Guidelines for Natural Hazard Risk Analysis on Public Conservation Lands and Waters

Part 2: Preliminary hazard and exposure analysis for landslides

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EXECUTIVE SUMMARY

This report presents a preliminary screening methodology for exposure to landslides hazards at specific locations ('point sites') within public conservation lands and waters (Department of Conservation [DOC]-managed land), such as huts, visitor centres and carparks, or at specific points along a linear site, such as tracks and roads. The preliminary screening methodology covers life-safety considerations and can be used to identify and prioritise areas within public conservation lands and waters for further risk analysis and risk-management actions.

The method can be used to estimate the individual spatio-temporal probability of exposure of visitors and workers to the landslide hazard. The method firstly determines if a credible landslide hazard exists via a field visit to the site. Secondly, the method assesses whether a site is affected by falling debris or slippage, which are terms mentioned in the Building Act (2004) and used in this report as follows:

1. **'Slippage'** includes the movement or loss (including partial loss) of land from a slope when it occurs beneath, for example, a structure, path, road, car park, etc.
2. **'Falling debris'** includes soil, rock, vegetation and snow or ice that may fall and 'runout' onto a site from upslope (the landslide source area), impacting or inundating the site.

For sites that may be impacted by falling debris, the maximum credible volume and most likely volume are estimated along with the probability of occurrence of each volume occurring. For each volume class, empirical runout relationships are used to determine the hazard footprint and therefore the number of people that may be exposed within the footprint(s) for the different hazard types. For slippage, the amount of slippage, area affected and probability of occurrence are estimated as well as the potential velocity of movement, which provides an assessment of both the life-safety risk and hazard footprint. The hazard probability of occurrence and exposure are then used to define the hazard and exposure class (Class 1–4) for a site, based on the hazard and exposure matrix. The risk-management actions associated with hazard and exposure class are:

1. **Class 1:** No further risk analysis required. DOC should develop appropriate risk-management plans and re-evaluate the risk-management plan if there is a change in hazard activity or the number of people exposed.
2. **Class 2:** Basic level of risk analysis required. The analysis should highlight and identify the potential impacts to persons on the public conservation lands and waters. Identified high-risk sites may require further advanced risk analysis and consideration of mitigation options.
3. **Class 3:** Urgent action is required. This may involve interim risk-management solutions (e.g. closures) while solutions are developed. Basic-level risk analysis must be undertaken, and an advanced-level analysis of risk may be required.
4. **Class 4:** Urgent action is required. This may involve interim risk-management solutions (e.g. closures) while solutions are developed. Basic-level risk analysis must be undertaken, and an advanced-level analysis of risk may be required. Class 4 represents the highest priority for further risk analysis and risk-management actions.

Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel. It is also important to note that, for the preliminary screening methodology, the uncertainties on the information provided are relatively large.

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1.0 INTRODUCTION

1.1 Purpose of Report

The purpose of the report is to outline and describe a method for undertaking landslide hazard and exposure analysis either at point sites or along linear sites within the public conservation lands and waters. The method forms a preliminary screening methodology used to identify and prioritise areas within the public conservation lands and waters for further risk analysis| and risk-management actions.

1.2 Concept

The purpose of the screening methodology is to identify whether more investigation and analysis is needed at a site, provide a guide to prioritising investigations and determine what level of analysis should be undertaken. The Part 1 report (de Vilder et al. 2024) sets out a flowchart that guides the user through the process, which ultimately ends with assigning the site a hazard and exposure class. The hazard and exposure class then recommends what level of future investigation and analysis is required (as set out in the Part 3 and 4 reports [de Vilder and Massey 2024a, 2024b]). It is intended that the hazards and exposure at each site are initially analysed using this screening methodology. The results would then go to the Department of Conservation (DOC) to be reviewed and confirm the level of any future analysis required. Further detail on landslide risk analysis is provided in the Part 3 and 4 reports, which should be used to help inform the analysis within the screening methodology.

The screening methodology allows the user to identify: (1) the different types of landslide hazards that could affect the site, (2) the magnitude and area affected (the 'hazard footprint') and (3) the probability of occurrence, which is how often the hazard could occur. This includes identifying whether a site could be affected by slippage or falling debris hazards, which are terms mentioned in the Building Act (2004) and used in this report as follows:

1. **'Slippage'** includes the movement or loss (including partial loss) of land from a slope when it occurs beneath, for example, a structure, path, road, car park, etc.
2. **'Falling debris'** includes soil, rock, vegetation and snow or ice that may fall and 'runout' onto a site from upslope (the landslide source area), impacting or inundating the site.

The areas affected by slippage or falling debris are defined to determine the hazard footprint and therefore the number of people that may be exposed within the footprint(s) for the different hazard types. As such, slippage and falling debris are defined relative to the element at risk (here being visitors and workers) and not the mechanics of the landslide, which is described by the landslide type classification. The hazard probability of occurrence and exposure are used in conjunction with the visitor site's risk threshold to define the hazard and exposure class (Class 1–4) for a site, based on the hazard and exposure matrix. The relative hazard and exposure matrix is broadly based on the risk-management framework contained in the original Risk Management Guidelines Companion to AS/NZS 4360:2004, which is now superseded by AS/NZS 31000:2009.

DOC's risk-tolerability guidance provides a consistent set of risk-tolerability criteria across public conservation lands and waters. The guidance classifies visitor sites into three different risk thresholds, as shown in Table 1.1.

Table 1.1 Department of Conservation natural hazard risk thresholds for visitor sites.

Natural Hazard Risk Thresholds – three acceptable risk thresholds for quantitative risk assessments	
Risk Threshold	**Type of DOC Visitor Site**
Lower Risk	• Short walks • Walking tracks • Grade 1 and 2 cycle trails • Campsites • Amenity areas
Medium Risk	• Easy tramping tracks, including Great Walks • Grade 3 and 4 cycle trails • Promoted marine sites, such as Goat Island
Higher Risk	• Tramping tracks • Routes • Grade 5 and 6 cycle trails

There are three different risk thresholds for natural hazard risk management at visitor sites (Figure 1.1). Linked to these thresholds are DOC's risk-reduction response categories (see Figures 1.1 and 1.2) The DOC risk-reduction response categories are also associated with internal DOC risk-management actions (Figure 1.2). For workers, DOC's risk-tolerability guidance outlines the tolerance to risk for workers and sets the risk level that is associated with each hazard and exposure class.

The hazard and exposure classes therefore help DOC determine whether further risk-management decisions are required, as each of the hazard and exposure classes have risk-management actions associated with them (Table 1.2). Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel (see the Part 1 report). Appendix 3 outlines the respective roles of the consultant and DOC staff throughout the risk analysis and risk-management process.

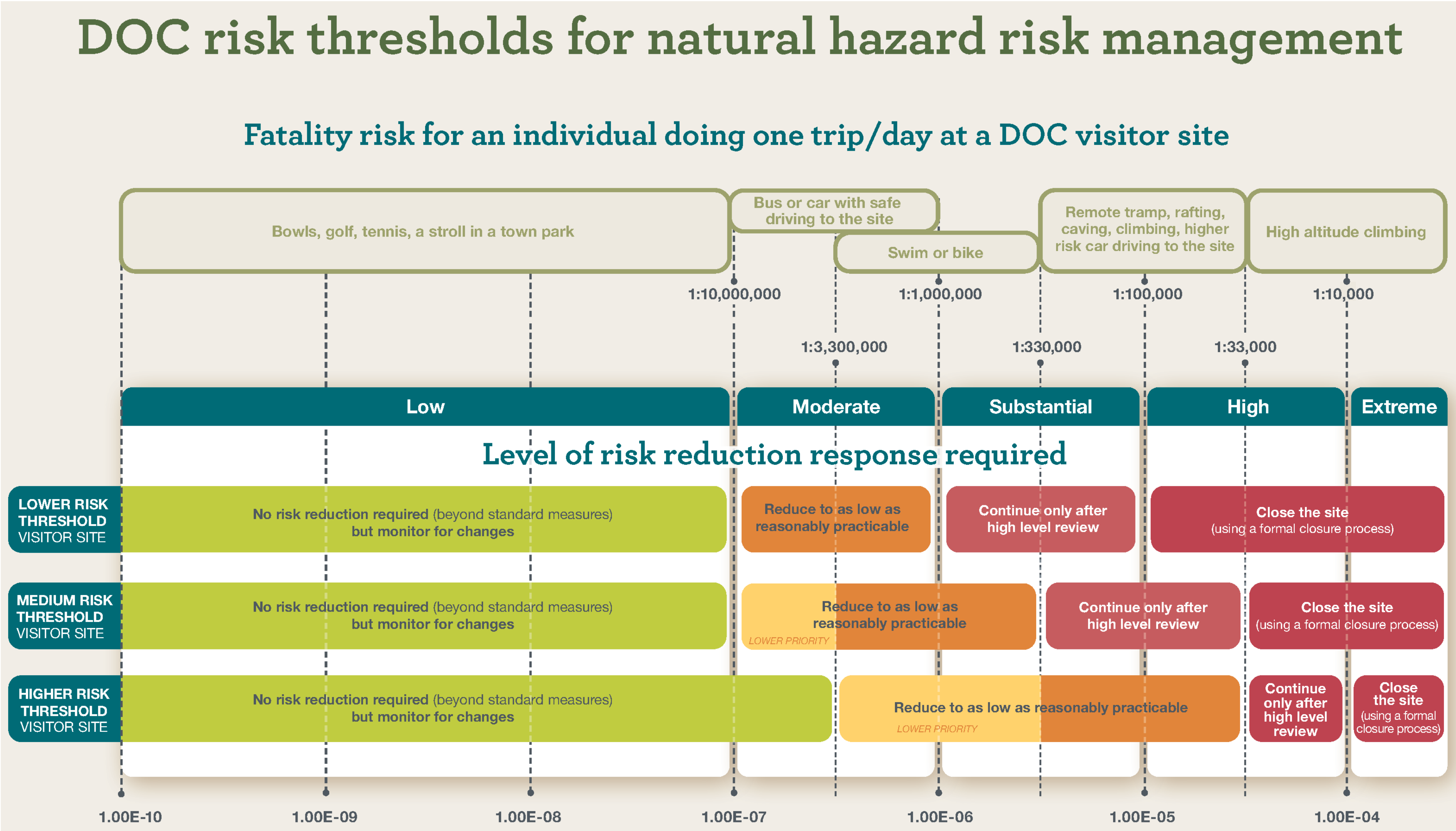

Figure 1.1 Department of Conservation natural hazard risk thresholds for visitor sites and associated level of risk-reduction response.

Natural hazard risk reduction response

What the risk reduction response categories mean for DOC:

No risk reduction required (beyond standard measures)

Risk is low.

- Follow DOC's normal visitor asset management and visitor safety communication standards.
- Informally monitor for changes.

Reduce to as low as reasonably practicable

Operations Manager leads a team process to establish suitable mitigations.

- Use local team and experts to decide on necessary actions using the hazard management guideline.
- Ensure that the mitigations selected are proportional to the risk. Avoid costly and resource intensive measures.
- Reassess the risk if the hazard changes – a formalised monitoring regime may be required to identify changes.

Continue only after high level review

Regional Director leads a team process to understand if the risk is acceptable and establish mitigations.

- Use local team and experts to identify suitable risk reduction options.
- Consider significant changes to reduce risk like moving infrastructure.
- A Trigger Action Response Plan (TARP) may be needed, along with a formal monitoring regime to identify changes and respond to increased risk.
- Close the site using the Visitor Safety Closures SOP if risk cannot be reduced to an acceptable level.

Close the site

Close the site using the Visitor Safety Closures SOP.

- Regional Director and experts across DOC decide the site's future. Brief the Senior Leadership Team on the discussions and decisions made.
- Unless the site can be redesigned to eliminate the risk (such as moving a hut or rerouting a track), permanent closure and disposal of the site's assets is very likely at this risk level.

Figure 1.2 The four Department of Conservation risk-reduction response categories and associated internal actions.

Table 1.2 Risk-management actions and associated hazard and exposure class.

Class	DOC Risk-Reduction-Response Categories	Risk-Management Actions
Class 1	No risk reduction required (beyond standard measures) but monitor for changes	No further risk analysis required. DOC should re-evaluate the risk if there is a change in hazard activity or the number of people exposed.
Class 2	Reduce to as low as reasonably practicable	Basic level of risk analysis required. The analysis should highlight and identify the potential impacts to persons on the public conservation lands and waters. Identified high-risk sites may require further advanced risk analysis and consideration of mitigation options.
Class 3	Continue only after high-level review	Urgent action is required. This may involve interim risk management solutions (e.g. closures) while solutions are developed. Basic-level risk analysis must be undertaken, and an advanced-level risk analysis may be required.
Class 4	Close the site (using a formal closure process)	Urgent action is required. This may involve interim risk-management solutions (e.g. closures) while solutions are developed. Basic-level risk analysis must be undertaken, and an advanced-level risk analysis may be required. Class 4 represents the highest priority for further risk analysis and risk-management actions.

1.3 Scope of Report

The methodology is only concerned with life-safety considerations for visitors and workers within the public conservation lands and waters. Workers may include DOC staff, contractors, volunteers and concessionaires. It assesses the exposure of the individual of interest, both visitors and workers, to the landslide hazard(s).

The preliminary screening methodology is used to assess landslide hazard and exposure at point sites and should be applied at specific points or sections along a linear site. These may include points or sections of previous and current landslides or points where persons may congregate (such as viewing or picnic areas).

1.4 Definitions

The terminology used for describing risk in this report is attached as Appendix 2. This is based on the terminology outlined in Corominas et al. (2015) and Fell et al. (2008). The terminology used for describing landslides is attached as Appendix 3. This is based on Cruden and Varnes (1996).

The terminology must be used by all consultants carrying out hazard and risk analyses for DOC.

1.5 Materials

It is assumed that the consultant undertaking the hazard and exposure analysis for a site has access to:

- An adequate ground model (contours) of the area. At a minimum, this is the 8 m National DEM as provided by LINZ (https://data.linz.govt.nz/), but higher-resolution ground models do exist for some areas and should be used if available.
- Information on exposure (occupancy and time spent) – to be provided by DOC.
- Information on visitor site type: Lower, Medium, Higher visitor risk site – to be provided by DOC.
- Historical aerial images for the site, which can be found on Retrolens (http://retrolens.nz/).

It is further assumed that the consultant will undertake a field visit for landslide characterisation as an integral part of the hazard and exposure analysis.

1.6 Structure of Report

Section 2 describes the specific steps required to conduct the hazard and exposure analysis, as well as providing data sources relevant to undertaking the analysis. Section 3 outlines how the analysis and report should be recorded and presented along with the information that a consultant should generate to support their hazard rating. Section 4 presents the report conclusion.

2.0 METHODOLOGY

2.1 Overview

The method is designed to identify and assess whether a credible landslide hazard exists at a site and, if so, whether people are likely to be exposed to the hazard. The framework and method are outlined in the flowchart in Figure 2.1. The method comprises an initial field visit to assess the landslide hazard. The flowchart (Figure 2.1) is then used to qualitatively assess:

1. What type(s) of landslide could occur.
2. Where they could occur (i.e. source area locations).
3. How big they could be (i.e. volume).
4. How likely they are to occur.
5. If they occur, whether debris would reach the site and the area that might be affected, i.e. the 'hazard footprint'. The hazard footprint is defined as the area within which a particular type of landslide hazard might impact.

The flowchart comprises the assessment of two main types of landslide hazards of slippage and falling debris. The two types of hazard are examined separately, as outlined in Figure 2.1, as they can have different consequences. For slippage, if the site is upslope of, or within, the landslide feature, the amount of slippage (movement) and area affected are estimated in order to assess whether the amount and speed of any landslide movement could credibly affect people at the site. This should include analysis of the potential for the entire landslide mass to fail catastrophically and therefore represent a life-safety risk. For falling debris, the method is used to assess whether there is a credible debris path from the landslide source area(s) downslope to the site, and therefore whether people at the site are exposed to landslide hazards.

Two exposure metrics are used:

1. The **individual spatio-temporal probability of a visitor**: the proportion of time (P) per trip per day that the individual of interest spends at a given location on the site.
2. The **individual spatio-temporal probability of a worker**: the proportion of time (P) per day that the individual of interest spends at a given location on the site.

The method should be used to estimate the temporal probability of the credible landslide volume(s) that could occur at a site. The temporal probability is combined with the estimates of exposure within the landslide impact zone, as defined by the area affected by slippage or within the landslide falling debris travel path, to determine the hazard and exposure rating from Class 1–4 in conjunction with the visitor site's risk threshold.

The method can be used to assess the hazard class at sites that may contain point sites, such as huts, or linear sites, such as paths, within the study area. This method does not assess landslide risk along roads or tracks where vehicles may travel. This should be assessed via another method to account for situations unique to vehicles (e.g. any slippage may present a risk if a vehicle has no warning and drives into the slippage area). If there are multiple sites within one study area, the method should be applied to each site separately. For linear sites, the study area may be relatively large. For such assessments, the method should be applied by adopting 'hazard zones' where the class of hazards within each hazard zone are estimated. Hazard zones are defined as: an area of ground within which the topography/morphology, geology, geomorphology and landslide hazard types are similar. If a site is affected by multiple types of landslide, the hazard footprints for each landslide type should be overlaid and the highest hazard class (assessed for the footprints) assigned.

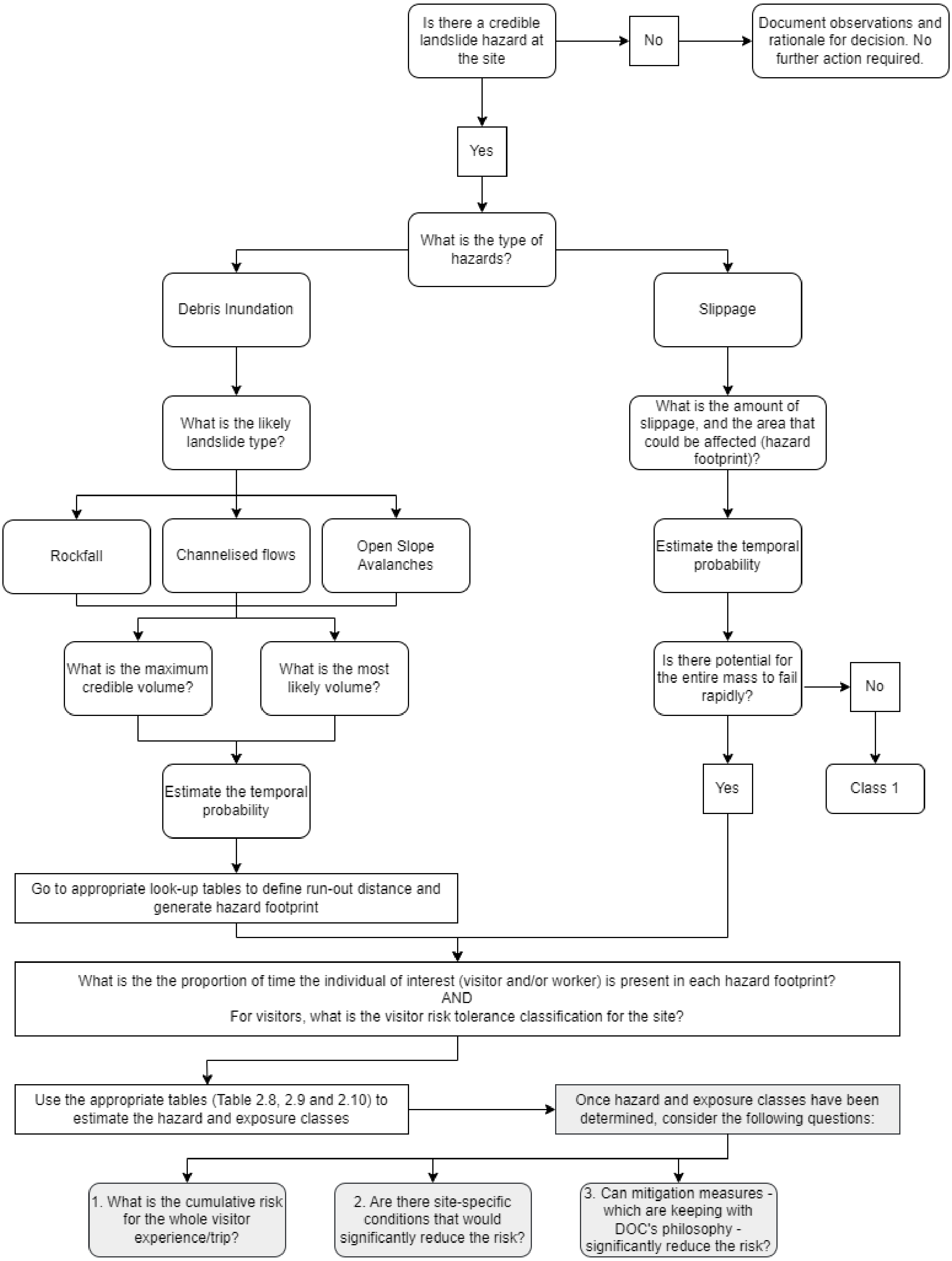

Figure 2.1 Flowchart outlining the steps required to determine the class rating from the hazard and exposure matrices.

2.2 Is there a Credible Landslide Hazard?

Determining whether there is a credible landslide hazard requires a field visit to the site(s). The field visit should include identification and basic mapping of existing landslides and geomorphic features, including observations of landslide and rockfall runout and areas of cracking (signs of possible incipient landslides), as well as evidence of their activity. The mapping can consist of clear hand-drawn maps and annotated photographs.

The field mapping and subsequent desktop-based analysis should identify possible landslide types, sizes and rates of movement. It should also identify possible landslide trigger events, such as earthquakes, heavy rainfall or snow-melt events. For example, are past earthquakes known to have caused landslides or rockfalls to occur at the site (Yes/No) and, if yes, what peak ground acceleration (PGA) or Modified Mercalli intensity (MMI) occurred. Information on PGAs for different return periods, derived from the National Seismic Hazard Model (NSHM; Stirling et al. 2012) assuming Site Class B properties, are included in the Part 3 report. The maps of PGAs can be used to inform the potential for earthquakes to trigger landsliding (cf. Table 4.8: Part 3 report). The same should also be identified for rainfall and storm events, e.g. how much rain occurred around the time of the landslide? The Part 3 report contains rainfall triggering thresholds for different physiographic regions in New Zealand (cf. Table 4.7: Part 3 report), as well as the High Intensity Rainfall Design System forecast (NIWA 2018) for all New Zealand. The Part 4 report contains further details on how to assess the severity of landsliding triggered by earthquakes and rainfall.

Table 2.1 presents a set of criteria for evaluating the potential for a landslide hazard at a site (based on Hancox [2008]), and Table 2.2 lists some typical landslide features and criteria for recognising them in the field. The table is not an exhaustive list of all factors that may make a slope susceptible to landsliding. Further information on landslide susceptibility and landslide-triggering factors is provided in the Part 3 and 4 reports.

Table 2.1 Typical criteria for assessing landslide hazards (adapted from Hancox [2008]).

Landslide Hazard Evaluation Criteria	Lower Susceptibility	Higher Susceptibility
Slope angle and local topographic effects	Flat to gentle slopes (<20°) Moderate slopes (20° to 35°) Broad ridges and saddles	Steep (35° to 45°) and very steep (>45°) slopes High, steep, narrow ridges
Site geology	Strong, sparsely jointed rock Moderately strong jointed rock Dense gravels and moraine	Closely jointed rock Open-jointed (dilated) rock Collapsing moraine, colluvium and alluvial deposits, saturated soils
Earthquake shaking effects	Point locations in low to moderate areas of seismicity	Point locations in areas of moderate to very high seismicity (e.g. Southern Alps, Fiordland, NW Nelson, Hawke's Bay) and history of large to moderate earthquakes
Flooding, erosion, debris flows, debris floods	Point locations on ridges, saddles and high river terraces or on low terraces with no flooding history and that are well clear of the river	Point locations on low terraces close (<50 m) to rivers, major rivers, 'flashy' side streams or debris fans. Point locations with a history of flooding, debris flows or debris floods
Volcanic landslide hazards	Point locations outside volcanic areas	Point locations within volcanic areas, particularly within valleys that may experience or have experienced lahars

Table 2.2 Typical landslide features and criteria for field recognition.

Landslide Features	Description of Features
Active Landslides (and Recently Active or Dormant Landslides)	
Landslide scar	Includes the source area and debris trail.
Source area	The area at the head of the landslide (zone of depletion) where the landslide mass (debris) is derived from.
Landslide debris	Material (rock, soil, vegetation) displaced from the source area and transported downslope by gravity.
Main scarp	The main scarp is the steep slope in undisturbed ground at the head of the slide (head scarp) – the visible part of the failure surface. Minor (secondary) scarps may be present within the displaced material of the landslide mass.
Tension cracks	Often located upslope of the landslide main scarp, these tend to be aligned in an arc; can be continuous or discontinuous but are essentially linear. These indicate horizontal (pull-apart) movement but may also show vertical and shear movement.
Hummocky ground	Ground surface irregular, often formed of low-amplitude hummocks, resulting from differential (compressional and shear) deformations within the displaced material – a feature of many landslides (active and inactive).
Ponds (un-drained)	Ponds formed in depressions, which are often un-drained, are present within the displaced material of many landslides, especially at the slide head; they may be filled by seepage from springs or by rainfall.
Springs, seepages	Give rise to areas of swampy or boggy ground; seepage water may accumulate in ponds.
Trees with curved trunks or that are leaning backwards	Wind, steep topography and ground movement can all give rise to non-vertical tree trunks, so care is required in their interpretation and additional supporting evidence of landslide movement is required.
Disruption of natural drainage	May be seen directly or inferred from seepages. May also be seen where landslide debris may have totally or partially blocked a drainage line or where the drainage line has been forced to alter its course.
Cracking to structures and paved surfaces and dislocation of drainage structures	These can also be related to local settlement of fill and foundations, so additional supporting evidence is required, e.g. presence of a source area or landslide debris, tension cracks, trees leaning backwards.
Relict Landslides (Inactive Old Landslides with Little Potential for Re-Activation)	
Relict landslides typically have eroded, rounded and subdued features, with no sharp features or bare scarps visible. The main scarp is generally eroded and well-vegetated. The displaced landslide mass often has ponds and hummocky and irregular ground. Generally, no cracks or indications of movement are visible. Trees and established vegetation show no evidence of tilting, non-vertical trunks or disturbance.	
Typical Erosion Features and Geomorphic Landforms	
Erosional river terraces, river/stream banks and bed, and water-eroded rills and gullies formed on slopes and other geomorphic surfaces by rapid runoff during rainstorms. Steep cliffs along streams, rivers, glaciers and the shores of lakes and coastal areas are also erosion features, formed by progressive erosional under cutting and collapses of these over-steepened slopes.	

2.3 Determining Landslide Volume

The maximum credible and most likely landslide volumes need to be defined for each type of landslide that could affect the site. This is important for sites that may be affected by falling debris. For sites that may be affected by slippage, the most likely and maximum credible volume may be one and the same or indistinguishable between the two categories. Both volume categories are estimated, as they may have different temporal probabilities and so result in different hazard and exposure class designation.

The volumes can be estimated via two sources of information: (1) analysis of the previous landslide features and activity in the vicinity of the site; and (2) topographic, geological and geomorphic controls and rock structure controls for rockfall on potential landslide size. This information should be derived from the field visit and associated mapping of landslide and geomorphic features and any historical information available. Further information can be provided from DOC staff and other local observations of landslide activity in the vicinity of the site. The landslide volume that can be produced from a slope will ultimately be limited by the size of the slope and, in many cases for shallow slides, the depth of accumulated colluvium and completely weathered rock. The landslide volumes should be described using the classes outlined in Table 2.3.

Table 2.3 Landslide volume classes and descriptions. Landslide size classification based on McColl and Cook (2024).

Class	Descriptor (with m^3 Quantity)	Minimum Volume (m^3)	Minimum Area (m^2)
14	Monster (trillions)	≥ 100,000,000,000,000	≥ 500,000,000,000
13		≥ 10,000,000,000,000	≥ 100,000,000,000
12		≥ 1,000,000,000,000	≥ 10,000,000,000
11	Giant (billions)	≥ 100,000,000,000	≥ 1,000,000,000
10		≥ 10,000,000,000	≥ 500,000,000
9		≥ 1,000,000,000	≥ 100,000,000
8	Large (millions)	≥ 100,000,000	≥ 10,000,000
7		≥ 10,000,000	≥ 1,000,000
6		≥ 1,000,000	≥ 500,000
5	Medium (thousands)	≥ 100,000	≥ 100,000
4		≥ 10,000	≥ 10,000
3		≥ 1000	≥ 1000
2	Small (ones)	≥ 100	≥ 500
1		≥ 10	≥ 100
0		≥ 1	≥ 10
-1	Very small (thousandths)	≥ 0.1	≥ 1
-2		≥ 0.01	≥ 0.5
-3		≥ 0.001	≥ 0.1

2.4 Estimating Landslide Temporal Probability

The temporal probability (also referred to as the probability of occurrence) is the probability that a landslide will occur in a given period of time in a specified area. For this method, it is the temporal probability of the most likely volume and maximum credible volume estimated for the landslides affecting the site. Four qualitative temporal probability classes are outlined in Table 2.4, along with the indictive recurrence interval. The recurrence interval is the long-term average elapsed time between landslide events at a particular site or in a specified area.

The temporal probability can be estimated from historical, geomorphological and geological evidence of the landslide hazards and processes at and/or within the vicinity of the site. It may also be assessed using expert elicitation, taking into account the frequency of landslide-triggering events such as rainfall and seismic loading. The resulting estimation of the temporal probability represents a best estimate and it is therefore important to be aware of the limitations in accuracy.

Table 2.4 Quantitative and qualitative descriptors of landslide temporal probability (based on Hancox [2008]).

Indicative Recurrence Interval (Years)	Relative Temporal Probability
<1	**Extremely High:** Hazard event will very likely occur multiple times per year
1–10	**Very High:** Hazard event will very likely occur in the near future
10–100	**High:** Hazard event is likely to occur
100–1000	**Medium:** Hazard event could possibly occur
1000–10,000	**Low:** Hazard event is unlikely to occur
>10,000	**Very Low:** Hazard event occurs rarely

2.5 Falling Debris

2.5.1 What is the Landslide Type?

For the hazard and exposure analysis, landslides are classified into three broad categories:

1. **Rockfall:** the detachment, falling, rolling and bouncing of rock blocks (Cruden and Varnes 1996).
2. **Channelised flows** (such as debris flows): very rapid to extremely rapid surging flows of saturated debris in a channel.
3. **Open-slope avalanches** (such as debris avalanches): many blocks falling simultaneously from a slope.

The designation of the three landslide categories is based on their different runout characteristics and extent. For sites affected by other types of landslide, i.e. none of the three categories, the landslide type should be described using the classification scheme of Cruden and Varnes (1996), as presented in Appendix 3.

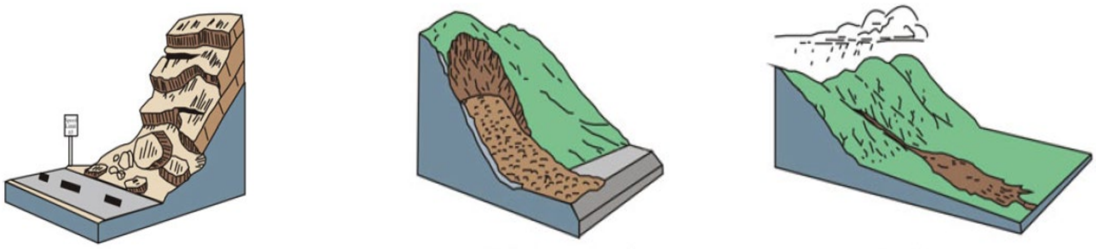

Figure 2.2 Schematic diagrams of the three main type of landslides.

2.5.2 What is the Landslide Travel Path?

In order to determine if the site can potentially be affected by falling debris and to define the hazard footprint, the runout extent of the debris/rocks needs to be estimated, which is dependent on the landslide type. The shadow angle (Evans and Hungr 1993) should be used to define the downslope limit of rockfall runout (Figure 2.3) along with field mapping of past rockfalls. For rockfalls, we recommend using a minimum shadow angle of 21° (after Massey et al. 2014) in conjunction with field mapping of any past rockfall boulders present on the site. The shadow angle should be projected using several representative cross-sections through the study area, which can then be used to define the rockfall hazard footprint – comprising the rockfall source area and shadow angle runout path or downslope limit of past rockfall boulders.

For channelised flows and open-slope avalanches, the 'Fahrböschung' (α) angle is used (Figure 2.3). The Fahrböschung angle is the tangent of the ratio of the fall height (H) to the horizontal runout distance (L) between the crest of the source zone and toe of the deposit (Heim 1932; Figure 2.3). The Fahrböschung angle is correlated with landslide volume. The scatter in the data allows the probability of runout exceedance, or limits of confidence for prediction, to be calculated for each landslide volume (e.g. Hungr et al. 2005; Berti and Simoni 2014). For example, the best fit line in Figure 2.4 represents an exceedance probability of 50%, where half of the landslides of a specified size and type will travel further than this line, and the 10% line represents a 10% chance that a similar landslide will travel further (McDougall 2017). GNS Science (Brideau et al. 2021) has recently compiled an empirical landslide dataset from New Zealand and landslides internationally for different landslide types and volumes, from which the values in Table 2.5 were derived. Further information on these empirical runout relationships can be found in the Part 4 report.

It is recommended that Table 2.5 be used as a 'look-up' table to determine the likely runout extents of channelised flows and open-slope avalanches for the given landslide volume classes, adopting the 10% passing probability relationship.

However, channelised flows (e.g. debris flows) can entrain significant amounts of material along their runout path from scour of channel bed sediment or collapse of stream banks. This results in a change to the volume of a debris flow. Experimental results from Iverson et al. (2011) have shown that pore water pressures, generated as wet bed sediment is overridden and progressively entrained by debris flows, can reduce friction and lead to a pronounced increase in flow momentum. The pore water pressure represents the pressure exerted by the water filling the voids in a soil, debris or rock mass. Changes in debris flow volume and momentum due to entrainment have the potential to influence debris flow velocity and travel distance (Iverson et al. 2011). Therefore, to estimate the potential travel path and hazard footprint of a debris flow, the Fahrböschung angle should be used in conjunction with geomorphic evidence (e.g. debris or alluvial fans) to determine the maximum extent of debris flow hazard footprint. More information on debris flow runout can be found in the Part 4 report.

The use of these look-up tables is for flows and avalanche landslide types. If the landslides affecting the site cannot be categorised into these two groups, expert elicitation should be used to determine the maximum runout extent for both the most likely volume and maximum credible volume. If evidence exists (historical, geomorphological or geological) that the runout travelled further than predicted by either the rockfall shadow angle or the Fahrböschung angle, this evidence should dictate the maximum runout extent to be used in the screening methodology.

The maximum runout extents for the landslide volumes should be presented on a cross-section and approximately shown on a map as hazard footprints, along with annotated photographs if appropriate.

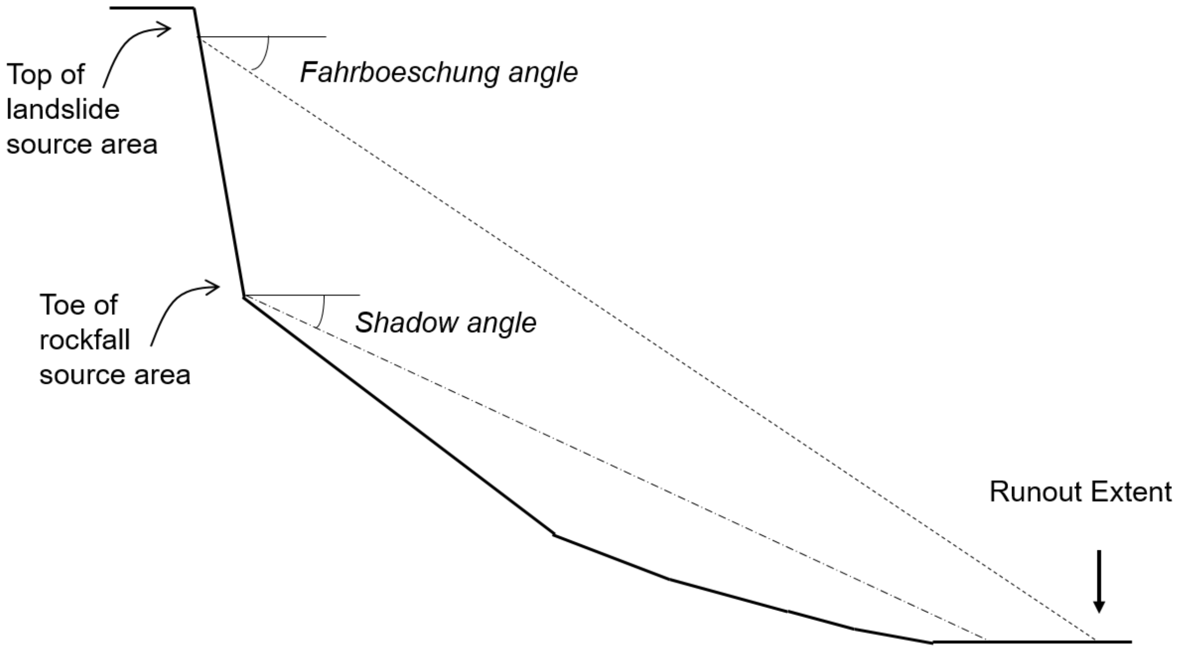

Figure 2.3 Conceptual cross-section displaying the rockfall shadow angle and Fahrböschung angle.

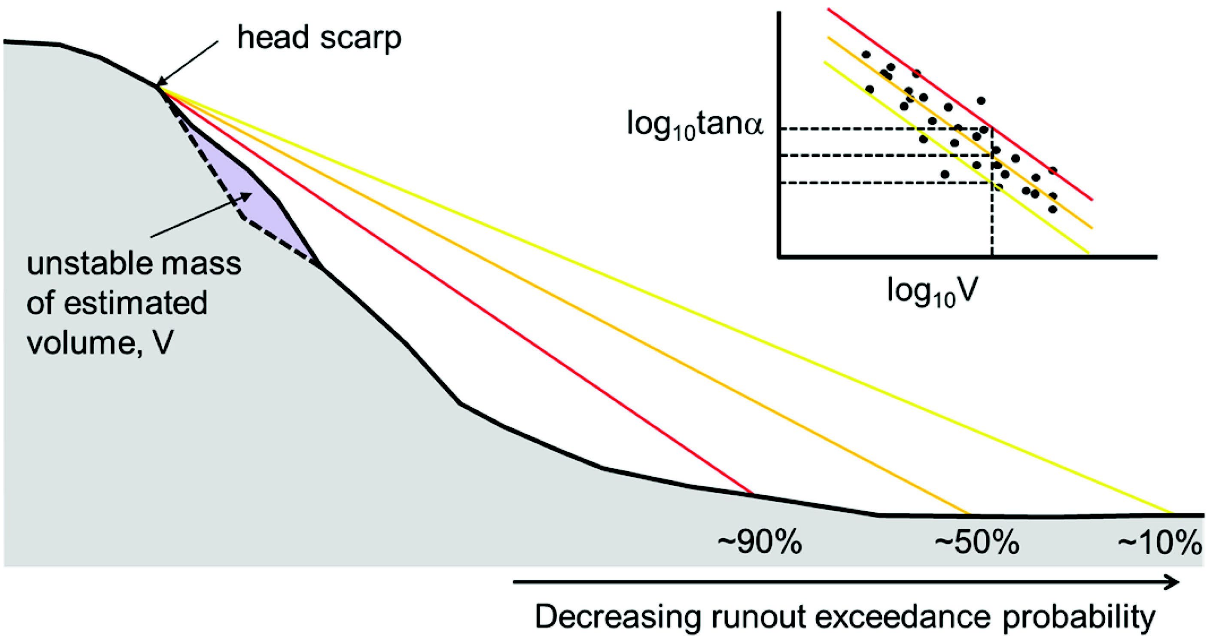

Figure 2.4 Calculation of the probability of runout exceedance based on the scatter in the empirical data (figure from McDougall [2017]).

Table 2.5 Fahrböschung angles for channelised flows and open-slope avalanches for different landslide volumes (Brideau et al. 2021).

Landslide Volume (m^3)	10%-Passing Fahrböschung Angle		
	Channelised Flow	Dry Avalanche	Wet Avalanche
10	22	38	29
100	18	36	25
1000	14	34	21
10,000	11	32	18
100,000	9	30	16
1,000,000	7	28	NA*

* Dataset (Brideau et al. 2021) contains no records of wet debris avalanches greater than 100,000 m^3.

2.6 Slippage

2.6.1 Determining the Amount of Slippage

During the field visit and subsequent desktop analysis, the amount of slippage that could occur and the area affected should be estimated from:

- The credible landslide hazard on the slope below, including the approximate volume of the landslide, and the type of landslide as outlined in the Cruden and Varnes (1996) classification scheme. The failure mode of the landslide, such as translation or rotation, may affect the magnitude of slippage.
- Evidence of slippage, including active or incipient foundation failure of infrastructure, and geomorphic indicators, such as tension cracks (Hancox 2008).
- Proximity to a slope edge. For example, a point location located within 20 m of a steep slope edge may be more susceptible than a point location situated on broad ridges and terraces that are 50 m to 100 m from the slope edge (Hancox 2008).

Slippage might include extremely rapid (5 m/s) to extremely slow (<16 mm/year) debris movement velocity.

2.6.2 Determining the Speed of Slippage

To determine if a life-safety risk exists from slippage, an assessment needs to be made of the potential for the landslide mass to fail rapidly – under certain conditions such as an earthquake or undercutting/erosion of the toe – and without usable warning time. Expert elicitation should be used to determine if this is a credible scenario for a site affected by slippage. The uncertainty around this expert judgement should be clearly noted.

2.7 Spatial Scale, Extent of Analysis and Study Area Boundary

The screening methodology should be used at all spatial scales from regional to site-specific in order to determine the level and scale of any future analysis. The spatial scale at which the preliminary screening methodology is applied will vary for the type of site, linear or point, and, in particular, the length of a linear site. For example, the analysis of a multi-day tramp along a linear route may require a more regional-scale analysis than that of a single day tramp along a linear route.

The initial study area boundary will be set by DOC when they initially scope the work. This boundary will be approximate and may need to be refined. This could be done at several stages and refined as/when needed. The preliminary screening methodology should identify the study area boundaries based on the extent of the identified hazard footprints and site(s) being assessed.

2.8 Hazard and Exposure Matrix

2.8.1 Falling Debris

2.8.1.1 Visitor Exposure

The spatio-temporal probability represents the proportion of time (P) over a trip per day that the individual of interest spends within the path of the landslide debris, as outlined in Table 2.6. The hazard and exposure classes are calculated for lower-, medium- and higher-risk threshold visitor sites, with the site classification provided by DOC.

To calculate the hazard and exposure class for visitors at lower- and medium-risk threshold visitor sites, Table 2.7 is used, where the individual of interest is a visitor who spends the most time within the path of the landslide debris for any one day (i.e. trip per day). For both the most likely volume and maximum credible landslide volume, the hazard and exposure class for the individual of interest per trip is estimated by combining the estimated recurrence interval with the spatio-temporal probability of the individual of interest (Table 2.7). The hazard and exposure classes are related to the risk per trip per day. Details are given in Appendix 4. To calculate the hazard and exposure class for visitors at higher-risk visitor sites, Table 2.8 is used, where the individual of interest is a visitor who spends the most time within the path of the landslide debris for any one day (i.e. trip per day).

The class level is dependent on which volume derives the highest rating. For example, if the individual of interest spends <0.001 of the proportion of the trip in the path of landslide debris for both the most likely and maximum credible landslide volume, but the most likely landslide has a temporal probability of ‘very high’ and the maximum credible volume has a temporal probability of ‘low’, the class rating should be Class 2.

Table 2.6 Spatio-temporal probability descriptors for the individual of interest.

Proportion of Time Spent at a Given Hazard Level in 24 Hours	This Approximately Equals:	Example Activity
>0.1	More than 3 hours	Staying at a hut
0.1–0.01	From ½ an hour to 3 hours	Picnic spot
0.01–0.001	From 2 minutes to ½ an hour	Stopping at viewing area
0.001–0.0001	From 10 seconds to 2 minutes	Crossing a swing bridge
<0.0001	Less than 10 seconds	Walking past a given point (e.g. 1 m^2)

Table 2.7 Hazard and exposure matrix for a visitor (individual of interest) per trip at lower and medium visitor risk sites.

Spatio-Temporal Probability of the Visitor	**Temporal Probability**					
Proportion of time over a trip per day that an individual spends at a given hazard level	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Extremely High**
>0.1	Class 1	Class 2*	Class 3	Class 4	Class 4	Class 4
0.1–0.01	Class 1	Class 1	Class 2*	Class 3	Class 4	Class 4
0.01–0.001	Class 1	Class 1	Class 1	Class 2*	Class 3	Class 4
0.001–0.0001	Class 1	Class 1	Class 1	Class 1	Class 2*	Class 3
<0.0001	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2*

* For medium visitor risk sites, Class 2 designation should have lower priority for risk-management actions, including any mitigation.

Note: Class 4 sites would receive consideration for the highest priority of investigations and analysis.

Table 2.8 Hazard and exposure matric for a visitor (individual of interest) per trip at higher visitor risk sites.

Spatio-Temporal Probability of the Visitor	**Temporal Probability**					
Proportion of time over a trip per day that an individual spends at a given hazard level	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Extremely High**
>0.1	Class 1	Class 1	Class 2	Class 3	Class 4	Class 4
0.1–0.01	Class 1	Class 1	Class 1	Class 2	Class 3	Class 4
0.01–0.001	Class 1	Class 1	Class 1	Class 1	Class 2	Class 3
0.001–0.0001	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2
<0.0001	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1

2.8.1.2 Worker Exposure

To calculate the hazard and exposure class for workers, Table 2.9 are used, where the individual of interest is the worker who spends the most time within the path of the landslide debris for any one day (i.e. the most exposed worker). As the most exposed worker may spend varying times at the site, the hazard and exposure classes are calculated for the different length of times that a worker may be present at the site, using information provided by DOC. The cumulative time spent over the course of a whole year should be summed to determine the total time exposed (e.g. if a worker is present in a hazard footprint for 10 minutes a day for three months a year, the total time exposed is 15 hours a day). For both the most likely volume and maximum credible landslide volume, the hazard and exposure class for the individual of interest is estimated by combining the estimated recurrence interval with the spatio-temporal probability of the individual of interest (Table 2.9). The hazard and exposure classes are related to the annual individual fatality risk. Details are given in Appendix 4.

Table 2.9 Hazard and exposure matrix for the worker (individual of interest).

Spatio-Temporal Probability of the Worker	Temporal Probability					
Proportion of time over a trip per year that an individual spends at a given hazard level	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Extremely High**
More than 3 months a year	Class 2	Class 3	Class 4	Class 4	Class 4	Class 4
3 months to 10 days a year	Class 2	Class 2	Class 3	Class 4	Class 4	Class 4
10 days to 1 days	Class 1	Class 2	Class 2	Class 3	Class 4	Class 4
1 day to 3 hours	Class 1	Class 1	Class 2	Class 2	Class 3	Class 4
3 hours to ½ hour	Class 1	Class 1	Class 1	Class 2	Class 2	Class 3
>½ hour	Class 1	Class 1	Class 1	Class 1	Class 2	Class 2

2.8.1.3 Changes to Hazard and Exposure Classes

Once an initial hazard and exposure class has been assigned for both visitors and workers, the two questions outlined in Figure 2.1 should be considered to see if any reduction in hazard and exposure class is justified. These two questions are:

1. Are there site-specific conditions that would significantly reduce the risk?
2. Can mitigation measures – which are in keeping with DOC's philosophy – be used to significantly reduce the risk?

The consultant must outline the logic and reasoning behind any reduction in hazard and exposure class. A significant reduction is defined as the ability for site-specific conditions or mitigations measures to reduce the hazard and exposure by one or more classes. The consultant must report both the unmodified hazard and exposure class and modified hazard and exposure classes.

2.8.2 Slippage

The hazard and exposure class for slippage is dependent on the potential for the credible landslide hazard to fail rapidly without warning. If there is the potential for rapid failure, then Tables 2.7 and 2.8 should be used to determine the hazard and exposure rating. However, if it is assessed that there is no potential for the credible landslide to fail rapidly without warning, then Class 1 should be assigned.

2.9 Risk-Management Actions

The aim of the preliminary screening methodology is to identify and prioritise areas within public conservation lands and waters for further risk analysis and risk-management actions. As such, the hazard and exposure classes from 1 to 4 have associated actions for further risk analysis/management. Table 1.2 outlines the actions for each class. Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel (see the Part 1 report). The four questions in Figure 2.1 should be considered in conjunction with the hazard and exposure classes to determine any further risk-management actions, both within the report and as part of a panel discussion.

These three questions are:

1. What is the cumulative risk for the entire experience?
2. Are there site-specific conditions that would significantly reduce the risk?
3. Can mitigation measures – which are in keeping with DOC's philosophy – be used to significantly reduce the risk?

A significant reduction is defined as the ability for site-specific conditions or mitigation measures to reduce the hazard and exposure by one or more classes.

It is important to note that, at this preliminary screening methodology stage, the uncertainties regarding the information provided will be relatively large. Any future analyses should be used to reduce these uncertainties. At this stage, the uncertainties on the estimated landslide volumes, runout distances, speed of failure (for slippage hazards), hazard footprints and temporal probability should be clearly noted in the report.

3.0 REPORT REQUIREMENTS

The information derived for each site, as set out in Section 2, should be summarised by the consultant in a letter report. This report should document the data gathered, logic applied and conclusion reached so that the decisions that determined the hazard and exposure class can be defended. The consultant will gather relevant data, assess the relevance of that data and present their results and uncertainties in a way that can be easily interrogated by others.

The general data to be presented, with reference to the study area boundary, include:

a. Executive summary that outlines the following:
    i. Summary of findings from the report.
    ii. Hazard and exposure classes.
    iii. Assumptions and uncertainty associated with the findings.
b. List of data sources used.
c. Discussion of investigation methods used and any limitations thereof.
d. Description of potential landslides within the study area, discussed in terms of the classification, volume or area and location in relation to site.
e. Description of landslide temporal probability, considering landslide-triggering factors.
f. Description of field visit(s); who went, where they went (e.g. GPS track log).
g. Map(s) and/or annotated photograph(s) of the potential landslide source areas explicitly considered, their estimated volumes and the resulting potential runout of falling debris or the approximate extent of areas affected by slippage relevant to the site.
h. Map showing the hazard footprints for the different types of landslide hazards identified in (f).
i. Assessed hazard and exposure classes for both slippage and falling debris hazards identified.
j. Description of the uncertainties associated with (a) to (j) and their impact on the hazard and exposure analysis results.
k. Recommendations for future analysis / risk mitigation.
l. Modified hazard and exposure classes, if appropriate, and the logic and reasoning behind the reduced hazard and exposure classes.

Where any of the above is not or cannot be completed, the report should document the missing elements, including an explanation as to why.

3.1 Peer-Review Requirements

Internal review by a competent consultant is required. As part of the expert panel, DOC will provide a 'high-level' quality check of the report.

4.0 CONCLUSION

The purpose of the screening methodology is to identify whether more investigation and analysis is needed at a site, provide a guide to prioritising the investigations and determine what level of analysis should be undertaken. The preliminary screening methodology is only concerned with life-safety considerations for visitors and workers within the public conservation lands and waters at point sites or at specific points or sections along a linear site and assesses the exposure of visitors and workers to the landslide hazard(s).

The screening methodology allows the user to identify: (1) the different types of landslide hazards that could affect the site; (2) the magnitude and area affected (the 'hazard footprint') and (3) the probability of occurrence, which is how often the hazard could occur. This includes identifying whether a site could be affected by slippage or falling debris hazards. The areas affected by slippage or falling debris are defined to determine the hazard footprint and therefore the number of people that may be exposed within the footprint(s) for the different hazard types. The exposure of both visitors and workers to the landslide hazard(s) is assessed. The hazard probability of occurrence and exposure are then used to define the hazard and exposure class (Class 1–4) for a site, based on the hazard and exposure matrix. The risk-management actions associated with hazard and exposure class are:

1. **Class 1:** No further risk analysis required. DOC should develop appropriate risk-management plans and re-evaluate the risk-management plan if there is a change in hazard activity or the number of people exposed.
2. **Class 2:** Basic level of risk analysis required. The analysis should highlight and identify the potential impacts to persons on the public conservation lands and waters. Identified high-risk sites may require further advanced risk analysis and consideration of mitigation options.
3. **Class 3:** Urgent action is required. This may involve interim risk-management solutions (e.g. closures) while solutions are developed. Basic-level risk analysis must be undertaken, and an advanced-level risk analysis of risk may be required.
4. **Class 4:** Urgent action is required. This may involve interim risk-management solutions (e.g. closures) while solutions are developed. Basic-level risk analysis must be undertaken, and an advanced-level analysis of risk may be required. Class 4 represents the highest priority for further risk analysis and risk-management actions.

Any further risk-management actions, including risk analysis, are at the discretion of DOC on the advice of the expert panel. It is also important to note that, for the preliminary screening methodology, the uncertainties regarding the information provided are relatively large.

5.0 ACKNOWLEDGEMENTS

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APPENDICES

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APPENDIX 1 RISK-MANAGEMENT WORKFLOW

APPENDIX 2 RISK TERMINOLOGY

The landslide hazard and risk terminology of the ISSMGE (International Society for Soil Mechanics and Geotechnical Engineering), ISRM (International Society for Rock Mechanics) and IAEG (International Association of Engineering Geologists) Joint Technical Committee working group (JTC1) has been adopted. Table A2.1 contains the main terms used within the report and is adapted from Corominas et al. (2015) and Fell et al. (2008). Each of the terms, such as landslide risk, landslide susceptibility and landslide hazard, have a specific definition, cannot be used interchangeably and should be used for landslide risk studies.

Table A2.1 Glossary of terms on landslide hazard and risk (adapted from Fell et al. [2008] and Corominas et al. [2015]).

Term	Definition
Conditional probability	The probability of an outcome, given the occurrence of some event.
Consequence	In the context of risk analysis, the outcome or result of a hazard being realised.
Danger (threat)	The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a menacing block). The characterisation of a danger or threat does not include any forecasting.
Elements at risk	Population, buildings and engineering works, infrastructure, environmental features, cultural values and economic activities in the area affected by an event (e.g. landslide).
Exposure	People, property, systems or other elements present in hazard zones that are thereby exposed to potential losses.
Extreme event	An Event, which has a very low annual exceedance probability.
Forecast	Definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area.
F–N curves	Curves relating the probability per year of causing N or more fatalities (F) to N. This is the complementary cumulative distribution function. Such curves may be used to express multiple fatality risk criteria and to describe the safety levels of particular facilities.
Fragility curve	A curve that defines the probability of failure as a function of an applied load level.
Individual risk to life	The increment of risk imposed on a particular individual by the existence of a hazard. This increment of risk is an addition to the background risk to life, which the person would live with on a daily basis if the hazard did not exist.
Landslide hazard	A condition that expresses the probability of a particular threat occurring within a defined time period and area.
Landslide inventory	A record of recognised landslides in a particular area. The landslides can be distinguished by typology, geometry and activity.
Landslide intensity	A set of spatially distributed parameters related to the destructive potential of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width or kinetic energy per unit area.
Landslide magnitude	The measure of the landslide size. It may be quantitatively described by its volume or indirectly by its area. The latter descriptors may refer to the landslide scar, landslide deposit or both, but this must be specified.

Term	Definition
Landslide probability	In the framework of landslide hazard assessment, the following types of probability are of importance: (i) Spatial probability – the probability that a given area is affected by a landslide. (ii) Temporal probability – the probability that a landslide will occur in a given period of time in a specified area. (iii) Size/volume probability – the probability that any given landslide has a specified size/volume. (iv) Runout probability – the probability that any given landslide will reach a specified distance or affect a specified area downslope.
Landslide susceptibility	A quantitative or qualitative assessment of the volume (or area) and spatial distribution of landslides, which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landslide.
Landslide susceptibility map	A map showing the subdivision of the terrain in zones that have a different probability that landslides of a given type may occur.
Mitigation	Measures undertaken to limit the adverse impact of, for instance, natural hazards, environmental degradation and technological hazards.
Multiple fatality risk	The risk to society of widespread or large-scale detriment from the realisation of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio-political response.
Recurrence interval	The recurrence interval, or return period, is the long-term average elapsed time between landslide events at a particular site or in a specified area.
Risk	Measure of the probability and severity of an adverse effect to life, health, property or the environment. Quantitatively, $Risk = Hazard \times Potential\ Worth\ of\ Loss$ This can be also expressed as ‘Probability of an adverse event times the consequences if the event occurs’.
Risk analysis	The use of available information to estimate the risk to individuals, populations, property or the environment from hazards. Risk analyses generally contain the following steps: definition of scope, danger (threat) identification, estimation of probability of occurrence to estimate hazard, evaluation of the vulnerability of the element(s) at risk, consequence analysis, and their integration.
Quantitative risk analysis	An analysis based on numerical values of the probability of occurrence of a potentially damaging event and vulnerability of the exposed elements and consequences that results in a numerical value of the risk.
Reach probability / runout probability	Probability that a specified landslide will reach a certain distance downslope or affect a specified area.
Risk assessment	The process of making a recommendation on whether existing risks are acceptable and present risk control measures are adequate, and, if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates the risk-analysis and risk-evaluation phases.

Term	Definition
Risk evaluation	The stage at which values and judgement enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences in order to identify a range of alternatives for managing the risks.
Risk management	The systematic application of policies, procedures and practises to the tasks of identifying, analysing, assessing, monitoring and mitigating risk.
Risk mitigation	Application of appropriate techniques and principles to reduce either probability of an occurrence or its adverse consequences or both.
Spatio-temporal probability of the element at risk	The probability that the element at risk is in the landslide path at the time of its occurrence. It is the quantitative expression of the exposure.
Tolerable risk	A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
Vulnerability	The degree of loss of a given element or set of elements exposed to the occurrence of a landslide of a given magnitude/intensity. It is often expressed on a scale of 0 (no loss) to 1 (total loss).

APPENDIX 3 LANDSLIDE CLASSIFICATION

The report uses the Cruden and Varnes (1996) update of the Varnes (1978) landslide classification system. Table A3.1 outlines that landslides are classified based on the type of movement and material type. For more information on the basis of the classification system, and associated definitions for each landslide type, see Cruden and Varnes (1996). Figure A3.1 contains the main types of landslides. More information on failure mode, speed of failure and material type is in Cruden and Varnes (1996).

Table A3.1 Summary of the landslide classification system (Cruden and Varnes 1996).

Type of Movement	Type of Material		
	Bedrock	Engineering Soils	
		Predominantly Coarse	Predominantly Fine
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Slide	Rock slide	Debris slide	Earth slide
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	Debris flow	Earth flow

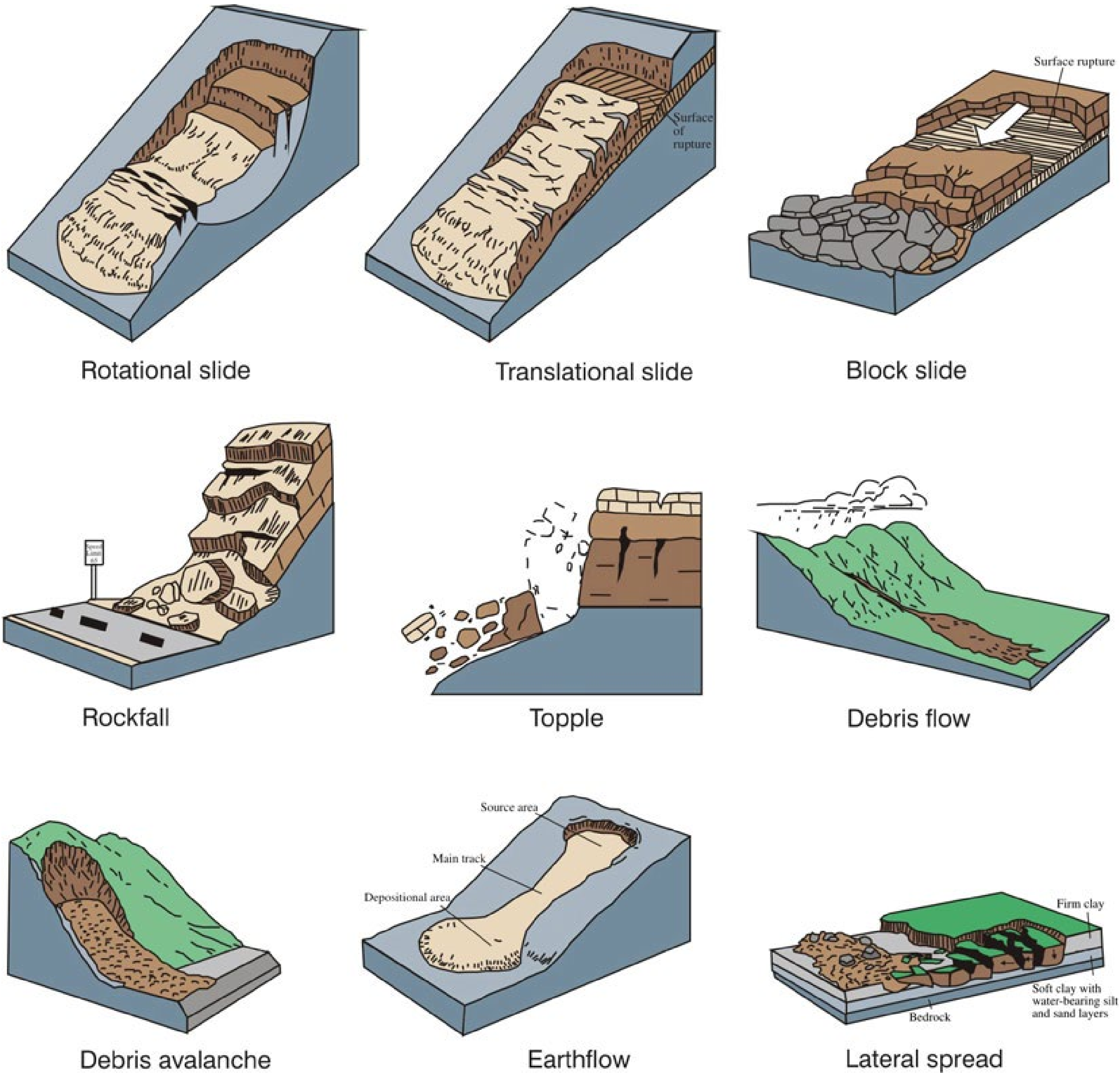

Figure A3.1 The main types of landslides (generalised after Cruden and Varnes [1996]).

APPENDIX 4 RISK CALCULATIONS FOR HAZARD AND EXPOSURE TABLES

To determine the hazard and exposure classes for visitors, the classes are approximately related to the risk per trip per day (Table A4.1).

Table A4.1 Matrix for calculating the individual hazard and exposure class using the temporal probability and spatio-temporal probability of the individual as inputs and using lower- to medium-risk threshold visitor sites.

Spatio-Temporal Probability of the Visitor	**Temporal Probability**					
Proportion of time over a trip per day that an individual spends at a given hazard level	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Extremely High**
>0.1	Class 1	Class 2	Class 3	Class 4	Class 4	Class 4
0.1–0.01	Class 1	Class 1	Class 2	Class 3	Class 4	Class 4
0.01–0.001	Class 1	Class 1	Class 1	Class 2	Class 3	Class 4
0.001–0.0001	Class 1	Class 1	Class 1	Class 1	Class 2	Class 3
<0.0001	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2

This relationship assumes that the vulnerability of a person exposed to a landslide is 1.

The relationship can be illustrated by example. Consider a picnic site at the medium temporal probability (100–1000-year return period) that the visitor visits for between half an hour and three hours (0.1–0.01 proportion of a 24-hour period). The annual probability of the hazard occurring at the site is therefore 10^{-2}–10^{-3}. The annual probability is divided by 365 days to calculate the daily probability of the hazard occurring. As vulnerability is assumed to be 1, the risk per trip per day is of the order of 10^{-6}–10^{-8}. Taking the geomean of this range on a logarithmic scale, the risk per trip per day is derived to be of the order of 10^{-8}.

Table A4.2 shows the resulting relationship between hazard and exposure class and the Annual Individual Fatality Risk (AIFR). The relationship can be illustrated by example. Consider a DOC hut site at the medium temporal probability (100–1000-year return period) that the worker visits for between half an hour and three hours (0.1–0.01 proportion of a 24-hour period) for three months a year. The sum of the worker's exposure over that three-month period is on the order of 10^{-3}. The annual probability of exposure to the hazard is then obtained by multiplication to be 10^{-4}–10^{-6}. As vulnerability is assumed to be 1, the AIFR is of the order of 10^{-4}–10^{-6}. Taking the geomean of this range on a logarithmic scale, the AIFR is derived to be of the order of 10^{-5}.

Table A4.2 Hazard and exposure matrix for the worker (individual of interest).

Spatio-Temporal Probability of the Worker	**Temporal Probability**					
Proportion of time over a trip per year that an individual spends at a given hazard level	**Very Low**	**Low**	**Medium**	**High**	**Very High**	**Extremely High**
More than 3 months a year	Class 2	Class 3	Class 4	Class 4	Class 4	Class 4
3 months to 10 days a year	Class 2	Class 2	Class 3	Class 4	Class 4	Class 4
10 days to 1 days	Class 1	Class 2	Class 2	Class 3	Class 4	Class 4
1 day to 3 hours	Class 1	Class 1	Class 2	Class 2	Class 3	Class 4
3 hours to ½ hour	Class 1	Class 1	Class 1	Class 2	Class 2	Class 3
>½ hour	Class 1	Class 1	Class 1	Class 1	Class 2	Class 2

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