



**REPORT**

# **New South Wales National Parks and Wildlife Service** *Guidelines for Quantitative Risk to Life Calculations for Landslides*

Submitted to:

**New South Wales National Parks and Wildlife Service**

New South Wales Government

Submitted by:

**Golder Associates Pty Ltd**

Building 7, Botanicca Corporate Park 570 – 588 Swan Street Richmond, Victoria 3121

Australia

+61 3 8862 3500

19120759-002-R-Rev5

2 June 2023



## Distribution List

1 Copy - NSW National Parks and Wildlife Service

1 Copy - Golder Associates Pty. Ltd.

---

# Table of Contents

1.0 INTRODUCTION .....	1
2.0 GUIDELINES.....	1
3.0 EXAMPLES.....	2
4.0 IMPORTANT INFORMATION.....	2
5.0 REFERENCES.....	2

## APPENDICES

**APPENDIX A**  
Guidelines for the Quantitative Calculation of Landslide Risk

**APPENDIX B**  
Worked Examples

**APPENDIX C**  
Technical Information

**APPENDIX D**  
Important Information

## 1.0 INTRODUCTION

The New South Wales National Parks and Wildlife Service (NPWS) has developed a policy and procedures for the assessment and management of risk associated with landslide in NSW national parks. In conjunction with A.S. Miner Geotechnical (ASM) and the University of Wollongong (UoW) Golder assisted in the development of the policy and procedures by providing peer review and feedback on a draft version of the policy and procedures documents. The Landslides and Rockfall Procedures were introduced in 2019 and include the following key information with respect to the management and landslide and rockfall hazards in NSW national parks.

- The incorporation of thresholds for the evaluation of risk to life from landslide and rockfall, including thresholds for the individual most at risk and for societal risk.
- Adopting the criteria for the individual most at risk as suggested in the Australian Geomechanics Society (AGS) Guidelines for Landslide Risk Management (AGS 2007).
- Adoption of criteria for societal risk adapted from ANCOLD 2022 where the population exposed to a hazard exceeds 10.

Guidelines were produced to accompany the Procedures. The guidelines are intended to provide clear guidance to geotechnical practitioners setting out preferred methods for calculating individual and societal risk so as to allow comparison with the evaluation criteria set out in the policy document.

This report presents guidelines and examples for the assessment the risk to the individual most at risk and societal risk within NSW national parks along with the technical basis for the guidelines presented. This fourth revision of the guidelines has been prepared in response to feedback received from practitioners following two years of implementation of the guidelines.

## 2.0 GUIDELINES

Guidelines for the calculation of risk to life are presented in Appendix A. These guidelines are intended to outline a step by step process for the calculation of individual and societal risk. The objective of providing these guidelines is to achieve consistency in how landslide risks are calculated and reported by different practitioners who might undertake landslide risk assessment work within NSW national parks.

The guidelines do not cover field techniques for landslide assessment. It is assumed that practitioners undertaking landslide risk assessment work will be suitably experienced in undertaking all the investigations and inquiries necessary to acquire the data to support inputs to the landslide risk assessment calculation. Further guidance on input selection is presented in AGS2007.

The guidelines are intended to cover common scenarios that might be encountered in national parks. However, they are not intended to cover all scenarios and it may be appropriate at times to undertake different calculations to those set out in the guidelines. Where this is done, it is expected that references and supporting calculations are provided for transparency. AGS2007 sets out the fundamentals of landslide risk assessment and provides a useful reference on which to base calculations.

The technical basis for the guidelines is set out in Appendix C.

### 3.0 EXAMPLES

Six worked examples have been compiled. Each example addresses a scenario that could be encountered within a national park and which is intended to demonstrate the application of different parts of the guideline.

These examples include:

Example 1 – Risk to a tourist cabin in a national park. This example may also be applicable to other types of buildings in or adjacent to parks.

Example 2 – Risk to visitors at a lookout point. This example may be of use to calculate risk to visitors to a point of interest or area where people may congregate such as picnic grounds and bus stops.

Example 3 – Risk to staff within an administration building. This example assumes the building is subject to multiple hazards and may provide guidance in a scenario where people are at risk from multiple hazards.

Example 4 – Risk to a ranger undertaking inspections. This example may be applicable to situations with a mobile element at risk where the same individual or few individuals are exposed to the hazard over multiple occasions or for an extended time. For example, work and maintenance crews.

Example 5 – Risk to the public on a walking track subject to hazards. This example may provide guidance in other situations where there are a large number of mobile elements at risk such as hikers or vehicles that must traverse areas at risk from landslide.

Example 6 – Risk to a tour bus. This example may provide guidance in scenarios where there are large numbers of people who are mobile and exposed to a hazard at the same time.

### 4.0 IMPORTANT INFORMATION

Your attention is drawn to the document - 'Important Information Relating to this Report' (LEG04, RL2), which is included in Appendix D of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

We would be pleased to answer any questions the reader may have regarding this document.

### 5.0 REFERENCES

AGS, 2007, Australian Geomechanics Society, Landslide Risk Management, Journal and News of the Australian Geomechanics Society, Volume 42 No 1, March 2007

AGS2007a, Australian Geomechanics Society, Guideline for Landslide Susceptibility, hazard and risk zoning for land use planning, Journal and News of the Australian Geomechanics Society, Volume 42 No 1, March 2007

AGS 2007c, Australian Geomechanics Society, Practice Note Guidelines for Landslide Risk Management, Journal and News of the Australian Geomechanics Society, Volume 42 No 1, March 2007

AGS 2007d Australian Geomechanics Society, Commentary on Practice Note Guidelines for Landslide Risk Management, Journal and News of the Australian Geomechanics Society, Volume 42 No 1, March 2007

ANCOLD 2022, Guidelines on Risk Assessment, Australian National Committee on Large Dams, Inc, Melbourne.

Lee, E.M., Jones, D.K.C. 2013, Landslide Risk Assessment, ICE Publishing.

NSW Roads and Maritime Service 2014, Guide to Slope Risk Analysis, Version 4, April 2014.

## Signature Page

**Golder Associates Pty Ltd**



Darren Paul  
*Principal Engineering Geologist*

DRP/SC/drp

Golder and the G logo are trademarks of Golder Associates Corporation

c:\users\dpaul\downloads\19120759-002-r-rev5.docx

**APPENDIX A**

**Guidelines for the Quantitative  
Calculation of Landslide Risk**



## INTRODUCTION AND SCOPE OF THIS GUIDELINE

This guideline sets out a method for calculating risk to life in NSW national parks. The principal objective of this guideline is to provide a standard method for quantitatively calculating risk to life for various scenarios that could be encountered in national parks and for which landslide risk assessment may be undertaken. It also provides criteria for risk acceptance and guidance on how to evaluate a calculated risk to life.

This guideline is not intended to cover:

- Landslide hazard analysis including landslide characterisation.
- The identification of landslide hazards.
- Landslide likelihood analysis.
- Landslide consequence analysis.
- The development of risk mitigation options.
- Qualitative risk assessment.
- The assessment of risks to vehicles impacting road obstructions arising from landslide (it is recommended that RMS 2014 be used to assess risk in this scenario). This guideline does cover direct impact to vehicles and other moving elements at risk from landslide.

Guidance on these aspects of landslide risk assessment, including the estimation of the parameters required for input into the calculations set out in this guideline is available in:

*Australian Geomechanics Society, Landslide Risk Management, Journal and News of the Australian Geomechanics Society, Volume 42 No 1, March 2007 (AGS 2007)*

This guideline is intended for use by geotechnical practitioners familiar with AGS 2007, quantitative landslide risk assessment and field assessment techniques. Whilst this guideline is intended to provide a consistent, repeatable method for calculating risk from landslide, it is acknowledged that a wide variety of landslide hazards and hazard scenarios are present within NSW national parks. Deviation from this guideline is permitted, provide clear justification, transparency and technical explanation is given for any deviation.

## PROCESS FOR CALCULATING RISK FROM LANDSLIDE

There are a variety of landslide hazards that can occur in National Parks, including hazards arising from a range of processes (rockfall, debris flow, earthworks failure, deep seated landslide etc.). Furthermore, risk to life from landslide could occur under a range of scenarios, for example mobile hikers on a track, people static on a lookout, people within a building etc. The calculations that must be undertaken to quantitatively assess risk in these various scenarios differ. The flow chart in Figure 1, provides guidance on steps to take in undertaking calculations of landslide risk and for evaluating the calculated risks against a criteria under various scenarios. The process set out in the chart considers the following key variables that affect the manner in which the calculations are undertaken:

- 1) Whether the element is mobile (for example hikers) or static (for example people on a lookout).
- 2) The number of people exposed to the hazard (less than 10 or 10 or more).
- 3) The number of hazards to which people are exposed (1 or more than 1).

The process has been set up such that there are two possible outcomes for each of the key variables listed above and therefore 8 different pathways through the flowchart in Figure 1. This is illustrated diagrammatically below.

Note that worked examples have been provided for 6 of the different pathways as indicated.

Static Element at Risk				Mobile Element at Risk			
<10 people		≥10 people		<10 people		≥10 people	
1 hazard	>1 hazard	1 hazard	>1 hazard	1 hazard	>1 hazard	1 hazard	>1 hazard

Each step on the flow chart in Figure 1 may be cross referenced to guidance on how to complete the step. These are included after the flow chart, noting different pathways require different steps to be implemented and not every pathway requires every step to be undertaken.

The assessed risks are compared to an evaluation criteria. The NPWS Procedures for landslide risk management should be consulted to ensure evaluation against the appropriate criteria. The criteria referred to in these guidelines are adapted from AGS2007c for risk to the individual and ANCOLD 2022 for societal risk.

## LIST OF ABBREVIATIONS

The following summarises abbreviations used in this guideline.

- d** The length of a track that could be impacted by a landslide. For rockfall,  $d$  = the boulder diameter.
- e** The exposed population (an integer), referring to the number of separate individuals exposed to a hazard over the course of a year.
- $e_s$**  The number of people within a subgroup of the exposed population,  $e$  that could be impacted by a single occurrence of a hazard.
- $e_{av}$**  The hypothetical average number of people exposed to a hazard assuming they are exposed for 100 % of the time.
- F** The probability of impact to the exposed population resulting in the death of  $N$  or more people.
- $F_C$**  The combined probability of loss of life of  $N$  or more people from multiple hazards.
- f** a reduction factor between 0 and 1 which describes the probability of a person being present when the landslide is triggered.
- l** a length of track affected by landslide in metres.
- n** the total number of traverses made annually by a mobile element at risk through an area at risk from landslide.
- $n_i$**  the number of traverses made annually by a specific individual, nominally the individual most at risk.
- N** the number people that are expected to be impacted and killed by a landslide hazard.
- $R_{(LOL)}$**  The probability of loss of life of the individual most at risk from a single hazard.
- $AvR_{(LOL)}$**  The average individual risk or probability of loss of life of the across all individuals in the exposed population or subgroup of the exposed population, used in the calculation of societal risk for mobile elements at risk.
- $R_{(LOLC)}$**  The combined probability of loss of life of the individual most at risk from multiple hazards.
- $P_{(H)}$**  The annual probability that a landslide or rockfall occurs.
- $P_{(S:H)}$**  The probability of spatial impact of the elements at risk.
- $P_{(T:S)}$**  The probability that persons will be in the area affected by the landslide or rockfall, i.e. the temporal spatial probability.
- $P_{(t)}$**  The probability, given a landslide occurs that rockfall or debris arising reaches a track or location where a person could be.
- s** The average speed in km/hr that a mobile element at risk moves through an area subject to a landslide hazard.
- $s_i$**  The speed in km/hr that the individual most at risk moves through an area subject to a landslide hazard.
- $V_{(D:T)}$**  The vulnerability of the individual given they are impacted by a hazard.

w The proportion of a track affected by the landslide and ranges between 0 (none of track affected) to 1 (full width of the track affected).

This guideline uses terminology as defined in AGS 2007. Refer to AGS 2007a, Appendix A for definitions of the terms used in AGS2007. In addition, the following terms are used in this guideline.

**Static element at risk** – A fixed element at risk within which people could be present. For example, a building or a lookout.

**Mobile element at risk** – An element at risk that is mobile. For example, a hiker or a vehicle.

**Track** – A pathway along which a mobile element at risk might move, for example a hiking track or road.

**Traverse** – The pass of a mobile element at risk through a zone at risk from landslide.

Guidance is provided on the quantitative calculation of individual risk and societal risk. For clarity, the definitions of each are provided below, noting that these definitions are adapted from AGS 2007.

**Individual Risk to Life** – The risk of fatality or injury to any identifiable (named) individual who is 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. In this guideline, individual risk to life is assessed for the individual most at risk, which is typically the person who has the greatest exposure to the landslide hazard.

**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. In this guideline, assessment of societal risk is recommended where the population exposed to the landslide hazard is 10 or more.

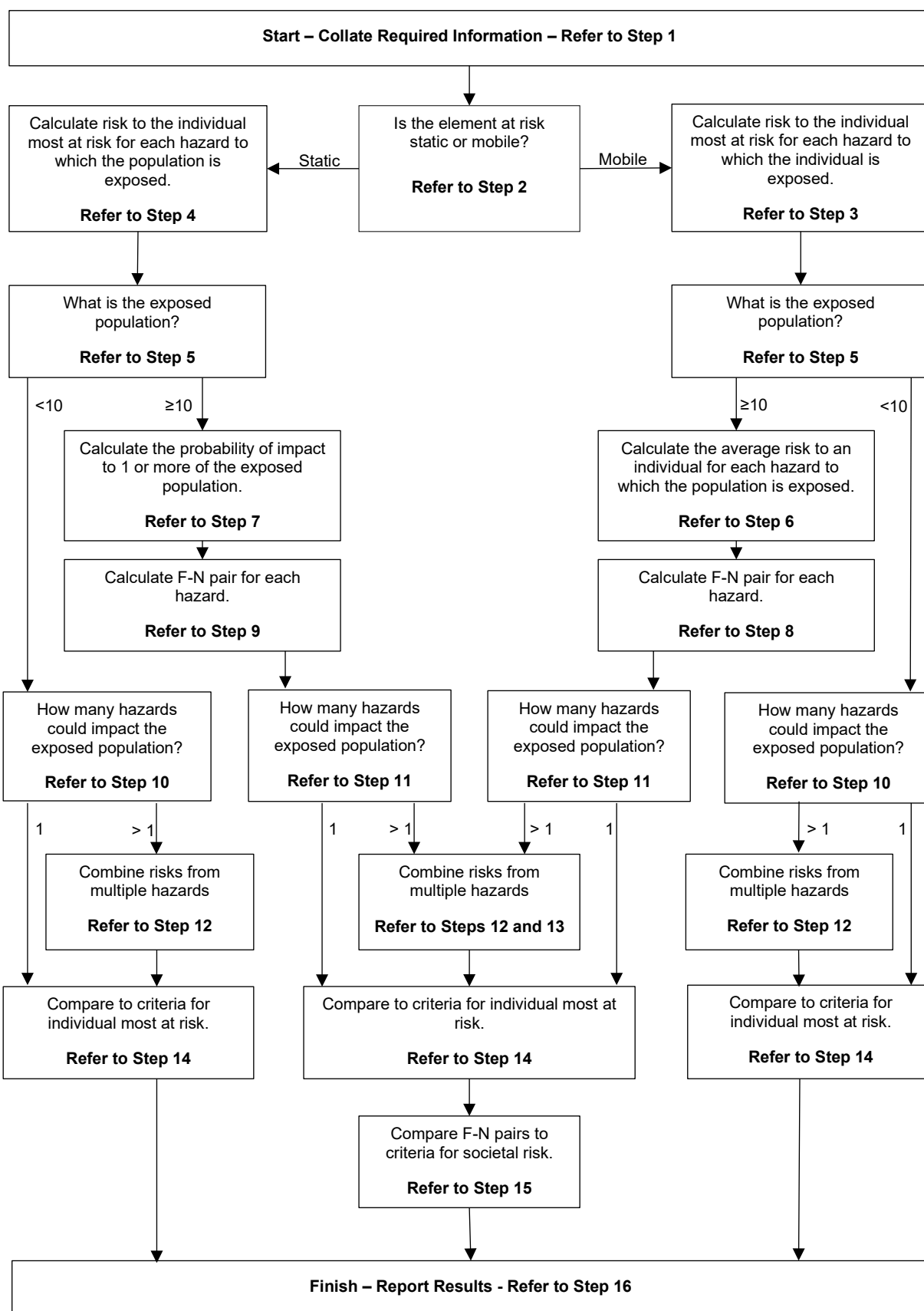


Figure 1 – Flow chart for the quantitative calculation of risk to life.

## Step 1. Information required to inform landslide risk assessment

Prior to commencing the risk calculations, the following minimum information is required:

- Hazard analysis, including hazard identification, volume and intensity estimation, and hazard trigger.
- An estimate of hazard frequency.
- An estimate of the number of people exposed to the hazard, including the total number of people exposed annually and the number that could be exposed in a single occurrence of the hazard.
- Whether the people exposed to the hazard are static or mobile.
- The number of independent hazards to which people might be exposed.
- Identification of the individual most at risk from the hazard.

## Step 2. Static versus mobile elements at risk

The 'element at risk' refers to an individual or group of people that could be impacted by a landslide, or the place where the individual or group could be. For example, the element at risk could be:

- A building containing people.
- A lookout on which people are standing.
- A person or group of people on a walking track.
- A vehicle containing people.

The calculation to determine the length of time an element at risk might be exposed to a hazard is undertaken slightly differently for mobile and static elements at risk, necessitating identification as to whether the hazard is static or mobile.

*Mobile elements at risk* – Applies where the element at risk moves at some nominated velocity through an area or location that is subject to landslide hazards. Typical examples in a park could include hikers on a walking track or people in moving vehicles. This guideline considers direct impact from landslides to mobile elements at risk. There may be circumstances that arise where a mobile element at risk impacts debris arising from a landslide. For example, a vehicle travelling on a road impacts a rock that has previously been detached and come to rest on the road. For these cases, it is recommended that risks are assessed in accordance with the NSW Roads and Maritime Service Guide to Slope Risk Analysis, Version 4, 2014.

*Static elements at risk* – Applies where the element at risk is static or near static in an area that could be subject to landslide hazards. Typical examples in a park include a lookout, a building, tents and caravans, houses adjacent to national parks and workers undertaking activities in a fixed location.

## Step 3. The Individual most at risk in a mobile scenario

Equations for calculating the risk to life for the individual most at risk, where the individual most at risk is mobile are presented below, including for rockfall, and for a hazard that could bury a person such as large landslide and debris flow. A general case is also provided which requires estimation of vulnerability. In the mobile scenario it is generally assumed that the mobile element at risk, usually a person or vehicle will be moving along a road or track. The term 'traverse' refers to a single pass through the area at risk from the hazard.

## General Case

The general case requires an estimate of vulnerability of the individual if they are impacted. In this case, Equation 1 may be used to estimate individual risk:

$$R_{(LOL)} = P_{(H)} P_{(t)} V_{(D:T)} n_i w f d \times 1.1 \times 10^{-7} / s_i \quad (1)$$

Where:

$R_{(LOL)}$  = the risk or annual probability of loss of life of the individual most at risk. This is usually the individual who is exposed to the hazard for the greatest duration which for a mobile hazard could be the person who walks slowest or makes the greatest number of traverses ( $n_i$ ).

$P_{(H)}$  = the annual probability that a landslide or rockfall occurs.

$P_{(t)}$  = the annual probability that rock or debris arising from the hazard impacts a location a person could be, for example that a rockfall impacts a track.

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted. Guidance is provided in AGS2007 on the selection of vulnerability.

$f$  = a reduction factor of between 0 and 1 and relates to the probability of a person being present when the landslide is triggered. For example, if the landslide trigger is heavy rain, and it is assumed that the individual is half as likely to be exposed to the hazard during heavy rain than at other times,  $f = 0.5$ . If unsure,  $f = 1$ . This parameter must be used with caution and if in doubt, assume  $f = 1$ .

$n_i$  = the number of traverses the individual most at risk makes within a year.

$w$  is the proportion of the width of the road or track affected by the landslide and ranges between 0 (none of track affected) to 1 (full width of the track affected). For example,  $w = 0.5$  indicates a person has a 50% chance on being on the side of the track impacted by the landslide hazard. If unsure,  $w = 1$ . For narrow, single file hiking tracks  $w$  is usually 1.

$d$  = the length of a track that could be impacted by a single occurrence of the landslide. For rockfall,  $d$  = the boulder diameter.

$s_i$  = the speed in km/hr that the individual most at risk moves through the area subject to the hazard. For estimating risk to the individual most at risk,  $s_i$  applies to the individual expected to move through the zone at risk at the slowest speed. For example, an infirm person using a walking track might move at speeds of less than 1 km/hr.

## Rockfall

For impact to a person from a rockfall, individual risk may be calculated using equation 2 where rockfalls are less than 0.5 m diameter<sup>1</sup> and equation 3 where rockfalls are greater than 0.5 m diameter:

For boulders or landslides less than 0.5 m diameter  $R_{(LOL)}$  is defined by equation 2 as:

<sup>1</sup> This equation assumes the suggested vulnerability values in Appendix F of AGS 2007c for a person in the open struck by rockfall. AGS2007 suggests a range of 0.1 to 0.7, which has been scaled in proportion to the boulder size. For boulders less than 0.5 m diameter,  $V_{(D:T)}$  is assumed to be 1.4 x the boulder diameter. For boulders greater than 0.5  $V_{(D:T)}$  is assumed to the maximum of the recommended range. Refer to Appendix C for more information. Other values for  $V_{(D:T)}$  may be used for rockfall at the discretion of the practitioner. The general case set out in Equation 1 can be used in this case.

$$R_{(LOL)} = P_{(H)}P_{(t)}n_iwfd^2 \times 1.6 \times 10^{-7} / s_i \quad (2)$$

For boulders greater than 0.5 m diameter<sup>2</sup>,  $R_{(LOL)}$  is defined by equation 3:

$$R_{(LOL)} = P_{(H)}P_{(t)}n_iwfd \times 8.0 \times 10^{-8} / s_i \quad (3)$$

#### ***Landslide and Debris Flow where a person could be buried***

Where the landslide is assumed to bury a person, for example as might occur in a debris flow event, equation 4 can be used to estimate risk to the individual most at risk:

$$R_{(LOL)} = P_{(H)}P_{(t)}n_iwfd \times 1.1 \times 10^{-7} / s \quad (4)$$

### **Step 4. Risk to the individual most at risk in a static scenario**

The annual risk of loss of life of the individual most at risk is defined in AGS 2007c by equation 5:

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (5)$$

Where:

$R_{(LOL)}$  = the risk or annual probability of loss of life of the individual most at risk. This is usually the individual who is exposed to the hazard for the greatest length of time or the individual with the highest vulnerability.

$P_{(H)}$  = the annual probability that a landslide or rockfall occurs.

$P_{(S:H)}$  = the probability of impact to the element at risk taking into account the travel distance, direction of the landslide and proportion of the element at risk impacted.

$P_{(T:S)}$  = the temporal spatial probability (e.g. of the specific individual being in an area or within an element at risk subject to landslide) given the spatial probability and allowing for evacuation if there is warning of the landslide or rockfall event. Consideration can be given to multiplying  $P_{(T:S)}$  by a reduction factor  $f$  if there are likely to be fewer people present when the hazard occurs. For example, fewer people at a lookout where the key trigger of the landslide is rainfall. Caution must be used if adopting this approach. If unsure, assume  $f = 1$ .

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted. Generally estimated using vulnerability tables presented in AGS 2007c.

#### ***Event tree analysis***

Direct estimate of the above parameters, in particular  $P_{(T:S)}$  would typically require an average estimate to be made. For example:

<sup>2</sup> Assumes  $V_{(D:T)} = 0.7$ , the maximum of the range recommended in AGS 2007 C, Appendix F for a person in the open struck by rockfall. Refer to Appendix C for more information.



- A cabin in a park might be expected to have a greater occupancy during summer and school holidays and less at other times.
- There might be the potential for evacuation or early warning before the hazard occurs.
- People are more likely to be inside the cabin during poor weather than during good weather.

There may be other factors which affect  $P_{(T:S)}$ . The examples presented in this guideline adopt the approach of estimating average temporal probability, typically estimated based on the average number of hours per year that a person is estimated to be exposed to the hazard. For example, the cabin might be occupied on average 8 hours per day over 300 days of the year.

However, more detailed analysis of the parameters in equation 5 can be undertaken using event trees. Event trees are expected to be most useful for estimating temporal probability,  $P_{(T:S)}$  but could also be used to estimate  $P_{(S:H)}$ , for example where there are multiple factors that could impact whether material arising from a landslide reaches the element at risk.

Event trees may be useful where an averaging approach is considered too inaccurate. Reference is made to Lee and Jones 2013 which discusses and provides examples of event tree analysis. A simple example is provided in Figure 2 for the estimate of  $P_{(T:S)}$  using an event tree, noting that an event tree can include as many factors and branches as desired.

For a cabin in a national park exposed to a landslide hazard, the following is estimated:

- The cabin has an occupancy rate of 60% for 3 months of the year during winter and 90% at other times of the year.
- When occupied, at night (assumed to be 8 hours per day) there are always people in the cabin. During the day, there are people in the cabin 20% of the time.

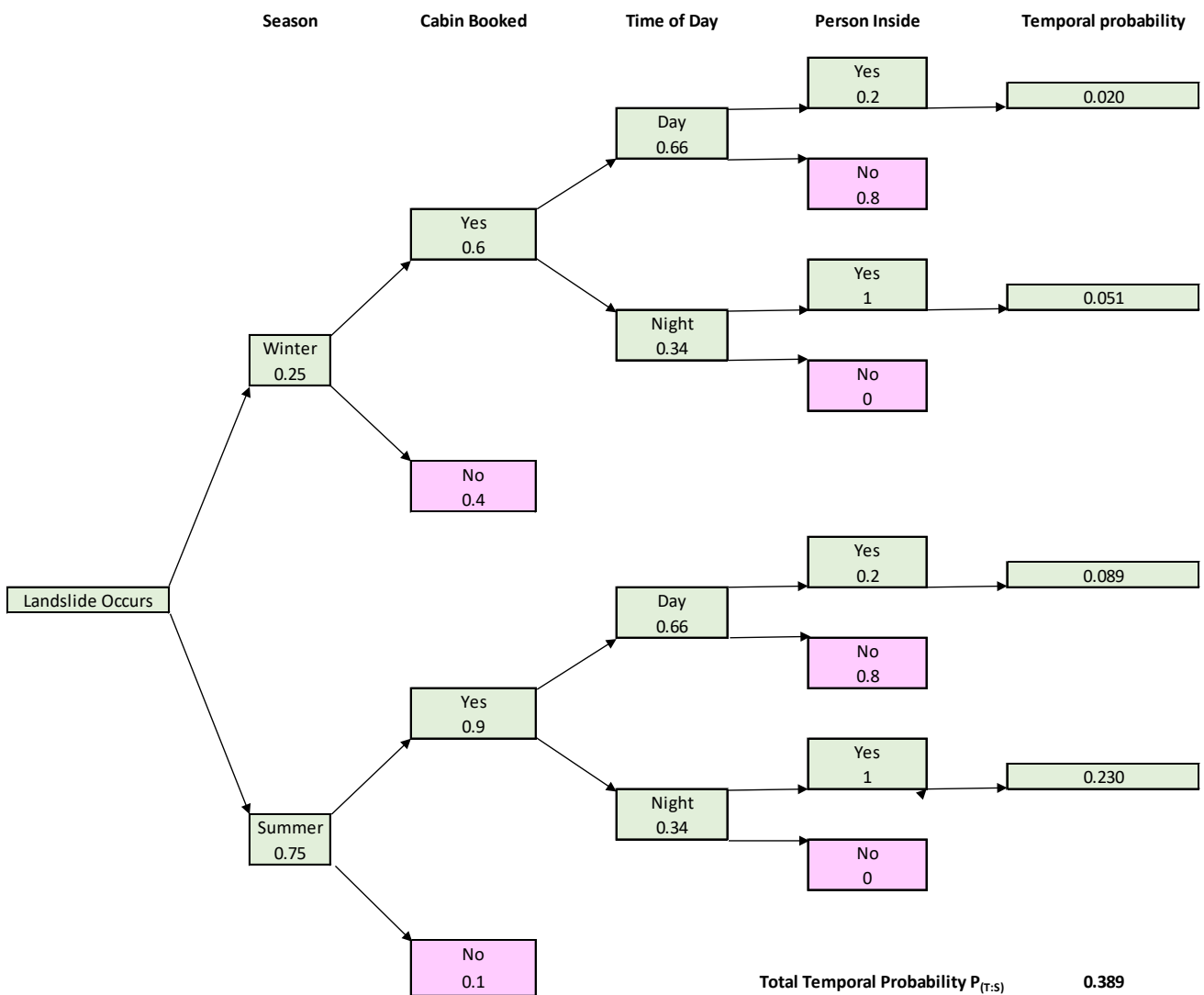


Figure 2 – Example of event tree to estimate temporal probability

**Step 5. The exposed population, e**

This refers to the number of people or separate individuals exposed to the hazard. For example, it could be the number of separate visitors that use a track within a year, the number of visitors to a campsite every year or the number of people who live in a house.

**Step 6. The average risk to an individual, mobile element at Risk, AvR<sub>(LOL)</sub>**

This is the average individual risk across the exposed population for a single traverse through the area at risk. It can be calculated using the risk to the individual most at risk as calculated in Step 3 and shown in equation 6:

$$AvR_{(LOL)} = siR_{(LOL)} / n_{is} \quad (6)$$

Where s refers to the average speed that an individual from the exposed population moves through the zone at risk from the landslide hazard. For example, the average speed hikers might move along a track (typically 2 km/hour to 3 km/hour).

Depending on the composition of the population it may be prudent to estimate  $AvR_{(LOL)}$  for subgroups of the exposed population. For example, if in addition to regular public, a particular track had a high proportion of school groups with higher vulnerability to the hazard. In this case,  $AvR_{(LOL)}$  can be estimated for the subgroup using equation 1 in Step 3, and using  $s$  as the average speed of the individuals comprising the subgroup. If this is done, a separate F-N pair will be calculated for each subgroup as described subsequently in Step 8.

## Step 7. The probability of impact to the static element at risk, F

This is calculated using equation 7:

$$F = P_{(H)} \times P_{(S:H)} \quad (7)$$

Where:

$P_{(H)}$  and  $P_{(S:H)}$  are as per the estimates made in Step 4.

## Step 8. Calculation of F-N pair for a mobile element at risk

The assessment of societal risk requires the calculation of F, and N (F-N pair). Each component is estimated as set out below.

***N = The number of people comprising each mobile element.***

For example:

- If the mobile element is a vehicle and it is assumed that each vehicle is occupied by 3 persons, then  $N = 3$ .
- In most walking track scenarios, each individual on the track is a mobile element at risk and  $N = 1$ .
- If it is assumed that people using a track always walk closely together in pairs, then  $N = 2$ .

***F = The probability of impact to the element at risk.***

For mobile elements at risk, F is estimated using Equation 8:

$$F = 1 - (1 - AvR_{(LOL)})^n \quad (8)$$

Where:

$AvR_{(LOL)}$  is calculated in accordance with Step 6.

$n$  = the total number of traverses made annually through the area at risk by the mobile element.

For most public hiking track scenarios where there are large numbers people passing once through the area at risk, it can generally be assumed that every person who uses the track in a given year does so once, ie. no account is made for repeat visitors. Where this is the case,  $n$  = the exposed population,  $e$ .

If for example the track is not a loop track, but involves a return journey along the same route, then the number of traverses through the area at risk,  $n$  would be twice the exposed population,  $e$ .

## Step 9. Calculation of F-N pair for a static element at risk

The assessment of risk to multiple people requires the calculation of F, and N (F-N pair). Each component is estimated as set out below.

***N = The number of people expected to be killed if impact occurs.***

N is calculated in accordance with Equation 9:

$$N = e_{av} V_{(D:T)} \quad (9)$$

Where:

$V_{(D:T)}$  = the average vulnerability of an individual within the exposed population.

$e_{av}$  = is the average number of people exposed to the hazard for an equivalent of 100% of the time as set out in Equation 10.

$$e_{av} = e_s \times [(P_{(T:S)1} \times e_{s1} / e_s) + (P_{(T:S)2} \times e_{s2} / e_s) + (P_{(T:S)3} \times e_{s3} / e_s) + \dots + (P_{(T:S)x} \times e_{sx} / e_s)] \quad (10)$$

Where:

$e_s$  is the maximum number of people that could be present where the hazard occurs, usually the maximum number of people that can occupy the element at risk, for example maximum number of people in a building.

$e_{s1}$  is the number of people within a subgroup of the exposed population. Note that the sum of the populations of all subgroups should equal  $e_s$ .

$P_{(T:S)1}$  is the temporal probability for a subgroup of the exposed population.

Population subgroups may apply where there are differences in the number of people exposed to the hazard at different times. For example, an office building might be occupied by 12 people during the day and 2 people overnight. In this case, two subgroups would be identified (day and night), each of which may have different temporal probability and number of people within the subgroup.

If there are no population subgroups, there is no need to calculate  $e_{av}$  and equation 9 reduces to:

$$N = e_s \times P_{(T:S)} \times V_{(D:T)}$$

***F = The probability the expected number of people are killed***

F is calculated as described in Step 7. If F-N pairs are developed for each subgroup, then  $F_1$ ,  $F_2$ , etc. will be the same.

### Alternative approach using f-N pairs

There may be scenarios where assuming the average number of people over 100% of the time is considered too crude of an approach. Where this is the case, separate f-N pairs may be developed for each subgroup, for example as set out in ANCOLD 2022<sup>3</sup>. In this case:

$$f_1 = P_{(H)1} \times P_{(S:H)1} \times P_{(T:S)1} V_{(D:T)1}$$

<sup>3</sup> See ANCOLD 2022, pg. 198

$$N_1 = e_{s1}$$

Note that an f-N pair differs from an F-N pair. Lowercase f is the probability of *exactly* N fatalities where N is a discrete number. Uppercase F refers to the probability of N *or more* fatalities. Cumulative probability can be calculated from f-N pairs using the approach described in Table 1 (Step 13).

## Step 10. Number of independent hazards to which an individual is exposed

There are some scenarios where the element at risk may be exposed to multiple hazards. Examples include:

- A walking track on which hikers must walk past several zones exposed to rockfall to complete the track.
- A building that is exposed to different types of independent hazards, for example failure of a cut batter and a natural landslide.
- A vehicle which must travel along a road that has several different road cuttings with potential for rockfall.

Where the element at risk is exposed to multiple hazards that present a risk to life, the effect of the multiple hazards must be considered. All hazards must be independent to allow them to be combined.

For each hazard identified, repeat the process to this point to estimate  $R_{(LOL)}$  for each hazard.

## Step 11. Number of independent hazards to which multiple people are exposed

There are some scenarios where the element at risk may be exposed to multiple hazards. Examples include:

- A walking track on which hikers must walk past several zones exposed to rockfall to complete the track.
- A building that is exposed to different types of hazards, for example failure of a cut batter and a natural landslide.
- A vehicle which must travel along a road that has several different road cutting with potential for rockfall.

Where the element at risk is exposed to multiple hazards, the effect of the multiple hazards must be considered. All hazards must be independent to allow them to be combined.

For each hazard identified, repeat the process to this point to estimate an F-N pair for each hazard, noting that for in some cases multiple F-N pairs may be developed for single hazards, for example where subgroups of the exposed population with a different risk profile have been identified.

## Step 12. Combining individual risks

Where multiple risks to the individual most at risk have been assessed, and the risk to the individual has been estimated for each hazard, the risk to life of an individual exposed to multiple hazards may be estimated using equation 10.

$$R_{(LOLC)} = 1 - [(1 - R_{(LOLH1)}) \times (1 - R_{(LOLH2)}) \times (1 - R_{(LOLH3)}) \times (1 - R_{(LOLH4)}) \dots (1 - R_{(LOLHX)})] \quad (10)$$

Where:

$R_{(LOLC)}$  = the combined risk of loss of life to the individual from multiple hazards.

$R_{(LOLH1)}$  = the risk of loss of life from hazard 1.

## Step 13. Combining risks to multiple persons

Where multiple people are exposed to multiple hazards and F-N pairs have estimated for each hazard, F-N pairs should be combined if N is the same for each hazard.

For hazards where an F-N pair has been calculated and N is the same, a combined F (or combined f if working with f-N pairs) may be estimated using equation 11.

$$F_C = 1 - [(1 - F_{H1}) \times (1 - F_{H2}) \times (1 - F_{H3}) \times (1 - F_{H4}) \dots (1 - F_{HX})] \quad (11)$$

Where:

$F_C$  denotes the combined risk of loss of life from multiple hazards.

$F_{H1}$  denotes F estimated in Step 8 for Hazard 1.

$F_C$  and N then may be evaluated against a criteria as described in Step 15, or if f-N pairs are used combined as set out below to develop F-N pairs.

If the N for two or more hazards is different, the cumulative probability must be estimated. This can be undertaken as indicated in Table 1. Note that the table assumes hazards are listed according to increasing N. ie.  $N_{H1} < N_{H2} < N_{H3}$  etc. For any hazards with common N that have been combined,  $F_C$  and N are entered into Table 1. Similarly, this approach can be used to combine f-N pairs (see Step 9) where  $F_{HX}$  is substituted for  $f_{HX}$  to derive F-N pairs<sup>4</sup>.  $f_{HX}$  is substituted for  $f_{HX}$  to derive F-N pairs<sup>5</sup>.

**Table 1 – Calculation of Cumulative Probability**

Hazard	N	F	$F_C$ , N or more fatalities.
1	$N_{H1}$	$F_{H1}$	$F_C = 1 - [(1 - F_{H1}) \times (1 - F_{H2}) \times (1 - F_{H3}) \times (1 - F_{H4}) \dots (1 - F_{HX})]$
2	$N_{H2}$	$F_{H2}$	$F_C = 1 - [(1 - F_{H2}) \times (1 - F_{H3}) \times (1 - F_{H4}) \dots (1 - F_{HX})]$
3	$N_{H3}$	$F_{H3}$	$F_C = 1 - [(1 - F_{H3}) \times (1 - F_{H4}) \dots (1 - F_{HX})]$

<sup>5</sup> ANCOLD 2022 includes an example whereby f-N pairs are used to estimate cumulative probability using an arithmetic summation. Note that this approach will yield similar values to the approach set out in Table 1 provided f and the resulting  $F_C$  is less than about  $10^{-3}$ . Where this is the case, this approach is a valid alternative.

4	$N_{H4}$	$F_{H4}$	$F_C = 1 - [(1 - F_{H4}) \dots (1 - F_{HX})]$
X	$N_{HX}$	$F_{HX}$	$F_C = 1 - [(1 - F_{HX})]$

Each pair, N, Fc arising from Table 1, is evaluated against criteria as described in Step 15.

### Step 14. Evaluate risk to the individual most at risk

The risk to the individual most at risk either from a single hazard  $R_{(LOL)}$  or multiple hazards  $R_{(LOLC)}$  is compared to a criteria as set out in Table 2.

**Table 2 – Criteria for the individual most at risk**

Situation	Criteria for Tolerable Loss of Life Risk for the Individual Most at Risk	Criteria for Acceptable Loss of Life Risk for the Individual Most at Risk
Existing slope/development	$R_{(LOLC)}, R_{(LOL)} < 10^{-4}$ per annum	$R_{(LOLC)}, R_{(LOL)} < 10^{-5}$ per annum
New constructed slope/development	$R_{(LOLC)}, R_{(LOL)} < 10^{-5}$ per annum	$R_{(LOLC)}, R_{(LOL)} < 10^{-6}$ per annum

New development generally refers to works planned in an area subject to landslide hazards or works that could create new hazards. For example:

- A new track in an area where there has not been a track before.
- A new building where a building has not been before.
- An activity in an area where no activity has previously been undertaken.
- New excavation or earthworks where those works have the potential to create new landslide hazards.

Existing development refers to existing elements at risk. For example:

- An existing track, building campground, lookout etc.
- Minor works undertaken to maintain existing assets, for example track realignment.

## Step 15. Evaluate F-N pairs to assess societal risk

F-N pairs developed for single (F) or multiple hazards ( $F_c$ ) are plotted on the charts presented in Figure 3 to identify which zone of the chart the F-N pair plots within. The relevant chart for existing or proposed assets must be used.

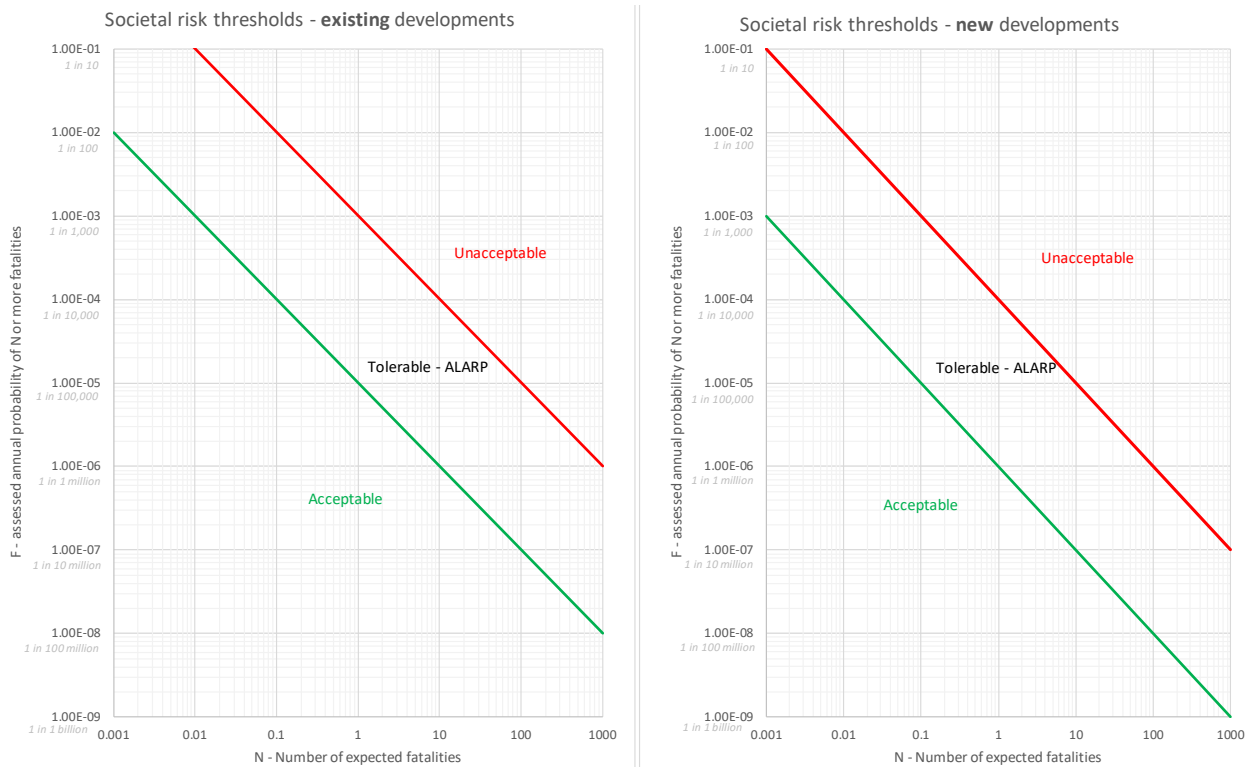


Figure 3 – Chart for evaluation of Societal Risk

## Step 16. Reporting Calculations

The risk calculations should be reported. The report should include as a minimum:

- A description of the hazard and basis for the selection of all inputs to the risk assessment.
- The method of calculation used. If a different calculation to those set out in this guideline is adopted, the basis for the calculation should be reported and the method clearly set out.
- The outcome of the risk assessment.
- Whether the risk has been assessed as acceptable, tolerable or unacceptable based on individual and societal risk criteria.
- The level of certainty in the assessment. Consideration could be given to undertaking calculations for a range of inputs so as to yield a range of risks that can be evaluated.



**APPENDIX B**

**Worked Examples**

## Introduction

Worked examples have been developed based on typical scenarios that might be encountered in parks. The examples have been selected to illustrate each of the different steps in the calculation process. The chart below illustrates the scenarios that each example is intended to illustrate.

Static Element at Risk				Mobile Element at Risk			
<10 people		≥10 people		<10 people		≥10 people	
1 hazard	>1 hazard	1 hazard	>1 hazard	1 hazard	>1 hazard	1 hazard	>1 hazard
		Example 1 Example 2	Example 3	Example 4		Example 6	Example 5

The following examples are provided:

Example 1 – Risk to a tourist cabin in a national park. This example may also be applicable to other types of buildings in or adjacent to parks.

Example 2 – Risk to visitors at a lookout point. This example may be of use to calculate risk to visitors to a point of interest or area where people may congregate such as picnic grounds and bus stops.

Example 3 – Risk to staff within an administration building. This example assumes the building is subject to multiple hazards and may provide guidance in a scenario where people are at risk from multiple hazards.

Example 4 – Risk to a ranger undertaking inspections. This example may be applicable to situations with a mobile element at risk where the same individual or few individuals are exposed to the hazard over multiple occasions or for an extended time. For example, work and maintenance crews.

Example 5 – Risk to the public on a walking track subject to hazards. This example may provide guidance in other situations where there are a large number of mobile elements at risk such as hikers or vehicles that must traverse areas at risk from landslide.

Example 6 – Risk to a tour bus. This example may provide guidance in scenarios where there are large numbers of people who are mobile and exposed to a hazard at the same time.

### Example 1 – Static element at risk, exposed population $\geq 10$ , single hazard

A cabin in a campground is subject to a landslide hazard. Field assessment by a suitably qualified practitioner indicates the following:

- The cabin is subject to one hazard, a debris flow that could originate upslope of and impact the cabin.
- The cabin is occupied on average by 4 persons for 12 hours of the day, 300 days per year. The 4 people are assumed to remain together – ie. the cabin is occupied by 4 persons or is vacant. The maximum stay allowed in the cabin is 2 nights.
- Frequency analysis indicates the likelihood of a debris flow originating upslope of the cabin is 1 in 200 per annum.
- Hazard analysis indicates that the spatial probability of a debris flow impacting the cabin is 0.5 based on analysis of debris flow paths.
- It is assumed that the cabin would be destroyed and that the vulnerability of the cabin occupants is 1.

Reference to the flow chart in Figure 1 of the guidelines indicates the steps required to undertake the assessment. The path is highlighted in Figure B2 and each step required to undertake the risk assessment for this scenario is described subsequently. The scenario is illustrated in Figure B1.

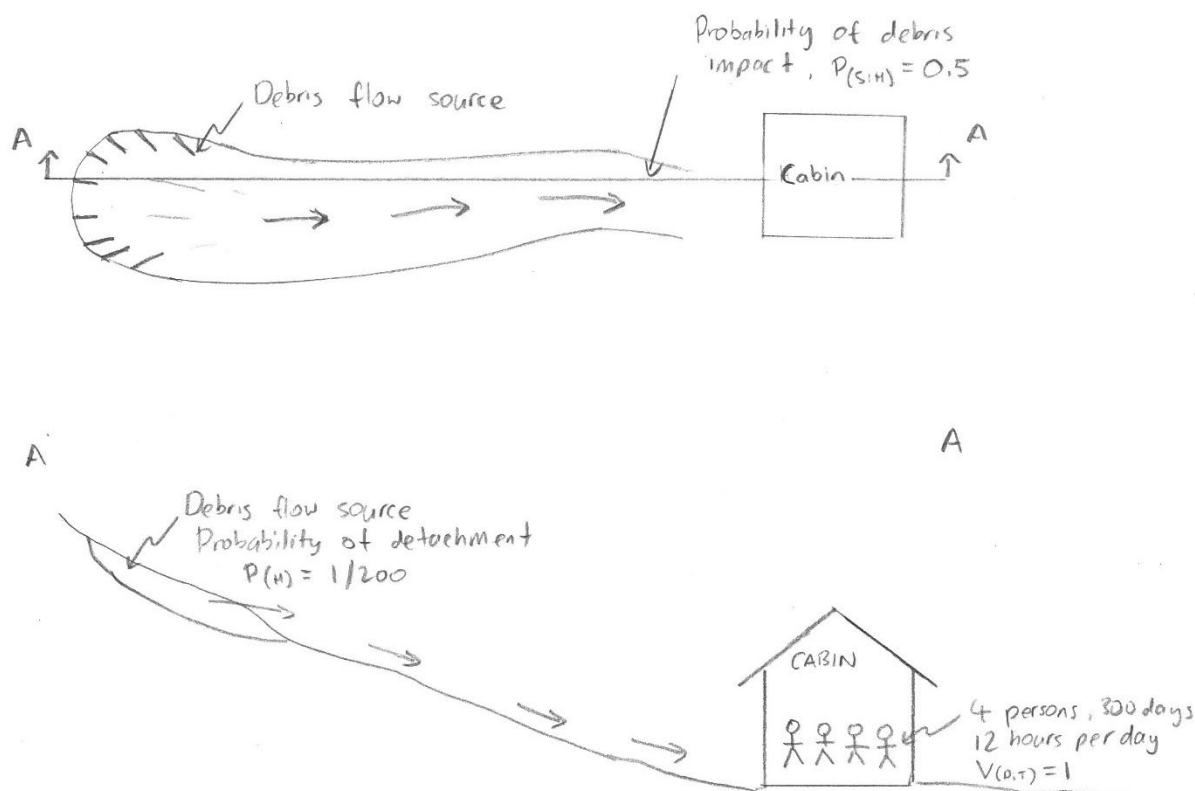


Figure B1 – Illustration of Example 1 hazard scenario

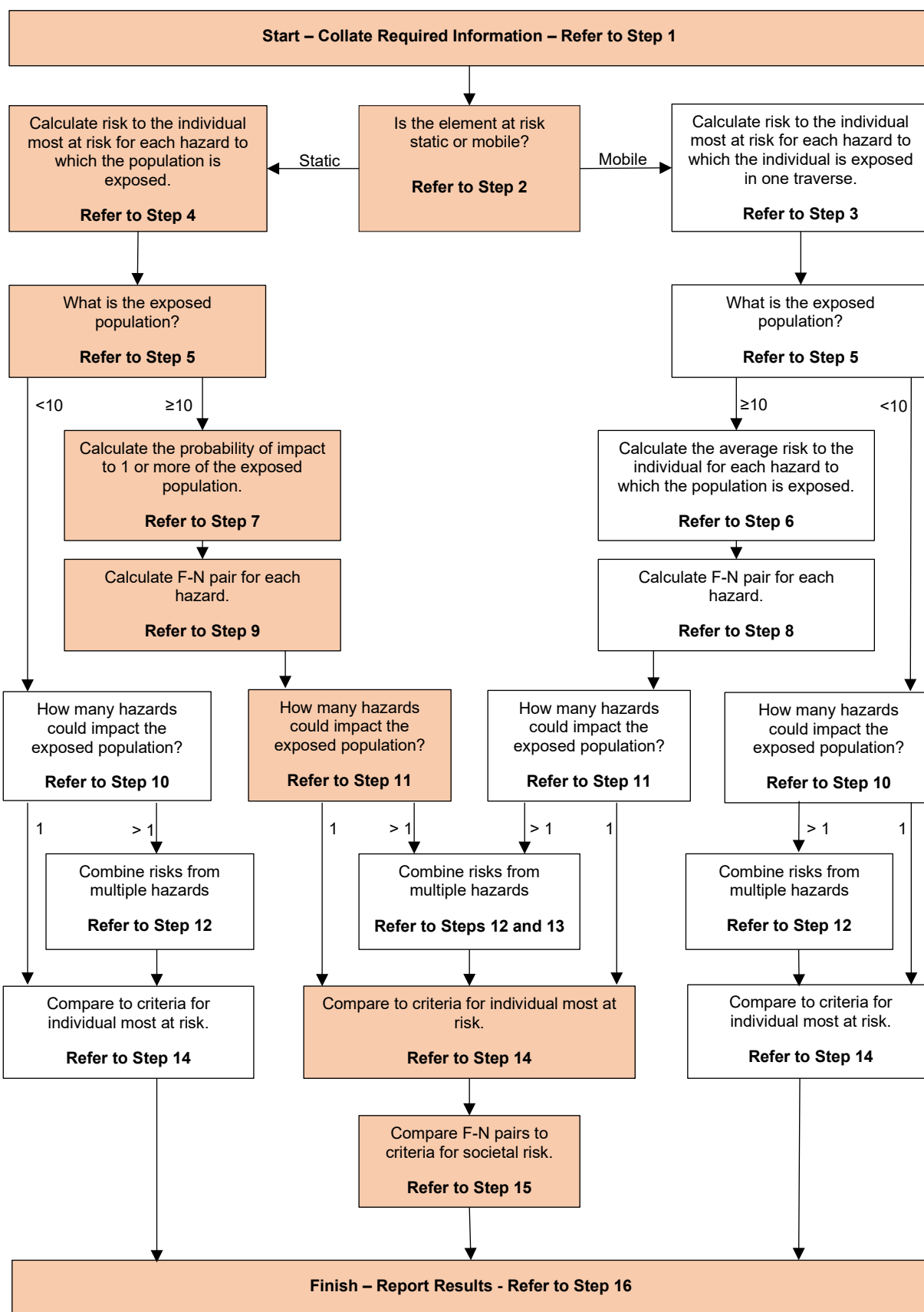


Figure B2 – Flow chart highlighting applicable calculation steps for Example 1

## Step 1. Information required to inform landslide risk assessment

In order to obtain the parameters required as input to the risk assessment, hazard analysis might include review of photogrammetry and LiDAR information to assess debris travel paths and past events, field assessment to assess the distribution of colluvium and debris arising from previous landslide events, review of landslide inventories, information from NPWS about occupancy rates etc.

## Step 2. Static versus mobile elements at risk

The cabin is a static element at risk.

## Step 4. Risk to the individual most at risk in a static scenario

The annual risk of loss of life of a specific individual, nominally the individual most at risk is defined in AGS 2007 by equation 5

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (1)$$

Where:

$R_{(LOL)}$  = the risk or annual probability of loss of life of the individual most at risk. This is usually the individual who is exposed to the hazard for the greatest duration.

$P_{(H)}$  = the annual probability that the debris flow occurs, estimated to be 1 in 200 ( $5 \times 10^{-3}$ ).

$P_{(S:H)}$  = the probability of spatial impact of the landslide impacting the element at risk taking into account the travel distance and direction of the landslide or rockfall. Estimated to be 0.5.

$P_{(T:S)}$  = the temporal spatial probability. The individual most at risk is one of the 4 people exposed to the hazard who occupies the cabin for 2 nights. This person is present for 12 hours per day, 2 days of the year. The proportion of time in the year they are present is  $(12 \times 2)/(24 \times 365) = 2.7 \times 10^{-3}$ .

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted. It is assumed that the debris flow would bury the cabin and  $V_{(D:T)} = 1$ .

Substituting into equation 1 to calculate  $R_{(LOL)}$ :

$$\begin{aligned} R_{(LOL)} &= 5 \times 10^{-3} \times 0.5 \times 2.7 \times 10^{-3} \times 1 \\ &= 6.8 \times 10^{-6} \end{aligned}$$

## Step 5. The exposed population, e

Assuming all people stay in the cabin for 2 nights and there are no repeat visitors, the number of people exposed to the hazard over the course of a year is  $150 \times 4 = 600$ .

## Step 7. The probability of impact to the static element at risk, F

F is calculated by:

$$F = P_{(H)} \times P_{(S:H)} \quad (7)$$

Where:

$P_{(H)} = 5 \times 10^{-3}$  as estimated in Step 4.

$P_{(S:H)} = 1$ . It is assumed that if the debris flow impacts the exposed population is certain to be impacted.

$$\begin{aligned} F &= P_{(H)} \times P_{(S:H)} \\ &= 5 \times 10^{-3} \end{aligned}$$

## Step 9. Calculation of F-N pair for a static element at risk

The assessment of societal risk requires the calculation of F, and N (F-N pair). Each component is estimated as set out below.

$P_{(T:S)}$  refers to the temporal probability of an assumed number of people being present when the hazard occurs. In this case, there are assumed to be 4 people who are present for 12 hours, 300 days per year.  $P_{(T:S)} = (300 \times 12)/(365 \times 24) = 0.41$

***N = The number of people expected to be killed if impact occurs.***

There are expected to be always 4 people in the cabin, so there is no requirement to identify subgroups. N can be calculated in accordance with Equation 9:

$$N = e_s P_{(T:S)} V_{(D:T)} \quad (9)$$

Where:

$e_s$  = the number of individuals within the exposed population that could feasibly be impacted by the hazard in a single occurrence given impact to the element at risk occurs. In this case, not more than 4 people can be impacted,  $e_s = 4$ .

$P_{(T:S)}$  refers to the temporal probability of an assumed number of people being present when the hazard occurs. In this case, there are assumed to be 4 people who are present for 12 hours, 300 days per year.  $P_{(T:S)} = (300 \times 12)/(365 \times 24) = 0.41$ .

$V_{(D:T)}$  = the average vulnerability of an individual within the exposed population = 1.

$$\begin{aligned} N &= 4 \times 0.41 \times 1 \\ &= 1.6 \end{aligned}$$

***F = The probability the expected number of people are killed***

F is as calculated in Step 7,  $F = 5 \times 10^{-3}$

## Step 11. Number of independent hazards to which multiple people are exposed

The cabin is exposed to a single debris flow hazard.

#### **Step 14. Evaluate risk to the individual most at risk**

The cabin is an existing element at risk, so based on Table 1, the criteria against which tolerable risk is assessed is:

$$R_{(LOL)} < 10^{-4} \text{ per annum}$$

With acceptable risk one order of magnitude lower. The estimated risk to the individual most at risk from Step 4 is:

$$R_{(LOL)} = 6.8 \times 10^{-6}$$

In this case comparison against the criteria for the individual most at risk indicates that the risk is less than  $10^{-5}$  per annum and therefore meets the acceptable criteria for an existing element at risk.

#### **Step 15. Evaluate F-N pairs to assess societal risk**

The F-N pair developed in Step 9 is  $F = 5 \times 10^{-3}$   $N = 1.6$ . Given this is an existing development, the F-N pair is plotted on the chart in Figure B3 for existing elements at risk. In this case the F-N pair plots in the unacceptable zone.

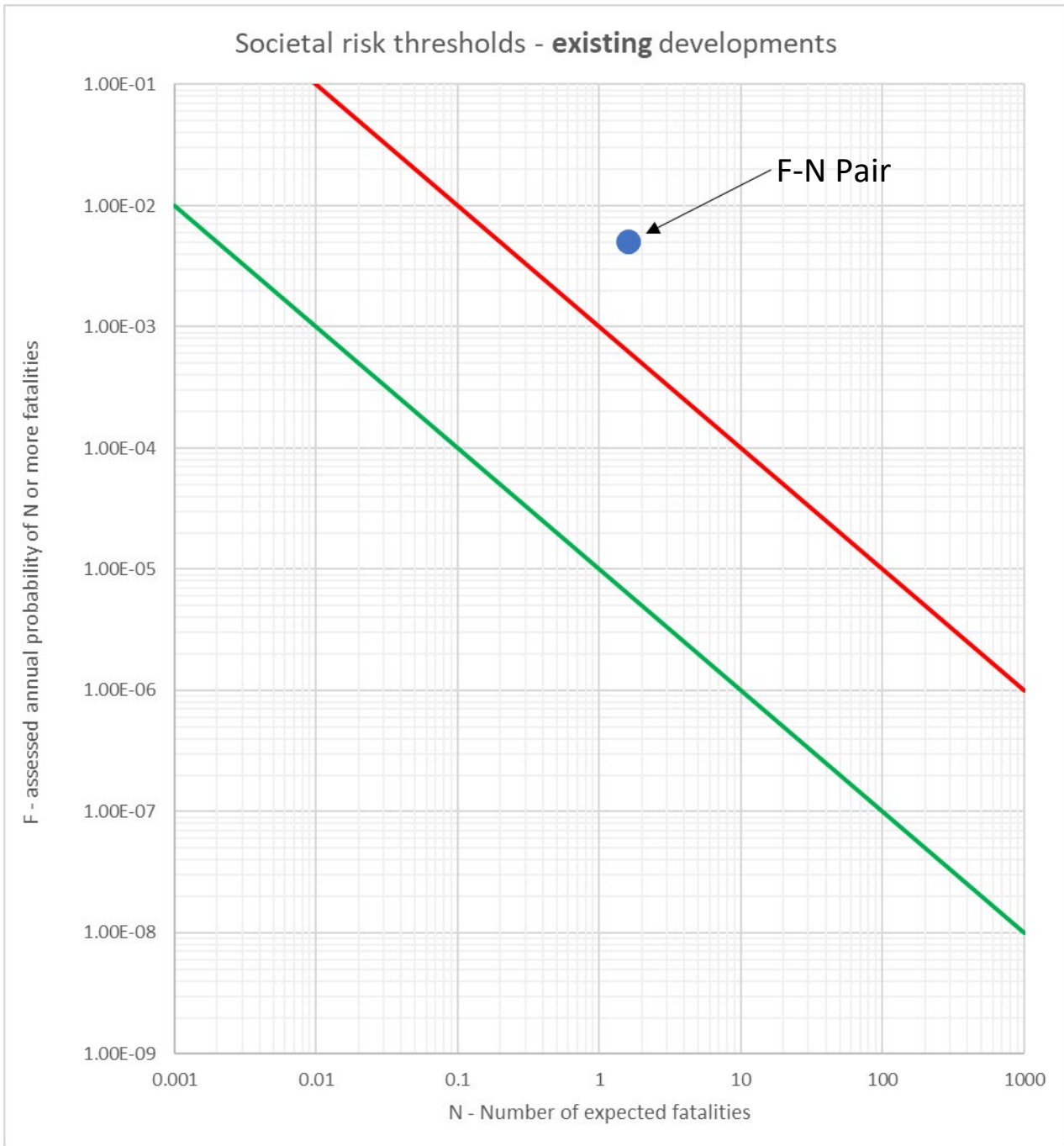


Figure B3 – Evaluation of societal risk for Example 1

### Step 16. Reporting Calculations

The above calculations and justification for the inputs would be included in the report. In this case, where the risk has been assessed as unacceptable, it would be typical to report actions that could be taken to further investigate or to mitigate the risk.



## Example 2 - Static element at risk, exposed population $\geq 10$ , single hazard

A lookout in a national park has been located on a rock ledge that has the potential to detach. Field assessment indicates the following:

- Detachment of the rock ledge on which the lookout is located is the only hazard to which the lookout and the people on it are subject.
- On average, there are 8 people located on the lookout for 10 hours per day, over 365 days of the year. Typically, a person will spend 15 minutes on the lookout.
- Frequency analysis based on observations of nearby rockfalls provides an estimate of detachment probability of 1 in 10,000 per annum.
- Hazard analysis indicates that if the detachment occurred, every person on the lookout would be affected.
- There is assumed to be no relationship between the presence of people on the lookout and the timing of the triggering mechanism.
- It is assumed that any person on the lookout when the detachment occurred is certain to be killed.

The hazard scenario is illustrated in Figure B4 and applicable calculation steps in Figure B5.

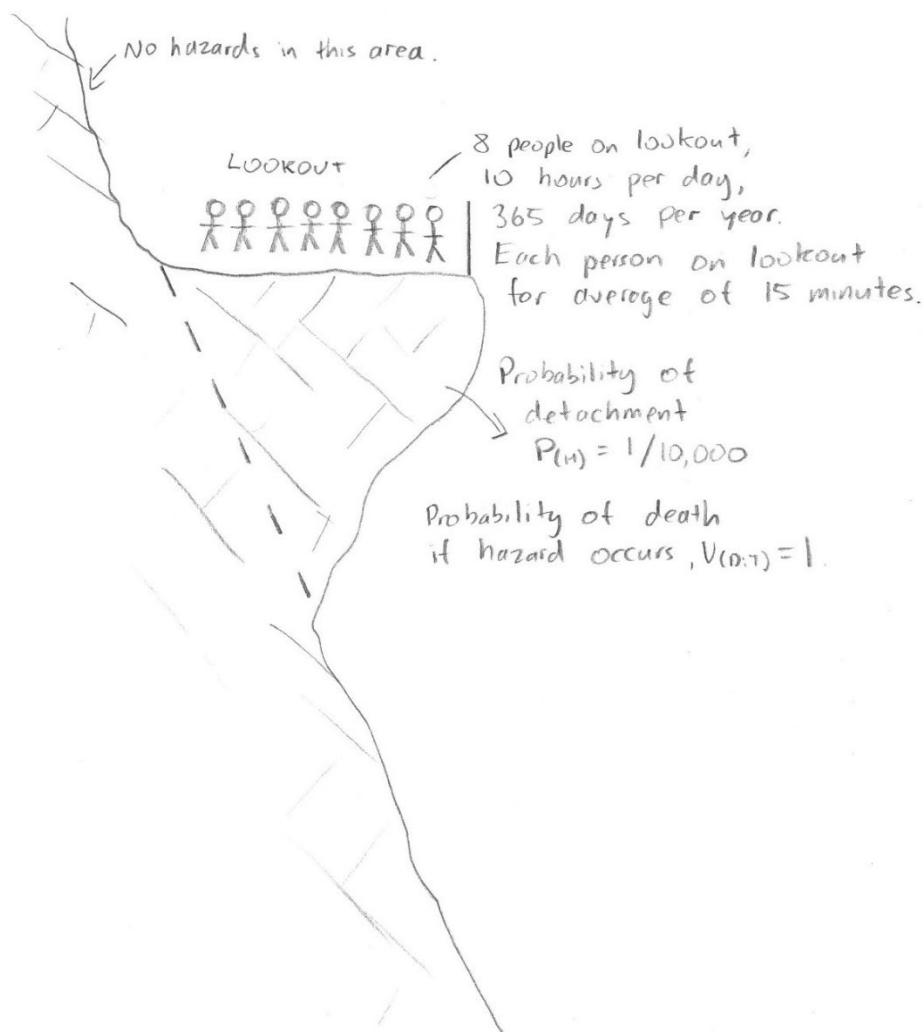


Figure B4 – Illustration of Example 2 hazard scenario

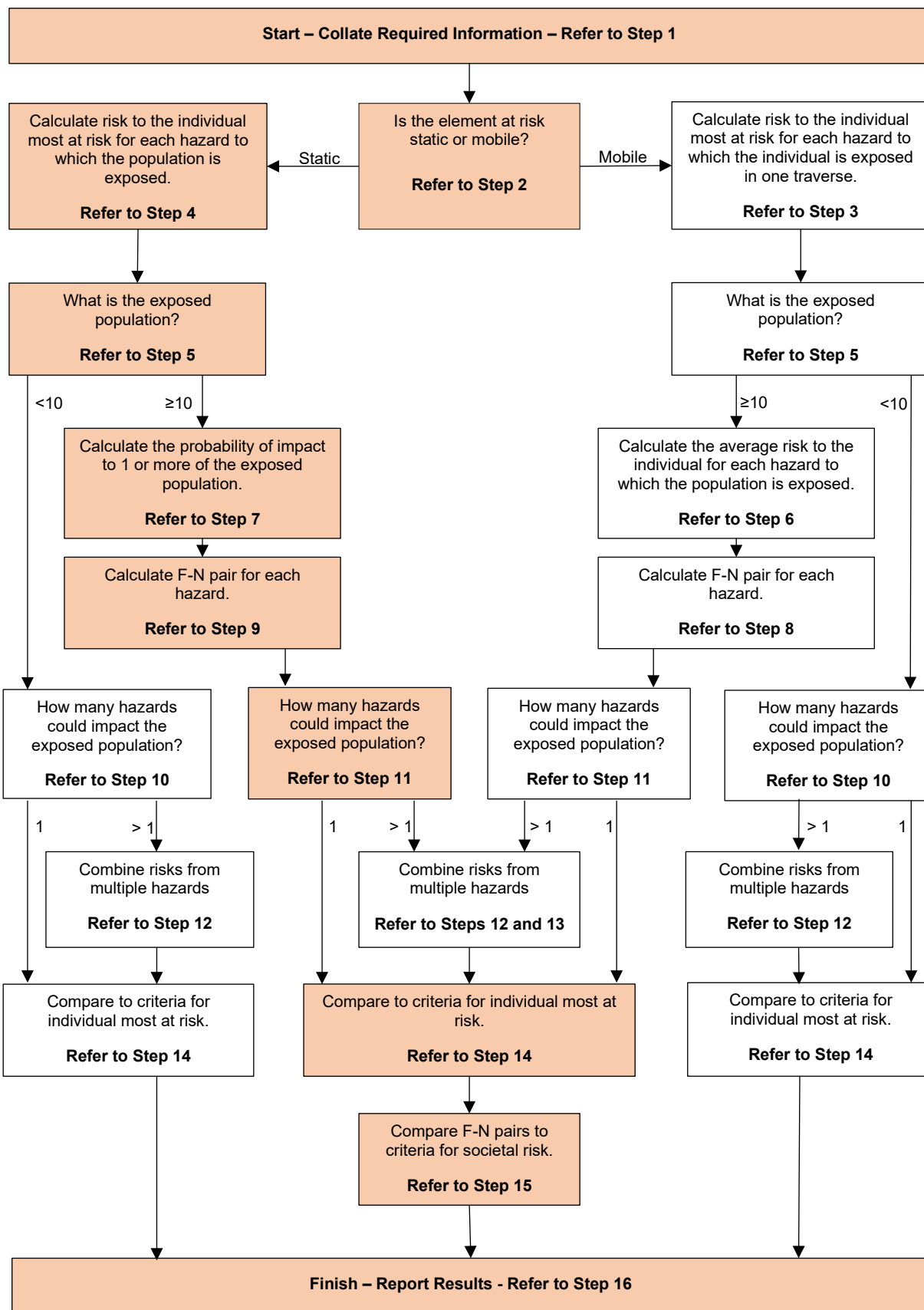


Figure B5 – Flow chart highlighting applicable calculation steps for Example 2

## Step 1. Information required to inform landslide risk assessment

In order to acquire the information to assess the risk to users of the lookout, investigation would be required, including the assessment of previous rockfalls and field mapping.

## Step 2. Static versus mobile elements at risk

The lookout is a static element at risk.

## Step 4. Risk to the individual most at risk in a static scenario

The annual risk of loss of life of the individual most at risk is defined by Equation 5

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

Where:

$R_{(LOL)}$  = the risk, or annual probability of loss of life of the individual most at risk. For the lookout, in a static scenario, no account is taken of the fact that the specific people on the lookout will change. The individual most at risk is assumed to be a generic person.

$P_{(H)}$  = the annual probability that the rock ledge detaches, estimated to be 1 in 10,000 ( $1 \times 10^{-4}$ ).

$P_{(S:H)}$  = the probability of spatial impact of the landslide impacting the element at risk taking into account the travel distance, direction of the landslide or rockfall. Estimated to be 1 given the lookout will be undermined by the detached block.

$P_{(T:S)}$  = the temporal spatial probability. The individual most at risk is one of the 8 people exposed to the hazard. This person is present at the lookout for 15 minutes (0.25 of an hour). The proportion of time in the year this person is present is  $0.25/(24 \times 365) = 2.9 \times 10^{-5}$

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted. It is assumed that all people on the lookout would be killed, and  $V_{(D:T)} = 1$ .

Substituting into equation 1 to calculate  $R_{(LOL)}$ :

$$\begin{aligned} R_{(LOL)} &= 1 \times 10^{-4} \times 1.0 \times 2.9 \times 10^{-5} \times 1 \\ &= 2.9 \times 10^{-9} \end{aligned}$$

## Step 5. The Exposed Population, e

There are assumed to be an average of 8 people on the lookout at any one time and each person is there for 15 minutes over 10 hours. This equates to 40 groups of 8 people, 320 people per day. Over 365 days per year, the exposed population, e is assumed to be  $365 \times 320 = 116,800$ .

## Step 7. The probability of impact to the static element at risk, F

F is calculated by:

$$F = P_{(H)} \times P_{(S:H)} \quad (7)$$

Where:

$P_{(S:H)} = 1$ . It is assumed that if the rockfall occurs the exposed population is certain to be impacted.

$$\begin{aligned} F &= 1 \times 10^{-4} \times 1 \\ &= 1 \times 10^{-4} \end{aligned}$$

## Step 9. Calculation of F-N pair for a Static element at Risk

The assessment of societal risk requires the calculation of F, and N (F-N pair). Each component is estimated as set out below.

***N = The number of people expected to be killed if impact occurs.***

It is assumed there is an average of 8 people on the lookout for 8 hours per day. Given there are no subgroups, N is calculated in accordance with equation 9:

$$N = e_s \times P_{(T:S)} \times V_{(D:T)} \quad (9)$$

Where:

$e_s$  = the number of individuals within the exposed population that could feasibly be impacted by the hazard in a single occurrence given impact to the element at risk occurs. In this case, there are assumed to be 8 people on the lookout who can be impacted,  $e_s = 8$ .

$P_{(T:S)}$  = the temporal probability of the assumed number of people present when the hazard occurs. In this case, there are assumed to be 8 people who are present on the lookout for 10 hours, 365 days per year.

$$= (365 \times 10) / (365 \times 24) = 0.42$$

$V_{(D:T)}$  = the average vulnerability of an individual within the exposed population = 1.

$$\begin{aligned} N &= 8 \times 0.42 \times 1 \\ &= 3.4 \end{aligned}$$

***F = The probability the expected number of people are killed***

F is calculated as described in Step 7,  $F = 1 \times 10^{-4}$

## Step 11. Number of independent hazards to which multiple people are exposed

The people on the lookout are exposed to a single hazard.

## Step 14. Evaluate risk to the individual most at risk

The lookout is an existing element at risk, so based on Table 1, the criteria against which tolerable risk is assessed is:

$$R_{(LOL)} < 10^{-4} \text{ per annum}$$

With acceptable risk one order of magnitude lower. The estimated risk to the individual from Step 4 is:

$$R_{(LOL)} = 2.9 \times 10^{-9}$$

In this case comparison against the criteria for the individual most at risk indicates that the risk is less than  $10^{-5}$  per annum and therefore meets the acceptable criteria for an existing element at risk.

### **Step 15. Evaluate F-N pairs to assess societal risk**

F and N as evaluated in Step 9 are plotted on the F-N chart in Figure B6 for existing elements at risk, where:

$$F = 1.0 \times 10^{-4}$$

$$N = 3.4$$

The F-N pair plots in the ALARP region of the chart and may be considered tolerable subject to risk management works.

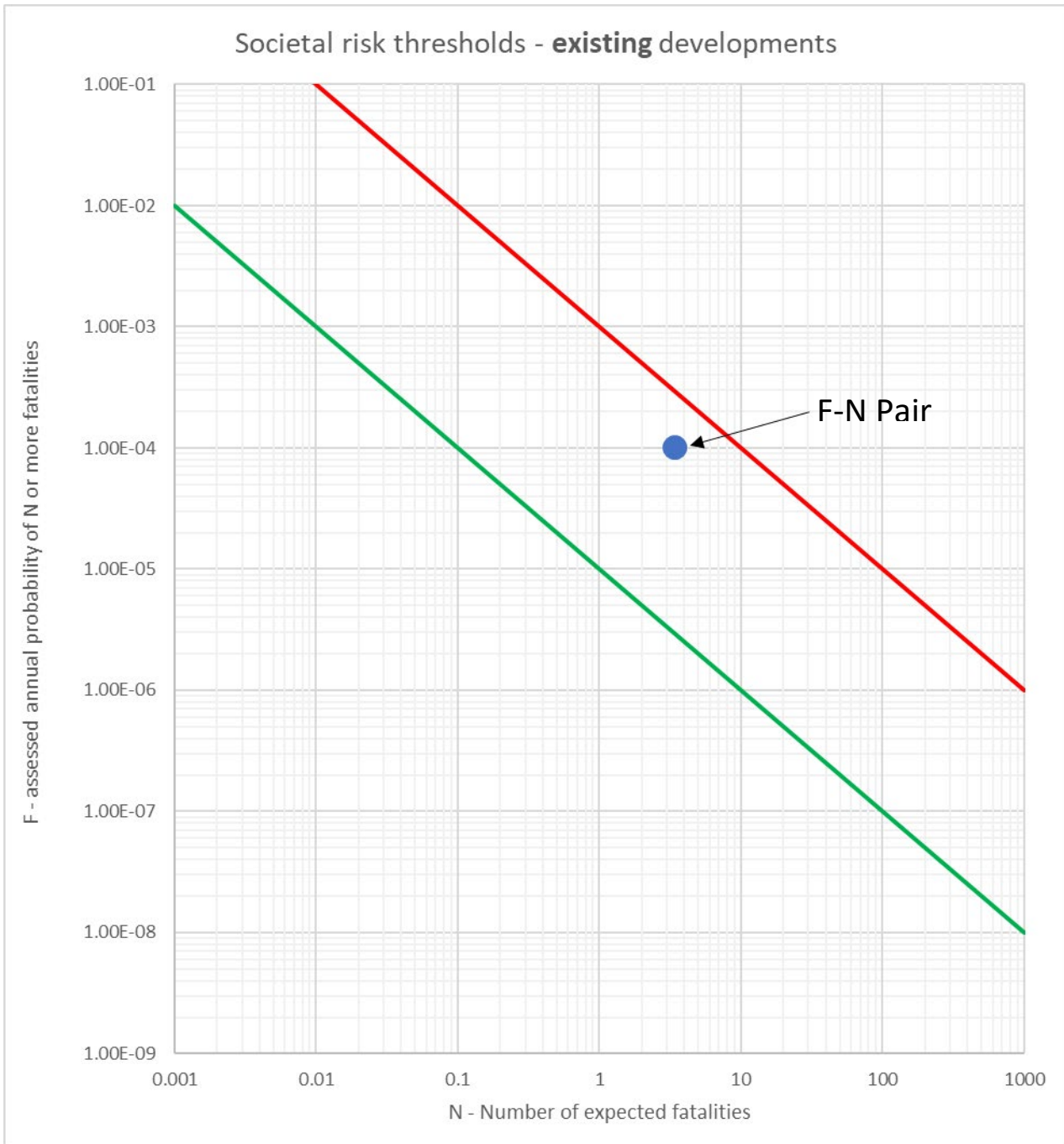


Figure B6 – Evaluation of societal risk for Example 2

### Step 16. Reporting Calculations

The report should set out the calculations undertaken. In this case, where the criteria for the individual most at risk is satisfied, but societal (F-N) criteria is not satisfied, one of the mitigation measures available might be to limit the number of people who can access the lookout at any one time.

### Example 3 - Static element at risk, exposed population $\geq 10$ , multiple hazards

An administration office within a national park is exposed to two landslide hazards, including failure of a road fill embankment upslope of the office and the detachment of a boulder from the slope between the office and road. Field assessment acquired the following information.

#### *Hazard 1 – Failure of fill embankment*

- Based on the history of fill embankment failure and on analysis, the probability of failure is estimated to be an annual probability of 1 in 500.
- Based on assessment of runout distance, it is estimated that debris will impact about halfway up the wall of the office.
- If the fill embankment fails, it is estimated that debris will impact about 10 m of the 20 m wide building.
- The vulnerability of people in the office is assumed to be 0.4 given that the building is not expected to be fully inundated.

#### *Hazard 2 – Detachment of boulder*

- The size of a boulder that could potentially impact the office is 0.5 m diameter. The width of the building where the boulder could impact is 20 m. It is estimated that the boulder would roll all the way to the office and penetrate the wall.
- Based on frequency analysis, the probability of boulder detachment is estimated to be an annual probability of 1 in 100.
- The vulnerability of a person in the building and struck by the boulder is estimated to be 0.5.

#### The Elements at Risk

- There are 12 staff members who occupy the office. Two administrative staff occupy the office for 8 hours per day, 260 days per year.
- The remaining 10 staff members are generally field based and occupy the office for 2 hours per day 260 days per year during morning and afternoon meetings. All 12 people are present in the office for 2 hours per day.

The hazard scenario is illustrated in Figure B7 and applicable calculation steps in Figure B8.

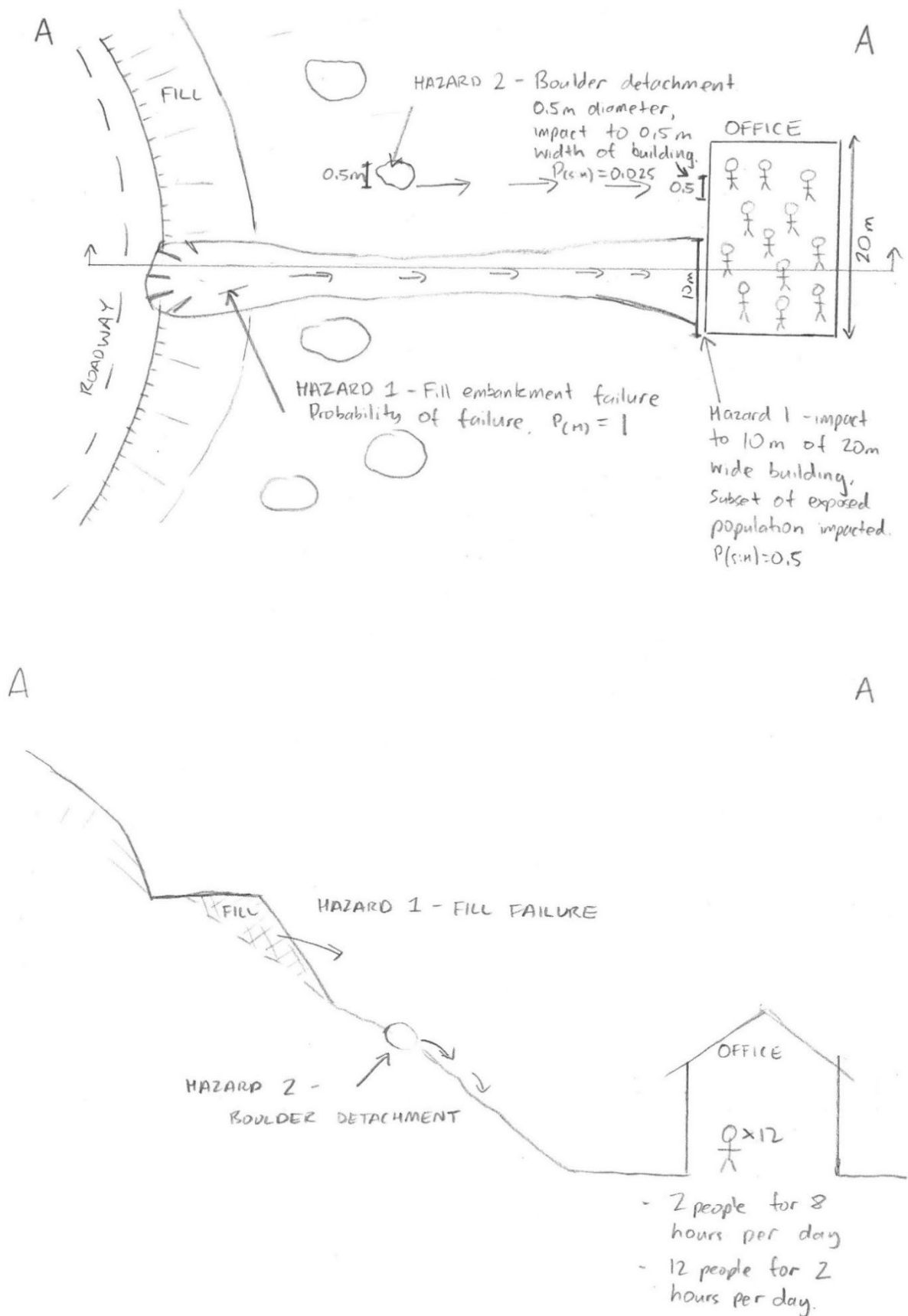


Figure B7 – Illustration of Example 3 hazard scenario



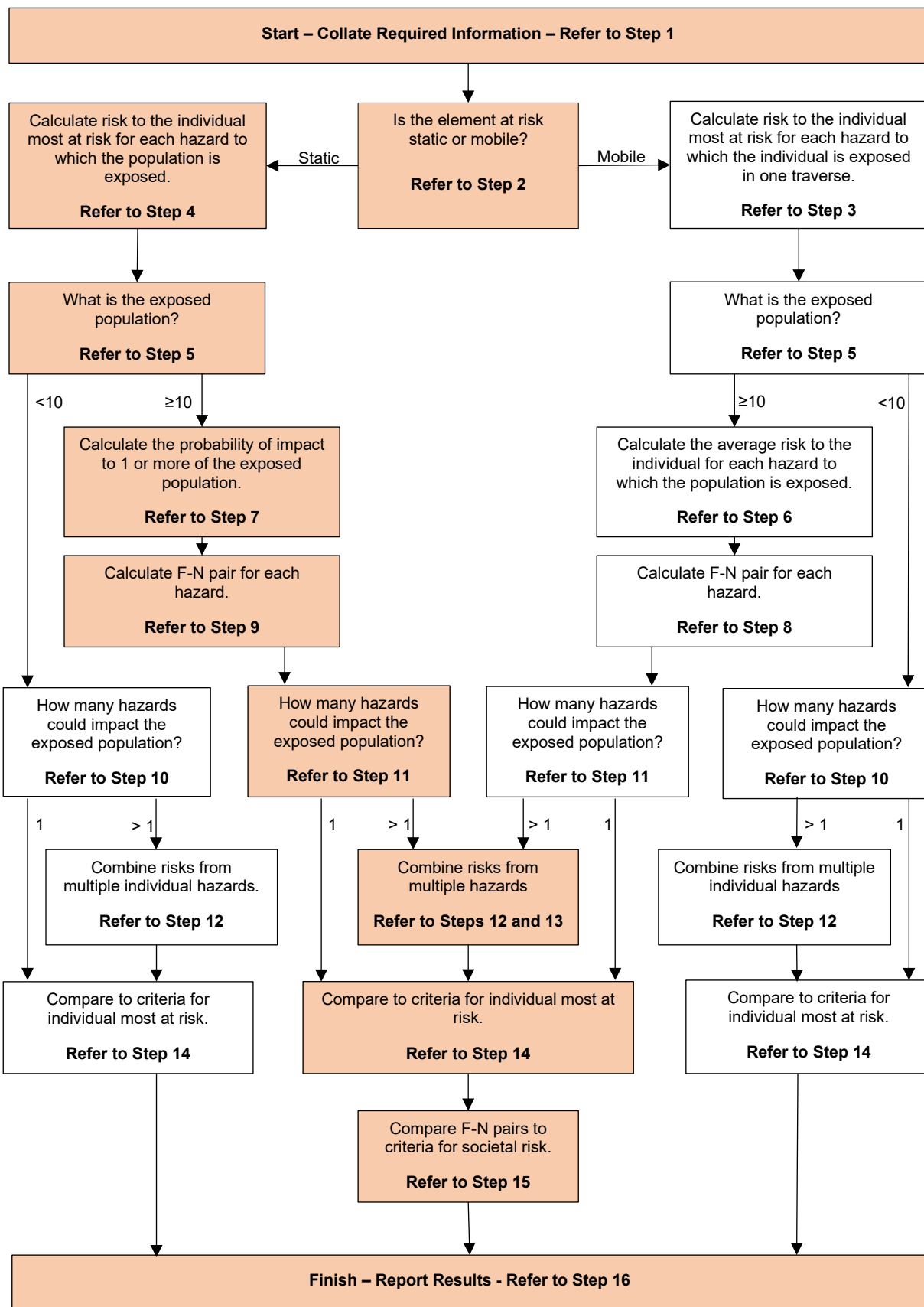


Figure B8 – Flow chart highlighting applicable calculation steps for Example 3

## Step 1. Information required to inform landslide risk assessment

Field assessment is undertaken to gather the information required to inform the landslide risk assessment. This includes field mapping of the road and road fill, assessment of the run out distance of other boulders, estimation of the shadow angle of fill and distance to which it might run out and information on building occupancy from NPWS.

## Step 2. Static versus mobile elements at risk

The office is a static element at risk.

## Step 4. Risk to the individual most at risk in a static scenario

The individual most at risk is one of the administrative staff who is in the building for 8 hours per day, 260 days per year. The risk of loss of life of this individual can be calculated for each hazard to which they are exposed:

### *Hazard 1 – Failure of fill embankment*

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

Where:

$R_{(LOL)}$  = the risk or annual probability of loss of life of the individual most at risk, one of the administrative staff.

$P_{(H)}$  = the annual probability that the fill embankment fails, estimated to be 1 in 500,  $2 \times 10^{-3}$ .

$P_{(S:H)}$  = it is estimated that if the fill batter fails, about 10 m out of 20 m, half the width of the building will be impacted, 0.5.

$P_{(T:S)}$  = the temporal spatial probability for the administrative staff. For a person present 8 hours per day, 260 days per year, the proportion of the year they are in the building is  $(8 \times 260)/(24 \times 365) = 0.24$

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted, estimated to be 0.4 given the building may be penetrated, but is not expected to collapse on impact.

$$\begin{aligned} R_{(LOLH1)} &= 2 \times 10^{-3} \times 0.5 \times 0.24 \times 0.4 \\ &= 9.6 \times 10^{-5} \end{aligned}$$

### *Hazard 2 – Boulder Detachment*

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

Where:

$R_{(LOL)}$  = the risk or annual probability of loss of life of the individual most at risk, one of the administrative staff.

$P_{(H)}$  = the annual probability that the boulder detaches, estimated to be 1 in 100, 0.01.

$P_{(S:H)}$  = it is estimated that if the boulder detaches, about 0.5 m out of 20 m, half the width of the building will be impacted, 0.025.

$P_{(T:S)}$  = the temporal spatial probability for the administrative staff. For a person present 8 hours per day, 260 days per year, the proportion of the year they are in the building is  $(8 \times 260)/(24 \times 365) = 0.24$

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted, estimated to be 0.5 given the building may be penetrated, but is not expected to collapse on impact.

$$\begin{aligned} R_{(LOLH2)} &= 0.01 \times 0.025 \times 0.24 \times 0.5 \\ &= 3.0 \times 10^{-5} \end{aligned}$$

## Step 5. The Exposed Population, e

Up to 12 people occupy the building giving an exposed population of 12.

## Step 7. The probability of impact to a static element at risk, F

### *Hazard 1 – Failure of fill embankment*

$$F_1 = P_{(H)} \times P_{(S:H)}$$

Where:

$F_1$  = the risk or annual probability of impact to the building.

$P_{(H)}$  = the annual probability that the fill embankment fails, estimated to be 1 in 500,  $2 \times 10^{-3}$ .

$P_{(S:H)}$  = it is estimated that if the fill batter fails, about 10 m out of 20 m, half the width of the building will be impacted.  $P_{(S:H)} = 0.5$ .

$$\begin{aligned} F_1 &= 2 \times 10^{-3} \times 0.5 \\ &= 1 \times 10^{-3} \end{aligned}$$

### *Hazard 2 – Boulder Detachment*

$$F_2 = P_{(H)} \times P_{(S:H)}$$

$F_2$  = the risk or annual probability of impact to the building.

$P_{(H)}$  = the annual probability that the boulder detaches, estimated to be 1 in 100, 0.01.

$P_{(S:H)}$  = it is estimated that if the boulder detaches, about 0.5 m out of 20 m of the building will be impacted, 0.025.

$$\begin{aligned} F_2 &= 0.01 \times 0.025 \\ &= 2.5 \times 10^{-4} \end{aligned}$$

## Step 9. Calculation of F-N pair for a Static Element at Risk

The assessment of societal risk requires the calculation of F, and N (F-N pair). Each component is estimated as set out below. For illustrative purposes, both an averaging approach and f-N approach are set out in this example. However, in most cases, estimating the F-N pair based on an average exposure ( $e_{av}$ ) will be sufficient.

The maximum number of people that could be exposed to the hazard at one time,  $e_s$  is 12.

Two subgroups can be identified in the exposed population, where one subgroup is comprised of 12 people ( $e_{s1}$ ) exposed for 2 hours (subgroup 1) of the day a second subgroup comprised 2 people ( $e_{s2}$ ) for 6 hours of the day (subgroup 2). The temporal probability can be calculated for each subgroup by estimating the annual proportion of time each subgroup is present, taking into account they are in the building for 260 days per year:

For 12 people (subgroup 1):  $P_{(T:S)1} = (2 \times 260)/(365 \times 24) = 0.059$

For 2 people (subgroup 2):  $P_{(T:S)2} = (6 \times 260)/(365 \times 24) = 0.18$

### Average Approach

The average number of people present for 100% of the time may be calculated in accordance with equation 10, where:

$$\begin{aligned} e_{av} &= e_s \times [(P_{(T:S)1} \times e_{s1} / e_s) + (P_{(T:S)2} \times e_{s2} / e_s)] \\ &= 12 \times [(0.059 \times 12 / 12) + (0.17 \times 2 / 12)] \\ &= 1.0 \end{aligned}$$

This is the equivalent number of people in the building for 100% of the time.

### ***N = The number of people expected to be killed if impact occurs.***

N is calculated for each hazard in accordance with Equation 9:

$$N = e_{av} V_{(D:T)} \quad (9)$$

Where:

$V_{(D:T)}$  = the average vulnerability of an individual within the exposed population.

$e_{av}$  = is the average number of people exposed to the hazard for an equivalent of 100% of the time as set out in equation 10.

#### *Hazard 1 – Failure of fill embankment*

$$\begin{aligned} N &= e_{av} V_{(D:T)} \\ &= 1.0 \times 0.4 \\ &= 0.4 \end{aligned}$$

*Hazard 2 – Boulder Detachment*

$$\begin{aligned}
 N &= e_{av} V_{(D:T)} \\
 &= 10 \times 0.5 \\
 &= 0.5
 \end{aligned}$$

**f-N approach**

It is also possible to estimate separate f-N pairs for each subgroup rather than use an averaging approach.

*Hazard 1 – Failure of fill embankment – Subgroup 1*

$$\begin{aligned}
 f &= P_{(H)1} \times P_{(S:H)1} \times P_{(T:S)1} \times V_{(D:T)} \\
 &= 2 \times 10^{-3} \times 0.5 \times 0.059 \times 0.4 \\
 &= 2.4 \times 10^{-5} \\
 N &= e_{s1} \\
 &= 12
 \end{aligned}$$

*Hazard 1 – Failure of fill embankment – Subgroup 2*

$$\begin{aligned}
 f &= P_{(H)2} \times P_{(S:H)2} \times P_{(T:S)2} \times V_{(D:T)} \\
 &= 2 \times 10^{-3} \times 0.5 \times 0.17 \times 0.4 \\
 &= 6.8 \times 10^{-5} \\
 N &= e_{s2} \\
 &= 2
 \end{aligned}$$

*Hazard 2 – Boulder Detachment – Subgroup 1*

$$\begin{aligned}
 f &= P_{(H)} \times P_{(S:H)} \times P_{(T:S)1} \times V_{(D:T)} \\
 &= 0.01 \times 0.025 \times 0.059 \times 0.5 \\
 &= 7.4 \times 10^{-6} \\
 N &= e_{s1} \\
 &= 12
 \end{aligned}$$

*Hazard 2 – Boulder Detachment – Subgroup 2*

$$\begin{aligned}
 f &= P_{(H)} \times P_{(S:H)} \times P_{(T:S)1} \times V_{(D:T)} \\
 &= 0.01 \times 0.025 \times 0.17 \times 0.5 \\
 &= 2.1 \times 10^{-5} \\
 N &= e_{s2} \\
 &= 2
 \end{aligned}$$

The f-N pairs can be combined for hazard 1 and 2.

Two F-N pairs have been calculated for each hazard as set out in the table below:

Hazard	Average approach		f-N approach			
			12 person subgroup		2 person subgroup	
	F	N	f	N	f	N
Hazard 1	$1.0 \times 10^{-3}$	0.40	$2.4 \times 10^{-5}$	12	$6.8 \times 10^{-5}$	2
Hazard 2	$2.5 \times 10^{-4}$	0.50	$7.4 \times 10^{-6}$	12	$2.1 \times 10^{-5}$	2

### Step 11. Number of independent hazards to which multiple people are exposed

There are two independent hazards, the failure of the fill embankment (Hazard 1) and detachment of a boulder (Hazard 2).

### Step 12. Combining Individual Risks

The risk to the individual calculated for each hazard in Step 4 can be combined as follows:

$$\begin{aligned}
 R_{(LOLC)} &= 1 - [(1 - R_{(LOLH1)}) \times (1 - R_{(LOLH2)})] \\
 &= 1 - [(1 - 9.6 \times 10^{-5}) \times (1 - 3.0 \times 10^{-5})] \\
 &= 1.26 \times 10^{-4}
 \end{aligned}$$

### Step 13. Combining Individual Risks to Multiple Persons

#### Average Approach

Two F-N pairs have been developed in Step 9 for the average of all people, each of which has a different N – one pair corresponding to Hazard 1 and one pair corresponding to Hazard 2.

The cumulative probability is calculated in accordance with the following table where the F-N pairs are listed in accordance with increasing N. Note that shaded rows indicate the formula used to calculate the values in the unshaded rows.

**Calculation of Cumulative Probability – Averaging Approach**

Hazard	Scenario	N	F	F <sub>C</sub> , N or more fatalities.
1		N <sub>H1</sub>	F <sub>H2</sub>	$F_C = 1 - [(1 - F_{H1}) \times (1 - F_{H2})]$
2		N <sub>H2</sub>	F <sub>H2</sub>	$F_C = 1 - [(1 - F_{H2})]$
1	Average	0.40	1.0 x 10 <sup>-3</sup>	1.2 x 10 <sup>-3</sup>
2	Average	0.50	2.5 x 10 <sup>-4</sup>	2.5 x 10 <sup>-4</sup>

**f-N Approach**

The following table indicates the calculation of cumulative probability where separate f-N pairs have been calculated for each subgroup. The f-N pairs are combined for hazards with the same N (2 and 12 respectively) then cumulative probability is calculated based on the result.

**Calculation of Cumulative Probability – f-N approach**

Hazard	N	f	Aggregate f	F <sub>C</sub> , N or more fatalities.
1	2 people	f <sub>H1</sub>	$f_{C2} = 1 - [(1 - f_{H1}) \times (1 - f_{H2})]$	$F_C = 1 - [(1 - f_{C2}) \times (1 - f_{C12})]$
2	2 people	f <sub>H2</sub>		
1	12 people	f <sub>H1</sub>	$f_{C12} = 1 - [(1 - f_{H1}) \times (1 - f_{H2})]$	$F_C = 1 - [(1 - f_{C12})]$
2	12 people	f <sub>H2</sub>		
1	2	6.8 x 10 <sup>-5</sup>	8.9 x 10 <sup>-5</sup>	1.2 x 10 <sup>-4</sup>
2	2	2.1 x 10 <sup>-5</sup>		
1	12	2.4 x 10 <sup>-5</sup>	3.1 x 10 <sup>-5</sup>	3.1 x 10 <sup>-5</sup>
2	12	7.4 x 10 <sup>-6</sup>		

**Step 14. Evaluate risk to the individual most at risk**

The office building is an existing element at risk, so based on Table 1, the criteria against which tolerable risk is assessed is:

$$R_{(LOL)}, R_{(LOLC)} < 10^{-4} \text{ per annum}$$

With acceptable risk one order of magnitude lower. The estimated risk to the individual most at risk are summarised in the following table.

Hazard	Risk to the individual most at risk	Evaluation
Hazard 1, $R_{(LOLH1)}$	$9.6 \times 10^{-5}$	Tolerable
Hazard 2, $R_{(LOLH2)}$	$3.0 \times 10^{-5}$	Tolerable
Combined, $R_{(LOLC)}$	$1.26 \times 10^{-4}$	Not tolerable

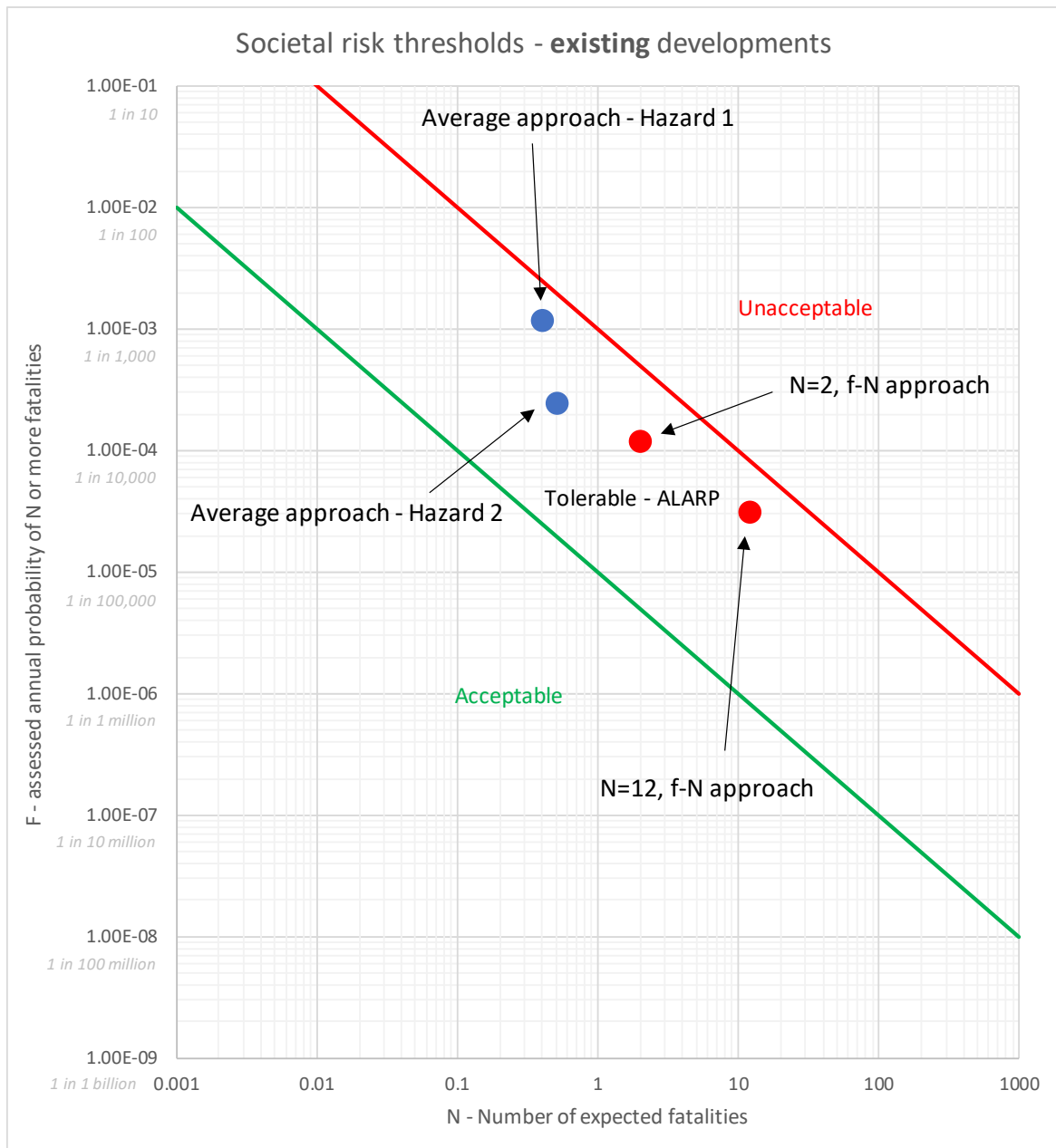
In this case, if either Hazard 1 or Hazard 2 is considered independently, the risk to life is assessed to be below the tolerable threshold for an existing element at risk. However, combined, the risk to the individual most at risk is not tolerable.

### Step 15. Evaluate F-N pairs to assess societal risk

F-N pairs were developed in Step 13 which can be plotted on the F-N curve in Figure B9 for existing elements at risk. Both the average approach and the f-N approach are provided for illustrative purposes.

Approach	Hazard	Fc	N
Average approach	Hazard 1	$1.2 \times 10^{-3}$	0.40
	Hazard 2	$2.5 \times 10^{-4}$	0.50
f-N approach	Combined	$1.2 \times 10^{-4}$	2
	Combined	$3.1 \times 10^{-5}$	12





**Figure B9 – Evaluation of societal risk for Example 3**

In this case, the average F-N pairs plot within the ALARP part of the chart and may be tolerable subject to the implementation of appropriate risk mitigation measures. The risk estimated using the average approach, or alternatively inspection of the f-N pairs allows an assessment of how risk reduction might be best achieved. In this example, the higher average hazard and f-N pairs are associated Hazard 1.

## Step 16. Reporting Calculations

The risk calculations should be reported, including showing the outcomes on the F-N curve. In this example, whilst societal risk criteria are satisfied (Step 15), the criteria for the individual most at risk, exposed to two hazards is not tolerable. In this case, the report may recommend means by which the risk to this individual could be reduced. For example, eliminating Hazard 2 by removing the boulder could serve to reduce the risks to a tolerable level.

#### Example 4 - Mobile element at risk, exposed population < 10, single hazard

A ranger must enter an area off limits to the public once per week to undertake inspections. To get to the area they need to inspect, the ranger must walk beneath a rock overhang that has been assessed as having some potential to detach. Field assessment indicates the following:

- The rock overhang is estimated to have a probability of detachment of 1 in 5 per annum and is certain to impact the track if it falls.
- The ranger walks through the area twice (to and back) on each inspection, once per week.
- The ranger walks at a speed of about 3 km/hour.
- The size of the rock block that could detach is estimated to affect a 2 m length of the track and the full width of the track would be impacted.
- Analysis of rainfall records indicates that heavy rain is the main trigger for rockfall. The ranger undertakes the inspection irrespective of whether it is raining.

The hazard scenario is illustrated in Figure B10 and calculation steps required in Figure B11.

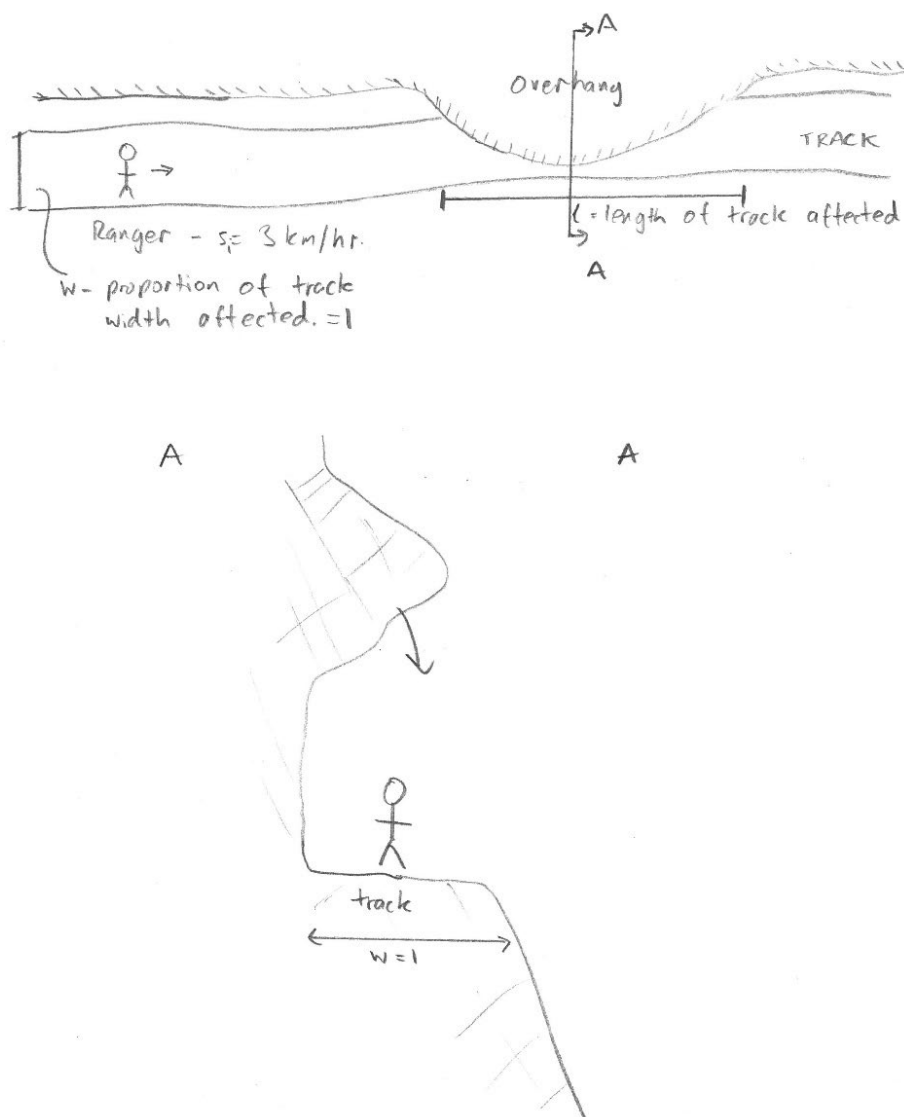


Figure B10 – Illustration of Example 4 hazard scenario

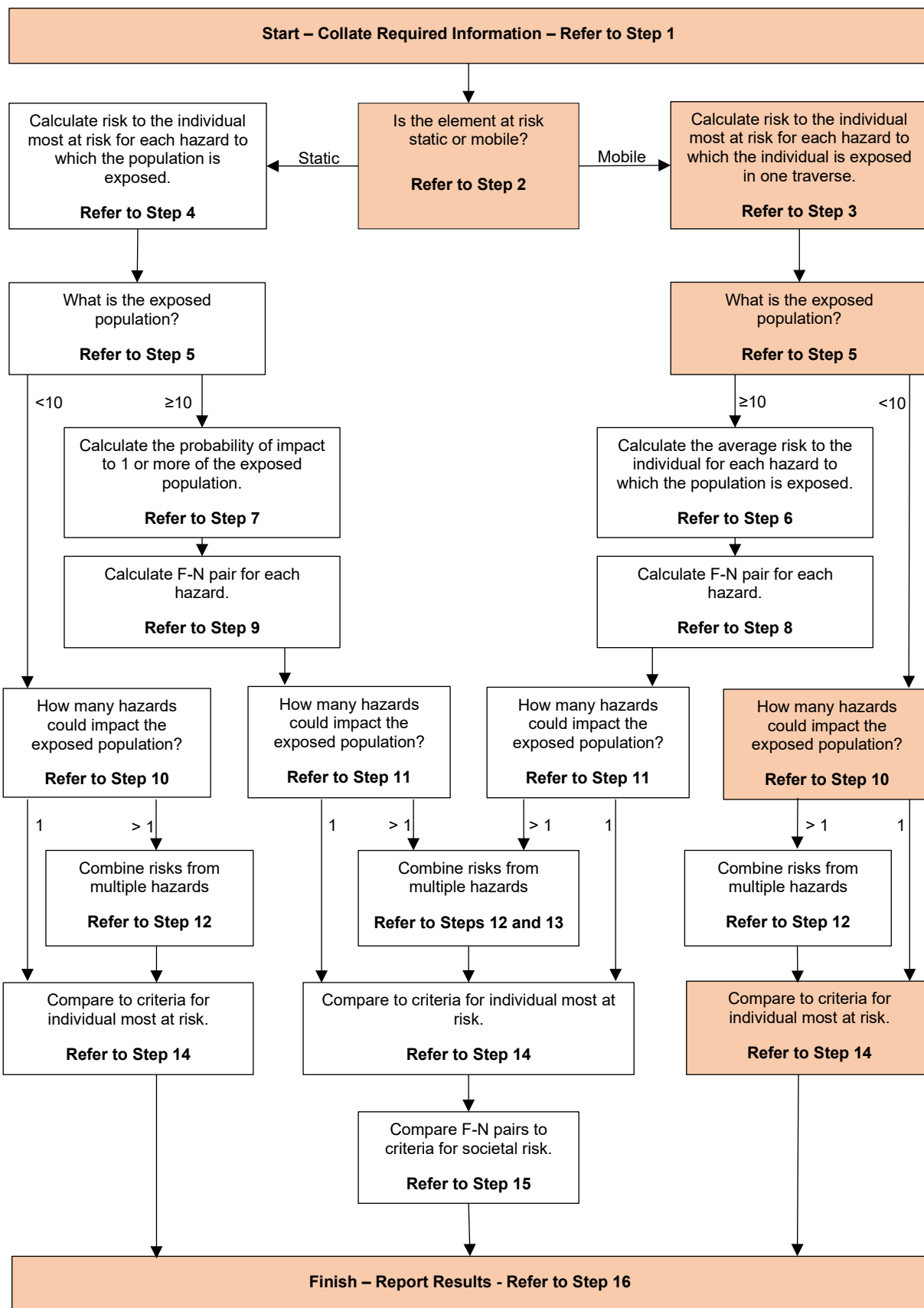


Figure B11 – Flow chart highlighting applicable calculation steps for Example 4

## Step 1. Information required to inform landslide risk assessment

Field work for this scenario could include:

- A site visit to map the overhang, measure and inspect defects that could act as release planes.
- Consultation of a landslide inventory to assess the frequency of past rockfall.
- Analysis of rainfall data along with the landslide inventory as a means of assessing landslide frequency.
- Consultation with NPWS to assess the number of people expected to be present and exposed to the hazard.

## Step 2. Static versus mobile elements at risk

The ranger is a mobile element at risk.

## Step 3. Risk to the Individual most at risk in a mobile scenario over one traverse

The hazard is related to impact from a boulder with an estimated 2 m diameter. In this case, the ranger is the individual most at risk. The estimation of risk of loss of life of the ranger in one traverse may be estimated from Equation 3:

$$= P_{(H)} \cdot P_{(t)} \cdot n_i w f d \times 8.0 \times 10^{-8} / s_i \quad (3)$$

$P_{(H)}$  = the annual probability that a landslide or rockfall occurs, estimated to be 1 in 5, 0.2.

$P_{(t)}$  = the probability of travel, estimated to be 1 because the rockfall is certain to reach the track.

$n_i$  = the number of traverses made by the individual most at risk in a year, 2 per week, 52 weeks of the year,  $n_i = 2 \times 52 = 104$ .

$f$  = a reduction factor between 0 and 1 relating to the probability of a person being present when the landslide is triggered. The ranger undertakes the inspection irrespective of weather. In this case  $f = 1$ . If for example, the ranger did not undertake the inspection during or for several days after heavy rain, it might be prudent to apply the reduction factor.

$w$  = the proportion of the track affected by the landslide ranging between 0 (none of track affected) to 1 (full width of the track affected). In this case, the full width of the track could be affected, and so  $w = 1$ .

$d$  = The length of a track that could be impacted by the landslide. For rockfall,  $d$  = the boulder diameter, which in this case is 2 m.

$s_i$  = the speed in km/hr that the individual moves through the area subject to the hazard. Assumed to be 3 km/hour for the ranger.

$$\begin{aligned} R_{(LOL)} &= P_{(H)} P_{(t)} \cdot n_i w f d \times 8.0 \times 10^{-8} / s_i \\ &= 0.2 \times 1 \times 104 \times 1 \times 1 \times 2 \times 8.0 \times 10^{-8} / 3 \\ &= 1.1 \times 10^{-6} \end{aligned}$$

**Step 5. The Exposed Population, e**

The ranger is the only person exposed to the hazard, so the exposed population is 1.

**Step 10. Number of independent hazards to which an individual is exposed**

The ranger is exposed to a single hazard.

**Step 14. Evaluate risk to the individual most at risk**

The track is an existing element at risk, so the criteria against which tolerable risk is assessed is:

$$R_{(LOL)} < 10^{-4} \text{ per annum}$$

With acceptable risk one order of magnitude lower. In this case, the estimated risk to the individual most at risk is  $1.1 \times 10^{-6}$ . Comparison against the criteria for the individual most at risk indicates that the risk is less than  $10^{-5}$  per annum and therefore meets the acceptable criteria for an existing element at risk.

**Step 16. Reporting Calculations**

The method of calculation and outcome should be reported.

## Example 5 - Mobile element at risk, exposed population $\geq 10$ , multiple hazards

A loop walking track has 120,000 hikers per year. Two hazards have been identified on the walking track past which all hikers must walk. The following information has been obtained from field assessment:

### *Hazard 1 – rockfall*

- The track passes through a zone subject to rockfall. The zone subject to rockfall is 150 m long.
- Based on observations of previous rockfalls, the track is estimated to be impacted by 1 rockfall of 0.3 m diameter every 2 years.
- The track is 1.5 m wide, so a 0.3 m diameter rockfall is estimated to impact a proportion of the track equivalent to  $0.3/1.5 = 0.2$ .
- The area at risk is very scenic and hikers are assumed to walk through the area at risk at relatively slow average speed of about 2 km/hour.
- The track facilitates disabled access, and the slowest person to use the track is estimated to move along the track at 1 km/hour.
- There appears to no correlation between rainfall and rockfall frequency.
- People are assumed to walk along the track generally in single file and it is assumed that people would generally only use the track once per year.

### *Hazard 2 – Fill Embankment Failure*

- Part of the track traverses a section of fill that has been placed on a steep slope and has the potential to detach and undermine the track. The zone of fill is 50 m long and the entire 50 m of track is assumed to be undermined in the event of a failure.
- Based on past failures, on tracks in the area, similar sections of fill have detached with a frequency of about 1 per 5 years.
- The fill failure generally always occurs during a storm event. It is estimated there are 5 times fewer people likely on the track during storm events.
- Hikers are assumed to walk across the fill at an average of about 3 km/hour.
- The track facilitates disabled access, and the slowest people to use the track are estimated to move along the track at 1 km/hour.
- It is assumed that if a person was on the fill when it was undermined, the probability of death (vulnerability) is 0.5.
- People are assumed to walk along the track generally in single file and each person no more than once per year.

The hazard scenario is illustrated in Figure B12 and calculation steps required in Figure B13.

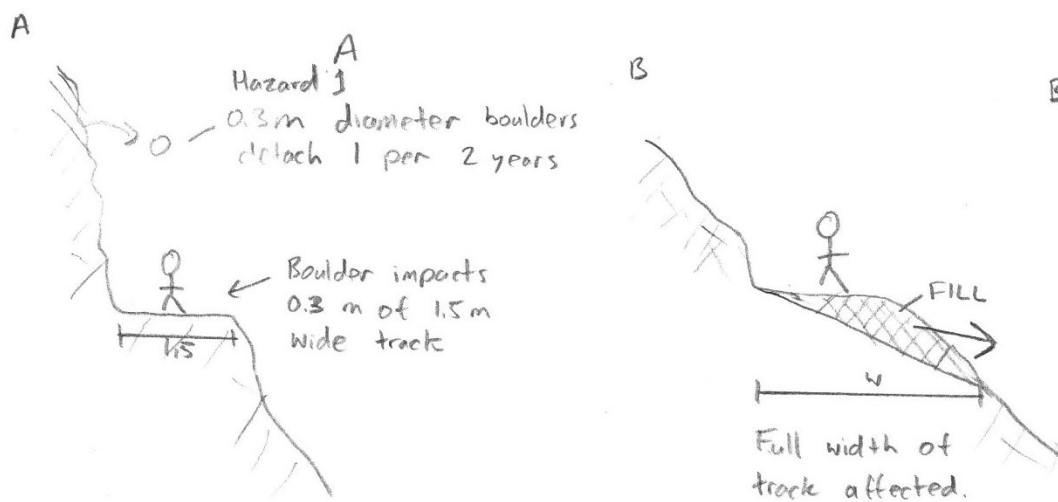
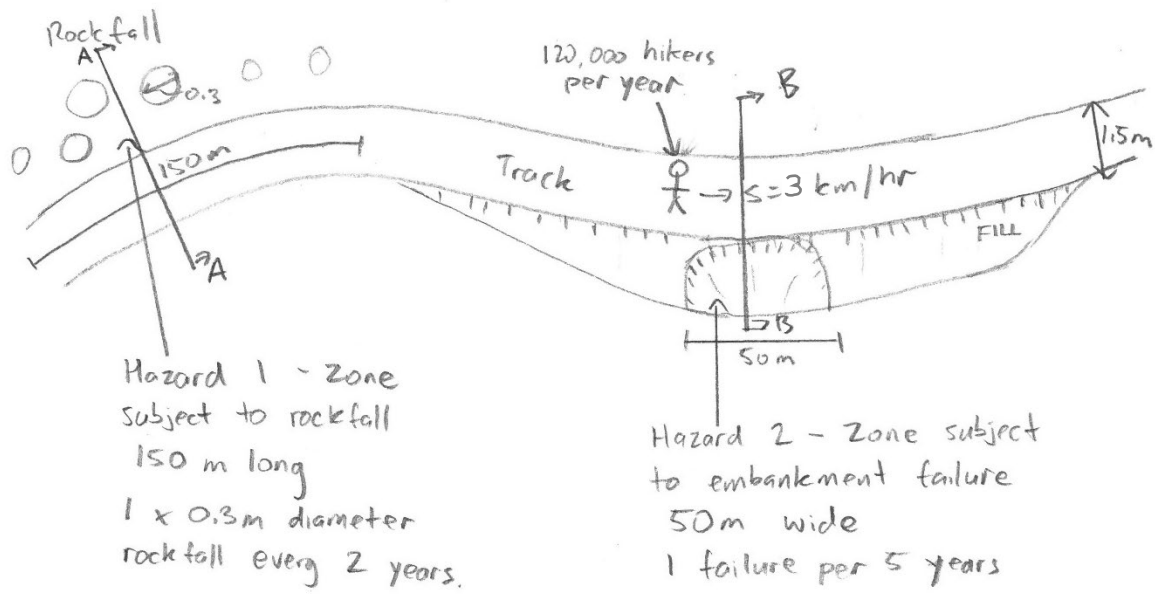


Figure B12 – Illustration of Example 5 hazard scenario



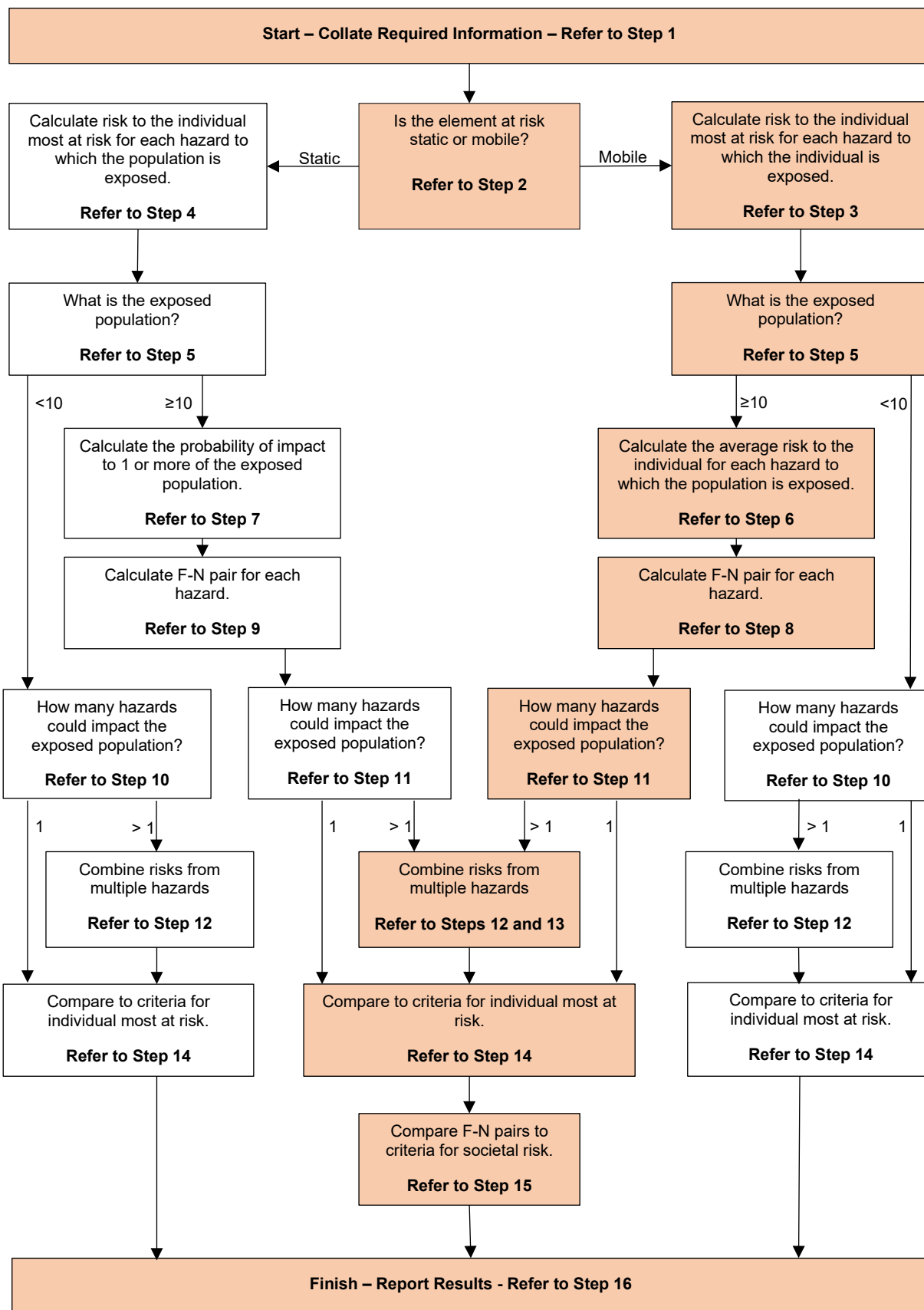


Figure B13 – Flow chart highlighting applicable calculation steps for Example 5

## Step 1. Information required to inform landslide risk assessment

Field work for this scenario could include:

- Remote sensing work as a means of assessing past fill failure events.
- A site visit to assess evidence for rockfall frequency.
- Consultation of a landslide inventory to assess the frequency of past rockfall and fill failure.
- Analysis of rainfall data along with the landslide inventory as a means of assessing landslide frequency.
- Consultation with NPWS to obtain information about track usage.

## Step 2. Static versus mobile elements at risk

The hikers on the track are mobile elements at risk.

## Step 3. The Individual most at risk in a mobile scenario

### Hazard 1 - Rockfall

The hazard is related to impact from a boulder with a diameter of 0.3 m. In this case, the estimation of risk of loss of life for the hiker which is the individual most at risk may be estimated from Equation 2:

$$R_{(LOL)} = P_{(H)} P_{(t)} n_i w f d^2 \times 1.6 \times 10^{-7} / s_i \quad (2)$$

$P_{(H)}$  = the annual probability that a landslide or rockfall occurs, estimated to be 1 every 2 years, 0.5.

$P_{(t)}$  = the probability the track is impacted, assumed to be 1.

$n_i$  = the number of traverses made in a year by the individual most at risk. In this case 1.

$f$  = a reduction factor between 0 and 1 relating to the probability of a person being present when the landslide is triggered. There appears to be no correlation between rainfall and rockfall frequency, therefore  $f = 1$ . i.e. even if there is a reduction in track usage during rainfall, this does not affect the risk.

$w$  = the proportion of the road or track affected by the landslide ranging between 0 (none of track affected) to 1 (full width of the track affected). In this case, the proportion of the width of track affected by a 0.3 m diameter rockfall is 0.2.

$d$  = the length of a track that could be impacted by the rockfall. For rockfall,  $d$  = the boulder diameter, which in this case is 0.3 m.

$s_i$  = the speed in km/hr that the individual most at risk moves through the area subject to the hazard. Assumed to be 1 km/hour for an infirm person.

$$\begin{aligned} R_{(LOL)} &= P_{(H)} P_{(t)} n_i w f d^2 \times 1.6 \times 10^{-7} / s_i \\ &= 0.5 \times 1 \times 1 \times 0.2 \times 1 \times 0.3^2 \times 1.6 \times 10^{-7} / 1 \\ &= 1.4 \times 10^{-9} \end{aligned}$$

### Hazard 2 – Fill Embankment Failure

The general case requires an estimate of vulnerability of the individual if they are impacted. In this case, equation 1 may be used to estimate individual risk:

$$R_{(LOL)} = P_{(H)} P_{(t)} V_{(D:T)} n_i w f d \times 1.1 \times 10^{-7} / s_i$$

Where:

$P_{(H)}$  = the annual probability that the failure of the fill occurs, 1 in 5 years, = 0.2.

$P_{(t)}$  = the annual probability that the track is impacted, assumed to be 1.

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted = 0.5.

$n_i$  = the number of traverses made in a year by the individual most at risk. In this case 1.

$f$  = a reduction factor between 0 and 1 and relates to the probability of a person being present when the landslide is triggered. For the fill embankment, failure is judged to occur mainly during storm events when there are anticipated to be about 5 times fewer people on the track,  $f = 1/5 = 0.2$ .

$w$  = the proportion of the road or track affected. The full width of the track is assumed to be affected,  $w = 1$ .

$d$  = The length of a track that could be impacted by the landslide, estimated to be 50 m.

$s_i$  = the speed in km/hr that the individual moves through the area subject to the hazard. For the individual most at risk,  $s = 1$  km/hour.

$$\begin{aligned} R_{(LOL)} &= P_{(H)} P_{(t)} V_{(D:T)} n_i w f d \times 1.1 \times 10^{-7} / s \\ &= 0.2 \times 1 \times 0.5 \times 1 \times 1 \times 0.2 \times 50 \times 1.1 \times 10^{-7} / 1 \\ &= 1.1 \times 10^{-7} \end{aligned}$$

### Step 5. The exposed population, e

Assuming each hiker traverses the track once per year, the exposed population is 120,000 per year.

### Step 6. The average risk to an individual, mobile element at risk, $AvR_{(LOL)}$

The average risk to hikers can be estimated using the average speed,  $s$  at which people walk through the area at risk, rather than speed of the individual most at risk as was assumed in Step 3, using equation 6.

#### Hazard 1 - Rockfall

$$\begin{aligned} AvR_{(LOL)} &= s_i R_{(LOL)} / n_i s \\ &= 1 \times 1.4 \times 10^{-9} / 1 \times 2 \\ &= 7.0 \times 10^{-10} \end{aligned}$$

#### Hazard 2 – Fill Embankment Failure

$$AvR_{(LOL)} = s_i R_{(LOL)} / n_i s$$

$$= 1 \times 1.1 \times 10^{-7} / 1 \times 3$$

$$= 3.7 \times 10^{-8}$$

## Step 8. Calculation of F-N pair for a mobile element at risk

The assessment of societal risk requires the calculation of F, and N (F-N pair). Each component is estimated as set out below

### *Hazard 1 - Rockfall*

***N = The number of people comprising each mobile element.***

In this case, it is assumed that people walk along the track in single file and that each hiker comprises one mobile element at risk, so N = 1.

***F = The probability of loss of life of the mobile element at risk.***

For mobile elements at risk, F is estimated by equation 8:

$$F = 1 - (1 - \text{AvR}_{(\text{LOL})})^n$$

Where:

$\text{AvR}_{(\text{LOL})}$  is calculated in accordance with Step 6 =  $7.0 \times 10^{-10}$ .

n = the total number of traverses made annually through the area at risk by the mobile element, a hiker = 120,000

$$F = 1 - (1 - 7.0 \times 10^{-10})^{120,000}$$

$$= 8.4 \times 10^{-5}$$

### *Hazard 2 – Fill Embankment Failure*

***N = The number of people comprising each mobile element.***

In this case, it is assumed that people walk along the track in single file and that each hiker comprises one mobile element at risk, so N = 1.

***F = The probability of loss of life of the mobile element at risk.***

For mobile elements at risk, F is estimated using Equation 8:

$$F = 1 - (1 - \text{AvR}_{(\text{LOL})})^n$$

Where:

$\text{AvR}_{(\text{LOL})}$  is calculated in accordance with Step 6 =  $3.7 \times 10^{-8}$ .

n = number of traverses by the mobile element at risk = 120,000

$$F = 1 - (1 - 3.7 \times 10^{-8})^{120,000}$$

$$= 4.4 \times 10^{-3}$$

Two F-N pairs have been calculated:

$$\text{Hazard 1} - F_{H1} = 8.4 \times 10^{-5} \quad N_{H1} = 1$$

$$\text{Hazard 2} - F_{H2} = 4.4 \times 10^{-3} \quad N_{H2} = 1$$

### Step 11. Number of independent hazards

Hikers on the walking track are exposed to two independent hazards, rockfall and fill embankment failure.

### Step 12. Combining Individual Risks

The risk to the individual calculated for each hazard in Step 3 can be combined as follows:

$$\begin{aligned} R_{(LOLC)} &= 1 - [(1 - R_{(LOLH1)}) \times (1 - R_{(LOLH2)})] \\ &= 1 - [(1 - 1.4 \times 10^{-9}) \times (1 - 1.1 \times 10^{-7})] \\ &= 1.1 \times 10^{-7} \end{aligned}$$

### Step 13. Combining Individual Risks to Multiple Persons

Two F-N pairs have been developed in Step 8 each of which has the same N, 1. These may be combined by:

$$\begin{aligned} F_C &= 1 - [(1 - F_{H2}) \times (1 - F_{H1})] \\ F_C &= 1 - [(1 - 4.4 \times 10^{-3}) \times (1 - 8.4 \times 10^{-5})] \\ &= 4.5 \times 10^{-3} \end{aligned}$$

### Step 14. Evaluate risk to the individual most at risk

The track is existing, so the criteria against which tolerable risk is assessed is:

$$R_{(LOLC)} < 10^{-4} \text{ per annum}$$

With acceptable risk one order of magnitude lower. The estimated risks to the individual most at risk are summarised in the following table.

Hazard	Risk to the individual most at risk	Evaluation
Hazard 1, $R_{(LOLH1)}$	$1.4 \times 10^{-9}$	Acceptable
Hazard 2, $R_{(LOLH2)}$	$1.1 \times 10^{-7}$	Acceptable
Combined, $R_{(LOLC)}$	$1.1 \times 10^{-7}$	Acceptable

In this case, the estimated risk to life is less than the criteria for tolerable risk.

### Step 15. Evaluate F-N pairs to assess societal risk

The track is an existing asset, so the criteria for existing assets is assumed to apply. The F-N pair developed in Step 13 indicates  $N = 1$ ,  $F_c = 4.5 \times 10^{-3}$ . Plotting the F – N pair in Figure B14, indicates it plots in the unacceptable zone. The F-N pairs for Hazards 1 and 2 are plotted separately for reference.

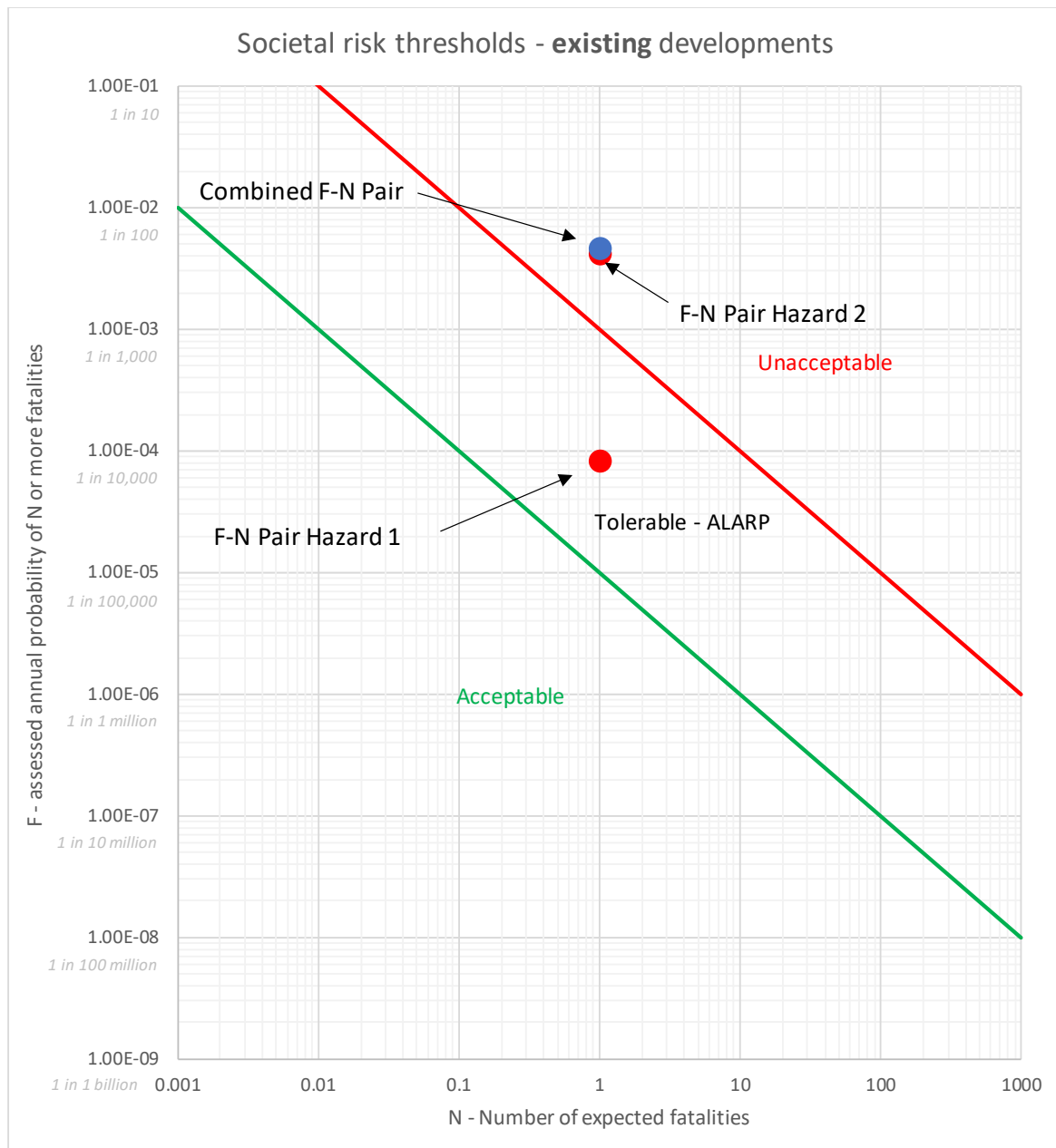


Figure B14 – Evaluation of societal risk for Example 5

### Step 16. Reporting Calculations

The method of calculation and outcome should be reported. In this case, the risk to the individual is acceptable, but societal risk is not acceptable. Methods available to mitigate risk may focus on Hazard 2 and might include reducing the number of hikers on the track, closing the track during rain events or undertaking works to improve the stability of the embankment fill.

### Example 6 - Mobile element at risk, exposed population $\geq 10$ , single hazard

A proposal has been put forward to offer a new four wheel drive tour in a national park. The tour will be delivered in a four wheel drive bus which accommodates 20 people including the driver and it is proposed to run the tour two times per day, 4 days per week over the whole year irrespective of weather. One of two drivers runs each tour with different passengers on each trip.

The track along which the tour will be undertaken is closed to the public. The track crosses a gully down which debris flow events have occurred in the past. There is a risk of the bus being struck by a debris flow as it crosses the gully. Field assessment indicates the following:

- Based on observations of previous debris flows, the debris flow frequency is estimated to be 1 per 10 years.
- The gully is 25 m wide and the bus traverses through the gully at 10 km/hour.
- Based on past debris flow events, the debris can fill the 25 m width of the gully.
- It is assumed that if a debris flow struck the bus, it would be engulfed and that the vulnerability of passengers on the bus would be 1.

The hazard scenario is illustrated in Figure B15 and calculation steps required in Figure B16.

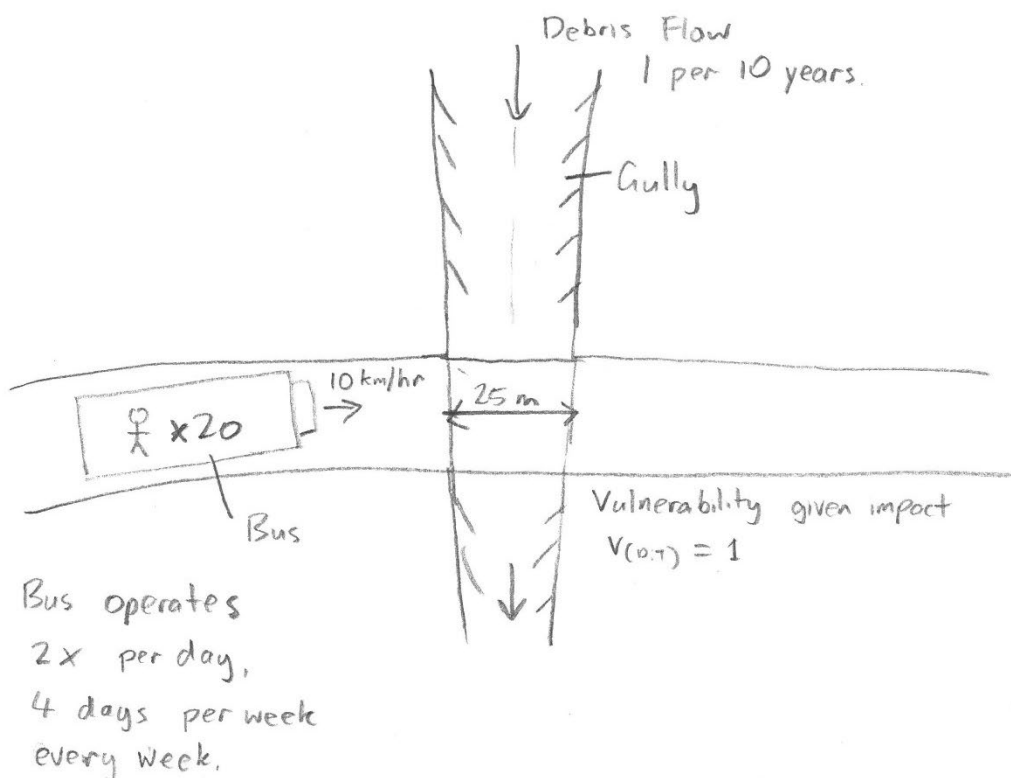


Figure B15 – Illustration of Example 6 hazard scenario



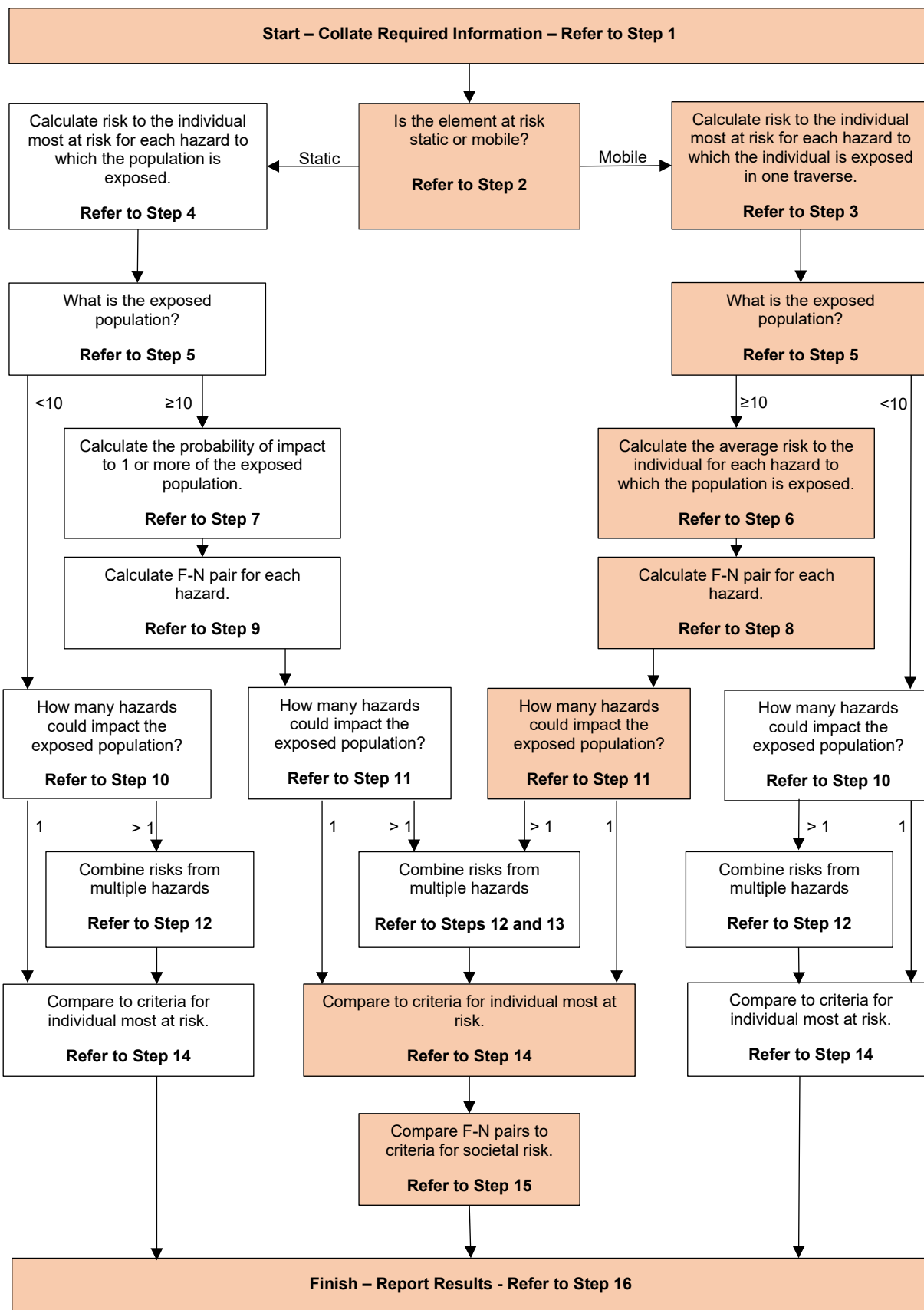


Figure B16 – Flow chart highlighting applicable calculation steps for Example 6

## Step 1. Information required to inform landslide risk assessment

Field work for this scenario could include:

- Remote sensing work as a means of assessing past fill debris flow events and mapping debris flow travel paths.
- Field investigation comprising drilling and test pits to examine debris from previous debris flows and assess debris flow frequency.
- Consultation of a landslide inventory to assess the frequency of past debris flow events.
- Analysis of rainfall data along with the landslide inventory as a means of assessing debris flow frequency.
- Consultation with NPWS to obtain information about usage and elements at risk.

## Step 2. Static versus mobile elements at risk

The 4WD bus is a mobile element at risk.

## Step 3. Risk to the Individual most at risk in a mobile scenario over one traverse

In this case, it is assumed that if a debris flow were to impact the bus it would be engulfed and that the vulnerability of a person on the bus would be 1. It is assumed that no individual on the bus is more at risk than any other. In this case, equation 4 would apply.

$$R_{(LOL)} = P_{(H)} P_{(t)} n_i w f d \times 1.1 \times 10^{-7} / s_i$$

Where:

$P_{(H)}$  = the annual probability that the debris flow occurs, 1 in 10 years, =0.1.

$P_{(t)}$  = the annual probability that the road is impacted, assumed to be 1.

$n_i$  = the number of traverses made by the individual most at risk in this case the driver. The total number of tours based on 2 tours per day, 4 days per week over the full year, is  $2 \times 4 \times 52 = 416$  traverses. Assuming the drivers share the tours, each driver takes 208 tours.

$f$  = a reduction factor between 0 and 1 and relates to the probability of a person being present when the landslide is triggered. In this case, the tour operates irrespective of weather, so  $f = 1$ .

$w$  is the proportion of the road or track affected. The full width of the track is assumed to be affected,  $w = 1$ .

$d$  = The length of a track that could be impacted by the landslide, estimated to be the width of the gully 25 m.

$s$  = the speed in km/hr that the element at risk moves through the area subject to the hazard. For the bus this is 10 km/hr.

$$\begin{aligned} R_{(LOL)} &= P_{(H)} P_{(t)} n_i w f d \times 1.1 \times 10^{-7} / s \\ &= 0.1 \times 1 \times 208 \times 1 \times 1 \times 25 \times 1.1 \times 10^{-7} / 10 \end{aligned}$$

$$= 5.7 \times 10^{-6}$$

### Step 5. The Exposed Population, e

As shown in Step 3, there are 416 traverses per year and each traverse is assumed to have 19 passengers. The exposed population is then  $19 \times 416$  passengers + 2 drivers = 7,906.

### Step 6. The Average Risk to an Individual, Mobile Element at Risk, $AvR_{(LOL)}$

Every person in the bus is travelling at the same speed and it is assumed that no individual is more at risk than any other. In this case equation 6 can be used to estimate the average risk to an individual on the bus.

$$AvR_{(LOL)} = s_i R_{(LOL)} / n_{is} \quad (6)$$

All people on the bus must travel at the same speed, so  $s_i$  and  $s$  cancel out.

$$\begin{aligned} AvR_{(LOL)} &= R_{(LOL)} = 5.7 \times 10^{-6} / 208 \\ &= 2.7 \times 10^{-8} \end{aligned}$$

### Step 8. Calculation of F-N pair for a Mobile Element at Risk

The assessment of societal risk requires the calculation of F, and N (F-N pair). Each component is estimated as set out below

***N = The number of people comprising each mobile element.***

In this case, it is assumed there are 20 people on the bus and that all 20 would be killed if the bus were impacted by a debris flow. In this case,  $e_s = 20$ , and  $N = 20$ .

***F = The probability of loss of life of the mobile element at risk.***

For mobile elements at risk, F is estimated by:

$$F = 1 - (1 - AvR_{(LOL)})^n$$

Where:

$AvR_{(LOL)}$  is calculated in accordance with Step 6 =  $2.7 \times 10^{-8}$ .

$n$  = the total number of traverses of the mobile element at risk, in this case the bus, 416

$$\begin{aligned} F &= 1 - (1 - 2.7 \times 10^{-8})^{416} \\ &= 1.1 \times 10^{-5} \end{aligned}$$

One F-N pair has been calculated:

**Hazard 1** –  $F_{H1} = 1.1 \times 10^{-5}$   $N_{H1} = 20$

### **Step 11. Number of independent hazards**

The debris flow hazard is the only hazard to which the bus is exposed.

### **Step 14. Evaluate risk to the individual most at risk**

The activity is a proposed new activity, so the criteria against which tolerable risk is assessed is that for proposed assets.

$$R_{(LOL)} < 10^{-5} \text{ per annum}$$

The estimated risk to the individual most at risk from Step 3 is  $5.7 \times 10^{-6}$ . In this case comparison against the criteria for the individual most at risk indicates that the risk is less than  $10^{-5}$  per annum and therefore meets the acceptable criteria for an existing element at risk.

### **Step 15. Evaluate F-N pairs to assess societal risk**

The F-N pair developed in Step 8 indicates  $F = 1.1 \times 10^{-5}$ ,  $N = 20$ . Plotting the F – N pair in Figure B17 on the chart for proposed assets and evaluating against the criteria indicates it plots in the unacceptable zone, suggesting risk mitigation measures are required to reduce the level of risk.

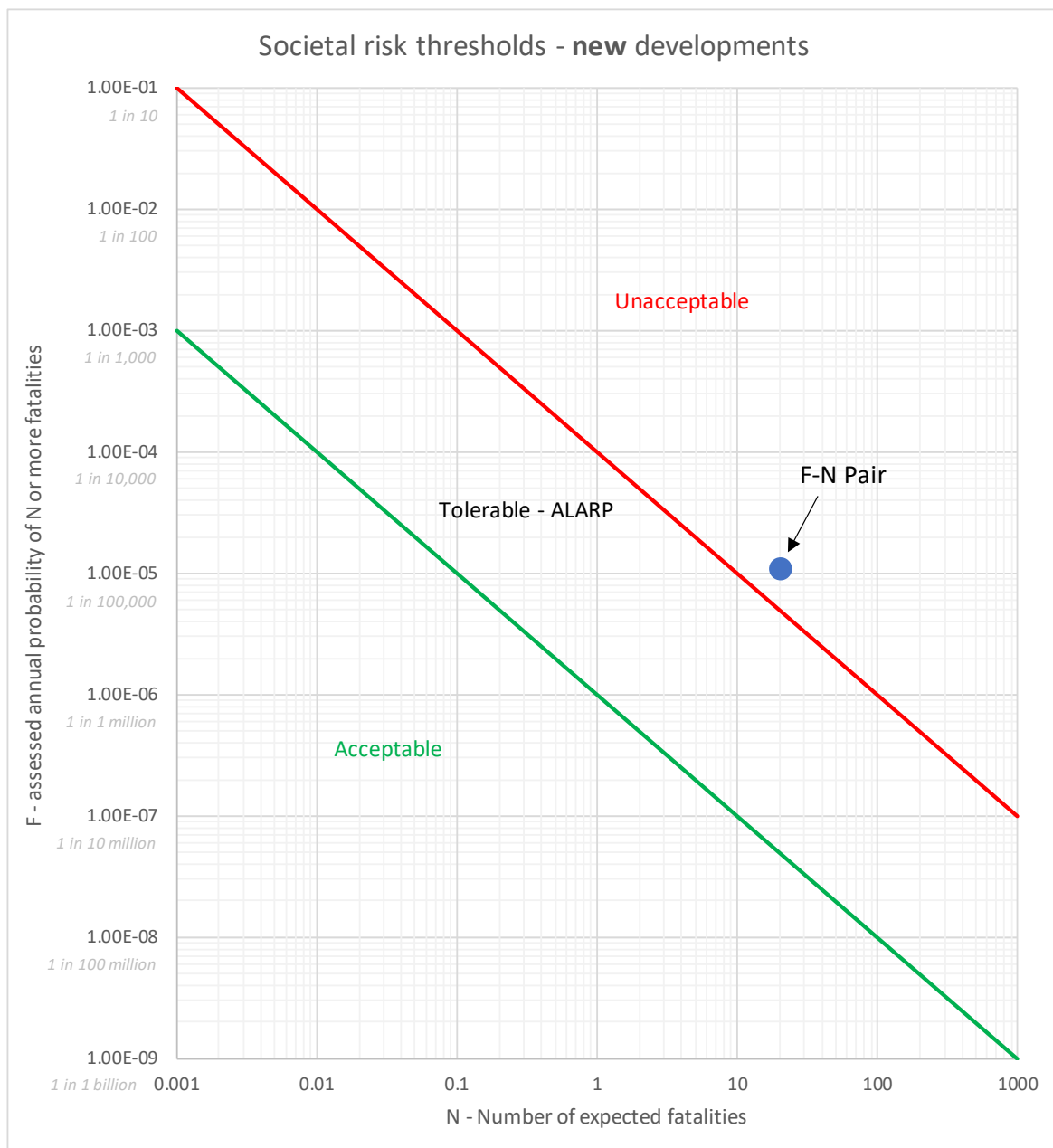


Figure B17 – Evaluation of Societal Risk for Example 6

### Step 16. Reporting Calculations

The method of calculation and outcome should be reported. In this case, mitigation measures would usually be recommended to reduce the risk. This could include not undertaking the tours in storms or at times when debris flow is more likely, re-routing or undertaking works to deflect debris flows away from the track, or reducing the number of passengers.

**APPENDIX C**

# Technical Information

## Introduction

The following provides additional technical basis and supporting information for the steps set out in the guideline. The steps described below are the same as those set out in the guideline.

### Step 1. Information required to inform landslide risk assessment

It is assumed that practitioners undertaking risk assessment in parks will be suitably qualified and experienced to undertake the assessment for which they have been commissioned. Furthermore, that they will be familiar with AGS2007 and have the competence to undertake the appropriate field investigations to identify, characterise and analyse landslide hazards and develop appropriate input parameters for landslide risk assessment.

### Step 2. Static versus mobile elements at risk

The means by which temporal probability is calculated and F-N pairs are developed differs depending on whether the element at risk is mobile or static. It is necessary to identify early in the calculation process whether the elements at risk are static or mobile.

### Step 3. Risk to the individual most at risk in a mobile scenario

The annual risk of loss of life of the individual most at risk is defined in AGS 2007c by equation 3.1:

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (3.1)$$

Where:

$R_{(LOL)}$  = the risk or annual probability of loss of life of the individual most at risk. This is usually the individual who is exposed to the hazard for the greatest duration.

$P_{(H)}$  = the annual probability that a landslide or rockfall occurs.

$P_{(S:H)}$  = the probability of spatial impact of the landslide impacting a mobile element at risk taking into account the travel distance and direction of the landslide or rockfall.

$P_{(T:S)}$  = the temporal spatial probability (eg. of the individual being in an area subject to landslide) given the spatial probability and allowing for evacuation if there is warning of the landslide or rockfall event.

$V_{(D:T)}$  = is the vulnerability of the individual given they are impacted.

The means of calculating each term is presented below.

#### *Annual Probability that the Landslide or Rockfall Occurs, $P_{(H)}$*

This is the annual probability that the landslide or rockfall occurs and is typically estimated based on geological and geomorphological studies considering the history of landsliding or rockfall and frequency of triggering events. In some cases, such as rockfalls, the annual probability of rockfall must be estimated based on site observations if there are no records of historical events.

### Spatial Probability, $P_{(S:H)}$

This is the probability that the individual most at risk is within an area where a landslide occurs and that the landslide reaches the area where the individual is located. It is assumed that a landslide or rockfall event will occur where the individual transits across an area where a landslide or rockfall hazard could occur. Generally, this would be a designated track or road. The term track is used here to refer to the path the individual might be moving along that could be impacted by a landslide. The area of track that could be affected is a function of the size of the landslide and how much of the track it could impact. The length of track within the area subject to the hazard is defined as  $l$  (m) and the proportion of track affected,  $w$ , where  $w$  ranges from 1 for the full width of track and 0 for none of the track. If half the track is affected,  $w = 0.5$ . For a boulder or landslide impacting the length of track subject to landslide of  $d$  m width/diameter, the area impacted is defined by  $d$  (m). The probability that the boulder or debris reaches the track after detaching is  $P_{(t)}$  and the spatial probability is defined by equation 3.2 as:

$$P_{(S:H)} = P_{(t)} wd/l \quad (3.2)$$

Equation 3.2 defines the proportion of the total area prone to the hazard that could be impacted by a single occurrence of the hazard. Where the length of the track subject to the hazard is equal to the width of the hazard, and the entire track width would be impacted, which might typically be the case for a landslide,  $P_{(S:H)} = 1$ . For a rockfall event over a length of track subject to rockfall  $P_{(S:H)}$  is typically much less than 1.

### Temporal Probability, $P_{(T:S)}$

This defines the probability that the individual most at risk is within the section of track over which the hazard has been identified at the time a landslide or rockfall event occurs. For an individual travelling  $n_i$  times per year through the area at risk at a speed of  $s_i$  (km/hr), across the length of track ( $l$ ) in metres subject to a hazard, the time,  $t$ , in hours that the individual most at risk will be exposed to the hazard is defined by equation 3.3:

$$t = n_i l / (1000 s_i) \quad (3.3)$$

If it is assumed that the landslide will occur in response to say rainfall or bushfire or at a time when the number of mobile elements at risk will be lower than usual, a reduction factor,  $f$ , may be used to reduce  $P_{(T:S)}$  in accordance with Equation 3.4:

$$t_{fy} = ft \quad (3.4)$$

The temporal probability per annum is then defined by the time per year in hours that the individual most at risk is exposed to the hazard divided by the total number of hours within a year:

$$P_{(T:S)} = t_{fy} / (24 \times 365) \quad (3.5)$$

Substituting (3.3) and (3.4) into (3.5), the temporal probability,  $P_{(T:S)}$  is defined as:

$$P_{(T:S)} = f n_i l / (24 \times 365 \times 1000 s_i) \quad (3.6)$$

### Vulnerability, $V_{(D:T)}$

Appendix F of AGS 2007c provides examples of vulnerability values,  $V_{(D:T)}$ . A value of  $V_{(D:T)}$  may be estimated from this table or other reference.

The following considers some specific, common scenarios that may commonly arise in NSW national parks.



For a person in open space struck by a rockfall, a range for  $V_{(D:T)}$  of 0.1 to 0.7 is recommended in AGS 2007c. It may be assumed that the probability of death given impact from a boulder increases the larger the size of the boulder. For boulders greater than 0.5 m in diameter, the maximum of this range, 0.7 can be assumed. For cobbles or boulders of 0.1 m to 0.5 m diameter,  $V_{(D:T)}$  can be varied between 0.1 and 0.7 on a sliding scale.

Where boulders are less than 0.5 m diameter:

$$V_{(D:T)} = 1.4d \quad (3.7)$$

Where boulders are of 0.5 m diameter or greater:

$$V_{(D:T)} = 0.7 \quad (3.8)$$

For landslides and debris flows where a person is expected to be buried

$$V_{(D:T)} = 1.0 \quad (3.9)$$

*Risk to the Individual Most at Risk,  $R_{(LOL)}$*

Substituting equations (3.2) and (3.6), into (3.1):

$$R_{(LOL)} = P_{(H)} P_{(t)} V_{(D:T)} n_i w f d \times 1.1 \times 10^{-7} / s_i \quad (3.10)$$

For specific vulnerability scenarios:

Substituting equations (3.7), (3.8), and (3.9) into (3.10):

For boulders or landslides less than 0.5 m diameter  $R_{(LOL)}$  is defined as:

$$R_{(LOL)} = P_{(H)} P_{(t)} n_i w f d^2 \times 1.6 \times 10^{-7} / s_i \quad (3.11)$$

For boulders greater than 0.5 m diameter:

$$R_{(LOL)} = P_{(H)} P_{(t)} n_i w f d \times 8.0 \times 10^{-8} / s_i \quad (3.12)$$

Where the person is buried:

$$R_{(LOL)} = P_{(H)} P_{(t)} n_i w f d \times 1.1 \times 10^{-7} / s_i \quad (3.13)$$

#### **Step 4. Risk to the individual most at risk in a static scenario**

This calculation of risk to an individual to a static element at risk is dealt with in AGS2007c, where the annual risk of loss of life of the individual most at risk is defined by equation 4.1

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (4.1)$$

This is a calculation with which most practitioners familiar with AGS2007 will have some familiarity. Note that in this case, the spatial probability term,  $P_{(S:H)}$  must also account for the probability of travel  $P_{(t)}$  which is explicit in the case of a mobile element at risk.

### **Step 5. The exposed population, e**

The exposed population refers to the total number of people exposed to the hazard within a year. In the case of static elements at risk where different people may occupy the element at risk, for example a tourist cabin, e refers to the total number of separate individuals who occupy the cabin over the course of a year.

For mobile elements at risk, e refers to the total number of separate individuals who pass through the zone at risk within a year. If for example the total number of passes made was 100 however, 60 of those traverses were made by one person and 40 by another, the exposed population is 2. The total number of traverses, n is 100 (see Step 8).

### **Step 6. The average risk to an individual, mobile element at risk, $AvR_{(LOL)}$**

The assessment of societal risk using F-N pairs requires a basic assumption that for each F-N pair, all people exposed to the hazard have a similar individual risk profile. For example, each person is exposed to the hazard for the same period of time and has the same vulnerability to the hazard. The average individual risk is must be estimated to allow the calculation of societal risk.

In most cases involving large numbers of public using a walking track, taking the average individual risk across the entire exposed population will be sufficient. However, depending on the composition of the exposed population, it may be prudent rather than averaging individual risk across the entire exposed population, that the individual risk across subgroups of the exposed population is estimated. If this is done, a separate F-N pair would be developed for each subgroup and each of those F-N pairs would be combined and evaluated against criteria.

Not that  $AvR_{(LOL)}$  is the individual risk for a person making a single traverse through the area at risk.

### **Step 7. The probability of impact to the exposed population, for static element at risk, F**

To evaluate societal risk using the expected value method, it is necessary to estimate the Frequency, F, which corresponds to the probability that impact to the element at risk from landslide occurs. Consideration must be given to the value of  $P_{(S:H)}$  selected for the evaluation of F, however generally this will be the same as that estimated for calculations for the individual most at risk.

### **Step 8. Calculation of F-N pair for a mobile element at risk**

In the case of a mobile element at risk, it is usually assumed that all persons exposed to the hazard have the same risk exposure. Societal risk is calculated by considering the number of people who are mobile and exposed to a hazard within a year and estimating the probability that a minimum number of people (typically 1 person) is killed.

The average risk,  $AvR_{(LOL)}$  to an individual in the exposed population is the probability that an individual using the track is killed. However, there will typically be many people using the track in a year, termed the exposed population resulting in many traverses through the area at risk.

If:

$k$  = a nominated number of persons being killed, and;

$K$  = the actual number of people killed,

then the probability of at least 1 person being killed can be defined as:

$$\Pr(K \geq k) = \Pr(K \geq 1) \quad (8.1)$$

For an individual who makes one traverse through the area at risk, there are two outcomes possible:

1. The person is not impacted by a landslide and killed.
2. The person is impacted by a landslide or rockfall and killed.

Given there are two possible outcomes, it follows that the probability of  $k$  persons being killed follows a binomial distribution. The binomial distribution is defined as:

$$\Pr(k) = \left( \frac{n!}{k!(n-k)!} \right) (AvR_{(LOL)})^k (1 - AvR_{(LOL)})^{n-k} \quad (8.2)$$

Where  $n$  is the number of 'trials'. In the case of a mobile element at risk,  $n$  is the number of traverses made by an individual through the area at risk, which would typically correspond to the number of people per year who pass through the area at risk from the hazard. However, if each person makes two traverses through the area at risk,  $n$  would be twice the exposed population.

The probability of at least 1 person being killed is equivalent to 1 minus the probability of 0 persons being killed:

$$\Pr(k \geq 1) = 1 - \Pr(k = 0) \quad (8.3)$$

Substituting (8.2) into (8.3):

$$\begin{aligned} \Pr(k \geq 1) &= 1 - \left( \frac{n!}{k!(n-k)!} \right) (AvR_{(LOL)})^k (1 - AvR_{(LOL)})^{n-k} \\ &= 1 - \left( \frac{n!}{0!(n-0)!} \right) (AvR_{(LOL)})^0 (1 - AvR_{(LOL)})^{n-0} \\ &= 1 - \left( \frac{n!}{n!} \right) (AvR_{(LOL)})^0 (1 - AvR_{(LOL)})^n \\ &= 1 - (1 - AvR_{(LOL)})^n \quad (8.4) \end{aligned}$$

Using Equation 8.4, the F-N pair would be  $N = 1$ , and  $F = 1 - (1 - AvR_{(LOL)})^n$ . It is possible to calculate other F-N pairs where  $N$  is not equal to 1.

The annual probability of multiple persons being killed can be calculated using a binomial distribution in the same manner as has been demonstrated above for an individual. Recalling the general equation for a binomial distribution, equation (8.2).

$$\Pr(k) = \left( \frac{n!}{k!(n-k)!} \right) (R_{(LOL)})^k (1 - R_{(LOL)})^{n-k}$$

and equation (8.3) for the probability that the actual number of fatalities,  $K$  exceeds a nominated number,  $k$ :

$$\Pr(K \geq k)$$

and recalling equation (8.1), for the probability of at least 1 person being killed:

$$\Pr(K \geq 1) = 1 - \Pr(k = 0)$$

It follows that the probability of at least 2 persons being killed in separate events is:

$$\Pr(K \geq 2) = 1 - \Pr(k = 0) - \Pr(k = 1)$$

and the probability of at least 3 persons being killed in separate events is:

$$\Pr(K \geq 3) = 1 - \Pr(k = 0) - \Pr(k = 1) - \Pr(k = 2)$$

and so on. In general terms:

$$\Pr(K \geq k) = \sum_k^n \left( \frac{n!}{k!(n-k)!} \right) (\text{AvR}_{(\text{LOL})})^k (1 - \text{AvR}_{(\text{LOL})})^{n-k} \quad (8.5)$$

The probability of  $K$  fatalities can be calculated and compared to societal risk criteria. In the case of multiple fatalities due to persons walking in groups, the same general calculation would apply, where:

$n$  = the number of groups of  $k$  persons using the track annually. The value calculated using equation (8.5) can similarly be plotted against societal risk criteria, noting that the F-N chart plots the nominated number of fatalities,  $k$  on the x axis and cumulative frequency  $\Pr(K \geq k)$  on the y axis.

## Step 9. Calculation of F-N pair for a Static Element at Risk

The calculation of an F-N pair for a static element at risk uses the 'expected value' method. This method is demonstrated in AGS2007 (refer to examples in AGS2007d). The 'N' of the F-N pair refers to the number of fatalities expected to be caused by the hazard and is the product of the number of people expected to be present when the hazard impacts and vulnerability.

There are multiple options for estimating the number of number of people expected to be present with selection of the most appropriate method dependent upon the scenario.

- Where all of the exposed population are present, then the number of people expected to be present is e multiplied by the temporal probability that they are present. For example, permanent residents in a house.
- Where a subset of the exposed population is exposed to the hazard, the number of people present is similarly the temporal probability of the subgroup being present multiplied by the number of people in the subgroup.
- If the number of people present varies over time, for example a very different number of people present in the day compared to night, subgroups of the exposed population can be identified, for example a night subgroup and a day subgroup. In this case, the equivalent number of people averaged across 100% of the time can be estimated by taking a weighted average. This method is described in Lee and Jones 2013.  $e_{av}$ , the average number of people present 100% of the time can be calculated. In this case, the temporal probability,  $P_{(T:S)}$  of  $e_{av}$  people being present is 1.

$$e_{av} = e_s \times [(P_{(T:S)1} \times e_{s1} / e_s) + (P_{(T:S)2} \times e_{s2} / e_s) + (P_{(T:S)3} \times e_{s3} / e_s) + \dots + (P_{(T:S)x} \times e_{sx} / e_s)] \quad (10)$$

- Alternatively, each subgroup can be considered independently and f-N pairs developed for each subgroup identified. The resulting f-N pairs can then be combined cumulatively to allow them to be evaluated to societal risk criteria based on cumulative probability. ANCOLD 2022 provides an example of this approach.

## Step 10. Number of hazards to which an individual is exposed

There are circumstances where an element at risk either static or mobile may be exposed to multiple hazards. This must be considered in the calculation of risk to that element at risk. The calculations set out in the guideline assume that where multiple hazards are present, those hazards are independent. There may be some circumstances where hazards are not independent in which case the calculations for combining risk set out in the guideline will not apply.

## Step 11. Number of independent hazards to which multiple people are exposed

Refer to commentary for Step 10.

## Step 12. Combining individual risks

The calculations described for combining individual risk assume that an individual can only be killed by one hazard. The premise of the method presented is to calculate the annual probability that a person will survive each hazard to which they are exposed. The probability of their surviving each hazard is:

$$1 - R_{(LOLHX)}$$

Where  $R_{(LOLHX)}$  is the risk to the individual from a hazard, or the annual probability that they are killed by the hazard.

The probability of surviving all hazards in a year is a conditional probability which assumes that a person survives hazard 1 and given they survive hazard 1, they also survive hazard 2, then given they survive hazard 2 and they also survive hazard 3 and so on. It is calculated by:

$$\text{Pr (survive all hazards)} = (1 - R_{(LOLH1)}) \times (1 - R_{(LOLH2)}) \times (1 - R_{(LOLH3)}) \times (1 - R_{(LOLH4)}) \dots (1 - R_{(LOLHX)})$$

The probability of the individual being killed is then 1 – the probability of surviving all hazards:

$$R_{(LOLC)} = 1 - [(1 - R_{(LOLH1)}) \times (1 - R_{(LOLH2)}) \times (1 - R_{(LOLH3)}) \times (1 - R_{(LOLH4)}) \dots (1 - R_{(LOLHX)})] \quad (12.1)$$

Where:

$R_{(LOLC)}$  denotes risk of loss of life to an individual exposed to multiple hazards.

$R_{(LOLH1)}$  denotes risk of loss of life from hazard 1.

## Step 13. Combining individual risks to multiple persons

This is done using a similar method to that set out above for Step 12, however individual risk  $R_{(LOL)}$  is substituted with F. The same premise applies of calculating the probability that the exposed population survives all hazards

then calculating  $1 -$  the probability of survival. However, to combine F in this manner, N, the number of people expected to be killed must be the same for each F combined in this manner.

Where calculations have yielded a series of F-N pairs (or f-N pairs if this approach is adopted) as might arise where the exposed population is at risk from multiple hazards, or where F-N pairs for subgroups of the exposed population are developed, the cumulative probability must be calculated for each N. An example is provided in AGS2007d (pp 151) of combining and assessing multiple F-N pairs. Note that in most examples (AGS 2007d, Lee and Jones 2013), the cumulative probability is calculated by adding F for each F-N pair. However, in this guideline, F is combined using a method similar to equation 12.1. Whilst the method set out here is mathematically more precise, we note that at probabilities less than about  $10^{-3}$ , there is negligible difference between the 2 methods.

### **Step 14. Evaluate risk to the individual most at risk**

The criteria for the individual most at risk are adopted from those suggested in AGS2007c.

### **Step 15. Evaluate F-N pairs to assess societal risk**

The F-N chart presented for the evaluation of societal risk is adopted from ANCOLD 2022. The previous 2003 version of the chart is also presented in AGS2007d along with examples demonstrating its use. Each F-N pair estimated is plotted on either a chart for existing or proposed development as appropriate. It is noted that in the most recent version of the ANCOLD guidelines published in 2022 (updated from a 2003 version), the area of Intense Scrutiny on the F-N plot has been removed, with the tolerable and acceptable zones extended into this range. Furthermore, the F-N criteria presented in ANCOLD 2022 includes only the boundary between unacceptable and tolerable risks. A boundary nominally one order of magnitude lower has been retained on the F-N criteria used in these guidelines indicating the boundary between Tolerable and Acceptable risk. This is consistent with AGS2007c which describes acceptable risks as being one order of magnitude lower than tolerable risks.

### **Step 16. Reporting calculations**

It is important to report the method of calculation undertaken to estimate risk is clearly described. Where an alternative method is adopted, it is similarly important to describe the reasons for the departure and for undertaking the alternative risk calculation.

**APPENDIX D**

# Important Information



GOLDER

## IMPORTANT INFORMATION RELATING OF THIS REPORT

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder's Client and persons acting on the Client's behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have trained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

**Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification.**





**[golder.com](http://golder.com)**