LANDSLIDE RISK MANAGEMENT CONCEPTS AND GUIDELINES

AUSTRALIAN GEOMECHANICS SOCIETY
SUB-COMMITTEE ON LANDSLIDE RISK MANAGEMENT

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LANDSLIDE RISK MANAGEMENT CONCEPTS AND GUIDELINES

Australian Geomechanics Society, Sub-Committee on Landslide Risk Management

1 INTRODUCTION

Slope instability occurs in many parts of urban and rural Australia and often impacts on housing, roads, railways and other development. This has been recognised by many local government authorities, and others, and has led to preparation of a number of landslide hazard zoning maps for specific areas, and to the requirement by many local government councils for stability assessments prior to allowing building development. Many such assessments have been based on the paper "Geotechnical Risk Associated with Hillside Development" (Walker *et al*, 1985) which was written by a subcommittee of the Australian Geomechanics Society Sydney Group.

That paper presented a risk classification for slope instability for use in the Sydney Basin (Newcastle-Sydney-Wollongong-Lithgow). It was intended for use by geotechnical consultants, to foster uniformity in the description of risk.

It has become apparent that there are significant deficiencies in the 1985 approach, including:

- The terms are poorly defined
- There was no quantification of risk
- There was no consideration of the potential for loss of life
- The emphasis was on the impact of landsliding occurring on the property to be developed, and did not sufficiently emphasise the importance of landsliding from slopes above a property
- The method was developed for the Sydney Basin and does not necessarily apply to other geological environments. Even within the Sydney Basin there were difficulties in applying the method to areas where very large ancient landslides may be present (e.g. in Wollongong and Newcastle), and to some rock slope situations.

In recognition of this, the National Committee of the Australian Geomechanics Society set up a sub-committee to review what was needed, and establish new guidelines. During this process it became apparent that there is a need for guidance to help practitioners carry out stability assessments for housing allotments, and for use more widely in slope engineering, using risk assessment procedures.

The purpose of this guideline is:

- to establish a uniform terminology;
- define a general framework for landslide risk management;
- provide guidance on methods which should be used to carry out the risk analysis;
- provide information on acceptable and tolerable risks for loss of life.

Such guidelines also have a role in explaining to the public, regulators and the legal profession the process and limitations of Landslide Risk Management.

It is recommended that practitioners and regulators cease using the methods described in Walker *et al* (1985), and follow these guidelines.

2 FRAMEWORK FOR LANDSLIDE RISK MANAGEMENT

2.1 BACKGROUND

Landslide and slope engineering has always involved some form of risk management, although it was seldom formally recognised as such. This informal type of risk management was essentially the exercise of engineering judgement by experienced engineers and geologists. The Walker *et al* (1985) classification system included some risk assessment and treatment concepts.

Procedures for landslide risk assessment have not been standardised in the past, although the use of "risk" or "hazard" zoning maps is widespread internationally. The papers by Varnes (1984), Whitman (1984), Einstein (1988), Morgan *et al* (1992), Fell (1994), Leroi (1996), Wu, Tang & Einstein (1996), Einstein (1997), and Fell & Hartford (1997), give overviews of the subject. Papers by Fell (1992), Moon *et al* (1992) and Moon *et al* (1996) give some examples of landslide risk and hazard assessments in Australia. Flentje & Chowdhury (1999) present an example of quantification of landslide features to enable ranking of the landslides described within a database and to enable assessment of the probability of landslide reactivation.

AS/NZS 4360:1999 "Risk Management" provides a generic framework which has been used as a basis for this guideline. Fell & Hartford (1997) also consider the concepts in some detail, though it should be noted that some of the terminology in Fell & Hartford is slightly different to that adopted here.

2.2 RISK MANAGEMENT PROCESS

The Risk Management process comprises three components:

- Risk Analysis
- Risk Evaluation, and
- Risk Treatment.

Figure 1 shows the process in a flow chart form. In simple form, the process involves answering the following questions:

- What might happen?
- How likely is it?
- What damage or injury may result?
- How important is it?
- What can be done about it?

Figure 2 illustrates some of these considerations for a range of simple landslide scenarios.

It is important to recognise that part of the process involves comparing the assessed risks (of property loss and damage, and loss of life) against acceptance criteria. It is recommended that this comparison be carried out with the involvement of the client, owner and regulators.

Sections 3, 4 and 5 discuss the components of the Landslides Risk Management process in more detail.

2.3 RISK MANAGEMENT TERMINOLOGY

There is no single well established terminology in risk management. To further complicate matters, risk management terminology is often misinterpreted and misused, and "risk" means different things to various people and professions.

The ambiguity has been recognised by the International Union of Geological Sciences (IUGS). The Committee on Risk Assessment of their Working Group on Landslides has been developing specific terminology to be used internationally for use in Landslide Risk Management. This terminology, as adopted in this paper, has been designed to be consistent, so far as practicable, with national standards including the Australian New Zealand Standard AS/NZ 4360:1999 for Risk Management.

These definitions are presented in Appendix A. It is recommended that they be used. In addition, usage should be explained in reports, either by providing a copy of the definitions attached to all reports on Landslide Risk Assessment or by defining appropriate key terms in the text.

3 RISK ANALYSIS

3.1 SCOPE DEFINITION

To ensure that the analysis addresses the relevant issues, and to qualify the limits or limitations of the analysis, it is important to define:

- The site, being the primary area of interest
- Geographic limits that may be involved in the processes that affect the site

- Whether the analysis will be limited to addressing only property loss or damage, or will also include injury to persons and loss of life
- The extent and nature of investigations that will be completed
- The type of analysis that will be carried out
- The basis for assessment of acceptable and tolerable risks

It is recommended that these issues should be clearly identified and discussed with the client, preferably before beginning the analysis.

It will be at this stage that a decision should be made as to the degree of quantification that will be undertaken. It is recommended that in all cases it will be important to establish some degree of quantification, even if it is on a crude or preliminary basis. For subsequent ease of communication, it may be appropriate to express the results in a qualitative framework. For assessments involving loss of life, it is recommended that risks be quantified, even if only approximately, to allow comparison with acceptance criteria for the risk of loss of life.

Technical input can also be provided to help other parties (such as owners, accountants and lawyers) to identify:

- The various stakeholders that may be affected (including the owners, occupiers, and regulatory authorities) and their inter-relationships
- The operational and financial constraints
- Legal obligations and responsibilities

3.2 HAZARD IDENTIFICATION

3.2.1 GENERAL PRINCIPLES

Hazard (landslide) identification requires an understanding of the slope processes and the relationship of those processes to geomorphology, geology, hydrogeology, climate and vegetation. From this understanding it will be possible to:

- Classify the types of potential landsliding: the classification system proposed by Varnes (1984) as modified by Cruden & Varnes (1996) forms a suitable system. Its use is recommended and the system has been included in Appendix B for ease of reference. It should be recognised that a site may be affected by more than one type of landslide hazard e.g., deep seated landslides on the site, and rockfall and debris flow from above the site.
- Assess the physical extent of each potential landslide being considered, including the location, areal extent and volume involved.
- Assess the likely initiating event(s), the physical characteristics of the materials involved, and the slide mechanics.
- Estimate the resulting anticipated travel distance and velocity of movement.
- Address the possibility of fast acting processes, such as flows and falls, from which it is more difficult to escape.

Methods which may be used to identify hazards include geomorphological mapping, gathering of historic information on slides in similar topography, geology and climate, (e.g. from maintenance records, air photographs, newspapers, review of analysis of stability etc). Some form of geological and geomorphological mapping is a recommended component of the fieldwork stage when assessing natural landslides, which requires understanding the site whilst inspecting it. Stapledon (1995) and Baynes & Lee (1998) provide further guidance on the role of geology and geomorphology in landslide investigations.

A list of possible hazards should be developed. Consideration must be given to hazards located off site as well as on the immediate site as it is possible for landslides both upslope and downslope to affect a site. It is vital that the full range of hazards (e.g. from small, high frequency events to large, low frequency events) be included in the analysis. Often the risk is dominated by the smaller, more frequent slides. The effects of proposed development should also be considered, as these effects may alter the nature and frequency of possible hazards.

It is important that persons with training and experience in landsliding and slope processes are involved in this stage of the analysis because the omission or under/over estimation of the effects of different hazards will control the outcomes of the analysis.

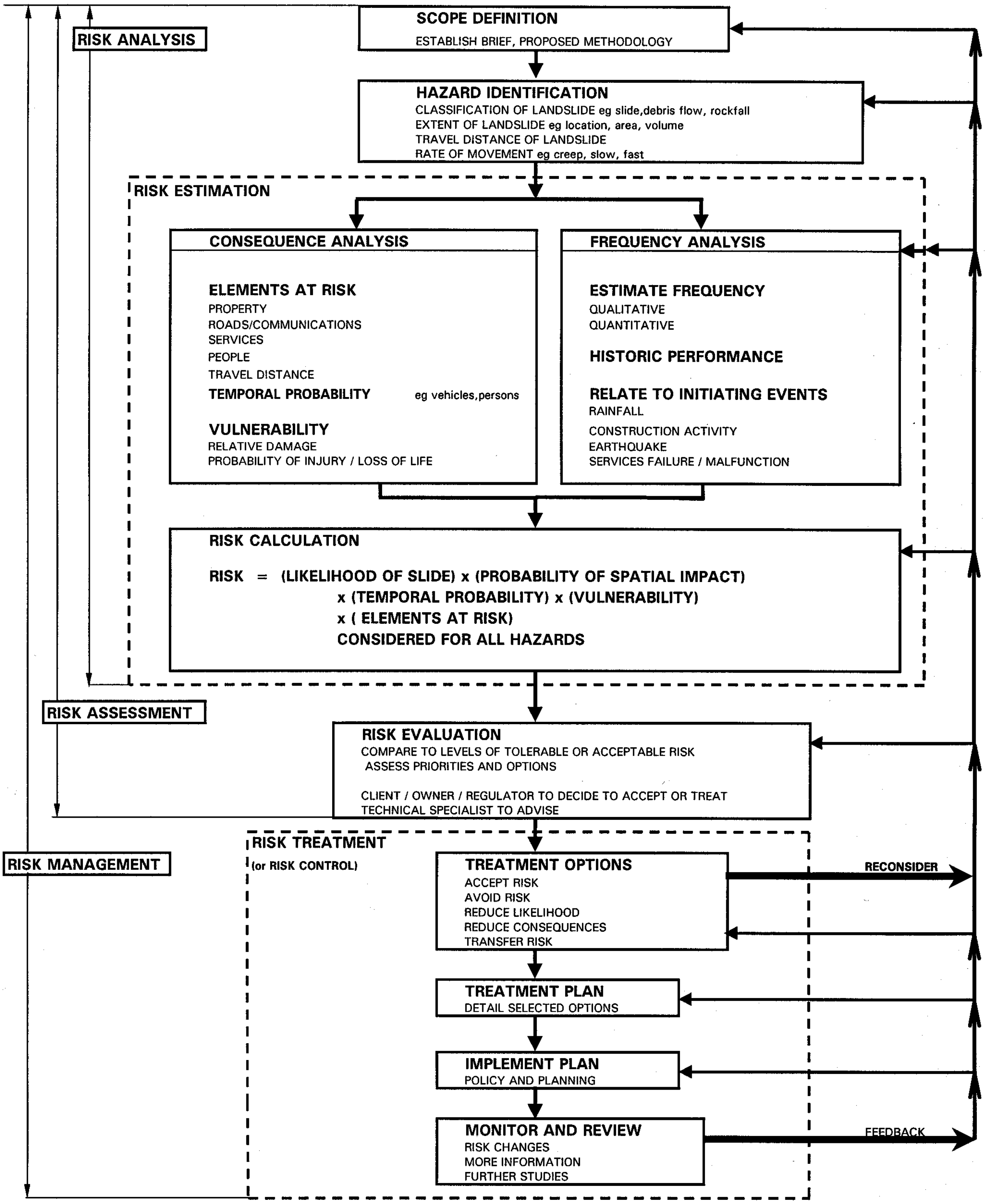

Figure 1 Flowchart for Landslide Risk Management

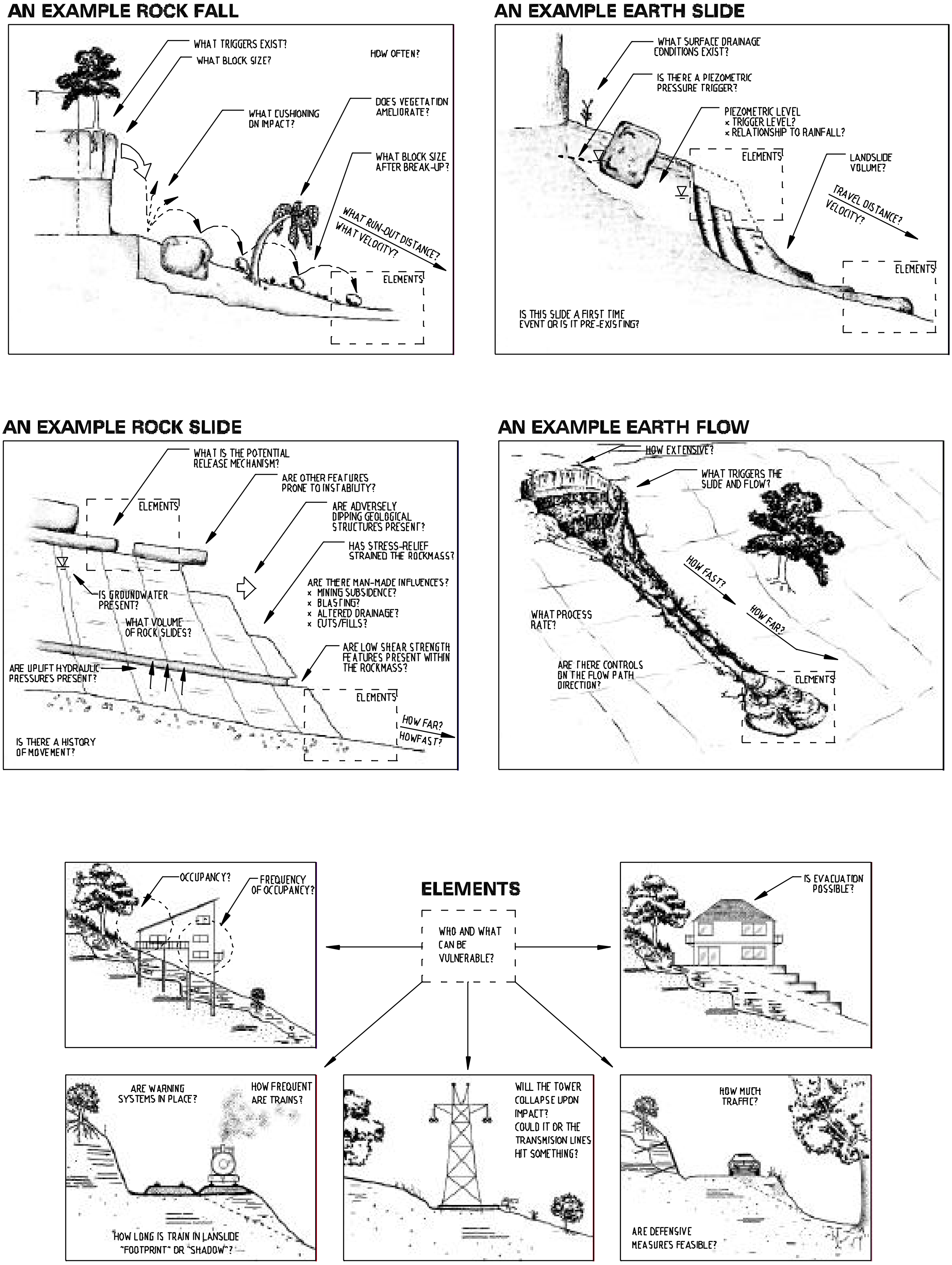

Figure 2 Examples of Landslide Risk Assessment Issues

3.2.2 ESTIMATION OF TRAVEL DISTANCE AND VELOCITY

When assessing risk arising from landsliding, it is important to be able to estimate the distance the slide mass will travel and its velocity. These factors determine the extent to which the landslide will affect property and persons downslope, and the ability of persons to take evasive action.

The travel distance depends on:

- Slope characteristics
  - Height
  - Slope
  - Nature of material
- Mechanism of failure and type of movement, such as
  - Slide, fall, topple etc.
  - Sliding, rolling, bouncing, flow
  - Strain weakening or not
  - Collapse in undrained loading (static liquefaction)
  - Influence of surface water and groundwater
  - Comminution of particles
- Characteristics of the downhill path
  - Gradient
  - Channelisation
  - The potential for depletion/accumulation
  - Vegetation

Information on travel distance from previous events on or near the site may be collected during the site inspection. Predictions of travel distance may be based on the assessed mechanism of future events.

For rotational landslides which remain essentially intact, the method proposed by Khalili *et al* (1996) can be used to estimate the displacement. This 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.

For slides which break up, and in some cases become flows, the travel distance is usually estimated from the apparent friction angle or “shadow angle” (this being the angle from the horizontal between the top of the slide source, and the toe of the slide debris, ϕ_a, as shown in Figure D1, Appendix D). The most comprehensive data is in Corominas (1996). Other data is presented in Finlay *et al* (1999), Wong & Ho (1996) and Wong *et al* (1997). The data from Finlay *et al* is reproduced in Appendix D.

These methods are only approximate, and the wide scatter of data on apparent friction angles reflects the range of topographical, geological and climatic environments, different slide mechanisms and limited quality of data from which the methods are derived If these methods are to be used for predictions, much judgement will be required and it is important to try to calibrate the methods with landslide behaviour in the study area. It is often useful to allow for a range of travel distances in the calculation and express that range in probabilistic terms. For example:

Travel Distance	**Probability**	**(determined for a particular site)**
<20m	0.2	
20m – 30m	0.6	
30m – 40m	0.2	
	1.0	

There are more sophisticated computer programs available to model flows (e.g. Hungr (1996, 1998)), but these are not yet commercially available. For boulder falls, there are commercially available computer programs, such as the Colorado Rockfall Simulation Program (CRSP).

Some of the methods described above also allow estimation of slide velocity, but in most cases it is sufficient to classify likely movement velocity in broad descriptive terms based on the slide classification, such as using the terms given in Appendix B.

3.3 FREQUENCY ANALYSIS

This is usually the most difficult part of the process and will require the majority of effort. It is, however, the key step in Risk Analysis.

The frequency of landsliding can be expressed as:

- The annual frequency of occurrence of landsliding in a nominated part of the landscape (a study area or particular slope facet) based on previous rates of occurrence.
- The probability of an existing landslide moving or a particular slope, cut or fill failing in a given period (e.g. a year), based on an understanding and analysis of the controls on stability.
- The driving forces exceeding the resisting forces in probability or reliability terms, expressing it as an annual frequency.

Different levels of site investigation may be used to assess the frequency such as

- Inspection and observation.
- Mapping (ranging from large-scale regional to small-scale structural), production of sections and interpretation of the geological, hydrogeological, geomorphological and engineering history of the site and environs to form appropriate models.
- The collection of data on history, movement, occurrence, seismicity, rainfall etc using sources such as old newspapers, eyewitness accounts, historical records, previous survey plans, published data, reports etc
- Subsurface investigations such as using pits, drilling, piezometers, monitoring etc to assess geometry, strength, groundwater conditions etc.

Each level of investigation allows increased understanding of the landslide hazards, and therefore of the frequency or probability of occurrence. Stapledon (1995) provides useful lists of investigation questions and emphasises the importance of geological models.

It is considered reasonable to form a judgement as to the hazard and frequency at any level of investigation.

Having made an assessment, if the resulting risks appear unacceptable, then further investigations may help to resolve uncertainties and to formulate an engineering solution. However, in many circumstances a reasonable engineering decision may be reached without more detailed investigations.

There are a variety of methods of estimating frequency from the disparate sets of information that may be assembled. These are detailed in Appendix C (based on Mostyn & Fell (1997) and Baynes & Lee (1998)) and may be summarised as follows:

- Observation and experience – in which the site is viewed, the geology and geomorphology mapped, and a practitioner forms a judgement as to the probability based on experience.
- Inventories – involving the statistics of large number of landslides in time and space and using the relative frequency to predict quantitatively, or ranking to predict qualitatively.
- Triggering – in which the triggering event is identified and the probability of that event equated to the probability of landslide, eg rainfall events.
- Cause and effect – in which a geomorphological understanding is expressed mathematically, eg process rates.
- Deterministic/Probabilistic – in which a deterministic stability model is generated and the inputs are expressed in probabilistic terms.

A combination of methods may be appropriate for any particular landslide hazard. The methods are usually limited by the data available at a particular level of study.

The common types of landslide hazards and the methods which have been found to be useful to assess the likely frequency are summarised in Table 1.

Hazard Scenario	**Applicable Methods** (1)
	Natural Slopes
First time slides and shallow existing slides not identified specifically	Hazard zones based on geomorphological mapping and interpretation should identify areas or slope facets more prone to failure. Frequency may be derived from inventories of the historic occurrence of landslides in a part of the landscape. Associations of occurrences with major triggers such as rainfall and seismic events may also form part of the analysis.
Rockfalls, boulder falls and debris flows	Hazard zones based on geomorphological mapping and interpretation should identify areas prone to failure and knowledge of apparent friction angles should indicate travel distances. Frequency may be derived from knowledge of the process rate within hazard zones allowing assessment of recurrence intervals. Associations of occurrences with major triggers such as rainfall and seismic events may also form part of the analysis. Note that process rate may change with time.
Deep slides in rock or soil	Geomorphological mapping of slide and environs should establish extent, geometry, controls and potential area of influence. Movement is likely to reflect piezometric response to rainfall or other source of water. Appropriate soil/rock mechanics principles will assist formulation of a geotechnical model. Frequency may be derived from regional studies of similar occurrences, geological history of site and timing of major movements, records of movement measurements, and/or recurrence interval of triggers such as rainfall patterns or seismic events in conjunction with stability analyses.
	Constructed Slopes
Cuts and fills	Geological and geotechnical mapping and inspection should establish typical performance of similar cuts or fills and information on existing failures. Data collection on the controls on stability (especially defects in rock masses) may provide statistical information for analysis. Engineering assessment of construction quality, performance history, drainage adequacy etc is useful. Frequency may be derived from statistics of similar cuts or fills, recurrence intervals of triggers such as rainfall patterns, or seismic events. Deterministic/probabilistic analyses based on geological and geotechnical data and soil/rock mechanics may be useful for very important cuts or fills in conjunction with other methods.

Note (1): Choice of applicable method may depend on whether a preliminary study or more detailed study is being carried out.

Table 1 Methods for estimating the frequency of landsliding

Many landslide assessments are carried out on the basis of initial studies only. Even if extensive investigation is carried out, assessing the probability of landsliding (particularly for an unfailed natural slope) is difficult and involves much uncertainty and judgement. In recognition of this uncertainty, it has been common practice to report the likelihood of landsliding using qualitative terms such as “likely”, “possible” or “unlikely”.

When qualitative terms are used to describe landslide likelihood, it is recommended that the basis of the assessment is explained and a judgement made of the indicative probability. For example, the basis for assessing the likelihood of landslides within an area to be unlikely may be because the assessor sees no evidence of instability on the site and is unaware of landslides on similar slopes (geology, geomorphology) in the area and elsewhere. The quality of the assessment depends on both the knowledge (the ability to recognise what is a similar slope) and experience (seen or knows about the performance over time of many similar slopes) of the assessor. In these circumstances an experienced assessor may be able to judge that the annual probability of a landslide at a site is likely to be less than 10^{-3} on the basis that:

- the assessor has knowledge of at least 100 similar slopes over an average period of 10 years;
- the slopes are likely to have been subject to some extreme rainfall events.

The example illustrates that individual stability assessments cannot be made in isolation and the role of knowledge, experience and judgement in the assessment. A different assessor, with different knowledge and experience, may arrive at a different judgement. Additionally, care is needed when assessing the long term behaviour of cut slopes in clays if only a short term history is available due to the possibility of delayed failures.

Where links between qualitative terms and indicative probabilities are made, the link should be explained and defined. An example of such a link is given in Appendix G.

Purely qualitative assessments of relative likelihood (without even an indicative link to probability) may be used to rank likelihoods of landslide hazards in a particular area. However, they do not allow the risks to be quantified and do not allow comparison of landslide risk with risks associated with other hazards (e.g. floods, fires, car accidents etc). As discussed in Section 3.5.2 at least indicative quantification of likelihood is recommended where there is concern about loss of life.

Where there is knowledge of previous slope failures it may be possible to assess frequency directly. For example: if the failure of an old roadfill behind a house is thought possible and there is knowledge of one or two road fills which have failed on average each year out of one or two thousand in similar geological, topographic, and climatic environments, an indicative annual probability of failure of 10^{-3} may be applied. Alternatively, collation of the failure history may enable a simplistic calculation, such as: If 10 fill slopes out of an estimated 250 slopes are known to have failed over a 20 year period, the indicative annual probability would be 1 in 500 ($2x10^{-3}$), assuming all slopes are similar.

If on the other hand the roadfill was new, known to be well designed and constructed, the failure might be considered less likely than might be suggested by the knowledge of fill performance and an indicative annual probability of failure of 10^{-5} might be applied on the basis that it is judged to be two orders of magnitude less likely.

Such estimates of probability may be sufficient to enable identification of potentially high risk situations, which once identified can be studied in more detail.

3.4 CONSEQUENCE ANALYSIS

The consequences may not be limited to property damage and injury/loss of life. Other consequences include:

- public outrage
- political effects
- loss of business confidence
- effect on reputation
- social upheaval
- consequential costs, such as litigation

Many of these may not be readily quantifiable and will require considerable judgement if they are to be included in the assessment. Consideration of such consequences may form part of the risk evaluation process by the client/owner/regulator.

3.4.1 ELEMENTS AT RISK

The elements at risk will include:

- Property, which may be subdivided into portions relative to the hazard being considered.
- People, who either live, work, or may spend some time in the area affected by landsliding.
- Services, such as water supply or drainage or electricity supply.
- Roads and communication facilities.
- Vehicles on roads, subdivided into categories (cars, trucks, buses).

These should be assessed and listed for each landslide hazard.

3.4.2 CALCULATION OF TEMPORAL PROBABILITY

When the elements at risk are mobile (e.g. persons on foot, in cars, buses and trains) or where there is varying occupancy of buildings (e.g. between night and day, week days and weekends; summer and winter) it is necessary to make allowance for the probability that persons (or a particular number of persons) will be in the area affected by the landslide. This is called the Temporal Probability.

For varying occupancy it is simply a calculation of the proportion of a year (0 to 1.0) which the number of persons being considered occupy the building.

Examples of how temporal probability is calculated for moving vehicles is given in Bunce *et al* (1997). Roberds *et al* (1997) give more general methods. Appendix E gives a summary of the methods for calculating the probability of a vehicle being hit by a rock fall or slide of limited width.

There is a further factor which should be considered in relation to temporal probability. This arises when a person is on or in the area affected by a landslide run out (i.e. in the travel distance region), and the question arises as to whether the person may have sufficient warning to evacuate the area.

Each case should be considered by taking account of the details of the situation. Generally persons on a landslide are more likely to observe the initiation of movement and move off the slide, than those who are below a slide which falls or flows onto them.

3.4.3 VULNERABILITY

(a) Property

The factors which most affect vulnerability of property are:

- The volume of the slide in relation to the element at risk
- The position of the element at risk, e.g. on the slide, or immediately downslope
- The magnitude of slide displacement, and relative displacements within the slide (for elements sited on the slide)
- The rate of slide movement.

It should be noted that the vulnerability refers to the degree of damage (or damage value in absolute or relative terms) which is judged to be likely if the landslide does occur.

Slides which move slowly (particularly those with a near planar, horizontal surface of rupture) may cause little damage, other than to structures which are on the boundaries of the slide and hence experience differential displacement.

The rate of movement is less important for structures than it is for loss of life, except insofar as it affects the time rate of damage, i.e. buildings on a slow moving slide (which moves every year) can be expected to have a lower vulnerability than those on a fast moving one.

It will sometimes be better to consider vulnerability of a small part of the element at risk as possible. For example, a room in a house which may be affected by a small slide 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.

(b) Persons

The following factors influence the likelihood of deaths and injuries or “vulnerability” of persons who are impacted by a landslide:

- Volume of slide
- Type of slide, mechanism of slide initiation and velocity of sliding
- Depth of slide
- Whether the landslide debris buries the person(s)
- Whether the person(s) are in the open or enclosed in a vehicle or building
- Whether the vehicle or building collapses when impacted by debris
- The type of collapse if the vehicle or building collapses.

Finlay *et al* (1999) provide some data on vulnerability derived from Hong Kong. They found that a person is very vulnerable in the event of complete or substantial burial by debris, or the collapse of a building. If the person is buried by debris, death is most likely to result from asphyxia rather than crushing or impact. If the person is not buried, injuries are much more likely than death. It should be noted that even small slides, and single boulders, can kill persons. The ability to escape from landslides relates to their speed of movement. Fast moving debris flows are particularly deadly in this respect.

Appendix F provides some more detailed data.

3.5 RISK ESTIMATION

Risk estimation may be carried out quantitatively, semi quantitatively or qualitatively. The quantitative approach is explained first below to illustrate the principles involved. Wherever possible, the Risk Estimate should be based on a quantitative analysis, even though the results may be summarised in a qualitative terminology.

3.5.1 QUANTITATIVE RISK ESTIMATION

Quantitative risk estimation involves integration of the frequency analysis and the consequences.

For property, the risk can be calculated from:

$$R_{(Prop)} = P_{(H)} \text{ x } P_{(S:H)} \text{ x } V_{(Prop:S)} \text{ x } E \qquad (1)$$

where

$R_{(Prop)}$ is the risk (annual loss of property value)
$P_{(H)}$ is the annual probability of the hazardous event (the landslide)
$P_{(S:H)}$ is the probability of spatial impact by the hazard (i.e. of the landslide impacting the property, taking into account the travel distance) and for vehicles, for example, the temporal probability
$V_{(Prop:S)}$ is the vulnerability of the property to the spatial impact (proportion of property value lost)
E is the element at risk (e.g. the value or net present value of the property)

For loss of life, the individual risk can be calculated from:

$$R_{(DI)} = P_{(H)} \text{ x } P_{(S:H)} \text{ x } P_{(T:S)} \text{ x } V_{(D:T)} \qquad (2)$$

where

$R_{(DI)}$ is the risk (annual probability of loss of life (death) of an individual)
$P_{(H)}$ is the annual probability of the hazardous event (the landslide)
$P_{(S:H)}$ is the probability of spatial impact by the hazard (e.g. of the landslide impacting a building (location) taking into account the travel distance) given the event
$P_{(T:S)}$ is the temporal probability (e.g. of the building being occupied by the individual) given the spatial impact
$V_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

A full risk analysis involves consideration of all landslide hazards for the site (e.g. large, deep seated landsliding, smaller slides, boulder falls, debris flows) and all the elements at risk.

For total risk (whether for property or for life) the risk for each hazard for each element is summed.

It is useful to report the risk calculations as:

(1) Property:
  - Annual total risk
  - Annual probability and consequences for the different levels of hazards, e.g. for a specified hazard there may be different probabilities for different amounts of movement;

Hazard	Annual Probability	Consequences $
(a) 0.1m movement	0.1	5,000
(b) 1m movement	0.01	25,000
(c) 3m movement	0.001	200,000

(a) and (b) might represent different scales of damage, while (c) might represent complete loss of the property.

(2) Loss of life:
   - annual individual risk for the person most at risk i.e. the annual probability that this person may be killed
   - annual total risk (summing the individual risk of all the persons affected by the landslide hazards)
   - the societal risk i.e. the pairs of probability that N or more persons may be killed, versus the number of persons killed (N). Such a table should also identify the landslide hazard relating to each pair.

Appendix I discusses some issues regarding the calculation of the risk from a number of hazards using an example of risk along a highway.

3.5.2 SEMI QUANTITATIVE AND QUALITATIVE RISK ESTIMATION FOR PROPERTY

When considering the risk to property, it may be useful to use qualitative terms to report the results of the analysis, rather than quantitative values. The risk calculation may be completed quantitatively or by the use of qualitative terms.

A semi quantitative analysis (where the likelihood is linked to an indicative probability) or a qualitative analysis may be used.

- As an initial screening process to identify hazards and risks which require more detailed consideration and analysis.
- When the level of risk does not justify the time and effort required for more detailed analysis.
- Where the possibility of obtaining numerical data is limited such that a quantitative analysis is unlikely to be meaningful or may be misleading.

The terms to be used should be defined for a specific project. Appendix G gives an example of qualitative terminology which should be used unless a site specific terminology is needed. These terms are not consistent with those in the Walker *et al* (1985) paper. Whilst other terms may be used if required, there will be advantages in adoption of Appendix G by most practitioners. For some assessments it may be useful to develop a simpler system with less terms for likelihood, consequence and risk. Whatever terminology is to be used, terms must be defined and this may be done by attaching as an appendix of definitions to the report. In some cases dual descriptors for likelihood, consequence and risk can be useful to reflect the uncertainty in the estimates.

3.5.3 SEMI QUANTITATIVE RISK ESTIMATION FOR LOSS OF LIFE

Risk for loss of life should be quantified because the risk acceptance criteria used in society for loss of life are quantified. To assist in this regard, some indicative annual probabilities are given for the likelihood terms in Appendix G, so that some consistency between loss of life and property risk calculation can be retained. The probabilities are only approximate, and one order of magnitude either way from the indicative values would be possible.

In some situations where risk of loss of life is identified as an issue in semi quantitative analysis, it may be possible to take immediate risk reduction measures without further assessment. If this is not possible it is recommended that quantitative analysis be carried out. Quantification will enable the risk to be evaluated against risk acceptance criteria (Section 4.2.2). Loss of life as a result of landslides often involves combinations of events. Quantifying the risk may involve multiplying together many quantified judgements. It is good practice to explain the basis of the judgements and the uncertainty involved.

The important first stage for the landslide risk assessor is to identify whether loss of life is an issue. If the assessor has little experience of the hazard or of quantitative risk analysis, it may be useful to involve another person with more experience of these areas.

3.6 SENSITIVITY ANALYSIS AND UNCERTAINTY

As estimates made for an analysis will be imprecise, sensitivity analyses are useful to evaluate the effect of changing assumptions or estimates. Wherever possible, such assumptions and the resulting sensitivity should be stated or expressed in the report. Variation in the estimate of risk by one or two orders of magnitude, or perhaps three orders of magnitude at low risks, will not be uncommon. The resulting sensitivity may aid judgement as to the critical aspects requiring further investigation or evaluation.

If a sensitivity analysis is not carried out, it is good practice to explain some of the limitations and uncertainty in the risk estimates. In detailed studies, the uncertainty can be formally modelled.

4 RISK ASSESSMENT / RISK EVALUATION

Risk Evaluation is the final step in the Risk Assessment process (Figure 1).

4.1 OBJECTIVE AND PROCESS OF RISK EVALUATION

Risk analysis alone has limited benefits and it is normal to carry the process to the next stages of risk evaluation and risk treatment.

The main objectives of risk evaluation are usually to decide whether to accept or treat the risks and to set priorities. The decision is usually the responsibility of the owner/client/regulator. Involvement of those indirectly affected is desirable. Non- technical clients may seek guidance from the risk assessor on whether to accept the risk. In these situations, risk comparisons, discussion of treatment options and explanation of the risk management process can help the client make their decision.

Risk evaluation involves making judgements about the significance and acceptability of the estimated risk. Evaluation may involve comparison of the assessed risks with other risks or with risk acceptance criteria related to financial, loss of life or other values. Risk evaluation may include consideration of issues such as environmental effects, public reaction, politics, business or public confidence and fear of litigation. In a simple situation where the client/owner is the only affected party, risk evaluation may be a simple value judgement. In more complex situations, value judgements on acceptable risk appropriate to the particular situation are still made as part of an acceptable process of risk management.

Risk acceptance for a quantitative analysis is likely to be based, at least partly, on quantitative values with consideration of the uncertainty and defensibility of the assessment. For a qualitative or semi quantitative assessment the acceptance criteria may be qualitative. Explaining the acceptance criteria adopted facilitates review and may make the judgement more defensible. With the wide variety of issues which need to be considered, and the varying attitudes to risk, it may not be possible to pre-define acceptance criteria.

Assessment of the risk may involve consideration of values such as:

(a) For property or financial losses:

- Cost benefit ratio
- Financial capability
- Annualised cost
- Corporate impact
- Frequency of accidents

(b) For loss of life

- Individual risk
- Societal risk, e.g. as frequency versus number of deaths (known as f-N) or cumulative frequency versus number of deaths (known as F-N) criteria. (Refer to Fell & Hartford (1997) for further explanation and examples).
- Annualised potential loss of life
- Cost to save a life.

It is desirable, if not essential, that the risk analyst be involved in the decision making process because the process is often iterative, requiring assessment of the sensitivity of calculations to assumptions, modification of the development proposed and revision of risk mitigation measures.

4.2 ACCEPTABLE AND TOLERABLE RISKS

It is important to distinguish between acceptable risks which society desires to achieve, particularly for new projects, and tolerable risks which they will live with, even though they would prefer lower risks. This applies to both property and loss of life.

4.2.1 PROPERTY

Factors that affect an individual’s attitude to acceptable or tolerable risk will include:

- Resources available to treat the risk.
- Whether there is a real choice, e.g. can the person afford to vacate a house despite the high risk.
- The individual's commitment to property and relative value.
- Age and character of the individual.
- What exposure the individual has had to risk in the past, especially risk associated with landslides.
- Availability of insurance.
- Regulatory or policy requirements.
- Whether the risk analysis is believed.

Acceptable and tolerable risks for property loss and damage must be determined by the client, owner and if appropriate, regulator.

Appendix G gives an example of qualitative risk terms which could be used for risk to property. Other terms may be defined and used. The "example and implications" shown in Appendix G are a hypothetical example for a particular situation. It is for the owner/client and regulating authority (e.g. local government council) to assess what is acceptable. The amount of investigation required, and cost of treatment, is not necessarily related to the level of risk. For example, if the high risk is associated with a single large boulder on a steep slope, it may be relatively easy to remove the boulder and reduce the risk.

4.2.2 LOSS OF LIFE

There are no established individual or societal risk acceptance criteria for loss of life due to landslides in Australia or internationally. It is possible to provide some general principles and some information from other engineering industries, e.g. petrochemical and dams. These can be used to obtain a general appreciation of the risks and to suggest some acceptance criteria for landslides. Nonetheless, the decision on risk acceptability (or tolerance) must be made by the client, owner, regulator and those at risk, where they are an identified group.

There are some common general principles that can be applied when considering tolerable risk criteria. These are taken from IUGS (1997):

(a) The incremental risk from a hazard should not be significant compared to other risks to which a person is exposed in everyday life.
(b) The incremental risk from a hazard should, wherever reasonably practicable, be reduced: i.e. the As Low As Reasonably Achievable (ALARA) principle should apply.
(c) If the possible loss of large numbers of lives from a landslide incident is high, the probability that the incident might actually occur should be low. This accounts for society's particular intolerance to incidents that cause many simultaneous casualties and is embodied in societal tolerable risk criteria.
(d) Persons in society will often tolerate higher risks than they regard as acceptable when they are unable to control or reduce the risk because of financial or other limitations.
(e) Higher risks are likely to be tolerated for existing slopes than for planned projects, and for workers in industries with hazardous slopes, e.g. mines, than for society as a whole.

These principles are common with other hazards such as Potentially Hazardous Industries (PHI) and dams. There are other principles that are applicable only to risks from slopes and landslides:

(f) Tolerable risks are thought to be higher for naturally occurring landslides than those from engineered slopes, but this has not been proven.
(g) Once a natural slope has been placed under monitoring, or risk mitigation measures have been executed, the tolerable risks may approach those of engineered slopes.
(h) Tolerable risks may vary from country to country and within countries, depending on historic exposure to landslide hazard, the system of ownership and control of slopes and natural landslide hazards, and the risks a person is exposed to in everyday life.

There is reasonable consistency between the PHI and various dam authorities in acceptable individual risk criteria. These are summarised in Appendix H, which is taken from Fell & Hartford (1997). Based on this, it might reasonably be concluded that the following criteria apply to constructed slopes.

Situation	Suggested Tolerable Risk for Loss of Life
Existing Slopes	10^{-4} person most at risk 10^{-5} average of persons at risk
New Slopes	10^{-5} person most at risk 10^{-6} average of persons at risk

Acceptable risks are usually considered to be one order of magnitude smaller than the above Tolerable Risks.

The situation for societal risk is more contentious. Some organisations (e.g. Great Britain Health and Safety Executive, and NSW Department of Planning) only use qualitative terms for societal risk.

The Australian National Committee on Large Dams have criteria which were published in ANCOLD (1994). These are under review. The most recent published draft of the review is shown in Appendix H. This is subject to further review. In the absence of other information this might be used as an indication of the societal risks.

Fell & Hartford (1997) gives some details on the use of societal risk plots when considering individual and societal risk criteria. It should be remembered that (taken from IUGS 1997):

(i) Estimates of risk are inevitably approximate and the acceptance criteria should not be considered as absolute values. The assessed risk may span the acceptance criteria. Judgement is needed as to whether that may be acceptable in the light of the defensibility of the assessment. Variations by up to, say, one order of magnitude may be appropriate for the acceptance criteria for particular circumstances.

(ii) Tolerable risk criteria, such as those published for PHI and dams, are themselves not absolute boundaries. Society shows a wide range of tolerance to risk and the risk criteria are only a mathematical expression of general societal opinion.
There may be cases where risks higher than the upper limit tolerable risk criteria are adopted, because the ALARA principle, or Best Practical Technology (BPT), indicates it is not practicable to further reduce the risk.

(iii) It is often useful to consider several different tolerable risk criteria (e.g. individual and societal risk, cost to save a life, etc).

(iv) It must be recognised that risk estimation is only one input to the decision process. Owners, society and regulators will also consider political, social and legal issues in their assessments and may consult the public affected by the hazard.

(v) The risk can change with time because of natural processes and development. For example:
  - Removal of debris from slopes can lead to reduction in risk
  - Removal of vegetation by natural processes (e.g. fire or human intervention) can lead to an increase in risk
  - Construction of roads on, below or above a slope may increase the probability of landsliding and/or the elements at risk, and hence the risk.

(vi) Extreme events should be considered as part of the spectrum of events. Inclusion of extreme events is important in assessing the triggers (landslides, earthquake), the size of the landslide and the consequences. However, often it is the smaller, more frequent, landslides that contribute most to risk, not the extreme event.

4.3 SUMMING THE RISK FROM SEVERAL HAZARDS

Care needs to be taken when assessing the risk from individual slopes, to take into account whether the risk needs to be considered along with the risk from other slopes to which the public is exposed. For example, it is usually more relevant to sum the risk from all landslides for persons travelling on a highway between their home and destination, than to only consider the risk from one slope.

Appendix I provides some insight to this issue.

4.4 LIMITATIONS, BENEFITS AND DEFENSIBILITY OF RISK ASSESSMENT

There are a number of limitations to risk assessment for slopes and landslides:

- The judgement content of the inputs to any analysis may result in values of estimated risks with considerable inherent uncertainty.

- The variety of approaches that can reasonably be adopted to analyse landslide risk can result in significant difference in outcome for the same situation when considered separately by different practitioners.
- To complete a risk assessment, time and skills are required to make and interpret the field observations and develop the insight and understanding of the slope process applicable. Greater experience and understanding of the processes will improve the reliability of the analysis.
- Revisiting an analysis can lead to significant change due to increased data, a different method or changing circumstances.
- The consequences of an inability to recognise a significant hazard will be underestimation of the risk.
- The results of an assessment are seldom verifiable, though peer review can be useful.
- The methodology is currently not widely accepted and thus there sometimes is an aversion to its application.
- It is possible that the cost of the analysis may outweigh the benefit of the technique in making a decision, especially where complex detailed sets of data are required. However, this is really an issue of matching the analysis method to the scale of problem and the resources available.
- There may be difficulty in completing a quantitative analysis due to the difficulty of obtaining sufficient data for reliable evaluation of the frequency of events.
- It is difficult to accurately analyse risk for low probability events.

Most of the above limitations are inherent in any approach to assessing landslides. Risk analysis has the benefit of encouraging a systematic approach to a problem and promoting a greater understanding of consequences. In many situations, an indicative estimate of the probability of a hazard (such as using those given in Appendix G) and an assessment of the consequences can be readily conducted.

As noted above, some of the inputs to the analysis may be largely judgmental. Even so, it is important that the judgement be “defensible” by reporting the basis or logic on which the judgement is based. Thus the “defensibility” of the assessment becomes a measure of the quality of the information available/used and the methods used. Methods for developing defensible subjective probability assessments are discussed by Roberds (1990).

5 RISK MANAGEMENT / RISK TREATMENT

Risk Treatment is the final stage of the Risk Management process and provides the methodology of controlling the risk.

5.1 RISK TREATMENT

At the end of the evaluation procedure, it is up to the client or policy makers to decide whether to accept the risk or not, or to decide that more detailed study is required. The landslide risk analyst can provide background data or normally acceptable limits as guidance to the decision maker, but as discussed above, should not be making the decision. Part of the specialist advice may be to identify the options and methods for treating the risk.

5.1.1 TREATMENT OPTIONS

Typical options would include:

- ***Accept the risk;*** this would usually require the risk to be considered to be within the acceptable or tolerable range.
- ***Avoid the risk;*** this would require abandonment of the project, seeking an alternative site or form of development such that the revised risk would be acceptable or tolerable.
- ***Reduce the likelihood;*** this would require stabilisation measures to control the initiating circumstances, such as reprofiling the surface geometry, groundwater drainage, anchors, stabilising structures or protective structures etc. After implementation, the risk should be acceptable or tolerable, consistent with the ALARA principle.
- ***Reduce the consequences;*** this would require provision of defensive stabilisation measures, amelioration of the behaviour of the hazard or relocation of the development to a more favourable location to achieve an acceptable or tolerable risk.
- ***Monitoring and warning systems***; in some situations monitoring (such as by regular site visits, or by survey), and the establishment of warning systems may be used to manage the risk on an interim or permanent basis. Monitoring and warning systems may be regarded as another means of reducing the consequences.
- ***Transfer the risk;*** by requiring another authority to accept the risk or to compensate for the risk such as by insurance.
- ***Postpone the decision;*** if there is sufficient uncertainty, it may not be appropriate to make a decision on the data available. Further investigation or monitoring would be required to provide data for better evaluation of the risk

and treatment options. It should be made clear that this situation is temporary while the further work being carried out. During this period, the situation is being temporarily accepted even though the risks may not be acceptable or tolerable.

The relative costs and benefits of the options need to be considered so that the most cost effective solutions, consistent with the overall needs of the client, owner and regulator, can be identified. Combinations of options or alternatives may be appropriate, particularly where relatively large reductions in risk can be achieved for relatively small expenditure. Prioritisation of the options is likely to assist with selection.

Guidance on good engineering practice for hillside design and construction is given in Appendix J which has been adapted from Walker *et al* (1985).

5.1.2 TREATMENT PLAN

A treatment plan for each option may be used to explain how the option will be implemented.

Where possible, each plan needs to identify responsibilities for each party during and after implementation, the extent of work required, cost estimates and programme, performance measures and the expected outcome. The level of detail will depend on the priority for the option and stage of the evaluation process. There may be interaction between a number of parties to resolve all of these issues, such as the planner, the owner and the regulator.

A treatment plan may include an emergency plan, which should establish from the outset the sequence of events that will be initiated if warning signs indicate a potential instability. It should establish what the different warning levels will be and, depending on which level is achieved,

- establish the hierarchy for dealing with the emergency and the lines of communication that will be used,
- send out the appropriate warnings to those who may be affected,
- ensure the warnings are understood in the context of the risk and
- ensure that personnel, materials and equipment will be available within an acceptable time for dealing with the instability.

An effective treatment plan aids implementation and should be developed on an explicit basis where possible. However, for some cases a treatment plan may not be necessary.

5.2 MONITOR AND REVIEW

Monitoring of the treatment plan and risks is needed to ensure the plan is effective and that changes in circumstances do not alter risks. Factors which affect the likelihood and consequences may change with time. Thus, ongoing review of the treatment is essential for the management process.

Construction of stabilisation measures may yield further data or show that assumed subsurface models were not appropriate. Hence, during construction it is reasonable for the design to be reviewed and the risks to be reassessed.

It is essential to reconsider all stages of the analysis, assessment and prioritisation as the treatment plan evolves and is implemented. The results of monitoring may enable feedback for reassessment of the risks.

6 HAZARD ZONING

Risk assessment principles can be applied to producing maps showing hazard zones. This involves:

- Generation of maps summarising observations on geology, geomorphology, and in particular the distribution of landslide processes including use of local records, interpretation of photographs and field observations. Engineered slopes should also be identified. This is known as the process map.
- Collection of information on the landslide hazards identified from the above.
- Analysis of potential hazards including first time slides, deep seated existing slides, rock debris flows, cuts and fills.
- Identification of areas that may be impacted by such hazards.
- Transformation of the process map to a hazard map identifying the potential for spatial impact and probability of occurrence for all the hazards.

The maps should be accompanied by a description of each class of landslide hazard.

To convert this to risk, the person using the zoning maps would need to define the elements at risk, identify which hazards affect the elements, estimate temporal probability and the vulnerability, and then calculate the risk.

Where the elements at risk are not well defined, it is usually impractical to prepare a risk zoning map. Where an area is already developed, risk zoning may be practical for risk to property. An example of a study involving quantitative hazard and risk zoning in Australia is provided by Leiba, Baynes & Scott (in press).

7 CONCLUSION AND RECOMMENDATION

It is considered that risk assessment methods for landslides and slopes have been developed to a level that they are applicable in practical terms and form a useful tool to complement engineering judgement. The level of analysis possible will vary from project to project and may increase as further data becomes available.

It is recommended that these guidelines be adopted and that the use of the methods outlined in Walker *et al* (1985) be discontinued.

Risk assessment reports should define the terminology and approach being adopted. In some cases this may be achieved in the text of the report. In other cases it may be useful to include one or more of the following:

- Appendix A (entire or extract);
- List or table explaining terms used for likelihood, consequences and risks. Appendix G is an example;
- Appendix J;
- Figure 1.

Use of material from this paper will simplify presentation and establish some uniformity of practice; the above pages have been annotated with a footnote to facilitate their direct reuse.

The development of risk assessment methods is continuing, and practitioners should refer to published literature for improvements in the methods.

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APPENDIX A

DEFINITION OF TERMS

INTERNATIONAL UNION OF GEOLOGICAL SCIENCES WORKING GROUP ON LANDSLIDES, COMMITTEE ON RISK ASSESSMENT

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Hazard – A condition with the potential for causing an undesirable consequence (*the landslide*). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Elements at Risk – Meaning the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Probability – The likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes. Probability is expressed as a number between 0 and 1, with 0 indicating an impossible outcome, and 1 indicating that an outcome is certain.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Likelihood – used as a qualitative description of probability or frequency.

Temporal Probability – The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Risk Analysis – The use of available information to estimate the risk to individuals or populations, property, or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification, and risk estimation.

Risk Estimation – The process used to produce a measure of the level of health, property, or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis, and their integration.

Risk Evaluation – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk, and the implementation, or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Management – The complete process of risk assessment and risk control (*or risk treatment*).

Individual Risk – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental, and other losses.

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Tolerable Risk – A risk that society is willing to live with so as to secure certain net benefits in the confidence that it is being properly controlled, kept under review and further reduced as and when possible.

In some situations risk may be tolerated because the individuals at risk cannot afford to reduce risk even though they recognise it is not properly controlled.

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Note: Reference should also be made to Figure 1 which shows the inter-relationship of many of these terms and the relevant portion of Landslide Risk Management.

APPENDIX B

LANDSLIDE TERMINOLOGY

The following provides a summary of landslide terminology which should (for uniformity of practice) be adopted when classifying and describing a landslide. It has been based on Cruden & Varnes (1996) and the reader is recommended to refer to the original documents for a more detailed discussion, other terminology and further examples of landslide types and processes.

Landslide:
The term ***landslide*** denotes "the movement of a mass of rock, debris or earth down a slope". The phenomena described as landslides are not limited to either the "land" or to "sliding", and usage of the word has implied a much more extensive meaning than its component parts suggest. Ground subsidence and collapse are excluded.

Classification of Landslides:
Landslide classification is based on Varnes (1978) system which has two terms: the first term describes the material type and the second term describes the type of movement.

The material types are ***Rock***, ***Earth*** and ***Debris***, being classified as follows:-

The material is either rock or soil.

Rock:	is "a hard or firm mass that was intact and in its natural place before the initiation of movement".
Soil:	is "an aggregate of solid particles, generally of minerals and rocks, that either was transported or was formed by the weathering of rock in place. Gases or liquids filling the pores of the soil form part of the soil".
Earth:	"describes material in which 80% or more of the particles are smaller than 2mm, the upper limit of sand sized particles".
Debris:	"contains a significant proportion of coarse material; 20% to 80% of the particles are larger than 2mm, and the remainder are less than 2mm".

The terms used should describe the displaced material in the landslide before it was displaced.

The types of movement describe how the landslide movement is distributed through the displaced mass. The five kinematically distinct types of movement are described in the sequence ***fall***, ***topple***, ***slide***, ***spread*** and ***flow***.

Figure B1 gives examples of the types of movement.

Combining the two terms gives classifications such as Rock fall, Rock topple, Debris slide, Debris flow, Earth slide, Earth spread etc.

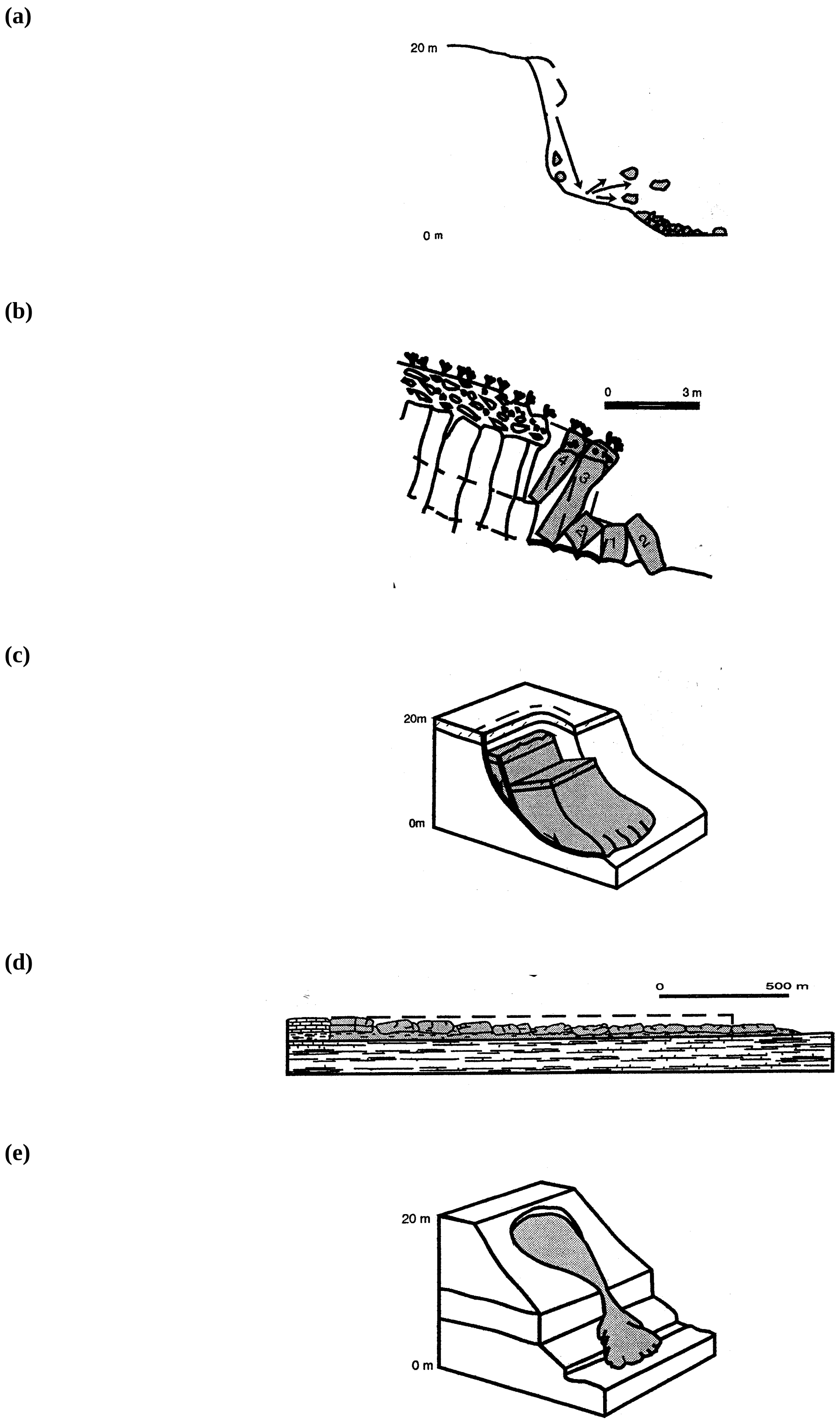

Figure B1 Types of movement: *(a) fall, (b) topple, (c) slide, (d) spread, (e) flow.* broken lines indicate original ground surfaces; arrows show portions of trajectories of individual particles of displaced mass; scales indicative for example chosen only (from "Landslides", copyright Registration Number 427735 of Consumer and Corporate Affairs, Canada, by kind permission of the author D.M. Cruden).

The name of a landslide can become more elaborate as more information about the movement becomes available. To build up the complete identification of the movement, descriptors are added in front of the two-term classification using a preferred sequence of terms. The suggested sequence provides a progressive narrowing of the focus of the descriptors, first by time and then by spatial location, beginning with a view of the whole landslide, continuing with parts of the movement, and finally defining the materials involved. The recommended sequence, as shown in Table B1, describes activity (including state, distribution and style) followed by descriptions of all movements (including rate, water content, material and type). Definitions of the terms in Table B1 are given in Cruden & Varnes (1996).

Second or subsequent movements in complex or composite landslides can be described by repeating, as many times as necessary, the descriptors used in Table B1. Descriptors that are the same as those for the first movement may then be dropped from the name.

For example, the very large and rapid slope movement that occurred near the town of Frank, Alberta, Canada, in 1903 was a *complex, extremely rapid, dry rock fall – debris flow.* From the full name of this landslide at Frank, one would know that both the debris flow and the rock fall were extremely rapid and dry because no other descriptors are used for the debris flow.

The full name of the landslide need only be given once; subsequent references should then be to the initial material and type of movement; for the above example, "the rock fall" or "the Frank rock fall" for the landslide at Frank, Alberta.

Activity

State	**Distribution**	**Style**
Active	Advancing	Complex
Reactivated	Retrogressive	Composite
Suspended	Widening	Multiple
Inactive	Enlarging	Successive
Dormant	Confined	Single
Abandoned	Diminishing	
Stabilised	Moving	
Relict		

Description of First Movement

Rate	**Water Content**	**Material**	**Type**
Extremely rapid	Dry	Rock	Fall
Very rapid	Moist	Earth	Topple
Rapid	Wet	Debris	Slide
Moderate	Very Wet		Spread
Slow			Flow
Very slow			
Extremely slow			

Note: Subsequent movements may be described by repeating the above descriptors as many times as necessary. These terms are described in more detail in Cruden & Varnes (1996) and examples are given.

Table B1 Glossary for forming names of landslides

Landslide Features:

Varnes (1978, Figure 2.1t) provided an idealised diagram showing the features for a *complex earth slide – earth flow,* which has been reproduced here as Figure B2. Definitions of landslide dimensions are given in Cruden & Varnes (1996).

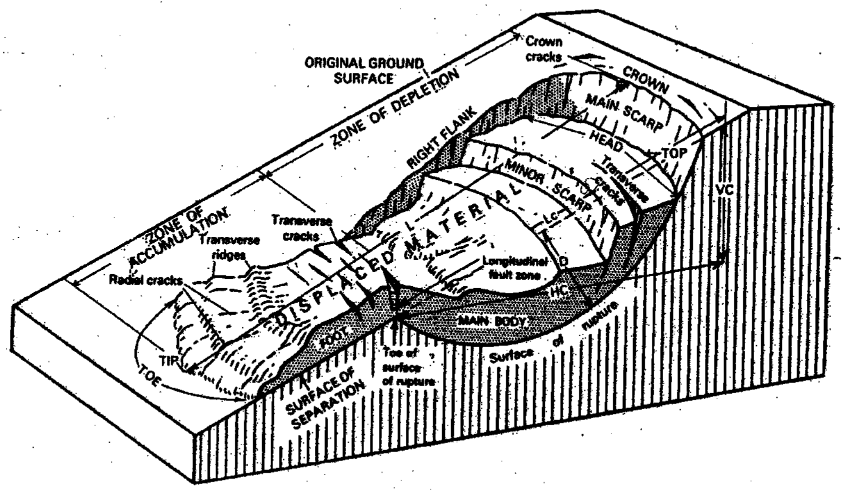

Figure B2: Block Diagram of Idealised Complex Earth Slide-Earth Flow (Varnes 1978, Figure 2.1t)

Rate of Movement:
Figure B3 shows the velocity scale proposed by Cruden & Varnes (1996) which rationalises previous scales. The term "creep" has been omitted due to the many definitions and interpretations in the literature.

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity	Probable Destructive Significance
7	Extremely Rapid			Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
		5×10^{3}	5 m/sec	
6	Very Rapid			Some lives lost; velocity too great to permit all persons to escape
		5×10^{1}	3 m/min	
5	Rapid			Escape evacuation possible; structures; possessions, and equipment destroyed
		5×10^{-1}	1.8 m/hr	
4	Moderate			Some temporary and insensitive structures can be temporarily maintained
		5×10^{-3}	13 m/month	
3	Slow			Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
		5×10^{-5}	1.6 m/year	
2	Very Slow			Some permanent structures undamaged by movement
		5×10^{-7}	15 mm/year	
	Extremely **SLOW**			Imperceptible without instruments; construction **POSSIBLE WITH PRECAUTIONS**

Figure B3: Proposed Landslide Velocity Scale and Probable Destructive Significance

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APPENDIX C

FREQUENCY ANALYSIS
A REVIEW OF THE METHODS AVAILABLE TO ESTIMATE THE PROBABILITY OF LANDSLIDING

(1) Assessment of the historic record of landsliding

In the simplest form this method consists of recording the number of landslides which occur each year in an area of interest, such as along a road or railway. It may be extended to include the type of sliding, e.g. on natural or constructed slopes, or on cuts and fills, and characteristics such as volume or area of landsliding. Chowdhury & Flentje (1998) discuss the use of a database to record such data in a systematic way.

Examples of this approach are given in: Morgan *et al* (1992) where the historic record of landsliding was used to assess the magnitude and probability of debris flows; Fell, Finlay & Mostyn (1996(a)), where records collected by the Geotechnical Engineering Office of Hong Kong were used to estimate the annual average probability of cut, fill, and retaining wall failures; examples which include rockfall are described in Moon *et al* (1992), Cruden (1997) and Moon *et al* (1996).

This method can be a useful way of estimating the average annual probability of landsliding, but usually does not discriminate between individual slopes and does not allow for the dependence of the landsliding on triggering factors, such as rainfall. A long representative period of record is needed, and even then there are potentially difficulties because of the non-linear relationship between the triggering event, e.g. rainfall and number of landslides, the influence of development, changes in vegetation, and runon and runoff of water. However, it can be a very valuable method for smaller landslides (e.g. in road cuts and fills), and as a check on more sophisticated methods.

(2) Empirical methods based on slope instability ranking system

These are methods which are devised by expert groups, and often are used for prioritising remedial works on roads, railways, and other constructed slopes. Examples are given in Koirala & Watkins (1988) and GEO (1995) for Hong Kong, and Mackay (1997) for railways. However, these are usually based on judgement for the factors to be included, may not be properly calibrated and therefore are often inaccurate, and are unable to quantify the probabilities. Flentje & Chowdhury (1999) indicate ranking of a landslide database on the basis of derived parameters such as volume, frequency or "hazard".

(3) Relationship to geomorphology and geology

This method is based on the principle put forward by Varnes (1984) that the past and present are guides to the future:

- hence it is likely that landsliding will occur where it has occurred in the past, and
- landslides are likely to occur in similar geological, geomorphological and hydrological conditions as they have in the past.

The method is the one most widely used in hazard and risk zoning studies, and is often performed with a judgemental, experience based approach, without quantification of the probability. Hence, the outputs are in qualitative terms, e.g. low, medium, high hazard or risk. Baynes & Lee (1998) discuss the role of geomorphology in landslide risk assessment.

The general issues in estimating the probability of landsliding in this method are discussed in Hutchinson (1988), Leroi (1996), and Soeters & Van Westen (1996). Some examples for specific projects are given in Siddle *et al* (1991), Carrera *et al* (1991 and 1992). Some details are given in Fell & Hartford (1997). Examples of where this method has been developed to a semi-quantitative level include Moon *et al* (1992) and Fell *et al* (1996(b)).

The use of geomorphology, geology and landslide records can be extended to include other factors such as slope angle, slope drainage, slope age, presence of groundwater, and evidence and history of instability; provided records are kept of such data. This was done by Finlay (1996) and reported in Fell *et al* (1996(a)) using the Geotechnical Engineering Office's (GEO) data for 3,000 landslides in Hong Kong. In this approach the probability of landsliding for individual slopes was assessed, using factors calibrated on the past performance of the slopes over a 10 year period.

In some cases quantification was possible on a reasonably rigorous basis (e.g. for slopes or cuts) but in others, a considerable degree of judgement was necessary. It also became apparent that the quality of the data was a limitation, because of difficulties in obtaining information on a slope failures in difficult conditions (e.g. rain, darkness etc).

(4) Relating the historic record of landsliding to rainfall intensity and duration and frequency

These methods relate the historic occurrence of landsliding to rainfall intensity and duration, and in some cases, to antecedent rainfall. They have been used in rural areas (e.g. by Siddle *et al*, 1985, Kim *et al* 1992) to delineate rainfall which is likely to lead to extensive landsliding.

Lumb (1975(a)), Brand *et al* (1984) and Premchitt *et al* (1994) have developed methods for relating rainfall intensity for 1 hour to 24 hours, with and without antecedent rainfall, to predict the incidence of landsliding in constructed and natural slopes in Hong Kong. These, and the Kim *et al* (1992) methods have largely been developed to determine what rain conditions lead to extensive landsliding, so that warning systems can be instituted to keep the population away from the high hazard areas in such times. Fell *et al* (1988) carried out a similar study for Newcastle, NSW. Flentje & Chowdhury (1999) have related reactivation of existing landslides in an area of North Wollongong to antecedent rainfall and have derived Antecedent Rainfall Percentage Exceedance Time (ARPET) curves which give a measure of the probability. Threshold values of antecedent rainfall have been suggested for movement and “catastrophic failure”.

Where the population of slopes is known, these methods can crudely estimate the average annual probability of any slope failing.

These methods generally have their uses, but are unable to allow discrimination between the relative probability of landsliding for different slopes within the population. In addition, they rely on the principles outlined in (3) above which may or may not apply, and need to be carefully applied to determine the critical rainfall duration and period of antecedent rainfall. For example, Premchitt *et al* (1994) have found that the 1 hour intensity is the most critical factor for Hong Kong’s relatively small, shallower slides in constructed and natural slopes and that antecedent rainfall was not important, but Fell *et al* (1988) found that the prediction was best using antecedent rainfall up to 30 to 60 days for the larger, deeper landslides in their study area in Newcastle (NSW). Flentje & Chowdhury (1999) found 90 day antecedent rainfall gave a good predictor for reactivation of existing landslides in North Wollongong.

Finlay (1996), reported in Finlay *et al* (1997), has extended these approaches to relate the number of landslides to the rainfall intensity, duration and antecedent rainfall, using records of landsliding in Hong Kong taken by the Geotechnical Engineering Office, and very detailed rainfall data (5 and 15 minute data was used).

The concept developed allows the prediction of the number of landslides which may occur for say a 1 in 100 AEP rain event, within a given area. However, in this case (and probably more generally), the incidence of landsliding varies non linearly with rainfall and is markedly affected by data from a small number of heavy rain events. This makes the extrapolation uncertain. In addition, it becomes apparent that a critical feature is the areal extent of the rain event, yet such data is seldom available. As for the other examples of this method, it is not possible to assess the probability of landsliding of individual slopes, only the average (assuming the population of slopes is known).

The methods described above have been extended by some authors to include the slope of the ground, potential depth of sliding, and piezometric pressure parameters which are limited to rainfall and infiltration. Examples are given in Keefer *et al* (1987), Omura & Hicks (1992). These methods have the apparent virtue of properly modelling the sliding process, e.g. for shallow sliding leading to debris slides. However, they invariably oversimplify the piezometric pressure component of the analysis, which in fact dominates the calculation, by for example:

- using constant infiltration rates and/or permeability
- ignoring the non-linear effects of partial saturation on infiltration
- ignoring the heterogeneity of the slope – e.g. ignoring layering in the soil, root holes, infiltration from the rock below the soil, etc.
- not modelling 3-dimensional (or sometimes even 2-dimensional) effects across and up and down slope
- not modelling the rainfall intensity-duration properly.

These simplifications are necessary for analysis, but in the process of simplification, reality may be lost.

A further difficulty is that the analytical models sometimes do not model the actual slide mechanisms properly, and are really modelling detachment (sliding), not the landslide flow initiation which is often what is critical for the slope.

Unless such methods are calibrated by field performance of the slopes, which in effect lumps the variables together, they are not any better, and are probably worse, than the apparently less rigorous methods described above.

An important factor which should be considered is the relationship of landsliding to the ability of the surface drainage system to carry rainfall runoff. This is particularly important for road and rail line fills if the culverts do not have a high capacity. In these cases the frequency of sliding may directly relate to the annual exceedance probability of the drainage system being over-taxed.

(5) Direct assessment based on expert judgement

There are few examples of this approach in the literature. A form of this approach has been used in portfolio risk assessments for dams in Australia and USA. In this case the average annual failure rate (by slope instability) of dams is known from historic data (Foster *et al* 1998), and the probability for an individual dam is assessed from this as a starting point, allowing for steepness of the slope (or factor of safety), slope deformation, seepage etc.

(6) Modelling the primary variable e.g. piezometric pressure

The method outlined in Fell *et al* (1991) is an example of this approach, where piezometric levels recorded over some period (in that case 3 years) are related to rainfall, and the probability of various piezometric levels being reached is assessed by analysing the modelled piezometric levels for the period of record (in that case 100 years). Other examples are given in Haneberg (1991) and Okunushi & Okumura (1987).

The method is ideal in principle for a single, relatively deep-seated landslide. However, in reality it is difficult to achieve any accuracy in the modelling because of the complex infiltration processes involved, heterogeneity of the soil and rock in the slope, and groundwater seeping into the slide from below. It is also apparent that a lengthy period of calibration (years) is likely to be necessary, to experience a range of rainfall and piezometric conditions.

(7) Application of formal probabilistic methods

There has been extensive research into formal probabilistic analysis of slopes. The state of the art for these calculation methods is well established, and the methods can be applied with confidence. Mostyn & Fell (1997), Li 1991, 1992(a) and 1992(b) give overviews. The application of such methods should include consideration of the following aspects to give realistic outcomes:

- surface and subsurface geometry
- hydrogeology
- variation of pore water pressures with time
- material strengths
- discontinuities in rocks, including persistence
- spatial variation of parameters.

In addition, the problem must be viewed as a system of potential failure surfaces rather than just a single, sometimes critical, failure surface. Various "levels" of data on uncertainty should be used, these range from pure judgemental to statistically robust parameter estimation.

It should be noted that often the greatest area of uncertainty is the prediction of pore pressures in a slope, and no degree of sophistication on the uncertainty in shear strength and geometry can give realistic answers unless a defensible, properly modelled assessment is made of pore pressures. In other cases, properties such as defect persistence are most critical and must be modelled correctly.

This is difficult to achieve and leads back to the more subjective methods or to a combination of subjective and analytical methods. Roberds (1990) describes methods for developing defensible subjective probability assessments.

Quantitative and semi-quantitative methods for estimating the probability of landslides are well developed and are equally valid.

The method to be used will depend on the level of the study, e.g. feasibility or detailed design; and on whether the slope is constructed or natural. Quantitative methods are more applicable to constructed slopes, where detailed investigation, laboratory testing and monitoring/prediction of pore pressures is possible. For natural slopes, semi-quantitative methods are more likely to be applicable.

APPENDIX C

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APPENDIX D

METHOD FOR ESTIMATING TRAVEL DISTANCE OF LANDSLIDES – FOR SLIDES WHICH BREAK UP, AND FOR FLOWS

The following information is from Finlay *et al* (1999).

Allowance should be made for the likely mechanics of movement. It should be noted that for fills which are well compacted (and hence dilatant in shear), the larger values of the apparent friction angle $Ø_a$ or F (=tan $Ø_a$) are likely to apply, while for fills which may collapse and flow, the low values of F are likely to apply. Risk calculations should allow for the uncertainty in the estimated F (=tan $Ø_a$) value.

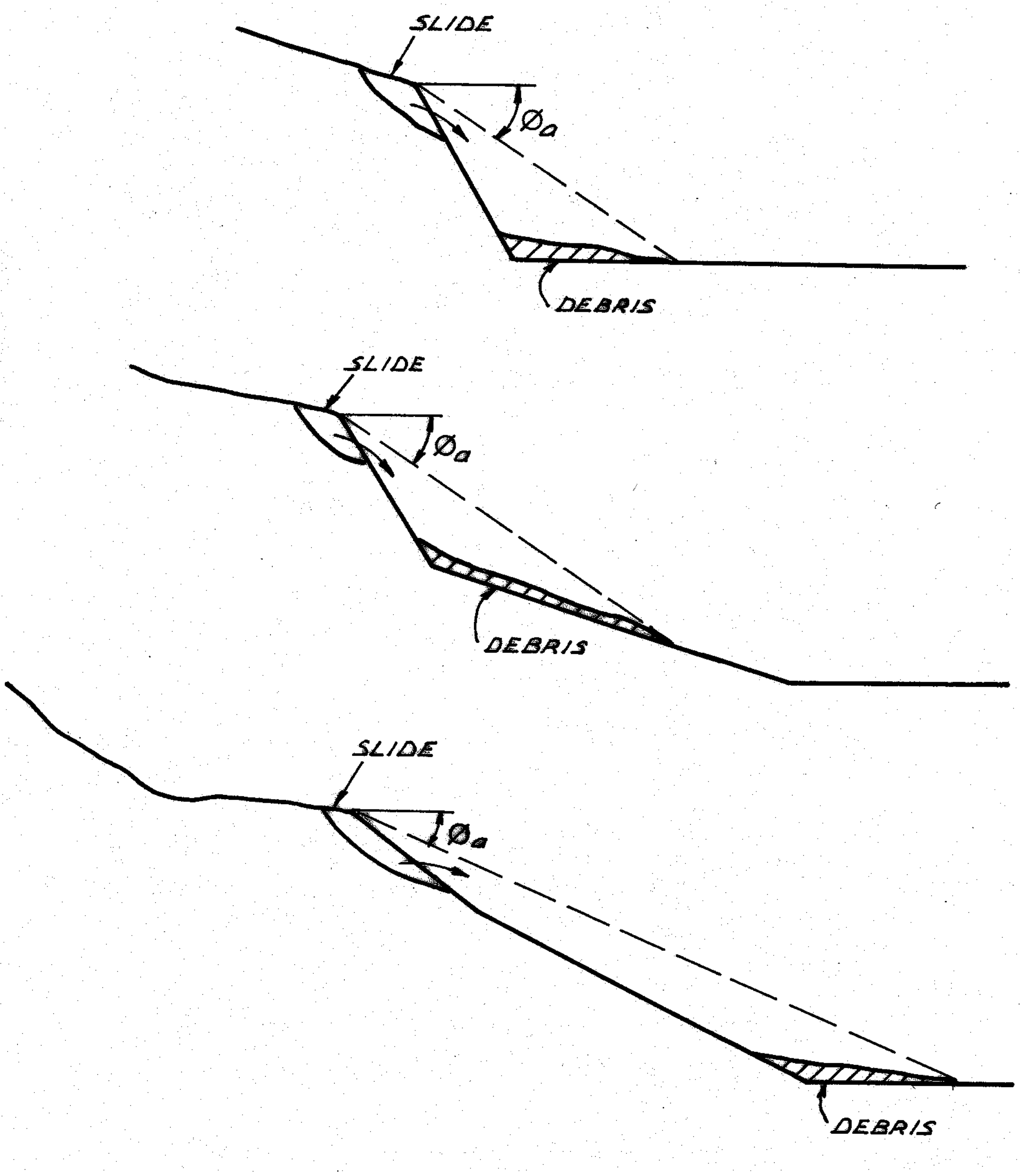


Figure D1 Examples of the Apparent Friction Angle θ_a

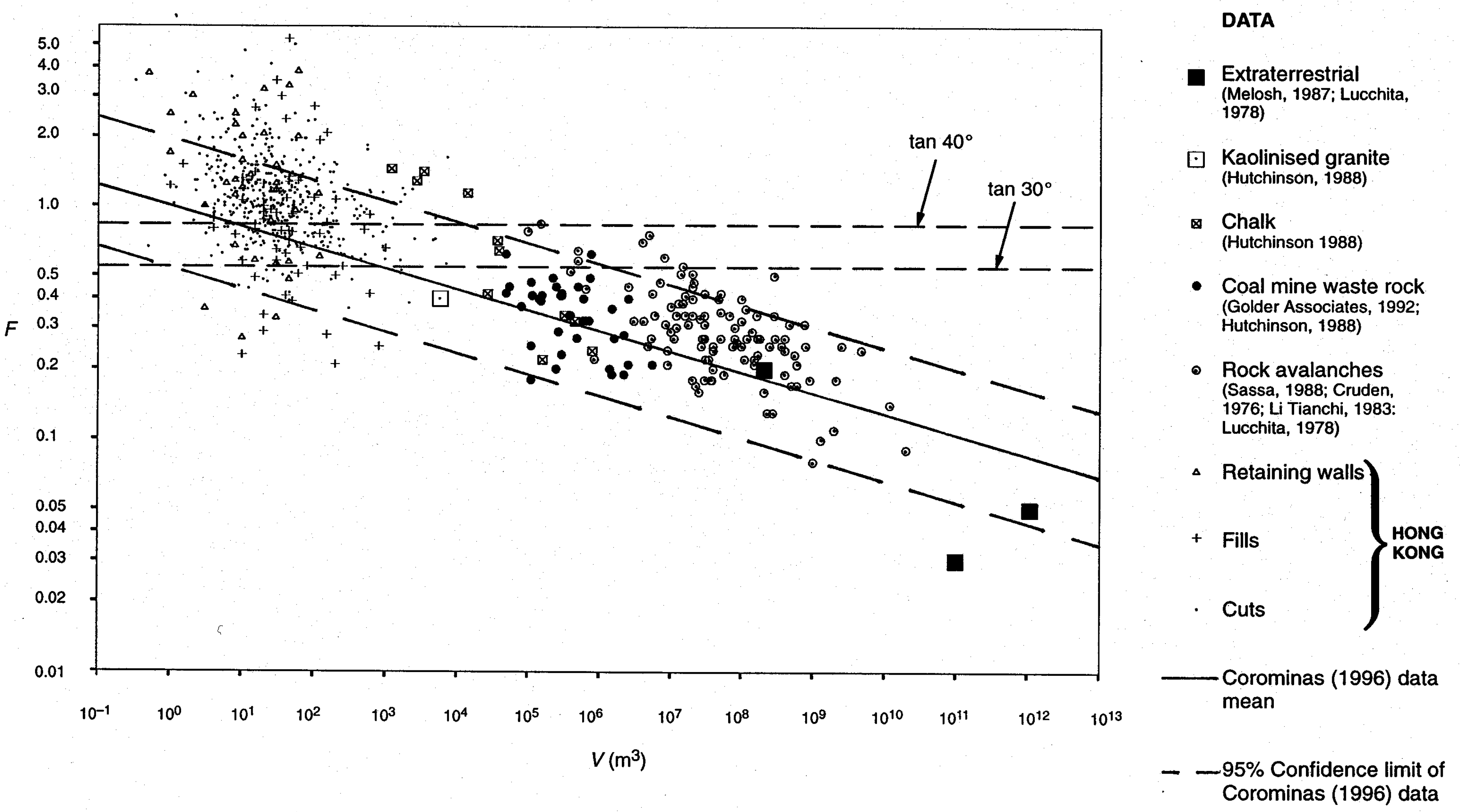
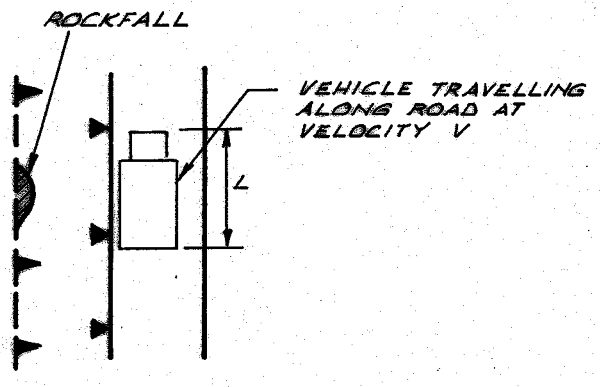


Figure D2: Plot of logF versus logV for various landslides (Finlay *et al* 1999)
where F = tanϕ_a (refer to Figure D1)
V = volume of the landslide

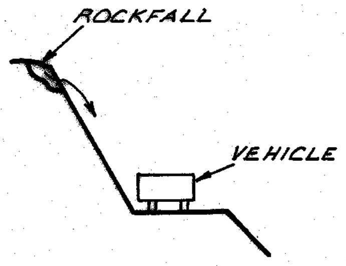
Note: The Hong Kong data has been derived from landslide records. It should be used with care as it includes some wash outs and channelised flows as well as incipient failures.

APPENDIX E

METHOD FOR CALCULATING THE PROBABILITY OF A ROCK FALLING ONTO A MOVING VEHICLE



PLAN



SECTION

$P_{(S)} = 1-(1-(P_{(S:H)}))^{N_R}$ ………………………………………….. (E1)

WHERE

$P_{(S)}$ = PROBABILITY OF ONE OR MORE VEHICLES BEING HIT
$P_{(S:H)}$ = PROBABILITY OF A VEHICLE OCCUPYING THE PORTION OF THE ROAD ONTO WHICH ROCK FALLS
N_R = NUMBER OF ROCK FALLS/DAY

AND

$P_{(S:H)} = \frac{N_V}{24} \cdot \frac{L}{1000} / V_v$ ………………………….. (E2)

N_V = NUMBERS OF VEHICLES/DAY
L = LENGTH OF VEHICLE (m)
V_V = VELOCITY OF VEHICLE/HOUR (km/hour)

NOTE: N_R can be estimated from maintenance records, impact marks on the roadway, the geology, geometry of the slope. Allowance should be made for proximity to the slope, and the presence or absence of rock catch ditches.

APPENDIX F

SUMMARY OF HONG KONG VULNERABILITY RANGES FOR PERSONS, AND RECOMMENDED VALUES FOR LOSS OF LIFE FOR LANDSLIDING IN SIMILAR SITUATIONS

The following table is adapted from Finlay *et al* (1999).

Case	Range in Data	Recommended Value	Comments
Person in Open Space			
If struck by a rockfall	0.1 – 0.7	0.5	May be injured but unlikely to cause death
If buried by debris	0.8 – 1.0	1.0	Death by asphyxia almost certain
If not buried	0.1 – 0.5	0.1	High chance of survival
Person in a Vehicle			
If the vehicle is buried/crushed	0.9 – 1.0	1.0	Death is almost certain
If the vehicle is damaged only	0 – 0.3	0.3	High chance of survival
Person in a Building			
If the building collapses	0.9 – 1.0	1.0	Death is almost certain
If the building is inundated with debris and the person buried	08 – 1.0	1.0	Death is highly likely
If the debris strikes the building only	0 – 0.1	0.05	Very high chance of survival

The above data should be applied with common sense, taking into account the circumstances of the landslide being studied. Judgement may indicate values other than the recommended value are appropriate for a particular case.

APPENDIX G

LANDSLIDE RISK ASSESSMENT – EXAMPLE OF QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

Qualitative Measures of Likelihood

Level	Descriptor	Description	Indicative Annual Probability
A	ALMOST CERTAIN	The event is expected to occur	$>\approx 10^{-1}$
B	LIKELY	The event will probably occur under adverse conditions	$\approx 10^{-2}$
C	POSSIBLE	The event could occur under adverse conditions	$\approx 10^{-3}$
D	UNLIKELY	The event might occur under very adverse circumstances	$\approx 10^{-4}$
E	RARE	The event is conceivable but only under exceptional circumstances.	$\approx 10^{-5}$
F	NOT CREDIBLE	The event is inconceivable or fanciful	$<10^{-6}$

Note: "≈" means that the indicative value may vary by say ± ½ of an order of magnitude, or more.

Qualitative Measures of Consequences to Property

Level	Descriptor	Description
1	CATASTROPHIC	Structure completely destroyed or large scale damage requiring major engineering works for stabilisation.
2	MAJOR	Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works.
3	MEDIUM	Moderate damage to some of structure, or significant part of site requiring large stabilisation works.
4	MINOR	Limited damage to part of structure, or part of site requiring some reinstatement/stabilisation works.
5	INSIGNIFICANT	Little damage.

Note: The "Description" may be edited to suit a particular case.

Qualitative Risk Analysis Matrix – Level of Risk to Property

LIKELIHOOD	CONSEQUENCES to PROPERTY				
	1: CATASTROPHIC	2: MAJOR	3: MEDIUM	4: MINOR	5: INSIGNIFICANT
A – ALMOST CERTAIN	VH	VH	H	H	M
B – LIKELY	VH	H	H	M	L-M
C – POSSIBLE	H	H	M	L-M	VL-L
D – UNLIKELY	M-H	M	L-M	VL-L	VL
E – RARE	M-L	L-M	VL-L	VL	VL
F – NOT CREDIBLE	VL	VL	VL	VL	VL

Risk Level Implications

Risk Level		Example Implications(1)
VH	VERY HIGH RISK	Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to acceptable levels; may be too expensive and not practical
H	HIGH RISK	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels
M	MODERATE RISK	Tolerable provided treatment plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options.
L	LOW RISK	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note:

(1) The implications for a particular situation are to be determined by all parties to the risk assessment; these are only given as a general guide.

(2) Judicious use of dual descriptors for Likelihood, Consequence and Risk to reflect the uncertainty of the estimate may be appropriate in some cases.

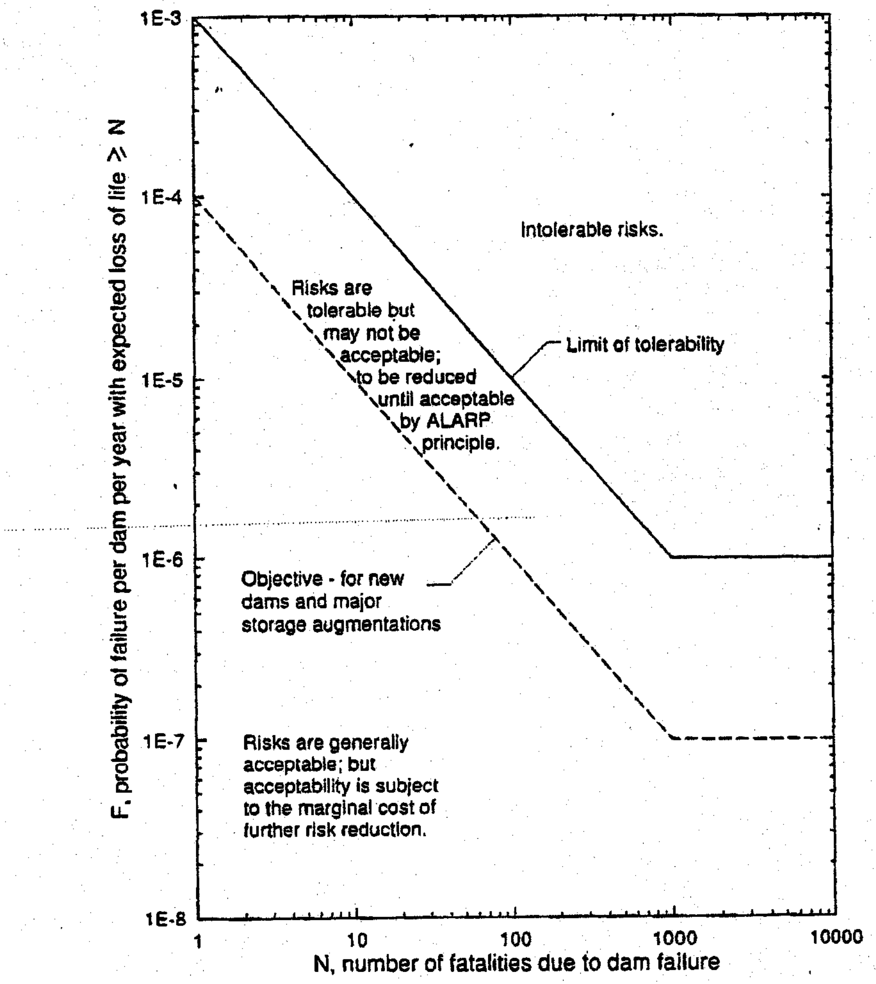
APPENDIX H

ACCEPTABLE AND TOLERABLE RISK CRITERIA

(a) Summary of Individual Risk Criteria (taken from Fell & Hartford, 1997)

Source	Lower Bound (Acceptable)	Upper Limit (Tolerable)
Health and Safety Executive (1989a)	10^{-6} of dangerous dose equivalent to 0.33 x 10^{-6}	10^{-5} of dangerous dose equivalent to 0.33 x 10^{-5}
Health and Safety Executive (1988)	10^{-6} broadly acceptable	10^{-3}, divide between just tolerable and intolerable 10^{-4} any individual member of public from large scale industrial hazard
New South Wales Department of Planning (1994)		10^{-6} residential 5 x 10^{-5} residential
Hong Kong Government Planning (1994)	Not defined	10^{-5}
BC Hydro (1993)		10^{-4}
ANCOLD (1994) Existing dams		10^{-5} average 10^{-4} person most at risk
USBR (Von Thun, 1996)	None stated	
Finlay and Fell (1997)	10^{-5} to 10^{-6} 10^{-3} to 10^{-4} acceptable for property	10^{-3} tolerated

(b) ANCOLD Amended Interim Societal Risk Criteria (ANCOLD 1998) (Subject to Further Revision)



Important note : Where fatalities are expected, as part of a risk-based decision at a specific dam, consultation with the affected public is required as part of the final decision process.

APPENDIX I

SUMMING RISKS FROM A NUMBER OF LANDSLIDE HAZARDS

The following is taken from Fell & Hartford (1997)

Considering risk due to landsliding on a highway, how do we sum the risk? What criteria should be considered? If we have a highway between Towns A and B which is 30km in length and has the following landslide hazards:

- Rockfall from 40 engineered cuttings
- Debris slides from 25 natural slopes
- Potential large scale (say 1 million m^3) fast moving landsliding from natural slopes on the highway at one location
- Potential collapse of 5 fills supporting the road.

Let us also assume the owner of this highway is also responsible for a further 2000km of highways in the state.

Some questions which need to be answered for the management of landslide risk are:

Is it required that acceptable individual risk and societal risk criteria are met for

(i) each landslide hazard above, i.e. each cutting or single debris slide
OR (ii) for all cuttings (only) on the highway from A to B
OR (iii) for all landslide hazards on the highway from A to B
OR (iv) is it required that the acceptable risk criteria are met for all landslide hazards under the management of the owner of the highway properly modelling the traffic and hazard to represent the overall picture?
OR (v) is it required that the acceptable risk criteria are met for all landslide hazards on all roads in the state regardless of the owner?
(vi) what if there are other hazards on the road(s), e.g. flood, avalanche, bridge collapse? Should these risks be added to the risks due to landslide?
(vii) should the risk due to landsliding affecting the population in their place of residence and workplace, for example, also be considered.

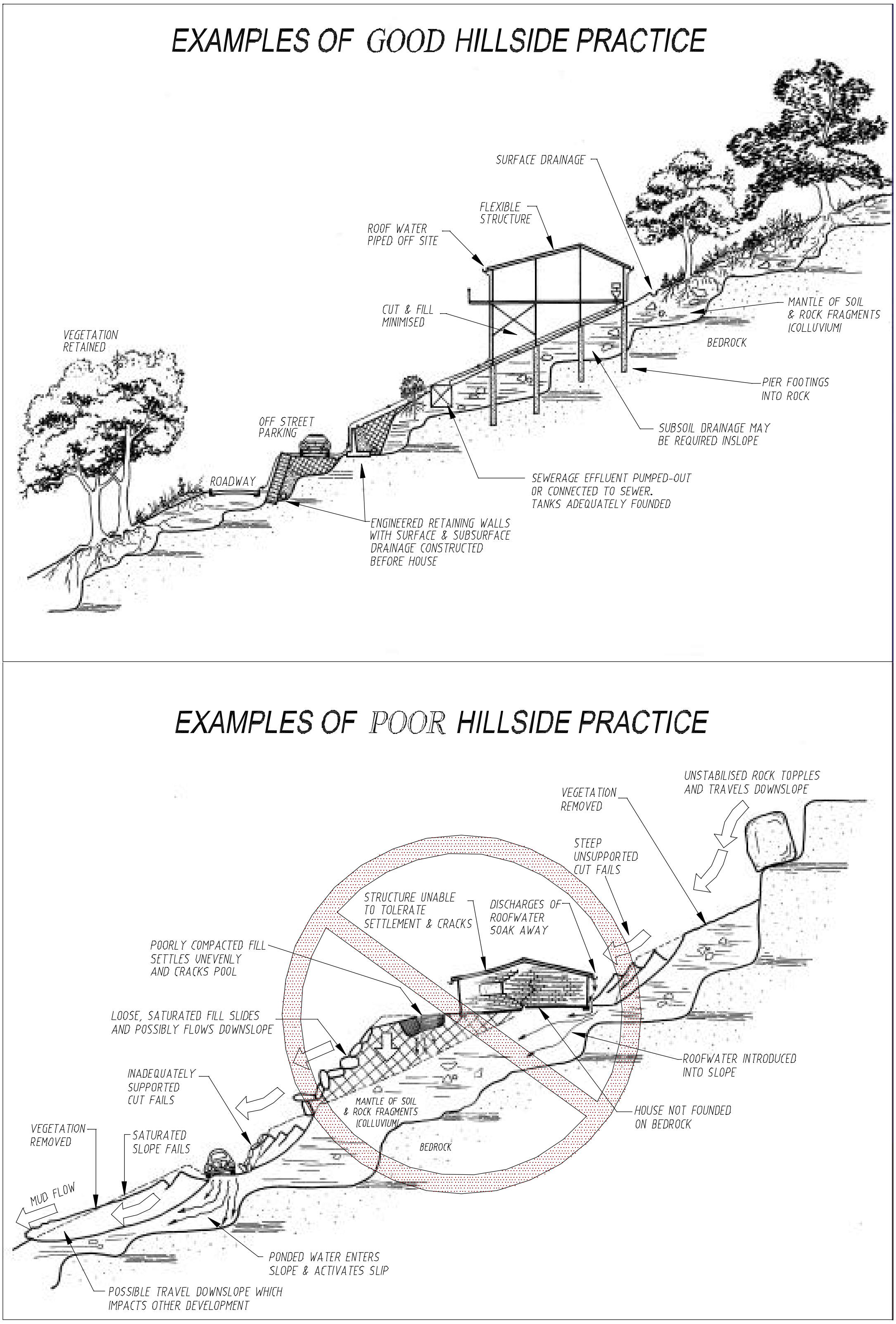
To the authors, it seems clear that:

(i) and (ii) Are clearly not the case, since persons driving from A to B are not particularly interested in each cutting, or individual debris slide (or cuttings separate from debris slides). They are interested in the landslide risk in travelling from A to B.
(iii) May be applicable, but only if the highway is "special", and separate in the mind of the population.
(iv) Would seem more likely to apply, if it is one of many similar highways.
(v) Would seem possible – the public are unlikely to differentiate between different owners of highways.
(vi) Should in principle apply. In practice, apart from avalanches, the other hazards may contribute little to risk.
(vii) Would seem unlikely to be required of society in most situations, as they would possibly separate the highway hazard from the others. However, the situation would be less clear in a place like Hong Kong, where government imposes controls on all landslide related works, and is known to do so by the population.

APPENDIX J

SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

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



EXAMPLES OF GOOD HILLSIDE PRACTICE

EXAMPLES OF POOR HILLSIDE PRACTICE

Figure J1 Illustrations of Good and Poor Hillside Practice