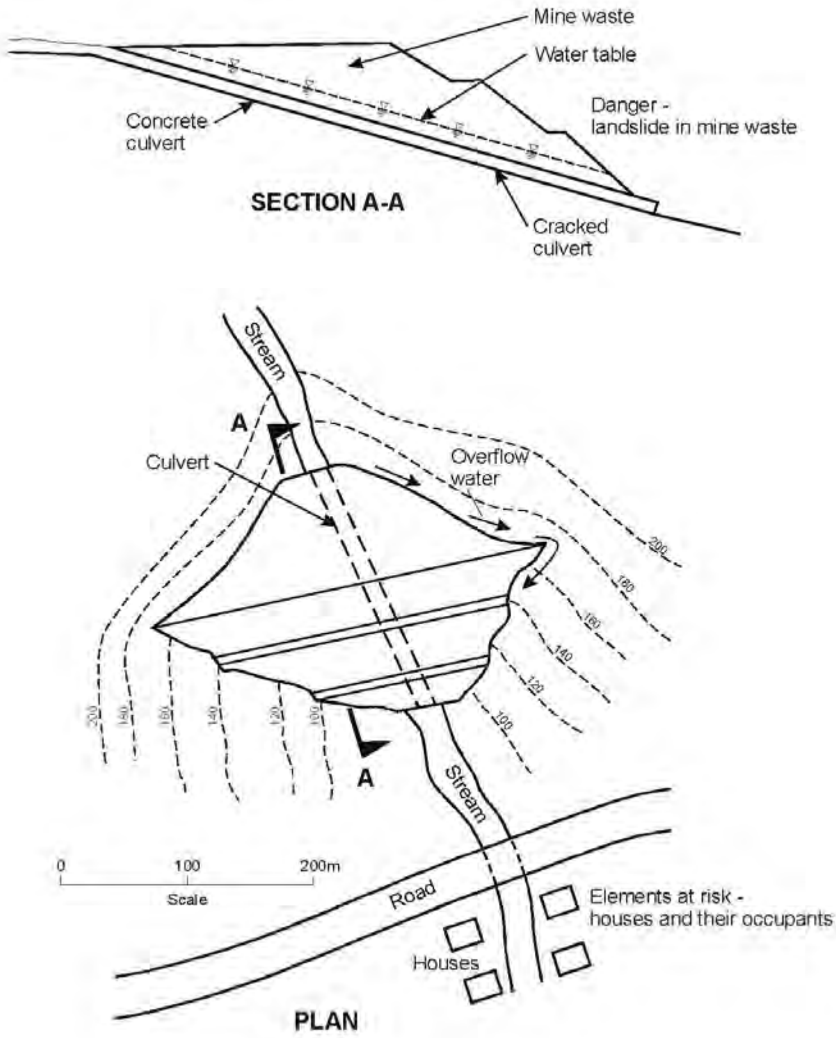
(a) Individual risk

From Table 1, the tolerable individual risk for existing slopes is 1 x 10^{-4}/annum. So for the individual most at risk, with $P_{(LOL)}$ = 2.17 x 10^{-7}/annum, the risks are within the tolerable limit. For an individual who drives on the road only once per year, the risk is 5.9 x 10^{-10}/annum, which would be acceptable. The societal risk limit of tolerability for one life lost is 10^{-3}/annum (see Figure 4). The estimated probability of one or more lives lost is about 5 x 10^{-4}/annum, near the tolerable limit.

(ii) Comment

(a) It is considered reasonable to sum the risks for all the road cuttings because the road is the responsibility of one organization.
(b) At this time, risk mitigation options would be considered. These could include engineering option to reduce the frequency of rockfalls (rock-bolting, shotcreting, scaling of loose rocks in a regulated manner); reducing the probability the rocks will fall onto the road (e.g. mesh protection over the slope, catch drain); or reducing the probability of vehicles being below a rockfall when it occurs (e.g. closing the road in periods of heavy rain if it could be demonstrated that is when most rockfalls occurred).
(c) See SOA Paper 5 for the equations for estimating risk.

Figure 6. (*Continued*)



1. SCOPE DEFINITION

Calculate the risk to persons living in the houses and travelling on the road below the mine waste dump. Assess the tolerability of these risks against individual and societal tolerable risk criteria.

2. RISK ANALYSIS

(i) Danger (landslide) characterisation

The mine waste is silty sandy gravel and gravelly silty sand coarse reject from a coal preparation plant (washery). It was deposited over 50 years by end tipping. Geotechnical site investigations, hydrological and engineering analyses have shown that:

(a) The waste is loose, and the lower part is saturated.

(b) The waste is likely to liquefy and flow liquefaction occurs for earthquakes loadings larger than 10^{-3} AEP.

Figure 7. Example III – landsliding of a mine waste dump

(c) The culvert through the waste dump exceeds its capacity and runs full for floods greater than 0.1 AEP. For floods larger than this water flows over the sides of the waste dump and leaks onto the waste material through cracks in the culvert, increasing the pore pressures in the waste.
(d) The factor of safety of the dump under static loading is about 1.2 for water table levels which are reached annually.
(e) If the dump slides even under static loading, it is likely to flow because of its loose, saturated granular nature. The probability of this occurring given sliding occurs and the resultant debris flow reaching the houses is 0.5 based on post liquefaction shear strengths, and empirical methods for estimating travel distance.
(f) The volume of the anticipated landslide and resulting debris flow is about 100,000m^3 and the debris flows are likely to be travelling at a high velocity when they reaches the road and houses.

(ii) Frequency analysis

The potential failure modes are:

(a) Culvert runs full, water leaks, saturates downstream toe, causes slide.
(b) As for (a), but a smaller slide, blocks/shears culvert, causes slide.
(c) Culvert collapses, flow saturates downstream toe, causes slide.
(d) A bigger flood, causes the culvert overflow, saturates fill, causes slide.
(e) As for (d), but scour of flowing water at toe of fill initiates slide.
(f) Rainfall infiltration, remobilizes slide.
(g) Earthquake causes liquefaction.

Based on the hydrology of the catchment, the hydraulics of the culvert, stability analyses and engineering judgement, it is estimated that the frequency of landsliding of the waste for modes (a) to (f) is 0.01/annum.

Based on an analysis of liquefaction using a Youd et al (2001) approach, and post liquefaction stability analysis, it is estimated that the frequency of landsliding for mode G is 0.005/annum.

Hence the total $P_{(L)}$ = 0.015/annum.

(iii) Consequence analysis

(a) Temporal spatial probability ($P_{(S:T)}$) of the persons in the houses, and on the road

A survey of occupancy of the houses shows that the person most at risk in one of the houses is in the house on average 18 hours/day, 365 days per year, so $P_{(S:T)}$ = 0.75.

Each house is occupied by a further 4 persons, for 10 hours/day, 325 days/year. Assuming they are all in the houses at the same time. So:

$$P_{(S:T)} \text{ for 16 persons} = \frac{10}{24} \times \frac{325}{365} = 0.36$$

Vehicles on the road travel at an average velocity of 30 km/hour as they pass by the 100 metres of road potentially affected by the debris flow. So for each time the vehicle drives along the road,

$$P_{(S:T)} = \frac{100}{30{,}000 \times 365 \times 24} = 3.8 \times 10^{-7}$$

If a vehicle travels along the road 250 times a year (such as the school bus)

$$P_{(S:T)} = 250 \times 3.8 \times 10^{-7} = 9.5 \times 10^{-5}$$

The critical vehicles for risk assessment are buses which travel 250 days/year.

(b) Vulnerability of persons ($V_{(D:T)}$)

Bases on the likely high velocity of sliding and large volume, it is estimated that the vulnerability of persons in the houses is 0.9, and in a bus, 0.8.

Figure 7. *(Continued)*

(iv) Risk estimation

The annual probability of the person most at risk losing his or her life is

$$P_{LOL} = p_{(L)}\ x\ P_{(T:L)}\ x\ P_{(S:T)}\ x\ V_{(D:T)}$$

$$P_{LOL} = (0.015)\ x\ (0.5)\ x\ (0.75)\ x\ 0.9/\text{annum}$$

$$= 5\ x\ 10^{-3}\ /\ annum$$

If all four houses are hit by the landslide, 0.9 x 16 or say 14 of the 16 persons would be killed. The annual probability that this would happen is:

$$= 0.015\ x\ 0.5\ x\ 0.36/\text{annum}$$

$$= 2.7\ x\ 10^{-3}/\text{annum}$$

If a bus with 40 persons on it is hit by the landslide, 0.8 x 40 = 32 persons would be killed. The annual probability this would happen is:

$$= 0.015\ x\ 0.5\ x\ 9.5\ x\ 10^{-5}/\text{annum}$$

$$= 7.1\ x\ 10^{-7}/\text{annum}$$

So if loss of life of persons in other vehicles on the road is ignored, the cumulative F-N pair are:

One or more lives $F = 5\ x\ 10^{-3} + 2.7\ x\ 10^{-3} + 7.1\ x\ 10^{-7} = 7.7\ x\ 10^{-3}\ /\ annum$

15 *or more lives* $= 2.7\ x\ 10^{-3} + 7.1\ x\ 10^{-7} = 2.7\ x\ 10^{-3}\ /\ annum$

33 *lives* $F = 7.1\ x\ 10^{-7}\ /\ annum$

3. RISK ASSESSMENT

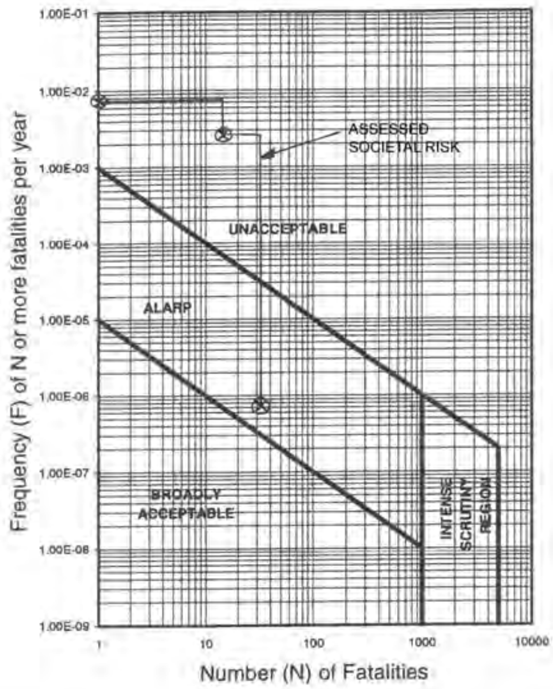


Figure 7. (*Continued*)

(i) Risk evaluation

(a) Individual risk.

The risk for the person most at risk is 5×10^{-3}/annum which is well in excess of the tolerable individual risk in Table 1.

(b) Societal risk

The three points on the F-N curve are shown below. It can be seen that the risks are well in excess of the tolerable for 1 and 15 lives, but in the ALARP range for 33 lives lost in a bus.

(ii) Comment

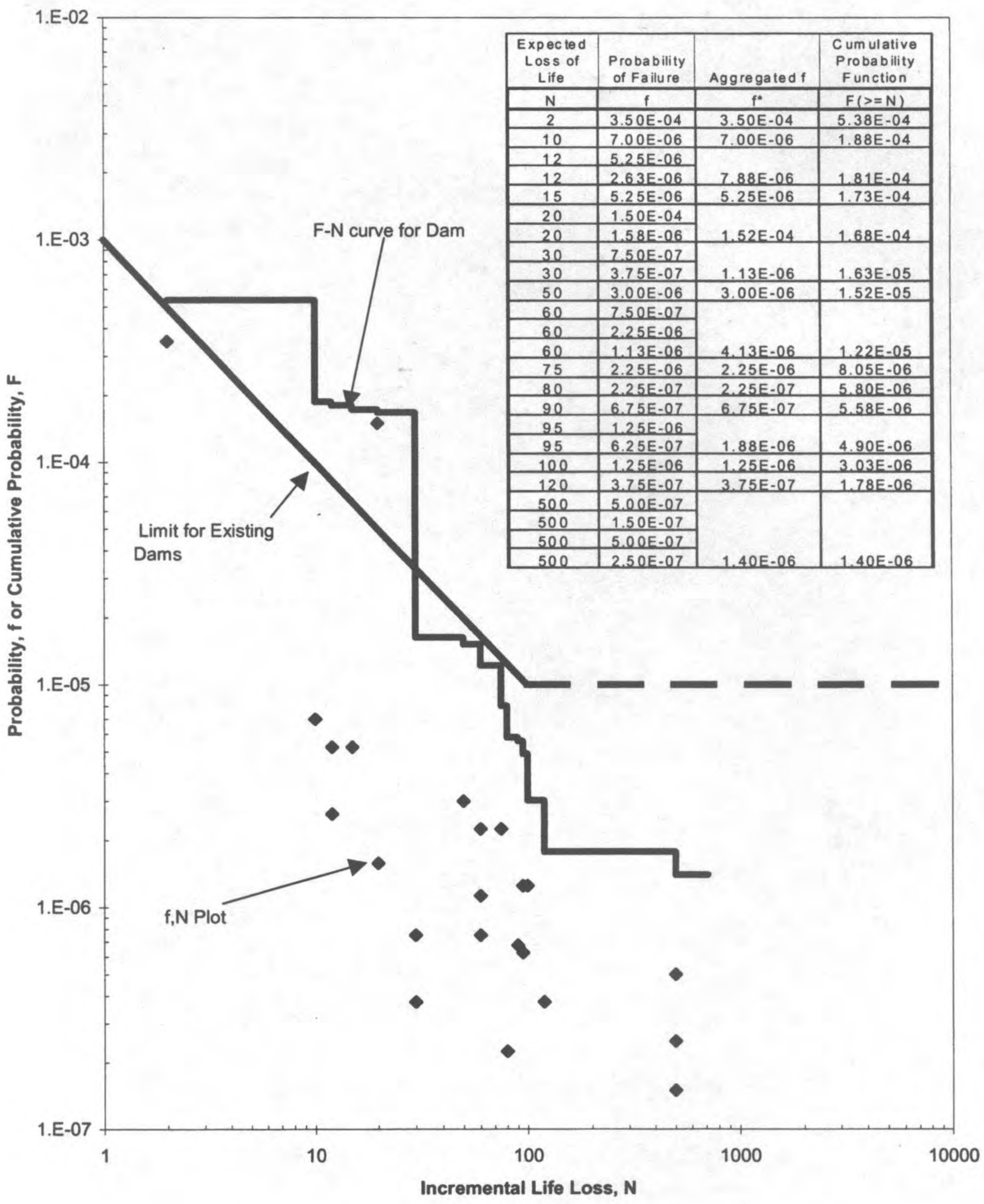
At this point, possible risk mitigation options would be considered, and the risks recalculated. The mitigation options could include reducing the probability of sliding by repairing the cracks in the culvert, controlling water which overflows when the culvert capacity is exceeded; removing and replacing the outer waste well compacted so it will not flow if it fails; adding a stabilizing berm; installing a warning system so persons in the houses can be evacuated and the road blocked to traffic when movement is detected in the waste.

Figure 7 *(Continued)*

APPENDIX CB: EXAMPLE OF SOCIETAL RISK CALCULATION

Calculation of societal risk is discussed in ANCOLD (2003) and this should be referred to if a societal risk calculation is to be performed.

An example plot is given in ANCOLD (2003) as reproduced below.



Expected Loss of Life	Probability of Failure	Aggregated f	Cumulative Probability Function
N	f	f*	F(>=N)
2	3.50E-04	3.50E-04	5.38E-04
10	7.00E-06	7.00E-06	1.88E-04
12	5.25E-06		
12	2.63E-06	7.88E-06	1.81E-04
15	5.25E-06	5.25E-06	1.73E-04
20	1.50E-04		
20	1.58E-06	1.52E-04	1.68E-04
30	7.50E-07		
30	3.75E-07	1.13E-06	1.63E-05
50	3.00E-06	3.00E-06	1.52E-05
60	7.50E-07		
60	2.25E-06		
60	1.13E-06	4.13E-06	1.22E-05
75	2.25E-06	2.25E-06	8.05E-06
80	2.25E-07	2.25E-07	5.80E-06
90	6.75E-07	6.75E-07	5.58E-06
95	1.25E-06		
95	6.25E-07	1.88E-06	4.90E-06
100	1.25E-06	1.25E-06	3.03E-06
120	3.75E-07	3.75E-07	1.78E-06
500	5.00E-07		
500	1.50E-07		
500	5.00E-07		
500	2.50E-07	1.40E-06	1.40E-06

Fig. I.1 Example Plot of F-N Line and f,N pairs

The data used to generate this plot (shown as Figure 5 in Leroi *et al.*, 2005) are presented in the following table from Leroi *et al.,* (2005).

Table 1. Data for the F-N plot in Figure 5 (Fell & Hartford 1997, after D. Bowles).

Failure Mode			Prob (Failure mode) (A)	Exposure			Incremental life loss N(C)	Prob (incremental life loss) f(A × B)	(C) × (D)
Initiating event	Dam component	Failure mechanism		Season	Day/ night	Prob-ability (B)			
Flood	Embankment	Erosion	5.00E-04	Spring	Day	0.7	2	3.50E-04	7.00E-04
				Spring	Night	0.3	20	1.50E-04	3.00E-03
	Stilling basin	Headcut	1.00E-05	Spring	Day	0.7	10	7.00E-06	7.00E-05
				Spring	Night	0.3	50	3.00E-06	1.50E-04
Seismic	Embankment	Liquefaction	1.00E-05	Summer	Day	0.075	60	7.50E-07	4.50E-05
				Summer/open	Day	0.05	500	5.00E-07	2.50E-04
				Summer	Night	0.125	100	1.25E-06	1.25E-04
				Non-summer	Day	0.525	15	5.25E-06	7.88E-05
				Non-summer	Night	0.225	75	2.25E-06	1.69E-04
	Outlet works	Rupture	3.00E-06	Summer	Day	0.075	80	2.25E-07	1.80E-05
				Summer/open	Day	0.05	500	1.50E-07	7.50E-05
				Summer	Night	0.125	120	3.75E-07	4.50E-05
				Non-summer	Day	0.525	20	1.58E-06	3.15E-05
				Non-summer	Night	0.225	90	6.75E-07	6.08E-05
Internal	Embankment	Piping	1.00E-05	Summer	Day	0.075	30	7.50E-07	2.25E-05
				Summer/open	Day	0.05	500	5.00E-07	2.50E-04
				Summer	Night	0.125	95	1.25E-06	1.19E-04
				Non-summer	Day	0.525	12	5.25E-06	6.30E-05
				Non-summer	Night	0.225	60	2.25E-06	1.35E-04
	Outlet works	Piping	5.00E-06	Summer	Day	0.075	30	3.75E-07	1.13E-05
				Summer/open	Day	0.05	500	2.50E-07	1.25E-04
				Summer	Night	0.125	95	6.25E-07	5.94E-05
				Non-summer	Day	0.525	12	2.63E-06	3.15E-05
				Non-summer	Night	0.225	60	1.13E-08	6.75E-05
		Total	5.38E-04				Total	5.38E-04	Total 5.70E-03 Risk

The method of calculation in this table is shown on the column headings. To form the table in Figure I.1, the data pairs for f (probability of incremental life loss, column D) and N (incremental life loss, column C) are sorted by N increasing as shown. Where there are two or more data pairs for the same N, the probability values are aggregated. Then to derive the Cumulative Probability Function F (>=N) the Aggregated probability values are added from the bottom upwards. The resulting F-N line is then plotted from the resulting F-N pairs.

Other example calculations and plots are given in Lee and Jones (2004) and Mostyn and Sullivan (2002).

APPENDIX CC: REVIEW OF APPENDIX G AGS(2000) AND DERIVATION OF THE REVISED RISK MATRIX

CC1 SHORT COMINGS IN APPENDIX G

Experience in use of the terminology in Appendix G of AGS (2000) since publication has shown the system to be reasonable, but that there are a number of short comings. Specifically:

- ***Indicative likelihood values were given at the centre of each "box" or level***. Consequently it could be argued that the boundaries between each level were unclear and subject to challenge. De Ambrosis & Mostyn (2004) proposed assigning the indicative likelihood values at the boundary between each level, thereby removing the uncertainty. However, this may have the result of, in effect, increasing the assessed indicative likelihood by half an order of magnitude. The revised scheme has maintained the indicative likelihood values at the centre of each box.
- ***Experience has shown that practitioners were making a qualitative assessment of likelihood based solely on the Description or Descriptor when considering risk to property*** (as discussed in C5.4.2 above). The associated indicative probability was then used for quantitative risk to life analysis, resulting in a semi quantitative assessment. For this process using the de Ambrosis and Mostyn (2004) scheme, the practitioner may have some uncertainty as to what probability value would be appropriate to use in subsequent risk to life calculations. If the procedure of making a best estimate of likelihood, as outlined in C5.4.2 is adopted, then this should not occur. The revised scheme has adopted both a Notional Boundary between each level and an Indicative Value for each level to clarify this issue where needed.
- ***Consequences to property were poorly defined.*** The descriptions given were subject to interpretation and mean different things to different people, especially if people have different experience and/or knowledge. de Ambrosis and Mostyn (2004) proposed defining the assessment of consequences in relation to Market Value. A subjective assessment of the extent of damage is still required, but for a given assessment a "best estimate" of the cost could be prepared and documented. It has been argued (in discussions) that such a methodology suffers from being a "moving target" with time, since land and property values do not move in the same ratio or at the same rate as the remedial works costs. Whilst this may be true, it is unlikely to be a real constraint in practical terms given the necessary lack of precision of the approximate cost estimates and the relatively broad scale of consequences for a given category. An unambiguous scheme is preferred, even if the input estimates may be subject to debate, and the practitioner has to work with the available "best estimate" possible at the time. With appropriate documentation, the assessment is defensible and able to be reviewed at a later date. The revised scheme has adopted both a Notional Boundary between each level of consequence and an Indicative Value for each level.
- ***Dual risk terms (eg L-M, or VL-L) were included in the matrix.*** This was done intentionally with the intention that the practitioner could use judgment within the range to assign an appropriate term, which may well be a dual term to identify uncertainty in the outcome. However, the dual terms were interpreted as another risk class. Therefore, this became confusing, particularly in relation to acceptance of risk by the regulator based on Low risk. To remove this confusion, the revised risk matrix has been amended to single risk classes for each "box" (though cell A5 may be subdivided as noted).
- ***The term Not Credible is too extreme.*** The lowest level of likelihood has a revised term BARELY CREDIBLE which is more appropriate.
- ***Some practitioners were incorrectly deriving indicative probability values for risk to life analysis.*** Appendix G Likelihood table was being used from left to right; that is a descriptor was selected from the description (or even by preference for the descriptor), and then the indicative probability assigned accordingly. This method is wrong.

  The Likelihood Table has now been reordered to indicate the correct sequence of logic from left to right and as discussed in section C5.4.2, an estimate of the probability should be made based on apparent performance, trigger probabilities etc, and then the descriptor assigned accordingly.

A number of variations have been considered for the boundaries between different levels of Likelihood, Consequence and Risk. Earlier versions were considered by the Landslide Taskforce. The following considerations have been applied in deriving the revised scheme presented in the Practice Note Appendix C which supersedes the Appendix G AGS (2000) scheme which should no longer be used.

CC2 REVISIONS TO LIKELIHOOD TABLE

The Notional Boundary between Likelihood terms has been set at '5' times the exponent. An alternative at 3 times the exponent was considered. The Taskforce favoured 3 times the exponent during discussion of the issue as this value represents the half way on a log scale as identified in Appendix G, AGS (2000).

However, it is now considered that 5 times the exponent is better on a cumulative probability basis. The advantage of the choice is particularly evident at the boundary from Almost Certain to Likely when considering the plots of Indicative Probability of Occurrence after a Given Number of Years (as shown by Figure 2 of the Practice Note for 5 times the exponent). That is, if we adopt 5 times the exponent, then the numerical cumulative probability values after any particular elapsed time period are higher than the values for 3 times so that the 5 times values look more reasonable. The relevant numerical values are included in the side table to the matrix calculation sheet presented in Tables CC1 and CC2.

CC3 REVISIONS TO CONSEQUENCE TABLE

The Consequences table has been revised to use the Approximate Cost of Damage as the basis for deriving the consequence scale and appropriate descriptors.

The Consequence scale has been adjusted based on comments received from the Taskforce. The revised version is considered to give reasonable values within the matrix. The "road testing" of this scale by the Working Group has shown the scale values to be reasonable and the risk outcomes reasonable in relation to experience and expectation.

It is considered that the nominated consequence scale is preferable to the order of magnitude scale in de Ambrosis and Mostyn (2004) as the nominated scale enables a better subdivision of risk in the Medium and Major categories (10% to 100% consequences) and shifts the descriptors towards the higher consequences, which is more realistic.

CC4 REVISED MATRIX FOR RISK TO PROPERTY

As AGS (2000) Appendix G risk matrix has been used extensively, the revisions adopted have not been major though some of the cells in the risk matrix have a revised risk level. It is considered that the revisions have enabled clarification for the use of the system. The AGS (2000) Appendix G risk matrix should no longer be used.

The risk matrix has been evaluated based on an annualised cost of property damage. The annualised cost has been calculated as:

Annualised Cost = (Market Value $) x (Likelihood pa) x (Approximate proportion of damage)

Indicative values of annualised cost are presented for the indicative values of likelihood and consequence (ie at the centre of each matrix box) on the risk matrix tables in Tables CC1 and CC2.

For illustrative purposes the Market Value (MV) has been assumed as $1,000,000 (Table CC1) or $300,000 (Table CC2) to demonstrate the annualised cost values across the risk matrix. These MV are considered to be reasonable for current indicative values in a "prime coastal location" or in "an average suburban" / "country town location" respectively. The resulting annualised costs have been used to assign the risk categories. The assigned risk values within the Matrix have also been "juggled" based on comments from the Taskforce. Summary annualised risk values are given at the bottom of Tables CC1 and CC2.

The risk level has been skewed down in favour of consequence (as discussed by de Ambrosis and Mostyn (2004)) for the lower value consequences. From the values shown on Tables CC1 and CC2 it can be seen that the annual indicative risk to property for Moderate risk increases from 2E-05 for cell E1 to 5E-04 in cells C3 and A5.

Review of earlier drafts raised two examples for consideration being cells C4 (Possible / Minor) and D1 (Unlikely / Catastrophic) which are discussed below in relation to Table CC1.

For cell C4: there is a 1 in 20 chance of up to 10% damage in a 50 year design life for the structure. That implies in a 20 house subdivision, one of them will have up to $100,000 damage (based on $1M MV) or more likely about $50,000 damage over the design life. These dollar values are not the sort of expenditure that an average family will factor into their long term financial plan. Therefore, if you are unlucky enough to be the one affected, the occurrence would be a financial "disaster". Therefore, it would more likely be considered Tolerable (given the chance of it occurring) than Acceptable. Hence Moderate Risk has been assigned based on the recommended criteria given below.

For cell D1: there is a 1 in 200 chance of 100% or more damage in a 50 year design life for the structure. That implies a total loss of $1M MV, or worse, of one house in a 200 house subdivision over the 50 year design life. In Pittwater area of Sydney, there have been three houses lost over about 32 years out of about 7600 properties in the landslide risk zone (MacGregor et al 2007); say about 1 in 2500 chance over a 32 year period. The corresponding cumulative probability over 32 years for the indicative annual probability of 10^{-4} (for row D) is about 1 in 3000, which is a reasonably similar cumulative probability. The community reaction is that this is unacceptable, and therefore cell D1 should be High Risk as adopted.

In addition, cell A5 (Almost Certain / Insignificant)has been subdivided in recognition of the practicality of hazards that result in very low value consequences and are readily accepted by most owners. This subdivision agrees with feed back from practitioners on currently adopted assessments.

Cells B4, C3 and D3 present an uncertainty / dilemma. For consistency of annualised dollar value these should be High, High and Moderate risk respectively. The lower risk levels have been adopted by skewing the risk level down in favour of consequence. That is, it is judged that higher consequences are more readily accepted or tolerated at the lower consequence values.

Therefore, based on the above considerations, the risk matrix has been revised based on the recommendation that for normal residential dwellings (Importance Level 2 structures) MODERATE risk is only TOLERABLE and that LOW risk is ACCEPTABLE as discussed in section C8.2. The risk levels have been adjusted accordingly on the Practice Note Appendix C risk matrix. The Working Group came to this view following the Taskforce discussions due to the cost impacts of actual damage on most home owners and the fact that home owners are likely to be risk averse due to the lack of insurance availability. If insurance against landslide damage was available, then an annualised cost of damage equivalent to an insurance policy cost would be a reasonable and rational division for acceptability.

It could be argued that it might be more rational to combine our Major and Medium to give a 4 level consequence scheme, with notional boundaries on the order of magnitude as per de Ambrosis and Mostyn (2004). We consider this does not allow sufficient differentiation in the middle of the matrix. The lower risk values for cells C3 and D3 of M and L, (or possibly M and M) as adopted, justify the 5 level scheme.

CC5 OTHER CONSIDERATIONS

At first comparison, the resulting risk matrix appears to be more conservative than the de Ambrosis and Mostyn (2004) version, as the risk levels for Medium and Minor the Practice Note Appendix C risk matrix are higher than theirs for the same descriptors. However, if de Ambrosis and Mostyn is adjusted so that comparison is made for the same percentage damage they are very similar. That is, Medium damage in de Ambrosis and Mostyn is the same as Minor Damage in Practice Note Appendix A matrix, and their Minor is similar to Insignificant. The resulting similarity / consistency is reassuring.

The recommended acceptance criteria for risk to property raises the question as to the possible economic impact on the community. Such a concern was raised when the Draft Pittwater policy was published for comment. Some practitioner's experience within Pittwater is that the need for more extensive stabilisation measures than previously adopted has not been as wide spread as expected. It is not clear whether this has arisen from assigning lower probability values and/or less consequences during the assessments.

Comment has been made on the comparison of risk arising between damage to houses in say Orange (market value say $300,000) and Pittwater (market value say $1,000,000). If landslides of similar likelihood cause a similar dollar value of damage, then the risk is higher for the lower market value property. This is an unavoidable outcome from a dollar value based system. There is implied acceptance of higher dollar values of damage where MV is higher. As an alternative, an index based on percentage area of property affected with a weighting factor for dwellings/structures affected has been suggested as a possibility, but not developed to a workable alternative as yet.

For some cases, such as within subdivisions or even on sites with portions having differing characteristics, it may be appropriate to subdivide the site into areas of different risk, rather than having a single risk for the entire site. Clearly the risk management requirements would similarly vary across the portions depending on the risk and nature of the development affected by the landslide.

Consideration needs to be given to the failure probability of a properly engineered and constructed stabilisation scheme. It has been suggested by some practitioners that Barely Credible would be appropriate. If construction is not rigorously supervised, then Rare may be more appropriate. Other practitioners have the view that Rare was more appropriate for the properly engineered and constructed stabilisation measures. If Rare is more realistic for most cases, then any site for which consequences of failure of the stabilisation scheme is Catastrophic would have a Moderate risk (in accordance with Practice Note Appendix C risk matrix) which is not recommended to be acceptable. To have an acceptable (low) risk, the stabilisation measures would have to have a Barely Credible likelihood of failure. To achieve a likelihood of Barely Credible, the stabilisation design should consider the extremes and still have a design Factor of Safety of greater than 1.0 for all credible combinations of loads and strengths. That is the design must satisfy a credible strength limit state. Necessary supervision and testing during construction must be specified by the designer to achieve the Barely Credible likelihood. This then enables derivation of stabilisation measures having acceptable risk.

In relation to the above it is noted that MacGregor *et al*. (2007) have concluded that the suggested annual probability of failure for all locations in Pittwater for soil cuts with wall support or fills with wall support would be $2x10^{-4}$. That is, a likelihood of UNLIKELY. As these data undoubtedly include a lot of unengineered walls, it would be reasonable to expect engineered walls to be at least one order of magnitude less likely to fail, that is would be RARE. Adoption of appropriate conservative design and supervision during construction should reasonably achieve a lower likelihood again, showing that BARELY CREDIBLE can be achieved.

APPENDIX CC: REVIEW OF APPENDIX G AGS (2000) AND DERIVATION OF THE REVISED RISK MATRIX

TABLE CC1 EVALUATION OF LEVELS OF RISK TO PROPERTY FOR MV = $1M

Assumes Consequence Cost is TOTAL COST
including consequential costs

LIKELIHOOD (pa)	Indicative Value	Notional Boundary	CONSEQUENCES (Total Cost as percentage of Market Value = $1,000,000) 1: CATASTROPHIC	2: MAJOR	3: MEDIUM	4: MINOR	5: INSIGNIFICANT		Implied Probability of Landslide within nominated Design Life — DESIGN LIFE (Years) 20	60	100
			200%	60%	20%	5%	0.5%	0.05% Note 1			
			100% $1,000,000	40% $400,000	10% $100,000	1.0% $10,000	0.1% $1,000	0.01% $100			
		1	1.0E+00	4.0E-01	1.0E-01	1.0E-02		1.0E-04	100%	100%	100%
A: ALMOST CERTAIN	1.E-01		VH 2.0E-01 $200,000	VH 6.E-02 $60,000	VH 2.E-02 $20,000	H 5.E-03 $5,000	M 5.E-04 $500	L 5.E-05 $50	1 in 1.1 *88%*	1 in 1 *100%*	1 in 1 *100%*
		5.E-02	5.0E-02	2.0E-02	5.0E-03	5.0E-04		5.0E-06	64%	95%	99%
B: LIKELY	1.E-02		VH 2.0E-02 $20,000	VH 6.E-03 $6,000	H 2.E-03 $2,000	M 5.E-04 $500	L 5.E-05 $50		1 in 6 *18%*	1 in 2.2 *45%*	1 in 1.5 *63%*
		5.E-03	5.0E-03	2.0E-03	5.0E-04	5.0E-05		5.0E-07	10%	26%	39%
C: POSSIBLE	1.E-03		VH 2.0E-03 $2,000	H 6.E-04 $600	M 2.E-04 $200	M 5.E-05 $50	VL 5.E-06 $5		1 in 50 *2.0%*	1 in 17 *5.8%*	1 in 10 *9.5%*
		5.E-04	5.0E-04	2.0E-04	5.0E-05	5.0E-06		5.0E-08	1.0%	3.0%	4.9%
D: UNLIKELY	1.E-04		H 2.0E-04 $200	M 6.E-05 $60	L 2.E-05 $20	L 5.E-06 $5	VL 5.E-07 $1		1 in 500 *0.2%*	1 in 167 *0.6%*	1 in 100 *1.0%*
		5.E-05	5.0E-05	2.0E-05	5.0E-06	5.0E-07		5.0E-09	0.1%	0.3%	0.5%
E: RARE	1.E-05		M 2.0E-05 $20	L 6.E-06 $6	L 2.E-06 $2	VL 5.E-07 $1	VL 5.E-08 $0		1 in 5000 *0.02%*	1 in 1670 *0.06%*	1 in 1000 *0.10%*
		5.E-06	5.0E-06	2.0E-06	5.0E-07	5.0E-08		5.0E-10	0.0%	0.0%	0.0%
F: BARELY CREDIBLE	1.E-06		L ≤ 2.0E-06 $2	VL 6.E-07 $1	VL 2.E-07 $0	VL 5.E-08 $0	VL 5.E-09 $0		*0.00%*	*0.01%*	*0.01%*

Showing indicative annualised cost based on Market Value

Note 1 Cell A5 is partitioned at a Consequence value of 0.1%, does not apply to rows below A.

Risk Levels	Indicative Annualised Cost	Upper Bound Annualised Cost	Risk Cell	Recommended Risk Evaluation	
VH	$2,000 to $200,000 >	$1,000,000	A1	UNACCEPTABLE	
H	$200 to $5,000	$100,000	A4	UNACCEPTABLE	
M	$20 to $500	$10,000	A5	TOLERABLE	for existing structures, but treatment to reduce risk to L should be identified and implimented as soon as practicable
L	$2 to $50	$1,000	A5 (1)	ACCEPTABLE	for new and existing slopes/works
VL	≤ $5	$50	C5	ACCEPTABLE	for new and existing slopes/works

NOTE: This table supersedes Appendix G in AGS (2000)

TABLE CC2 EVALUATION OF LEVELS OF RISK TO PROPERTY FOR MV = $300,000

Assumes Consequence Cost is TOTAL COST
Including consequential costs

CONSEQUENCES (Total Cost as percentage of Market Value = $300,000)

LIKELIHOOD (pa)	Indicative Value	Notional Boundary	1: CATASTROPHIC 200%	100% $300,000	2: MAJOR 60%	40% $120,000	3: MEDIUM 20%	10% $30,000	4: MINOR 5%	1.0% $3,000	6: INSIGNIFICANT 0.5%	0.1% $300	0.05% Note 1	0.01% $30
		1		1.0E+00		4.0E-01		1.0E-01		1.0E-02				1.0E-04
A: ALMOST CERTAIN	1.E-01		VH 2.0E-01 $60,000		VH 6.E-02 $18,000		VH 2.E-02 $6,000		H 5.E-03 $1,500		M 5.E-04 $150		L 5.E-06 $15	
		5.E-02		6.0E-02		2.0E-02		5.0E-03		5.0E-04				5.0E-06
B: LIKELY	1.E-02		VH 2.0E-02 $6,000		VH 6.E-03 $1,800		H 2.E-03 $600		M 5.E-04 $150		L 5.E-05 $15			
		5.E-03		6.0E-03		2.0E-03		5.0E-04		5.0E-05				5.0E-07
C: POSSIBLE	1.E-03		VH 2.0E-03 $600		H 6.E-04 $180		M 2.E-04 $50		M 5.E-05 $15		VL 5.E-06 $2			
		5.E-04		6.0E-04		2.0E-04		5.0E-05		5.0E-06				5.0E-08
D: UNLIKELY	1.E-04		H 2.0E-04 $60		M 6.E-05 $18		L 2.E-05 $6		L 5.E-06 $2		VL 5.E-07 $0			
		5.E-05		6.0E-05		2.0E-05		5.0E-06		5.0E-07				5.0E-09
E: RARE	1.E-05		M 2.0E-05 $6		L 6.E-06 $2		L 2.E-06 $1		VL 5.E-07 $0		VL 5.E-08 $0			
		5.E-06		6.0E-06		2.0E-06		5.0E-07		5.0E-08				5.0E-10
F: BARELY CREDIBLE	1.E-06		L ≤ 2.0E-06 $1		VL 6.E-07 $0		VL 2.E-07 $0		VL 5.E-08 $0		VL 5.E-09 $0			

Implied Probability of Landslide within nominated Design Life

DESIGN LIFE (Years)	20	60	100
	100%	100%	100%
A	1 in 1.1 **88%**	1 in 1 **100%**	1 in 1 **100%**
	64%	95%	99%
B	1 in 6 **18%**	1 in 2.2 **45%**	1 in 1.5 **63%**
	10%	26%	39%
C	1 in 50 **2.0%**	1 in 17 **5.8%**	1 in 10 **9.5%**
	1.0%	3.0%	4.9%
D	1 in 500 **0.2%**	1 in 167 **0.6%**	1 in 100 **1.0%**
	0.1%	0.3%	0.5%
E	1 in 5000 **0.02%**	1 in 1670 **0.06%**	1 in 1000 **0.10%**
	0.0%	0.0%	0.0%
F	**0.00%**	**0.01%**	**0.01%**

Showing indicative annualised cost based on Market Value

Note 1 Cell A5 is partitioned at a Consequence value of 0.1% , does not apply to rows below A

Risk Levels	Indicative Annualised Cost	Upper Bound Annualised Cost	Risk Cell	Recommended Risk Evaluation	
VH	$600 to $60,000	> $300,000	A1	UNACCEPTABLE	
H	$60 to $1,500	$30,000	A4	UNACCEPTABLE	
M	$6 to $150	$3,000	A5	TOLERABLE	for existing structures, but treatment to reduce risk to L should be identified and implimented as soon as practicable
L	$1 to $15	$300	A5 (1)	ACCEPTABLE	for new and existing slopes/works
VL	≤ $2	$15	C5	ACCEPTABLE	for new and existing slopes/works

NOTE: This table supersedes Appendix G in AGS (2000)

APPENDIX CC: REVIEW OF APPENDIX G AGS (2000) AND DERIVATION OF THE REVISED RISK MATRIX