Landslide Planning Guidance

Reducing Landslide Risk through Land-Use Planning

January 2024

GNS Science Te Pū Ao
Toka Tū Ake EQC
Ministry of Business, Innovation & Employment Hīkina Whakatutuki Building Performance
New Zealand Geotechnical Society Inc

Cover image: *Landslide damage, Nelson Storm, 2022. Photo: Dougal Townsend.*

FORMULATION OF THIS GUIDANCE

This guidance was produced as an output for the Ministry of Business, Innovation & Employment (MBIE) Endeavour-funded 'Earthquake-Induced Landscape Dynamics' programme (https://slidenz.net/) and updates the *Guideline for assessing planning policy and consent requirement for landslide prone land* (Saunders and Glassey 2007).

This guidance was compiled by Saskia de Vilder, Scott Kelly, Robert Buxton, Sylvia Allan and Phil Glassey of GNS Science.

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LIMITATIONS

This guidance document has been prepared based on current legislative and regulatory frameworks as they relate to the management of natural hazards at the date of publication. Should there be relevant changes made to either of these frameworks, it is intended that this guidance will be reviewed and updated as necessary.

DISCLAIMER

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KEY MESSAGES

1. ***Landslides***[1] have killed more people in Aotearoa New Zealand than other geological ***hazards*** combined. ***Risks*** from landslides to people, property, infrastructure and environment are substantial, and the effects of climate change will exacerbate landslide hazards and risk over time.
2. A ***risk-based*** approach should be applied in strategies, plans and development to manage the hazards and reduce risks from landslides.
3. Landslide risk is a measure of the ***likelihood*** and ***consequence*** of landslides to life, health, property, infrastructure and the environment from a landslide hazard. Risk can often be confused with likelihood; for example, the likelihood of a landslide occurring may be low but, when combined with the consequences, the risk may be high.
4. Five levels of susceptibility, hazard and ***risk analysis*** can be considered, which range from Level A, a simple assessment (i.e. ***landslide susceptibility*** analysis), through to Level E, a full probabilistic ***quantitative risk analysis***. This guidance recommends a minimum level of analysis for strategies/plans, resource consents and building consents; however, higher levels of analysis will be more effective.
5. Landslide susceptibility, hazard and risk maps provide information for developing strategies and plans. These should be at the appropriate scale for the intended purpose and depict areas or gradations of hazard and/or risk.
6. Landslide risk should be considered within a risk tolerability framework that sets out what levels of risk are ***acceptable***, ***tolerable*** and ***intolerable***. Risk tolerability should be determined through community engagement.
7. Risk analysis contains uncertainty. Further information and/or more detailed levels of analysis may be required to reduce uncertainty to make decisions regarding risk tolerability. This may be particularly important when the risk is high or close to the tolerability limit.
8. Landslide susceptibility, hazard and risk may be increased through human actions such as construction of buildings, earthworks, changes to surface or subsurface drainage, and vegetation removal. For these reasons, some activities should be avoided (prohibited) or carefully managed in some areas through plan provisions and resource consent conditions.
9. Landslide risks can be managed through:
   - Strategies/plans, policy and rules, including controls over activities, development, structures, earthworks, drainage and vegetation removal.
   - Assessment of all subdivision and building consents.
   - Rules can be used to remove or restrict existing use rights if risk is found to be intolerable.
10. Planners and building consent officers need to be familiar with landslide hazard and risk methodologies and terminology and to be prepared to question the information provided to them, including what level of analysis has been used and why.
11. Where landslide hazard or risk is proposed to be mitigated through engineered solutions, the practicality and lifespan of the solution – including the cost of maintenance, repair and replacement; monitoring of effectiveness; and any ***residual risk*** – should be considered and addressed.
12. Landslide susceptibility, hazard and risk information needs to be updated when new information becomes available. Maps and information outside of statutory plans can be constantly updated and contribute to Land Information Memorandums (LIMs), Project Information Memorandums (PIMs), subdivision and land-use assessments and building consent decisions.

1 Terms styled in gold bold italic are included in the glossary of Appendix 2.

CONTENTS

1. INTRODUCTION

Image: *Mount Haast rock avalanche, 2013. Photo: Royden Thomson.*

1.1 Aotearoa New Zealand's landslide hazard

Much of Aotearoa New Zealand is hilly or mountainous. Our land is often composed of weak or highly fractured rocks, and many of the soils that overlie these rocks are only marginally stable and regularly compromised by rainfall and earthquakes. Consequently, landslides are an existing or potential hazard in many parts of the country.

Risks from landslides to people and infrastructure, and the costs to the Aotearoa New Zealand economy, are substantial (Bruce 2022; Page 2015).

There have been more than 1500 recorded fatalities from landslides in Aotearoa New Zealand since 1760, with 743 fatalities as the result of natural events and 765 fatalities due to human activity, such as ***cut slopes***, mining or land clearance (Bruce 2022). More fatalities have occurred from landslides than from earthquakes (501), volcanic activity (179) and tsunami (1)[2] combined over the past 160 years. The largest natural landslide fatality events were due to four large hydrothermally induced landslides (231 fatalities), followed by two major lahars (162 fatalities), rainfall-induced landslides (157 fatalities), earthquake-induced landslides (63 fatalities) and landslides with no direct causes (59 fatalities) (Bruce 2022).

It is estimated that landslides cost Aotearoa New Zealand at least $250 million (M) per annum, with an average of $300M per annum (Page 2015). Individual rain-induced landslide events range from large events costing up to ~$350M (e.g. Cyclone Bola) to small rainfall events of ~$3.5M (Page 2015).

However, the costs of landslides are often combined with other natural hazard events, most often storms, floods or earthquakes. After the 2010/11 Canterbury earthquakes, owners of 475 houses impacted by landslides, or at risk from landslides and ***rockfall***, were offered buy-outs, with losses estimated to be around $330M. The 1979 Abbotsford landslide on a Dunedin hillside resulted in the loss of 69 houses and the evacuation of over 600 people (Page 2015). It is the largest individual landslide to have occurred in an urban area in Aotearoa New Zealand, and the cost of the damage was estimated at $10–13M[3] (Hancox 2008). These costs can be reduced ahead of events. Estimates of savings from ***mitigation*** measures implemented prior to natural hazard events range from $4 to $11 for every $1 spent (NIBS Multi-Hazard Mitigation Council 2019).

The 2016 Mw 7.8 Kaikōura Earthquake generated thousands of landslides and hundreds of landslide dams, resulting in damaged hillslopes that are now susceptible to failure during rainstorms and ground shaking. When mobilised, the landslide debris creates new hazards, including further landslides and dams, increased sedimentation into rivers, rapid aggradation and formation of alluvial ***fans*** and floodplains and increased river channel instability. These consequences can persist for decades, requiring active management by the impacted communities and stakeholders. The cost of restoring State Highway 1 (SH 1) and the railway line after the Kaikōura Earthquake was

2 Up to 32 people may have died in the Chatham Islands as a result of a tsunami in 1868 (Thomas 2018).
3 Approximately $66–87M in terms of 2022.

in the order of $2 billion (B), excluding costs related to post-event disruption.

These examples illustrate the destructive potential of landslides. While not all landslides result in such costly consequences, they cumulatively have potential to cause damage, disruption and loss of life. Under climate-change ***scenarios***, the risk from landslides is likely to increase due to changing patterns in rainfall, snow and sea-level rise.

As this guidance was nearing completion, three significant weather events occurred:

- Cyclone Hale, 10–11 January 2023.
- Auckland Anniversary Weekend storm, 27 January 2023.
- Cyclone Gabrielle, 11–14 February 2023.

Several regions declared a state of emergency, with this escalating to a state of national emergency. These events resulted in considerable landslide and flood damage across the north and eastern parts of the North Island, estimated to be between $9B and $14.5B (Treasury 2023), with about $1.5B attributed to landslide (McMillian et al. 2023).

While three events in quick succession may be unprecedented, many other cyclone events have occurred in past years. Such events demonstrate the contribution of landslides to the cascading hazard of debris-laden flood flows and associated impacts. Hence, landslide hazard and risk must be considered and managed beyond the built urban environment to reduce downstream and cascading, as well as cumulative, impacts.

These damaging events emphasise the importance of considering not only likelihood but also consequence. They highlight the impact of landslides on buildings, infrastructure, agriculture and livelihoods and reinforce the need to revise land use in upstream catchments, as well as that the effects of climate change must be considered. It is hoped that these events will be a catalyst in changing land-use planning and practise, utilising tools such as this guidance, so that future impacts of landslides will be reduced.

1.2 Guidance overview

This Landslide Planning Guidance document sets out how landslide risk can be reduced through consistent land-use planning practises and approaches, updating the 2007 guideline (Saunders and Glassey 2007). It is provided primarily for planning, policy and building compliance agents, but may also be of use to consultants, developers, infrastructure asset managers and professionals who provide landslide susceptibility, hazard and risk analyses.

Planners are not expected to undertake assessments on landslide hazards or consequent risks but should understand the process by which a landslide specialist (Information Box 1) provides advice. Early consultation with landslide specialists is recommended so that slope conditions can be assessed when new areas are being considered for development, as well as internal consultation with natural hazards staff and the use of existing databases. By seeking appropriate advice, the land's suitability for development can be determined and measures to mitigate, reduce or avoid the effects of landslides identified.

This guidance is part of a suite of natural-hazard- and climate-change-related guidance for decision makers, planners and policy analysts (see Appendix 3). It is acknowledged that many land-use policy and planning documents are prepared that deal with natural hazards generally, and there is also general guidance available, including:

- *Planning for risk: incorporating risk-based land use planning into a district plan* (Beban and Saunders 2013).
- *Risk-based land use planning for natural hazard risk reduction* (Saunders et al. 2013).
- *Good practice case studies of regional policy statements, district plans, and proposal plans* (Grace and Saunders 2016).

This guidance provides examples of how landslide susceptibility, hazard and risk analysis can support and be incorporated into planning documents and assist in formulating policy; decision making; and preparing and assessing land-use, subdivision and building consent applications.

For a landslide specialist, this guidance provides an overview of how landslide susceptibility, hazard and risk analyses should be incorporated into planning, policy and consent processes and decisions. Landslide specialists are encouraged to read this guide alongside other slope stability guidance documents being prepared by the New Zealand Geotechnical Society, which will be made available once completed in 2024.

Any assessment of natural hazards must take into account Te Tiriti o Waitangi, te ao Māori (Māori perspectives) and mātauranga Māori (Māori knowledge). The key to this is ensuring early engagement with iwi and hapū, and some insight into engagement is covered in the Ministry for the Environment Climate Change Risk Assessment publications (Ministry for the Environment 2019, 2020, 2021). An initial step prior to engagement would be to consider any Iwi or Hapū Management Plans; see Saunders (2017) and Saunders (2018).

Information Box 1 – Landslide Specialists

Councils and others needing specialist advice on landslide susceptibility, hazard and risk must be satisfied that they are engaging the right expertise. Landslide susceptibility, hazard and risk analysis is a science that should be undertaken by appropriately qualified geologists, geomorphologists, earth scientists or geotechnical professionals who are experienced in mapping and who understand slope processes, risk analysis calculations and geotechnical slope engineering.

Expertise in regional- and district-scale identification, mapping and analysis of landslide susceptibility and hazard is most likely to be held by **geologists**, **earth scientists** and **geomorphologists** who have an in-depth understanding of the causes of landslides and can apply this knowledge in providing advice on existing and potential risks. Such expertise may be found in universities, Crown research institutes, larger multi-disciplinary consultancies or with specialist practitioner firms. These specialists can provide the data and information that underpins identification of susceptibility and hazard areas and mapping of risk-related overlays, including more local and site-specific investigations, as part of any development process.

When land with known landslide susceptibility, hazard and/or risk is already zoned for subdivision and development, or when specific infrastructure options and development proposals are being evaluated, different expertise is required. This may include detailed geotechnical investigations and engineering analyses of development options, including location of key elements prior to subdivision (to ensure that each lot has a 'safe' building platform and access). When considering mitigation measures, such as earthwork controls, drainage design, special foundations or limitations on intensity of development, the skills held by an **engineering geologist** or **geotechnical engineer** are typically required.

Expertise in risk analysis, including ***vulnerability*** assessments and risk calculation functions, are most likely to be held by risk analysts and risk scientists. Some geologists, earth scientists, geomorphologists and engineering geologists who have experience in risk analysis can also be described as risk scientists.

Some plan policies or rules specifically require the involvement of a 'suitably qualified and experienced practitioner' for resource consent applications in identified hazard areas. This should be someone who can provide expert evidence in a hearing and whose qualifications and experience are acceptable in that context. Some planning documents specify the requirement in more detail. For example, in some hazard overlay areas, Christchurch City Council requires a report from a chartered professional engineer with experience in geotechnical engineering or a professional engineering geologist (registered with Engineering NZ). Nelson City Council has been using the terminology 'geotechnical professional' in its resource consent conditions to encompass both engineering geologists and engineers.

Consultants proposing to carry out landslide susceptibility, hazard and risk analysis should demonstrate that they have personnel who will work on the project with the relevant skills and experience. It is not sufficient that a geotechnical company has done such studies previously, as it is the personnel directly involved that are important (see Fell et al. [2008] for more information).

Role Definitions

A **Geologist** is a scientist who studies the dynamics and physical history of the earth; the rocks of which it is composed; and the physical, chemical and biological changes that the earth has undergone or is undergoing.

An **Engineering Geologist** is a geologist skilled in applying geological knowledge and principles to investigating and evaluating naturally occurring rock and soil for use in civil engineering works, as well as the evaluation of geological hazards (including landslides) that may affect these works.

A **Geotechnical Engineer** is a civil engineer skilled in applying soil and rock mechanic principles to investigating, evaluating and designing civil works, including geological hazards that affect these works. A geotechnical engineer is involved in site-specific designs for these structures or works.

Risk Scientists develop the models and methodologies for undertaking ***risk assessments***. They work closely with other disciplines to ensure that the most reliable data is utilised and to understand uncertainties in model outputs.

There are also **Earth Scientists** with training and experience in landslides who are neither geologists nor engineers, such as **geomorphologists**, who are also regarded as specialists in this field.

This guidance comprises the following sections and accompanying glossary and appendices:

- **Section 1:** Sets out Aotearoa New Zealand's landslide hazard and past consequences and the outline of this guidance.
- **Section 2:** Summarises the legislative context for managing landslide risk.
- **Section 3:** Describes landslides, including classifications, processes and causes of landslides, triggers, and the impact of land development on landslides.
- **Section 4:** Outlines landslide susceptibility, hazard and risk analyses and how these can be undertaken at a wide range of scales and levels of detail.
- **Section 5:** Sets out approaches to assess and plan for landslide risk.
- **Section 6:** Provides advice for using planning tools to manage and reduce landslide risk.
- **Section 7:** Provides examples of landslide susceptibility, hazard and risk being addressed in land-use planning.
- **Appendix 1:** Provides additional examples in practise from case law.
- **Appendix 2:** Provides a glossary of terms.
- **Appendix 3:** Provides a reference list of other natural hazards planning guidance.

It is envisaged that the guidance will be regularly reviewed and updated as knowledge and technology improve and legislative changes occur.

2. LEGISLATIVE CONTEXT FOR LANDSLIDE RISK MANAGEMENT

***Image:** Rockfall, Redcliffs, Christchurch, following the Christchurch Earthquake, 2011. Photo: Graham Hancox.*

This section provides an overview of the legislative context for managing landslide risk. The primary Act for managing risk from landslides is currently the Resource Management Act 1991 (RMA). The Building Act 2004 has a role in managing risk when land is already zoned and subdivided for use and development.

The Civil Defence Emergency Management Act 2002 (CDEM Act), Local Government Official Information and Meetings Act 1987 and Local Government Act 2002 also contribute to managing landslide risk via land-use planning, as shown in Figure 2.1.

This material is set out in other documents on natural hazards planning (Saunders et al. 2013; Saunders and Beban 2012) and is therefore only briefly summarised below. Most recent legislation also specifically refers to the requirements of Te Tiriti o Waitangi, although Te Tiriti has an over-arching place in all government legislation.

2.1 Legislation

Figure 2.1 (over the page) shows the RMA and Building Act 2004 and their subsidiary plans, as well as other legislation and related documents that contribute to the management of natural hazards.

2.2 Resource Management Act 1991

Key aspects of the RMA relating to natural hazard ***risk management*** are:

1. Landslides are not specifically referred to but are covered under a general definition of natural hazards, which includes landslip (s2).
2. The management of significant risks from natural hazards is a matter of national importance [s6(h)].
3. Regional councils have the function of controlling the use of land to avoid or mitigate natural hazards, including an ability to extinguish existing uses [s10(4) and s30(1)(c)(iv)].
4. Territorial authorities have the function of controlling the effects of the use, development and protection of land to avoid or mitigate natural hazards [s31(1)(b)(i)].
5. Local authorities (i.e. regional councils and territorial authorities) are required to keep records of natural hazards [s35(5)(j)].
6. Due to the overlap in responsibilities between regional councils and territorial authorities, regional policy statements must identify how natural hazard management responsibilities are assigned [s62(1)(i)(i)]. Territorial authorities are usually allocated the responsibility of managing or addressing the risk of landslides.
7. A territorial authority may refuse a subdivision consent application, or grant a subdivision consent subject to conditions, if it considers that there is a significant risk from natural hazards (s106). Note that there is currently no equivalent 'catch all' provision for land-use consents, and existing use rights under RMA s10 may result in re-instatement of buildings and activities in areas of higher risk. Such rights can only be limited or extinguished by regional rules [s10(4)(a)].

Regional policy statements (see Section 6.4.1) have the over-arching role of setting out policy, including policy relating to natural hazards, which must be given effect to through regional and district

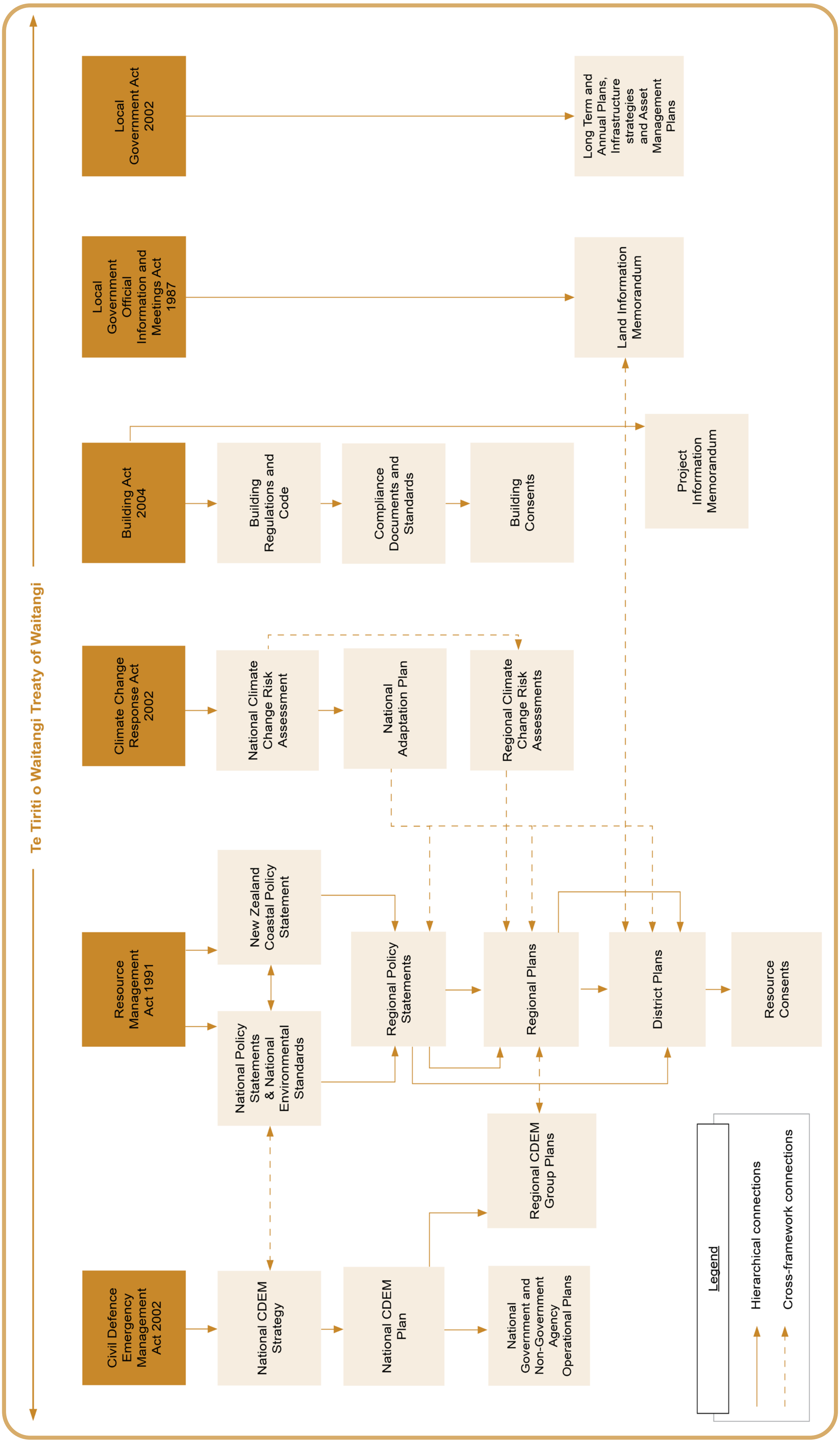


Figure 2.1: Legislative framework for natural hazards management in Aotearoa New Zealand (modified after Saunders and Beban [2012]).

plans (see Sections 6.4.2 and 6.5.1). Regional plans can include land-use provisions, including rules, where there are significant risks and where that responsibility has been assigned to the regional council, including in developed areas. However, most provisions relating to landslide hazards can be expected to be embedded in district plans alongside other detailed land-use controls.

2.3 Building Act 2004

Where land is subject to natural hazards, the Building Act provides for identification and consideration of landslide hazard as follows:

1. Landslides are not specifically referred to but are covered under the definition of natural hazards, which includes ***falling debris*** and ***slippage*** (s71).
2. A Project Information Memorandum (PIM) for proposed building work should be expected to identify potential natural hazards known to the territorial authority [s35(1)(a)(ii)].
3. A building consent authority can restrict the construction of new buildings or major alterations on land subject to hazards. A building consent authority must refuse to grant a building consent if the land is subject to or likely to be subject to one or more natural hazards; or the building work accelerates, worsens or results in a natural hazard on the land or any other property (s71). However, if the building consent authority considers that adequate provision has been or will be made to address these matters, the building consent authority must grant a building consent (s72).
4. If a building consent authority issues a building consent on land subject to natural hazards, the building consent authority must have the particulars about the natural hazard identified on the land title (s72–74). MBIE Determination 2019/067[4] provides a decision tree as a simplified tool for applying s71–73.

The Building Act and RMA overlap in terms of addressing natural hazards, causing tensions and issues (Carter et al. 2021). RMA policy statements and plans should identify areas and include policy and rules where development and some types of uses need to be avoided or carefully managed through plan rules. Where areas are already zoned for use and development, the Building Act has a complementary role to ensure that building works do not:

> *"... accelerate, worsen, or result in a natural hazard on the land on which the building work is to be carried out or any other property."* [s72(a)]

Following the severe weather events of early 2023, the Ministry for Business, Innovation & Employment (MBIE) published guidance on the natural hazard provisions of the Building Act 2004 (MBIE 2023). While the focus of that guidance is on flooding, the overview it provides is relevant to all natural hazards under the Building Act 2004.

The Building Act can address many of the risks posed by landslides, not only for buildings but also for earthworks and drainage. Even building work that is exempt from requiring a building consent still needs to comply with the Building Act and Building Code. However, reliance upon the Building Act as a process to manage natural hazard risk is not good resource management practise and potentially results in RMA requirements not being achieved.

To reduce duplication of roles and consenting processes, some district and regional plans have included provisions that limit this overlap between the Building Act and the RMA. For example, the proposed Dunedin City Second Generation District Plan, the Clutha District Plan 1998 and the Nelson Resource Management Plan 2004 permit earthworks if those earthworks or the associated structure have been authorised by building consent, or if the earthworks are within 1.8 m of a building authorised by building consent.

Although the Building Act can address many landslide issues, the Building Act process is typically at the end of any planning and consenting processes and, through those processes, expectations may have been created that land subject to landslides can be developed without constraint.

The focus of the Building Act is on managing the hazard, not managing the risk. There may also be limitations to the Building Act in terms of how it may be interpreted or how widely natural hazards are considered beyond the site.

The Building Act does have a major role in controlling activities that could cause induced landslides, such as additional earthworks or buildings or poorly designed drainage. The Building Act may require consent for earthworks and retaining walls and can control the collection, diversion and discharge of stormwater. It is important that stormwater and wastewater be directed away from the building envelope, and all water collected in drains (e.g. behind retaining walls) should discharge to an acceptable outlet.

4 https://www.building.govt.nz/assets/Uploads/resolving-problems/determinations/2019/2019-067.pdf

2.4 Other legislation/law

2.4.1 Local Government Official Information and Meetings Act 1987

This Act provides for a Land Information Memorandum (or LIM, as shown in Figure 2.1) to be requested from the territorial authority. As amended by the Local Government Official Information and Meetings Amendment Act 2023 (LGOIMA Act), from 1 July 2025, the LIM must include information known to local authorities about natural hazards and the impacts of climate change that exacerbate natural hazards. The LGOIMA Act requires councils to better share information about natural hazards via LIMs. This amendment seeks to improve natural hazard and risk awareness within the general public by requiring regional councils to provide hazard information to territorial authorities, as well as that LIMs include this information. This will result in more-informed property decisions.

2.4.2 Civil Defence Emergency Management Act 2002

This Act is primarily focused on planning and preparing for emergencies. Regional CDEM Groups are based around regional council boundaries and provide a ***qualitative*** or semi-quantitative assessment of risk across the region. The functions of a CDEM Group in relation to relevant hazards and risks are to:

1. Identify, assess and manage those hazards and risks.
2. Consult and communicate about risks.
3. Identify and implement cost-effective risk reduction (i.e. mitigation measures and land-use planning initiatives).

These functions are outlined in each CDEM Group Plan and provide a source of hazard information for planners that should be taken into account to ensure coordination. In December 2021, the National Emergency Management Agency (NEMA) commenced the Regulatory Framework Review Programme (Trifecta Programme)[5], which includes review and replacement of the CDEM Act with an Emergency Management Act.

2.4.3 Local Government Act 2002

This Act provides for local government (regional councils and territorial authorities) and their responsibilities and processes. In relation to natural hazards and landslides, it provides for the financial planning of risk reduction activities via Long-Term Plans. Long-Term Plans are required to include infrastructure strategies that:

> *"… must outline how the local authority intends to manage its infrastructure assets, taking into account the need to … (e) provide for the resilience of infrastructure assets by identifying and managing risks relating to natural hazards and by making appropriate financial provision for those risks."* [s101(3)(e)]

2.4.4 Earthquake Commission Act 1993

This Act established the Earthquake Commission (now Toka Tū Ake EQC), the functions of which include *"… administer the insurance against natural disaster damage …"* [s5(a)]. This includes natural landslip, which is a defined term. The Natural Hazard Insurance Act will replace the Earthquake Commission Act 1993 and is anticipated to commence by 1 July 2024. The Act provides natural hazard cover (insurance) for residential buildings and land and includes a definition of landslide:

> *Landslide means movement (by way of 1 or more of falling, sliding, or flowing) of ground-forming materials (being 1 or more of natural rock, soil, or artificial fill) that, before they moved, formed an integral part of the ground, but not movement of the ground due to below-ground subsidence, soil expansion, soil shrinkage, or soil compaction.*

In terms of Common Law, there is the requirement for 'natural servitude' for receiving overland flows from above, but, conversely, those above must not affect the natural flow. This can be important where stormwater or overland flow may be concentrated by work on land if its eventual discharge were to cause or worsen a landslide. There is also Common Law on nuisance and negligence which could cover, for example, not maintaining a retaining wall.

5 https://www.civildefence.govt.nz/cdem-sector/regulatory-framework-review-trifecta-programme/

3. LANDSLIDE HAZARDS

***Image:** Houses inundated by the Matatā debris flow, Bay of Plenty, 2005. Photo: Whakatāne Beacon.*

This section gives an overview of landslides and the terminology associated with classification of landslides, as well as why these hazards occur. It draws on definitions and terminology that are internationally recognised standards.

3.1 What is a landslide?

A landslide is a gravitational movement of rock, debris or soil down a slope (Cruden 1991). Terms such as 'landslip', 'slippage' and 'falling debris' are also used for landslide-type features in Aotearoa New Zealand statutes, such as the Building Act 2004. Landslides are also termed '***slope instabilities***', 'slope failures', 'mass movements' or 'rockfalls', depending on context.

A landslide hazard is the ***probability*** of a landslide that poses a threat occurring within a defined time period and area (Corominas et al. 2015). In the landslide source area (see Figure 3.1), hazards include the undermining of land due to the initiation of a landslide beneath, resulting in a movement or loss (including partial loss) of land. In the landslide ***runout*** area (see Figure 3.1), hazards include inundation by rock, debris, soil and other material that may fall, slide, flow or avalanche down a slope (from the landslide source area). The Building Act 2004 terms of 'slippage' and 'falling debris' relate to landslide source and runout areas, respectively, but are not used in modern geotechnical practise.

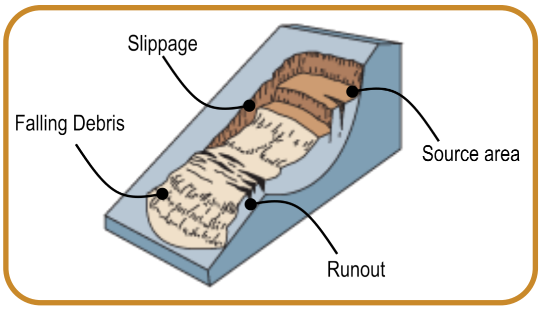


Figure 3.1: Schematic diagram displaying landslide hazards in terms of falling debris and slippage.

3.2 What determines landslide hazard?

3.2.1 Types of landslides

Understanding the different types of landslides that could occur in an area of interest is important, as landslide type will determine the speed of movement, likely volume of displacement and distance of runout, and therefore the potential hazard and risk posed. Landslide type will also influence which risk management and mitigation procedures (if any) are likely to be effective and appropriate. These can be classified into different types based on type of movement and type of material involved (categorised into rock and soil, with earth and debris included in the soil category). The main landslide types and examples experienced throughout Aotearoa New Zealand are shown in Figure 3.2 and are based on international practise (Hungr et al. 2014).

3.2.2 Landslide velocity

Landslide velocity is important for assessing landslide hazards. Rapid landslides may result in loss of life, as there is insufficient time to evacuate, as well as property damage. Slower-moving landslides may not present a threat to life but can still affect many properties and cause significant damage to assets and infrastructure. Some landslide types are always likely to be rapid, such as rockfalls, rock and **debris avalanches** and **debris flows**. Other landslide types can be either rapid or slow-moving, such as **rotational** and translational slides.

3.2.3 Landslide size

Landslides can range in size from a single boulder in a rockfall to a very large avalanche of debris with huge quantities of rock and soil that spread across many kilometres, making size an important component of determining hazard impact area.

As with other hazards, landslides follow magnitude-**frequency** principles, whereby smaller landslides occur more frequently than larger ones. Even though larger landslides travel further and have a larger impact area, they occur less frequently. Determining the magnitude frequency of landslides, and therefore the probability of a landslide of a particular size occurring, is an important consideration in understanding landslide hazards and risk.

3.2.4 Landslide runout

Estimating the potential runout distance of a landslide and its associated impact area is an important component of landslide susceptibility, hazard and risk analysis. **Landslide hazard analysis** often focuses on the main body of the landslide (particularly the source area), such as the 1979 Abbotsford landslide in Dunedin. However, the runout area is just as important to consider because it can impact larger areas and result in more severe consequences. Runout areas can comprise land that is considered stable and therefore more likely to be developed.

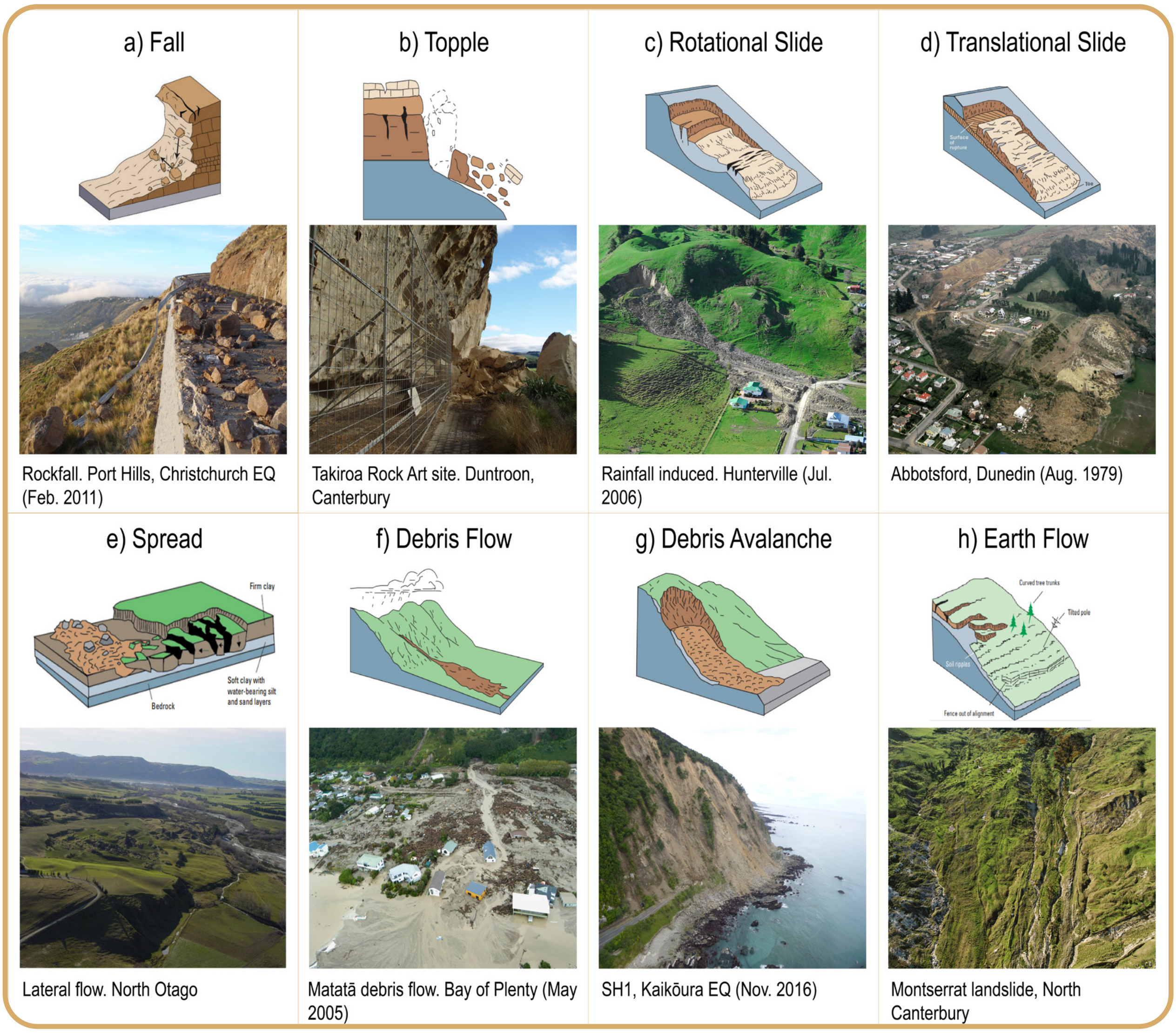


Figure 3.2: Schematic block diagrams of different landslide types and example landslides. Photo sources: (a) Julian Thomson, GNS Science. (b) Simon Cox, GNS Science. (c) Graham Hancox, GNS Science. (d) Lloyd Homer, GNS Science. (e) Crozier (2010b). (f) Whakatāne Beacon. (g) Sally Dellow, GNS Science. (h) Lloyd Homer, GNS Science. The original block diagrams and more detailed information can be found at www.usgs.gov/publications/landslide-handbook-a-guide-understanding-landslides.

Past fatal landslides in Aotearoa New Zealand (e.g. landslides triggered by the 1929 Murchison earthquake) have shown that even areas of flat land on valley floors approximately 500–1000 m from the base of unstable slopes can be over-run by landslide debris.

Landslides that travel further are likely to have a larger impact area. Landslide runout changes for different landslide types (e.g. rockfall, debris avalanches, debris flows). Landslide runout can be determined via several methods, including empirical analysis or numerical physics-based modelling. Landslide runout, the distance that a landslide travels from its source area, may be correlated with landslide volume, with larger landslides generally travelling further than smaller landslides. The initial water content of landslide material also determines how far a landslide may travel, with wetter material being more mobile and travelling further, resulting in a larger impact area.

3.2.5 Fans

Fans are cone-shaped landforms that occur when confined watercourses (e.g. gullies, creeks, rivers) become wider and thus less confined (e.g. when watercourses enter valleys, plains or lakes), allowing material to be deposited. Figure 3.3 presents several examples from around Aotearoa New Zealand. Developments on debris fans are at particular risk from ***debris floods*** and flows. Debris flows travel down the confined watercourse and deposit debris on the fan. The channels on fans can change position rapidly (called avulsion), with this representing a dynamic hazard (Figure 3.3d). Additionally, fans that were inactive (and have since been built on) can re-activate and start actively eroding or receiving sediment via debris flows and floods.

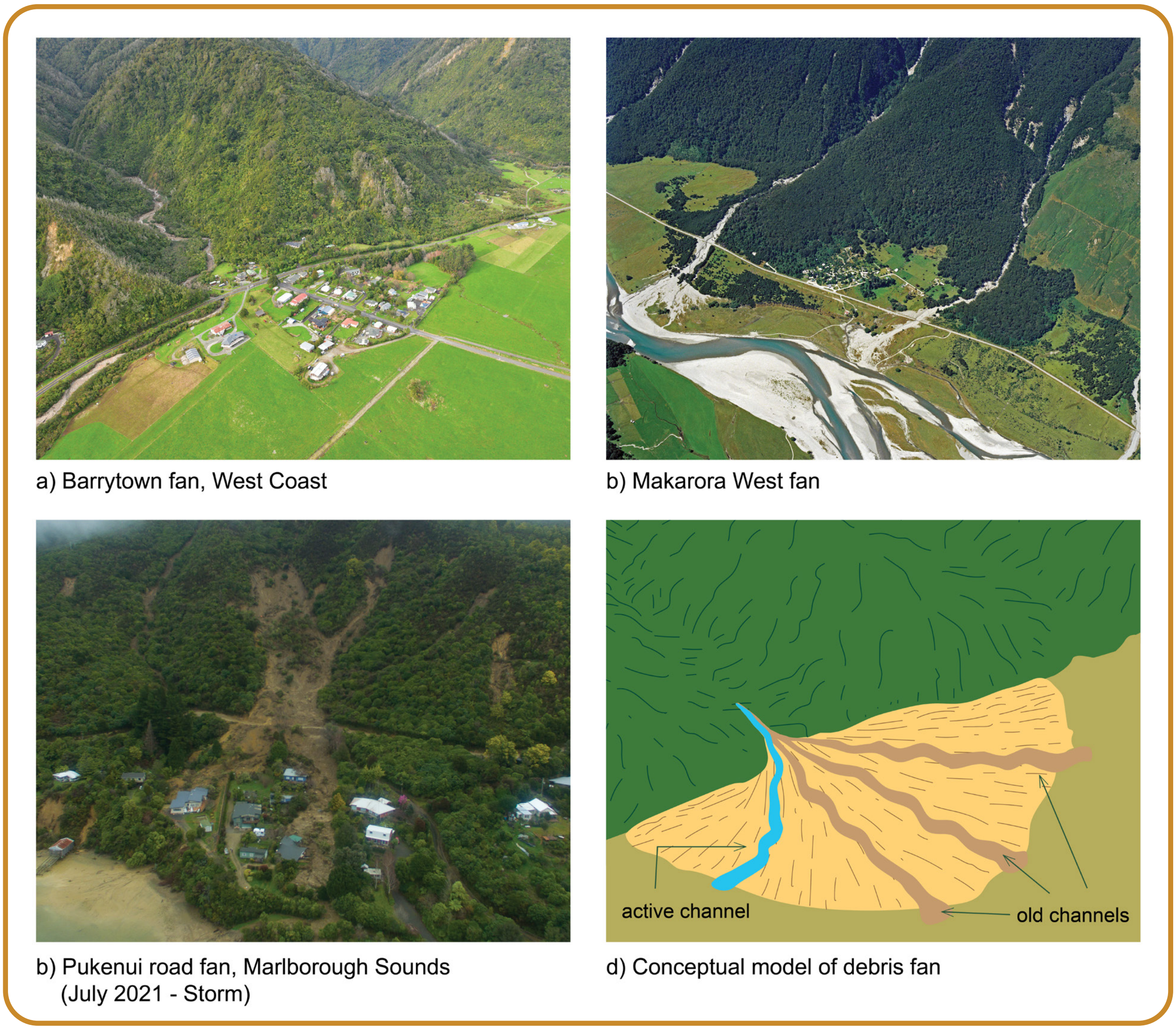


Figure 3.3: Examples of fans in Aotearoa New Zealand. (a) Barrytown, West Coast, which is built on top of a fan (Photo: Dougal Townsend, GNS Science). (b) Makarora West township, Otago, located between two active fans (Photo: Lloyd Homer, GNS Science). (c) Debris flows impacting homes built on a fan in Pukenui Road, Marlborough Sounds, following the July 2021 storm (Photo: Andrew Boyes, GNS Science). (d) Conceptual model of a debris fan, displaying one active channel and several old channels that were abandoned when avulsion occurred.

3.2.6 Cascading and cumulative hazards

Secondary hazards are hazards that occur as the result of a primary hazard. These may also be referred to as cascading hazards.

Landslides can have cascading secondary hazards, such as landslide dams. These occur when a landslide blocks a river's flow, causing a lake to form behind the blockage. These lakes can last for a long time, or they may suddenly release and result in a downstream dam flood. Recent examples of this in Aotearoa New Zealand are the Kaiwhata landslide dam, the 470 landslide dams triggered by the 2016 Kaikōura Earthquake and the Young River ***rock avalanche*** and landslide dam (Morgenstern et al. 2023).

Other secondary cascading hazards include the potential for a landslide-generated tsunami or seiche (e.g. within Milford Sound; Dykstra 2012) and glacier multi-phase mass movements, where a landslide impacts a glacier, causing glacial collapse and runout (Robinson and Davies 2013). The sediment generated by landsliding can impact rivers and how they behave. The increase in sediments on the valley flow can increase flood frequency and channel instability (Korup 2004).

Cumulative hazards are interactions between unrelated hazards that can occur in the same area. For example, a volcanic eruption and severe landslide-initiating weather event occurring simultaneously is possible, or an earthquake that triggers many landslides followed by a heavy rainfall event that mobilises existing landslide debris and triggers new landslides.

3.3 Why do landslides occur?

Landslides occur when the stress acting on a slope is greater than the strength of the slope. Events such as earthquakes and rainfall can increase the stress on a slope or decrease its strength. For these events, if the stress exceeds strength, failure can occur, resulting in a landslide. Figure 3.4 illustrates how changes in stress and strength of the slope may result in a landslide. Additionally, cycles such as wetting and drying, heating and cooling, and tidal cycles reduce the strength of a slope over time until a landslide occurs without an obvious trigger.

Common triggers for landslides in Aotearoa New Zealand are shown in Figure 3.5. Dynamic events, such as earthquakes and heavy rainfall, can trigger multiple landslides. For earthquakes, the characteristics and magnitude of ground shaking will determine ***landslide intensity*** and distribution. Multiple landslides typically only occur for earthquakes with a peak ground acceleration (PGA) of ≥0.2 g and a Modified Mercalli (MM) intensity greater than 5 (Dowrick et al. 2008; Hancox et al. 2014, 2016; Massey et al. 2018). The size of an earthquake is often described using magnitude, which is the amount of energy released during an earthquake. However, not all energy released in an earthquake will necessarily be felt at the surface, depending on its depth and distance. Given this, the PGA value and MM intensity scale is a better indicator of an earthquake's effect on people and their environment. Increases in MM intensity and PGA result in more widespread and a greater number and magnitude of landslides.

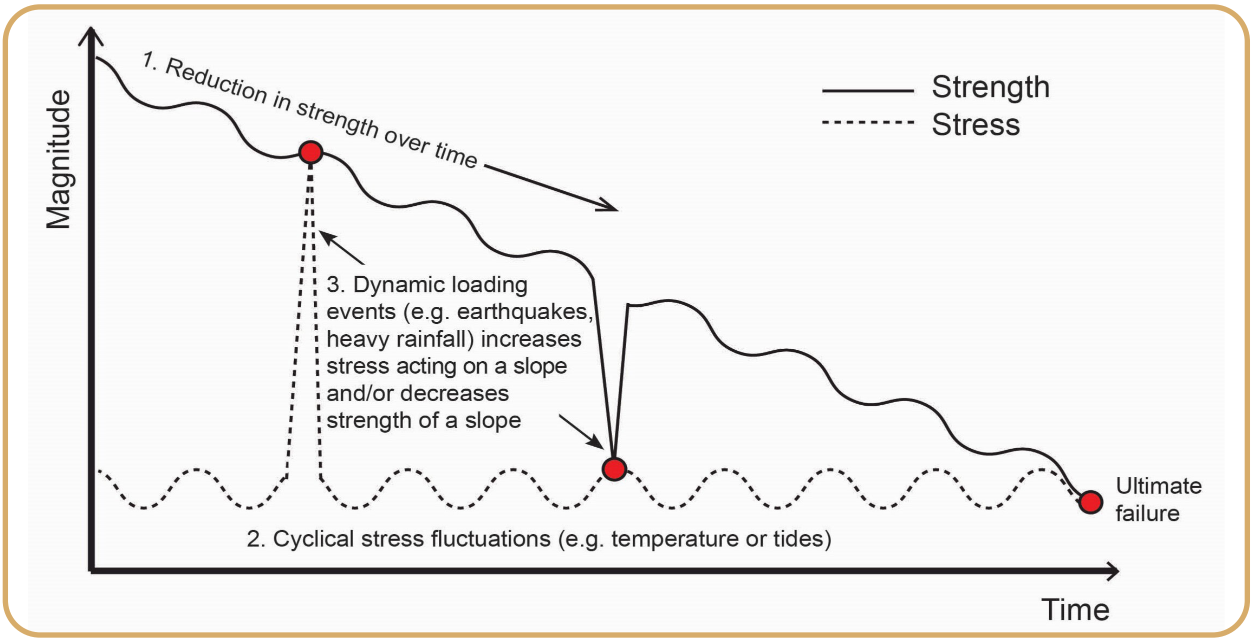


Figure 3.4: The factors that reduce the strength (y-axis) of a slope and increase the stresses acting upon it over time (x-axis). The red dots represent when failure conditions are met and landslides can occur. The gradual reduction in slope strength is driven by environmental cycles. Dynamic loading events can increase the stress acting on a slope or decrease the strength of the slope, which allows failure to occur (modified from Gunzburger et al. [2005]).

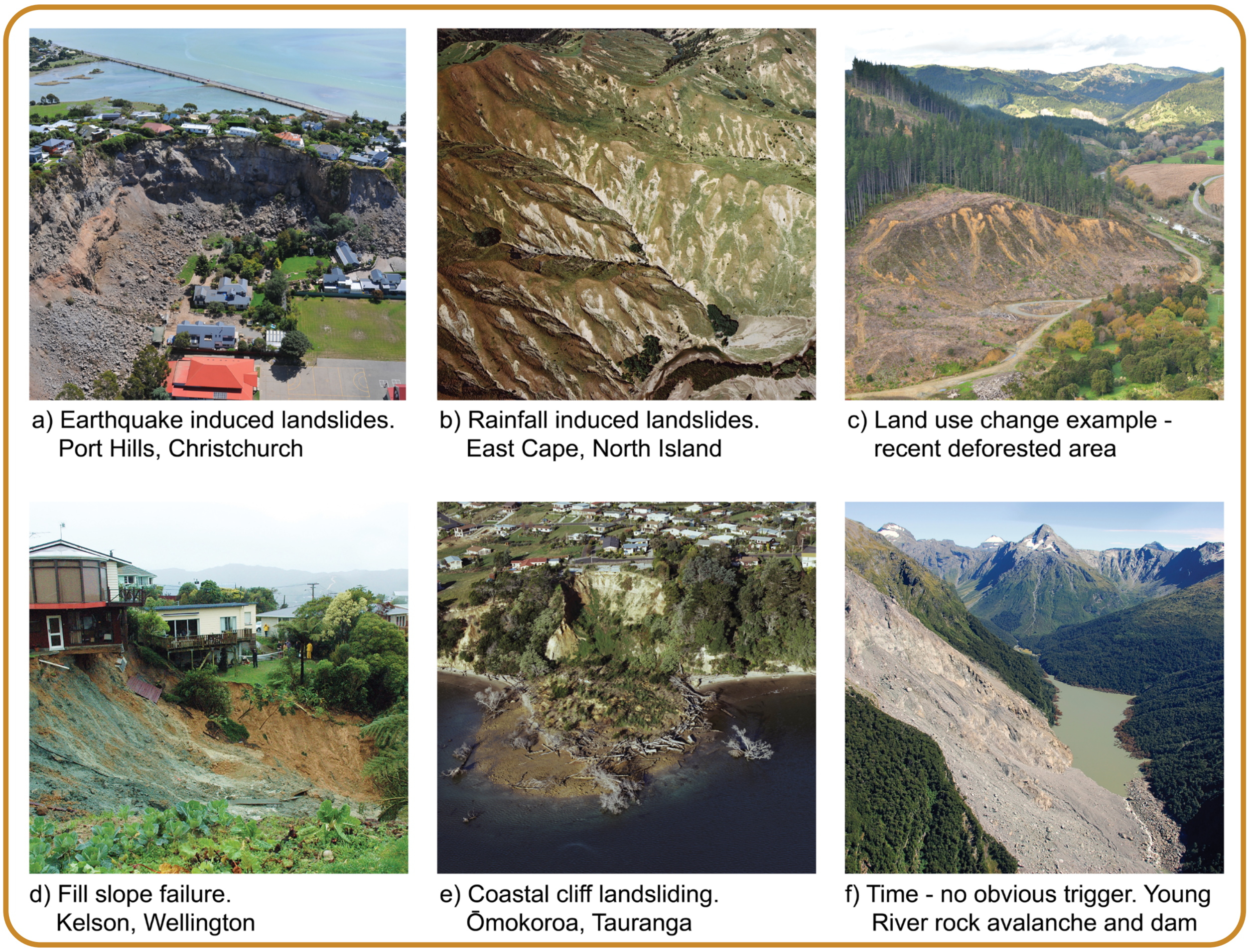


Figure 3.5: Common triggers for landslides in Aotearoa New Zealand. (a) Debris avalanches triggered during the 22 February 2011 Christchurch Earthquake (Photo: Graham Hancox, GNS Science). (b) Landslides in East Cape Hill Country triggered by a heavy rainfall event (Photo: Lloyd Homer, GNS Science). (c) Increased landsliding on a recently deforested slope, East Cape (Photo: Dougal Townsend, GNS Science). (d) An anthropogenic-induced landslide that occurred in Kelson, Wellington, in 2006, where a slope consisting of fill material collapsed beneath multiple homes (Photo: Graham Hancox, GNS Science). (e) Coastal, estuarine and fluvial process can trigger landslides, as seen in this cliff collapse in Omokoroa, Tauranga (Photo: Lloyd Homer, GNS Science). (f) The Young River rock avalanche occurred near Lake Wānaka, Otago, on 29 August 2007. The massive rock avalanche occurred without any discernible trigger and formed a landslide dam. This dam presented a flood threat to the downstream communities (Photo: Graham Hancox, GNS Science).

Similarly for rainfall, the amount of rain, rate, duration and spatial extent, as well as how wet the ground was preceding the event, will determine the distribution and intensity of landslides. Areas across Aotearoa New Zealand have different susceptibilities to rainfall-induced landslides due to different geology, topography, physiography and land cover, therefore the amount of rainfall required to trigger landslides varies across the country.

Climatic changes will impact the frequency and intensity of landsliding. For example:

- Rainfall-induced landslides and their associated impacts are expected to increase both due to an overall increase in rainfall for some parts of Aotearoa New Zealand and also due to more extreme storm activity (Crozier 2010a) and increased rainfall intensity.
- Rockfalls and rock avalanches in alpine areas may increase with summer heat waves and associated changes in permafrost (e.g. Ravanel et al. 2017).
- Increased wildfire activity may result in more burned slopes with no vegetation and increased likelihood of debris flows following rainfall (e.g. Kean et al. 2019).
- Increased sea level and changes in marine and storm activity may also result in greater coastal ***erosion*** and landsliding (e.g. Jakob 2022).

The National Institute of Water & Atmospheric Research (NIWA)'s High Intensity Rainfall Design System (HIRDS)[6] can be used for future projections of rainfall for different ***return periods*** and event durations based on historical rainfall and climate-change scenario Representative Concentration

6 https://niwa.co.nz/information-services/hirds

Pathways (RCP).[7] The National Adaptation Plan recommends the use of SSP2-4.5 and SSP5-8.5 scenarios for risk assessment when available (or, until available, the use of RCP4.5 and RCP8.5).[8] Climate projections based on Shared Socioeconomic Pathway (SSP) scenarios are expected to be available from mid-2024.

Differences in topography (slope angle, elevation, drainage), geology (e.g. weak versus strong rock mass), soil (e.g. soil type and depth), land use (e.g. pasture, urban, forest) and hydrology (e.g. water table) mean that some slopes are more susceptible to landslides than others. Landslides can occur on very shallow slope angles (e.g. in mudstones, Auckland Unitary Plan; see Section 7.1), being a function of the underlying geology and structure of the rock and soil.

Land-use changes and anthropogenic modifications can increase the susceptibility of a slope to landslides and can trigger failures, as shown in Figure 3.5c and d. The removal of ***toe*** support from the bottom of a slope, either by natural erosion or anthropogenic modification, can trigger landslides. Often there is a time lag (sometimes years) between the alteration of a slope and such a landslide. Anthropogenic modifications can include cut and ***fill slopes***, excavation at the toe of the slope, leaking pipes and changes in drainage. The Stability of Land in Dynamic Environments (SLIDE) project[9] identified 1600 fill bodies and 3000 cut slopes in central Wellington alone; these modified slopes can be more susceptible to failure than natural slopes. The addition of material at the top of a slope (such as fill) or excavation of material from the base of the slope (cut slopes) changes the stresses and strength of a slope, increasing the likelihood that it will collapse.

Stormwater management in urban areas is a critical factor in land stability. Stormwater systems, impermeable surfaces and changes to landform can concentrate or divert overland flows, which can induce landslides. Placing structures/fill on sloping land adds weight, which can also trigger landslides.

Table 3.1: Overview of the potential consequences of landslides.

Land	• Permanent loss or degradation of valuable land. • Ground cracking and ***rock slope deformation***. • Removal of topsoil. • Formation of landslide dams with potential upstream inundation and downstream flood and breach hazard.
Environment	• Disrupted drainage. • Discharge of sediment/debris into waterways. • Impact on water quality and habitat. • Sediment deposition – potentially contaminated and creating fine airborne dust when dried. • Loss of soil carbon.
Buildings	• Undermining and collapse of buildings. • Inundation and damage to buildings. • Warping of buildings. • Damage to service connections
Infrastructure	• Damage due to undermining or inundation of access/parking, roads, bridges, stop banks, surface and underground services, facilities such as hospitals. • Debris-laden flood flows in waterways, resulting in damage to roads, bridges, stop banks, surface and underground services, buildings and facilities adjacent to waterways.
Economic	• Loss of productivity due to impact on commercial facilities and disruption to utilities and transport networks. • Loss of agriculture/horticultural productivity due to sediment deposition or erosion. • Cost of damage repair.
Social	• Death or injury. • Psychological health issues caused by stress and fear of further loss. • Isolation of communities due to infrastructure damage. • Community disruption and displacement with associated psychological health issues.

7 More information on climate-change scenarios can also be found at https://niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios and https://environment.govt.nz/publications/climate-change-projections-for-new-zealand/

8 Bodeker et al. (2022) undertook a review of RCP projection and considered these to remain fit for purpose until SSP projections are available.

9 https://www.gns.cri.nz/research-projects/slide-stability-of-land-in-dynamic-environments/

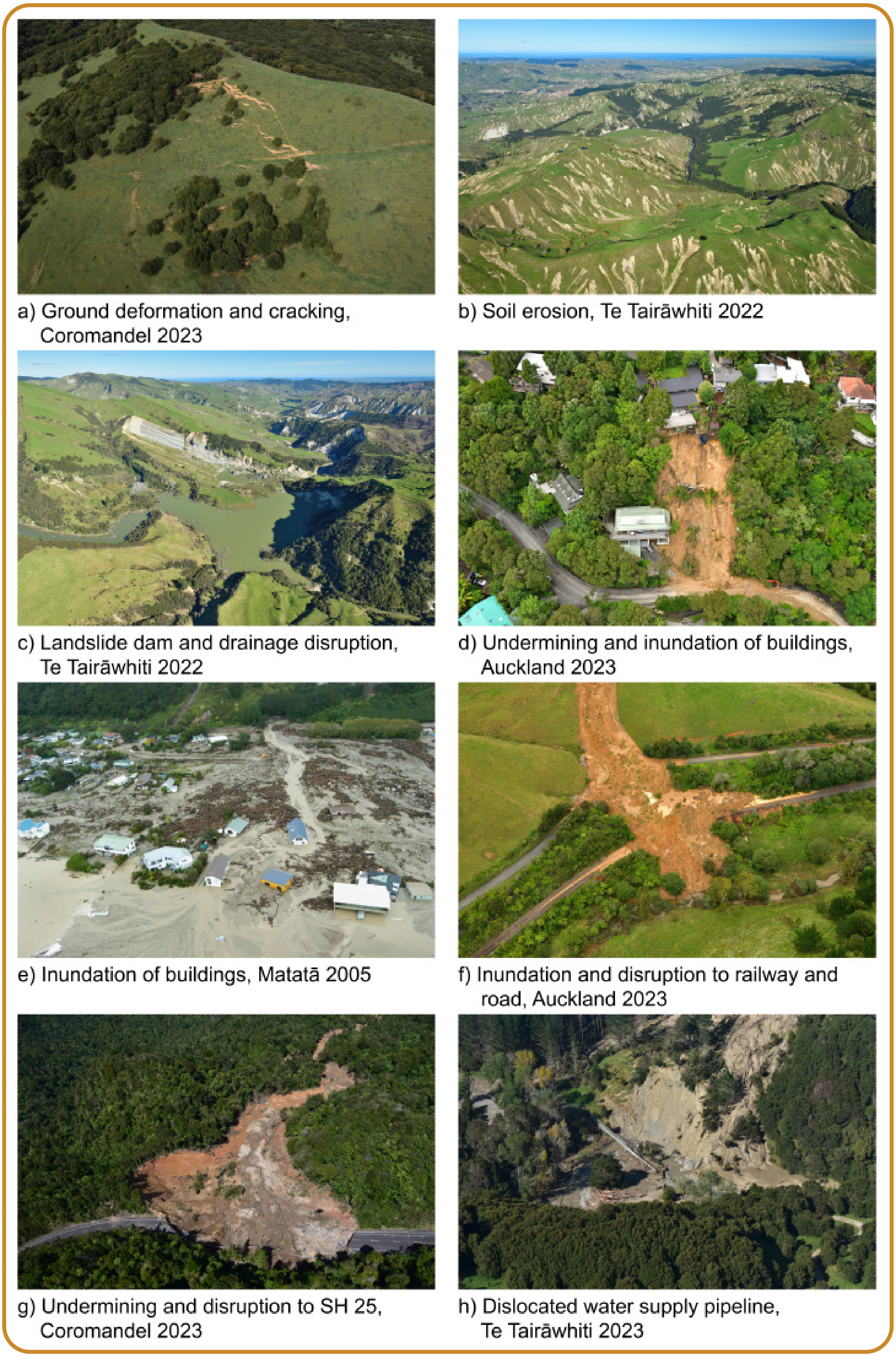


Figure 3.6: Examples of some of the consequences of landsliding. Photos: (a), (h) Andrew Boyes (GNS Science); (b)–(d), (f), (g) Dougal Townsend (GNS Science); (e) Whakatāne Beacon; (i) Andrea Wolter (GNS Science).

3.4 Consequences of landslides

Landslide consequences are summarised in Table 3.1 and Figure 3.6. As previously noted, landslides have caused more deaths in Aotearoa New Zealand than other natural hazards combined (Bruce 2022) and, on average, cause at least $300M damage per annum (Page 2015). Damage results primarily from undermining and inundation of infrastructure and buildings. Debris from landslides can dam rivers and contribute to debris-laden flood flows that increase damage to infrastructure close to waterways (such as roads and bridges), with this entrained debris being deposited across floodplains, arable land and coastlines, as recently demonstrated in the Cyclone Gabrielle event of 2023.

Cyclone Gabrielle in February 2023 caused flooding and widespread landsliding to a large part of the North Island and is perhaps the single largest landsliding event to have occurred in Aotearoa New Zealand in terms of number of landslides. Sadly, the landslides resulted in the death of five people. A significant impact of landslides during this event was delivering debris and sediment to floodwaters, which caused damage to infrastructure, especially roads and bridges, and deposited debris and sediment across flood plains, which inundated buildings and infrastructure and destroyed crops. This event has displaced people and caused significant economic losses that are still being tallied. Events of this magnitude are likely to become more common because of climate change.

4. LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ANALYSIS

***Image:** House impacted by rockfall, Sumner, Christchurch, following the Christchurch Earthquake, 2011. Photo: Graham Hancox.*

4.1 Overview

Before the losses from landslides can be reduced, the hazard must be recognised and the risk appropriately assessed. One of the main purposes of this guidance is to improve the understanding of how landslide susceptibility, hazard and risk are assessed. A landslide susceptibility, hazard and/or risk analysis, commonly in the form of a map, provides a way to identify areas where landslides exist or could occur, what they may impact and, therefore, the risk that they pose. This section outlines the general risk analysis and risk management process (Section 4.2) before detailing the landslide risk analysis process (Section 4.3). Five levels of susceptibility, hazard and risk analysis are specified that may need to be undertaken by a local authority, developer or individual. The five levels of analysis are:

- **Level A:** Susceptibility Analysis.
- **Level B:** Hazard Analysis.
- **Level C:** Semi-Quantitative Risk Analysis.
- **Level D:** Basic Quantitative Risk Analysis.
- **Level E:** Detailed Quantitative Risk Analysis.

4.2 Risk analysis and the risk management process

The simplest way to consider risk is as "*the likelihood and consequences of a hazard*" (CDEM Act). The International Standard for Risk Management (ISO 31000:2018 [AS/NZS 2004]) defines risk as the "*effect of uncertainty on objectives*" and notes that it is "*... usually expressed in terms of risk sources, potential events, their consequences and their likelihood.*" Corominas et al. (2015) defines landslide risk as a measure of the probability and severity of an adverse effect to life, health, property or the environment.

Risk management is the systematic application of policies, procedures and practises to the tasks of identifying, analysing, assessing and managing risk. This guidance follows the risk management process defined in ISO 31000:2018.

Risk management addresses the following questions (adapted from Ho et al. 2000; Lee and Jones 2014):

Identification and Analysis

1. *Landslide risk identification and susceptibility: What can cause harm?*
2. *Landslide frequency: How often might this occur?*
3. *Consequence analysis: What can go wrong and how bad could it be?*
4. *Risk estimation: What is the probability of loss?*

Assessment

5. *Risk Evaluation: What does the risk value mean and are the risks tolerable?*

Management

6. *Risk Treatment: What can be done, at what cost, to manage and reduce intolerable levels of risk?*
7. *Monitoring and Review: Was the treatment successful; what is the residual risk and/or does it need re-analysis and re-assessment?*

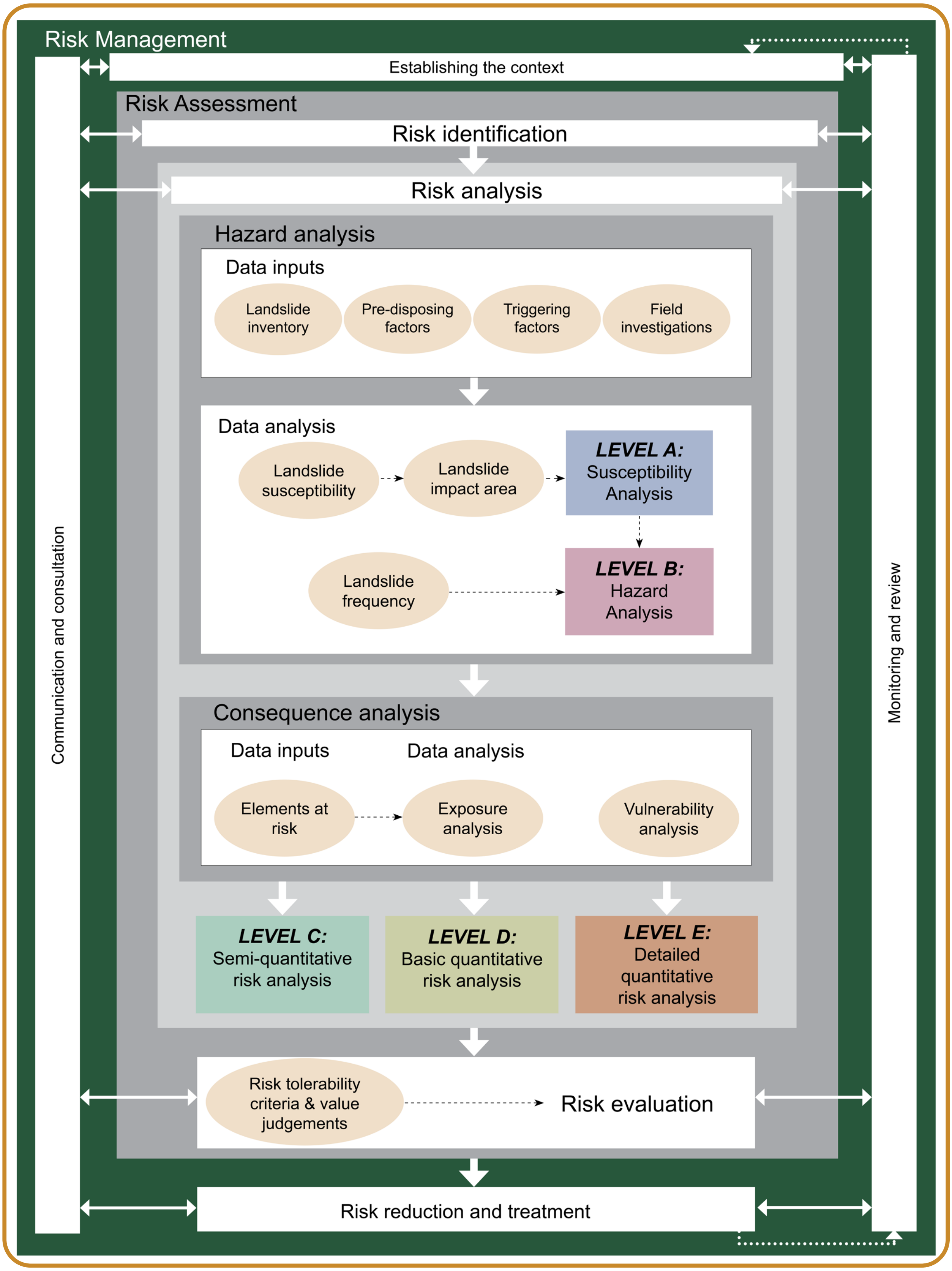


Figure 4.1: Schematic of the components of the landslide risk management process, including where the different recommended levels of analysis fit within the landslide risk analysis and wider risk management process (adapted from AGS [2007a–d] and ISO 31000:2018 [AS/NZS 2004]).

4.3 Landslide risk analysis process

The landslide risk analysis process is shown in context in Figure 4.1. The risk analysis methodology used to estimate the risk from landslide hazards is based on the accepted Australian Geomechanics Society (AGS) landslide risk management guidelines (AGS 2007a–d). At the same time, and in conjunction with AGS, the Joint Technical Committee-1 (JTC-1)[10] developed guidelines on landslide susceptibility, hazard and risk zoning for land-use planning (Fell et al. 2008) to help establish 'best practise' landslide risk analysis methods.

Landslide hazard and risk analysis involves determining:

1. The different types of landslides that can occur (landslide hazard identification; see Figure 3.2 and Section 3.2).
2. Where they might occur (source area and susceptibility; see Section 3.2).
3. How big are they likely to be (landslide size; see Section 3.2.3).
4. How often are they likely to occur (frequency; see Section 3.2.3).
5. If they do occur, what the hazard footprint is likely to be (landslide runout assessment; see Section 3.2.4).

Steps 1–4 above determine the probability of a landslide event of a certain size occurring in a given time in a specified area. Steps 1–3 and Step 5 determine the probability that the landslide will reach the person/property/asset of interest. The type of landslide, its magnitude, its source area and the slope above or below will influence the hazard footprint of the landslide (both area of slippage and falling debris; Section 3.1). Figures 4.1 and 4.2 display the hazard analysis process, including the different inputs and types of analysis required. Landslide hazard analysis is undertaken using base datasets that inform landslide susceptibility, magnitude frequency, source areas and runout analysis. These base datasets include:

1. Engineering geological and geomorphological mapping and modelling, which inform:
   - ***landslide inventories***, which detail past landslide occurrences;
   - **pre-disposing factors**, which may pre-dispose a slope to failure; and
   - **triggering factors**, which result in landslide occurrence.

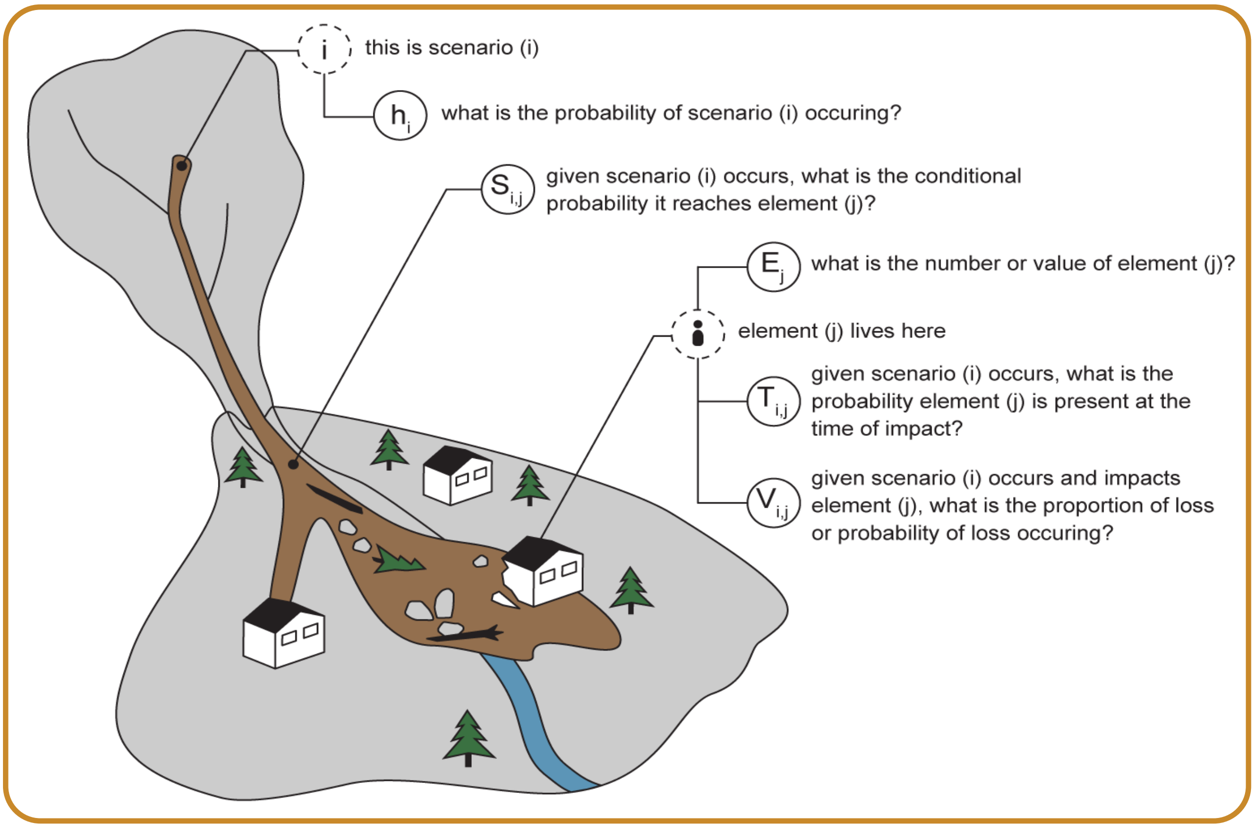


Figure 4.2: Schematic of a debris-flow event, which displays the different probabilities that need to be estimated in order to calculate the risk from that debris-flow event (schematic created by Sophia Zubrycky in Strouth et al. [in press]).

10 Comprising members from the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), the International Society for Rock Mechanics (ISRM) and the International Association of Engineering Geologists (IAEG).

Landslides are likely to occur in similar geological, geomorphological and hydrological conditions as they have in the past (Varnes 1984). Figure 4.3 displays example maps of different base datasets. As noted, because landslide features are complex and often subtle, landslide mapping is best undertaken by landslide specialists with appropriate expertise (see Information Box 1). It is imperative to look beyond the boundary of a site to identify any landslide features that could impact the site or indicate landslide susceptibility in the area. Digital surface models can be used to identify and map landslides. High-resolution models derived from LiDAR (Light Detection and Ranging) should be used where available and as appropriate (see Figure 4.3c).

The likely range of consequences from the landslide hazards is then identified via ***exposure*** and hazard analysis, as well as an estimation made of the magnitude of the consequences and the probability of a certain magnitude of consequence occurring.

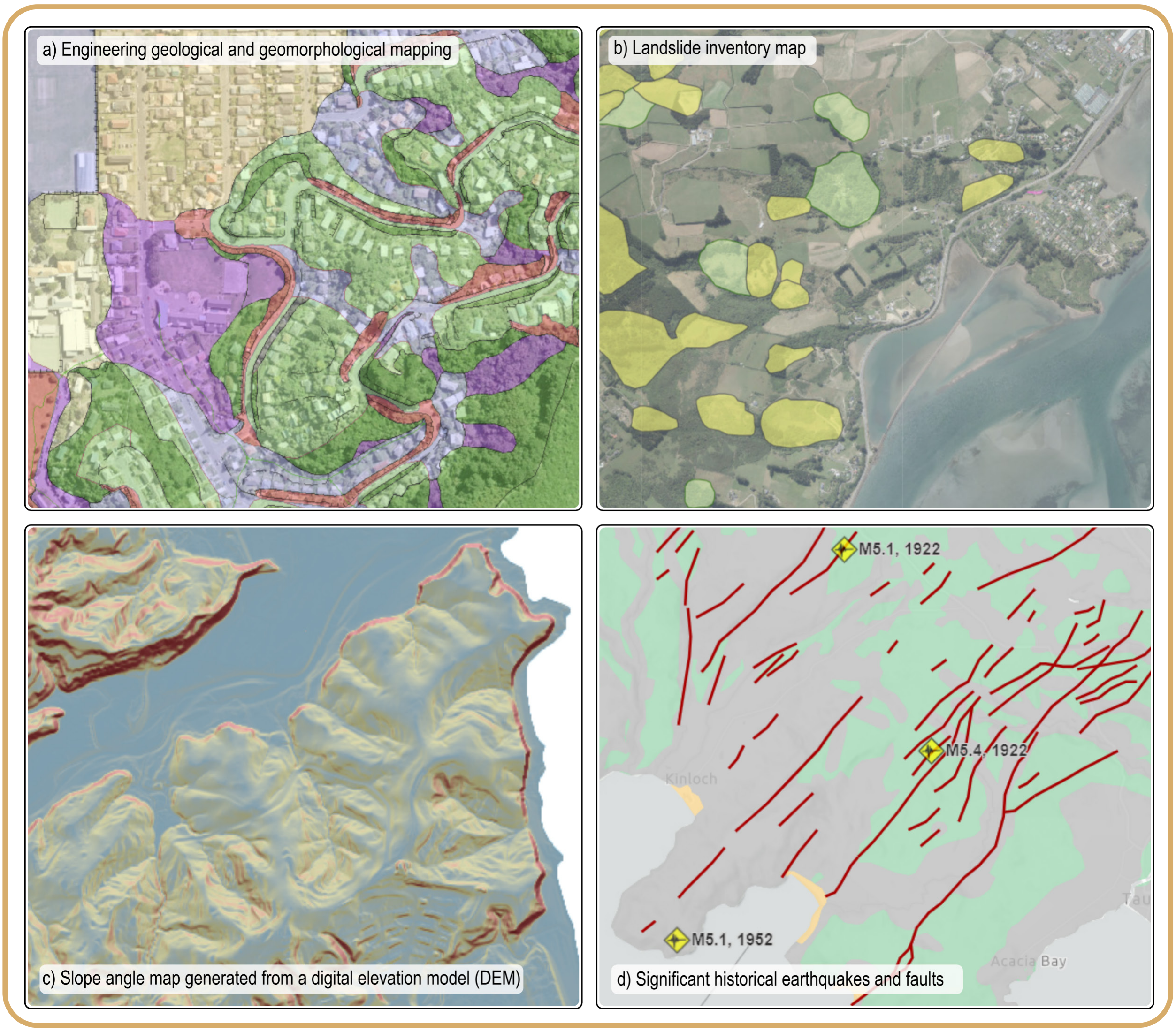


Figure 4.3: Example base data maps. (a) Engineering geological and geomorphological map of part of Wellington, where the colours show the interpreted near-surface materials: red is fill, green is rock, light green is mixed rock and fill, purple is colluvium, light purple is mixed colluvium and fill, light yellow is alluvium. More information on the dataset is presented in Townsend et al. (2020), and the map is hosted on the Wellington City Council website[11]. (b) Landslide inventory map of Dunedin, compiled by Barrell et al. (2017), as shown in the Otago Natural Hazards Portal[12], coloured on the 'certainty' attribute – green (possible) and yellow (likely). (c) Pre-disposing factors, such as a slope angle map overlaid on a digital elevation model (DEM) of North Auckland, where the colour continuum represents increases in slope angles from blue (low angle) to red (steep). Data is sourced from https://data.linz.govt.nz/. (d) Triggering factors, such as maps of significant historical earthquakes, onshore faults (red lines) and liquefaction potential (green and yellow areas on map) recorded in the Waikato region. Map can be viewed here in the Waikato Regional Hazards Portal.[13]

11 https://wcc.maps.arcgis.com/apps/webappviewer/index.html?id=b7b5ad358c66476087fd3163f693b4ff
12 https://maps.orc.govt.nz/portal/apps/MapSeries/index.html?appid=b24672e379394bb79a32c9977460d4c2
13 https://waikatoregion.maps.arcgis.com/apps/MapSeries/index.html?appid=f2b48398f93146e8a5cf0aa3fddce92c

Consequence analysis, as shown in Figure 4.1, is then a function of:

- **The hazard**, which includes both the probability of the landslide occurring and the probability that the landslide hazard footprint (in terms of slippage or falling debris) will reach the person, property, road, river or asset of interest. 'Landslide' is a catch-all term for different types of landslides hazards, and not all landslide hazards will have the same impact.
- **Exposure Analysis**, which is the assessment of the exposure of an ***element of risk*** to the hazard. Elements at risk can be both dynamic (e.g. people spending 50% of their time in their home) or static (e.g. a road or pipeline *in situ* 100% of the time). Elements at risk can include people, property, infrastructure, environmental features, cultural values and economic activities in the area affected by a potential landslide.
- **Vulnerability assessment**, which is the conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, community, assets or systems to the impacts of hazards. It is often expressed on a scale of 0 (no loss) to 1 (total loss). The type of landslide hazard and size of the landslide and hazard footprint area, along with building design and building use, can affect vulnerability.

From this consequence analysis, risk can be calculated. Figure 4.2 displays an example of the different elements that are required to calculate landslide risk:

- The probability (or likelihood) of a certain scenario (e.g. debris flow of a particular size) occurring needs to be determined.

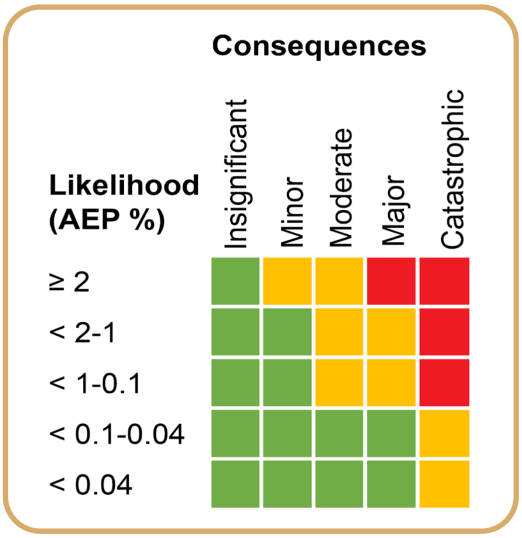


Figure 4.4: Example semi-quantitative risk matrix, where red, orange and yellow represent high, medium and low risk, respectively (Bay of Plenty Regional Policy Statement [BOPRC c2023]).

- The conditional probability that it reaches the person/property/asset of interest then needs to be determined.
- From this, the exposure of the element at risk, or the probability that the element at risk is present at the time of impact, needs to be calculated, along with the vulnerability of the element of risk. That is, if the given scenario occurs and impacts the element, what is the proportion or probability of loss occurring?
- For property and assets, a value (e.g. repair cost) can be associated with the element of risk, while, for people, the risk (e.g. injury and death) can be evaluated for an individual or a group (one or more people).

4.4 Risk metrics

4.4.1 Semi-quantitative risk metrics

A semi-quantitative risk analysis uses relative rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur (Corominas et al. 2015). The outputs from a semi-quantitative risk analysis, as outlined in Lee and Jones (2014), can take the form of a:

- **Relative risk rating:** A scoring system where the risk score is assigned a relative value or category. This type of rating is used where it is not possible to assign all elements of the risk analysis a meaningful numerical value.
- **Risk ranking matrix:** Combines the probability of a landslide hazard occurring (see Section 4.3) with the magnitude of the consequences (see Figure 4.4).

A semi-quantitative risk ranking matrix example is provided in Figure 4.4 from the Bay of Plenty Regional Policy Statement (BOPRC c2023), where the ***Annual Exceedance Probability (AEP)*** for a hazard event occurring versus the qualitative consequence categories is used to assign a risk category. However, using a semi-quantitative risk matrix does not easily allow for the uncertainties associated with the hazard and consequence to be assessed, as it represents a best estimate rather than a range of risk estimates.

Further information on the Bay of Plenty Regional Policy Statement approach is available in Appendix L of the statement, as well as in Saunders et al. (2013) and Kilvington and Saunders (2015). This framework in practise is outlined in Section 7.4, and the Proposed Otago Regional Policy Statement sets out a similar approach.

4.4.2 Quantitative risk metrics

Quantitative risk analysis can be systematic and objective, enabling the risk from multiple hazards at the same location or various locations to be compared and combined (Corominas et al. 2014). The quantitative risk metric provides a consistent basis from which to determine risk tolerance and acceptability levels, providing stakeholders, planners and policy makers with a sound methodology on which to base decisions. The resultant risk estimates can be presented in the form of different types of risk metrics. The risk metrics that have been used in a planning context include the ***local personal risk***, ***annual individual fatality risk***, ***annual property loss/risk*** and ***societal risk***. These types of risk metrics are explained in Sections 4.4.2.1–4.4.2.4 below.

As risk is inherently uncertain, quantitative risk analysis also provides a systematic way of dealing with uncertainties by providing a means to document the uncertainties at each stage. This also enables practitioners undertaking quantitative risk analysis to identify gaps in the data, as well as understand the weaknesses (i.e. lack of data quality) of the process (Corominas et al. 2014). The output and associated uncertainties may inform risk-reduction options. The uncertainty and assumptions associated with the risk analysis should be documented. Uncertainty will decrease with increasing spatial scale and increasing level of analysis, but data gaps may remain; therefore, uncertainty cannot be eliminated.

Because of uncertainty, risk should not be presented as a single value but rather as a range or band. The band should include lower, central and upper estimates of risk. Risks are also dynamic and can change through time (e.g. Massey et al. 2022a; de Vilder et al. 2022). Figure 4.5 shows how risk can increase through time. Under climate-change

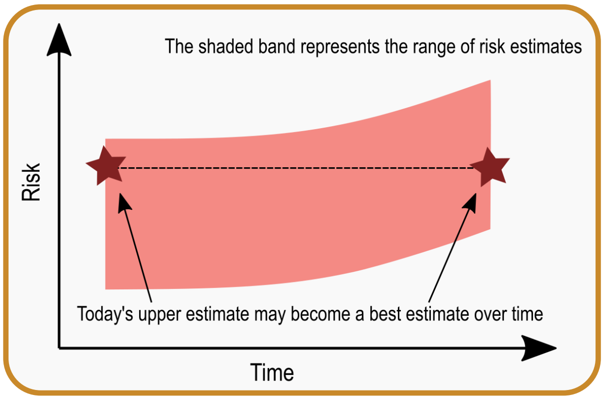


Figure 4.5: Today's precautionary risk estimate may become tomorrow's central estimate (or vice versa) (Taig et al. 2012).

scenarios, risk is expected to increase. Therefore, what is currently a precautionary estimate may eventually become the central estimate. Conversely, risk can decrease through time, as seen in the Port Hills, Christchurch, following the Canterbury earthquake sequence, where rockfall risk remained elevated but decreased through time as the probability of a trigger event (earthquake) reduced (Taig et al. 2012).

The Natural Hazards chapter in the Christchurch District Plan includes a formal process by which people can 'challenge the line'. Policy 5.2.2.4.2 enables a site-specific risk analysis to be undertaken and the site's annual individual fatality risk to be re-classified using the stated methodology. This is an example of a policy response based on the presence of uncertainty in a risk line on a map.

The risk metrics used are generally relatively small in terms of the likelihood of a specific risk. For example, the probability of an outcome occurring (e.g. a person killed, a number of people killed or a house sustaining an amount of damage) from an event is often reported in terms of numbers such as 10 to the power of negative *x* (10^{-x}) per annum. These numbers can easily be translated into more familiar terms, as shown by Table 4.1.

4.4.2.1 Local Personal Risk

Local Personal Risk (LPR) is the annual probability of death for a hypothetical person present at a particular location for 100% of the time (24 hours a day and 365 days a year). LPR is a metric used in flooding and seismic hazard studies (Crowley et al. 2017; Jonkman et al. 2003; van Elk et al. 2019) and can be used for planning purposes by visualising the spatial distribution of risk. In such an assessment, vulnerability can be assumed to be 1,[14] and therefore we calculate the annual probability of being impacted by a landslide if a person or building is present in a specific location 100% of the time. The Kaikōura District Plan uses LPR maps as a basis for overlay development and associated land-use planning provisions.

4.4.2.2 Annual Individual Fatality Risk

Annual Individual Fatality Risk (AIFR) is the fatality risk of an individual (probability of death) over one full year of working or living in a given area (i.e. not present 100% of the time). This risk is often calculated for the most exposed person. For example, in a 2018 Environment Court decision[15] on the Queenstown Skyline gondola (see Appendix 1), the consequences of rockfall in the Queenstown

14 Where the person is in that location 100% of the time; alternatively, vulnerability could be 0.5, where they are assumed to be in that location half of the time.

15 Skyline Enterprises Limited v Queenstown Lakes District Council, Interim decision [2018] NZEnvC 242.

Table 4.1: Translation of the '10 to the power of negative … per year' terminology into more familiar terms. 'Per lifetime' is based on average Aotearoa New Zealand life expectancy of about 80 years (from 2008 mortality and population data).

'10 to the negative … per year'	Is the same as … (per year)	Is approximately the same as once in …	Is the same as …
10^{-3}	0.001 or 0.1%	1000 years	8% per lifetime
10^{-4}	0.0001 or 0.01%	10,000 years	0.8% per lifetime
10^{-5}	0.00001 or 0.001%	100,000 years	0.08% per lifetime
10^{-6}	0.000001 or 0.0001%	1,000,000 years	0.008% per lifetime

gondola parking area were focused on a bus driver waiting in the bus, rather than visitors who park a car and leave the area of risk to travel by gondola. The bus driver represents the person most exposed to the risk because of the relative amount of time spent in the area. Section 7.6 provides an example of AIFR used in the Christchurch District Plan.

4.4.2.3 Annual Property Loss/Risk

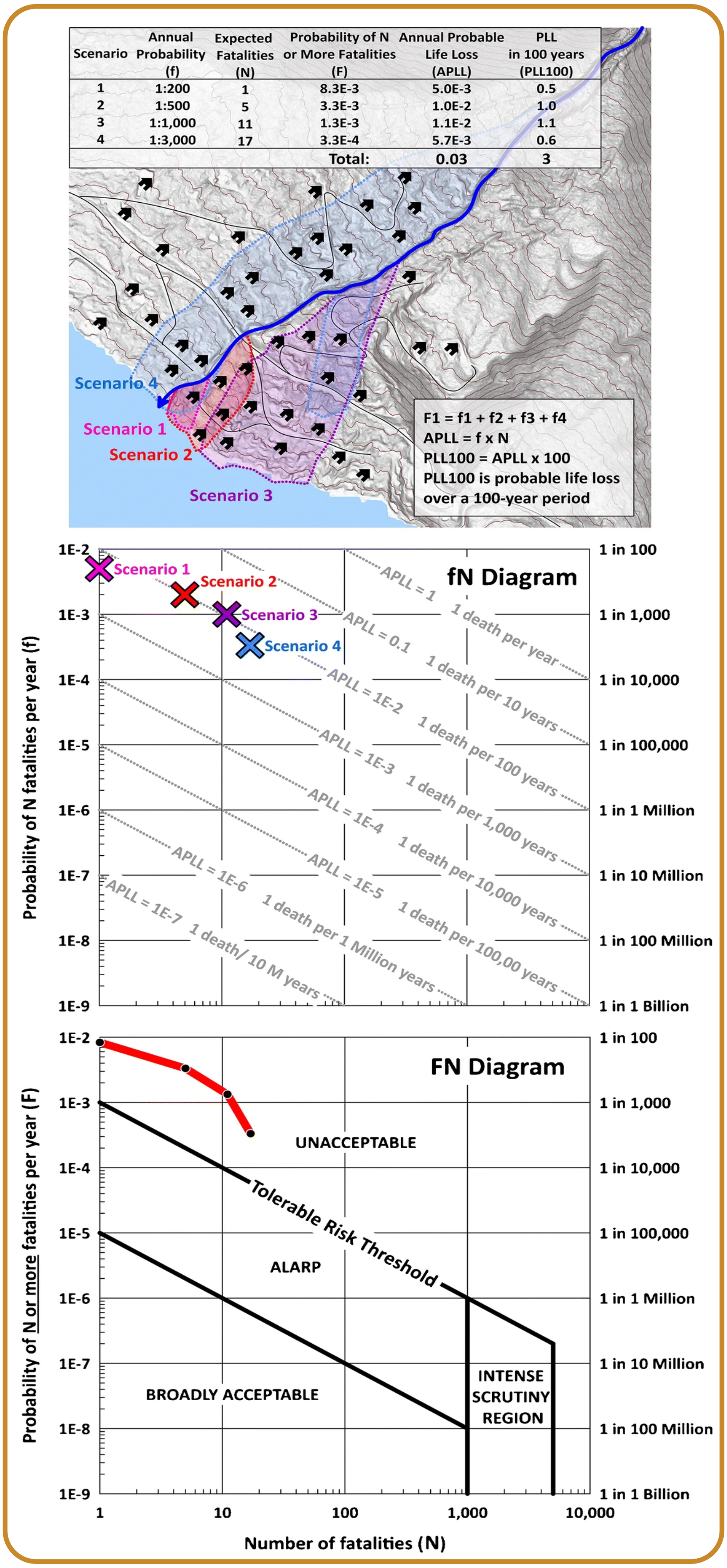
Annual Property Loss/Risk (APL/APR) is the risk that a property will experience loss (i.e. damage) over one full year, also called the probability of loss. It can also be calculated in terms of the value or net present value of the property. Section 7.5 provides an example of APR used in debris flow and rockfall analysis in Queenstown. The Proposed Otago Regional Policy Statement utilises APL/APR for total property loss (relating to permanent structures) in its natural hazard risk assessment methodology. It proposes a 'tolerable' threshold for this of 10^{-6}–10^{-4} depending on whether the development is new or existing.

4.4.2.4 Societal risk

Societal risk refers to the potential adverse impacts and consequences that hazardous events or disasters can have on a community, population or society. It encompasses the likelihood of such events occurring and the extent of harm that they could cause to people, property, infrastructure, the environment and the overall wellbeing of the affected population. Societal risk takes into account factors such as the number of fatalities, injuries, economic losses and social disruption that may result from these events. It involves evaluating the acceptable level of risk that a society is willing to tolerate and making informed decisions and policies to minimise and manage these risks for the safety and resilience of the community.

Fatal accidents are regrettable occurrences, but society tends to be more concerned about incidents where multiple fatalities happen together. While these infrequent but high-impact events might pose a low individual risk, they become unacceptable when they expose a large number of people. This concept is part of societal risk, involving the risk that a society faces from significant widespread consequences caused by events like major landslides triggered by earthquakes or heavy rainfall, which could result in multiple fatalities. Societal risk is scenario-based. Two broad quantitative risk metrics are often considered for societal risk (see Figure 4.6), which include:

1. ***fN pairs***: Calculated by linking some specific scenarios that relate the number of people who might be in a group with the likelihood of them being killed if a hazard of a given magnitude were to occur (N) and the probability of that hazard occurring (f). The scenario fN pairs can be plotted on an fN diagram and used to create an ***fN curve***. Societal risk thresholds are usually defined using such an fN diagram and are called fN criteria (Figure 4.6), with the threshold line defined by an anchor point and a slope. The anchor point is the tolerable probability of a disaster, which typically involves multiple people and is unrelated to individual risk. For example, if a community considers the death of 10 or more people in a landslide to be intolerable, and they are willing to accept a 1-in-10,000 chance of that happening each year, then the anchor point on the graph would be at 10 deaths and a probability of 10^{-4}. The slope of the line on the graph shows how much a society wants to avoid events that cause many deaths. The fN diagram in Figure 5.4 displays the Hong Kong ***risk evaluation*** criteria for societal risk (multiple fatality risk) (GEO 1998) and therefore may not be applicable for an Aotearoa New Zealand context (figure from Strouth and McDougall [2021]).
2. ***Annual Probable Lives Lost (APLL)***: This metric multiplies the probability of a hazard occurring (f) by the potential number of fatalities (N) to estimate the expected number of deaths over a year. The APLL is calculated for each scenario and then summed to give the total APLL (see Figure 4.6 for more detail).



Scenario	Annual Probability (f)	Expected Fatalities (N)	Probability of N or More Fatalities (F)	Annual Probable Life Loss (APLL)	PLL in 100 years (PLL100)
1	1:200	1	8.3E-3	5.0E-3	0.5
2	1:500	5	3.3E-3	1.0E-2	1.0
3	1:1,000	11	1.3E-3	1.1E-2	1.1
4	1:3,000	17	3.3E-4	5.7E-3	0.6
			Total:	0.03	3

Figure 4.6: A hypothetical example of multiple-fatality landslide risk at a debris-flow fan. The spatial map displays the different debris-flow events (Scenarios 1–4) that can result in one or more fatalities. The fN diagram displays the scenario fN pairs and is used to create an fN curve that can be plotted on a fN diagram. It displays the Hong Kong risk evaluation criteria for societal risk (multiple fatality risk) (GEO 1998) and therefore may not be applicable for an Aotearoa New Zealand context (figure from Strouth and McDougall [2021]).

4.5 Level of detail for landslide susceptibility hazard and risk analysis

This section outlines and describes five levels of landslide susceptibility, hazard and risk analysis that can be undertaken for planning and consenting purposes, including their key features, required inputs, outputs and where such levels should be applied. The appropriate level of analysis is determined by the intended purpose(s), as well as how uncertainty in the analysis results could affect decision-making.

The five levels of landslide susceptibility, hazard and risk analysis are outlined in Table 4.2 and Figure 4.8, with the level of detail increasing from a susceptibility analysis (Level A) to a full probabilistic quantitative risk analysis (Level E). Figure 4.7 provides example maps and outputs for each level of landslide hazard and risk analysis. As the level of detail increases, the associated uncertainty generally decreases. With an increasing level of detail, there is usually an increase in time and cost. Ideally, the detail of the landslide, susceptibility, hazard and risk analysis will be sufficient, but not excessive, for the intended purpose. A key consideration in scoping each analysis is to provide clarity about its purpose and the appropriate level of detail.

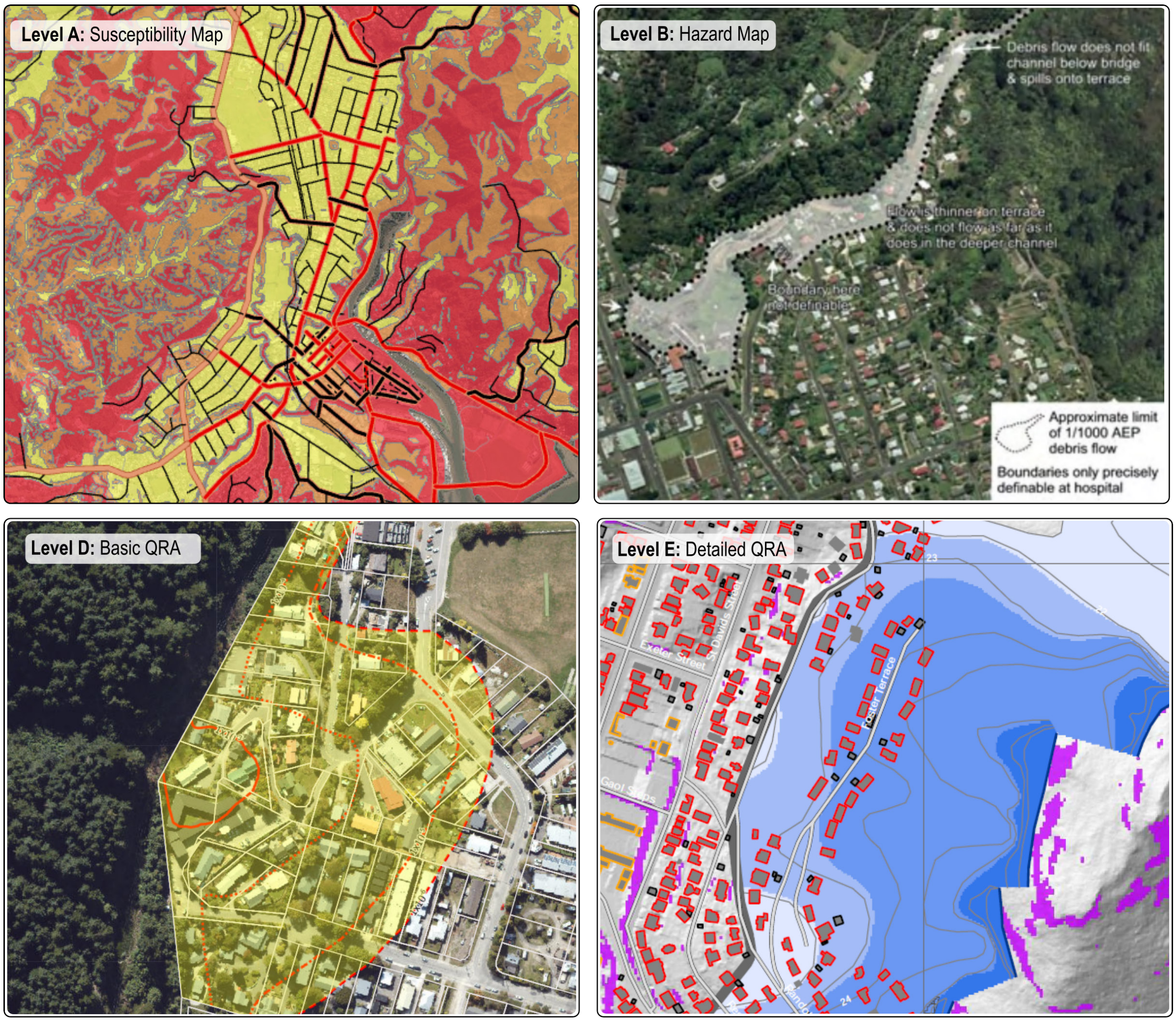


Figure 4.7: Example maps displaying the different levels of landslide susceptibility, hazard and risk analysis. **Level A:** Landslide susceptibility map of Whangārei District (Tonkin & Taylor 2022). Red, orange and yellow colours represent high, medium and low areas of landslide susceptibility. Runout has not been included in this map. **Level B:** Landslide hazard map showing the probability of a 1-in-1000-year AEP debris-flow event impacting the Thames Hospital (McSaveney and Beetham 2006). **Level D:** Basic quantitative risk assessment example, where debris-flow AIFR from three scenarios (small, moderate and large debris flows) was calculated for Gorge Road, Queenstown.[16] **Level E:** Detailed quantitative risk assessment example, where rockfall AIFR risk is calculated for the full range of earthquake and non-earthquake triggers that could occur in the Port Hills, Christchurch (Massey et al. 2012).

16 https://www.arcgis.com/apps/webappviewer/index.html?id=47539c9e9ba1458682033ea99f36de0d

Table 4.2: Level of detail for landslide susceptibility, hazard and risk analyses, including key features, information required, outputs of each level, residual uncertainty and application of each level for planning purposes.

Level of Analysis	Key Features	Information Required
A: Susceptibility Analysis	A susceptibility analysis involves mapping existing landslides and land potentially susceptible to landslide in a study area. It should also include mapping existing and potential runout areas, given the potential impacts on future development. The susceptibility analysis should utilise a SSP5-8.5 climate-change scenario (or, while unavailable, use RCP8.5) to 2130 in line with the National Adaptation Plan recommendation.[17] It typically does not include information on landslide frequency and so is technically not a hazard or risk analysis. This can typically be completed as a desktop study based on existing information (e.g. LiDAR, landslide inventory, geological maps). Given the variety of landslide types, the susceptibility analysis may concentrate on the landslide types and hazards that pose the biggest threat. This should be decided in consultation with expert landslide and natural hazard specialists and based on any relevant available landslide data.	• Inventory of recorded landslides in the study area or adjacent areas (including the New Zealand Landslide Database: https://data.gns.cri.nz/landslides/wms.html). • Highest-resolution DEM for the study area (at a minimum, this will be the national 8 m DEM: https://data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012). • Topographic analysis of the DEM (e.g. slope angle, curvature, aspect). • Regional information on geology, soils, geomorphology, land use and hydrology (includes QMAP, Active Faults Database: https://data.gns.cri.nz/af/). • Information on past triggering events from previous studies, reports, newspaper articles and records. • Local, including community, CDEM Group, council and landslide specialist experience of landslide occurrence across an area. • Walkover examinations of the area being mapped (for small study areas) or of typical examples of key geological features (for large study areas). • Information on landslide impact area, including landslide runout area and areas affected by slippage (e.g. landslide source areas).
B: Hazard Analysis	Uses the outcomes of landslide susceptibility mapping and assigns an estimated frequency (i.e. annual probability) to the potential for landslides, including under a SSP5-8.5 climate-change scenario (or, while unavailable, RCP8.5). It should also consider all landslides that could affect the study area, including landslides that are above the study area but may travel onto it and landslides that are below the study area but may retrogressively fail up-slope into it.	As above, plus: • Information on landslide frequency for a selected number of landslide sizes (e.g. most likely landslide and the maximum credible landslide), determined from the landslide inventory and triggering factors (e.g. return period of earthquakes and rainfall events of a certain size). • Information on landslide impact area, including landslide runout area linked to the different landslide sizes and area affected by slippage.
C: Semi-Quantitative Risk Analysis	A semi-quantitative assessment of the risk from a limited range of landslide sizes triggered by a certain event, for example, the most likely landslide size and maximum credible landslide size that could occur for a 100-year rainfall event. Consideration should be given to assess climate-change scenarios.	As above, plus: • Information on exposure and consequence scenarios (e.g. if the event was to occur, what the consequences would be).
D: Basic Quantitative Risk Analysis	A quantitative assessment of the risk from landslides triggered for certain scenarios (e.g. 1-in-100-year rainfall event, 1-in-500-year earthquake event), including SSP5-8.5 and SSP2-4.5 climate-change scenarios (or, while unavailable, RCP8.5 and RCP4.5) per the National Adaptation Plan and/or for a limited range of landslide sizes and landslide types.	As above, plus higher-resolution and more detailed base datasets that include the landslide inventory, topographic ground model, pre-disposing factors and exposure of population/property/infrastructure at risk, as well as: • Detailed analysis of the size and frequency of landslides that could occur for certain scenarios, determined from magnitude-frequency analysis of the landslide inventory. • Detailed modelling of landslide runout for the full range of landslide sizes. • More in-depth analysis of the vulnerability of people/property/infrastructure to different landslide sizes.
E: Detailed Quantitative Risk Analysis	A quantitative assessment of the risk from landslides that considers the full range of triggering events, including climate-change scenarios, landslide types and landslide sizes that could occur. This requires detailed regional or site-specific modelling. May require significant investment of both time and cost in obtaining more base data and more complex analysis.	As above, plus: • More detailed information on the full range of triggering scenarios that may result in landslides (e.g. full range of earthquake sizes, rainfall events and climate-change scenarios). • More detailed analysis linking the triggering scenarios to the number and size of landslides generated.

17 https://environment.govt.nz/assets/publications/climate-change/MFE-AoG-20664-GF-National-Adaptation-Plan-2022-WEB.pdf

Outputs	Residual Uncertainty	Application and Responsibilities
Landslide susceptibility map that shows areas that could be affected by landslides. Susceptibility descriptors can be qualitative (i.e. low/medium/ high), simple statistical descriptors (e.g. number of landslides/km^2) or probability-based. It will generally be necessary to independently assess the source areas of landslides and the runout/impact areas of landslides.	The primary focus is identifying land where there is a high degree of certainty that landslide hazard and risk is unlikely (so it can be excluded from further assessment). For other areas, significant uncertainty remains over the frequency of landslides occurring, the impact of climate change and what the consequences of this may be. These areas therefore require further investigation should development be sought.	A susceptibility analysis is the gateway assessment that determines where further assessment is required, and where it will not be required. It is suitable for use in a Natural Hazards portal and forms the recommended minimum basis for plans when zoning land as general rural, rural production, open space or sport and active recreation, as well as spatial plans or strategies. Areas identified as 'susceptible' indicate where further analysis should be undertaken by a landslide specialist when land-use, subdivision and building consents are sought or a plan change undertaken. **Responsibility to undertake:** Local authorities. Due to the scale of the assessment, and for consistency, it is recommended that this be undertaken across a region, led by the regional council in partnership with territorial authorities.
Landslide hazard map that shows or expresses the landslide hazard as the frequency of a particular type of landslide of a defined volume; or landslides of a particular type, volume and velocity (which may vary with distance from the landslide source).	Significant uncertainty remains regarding the potential consequences of the landslide hazard, as only a limited range of landslide sizes for a certain scenario are considered, which are not linked to exposure and vulnerability. Uncertainty may also remain regarding landslide frequency due to lack of or limited input information.	A hazard analysis is the recommended minimum for plan-making and plan changes for rural zones (rural lifestyle and settlement), commercial and mixed use, industrial, residential (large lot or low density) and future urban zones. **Responsibility to undertake:** Territorial authority initiating the process requiring assessment.
Semi-quantitative risk ranking that can be shown as risk areas on a map. The risk ranking links the probability of the landslide occurring to the consequences if the landslide happens (see Section 4.4.2 for more information). The risk ranking is based on semi-quantitative categories (example in Figure 4.4).	Uncertainty remains regarding landslide risk and the full risk profile, as only a limited range of landslide sizes for a certain scenario are considered.	A semi-quantitative risk analysis is the recommended minimum for plan-making and plan changes for general residential zones, medium- and high-density residential zoning and tertiary education zones. For these zones, it is anticipated that the type of development that will occur can be predicted with sufficient accuracy for a risk analysis to be undertaken. For land-use, subdivision and building consents, this analysis is the recommended minimum when establishing a Building Importance Level 2 building or natural-hazard-sensitive activity in areas identified as high or moderately susceptible to landslides. **Responsibility to undertake:** Person/authority initiating the process requiring assessment.
Quantitative risk metric (e.g. LPR, AIFR, APL – see Section 4.4.2 for more information on metrics) that can be displayed as risk areas on a map.	The information analysed is sufficient to determine the impact of landslides from an event with a moderate degree of confidence.	A basic quantitative risk analysis can form the basis for district plans, as well as site-specific analysis. For plan-making and plan changes, this analysis is the recommended minimum for hospital zones. For building consents, it is the recommended minimum for Building Importance Levels 3, 4 and 5. **Responsibility to undertake:** Person/authority initiating the process requiring assessment.
Quantitative risk metric (e.g. LPR, AIFR, APL – see Section 4.4.2 for more information on metrics) that can be displayed as risk areas on a map.	The information and analysis are sufficient to determine the level of landslide risk with a high degree of confidence. However, the scientific understanding of landslide risk, seismic hazard and rainfall under climate-change scenarios is imperfect and dynamic, so there will always be some residual uncertainty.	A detailed quantitative risk analysis can form the basis for district plans, plan changes, land-use, subdivision and building consents. This may be important for plan changes and consents where a larger number of people or properties may be subject to a large hazard event. **Responsibility to undertake:** Person/authority initiating the process requiring assessment.

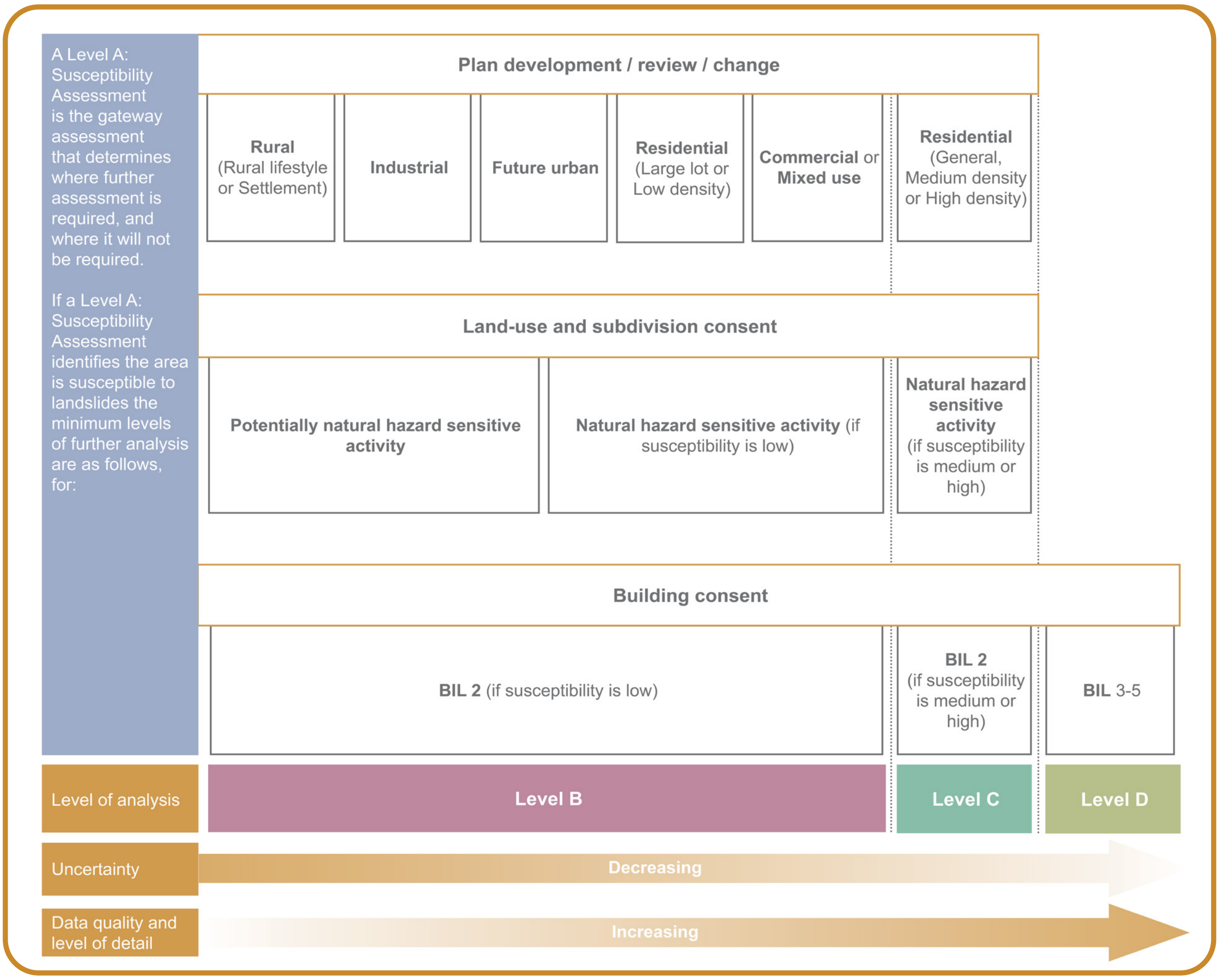


Figure 4.8: Different levels of analysis recommended for plan development/review/change, land-use and subdivision consent and building consent. See Section 6 and Table 4.2 for more detailed information.

Another important consideration is supporting climate-resilient development by considering climate-change scenarios. The National Adaptation Plan outlines that an SSP5-8.5 (while unavailable, use RCP8.5) climate-change scenario should be considered at a screening stage (equivalent to the Level A Susceptibility Analysis and Level B Hazard Analysis) and both an SSP5-8.5 and SSP2-4.5 (where unavailable, use RCP8.5 and RCP4.5) climate-change scenario at a more detailed assessment stage (equivalent to a Level C, D or E Risk Analysis).

Figure 4.8 outlines the link between levels of analysis and planning application. Section 6 provides more detail on the application of these levels of analysis within a planning context. Figure 4.8 is set out as a decision tree in Figures 6.1a–c.

Level A is a susceptibility analysis that identifies areas that may be susceptible to landsliding (this includes both source areas and landslide runout). It involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding (Fell et al. 2008). Susceptibility analysis does not need to be undertaken for areas that may experience no landslide hazards, such as flat land away from hillslopes. However, flat land may be at risk from landslide runout and ***retrogression***, with these areas identified during the susceptibility analysis process. This mapping and modelling can be used to identify areas where landslides are unlikely and do not require further consideration in a decision-making process.

Susceptibility models and their outputs, which are typically maps, are determined using information from landslide inventories and associated datasets. Models are typically developed by comparing where landslides have occurred spatially to the different 'forcing' (e.g. earthquake shaking, rainfall, pore-water pressure) and 'pre-disposing' (e.g. slope angle, geology, land cover) factors, which might account for their occurrence. The models are created using one of three methods:

1. **Heuristic techniques**, where expert knowledge and relative ranking scales are used to assign a rank of susceptibility from low to high for a particular combination of forcing and/or pre-disposing factors.

2. **Statistical techniques**, where combinations of forcing and/or pre-disposing factors are evaluated statistically, with susceptibility expressed in terms of probability or some other quantified metric.
3. **Deterministic techniques**, where physics-based models are applied to site-specific slopes to determine their susceptibility to failure. Results might be expressed in terms of probability of failure or amount of displacement.

Level A Susceptibility Analysis represents an important step in determining whether an area should be considered for further analysis. The output of a Level A Susceptibility Analysis can either be:

- A **binary output**, where a slope is assessed as being either susceptible to landslides or not.
- A **tiered output**, where qualitative descriptions (e.g. low, medium, high) are assigned to levels of landslide susceptibility such as those outlined in the AGS (2007a–d) guidelines and international guidelines (Fell et al. 2008); shown in Table 4.3.
- A **continuous output**, where quantitative variables such as probability are used to describe landslide susceptibility.

For all outputs from the different model types, it is important to ask the landslide specialists for limits to be placed on the extent of the susceptibility maps to identify areas that are not susceptible to landsliding (e.g. flat land away from hillslopes). For example, for a statistical susceptibility model that consists of a continuous quantitative output, such as probability, the landslide specialists can derive a statistical cut-off value (e.g. standard deviation) that can be applied to the modelled outputs as a threshold below which the susceptibility is assessed as being negligible. Alternatively, the landslide specialists can place limits on the spatial extent of susceptibility model outputs by, for example, determining the minimum slope angle that landslides can occur on in the map area (taken from the landslide inventory), the maximum distance that a slope may retrogress and/or the maximum runout distance that a landslide may travel from its source area.

If an area is within a landslide-susceptible area, then additional Level B or C analyses are recommended dependent on the land-use zoning. Levels B–D risk analyses are recommended for resource or subdivision consent, dependent on the hazard sensitivity of the activity (Bretherton et al. 2023) and for building consents dependent on the Building Importance Levels (as defined in the Building Act 2004). More detail on when to apply the different levels of analysis is provided in Table 4.2 and Section 6.

The local authority may determine that only areas of medium or high susceptibility need further consideration, while low-susceptibility areas could be assumed to have landslide risk levels that may be acceptable and tolerable (see Section 5.3 for more information on risk tolerability). However, if low-susceptibility (or similar) areas are excluded from further analysis, there may still be circumstances that warrant analysis of low-probability, high-consequence events in these areas (e.g. a hospital zone or Building Importance Level 4 structure).

4.5.1 Use of scales and recording of information

Landslides and associated information should be mapped and modelled at a scale appropriate for its end use. For land-use plans, the appropriate scale is 1:250,000–1:25,000, with an increase in spatial resolution for plan changes and consenting activities. Levels A–E of analysis can be applied at all scales (see Sections 7.6 and 7.7 for examples of Level E applied to district plan changes); however, the recommended minimum levels of analysis correspond to different planning tools (e.g. plan changes, consenting) and the associated appropriate spatial resolution.

Compatibility of scale is important when the map is to be combined with other thematic information (e.g. building footprints) to yield a hazard, risk or land-use management map, as differences in scale and resolution may result in inaccurate interpretations of the susceptibility, hazard and risk. For example, a landslide susceptibility/hazard/risk map should be at a scale not markedly different from the data used to produce it (e.g. risk is not displayed with 1 m

Table 4.3: Example descriptors for landslide hazard that could be adapted for landslide susceptibility descriptors (Fell et al. 2008). The table is meant for a given landslide magnitude class (i.e. landslide volume, area etc.).

Qualitative Hazard Descriptor	Rockfalls from Natural Cliffs or Rock Cut Slopes (Number/annum/km of cliff or rock cut slope)	Slides of Cuts and Fills on Roads or Railways (Number/annum/km of cut or fill)	Small Landslides on Natural Slopes (Number/km^2/annum)
Very high	>10	>10	>10
High	1–10	1–10	1–10
Moderate	0.1–1	0.1–1	0.1–1
Low	0.01–0.1	0.01–0.1	0.01–0.1
Very low	<0.01	<0.01	<0.01

resolution when the data used to create the risk map is at a 5 m resolution). Geographic Information Systems (GIS) readily allow for the combination of various land information, but planners should be aware that this easily allows inappropriate combination of data at differing scales. When included in public-facing portals, it is important to communicate the limitations and scale of the mapping and/or modelling or to limit the scale shown on the map, for example, by not allowing users to zoom in past a fixed scale.

It is recommended that local authorities maintain a record of all landslide susceptibility, hazard and risk analyses undertaken within their district or region. Ideally, this would be in a geospatial information system that records the extent, level of detail and categorisation results for each analysis, as well as the reason why the analysis was undertaken. At a minimum, copies of all technical reports should be permanently retained.

5. RISK-BASED PLANNING

Image: Rainfall-induced landsliding resulting in undermining of houses, Ohiwa, Bay of Plenty, 2004. Photo: Graham Hancox.

5.1 Overview

This section focuses on risk evaluation (Section 5.2) and what this means for risk tolerability (Section 5.3) as part of the risk management process.

Risk-based planning comprises the use of risk analysis and management methodologies to inform a decision-making process under the planning framework. Saunders et al. (2013) sets out the *Risk-based land use planning for natural hazard risk reduction*. Figure 5.1 provides a summary of the approach from that guideline.

An indicative example of a district plan chapter is given in Beban and Saunders (2013). A risk-based approach to planning for natural hazards has also been applied in guidelines for active faults (Kerr et al. 2003), liquefaction (MBIE 2017) and tsunami (Beban et al. 2019). The underpinning intent is that the risks are managed, rather than just the hazard.

As recommended by Saunders et al. (2013), five steps are required to implement a risk-based approach:

1. Know your hazard.
2. Determine the severity of the consequences.
3. Evaluate the likelihood of an event.
4. Take a risk-based approach.
5. Monitor and evaluate.

Although Figure 5.1 shows consecutive steps, there will be connections between several of them. Steps 2 and 3 can be undertaken in reverse order or iteratively. Although Step 3 refers to evaluating likelihood (or probability), it does not mean that all likelihood consideration only occurs at Step 3. The likelihood of a landslide(s) (such as 1-in-100-year/1-in-250-year occurrence or maximum credible event likelihood) may be determined as part of Step 1. Step 2 would scope potential consequences, including through stakeholder and community engagement. Step 3 would involve combining all likelihood aspects – such as likelihood of the landslide occurring, likelihood of a building being damaged and likelihood of someone being present in the building – thereby providing a comprehensive understanding of the consequences of an event.

The diagram in Figure 5.1 relates to the diagram in Figure 4.1 as follows:

Risk-Based Planning Approach (Figure 5.1)	Landslide Hazard / Risk Tools (Figure 4.1)
1. Know your hazard	Landslide Susceptibility and Hazard Analysis
2. Determine the severity of the consequences	Consequence Analysis
3. Evaluate the likelihood of an event	Risk Estimation
4. Take a risk-based approach	Risk Evaluation and Treatment
5. Monitor and evaluate	Part of Risk Management

5.2 Risk evaluation

Risk assessment involves evaluating risks and potential remedial options and mitigation measures for decisions on the acceptability or adoption of the risks to be made. Such assessments depend on the likelihood and consequences of the landslide hazard events being considered, as well as societal acceptance of certain risk levels. This is where policy- and decision-makers work with landslide specialists to make decisions about risk and appropriate development options.

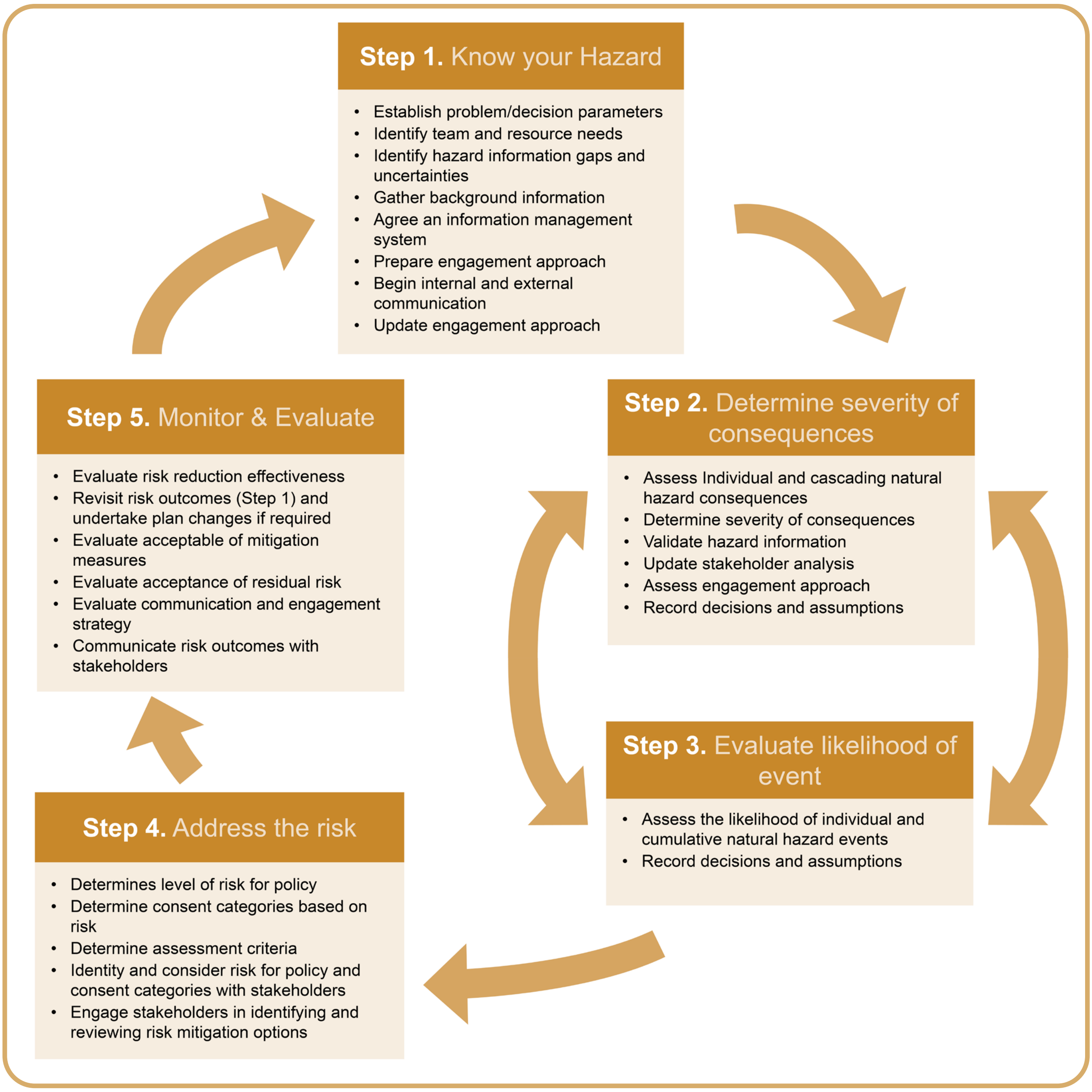


Figure 5.1: Risk-based planning approach (adapted from Saunders et al. [2013]).

Risk evaluation is inherently uncertain. The level of uncertainty associated with the risk outputs should also form part of the risk evaluation. If the uncertainty is too high, the uncertainty may need to be reduced via further detailed study (e.g. increasing the level of landslide analysis [Table 4.2] before decisions are made [as shown in Figure 5.2]). Additionally, a risk output may have relatively low uncertainty but be close to the border between a tolerable or intolerable risk and therefore may require uncertainty to be further reduced. Uncertainty and the need for further analysis can be explored by asking (modified from Strouth et al. [in press]):

1. Is there enough information to guide the decision? A good test is asking whether the evidence is robust enough to be defended in Environment Court.
2. Do all plausible risk estimates (the full range of risk estimates) support the same decision? (E.g. all risk estimates indicate intolerable risk levels.)
3. If not, is it feasible to reduce uncertainty?
4. What is able to be confidently and clearly communicated?

Having considered these questions, it is also important to assess whether the additional time and cost associated with further assessment is justified. As shown in Figure 5.2, high uncertainty can be tolerated in some circumstances.

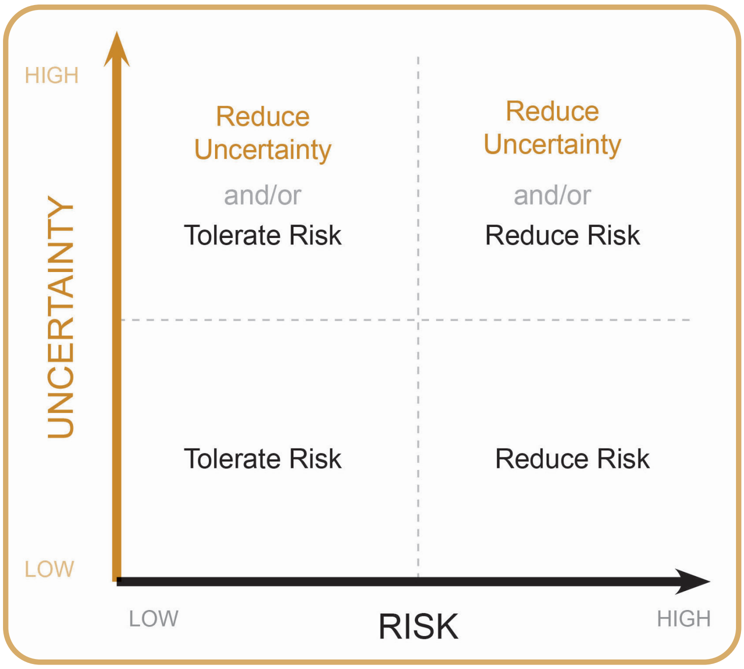


Figure 5.2: Risk evaluation actions as a function of risk level and uncertainty level. Adapted from USBR, USACE (2019).

5.3 Risk tolerance

A cornerstone of a risk-based planning framework is tolerability of risk that determines the criteria against which decision-making occurs. Risk-tolerability frameworks typically categorise risk into acceptable, tolerable and intolerable, as shown in Figure 5.3, ISO 31000:2009 (AS/NZS 2004)[18] and Toka Tū Ake EQC's risk tolerability methodology (Toka Tū Ake EQC 2023a) and associated literature review (Toka Tū Ake EQC 2023b).

Other frameworks categorise risk as low, medium/moderate, high (e.g. Bay of Plenty Regional Policy Statement and Proposed National Policy Statement for Natural Hazard Decision-making); tolerable, tolerable with management actions required, intolerable – seek advice (DOC 2018); low, moderate, high, extreme (Ministry for the Environment 2021); acceptable, tolerable, significant (e.g. Proposed Otago Regional Policy Statement).

An acceptable risk is a risk that everyone impacted is prepared to accept, with further risk reduction generally not required, while a tolerable risk is a risk within a range that society can live with in order to secure certain net benefits. Tolerable risks may require ongoing review and risk-reduction measures to reduce the risk further (Corominas et al. 2015) or maintain it at a tolerable level. Intolerable risks are risks that are considered to be so high that they are not taken, regardless of the benefits. Figure 5.3 sets out a risk tolerability framework developed by the UK Health & Safety Executive (HSE 2001) as a basis for flexible and adaptable risk-informed decision-making.

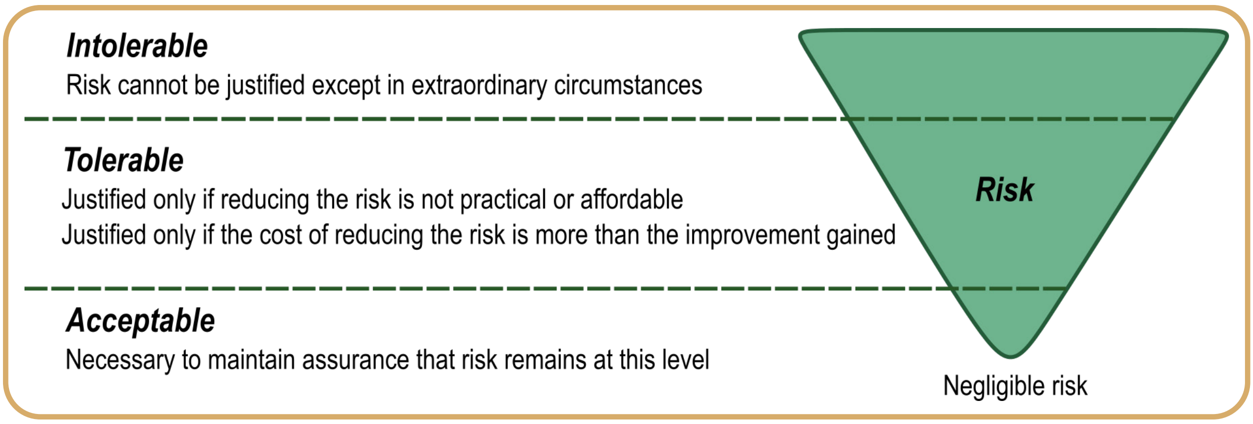


Figure 5.3: Tolerance levels of risk (HSE 2001).

18 ISO 31000:2009 makes reference to acceptable and tolerable risk, with risks that are not tolerable presumably being intolerable and identified as being subject to ***risk treatment*** until they are tolerable.

Risk tolerance is something that should be determined between decision-makers, experts and the community. The risk categorisation and associated tolerance of the risk matrix in the Bay of Plenty Regional Policy Statement (Figure 4.4) was determined based on community consultation. Risk tolerability may differ from community to community. Determining what may be intolerable requires community engagement and education, which can be achieved through the preparation process of a national policy statement, regional policy statement or regional or district plan (see Sections 7.4 and 7.6).

Note case law in Appendix 1 (Skyline Enterprises Limited v Queenstown Lakes District Council) where the intolerable risk as proposed by expert witnesses, which had not been considered through a community process, was not accepted by the Environment Court.

Landslide susceptibility, hazard and risk analyses can occur at different levels of detail (see Section 4.5). Using a semi-quantitative (Level C) risk ranking matrix (Figure 4.4) links risk to risk tolerability as follows:

- A low level of risk is equated to acceptable risk.
- A medium level of risk is equivalent to tolerable risk.
- A high level of risk is equivalent to intolerable risk.

Risk tolerability is well developed for AIFR and societal risk, and examples of this are examined below. How these can be related to plan development and activity status is explained in Section 6.

In assessing landslide susceptibility, hazard and risk, a local authority should also take account of the following questions:

- What is the risk metric (see Section 4.4 for examples) that it would like to evaluate? What social, economic, cultural and environmental aspects of risks would the local authority like to evaluate?
- Which areas of the district are, or are likely to be, under pressure for development?
- What infrastructure and development already exists near a landslide hazard (buildings, network utilities, etc.) and what is the value of those assets?
- What level of risk is the community prepared to accept or tolerate or not tolerate? (In practise, it may be easier to define what the community will not tolerate using community reactions to past events as a guide.)
- What is the feasibility (effectiveness versus cost) of possible engineering solutions or other risk-reducing mitigation works?

5.3.1 Annual individual fatality risk tolerance

For quantitative outputs (Level D and E Susceptibility Analysis), quantitative risk thresholds are often applied to life-loss risk, in particular, AIFR (see Section 4.4.3.1). Table 5.1 shows some international and national quantitative risk tolerance thresholds. Of interest in Table 5.1 is that there may be a lower risk tolerance for undeveloped slopes compared to slopes with existing development, and a higher risk tolerance for buildings less occupied (such as retail commercial buildings) compared to a building occupied for longer periods (e.g. permanent residences) or by vulnerable people (e.g. hospitals and schools). Intolerable risk in terms of natural hazards, including landslides, is typically in the order of greater than 10^{-4} (1 in 10,000) AIFR, and this can be a useful starting point (Taig et al. 2012). Various examples of the use of risk tolerability (particularly AIFR) are included in Table 5.1. Given that a quantitative risk tolerability framework has not been developed or endorsed nationally, existing examples present the best guide for developing such a framework at a regional or district level.

The thresholds for acceptable, tolerable and intolerable risk need to be identified within plan policy. In practise to date, these thresholds have been identified within a regional policy statement to be applied across the region – for example, see the Bay of Plenty Regional Policy Statement and Proposed Otago Regional Policy Statement (Table 5.1). Risk tolerability thresholds can take account of whether the site is undeveloped or developed, as well as the types of development. For example, an AIFR threshold of 10^{-5} could be used for undeveloped land and 10^{-4} for developed land, reflecting that, once an area has begun to be developed, there can be greater resistance to control and greater costs to mitigate risks.

5.3.2 Societal risk tolerance

Societal risk tolerance thresholds are used worldwide to determine how much ***danger*** a community can withstand/absorb before taking action. These rules are based on the idea that people are less willing to accept hazards that cause many deaths. Societal risk thresholds are usually defined using an fN plot, on which fN curves are plotted, and are called fN criteria (Figure 5.4), with the threshold line defined by an anchor point and a slope. The anchor point is the tolerable probability of a disaster, which typically exposes multiple people and is unrelated to individual risk. Societal risk is typically expressed as a number of casualties but may also be determined based on other risks, such as building or property damage, economic loss or environmental or cultural damage. For example, if a community considers the death of 10 or more people in a landslide to be

Table 5.1: International and national risk tolerance threshold examples (adapted from Leroi [2005]).

Organisation	Industry	Description	Risk Tolerance (AIFR, unless otherwise specified) [1]
UK HSE	Land-use planning around industries	• Broadly acceptable risk • Tolerable limit (see Figure 5.3)	• 10^{-6} per annum: public and workers • 10^{-4} per annum: public [2] • 10^{-3} per annum: workers
Netherlands Ministry of Housing	Land-use planning	Tolerable limit [3]	• 10^{-5} per annum: existing installation • 10^{-6} per annum: proposed installation
Department of Urban Affairs and Planning, New South Wales, Australia	Land-use planning for hazardous industries	'Acceptable' (tolerable) limits	• 5×10^{-7} per annum: hospitals, schools, childcare facilities, aged-care housing • 10^{-6} per annum: residential, hotels, motels • 5×10^{-6} per annum: commercial developments • 10^{-5} per annum: sporting complexes
Australian National Committee on Large Dams	Dams	Tolerable limit	• 10^{-4} per annum: existing dam, public most at risk subject to ***ALARP*** • 10^{-5} per annum: new dam or major augmentation, public most at risk, subject to ALARP
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	• AIFR: - 10^{-4} per annum: public most at risk, existing slope - 10^{-5} per annum: public most at risk, new slope • APR: Makes suggestions for descriptors but does not suggest limits; suggests that these should be defined by local authorities
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	• 10^{-4} per annum: public most at risk, existing slope • 10^{-5} per annum: public most at risk, new slope
Iceland Ministry for the Environment hazard zoning	Avalanches and landslides	'Acceptable' (tolerable) limit	• 3×10^{-5} per annum: residential, schools, day care centres, hospitals, community centres • 10^{-4} per annum: commercial buildings • 5×10^{-5} per annum: recreational homes [4]
Roads and Traffic Authority, NSW, Australia	Highway landslide risk	Implied tolerable risk	• 10^{-3} per annum [5]
Bay of Plenty Regional Council	Land-use planning	Tolerable limit	• AIFR (population in care): 10^{-4} • AIFR: 10^{-4}
	Land-use planning (Matatā)		• AIFR: 10^{-5} – lower tolerance level influenced by limitations within the modelling to ensure that the risk was not under-estimated and to better reflect the area of high risk.
Proposed Otago Regional Policy Statement	Land-use planning	Significant risk	• AIFR and APR: - New development: $>10^{-5}$ - Existing development: $>10^{-4}$
		Tolerable limit	• AIFR and APR: - New development: 10^{-6} to 10^{-5} - Existing development: 10^{-5} to 10^{-4}
		Acceptable risk	• AIFR and APR: - New development: $<10^{-6}$ - Existing development: $<10^{-5}$
Christchurch District Plan	Land-use planning	Life risk – rock fall / land stability	• AIFR: 10^{-4}

[1] While risk tolerance can be established for any type of risk (e.g. fatality, injury, property, building, social, economic, cultural or environmental), the majority of established quantitative thresholds relate to fatality.

[2] For new developments, HSE (2001) advises against giving planning permission where individual risks are $>10^{-5}$ per annum.

[3] Based on a temporal spatial probability of 1.0.

[4] Assumes temporal spatial probability of 0.75 for residential, 0.4 for commercial and 0.05 for recreational.

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

intolerable, and is willing to accept a 1-in-10,000 chance of that happening each year, then the anchor point on the graph would be at 10 deaths and a probability of 10^{-4}. The slope of the line on the graph shows how much a society wants to avoid events that cause many deaths.

Societal risk tolerance thresholds vary widely based on the scale of application, the purpose and the region. These are not directly transferable from one region to another (e.g. Figure 5.4; Ball and Floyd 1998; Hungr and Wong 2007; Strouth and McDougall 2021; Sim et al. 2022). It is important to note that defining societal risk threshold tolerance involves a complex balancing act, considering both the desire to prevent harm and the practical realities of resource allocation and decision-making. Different regions and communities may adopt varying approaches and criteria based on their unique circumstances and values.

For example, the Hong Kong criteria are intended for evaluating risk at individual landslide sites that are densely populated (GEO 1998). The Hong Kong criteria may not be applicable for evaluating landslide risk for an entire city, region or country, given differences in building types, landslide hazards, etc. It is noteworthy that several landslide disasters in Hong Kong prior to the instatement of the societal risk criteria involved constructed slopes and retaining structures, which the government had allowed as development sites. In Western Canada, where natural landslide hazards dominate the risk profile, there have been difficulties applying the Hong Kong criteria (see Strouth and McDougall [2021] for more information).

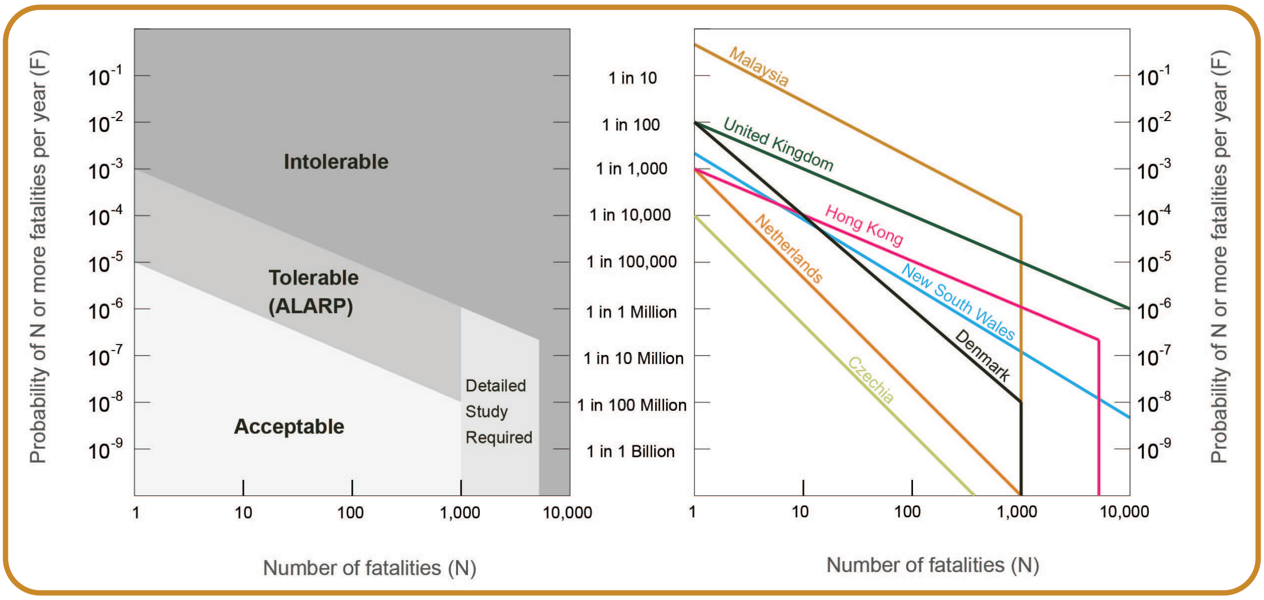


Figure 5.4: Comparison of fN criteria developed in different places for different hazards and different scales, adapted from Sim et al. (2022). The boundary between intolerable and tolerable (ALARP) and detailed study region in the fN curve on the left represents the coloured lines on the right.

6. PLANNING TOOLS FOR REDUCING RISK

***Image:** Papatea landslide, Kaikōura, as a result of the November 2016 Mw 7.8 earthquake. Photo: Steve Lawson.*

6.1 Overview

Plans and policy statements are critical tools for reducing landslide risks. Objectives and policies in planning documents must be well constructed to provide a robust policy framework to support planning rules. This section provides specific guidance for:

- Regional policy statements and plans.
- District plan preparation/review/changes.
- Assessing resource/building consents.

6.2 Decision-tree framework for landslide analysis

In the development of any policy and plan or through a consenting process, landslide hazards and risks should be considered at the earliest opportunity. A first step is to determine whether existing landslide hazard and risk information is sufficient or needs to be updated. Figures 6.1a–c outlines a decision-tree framework that identifies the minimum levels of landslide analysis appropriate for:

1. Plans and plan changes, based on planning zones.
2. Building consent, based on Building Importance Level (BIL).[19]
3. Resource or subdivision consent based on the sensitivity of the activity.

6.2.1 Level A: Susceptibility Analysis – a bare minimum requirement

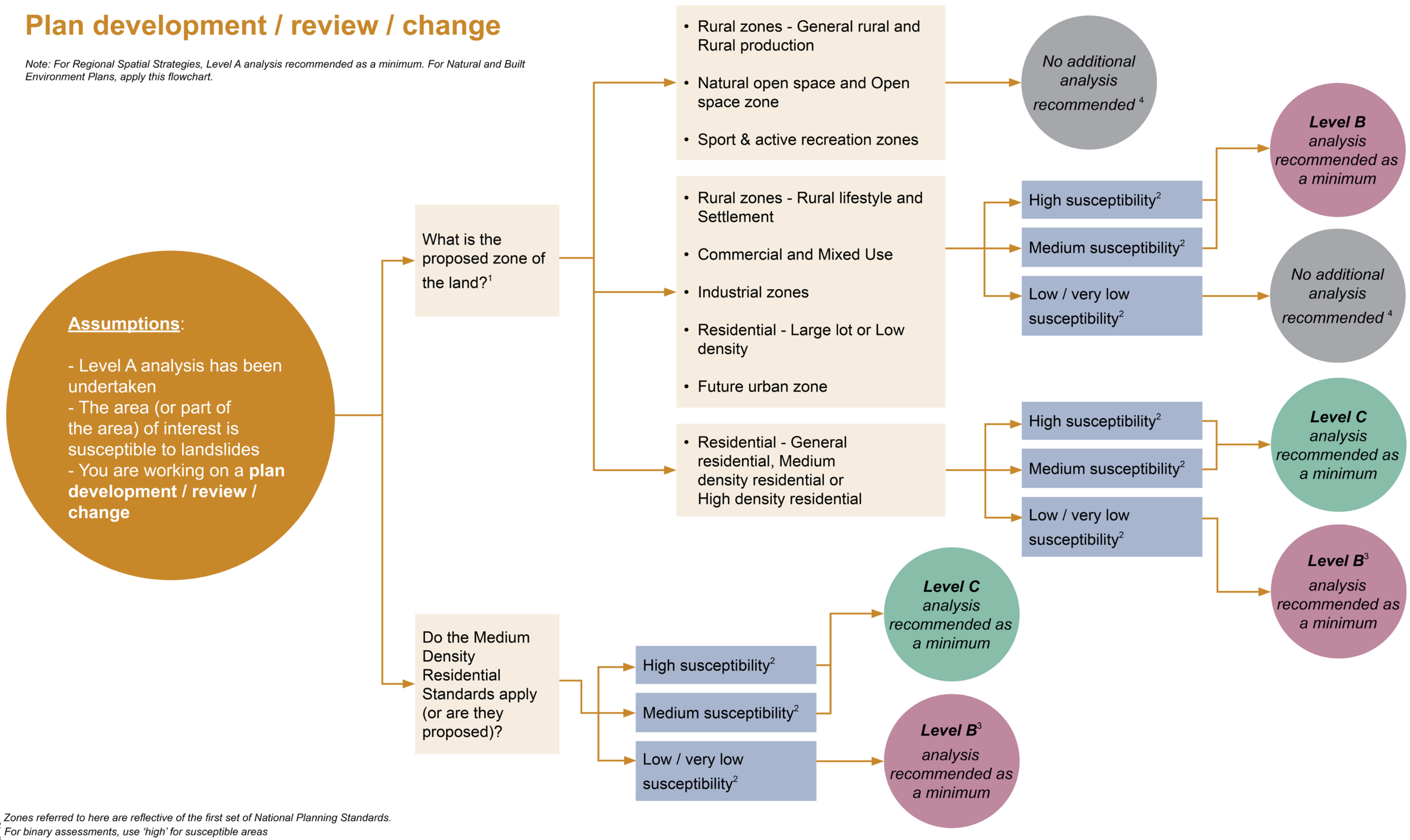
The decision-tree process requires that, as a bare minimum, a landslide susceptibility analysis has been undertaken. This mapping can be used to identify areas where landslides are unlikely and do not require further consideration, such as flat land well clear of potential landslide runout or retrogression. Level A Susceptibility Analysis is suitable to direct where further investigation is needed and is also sufficient for any broad-scale spatial strategy/plan or land-use zones or activities unlikely to give rise to higher levels of risk. If a spatial strategy/plan refers to specific zones, then the minimum recommended analysis for that zone, as shown in Figure 6.1a, should be applied.

Susceptibility analysis can take several forms (see Section 4.5). The AGS (2007a) guideline proposes four susceptibility descriptors based on probability (rockfall) or proportion of area in which landslides may occur. Nelson City Council utilised three susceptibility descriptors (Barrett 2021; see Section 7.2). Binary descriptors (susceptible or not susceptible) are the simplest expression. Each of these is considered in Figures 6.1a–c (see blue boxes).

6.2.2 Levels B–E: Hazard and Risk Analyses

Where a Level A Susceptibility Analysis identifies land susceptible to landslide, further landslide analysis may be required. The areas to be assessed and the level of hazard and risk analysis to be undertaken (see Section 4.5) should be determined using the decision trees (Figures 6.1a–c) and in consultation

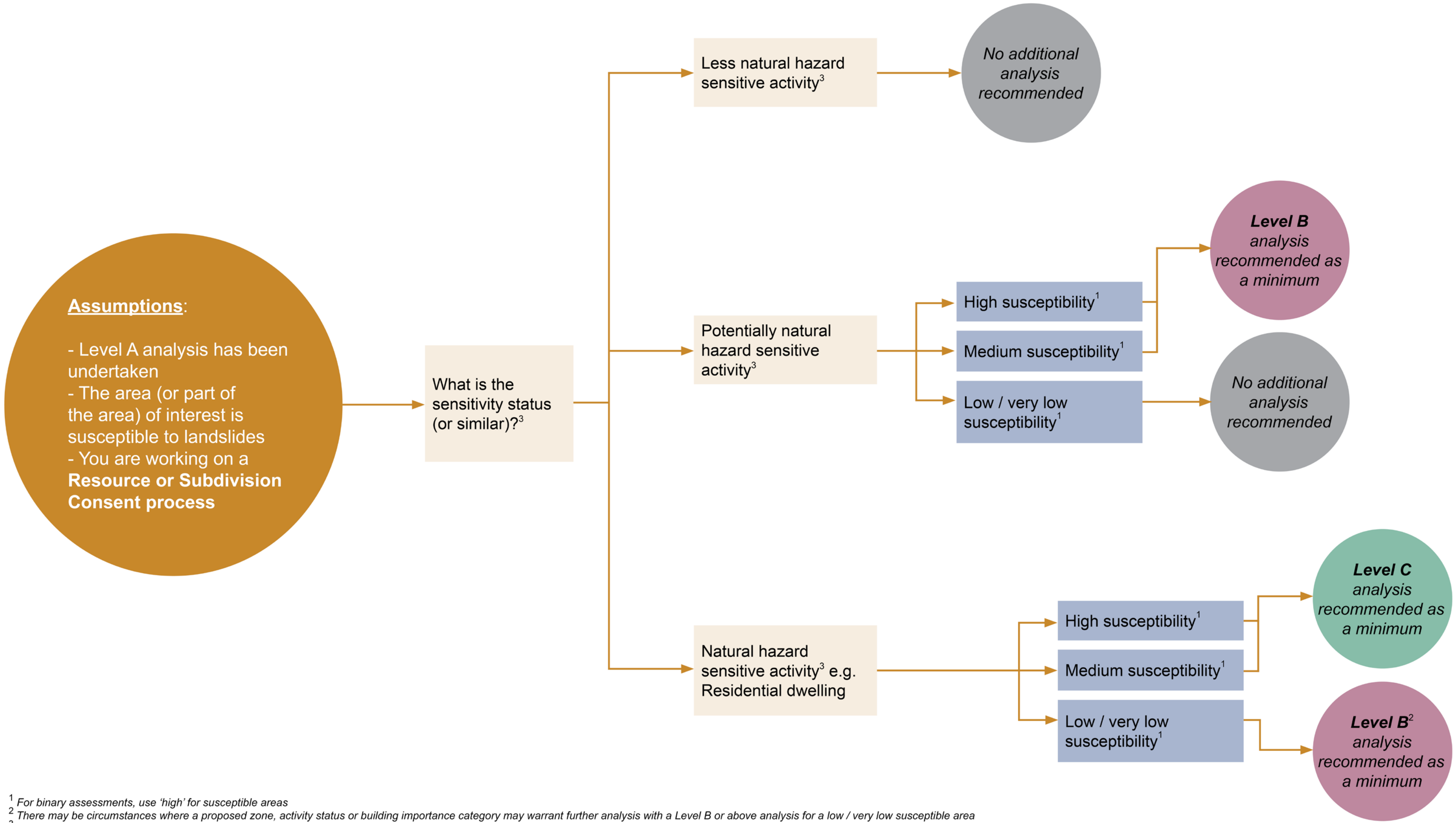
19 From the Building Regulations 1992, i.e. the Building Code.



[1] *Zones referred to here are reflective of the first set of National Planning Standards.*
[2] *For binary assessments, use 'high' for susceptible areas*
[3] *There may be circumstances where a proposed zone, activity status or building importance category may warrant further analysis with a Level A, B or above analysis for a low / very low susceptible area*
[4] *Although no further analysis may be necessary, rules within the zones may require resource consents for specific activities within any landslide susceptibility overlay.*

Figure 6.1a: Flowchart outlining the links between the different levels of analysis and planning purposes for plan development, review and/or change.

Resource or Subdivision Consent



[1] *For binary assessments, use 'high' for susceptible areas*
[2] *There may be circumstances where a proposed zone, activity status or building importance category may warrant further analysis with a Level B or above analysis for a low / very low susceptible area*
[3] *Plans that refer to sensitive activities use a variety of terms including 'Sensitive activities', 'Hazard sensitive activities', 'Natural hazard sensitive activities' or may replace 'sensitive' with 'vulnerable'. Definitions of sensitive or vulnerable activities typically include residential activities, care/medical/education/community facilities, visitor accommodation, marae, etc.*

Figure 6.1b: Flowchart outlining the links between the different levels of analysis and planning purposes for resource or subdivision consent.

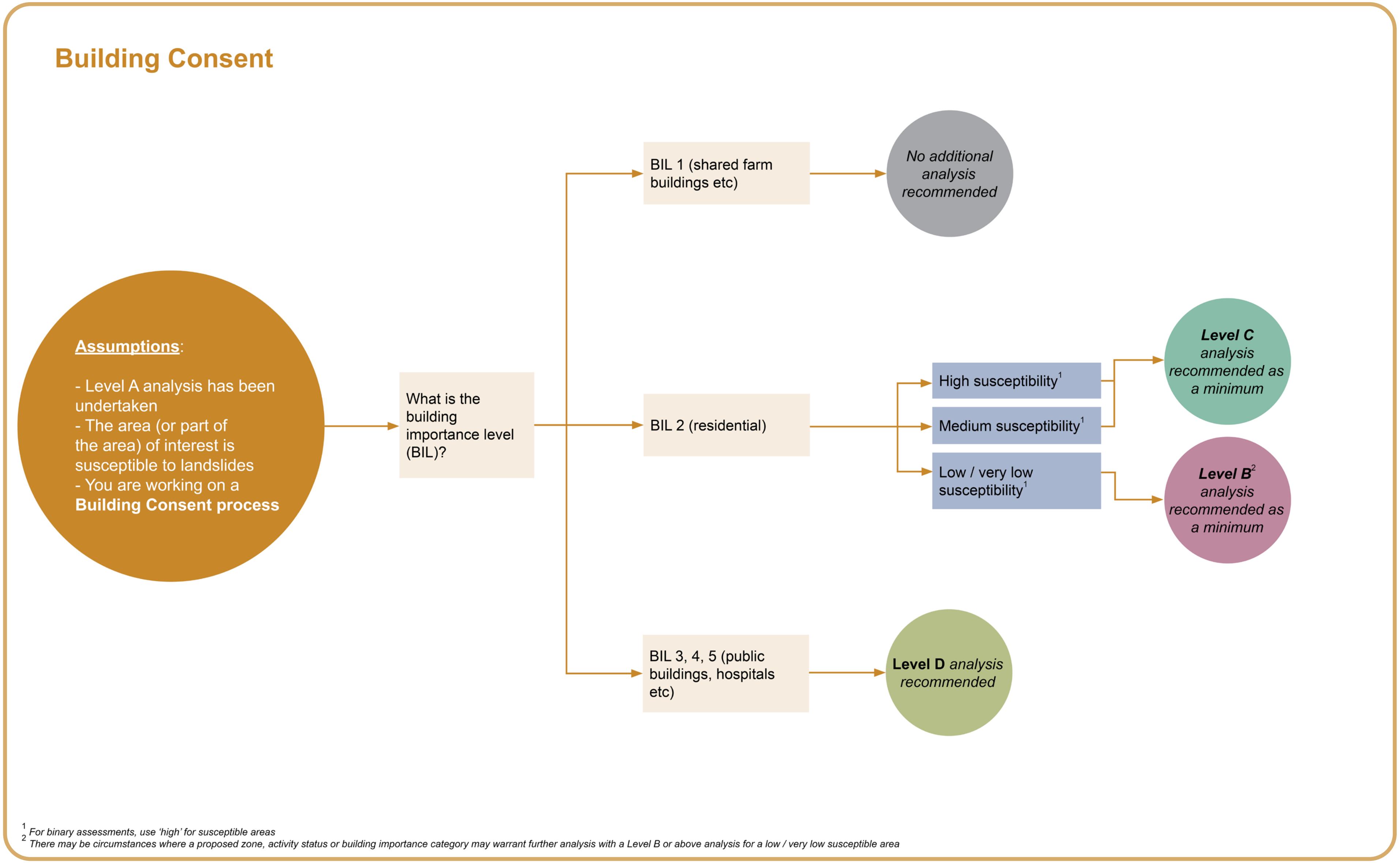


Figure 6.1c: Flowchart outlining the links between the different levels of analysis and planning purposes for building consent.

with a landslide specialist. The greater the level of analysis (i.e. Levels C–E), the more certainty is associated with the results, which can be reflected in planning documents. Where the level of analysis is lower (i.e. Levels A–B), more discretion may be needed in policy and rule frameworks.

Level E (Detailed Quantitative Risk Analysis) is the most comprehensive and can be the basis for district plans; plan changes; and land-use, subdivision and building consents. It is best applied for plan changes and consents where a larger number of people or properties may be exposed to a hazard event with major or extreme consequences. Following earthquake events, Level E risk analyses have been applied to plan changes in Christchurch and the Kaikōura district (see Sections 7.6 and 7.7); however, it is considerably more cost-effective to apply this level of analysis prior to a major event. The NIBS Multi-Hazard Mitigation Council (2019) reported that the benefit cost ratio for mitigation measures implemented prior to natural-hazard events ranges from $4 to $11 for every $1 spent. Adopting model codes provides the maximum benefit of $11 per every $1 spent.

6.2.2.1 Plan-making, plan change, plan review

Level A Susceptibility Analysis, when combined with planning processes, identifies the level of further analysis if required. Figure 6.1a shows the process if an area is identified as potentially susceptible to landslides. As a minimum, additional levels of hazard or risk analysis (Level B or C) will generally be required for plan development and/or plan changes depending on National Planning Standards[20] land-use zones or whether Medium Density Residential Standards apply [Resource Management (Enabling Housing Supply and Other Matters) Amendment Act 2021].

It should be noted that Special Purpose zones (from the National Planning Standards) are not included in Figure 6.1a, as these require more nuanced consideration. Special Purpose zones require specialist advice and stakeholder and partner engagement at all stages of the risk assessment process. In some cases, they require consideration of all possible landslide scenarios if any level of landslide susceptibility is identified (e.g. for a Hospital Zone). In this case, a Level D Risk Analysis would be recommended as the minimum via Figure 6.1c.

6.2.2.2 Consenting

If an area is identified as potentially susceptible to landslide, additional minimum levels of analysis (Level B or C) are recommended for land-use, subdivision and resource consents depending on the activity's natural-hazard sensitivity (Figure 6.1b). For building consents (Figure 6.1c), the level of recommended minimum further analysis (Level B, C or D) depends on the Building Importance Level (Buildings Regulations 1992, Schedule 1, Clause A3).

Information that should be provided for each type of analysis is given in Table 4.2. All limitations and uncertainties associated with analysis and map information should be clearly stated and/or annotated. The analysis should be peer-reviewed by an independent landslide specialist, which will assist credibility when the information is introduced to the public. A public process for releasing the maps should be considered soon after confirmation from peer review, particularly as the local authority has an obligation to include this information on a LIM report.

6.3 Planning and risk thresholds

Plans, policies and rules should be prepared based on the level of landslide hazard and risk (see Section 5.1). The level of risk should be expressed in terms of risk thresholds – acceptable, tolerable and intolerable – and taking into account:

- whether the area is undeveloped or developed, with consideration of a lower risk threshold for undeveloped land;
- whether there are different consequences (AIFR/LPR, APL/APR, societal risk); and
- whether the land-use activity is sensitive to natural hazards.

The risk thresholds may be included in policy at a regional level, for example, the Bay of Plenty Regional Policy Statement (see Section 7.4) or Proposed Otago Regional Policy Statement. Regional and district plans then need to be prepared in accordance with the Regional Policy Statement and therefore need to reflect the risk thresholds.

Policies and rules in plans should reflect the risk susceptibility, hazard or risk that the area (typically identified via an 'overlay') is exposed to, both now and in the future, including the context of existing and potential future use and development. Figure 6.2 shows the levels of risk tolerability (see Figure 5.3) related to activity status categories. Within the tolerable risk range, a number of activity status categories may be applied, taking into account the types of activities and potential exposure. When applying controlled or restricted discretionary status, matters of control and discretion must be stated within the rule framework. These should relate to the risk and potential consequences of the use, subdivision or development. For these activity categories, it may

20 https://environment.govt.nz/assets/publications/national-planning-standards-november-2019-updated-2022.pdf

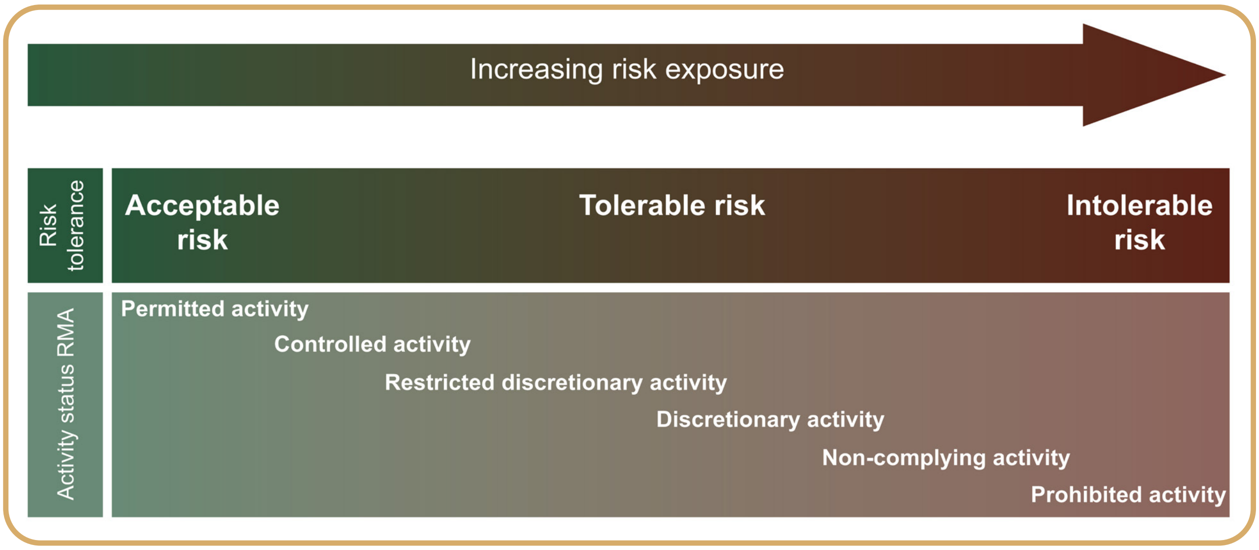


Figure 6.2: Risk tolerability and activity status for plan rules.

also be appropriate to apply standard conditions – for example, relating to provision of information at time of application and monitoring and reporting requirements.

Landslide susceptibility, hazard or risk assessment should be included in plans with policies and rules connected to these. The inclusion of Level A Susceptibility Analysis is suitable for use in a plan to identify where further analysis is required, while Levels B, C, D and E are suitable for determining whether proposed land uses are appropriate, and rules and policies can reflect this. Where it is determined that the risk is intolerable, a policy of avoidance or managed retreat should be considered, along with prohibiting activities (for example, see Chapter 20 and Plan Change 17 of the Bay of Plenty Regional Natural Resources Plan and Plan Change 1 of the Whakatāne District Plan on the Awatarariki Fan).

6.4 Regional policy statements and plans

6.4.1 Regional policy statements

Regional policy statements provide an overview of the resource management issues of a region and set out the policies and methods to achieve integrated management. Given the overlapping roles between regional councils and territorial authorities in respect to natural hazards, the regional policy statement needs to identify what each authority is responsible for, either in a leading or contributing role. Because territorial authorities manage subdivision and most land uses, the regional policy statement will generally assign management of landslide risk to territorial authorities. Therefore, it is territorial authorities that generally address landslide risk through preparation of their district plans and processing of resource consents.

Two matters that can be addressed at the regional level are the mapping of landslide susceptibility, hazard and risk and the policy framework for managing these.

The regional policy statement should also provide the framework and methodology for managing and assessing not only landslide hazard and risk but also natural hazard risk more broadly. The framework should be developed in collaboration with local authorities, communities, stakeholders and iwi/hapū. Examples of these types of frameworks can be found in the Bay of Plenty Regional Policy Statement, Proposed Otago Regional Policy Statement and Saunders et al. (2013). These policy provisions will have to be given effect to through either regional or district plans, or both, and so need to be clearly expressed.

6.4.2 Regional plans

Regional plans have been used to address existing uses where a susceptibility, hazard and/or risk assessment has found that the continuation of the use may be intolerable. Regional rules can:

- Extinguish the use of land for certain purposes.
- Enable an activity to be phased out in a certain area over time by requiring new consents to be obtained.
- Enable controls through conditions such as the duration of the activity.

While a district plan can introduce prohibited activity status rules for new activities / land uses or subdivision, existing legally established activities can remain under s10 of the RMA. The Awatarariki Fan / Matatā, Bay of Plenty, example of using a regional plan rule to over-ride existing use rights is covered in Section 7.4.

Regional plans can also address diversion and discharge of water, as well as earthworks, which can have a significant effect on landslide hazards. Generally, the control of stormwater and groundwater as it affects landslide hazards can be addressed by territorial authorities through subdivision and land-use controls. Where a regional plan can influence management of landslide risk is through provisions that enable or control hazard mitigation works, such as solutions to divert debris flows from flooded waterways.

6.5 District plans and processes

6.5.1 District plans

As territorial authorities manage subdivision and most land uses, a district plan is generally the best-placed document for landslide risk management. Each plan must address the district's strategic objectives and set out policies and methods (including rules) to address these objectives. Rules can require resource consent for activities located in landslide susceptibility overlays. The information that must be submitted with resource consent applications can be specified.

Mapping of landslide susceptibility, hazard and risk at a district level provides a consistent basis for territorial authorities and landslide specialists to address landslide risk. The scale and level of landslide susceptibility, hazard and risk analysis at a district level may be dependent on whether the territorial authorities have the resources to refine the mapping. If not, the regional council should consider taking the lead role in partnership with the territorial authority. At the very least, it is recommended that any regional mapping identify where landslide hazards may occur (Level A Susceptibility Analysis [see Section 4.5]) so that more detailed mapping and management can be focused on areas where there may be landslide risks (Level B–E analyses [see Section 4.5]).

As a starting point, responsibility for undertaking mapping should lie with the authority/person initiating a process requiring that mapping:

- Level A Susceptibility Analysis – regional councils, in partnership with territorial authorities.
- Levels B–C analysis for a council-led district plan review/change – the local authority.
- Levels B–E analysis to inform a consent application or private plan change – the applicant.

Plan provisions need to be appropriate to the community's circumstances. No one policy framework for landslide hazards will fit the needs of all communities within Aotearoa New Zealand. This is because the geology, topography and rainfall, and therefore types and locations of landslides, vary considerably between regions. Additionally, intolerance, tolerance and acceptance of risk may differ between communities. Therefore, community consultation is crucial in policy and rule development.

Examples of extensive community consultation are:

- Bay of Plenty Regional Council's 'I can live with this' public engagement on acceptable risk (Kilvington and Saunders [2015]; see Section 7.4); and
- Queenstown Lakes District Council's public engagement to assess and consider management options for alluvial fans of Brewery Creek and Reavers Lane (see Section 7.5).

6.5.2 District plan review and plan change

In any plan change process where there is known landslide susceptibility, hazard and risk, the provisions of the plan (including methods) should provide the ability to assess the risk and respond appropriately.

If an area is identified as potentially susceptible to landslide, and/or if an area is identified as having high or medium susceptibility to landslide, additional levels of analysis (Level B or C) may be required depending on land-use zonation. Consideration needs to be given to:

- The level of analysis (outlined in Table 4.2) and the appropriate spatial scale at which the analysis should be applied (outlined in Section 4.5).
- Whether the landslide analyses maps are included within a plan (usually as an overlay) or kept outside the plan:
    - It is preferable that maps are contained within the plan. This is particularly the case when specific policy and rules apply. Any maps used inside or outside of a plan need to be clearly cross-referenced and identifiable.
    - Once a map is included in a plan, any updates to that map would require a plan change, with associated time and cost. However, where the landslide hazard is well known with a good level of certainty, and there is specific policy and rules, the map should be included within the plan to provide the greatest certainty for plan users.
    - Maps kept outside of a plan can be constantly updated and can be used for LIMs, PIMS, building consents and evaluation of subdivision and land-use consent applications outside identified hazard overlay areas (where landslide hazard can still be assessed).
    - If the maps have high uncertainty, including them in a plan risks criticism at the proposed plan or plan-change stage, or, if not challenged through the plan preparation process, the information may be discredited through a resource consent process.

  - If maps do not provide complete coverage of the district, their inclusion within a plan may lead users to infer that those unmapped areas have no potential landslide hazard.
- Any mapping that forms the basis for specific policy and rules included within a district or regional plan should be peer-reviewed.

Where land is undeveloped and a hazard or risk analysis (Level B–E) undertaken, if a particular type of development could give rise to intolerable risk (see Section 5.3), a precautionary policy of avoidance of the landslide hazard should be considered (i.e. that type of development does not occur). The precautionary principle is addressed in *Coastal hazards and climate change: guidance for local government* (Bell et al. 2017), although not defined.

Where undeveloped land has been previously zoned for urban development, the existing zones should not simply be carried over in any review of the plan without analysis. New and improved information and climate change may require reconsideration of whether the existing zone and rules are appropriate, based on an assessment of the risk. While the RMA [s85(2)] provides for landowners to challenge rules that make land incapable of reasonable use, the risks of retaining an existing zone should be considered in any review.

Alternatively, the zone may be retained, but all or part of the land may be made subject to further rules to address the risk or to prevent landslides contributing to cascading hazards such as flooding. However, consideration should be given to the expectations generated from zoning land as 'residential'. Having risk tolerance thresholds in a regional policy statement or within the existing plan will assist in reviewing existing plan provisions.

For developed land, if a plan review identifies that the landslide risk is intolerable, consideration may need to be given to extinguishing existing use rights. Under the RMA, this can only be achieved through regional rules (see Section 7.4). Where the risk may be determined to be tolerable, the plan should ensure that risk does not become intolerable. Consideration should be given to requiring consent when a specified density of development is exceeded or for a natural-hazard-sensitive activity. Ongoing review of the hazard and development is required to monitor risk.

Zone boundaries often follow property boundaries. However, hazards are mapped as overlays and are agnostic of property boundaries. Different policies and rules can be applied to overlay areas to manage the landslide risk. Alternatively, if the property is sufficiently large and the risk is intolerable, consideration could be given to excluding the portion of the property containing the landslide hazard from a zone that anticipates residential activities. Changing the zoning to general rural or open space would remove any expectation that that portion of the site can be more intensively developed. In areas where residential activity is anticipated, development should be located outside of hazard areas unless the risk can be managed to a tolerable level.

The National Planning Standards require that all natural hazard provisions are contained within a hazards and risk chapter. Other chapters of the plan need to integrate with this hazard and risk chapter.

The activities that should be considered in any plan addressing landslides include:

- Subdivision.
- Land use – i.e. potentially hazard-sensitive activities.
- Buildings and structures.
- Earthworks.
- Stormwater (and wastewater) management.
- Infrastructure, energy and transport.
- Vegetation/forest clearance, ecosystems and biodiversity.

All subdivision activities are subject to the catch-all provisions in terms of natural hazards (RMA s106). This provision does provide a safety net, in that a landslide risk assessment can be required at the subdivision consent stage. However, the plan should not rely on this provision. It should also be noted that s106 references 'significant risk' without any definition of 'significant', and there is no case law that provides assistance in interpretation. All subdivisions require consent. Therefore, it is preferable that the plan requires a landslide risk assessment or more general natural hazard risk assessment through its subdivision policy and rules.

If a plan allows intensification of land use (e.g. multi-unit development) without first requiring subdivision, and without the ability to assess and manage landslide risk, there may be no opportunity to avoid increasing the risk that future development may be exposed to. For example, a plan may permit more than one residential unit within a site without subdivision, or may require consent for a restricted discretionary activity with discretion that refers to visual or amenity effects but not natural hazards. For this reason, plan reviews and plan changes should always consider natural hazard risks at the outset and tailor provisions to reduce risks for future generations. This is particularly important where risk is likely to change/increase under climate-change scenarios. The 2021 RMA amendment "*enabling housing supply and other matters*" provides for further intensification without subdivision, and councils need to ensure that natural hazards, including landslides, are considered as a qualifying matter through that process.

Choosing between no mapping or modelling, or mapping and modelling (Table 4.2; Figures 4.7 and 6.1a–c), will also require weighing the cost of mapping against the cost of requiring resource consents. If no mapping or a more basic level of analysis is chosen, then, due to greater uncertainty, an increased number of resource consents will be required to ensure that landslide susceptibility, hazard and risk is addressed. It is notable that, where significant events have occurred, such as earthquakes in Christchurch and Kaikōura, detailed analysis has been undertaken and policy and rules applied after the events. Ideally, this analysis and planning should take place prior to development or intensification to be more cost-effective, as noted in Section 6.1.

If a Level A Susceptibility Analysis has yet to be undertaken, a generic definition of 'land subject to land instability' should be included within the plan alongside an activity status that allows consideration of landslide hazard and a requirement for site-specific investigations (see Section 7.1). The generic definition(s) should be determined with a panel of local expert landslide specialists. Figure 6.3 shows an example checklist that steps through various definitions of land instability.

To ensure that no potential landslide hazard is overlooked, the angle and distance above and below the slope in this assessment may be very conservative, resulting in what may be perceived by applicants as unnecessary resource consents. A landslide hazard and risk assessment should be required if the definition of land instability is met. It should be noted that the use of this approach results in uncertainty for plan users and potential inconsistent application of plan rules.

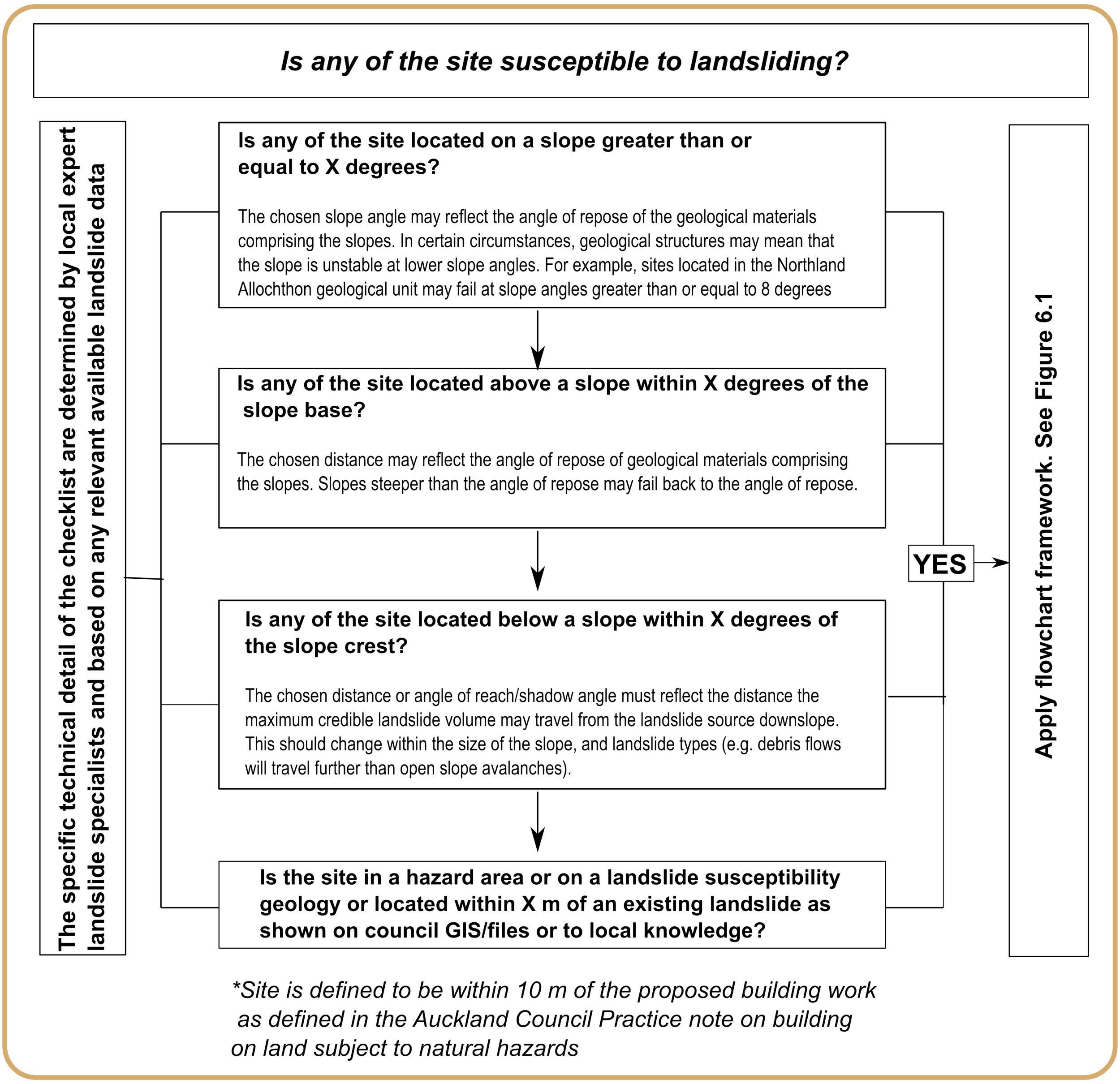


Figure 6.3: Example building consent checklist to be used when no Level A Susceptibility Analysis is available.

Earthworks provisions can, to some extent, provide a catch-all approach, given that most development on sloping land will require earthworks. Provisions that require earthworks consents exceeding specified volumes on a specified angle of slope will ensure that assessment of landslide risk must be carried out for developments on areas where the hazard has not been specifically identified.

Catch-all land-use or earthworks provisions that refer to land slope will not control development on potential debris flows, in runout areas or rockfall pathways over flatter land or on land that could be near the crown (top) of a potential landslide. For areas of interest with Level A or higher susceptibility analysis, consideration could be given to requiring plan provisions controlling land use, buildings and structures within a certain distance of a slope. For example, the definition of "*land which may be subject to land instability*" in the Auckland Unitary Plan (see Section 7.1) refers to horizontal distances from the top and bottom of cliffs, with cliffs being defined as having a slope of 45° or more and being greater than 3.5 m in height.

6.6 Land-use and subdivision consent applications

The decision-making process for a resource consent application that requires assessment of landslide risk is primarily guided by the objectives and policies within the regional, unitary or district plan. Information, objectives and policies underpin hazard overlays and other rules to manage hazards in a plan, but it is also important that the objectives and policies are developed in a way that assists in decision-making on resource consent applications.

The consent requirements will be dependent on the activity status of the rules in the plan; whether landslide susceptibility, hazard or risk has been mapped; and the level of analysis of any mapping. As landslide hazards can constrain or limit land use and development, it is important to identify landslide risk levels early in the planning for new proposals or projects. Figures 6.1a–c provides guidance on what level of analysis is required. Decisions can then be made as to which risk-reduction/management measures should be undertaken – avoidance, prevention or reduction of existing and future landslide hazards.

Although the level of analysis for the zoning of the land may have been sufficient to determine that the zone is generally appropriate, detailed analysis of a particular site within that zone will be required. This would need to be undertaken by the applicant's landslide specialist. As the planner processing any application cannot be expected to make technical judgements, a peer review should be undertaken by a suitably qualified and experienced professional. However, the processing planner should check that the analysis does not just focus on the site but includes consideration of surrounding land, as well as similar land nearby, and that the risks have been assessed.

For consent applications where a landslide hazard or risk may exist, Level C–E risk analyses are appropriate and dependent on the activity (Figure 6.1b).

The consenting process can be split into three stages:

1. Pre-application meeting.
2. Applications: submission, evaluation and review.
3. Making a decision: granting, requesting more information, declining.

Relevant consideration for landslide hazards and risk at each stage are discussed in the sections below.

6.6.1 Pre-application

Prior to a pre-application meeting, the planner should familiarise themselves with the wider area by checking:

- Council natural hazards records, including existing landslide susceptibility.
- Hazard and risk maps.
- Contour maps.
- LiDAR and aerial photography.

During a site visit, the planner should not only just focus on the site but also scan the adjacent surroundings for any potential landslide hazard. Although the planner cannot be expected to assess an application in terms of landslide hazard, being familiar with the wider area may assist them in making the applicant aware that a hazard assessment should be wider than the applicant's site.

Where a land-use change or new development is proposed for an area identified as having a potential landslide hazard, an appropriate geotechnical report should be required as part of the resource consent application. It is useful if this requirement is specified in the plan's assessment criteria. To ensure that an applicant submits a geotechnical report that adequately addresses the potential landslide hazard issues, planners and peer reviewers need to request the right information. Table 4.2 outlines the matters that should be addressed in a geotechnical landslide hazard and risk report where landslide hazards exist or potentially exist for a site.

It is important that the geotechnical landslide hazard report does not focus only on the site but also includes consideration of adjacent land. For example, a rural or lifestyle dwelling may be located away from an area of potential landslide and runout, but the accessway may have to pass through that area.

Councils can request an independent peer review of any geological/geotechnical assessments of landslide risk. The qualifications and experience of both the applicant's specialist and the council's peer reviewer need to be suitable for the task. See **Information Box 1** for appropriate skills at the detailed project level.

Information Box 2 outlines basic questions that a planner should ask of applicants when considering landslide hazard and risk.

6.6.2 Applications

An applicant lodging a resource consent application to subdivide, establish a new land use or build on or near at-risk land is required by s88 of the RMA to provide an adequate Assessment of Environment Effects (AEE) with any application. Schedule 4 of the RMA outlines what the AEE should include, in particular with regard to "*any risk to the neighbourhood, the wider community, or the environment through natural hazards.*" The district plan should set out what is required of resource consent applicants. An AEE should:

- Identify natural hazards (in this case, landslides).
- Provide a risk analysis of a detail appropriate to the activity.
- Consider risk management measures.
- Assess the proposal against the relevant natural hazard provisions.
- Determine residual risk with appropriate risk reduction.

Where there are specific rules in a district plan managing development in a landslide hazard area, the district plan needs to include assessment criteria that make it clear what factors will be considered when assessing resource consents for subdivision, land use and development. Such criteria may include:

- Risk to life, property and the environment posed by a natural hazard (Level C, D and E Risk Analysis).
- Likely frequency and size of landslide movement (Level B Hazard Analysis).
- Type, scale and distribution of any potential effects from the natural hazard (Level A Susceptibility Analysis).
- Degree to which the building, structural or design work to be undertaken can avoid or mitigate the effects of a landslide or slope instability.
- Accuracy and reliability of any engineering and geotechnical information, including limitations and uncertainties.

6.6.3 Making a decision

In determining or making a recommendation on an application in an area with potential landslide risks, a planner needs to ensure that the assessment criteria set out in the plan have been addressed.

Where a geotechnical report has been provided, this should be reviewed by a suitably qualified and experienced practitioner prior to a decision regarding the proposal.

Where effects associated with landslide hazards are identified because of the proposal, appropriate mitigation, at the discretion of the planner and landslide specialist, should be included in the proposal (potentially by way of a further information request) and subsequent conditions.

Information Box 2 – Questions for Applicants

Preliminary questions that planners need to ask when a development proposal is first being considered (i.e. at a resource consent pre-application meeting):

- Does the area have a history of landslides or slope instability problems?
- Are there any other hazard concerns in the area?
- Is there adequate landslide susceptibility, hazard and risk analysis information available? What level is the analysis (Level A through to Level E)?
- Have both earthquake- and rainfall-induced landslides been addressed in the analysis?
- Have the potential effects of climate change been considered in the analysis?
- Has any landslide analysis undertaken been through a peer-review process?
- Has all relevant landslide information and sources of landslide susceptibility, hazard and risk information been taken into account by the applicant?
- How likely is it that landslides will affect major and/or significant portions of the application area?
- Have any landslide risks been adequately addressed?
- Have any identified landslide risks been adequately treated to reduce risks to tolerable or acceptable levels?

6.7 Building consents

As noted earlier, there can be overlap between the controls in the RMA and Building Act 2004 (Carter et al. 2021). In general, duplication should be avoided if possible. However, it is even more important that there are no gaps in managing landslide risk, and these should be addressed in district plans and, in some circumstances, regional plans. Resource consent processes enable detailed consideration of hazard and risk, and decisions can include targeted conditions to avoid or reduce risk. In contrast, building consents usually come at the end of the process, so if regional or district plan provisions have not addressed landslide risk, there can be an expectation that a building consent will be issued. A district plan should not propose that building controls be used as the primary method for addressing landslide risks.

Where a building consent requires consideration of landslide risk, these guidelines generally apply, taking into consideration the constraints and interpretations of the Building Act 2004, particularly s71–74, as outlined in Section 2.3, and MBIE (2023). Those constraints and interpretations are addressed by the Building Consent Authority, such as in the Tauranga City Council and Whakatāne District Council *Practice Note – Managing Natural Hazards Under the Building Act 2004*[21] (or the Tauranga City Council Infrastructure Development Code) or Auckland Council Practice Note AC2229 *Building on land subject to natural hazards.*[22]

When processing building consent applications, officers should:

- Ensure that landslide hazards are considered and not overlooked, even if nearby development may have already occurred.
- Be aware of landslide hazards, risk analysis and risk-based planning (outlined in Sections 3, 4

Information Box 3 – Report Requirements

A landslide susceptibility, hazard or risk analysis report should document the data gathered, assumptions made, sources of uncertainty, logic applied, limitations of the methodology and conclusion reached in a defensible manner. The general data to be presented include:

- List of data sources.
- Discussion of investigation methods used and any limitations thereof.
- Description of potential landslides within the study area, including their type, size and location.
- Study area maps with locations of study area extent, locations of elements at risk and landslide-susceptible hazard or risk zones.
- Engineering geomorphological mapping results (and any associated GIS and metadata).
- Map of the landslide inventory.
- Description of field visits and validation of remote-sensing information.
- Description and/or map of landslide susceptibility classes.
- For hazard and risk analysis reports (Level B–E), magnitude-frequency scaling relationships for landslides for each trigger type.
- Map of the landslide source areas considered in the study area and the resulting potential landslide runout or slippage from these source areas.
- For risk-analysis reports, the assessed consequences to life and the resulting risk for each landslide type and overall landslide risk, including how the risk might change with climate-change scenarios.
- If applicable, assessment of potential risk-mitigation measures and options.
- If applicable, sensitivity analysis of the estimated susceptibility, hazard and risk should be reported.
- Where any of the above is not or cannot be completed, the report should document the missing elements and include an explanation as to why.

21 https://www.whakatane.govt.nz/sites/www.whakatane.govt.nz/files/documents/tauranga_city_council_and_whakatane_district_council_natural_hazards_practice_note_final.pdf

22 https://www.aucklandcouncil.govt.nz/building-and-consents/Documents/ac2229-building-on-land-subject-to-natural-hazards.pdf

and 5). By having some understanding of these processes, any expert report provided by the applicant (and any peer review) can be checked to see whether:

- the wider environment beyond the site has been considered;
- the different types of landslides have been considered (including rockfall and runout / debris flow); and
- uncertainty, including climate change, has been taken into account.

- Require the applicant to provide an appropriate level of landslide hazard risk analysis if the site is in or next to a landslide susceptible area. This may have already been provided to council as part of a subdivision consent or re-zoning. Figures 6.1a–c provides the recommended minimum level of landslide analysis for different Building Importance Levels within different susceptibility analyses. No susceptibility analysis will be required if the land clearly has no risk of landslide.
- Ensure that landslide hazards are considered for any access to the building platform and the works involved in creating that access, as well as any infrastructure.
- Ensure that any provision made to protect the land, building work or other property as outlined in s71(2) of the Building Act 2004 takes into account the ongoing maintenance, repair, alteration and eventual replacement of those provisions, as noted in Section 6.6.

6.8 Engineered solutions

Where engineered solutions are proposed, consideration must be given to the residual risk associated with the solution – that is, events beyond the design limits of the solution. Of note in this regard is the Waikato Regional Policy Statement HAZ-M12, which requires 'Residual Risk Zones' in District Plans with particular regard to the level of service provided by structural defences.

Any engineered structure has a lifespan; therefore, consideration should be given to the ongoing maintenance, repair and eventual replacement of that structure. If the structure is deemed appropriate, it is important to ensure that the structure will be able to be replaced in the future. Due to the ongoing liabilities and responsibilities for engineered solutions, policy should include a preference for natural rather than built approaches to mitigation of landslide risk and for soft structures over hard structures, as these result in less burden over their lifespan. Natural approaches may include greater setbacks or retention of vegetation, and a soft earth bund may be preferable to a fence to mitigate against rockfall, for example. The land may also require ongoing monitoring to ensure that the built solution meets design expectations.

In order to ensure that engineers take into account the lifespan of the engineering solution, a possible condition (based on a condition from a Dunedin City Council resource consent) could be along the lines of:

> *"Where the long-term stability of other's land or structures may rely upon the continued stability of retaining works, the designer must confirm that the retaining structure can be safely demolished following a complete design life without creating hazards for neighbouring properties."*

An example where the replacement of an engineering structure may have caused a landslide occurred in Dargaville, where a person died from a landslide on a site where a crib wall was being replaced. The likely cause was the methodology used to replace the existing crib wall with a retaining wall (Glassey and Hancox 1998).

Mechanical solutions can be particularly uncertain; for example, a drainage system to stabilise land that relies on pumping may be more likely to fail during a storm event when it is most required (e.g. from electricity being cut or debris blocking drains). Even subsurface gravity drainage that may be critical to the stability of the land will have a design life and eventually require replacement. The land may also require ongoing monitoring and reporting to ensure that the engineered solution meets design expectations. For any engineered solution, the responsibility for the maintenance, repair and eventual replacement of that structure and any monitoring must be clearly identified through the consent process and may need to be included on the title through a consent notice or covenant.

6.9 Recording information on land titles

To ensure that future owners are aware of any ongoing requirements and responsibilities and the existence of any geotechnical reports, a record of risk should be noted on land titles using a consent notice (subdivision stage) or land-use covenant (land-use consent) in the following instances:

- Where landslide susceptibility, hazard and risk analysis has been undertaken for either subdivision or land-use consents.
- Where the landslide risk will mean that future development requires further geotechnical assessment.
- If engineered solutions will require ongoing maintenance and replacement.

Note that the LGOIMA Act (see Section 2.5) may lessen the need to include information on land titles and will ensure that the most up to date information is available.

6.10 Other considerations

Where there is a potential landslide hazard, and the resource consent process does not include hazards as an assessment matter or provisions to manage the potential hazard on a property where development is proposed, applicants should be aware that, while landslide hazards may not be considered as part of resource consent processes, they may be addressed at the building consent stage – there may be no guarantee that a building consent will be granted. If resource consent is granted, consider including this message clearly on the consent certificate, rather than simply including it as an advice note.

Knowledge changes over time as the information about landslide hazards improves. It is important for local authorities to identify how this information is passed on to staff and the public. This is a particular issue where there is a high turnover of staff assessing proposed developments. The best way to improve staff knowledge of issues is through the development and implementation of a hazard management guidance for planning staff, as well as the use of hazard registers (regularly updated), GIS and databases, external datasets and training.

7. EXAMPLES IN PRACTISE

***Image:** House impacted by landslide debris during the Marlborough Storm, 2021. Photo: Andrew Boyes.*

This section contains examples of different approaches from around Aotearoa New Zealand. Table 7.1 provides a summary of these approaches and what they demonstrate.

Table 7.1: Summary of examples in practice.

District Plan or Report	Example of:
Auckland Unitary Plan	• Using rules tied to a catch-all definition of "*land which may be subject to land instability*" prior to mapping areas susceptible to land instability. • Using a qualitative and flexible risk-based approach, based on significant risk.
Nelson Resource Management Plan	• A planning response to a slope known to be unstable with existing development. • Prohibited activity status for further subdivision and more than one dwelling per site, implying intolerable risk. • Other activities regulated, including stormwater, wastewater and earthworks, implying tolerable risk.
Site assessment for Thames Hospital	• A risk-based approach for a hospital, which, as a critical facility, has a lower risk threshold. • Different levels of vulnerability, resulting in different risk tolerance.
Awatarariki fanhead, Matatā plan change	• Planning response following a destructive debris-flow event. • Removal of existing use rights under s10 of the RMA. • The Bay of Plenty Regional Policy Statement provided the risk planning framework. • Plan changes to the Bay of Plenty Regional Natural Resources Plan and Whakatāne District Plan identified high-, medium- and low-risk areas for the fanhead. In the high-risk area, future residential development was prohibited under the District Plan and existing residential uses were extinguished through the Regional Plan.
Brewery Creek and Reavers Lane – Queenstown Lakes District Council	• Application of a risk-based planning approach. • Quantitative risk assessment based on AIFR and APR. • Use of the modelling tool RiskScape to estimate monetary loss due to building damage expected for a range of hazard scenarios. • The preferred response package looks to apply a range of different approaches to manage different levels from rockfall and debris flow, including risk reduction across already-developed areas that are subject to significant risk from debris flow.
Christchurch Replacement District Plan	• A significant landslide event prompting a detailed risk-based approach that would have been more cost-effective if undertaken prior to development. • Detailed mapping undertaken around the Port Hills. • Quantitative risk approach based on AIFR, with a tolerable risk threshold of 10^{-4}. • Prohibited Activity status in areas mapped as having the highest risk of cliff collapse. • Less onerous activity statuses where risk is lower. • Applicants are able to contest 'the threshold line' through a specific policy.
Kaikōura District Plan	• A significant landslide event prompting a detailed risk-based approach that would have been more cost-effective if undertaken prior to development. • Detailed analysis focused on a study area that excluded areas with low likelihood of development. • In consultation with the community, a conservative tolerable risk threshold LPR of 10^{-4} was adopted. • The mapped Debris Inundation Overlay based on the LPR of 10^{-4} identified when a resource consent application would be required. • Incorporation of a climate-change scenario in risk analysis and significant related increase in risk.

7.1 Auckland Unitary Plan – no mapped approach

Example of:

- Using rules tied to a catch-all definition of "*land which may be subject to land instability*" prior to mapping areas susceptible to land instability.
- Using a qualitative and flexible risk-based approach, based on significant risk.

The Auckland Unitary Plan (AUP) combines regional policy statement and regional and district plan components into one planning document, with Auckland Council administering all functions. Chapter E36 of the AUP contains the natural hazards and flooding provisions, which are part of the district plan component of the AUP.[23]

The AUP identifies the natural hazards that affect Auckland, sorting them into frequent (including land instability) and infrequent occurrences, and describes a risk assessment process to identify current and future risks. The risk-based approach is described as flexible, with risk management applying to existing development and infrastructure and a risk-reduction approach (including avoidance, where appropriate) applying to greenfield development.

Auckland Council acknowledges that the level of detail and quality of natural hazards information in the AUP is variable and that work is ongoing to gather, assess and further refine information so that subdivision, use and development can be better managed.

7.1.1 Identification of land instability

The AUP seeks to identify land that may be subject to land instability [Policies E36.3(1) and E36.3(31)]. However, prior to any mapping, the Definitions section includes the following definition that is referred to in rules that address land instability:

> ***Land which may be subject to land instability***
>
> *Any land with one of the following characteristics:*
>
> 1. *Where the land which is underlain by Allochthonous soils has slope angles greater than or equal to 1 vertical to 7 horizontal;*
> 2. *Where the land which is underlain by Holocene or Pleistocene sediments which has a slope angle greater than or equal to 1 vertical to 4 horizontal;*
> 3. *Where the land is underlain by any other soil type and has a slope angle greater than or equal to 1 vertical to 3 horizontal;*
> 4. *On sloping sites where fill greater than 600 mm depth has been placed in uncontrolled conditions or not to engineered (certified) standards and where the original underlying natural terrain gradient was greater than or equal to:*
>   - *1 vertical to 7 horizontal for slope comprising Allochthonous soils;*
>   - *1 vertical to 4 horizontal for slopes comprising Holocene or Pleistocene soils; or*
>   - *1 vertical or 3 horizontal for slopes comprising any other soil types;*
> 5. *Within a horizontal distance of 2.5 times the cliff vertical height behind the base of any natural cliff; or*
> 6. *Within a horizontal distance of 2 times the cliff vertical height in front of the base of any natural cliff.*
>
> ***Note***
>
> *A natural cliff may be considered to be any slope with a vertical height of greater than 3.5 m and a gradient equal to or greater than 1 vertical to 1 horizontal (45-degrees). The vertical height of the cliff must only be measured over that part of the cliff where the slope gradient is equal to or greater than 45 degrees.*
>
> *Geological conditions, including soil types not mapped in the Plan and soil conditions as referred to in the above definition may be identified at a regional level through the following sources:*
>
> - *reference to information in GNS Science's QMAPs*
> - *Geology of Auckland (compiled by Edbrooke for IGNS 2001)*
> - *property files material and reports held by Council, and*
> - *by a suitably qualified professional.*

This approach identifies land-stability hazards through a definition as a stop-gap prior to undertaking mapping. However, the definition is primarily concerned with the source area of a landslide event and does not adequately address runout area.

23 See Chapter A1.4 of the AUP on identifying the different functions.

If adopting this approach in other areas, the definition of "*land which may be subject to land instability*" will need to be specific to the district, capturing geological and geomorphological conditions and the wide range of potential landslide hazards.

7.2 Slope risk overlay – Nelson Resource Management Plan (Level A Susceptibility Analysis)

Example of:

- A planning response to a slope known to be unstable with existing development.
- Prohibited activity status for further subdivision and more than one dwelling per site, implying intolerable risk.
- Other activities regulated, including stormwater, wastewater and earthworks, implying tolerable risk.

As a unitary authority, the Nelson Resource Management Plan (NRMP) is Nelson City Council's combined regional and district planning document. The Nelson Regional Policy Statement is a separate document. For landslide, the NRMP includes two areas, Grampians and Tahunanui, with three overlays: Grampians Slope Risk Overlay, Tahunanui Slump Core Slope Risk Overlay and Tahunanui Slump Fringe Slope Risk Overlay. These overlays link to controls that address landslide risks. The Tahunanui Slump overlays are shown in Figure 7.1. It should be noted that these controls are currently being reviewed by Nelson City Council following the August 2022 rainfall event.

The NRMP approach was established in 1996, and Nelson City Council embarked on a review of the NRMP in 2015. As part of this, an assessment of slope instability across the Nelson region was commissioned. The assessment (Punt and Barrett 2021) identified three tiers of slope instability across the Nelson region and potential runout areas (see Figure 7.2):

- **Tier I:** Area of known active instability with previous slope failures impacting residential properties that warrant specific planning regulations.
- **Tier II:** Areas identified as having elevated susceptibility to slope instability, including areas with existing deep-seated or ***earthflow*** instabilities and/or geologic units known to have an elevated susceptibility to instability.
- **Tier III:** Areas identified as susceptible to slope instability based on the geologic and geomorphic setting and/or that have previous records of slope instability failure.
- Areas potentially susceptible to debris runout.

The 2021 assessment increased the number of properties identified as being potentially subject to slope instability to approximately 7000 (Newman 2021).

Figure 7.1: Tahunanui slope risk overlays in the Nelson Resource Management Plan.

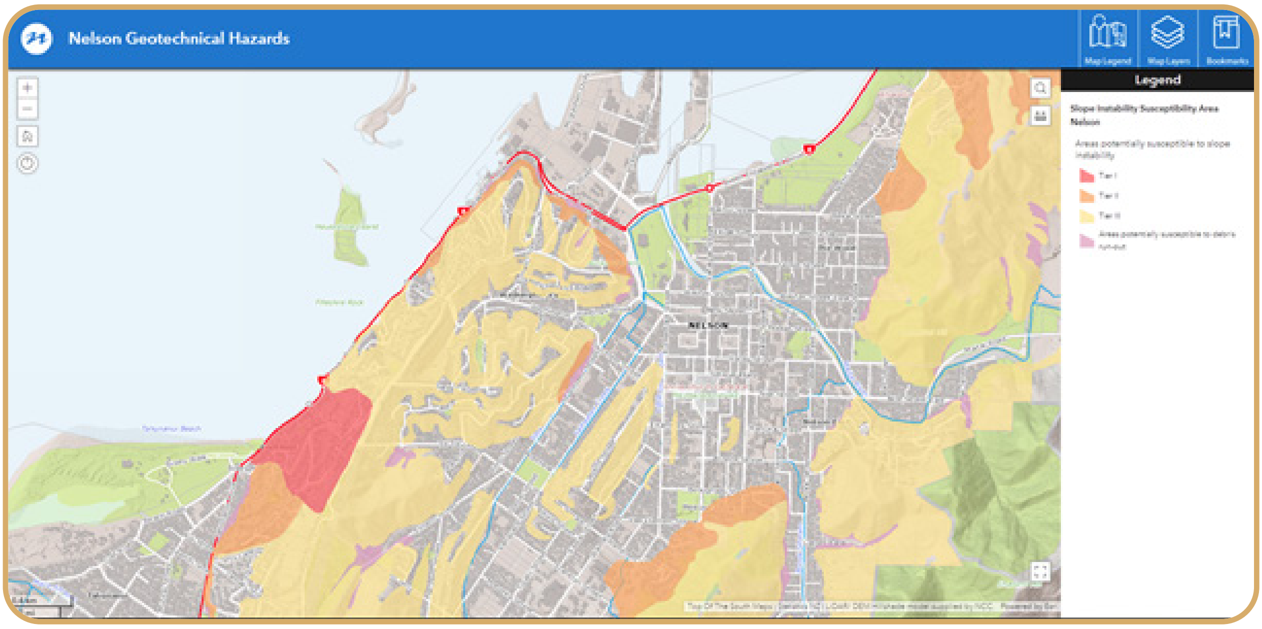


Figure 7.2: Three tiers of slope instability, along with runout areas identified in the Nelson City Council Slope Instability overlay report (Punt and Barrett 2021): Tier I (red), Tier II (orange), Tier III (yellow) and debris runout areas (purple). These zones were in place before the August 2022 events, where landslides occurred in several areas outside the zones and in Tier III. Consequently, these zones are being reviewed at time of writing. The GeoNet report for this event (Massey et al. 2022b) can be found here: https://static.geonet.org.nz/info/reports/landslide/SR2022-58.pdf

7.3 Thames Hospital – Level B Hazard Analysis

Example of:

- A risk-based approach for a hospital, which, as a critical facility, has a lower risk threshold.
- Different levels of vulnerability, resulting in different risk tolerance.

Following the 2005 debris flow disaster at Matatā, similarities in setting and climate suggested that a proposed new hospital building in Thames, Coromandel, might be at risk from a future debris flow. Thames has not experienced debris flows in its 140-year history. A site assessment indicated that Thames Hospital is on the apex of a fan-shaped deposit formed predominantly by repeated large debris flows from Karaka Stream. Engineering works mitigate debris-laden floodwater up to the 1-in-50 AEP, but not debris flows. Soil developed on the last debris-flow deposit indicated that debris flows reach the fan very infrequently.

The soil, climate, nature of the upper catchment and size and age of the fan suggested that large debris flows might reach the hospital site less frequently than once each 500 years on average, but probably more frequently than once each 1000 years. The slope of the land at the hospital and the substantial buildings make it unlikely that even very large debris flows could reach beyond the hospital. The proposed development is Building Importance Level 3 (having a high consequence for loss of life or very great economic or social consequence) and so should be designed to survive the 1-in-1000 AEP debris flow without endangering lives (even if it briefly loses serviceability). All of this information allowed the area likely to be affected directly by the 1-in-1000 AEP debris flow to be mapped (Figure 7.3).

This zone encompasses a number of residential properties of Building Importance Level 2 (having a medium consequence for loss of life or considerable economic or social consequence). They are not within the 1-in-500 AEP debris-flow hazard zone (not shown in Figure 7.3). A debris flow will be triggered by exceptionally heavy rain that is probably associated with a very severe thunderstorm, which can be tracked and monitored as it evolves, so adequate warning of heavy rain can be given. Future property owners are notified through LIM notations, but the assessed risk is not so great as to currently affect development up to and including Building Importance Level 2. There is a downstream flooding hazard associated with the debris flow, but the Thames flood hazard is well recognised and mitigated up to the 1-in-50 AEP and already notified via LIM for affected properties. A future debris flow at Thames will change local perceptions and may change these assessments.

Figure 7.3: Example of a landslide hazard assessment that includes risk. The annotated aerial photograph depicts the 1-in-1000 AEP debris-flow hazard zone at Karaka Stream, Thames, Coromandel, in relation to existing Building Importance Level 3 buildings in the Thames Hospital complex (H).

7.4 Awatarariki fanhead, Matatā plan change – Level D Risk Analysis

Example of:

- Planning response following a destructive debris-flow event.
- Removal of existing use rights under s10 of the RMA.
- The Bay of Plenty Regional Policy Statement provided the risk planning framework.
- Plan changes to the Bay of Plenty Regional Natural Resources Plan and Whakatāne District Plan identified high-, medium- and low-risk areas for the fanhead. In the high-risk area, future residential development was prohibited under the District Plan and existing residential uses were extinguished through the Regional Plan.

On 18 May 2005, intense rainfall in the catchments above Matatā caused flooding that generated a debris flow that destroyed 27 houses. Another 87 properties were damaged, and the state highway and railway line were cut (Figure 7.4). The debris flow was estimated to comprise 300,000 m^3 of material. The return period was initially thought to be 200–500 years, based on the rainfall event that generated it, but further analysis re-calculated it to be 40–80 years. The total value of damages was estimated to be $20M. Fortunately, there were no fatalities.

From 2005 to 2012, Whakatāne District Council investigated engineering options to manage the risk relating to future events. However, no viable solution was forthcoming. In 2013, Whakatāne District Council changed its risk management approach from an engineering-based to planning-based approach.

Assisting the planning-based approach, the Bay of Plenty Regional Policy Statement contains a *Natural Hazard Risk Management Policy Framework and Methodology for risk assessment* against which the Awatarariki debris-flow event could be assessed. The Bay of Plenty Regional Policy Statement sets out primary (qualitative) and secondary (quantitative) analysis, ultimately determining whether the risk from a natural hazard is high, medium or low, with associated policy directives:

Figure 7.4: Matatā, following the debris flow (Macdonald 2020).

- In natural hazard zones subject to high natural hazard risk, reduce the level of risk from natural hazards to medium levels (and lower if reasonably practicable).
- In natural hazard zones subject to medium natural hazard risk, reduce the level of risk from natural hazards to be as low as reasonably practicable.
- In natural hazard zones subject to low natural hazard risk, maintain the level of risk within the low natural hazard risk range.

The quantitative analysis utilises AIFR and classifies risk as 'high', 'medium' and 'low' on the following bases:

- High risk when AIFR or AIFR (PIC)[24] >1 x 10^{-4}.
- Medium risk when AIFR (PIC) >1 x 10^{-6} or AIFR is >1 x 10^{-5}.
- Low risk when AIFR (PIC) <1 x 10 or AIFR is <1 x 10^{-5}.

Tonkin & Taylor Ltd (2013a) undertook a quantitative landslide and debris-flow risk assessment for Matatā utilising debris-flow events of 50,000 m^3, 150,000 m^3, 300,000 m^3 and 450,000 m^3, with the cumulative risk of these events forming the final risk value.

Due to the uncertainty associated with the modelling, a precautionary approach to the risk contours was adopted, which found that an area of the Awatarariki fanhead presented a 'high' level of risk for residential development (Figure 7.5). As this was not able to be reduced to a 'medium' level of risk, avoidance and mitigation remained the only feasible option that would not be contrary to the policies.

Via a plan-change process (Plan Change 1), Whakatāne District Council introduced provisions into its District Plan to create an Awatarariki Debris Flow Policy Area with areas of 'high', 'medium' and 'low' risk in accordance with the natural hazard provisions of the Regional Policy Statement and to establish a rule framework prohibiting residential activities within the 'high' risk area.

However, s10 of the RMA protects existing use rights relating to the use of land in a manner that contravenes a rule in a district plan; therefore, Whakatāne District Council sought a parallel plan change (Plan Change 17) to the Regional Natural Resources Plan. Plan Change 17 introduced provisions relating to the Awatarariki Fanhead, making residential activities within the 'high' risk area a prohibited activity.

The risk assessment undertaken to inform the planning-based approach found that 45 properties were located in the 'high' risk area (Figure 7.5), 34 of which were in private ownership and 11 owned by public entities. Of the 34 privately owned properties, 16 contained dwellings and 18 were vacant sites or sites with unconsented structures (Farrell 2020). As set out above, the Bay of Plenty Regional Policy Statement risk tolerability threshold is 10^{-4}; however, in the Matatā case, 10^{-5} was utilised as the threshold following a peer review by Tonkin & Taylor in 2015.

24 PIC (Population In Care) refers to the population within the hazard assessment area that is in (a) hospitals, (b) aged-care facilities, (c) schools and (d) early education and infant day-care facilities.

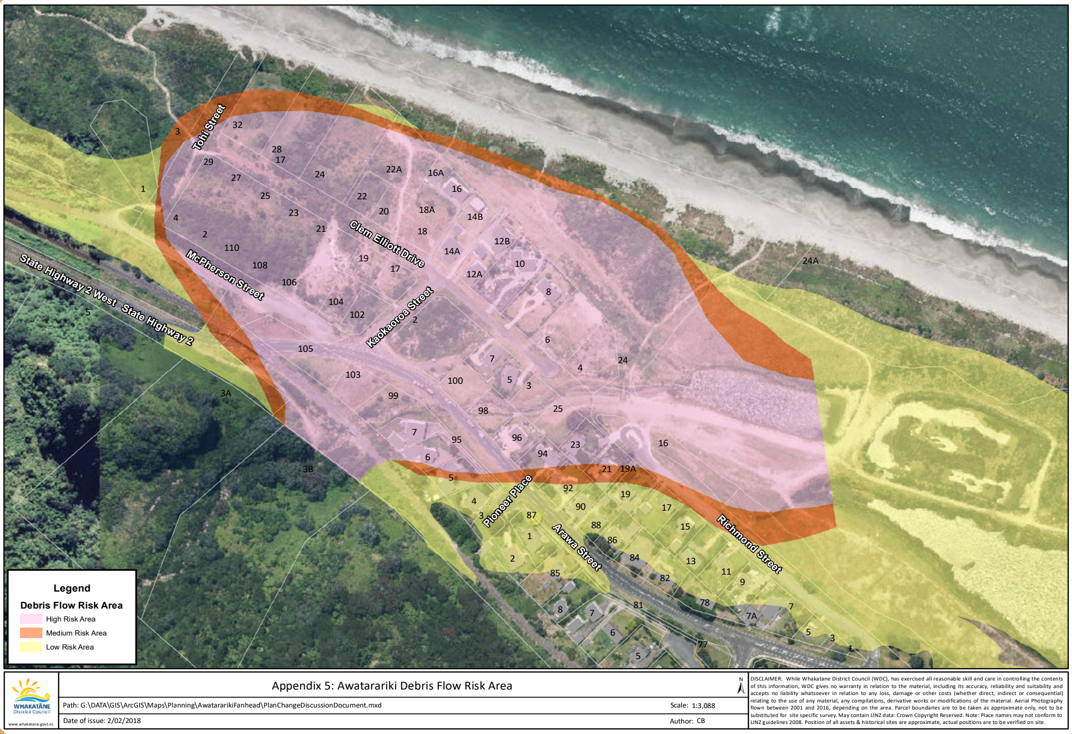


Figure 7.5: Awatarariki debris flow risk map. Source: Whakatāne District Council.[25]

The peer review recognised limitations in the modelling and therefore extended the area of high risk out to 10^{-5} in order to ensure that the risk was not under-estimated and to better reflect the area of high risk (Farrell 2020). Davies (2020) noted that the 10^{-5} AEP line modelled by Tonkin & Taylor (2013b) corresponds closely with the mapped limit of deposited boulders from the 2005 event.

The Bay of Plenty Regional Policy Statement directs that, in areas of high risk, the risk level is reduced to at least a medium level (Policy NH 3B). Policy NH 4B requires a low natural hazard risk level to be achieved on development sites after development is completed. To give effect to the above policies, several non-regulatory approaches were explored but were excluded due to not being 'reasonably practicable', in accordance with s32(1)(b)(i) of the RMA.

The planning-based approach utilised s10(4)(a) of the RMA to extinguish existing use rights. Plan Change 17 to the Bay of Plenty Regional Natural Resources Plan made residential activities on sites subject to high-risk classification a prohibited activity. The Whakatāne District Plan, via Plan Change 1, re-zoned those sites with a high-risk classification from 'Residential' to 'Coastal Protection Zone' and adopted the prohibited activity status for dwellings from the Regional Natural Resources Plan in these areas. Sites classified with medium risk, but that remained a 'Residential Zone', were also affected by Plan Change 1, requiring resource consent for a restricted discretionary activity for 1–3 dwellings, as opposed to the previous permitted activity status for 1–3 dwellings on sites in the Residential Zone.

Information Box 4 – Tools for Assessing Risk

RiskScape is a software tool for modelling natural hazard risks. This open-access software (https://riskscape.org.nz/) enables landslide specialists to assess risk to buildings, infrastructure and people from natural hazards, including landslides. The software enables users to create natural hazard scenarios. Results can include the number of exposed buildings and the degree of damage and economic loss, as well an estimate of human casualties. It can also estimate the disruption to lifelines, such as electricity, road and water networks.

An example of the application of RiskScape is given in Section 7.5, based on the Reavers Lane and Brewery Creek active alluvial fans in Queenstown.

25 https://www.whakatane.govt.nz/sites/www.whakatane.govt.nz/files/documents/appendix_5_awatarariki_fanhead_risk_map.pdf

7.5 Brewery Creek and Reavers Lane: Queenstown Lakes District Council – Level D Risk Analysis

Example of:

- Application of a risk-based planning approach.
- Quantitative risk assessment based on AIFR and APR.
- Use of the modelling tool RiskScape to estimate monetary loss due to building damage expected for a range of hazard scenarios.
- The preferred response package looks to apply a range of different approaches to manage different levels from rockfall and debris flow, including risk reduction across already-developed areas that are subject to significant risk from debris flow.

In 2019, Queenstown Lakes District Council identified that debris-flow and rockfall hazards at both the Brewery Creek and Reavers Lane alluvial fans presented a high enough risk to assess and consider management options. The fans are currently developed, predominantly with residential and business land uses. To inform the management approach, Queenstown Lakes District Council commissioned Beca to undertake an assessment of risk to people and property from debris-flow and rockfall hazards (Punt and Barrett 2021). Beca also assessed flooding and liquefaction hazards across the two-fan surface. GNS Science was commissioned to undertake loss modelling for debris-flow and rockfall hazard events using RiskScape (Woods et al. 2021).

Beca (2020) produced hazard layers for rockfall and debris-flow scenarios on the fans, each with different return periods (debris flow) or paths (rockfall). AIFR and APR results for debris flow and rockfall events on both fans were also produced, and the effect of climate change on the debris-flow risk was considered. Beca combined the quantitative risk outputs for debris flow and rockfall to produce risk contour maps. These risk contour maps identify AIFR values present across both fans that range between 1×10^{-3} and 1×10^{-6}.

Following the risk-identification exercise, Queenstown Lakes District Council developed a set of options that could be applied to manage risk from rockfall and debris-flow hazards. This included a 'status quo' option, a suite of 'engineering' options (informed by technical assessments from Beca [Punt and Barrett 2021]), a 'manage' option using land-use planning rules to manage future risk and a 'reduce' option that would see people and property moved out of harm's way, i.e. a form of managed retreat. Social and economic experts were commissioned to assess the range of social and economic costs and benefits of the four different risk management options (Foy et al. 2021). Woods et al. (2021) subsequently took this information and utilised RiskScape software to undertake loss modelling (the dollar value of damage from an event) of the events, integrating various built-form outcomes associated with the different risk-management options (see Figure 7.6).

Queenstown Lakes District Council undertook a number of consultation events to share information with the Brewery Creek and Reavers Lane community and to help develop their approach to risk management. The purpose of this consultation was to:

- Share findings from Beca's natural hazard risk assessment.
- Present the four options developed to manage risk from rockfall and debris flow.
- Inform the community of the costs and benefits of the different management options, including those findings of the loss modelling, social and economic assessments.
- Collect important feedback on the views and preferences of those affected by the natural hazard risk and management options.

Utilising all technical information and community feedback, Queenstown Lakes District Council developed a preferred response package to manage the different levels of risk from rockfall and debris flow. The preferred response package included four elements:

1. **Reduce:** Installation of rockfall fences and mesh – engineering structures to reduce rockfall risk to a tolerable or lower level. Properties protected by fences and mesh could continue to be occupied and developed.
2. **Manage:** Applying across areas subject to 'tolerable levels' of debris-flow risk – people and property would be able to remain within tolerable areas of risk, and some development would be enabled. The manage approach would use land-use controls in the District Plan to ensure that future development would not result in levels of risk that exceed tolerable levels or become significant.
3. **Avoid:** Applying across areas subject to 'significant levels' of debris-flow risk – the preferred response package would reduce risk in these areas by moving people and property away from significant risk.
4. **Intensify:** In areas not subject to 'significant' or 'tolerable' levels for risk from rockfall and debris flow – the preferred response package would enable further development in these locations.

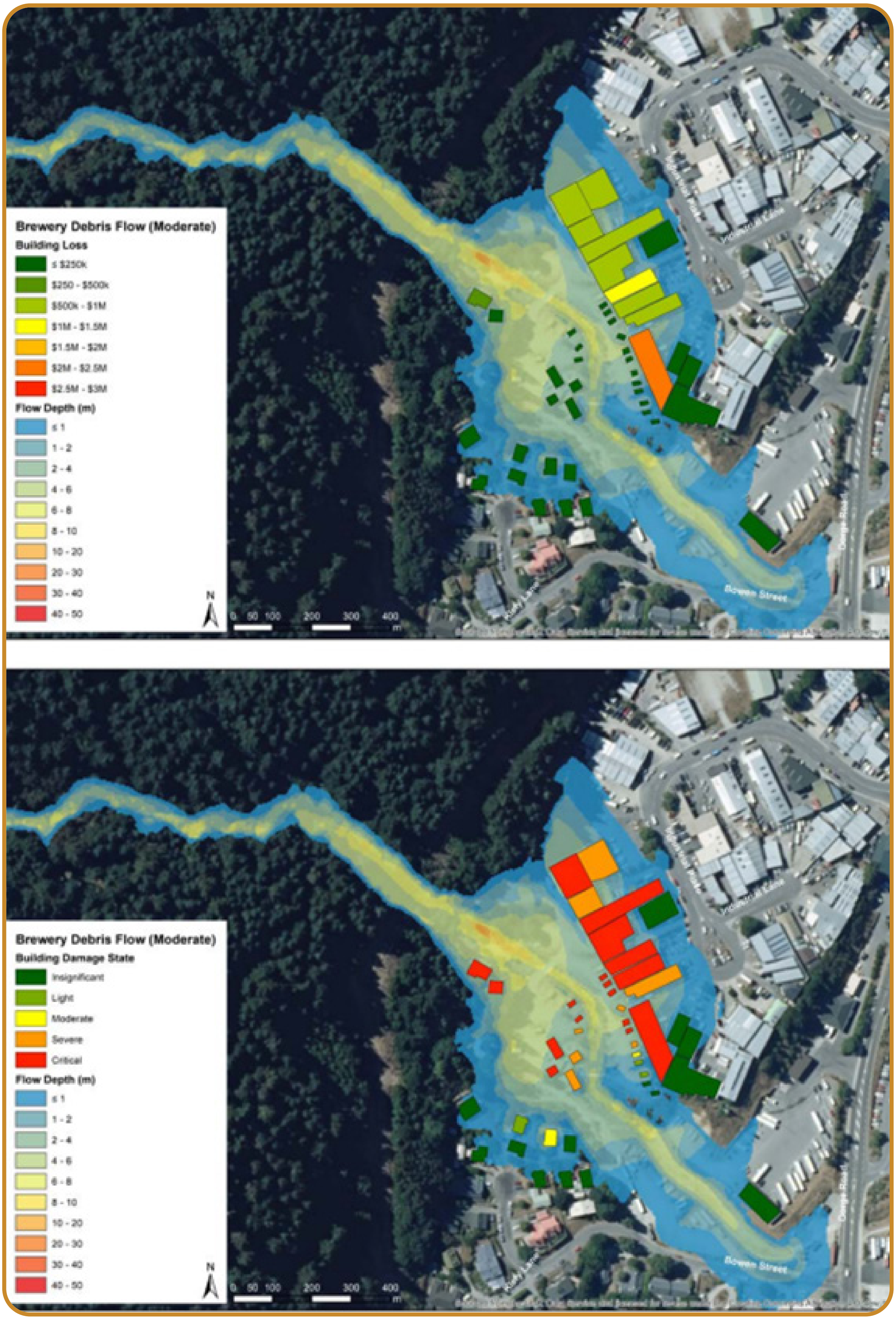


Figure 7.6: Example of building loss ($) and damage for Brewery Creek moderate debris flow using RiskScape, from Woods et al. (2021).

A further work programme is being developed to inform where the different elements recommended by the preferred response package will be applied (including the AIFR thresholds that define significant, tolerable and acceptable risk), as well as their detailed design. This further work programme will need to be progressed before the costs and benefits of the preferred package are fully understood and the preferred response package ready for implementation. This further work would address engineering, legal, financial and funding matters, as well as responsibilities for and the timing of implementation.

7.6 Christchurch replacement District Plan – Level E Risk Analysis

Example of:

- A significant landslide event prompting a detailed risk-based approach that would have been more cost-effective if undertaken prior to development.
- Detailed mapping undertaken around the Port Hills.
- Quantitative risk approach based on AIFR, with a tolerable risk threshold of 10^{-4}.
- Prohibited Activity status in areas mapped as having the highest risk of cliff collapse.
- Less onerous activity statuses where risk is lower.
- Applicants are able to contest 'the threshold line' through a specific policy.

Following the Canterbury earthquake sequence, Christchurch City Council embarked on the Christchurch Replacement District Plan project. A significant component of the project was to address the risk posed by slope instability (e.g. landslide, rockfall, cliff collapse and mass movement) in the Port Hills.

To assist with the development of a risk-based framework for the Christchurch District Plan, Taig et al. (2012) provided an overview of principles and criteria for the assessment of risk from slope instability in the Port Hills.

The framework utilised AIFR as the metric, and Taig et al. (2012) recommended that a 'sustainable threshold' be between 3 x 10^{-5} and 10^{-3} per year to remain consistent with risk levels tolerated in Aotearoa New Zealand and with regulatory practise elsewhere. To commence discussion on what tolerable risk should be set at, 10^{-4} was recommended as a suitable starting point, which is what Christchurch City Council settled on as its tolerability threshold.

Christchurch City Council's risk tolerability framework was applied to slope instability in the Port Hills. The slope instability hazard is grouped into eight hazard layers based on the hazard (cliff collapse, mass movement and rockfall), the percentage of the day that the property is occupied and the level of risk posed. The rule framework utilised these layers by prescribing activity statuses, with activities such as subdivision and earthworks prohibited in the highest-risk areas and less onerous activity statuses prescribed where risk is lower.

The Christchurch District Plan Natural Hazards chapter includes an example where there is a formal process built into the plan, by which people can 'challenge the line'. Policy 5.2.2.4.2 enables a site-specific risk analysis to be undertaken and the site's AIFR re-classified using the stated methodology. This change must be certified by the council and is valid for two years. A change to the AIFR may result in a change to the mapped layer, which may result in a change to the activity status. For example, a change in the AIFR from $>10^{-4}$ to $<10^{-4}$ in Cliff Collapse Management Area 2 would result in subdivision changing from a non-complying activity to a restricted discretionary activity.

The information from site-specific assessments of risk from rockfall and/or cliff collapse (which have been certified by Christchurch City Council) is made publicly available, and Christchurch City Council will regularly notify changes to the District Plan and change planning maps in order to reflect updated information.

The level of detail in the mapping and planning rules for the Port Hills reflects the focus and resources provided following the 2010/11 Canterbury earthquake sequence. Although some councils may consider that they do not have the resources to be able to undertake such a detailed approach, the 2010/11 Canterbury earthquake sequence shows that risk-based planning for landslides prior to development would have been even more cost-effective.

7.6.1 Christchurch District Plan maps

Slope hazard mapping focused on the Port Hills (Figure 7.7), with mapped layers for: Cliff Collapse Management Areas 1 and 2; Rockfall Management Areas 1 and 2; and Mass Movement Management Areas 1, 2 and 3. The remainder of the Port Hills and Banks Peninsula is included in a 'Remainder of Port Hills and Banks Peninsula Instability Management Area'. Elsewhere, there is no slope hazard mapping.

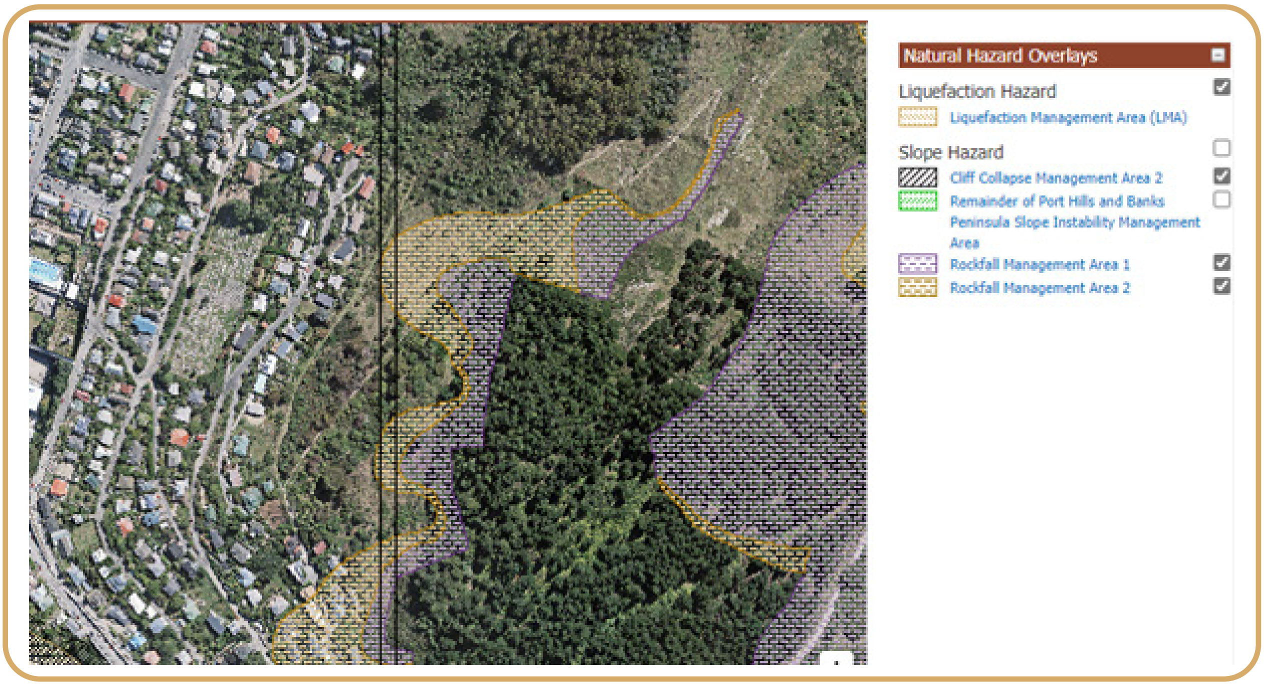


Figure 7.7: Natural Hazards layer of the Christchurch District Plan. Note: the green hatching for 'remainder' is not shown but would cover the remainder of the map in this case.

7.6.2 Christchurch District Plan: Chapter 5 – Natural Hazards Provisions

Policy for the slope-hazard mapped layers refers to:

- avoiding subdivision;
- use and development where the risk to life is unacceptable (i.e. greater than the 10^{-4} tolerability threshold); and
- managing subdivision, use and development where the risk of damage to property and infrastructure is mitigated to an acceptable extent.

Rules within the mapped slope-hazard overlays include controls on subdivision, earthworks, buildings, hazard-mitigation works, infrastructure, retaining walls, recreation activities and farm tracks.

7.6.3 Christchurch District Plan: Chapter 8 – Subdivision, Development and Earthworks Provisions

Although natural hazards are covered in the Natural Hazards chapter, policy for earthworks in general refers to avoiding earthworks that create a 'significant risk' to people and property. Rules for earthworks include permitted activity standards based on volume, depth and slope. Earthworks that have building consent and are within 1.8 m of the footprint of a building are exempt from the rules.

7.7 Plan Change 3 Kaikōura District Plan – Level E Risk Analysis

Example of:

- A significant landslide event prompting a detailed risk-based approach that would have been more cost-effective if undertaken prior to development.
- Detailed analysis focused on a study area that excluded areas with low likelihood of development.
- In consultation with the community, a conservative tolerable risk threshold LPR of 10^{-4} was adopted.
- The mapped Debris Inundation Overlay based on the LPR of 10^{-4} identified when a resource consent application would be required.
- Incorporation of a climate-change scenario in risk analysis and significant related increase in risk.

Environment Canterbury Regional Council and Kaikōura District Council commissioned GNS Science to map areas of the Kaikōura district that could be potentially affected by landslides triggered by earthquakes and/or rainfall.

When notified, Plan Change 3 to the Kaikōura District Plan included Landslide Debris Inundation and Debris Flow Fan overlays based on information presented in the GNS Science report *Deterministic mapping of potential landslide debris inundation in the Kaikōura district* (Brideau et al. 2020). This report quantified which parts of the study area could be subject to debris inundation from a range of different-sized landslides, triggered by either earthquakes or rainfall. The report also identified active debris-flow fans within the study area based on a review of detailed topographic (LiDAR) data and aerial imagery. It was beyond the scope of the investigation to quantify the likelihood of landslides or debris flows occurring within the mapped areas.

Prior to submissions on Plan Change 3 being heard, GNS Science completed a second report – *District-scale landslide risk analysis of debris inundation for the Kaikōura District* (Massey et al. 2021) – that built on its earlier work. This second report quantified risk based on LPR and AIFR (see Figure 7.8).

Included within this quantification of risk was an RCP8.5 climate-change scenario (Figure 7.8). The risk models indicate that rainfall-induced landslides dominate the risk profile over earthquake-induced landslides. The incorporation of the RCP8.5 climate-change scenario results in an approximate order-of-magnitude increase in risk, highlighting the importance of considering climate change.

In addressing submissions to Plan Change 3, Kaikōura District Council chose to use LPR data given that AIFR can be calculated from the LPR by estimating the probability of a person being present. The Kaikōura District Council also chose an LPR tolerance of 10^{-4} to define the area of a Debris Inundation Overlay (which combined the notified Landslide Debris Inundation and Debris Flow Fan overlays). The Debris Inundation Overlay is the trigger to require a site-specific landslide hazard assessment via a restricted discretionary consent pathway for any new 'hazard-sensitive building', a camping ground or a change of use to a building that created one that was 'hazard-sensitive'.

The level of detail of the analysis and planning rules for Kaikōura reflects the focus and resources provided following the Kaikōura Earthquake. Although some councils may consider that they do not have the resources to be able to undertake such a detailed approach, the Kaikōura Earthquake shows that risk-based planning for landslides prior to development would have been even more cost-effective.

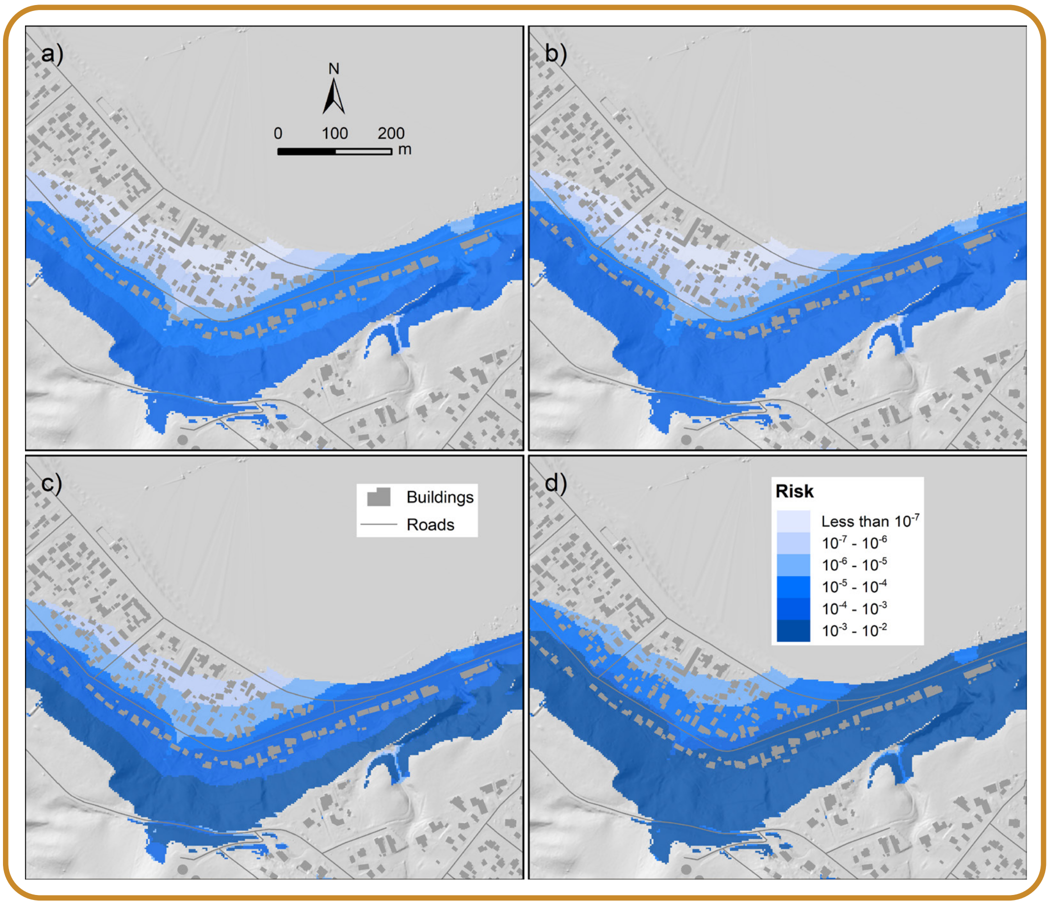


Figure 7.8: Risk results from Kaikōura, where (a) displays AIFR, assuming that a person is present in a building for 66% of the time; (b) displays LPR, assuming that a person is present in a building 100% of the time; (c) displays LPR with an RCP 8.5 rainfall scenario; and (d) displays LPR with an RCP 8.5 rainfall scenario and a vulnerability value of 1 (Massey et al. 2021).

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APPENDIX 1 RELEVANT CASE LAW

Case law can shed light on matters of practise and assist in understanding terminology and decision contexts. Although few Court decisions have directly addressed matters in this document, the ones that have provide some important guidance. This Appendix provides a summary of the content, relevance and outcomes of six cases. For more detail, the full decisions should be referred to.

The cases are:

- Skyline Enterprises Limited v Queenstown Lakes District Council – *risk thresholds and community consultation*.
- David Mulholland Consulting Engineer v Whanganui City Council – *who can provide a geotechnical report*.
- Peter William Mawhinney and the Trustees of Waitakere Forest Land Trust and the Trustees of Forest Trust v Auckland Council – *the importance of the subdivision stage*.
- Smaill v Buller District Council – *zoning and the need for early assessment of landslide risk*.
- Awatarariki Residents Incorporated v Bay of Plenty Regional Council and Whakatāne District Council – *application of a risk-based approach*.

Skyline Enterprises Limited v Queenstown Lakes District Council

Main Points

- Use of qualitative and quantitative risk thresholds.
- Need for community to determine risk-tolerability thresholds.

This case relates to a major upgrade to the gondola and facilities at the upper and lower terminals at Bob's Peak, Queenstown. The case was directly referred to the Environment Court for decision, rather than the normal processes of decision by the Queenstown District Council. The case proceeded in two parts: firstly, the gondola and facilities upgrade and then an application for a multi-level carpark building on a long flat terrace behind the lower terminal, which is located within a public reserve.

In an interim decision, [2018] NZEnvC 242, the Environment Court specifically looked at the management of land-instability risk (paragraphs 61–101 and 110–120). The Court decided it must make a "*properly informed response to identified hazards*" that "*would depend on what the evidence revealed as to the nature (including likelihood and seriousness) of the risk presented*". The Court referred to s6(h) of the RMA, as well as the objectives and policies of both the operative and proposed district plans. The Court was critical of Regional Policy Statement provisions that effectively left community acceptance of risk (risk tolerance) to be determined on an application-by-application basis.

Although risk-tolerability thresholds were discussed at the hearing, and thresholds, such as an AIFR of 10^{-4} used in the Christchurch Replacement District Plan, used by experts, the Court was not prepared to apply risk tolerability that had not been through a community consultation process. However, the Court was able to conclude that, given the evidence presented, it was satisfied that the residual risk presented by the proposal, with the mitigation measures in place, would not be intolerable.

Regarding the operative and proposed district plan policies on risk 'minimisation', all planners giving evidence at the hearing agreed that this should be interpreted as 'practicable' minimisation. They also agreed that, in order to be practicable, risk minimisation needed to be able to be done within the scope of the consent application and constraints of the Reserves Act 1977, as well as be commercially viable.

Consent was granted on the basis of conditions that:

- identified a reasonably practicable engineering design response to the risk; and
- provided for future review if community tolerance risk thresholds were included in any of the RMA statutory documents that indicated some adjustments to the conditions may be necessary to achieve the thresholds at the carpark.

David Mulholland Consulting Engineer v Whanganui City Council

Main Points

- Identifying who can provide a geotechnical report.

Decision [2018] NZEnvC 10 of the Environment Court specifically looked at the determination of the wording "*suitably qualified and experienced geotechnical engineer*" referenced as a performance standard in District Plan rules (earthworks, subdivision and structures) but not defined. The rule required such a person to provide a geotechnical report that confirmed the risks of the activity were no more than low and would not worsen or accelerate land instability on the site or surrounding area.

The Council disagreed that a report produced in support of particular works met the requirement. It relied on the IPENZ register of geotechnical engineers to determine that the engineer in this case did not meet the definition. The engineer was registered as a chartered professional engineer but had no notation on the IPENZ register as a geotechnical engineer. The Court determined that the District Plan wording required that:

> *"Not just any engineer will do – the person must be a geotechnical engineer. Further, the person must be suitably qualified and experienced in that type of engineering".*

The geotechnical report should assure protection, not only of the applicant but also of other landowners and the public generally, from what could be significant physical and financial risk in the event of structural failure.

The Court agreed with the Council's interpretation.

Peter William Mawhinney and the Trustees of Waitakere Forest Land Trust and the Trustees of Forest Trust v Auckland Council

Main Points

- The importance of the subdivision stage in land development.
- Adequacy of information at subdivision stage.
- Ability to refuse subdivision applications under RMA s106.
- The ability to attach conditions to subdivision consents.

Although this decision (Environment Court Decision No. [2017] NZEnvC 162) does not directly apply to a circumstance where natural hazards such as rockfall or landslide were directly an issue, it is useful in that it sets out the purpose of the RMA in managing subdivision. The decision traverses the changes that take place upon subdivision, confirms the importance of good information about natural hazards at the subdivision stage, describes the basis for a refusal of subdivision that otherwise would be allowed as a controlled (or even permitted activity) and outlines the types of conditions that may be attached to subdivisions.

In paragraphs 60–62, the Court points out that subdivision generally leads to intensification of uses; changed access; changed land values; expectations of greater residential use with flow-on effects, such as land clearance, earthworks, increased impervious surfaces and exposure to a higher probability of natural hazards; the need for increased infrastructure to cope with those flow-on effects; and that "*occupiers of smaller lots may suffer more serious consequences from natural hazards because their houses are located inappropriately*". The decision in paragraphs 70–75 pointed out that, to deal with these increased potential risks, a territorial authority is given two further powers under RMA s106 and s220 – the power to refuse a subdivision if the land or any structure on it is likely to be subject to material damage from natural hazards, or if the future use and development is likely to worsen natural hazards on that or any other land. RMA s220 provides powers to apply conditions that limit the location, bulk, height and floor-level height of structures on the land; that would protect land within or outside the subdivision against subsidence, erosion or slippage; or that require earthworks or filling. These can be registered as a consent notice on the title to be complied with in perpetuity.

The Court found that the appellant's view that subdivision was just lines on paper was entirely wrong. Sufficient information must be provided to the territorial authority at the time of an application for a subdivision consent to understand natural hazard exposure and risk. If risks cannot be managed appropriately through conditions, a subdivision can be declined.

(Note that the wording of s106 has been changed since this appeal was lodged, but the purpose and intent of the section remains unchanged).

Smaill v Buller District Council

Main Points

- The importance of historical information in contributing to an understanding of risk.
- The importance of identifying hazards and risks from an early stage to avoid ongoing uncertainties and risks of litigation for local authorities and other parties.
- Responsibilities and duties of care held by councils and their advisers on natural hazards.
- The ongoing nature of legal problems for numerous parties following poor decision-making.

While this case is relatively old and numerous changes have been made to statutes since, it is still of significant interest in terms of the various responsibilities of a council and other parties in areas with natural hazards. The replacement legal framework has retained the same principles.

This case focuses on a council's liabilities in relation to allowing zoning, subdivision and development to go ahead in an area of known geological instability. It is a High Court case (Smaill v Buller District Council [1998] 1 NZLR 190 [HC]) involving owners of land at Little Wanganui on the West Coast, some with undeveloped sections and some who had developed baches and other structures on their land. In 1973, the council had allowed a developer's request to have the land use of 40 ha of land changed from 'rural' to a 'resort zone' and undertake subdivision of part of the land into 48 lots suitable for the building of holiday cottages. The first subdivision was approved in 1973, although a further subdivision of 96 lots was refused in 1974 because of concerns about the size of the settlement that would result.

In 1975, a further subdivision was approved, bringing the total number of lots to 80, subject to meeting servicing requirements. The subdivided land fronts a public road and is described as a gently sloping area between the edge of a talus slope and the road. Behind and above the talus slope lie the Little Wanganui Bluffs, comprised of weathered Miocene sandstone, which rise to 100–130 m. The nature of the rock, including the angle of its bedding planes, coupled with the area's high rainfall, result in periodic rockfalls from the bluff, which have formed the talus slope. The subdivided land was noted by expert witnesses at the hearing as being 'hummocky', and this indicated a much more extensive spread of fallen debris from the cliffs, most recently in the 1929 Murchison Earthquake, when debris reached the nearby Little Wanganui River. This detail had been published in a 1937 paper by J. Henderson of the Geological Survey division of the Department of Scientific and Industrial Research (DSIR). There was expert agreement that this could happen again in the future, with the Court noting that there were three fault lines a short distance inland from Little Wanganui and that the main Alpine Fault line could also trigger a major failure.

In 1981, the council became aware of concerns about rockfalls from the bluffs behind the settlement, but, following inspection, took no further action. In 1983, the council was preparing its first comprehensive District Scheme (district plan) and obtained a background report on the geology of the district from DSIR. This identified risk of rockfall and recommended a hazard notation be put in place over part of Punakaiki township and further development halted within this area. The council then requested that DSIR define hazard areas at both Punakaiki and Little Wanganui. This was done for Punakaiki, but, in terms of Little Wanganui, the record of actions was not clear and DSIR's witness acknowledged that it appeared that "*the project lapsed*". When the District Scheme became operative in 1987, the policy for Little Wanganui was to encourage the development of holiday accommodation, subject to an upgrade of sewerage reticulation. There was no mention of rockfall risk or a hazard area.

In 1989, the council's then building inspector placed on record his long-term concern that there was a significant threat to land, buildings and the people living under the hillside at Little Wanganui and that the council may be liable over issue of building permits. This resulted from the concern of some residents about vegetation clearance being undertaken above and at the toe of the slope. The council tendered for a geological investigation and advice. The commissioned report (by Barrett Fuller and Partners, delivered in November 1990) found no evidence of debris having travelled beyond the toe of the talus slope and recommended an indicative building restriction line. At approximately the same time, the council notified its insurers of a potential public liability indemnity claim. The council then commissioned Barrett Fuller to undertake further investigation and refine the indicative building restriction line. The more comprehensive investigation reversed the findings of the earlier study and found that there was a potentially serious hazard of a larger rockfall, possibly to be triggered by an earthquake, and that most of the subdivided land was unsuitable for residential development. The receipt of the report in late November 1991 was followed by two significant block slides caused by heavy rain just before Christmas in 1991. On Christmas Day, the council issued a notice to all Little Wanganui residents that the area where they lived was subject to a potentially serious and unpredictable hazard and people should not occupy property in the area. It also advised that the council could not force residents to leave and it was up to individuals to decide whether to accept the risk and stay or to leave the area. Both the council and residents then took various steps intended to secure the removal of people from the area, including residents' claims to the Earthquake and War Damages Commission, which failed, and a council loan scheme to buy out properties, which was also not able to proceed. In mid-1992, the council introduced a hazard line into its District Plan that would prevent any further building in the area. Following a hearing on submissions on the proposal, the independent commissioners advised the council that the resort zone should stay in place, but any new building work approved should be subject to a notation on the land title under the provisions of the Building Act 1991. This would remove the council from any further risk of civil liability.

The residents then formed a ratepayers' association and commenced the case in the High Court. The case claimed that the council had acted negligently, firstly in the re-zoning of the land and secondly in granting subdivision approvals. It was alleged that the council had failed in a duty of care to adequately investigate the stability of the cliff at Little Wanganui and that such investigation would have confirmed the existence of a major problem, indicating that the land was unsuitable for a resort zone. Further, by re-zoning the land, it was alleged that the council should have known that future owners would expect to be able to safely use the land for its zoned purpose. The Court found that the council was technically protected by judicial immunity in relation to the land-use change, as the council had followed correct process and made a formal resolution on the matter. Conversely, the subdivision aspect was an administrative action and the decision not immune from judicial review.

However, both the land-use change and the subdivision had been considered together in an integrated way, so the Court looked at both aspects.

The Court considered the information available to the council at various times. Its finding was that it was not realistic for the council to have recognised the risk, despite the existence of various types of information and its availability to some people, until February 1984, when a site visit was made and a conversation held between a senior DSIR geologist and the new council engineer, at which the risk was discussed. Although the evidence of the discussion between the two men varied, the Court found that the geologist was the better witness with the better recall of the discussion and that the council was clearly on notice that the whole subdivision could be affected by a future rockfall from that time. However, there had been no adequate and timely response to the risk and the matter had been allowed to drift. The council was found to be negligent from February 1984, when there was:

> *"sufficient assessment of the risk, to require that decisive action be taken to properly evaluate the instability problem and adopt measures for the protection of people and property".*

This meant that the earlier decisions relating to the re-zoning and the subdivisions were not negligent.

The Court then went on to consider claims relating to the issue of building permits. While some claims could not be considered because of a 10-year limitation in the Building Act, other claims fell within the 10-year period. As the Court had found that the council was aware of an issue from February 1984, it was able to consider claims relating to building permits issued after that date. The Court undertook a careful examination of provisions of the relevant legislation (which within that time had moved from the Local Government Act to the Building Act). It noted that there had been no actual personal injury, physical damage or loss and that what was being claimed was strictly an economic loss – a decrease in property values. Based on earlier case law, the Court found that such loss could be recoverable where a breach of statutory duty, or duty of care, is established. In this case, it found that, from 1984, the council had issued building permits negligently and in breach of duty of care, as no steps had been taken to safeguard persons or property nor were permit holders warned of the risk of cliff failure.

The residents had also claimed that the Ministry of Works, which had a role in all changes of land use at the time of the 1971 re-zoning decision, had breached its statutory duty and/or had been negligent. The Court considered the information available and found that the Ministry was not in the same position as the Council in terms of information. Citing the initial finding of Barrett Fuller, the Court said that the Ministry would have no reason at the time to expect that a rockfall would extend beyond the talus slope.

As part of the overall case, the Council had made a third-party claim against DSIR. The Court found the Council negligent from February 1984 for failing to take decisive action following the initial advice of risk included in DSIR's report of April 1983. It also found DSIR negligent in failing to provide the detailed assessment of risk and a delineated hazard line that the Council had resolved to commission from it in June 1983. Had the Council actually received this advice, it would have no doubt acted upon it. That the Council had failed to ensure that the DSIR completed its brief before approving the District Scheme (without a hazard zone for Little Wanganui) was not sufficient to waive DSIR's duty of care. The Geological Survey section had the personnel and resources to undertake the work it had been briefed to do and report to the council. On that basis, the Court allocated equal fault and responsibility for damages to the council and DSIR.

The Court's decision went on to cover valuation evidence on loss of value and whether the Council's insurers should cover the Council's costs. In terms of the latter, the Court found that the insurers were protected because the Council had not disclosed the full circumstances to the company. Further information was sought on costs before a final decision was issued.

Awatarariki Residents Incorporated v Bay of Plenty Regional Council and Whakatāne District Council

Main Points

- The importance of historical information in contributing to an understanding of risk.
- Responsibilities and duties of care held by councils and their advisers on natural hazards.

This appeal, reported in Decision No. [2020] NZEnvC 2020, related to a single house located in the identified high-risk zone of the Awatarariki debris fan and the time by which it must be vacated as part of 'managed retreat' provisions in the Whakatāne District Plan and Bay of Plenty Natural Resources Plan. This was the final stage of an ongoing series of steps taken by the two councils to deal with ongoing risk exposure of people and properties to a debris flow from an elevated terrace nearby to the small coastal settlement of Matatā (see Section 7.4). The appeal also related to changes to the Regional and District Plans, but all aspects were resolved by consent. The circumstances were so unusual that the decision set out more detail than would be normal for a decision made by agreement of the parties.

The Court re-stated the findings of the hearing commissioners from the council hearings that:

> *"future debris flows in the catchment could be expected to occur as a result of any future storm known to be capable of generating them, so that the risk is both significant and as certain as any natural phenomenon can be The hearing commissioners also noted that there is clear evidence of previous debris flows having occurred at Matatā."*

Various risk assessments had preceded the district council's decision to proceed to change its own plan and undertake a 'private plan change' to the regional plan to extinguish existing use rights, which would have allowed existing dwellings to remain.

The following findings were made:

- The area is at high risk of a significant natural hazard (a debris flow). MBIE had determined, following its own risk assessment, that, under the Building Act, houses should not be built there. Therefore, any form of permanent accommodation should be precluded.
- Changes to the regional and district plan applied to an identified area in which both existing and future residential activities were prohibited. The status under the regional plan over-rides and has the effect of terminating existing use rights under the District Plan. This was appropriate.
- The Regional Policy Statement contained relevant provisions, which could only be given effect to in the circumstances by the two plan changes.
- The programme for voluntary managed retreat was commensurate with the risk exposure.
- The increase in risk exposure from the extension of one year sought for the single property would not generally give effect to the Regional Policy Statement but was a shorter period than had full litigation of the appeal been carried out. The owners/occupiers of the property had agreed to indemnify both councils against any claim.
- RMA s85, relating to whether the land was capable of reasonable use, was briefly discussed but, as determined in the original council decision, the plan changes were found not to deprive the landowners of the reasonable use of their land.
- The plan changes were appropriate in the circumstances and were confirmed.

The change to the Regional Plan was confirmed, subject to a modified date on one property, and the District Plan change was also confirmed.

APPENDIX 2 GLOSSARY OF TERMS

These definitions have come from several sources, including Hungr et al. (2014), Corominas et al. (2015), AGS (2007a–d) and AS/NZS ISO 31000 (2004, 2009 and 2018 terms have been sourced).

Acceptable risk: A risk that everyone impacted is prepared to accept. Action to further reduce such risk is usually not likely to be required (Corominas et al. 2015).

[AEP] Annual Exceedance Probability: The estimated probability that an event of specified magnitude will be exceeded in any one year (AGS 2007a).

[AIFR] Annual Individual Fatality Risk: The fatality risk of an individual (i.e. probability of death) over one full year of working or living in a given area.

[ALARP] As Low as Reasonably Practicable: 'Reasonably practicable' involves weighing a risk against the effort, time and money needed to reduce and manage it.

[APLL] Annual Probable Lives Lost: This metric multiplies the probability of a hazard occurring (f) by the potential number of fatalities (N) to estimate the expected number of deaths over a year.

[APL/APR] Annual Property Loss/Risk: The risk that a property will experience loss over one full year. It can be calculated in terms of the value or net present value of the property.

Consequence: The outcome or impact of an event. There can be more than one consequence from one event, and consequences can range from positive to negative. Consequences can be expressed qualitatively or quantitatively (AS/NZS 2004).

Creep: Extremely slow movement of surficial soil layers on a slope.

Cut slopes: Anthropogenically modified slopes where material has been cut or removed from a slope.

Danger (threat): The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a menacing block). The characterisation of a danger or threat does not include any forecasting.

Debris avalanche: Very rapid to extremely rapid flow of debris on a steep, open slope.

Debris flood: Very rapid flow of water, heavily charged with debris in a steep channel.

Debris flow: Very rapid to extremely rapid surging flow of saturated debris in a steep channel.

Earthflow: Rapid or slow intermittent flow, such as movement of clayey soil. Can be dormant for long periods of time, alternating with more rapid surges.

Elements at risk: Population, buildings and engineering works, infrastructure, environmental features, cultural values and economic activities in the area potentially affected by an event (e.g. landslide).

Erosion: Localised removal of rock or soil as a result of the action of water, ice, wind, coastal processes or mass movement.

Exposure: People, property, systems or other elements present in hazard zones that are thereby exposed to potential losses.

Falling debris: Refers to rock, debris, soil and other material that may fall, slide, flow or avalanche from up-slope (the landslide source area where slippage occurs), inundating the area below.

Fans: Cone-shaped landforms that occur when confined watercourses become wider and less confined, allowing sediment to be deposited.

Fill slopes: Anthropogenically modified slopes where material has been added to a slope or used to form a slope.

fN curves: Curves relating the probability per year of causing N or more fatalities (f) to N. This is the complementary cumulative distribution function. Such curves may be used to express societal risk criteria and describe the safety levels of particular facilities.

fN pairs: Refers to 'f', the probability of life loss due to failure for each scenario studied, and 'N', the number of lives expected to be lost in the event of such a failure scenario. The term 'N' can be replaced by any other quantitative measure of failure consequences, such as monetary measures.

Frequency: The number of times that an event occurs over a given time or in a given sample.

Hazard: An event with the potential of causing an undesirable consequence. Mathematically, the probability of a particular threat occurring in an area within a defined time period.

Intolerable risk: Risk that is so high it is not taken, regardless of the benefits.

Landslide: A gravitational movement of rock, debris or soil down a slope.

Landslide hazard analysis: The use of available information to estimate the zones where landslides of a particular type, volume, intensity and runout may occur within a given period of time.

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

Landslide inventory: A record of recognised landslides in a particular area. The landslides can be distinguished by type, geometry and activity.

Landslide susceptibility: A quantitative or qualitative assessment of the volume (or area) and spatial distribution of landslides that exist or may potentially occur in an area. Susceptibility should also include a description of potential landslide runout areas.

Likelihood: Used as a general description of probability or frequency. Can be expressed either qualitatively or quantitatively. The chance of something happening (AS/NZS 31000).

[LPR] Local Personal Risk: Annual probability of death for a hypothetical person who is present 100% of the time (24 hours, 365 days a year).

Mitigation: Application of appropriate techniques and principles to reduce either probability of an occurrence, probability of its adverse consequences, or both.

Probability: The likelihood of a specific outcome. In the framework of landslide hazard assessment, the following types of probability are of importance:

- Spatial – probability that a given area is hit by a landslide.
- Temporal – probability that a landslide will occur in a given period of time in a specified area.
- Size/volume – probability that any given landslide has a specified size/volume.
- Runout – probability that any given slide will reach a specified distance or affect a specified area downslope.

Qualitative risk analysis: An analysis that uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative risk analysis: An analysis based on numerical values of the probability of occurrence of a potentially damaging event, vulnerability of the exposed elements and consequences, resulting in a numerical value of the risk.

Residual risk: The remaining level of risk at any time before, during and after risk treatment has been implemented.

Retrogression: Up-slope progression of failure surface and source area of a landslide.

Return period / recurrence interval: The long-term average elapsed time between landslide events at a particular location or in a specified area.

Risk: "*The likelihood and consequences of a hazard*" (CDEM Act). ISO 31000:2018 (AS/NZS 2004) defines risk as the "*effect of uncertainty on objectives*" and notes that it is "*... usually expressed in terms of risk sources, potential events, their consequences and their likelihood.*" Corominas et al. (2015) defines landslide risk as a measure of the probability and severity of an adverse effect to life, health, property or the environment.

Risk analysis: The use of available information to estimate the risk to individuals, or populations, property or the environment, from hazard. Risk analyses generally contain the following steps: definition of scope, danger (threat) identification, estimation of probability of occurrence to estimate hazard and evaluation of the vulnerability of the element(s) at risk consequence analysis, as well as their integration.

Risk assessment: The process of making a recommendation on whether existing risks are acceptable and present risk-control measures adequate, and, if not, whether alternative risk-control measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases.

Risk-based: The use of risk analysis and management methodologies to inform a decision-making process.

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

Risk management: The systematic application of policies, procedures and practises to the tasks of identifying, analysing, assessing, monitoring and mitigating risk.

Risk treatment: Application of techniques, policies and principles to reduce either the probability of a landslide occurring or reduce the consequences if it were to occur.

Rock avalanche: Extremely rapid, massive, flow-like motion of fragmented rock from a large rock slide or rockfall.

Rockfall: Detachment, fall, rolling and bouncing of rock fragments. May occur as a single piece or in a cluster but with little interaction between the fragments. Usually tend to be smaller in volume.

Rock slope deformation: Deep-seated slow to extremely slow deformation of valley or hill slopes. Consists of sagging slope crests and development of cracks or faults.

Rotational slide ('slumps'): A landslide in which the surface of the rupture is curved concavely upward (spoon-shaped).

Runout: Down-slope extent of the displaced landslide material.

Scarp: Steep surface(s) at the edges of a landslide caused by movement of the landslide.

Scenario: A single realisation of the consequences of a given event (or a sequence of events) having a given probability of occurrence.

Slippage: Includes the movement or loss (including partial loss) of land from a slope when a landslide occurs beneath it (i.e. the source area).

Slope instability: The potential or actual movement of material on a slope. 'Landslide' refers to the actual movement of material on a slope, so 'slope instability' can be used as a catch-all term for potential and actual landslides.

Societal risk: The risk to society of a widespread or large-scale consequence, for example, a large landslide, or several smaller landslides triggered by a single event such as an earthquake, that could cause multiple fatalities in a single event.

Toe: The margin of displaced material most distant from the top of the landslide (main scarp).

Tolerable risk: A risk within a range that society can live with to secure certain net benefits. Further risk reduction is possible.

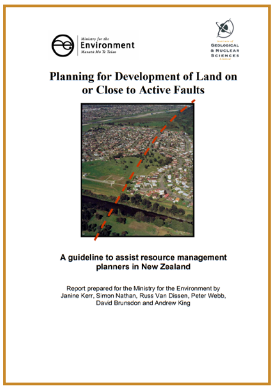
Topple: A block of rock that tilts or rotates forward, eventually to fall, bounce or roll down the slope.

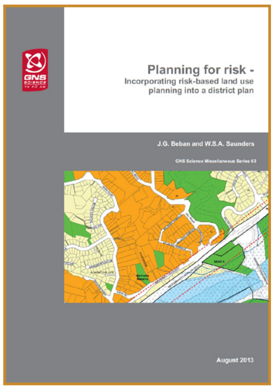
Transitional/planar slide: Sliding of a mass of material on a planar rupture surface with little internal deformation.

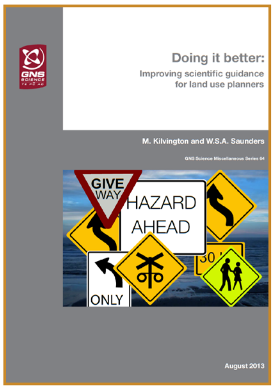
Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, community, assets or systems to the impacts of hazards. It is often expressed on a scale of 0 (no loss) to 1 (total loss). The type of landslide hazard, size of the landslide and hazard footprint area, along with building design, building use, etc., can affect vulnerability.

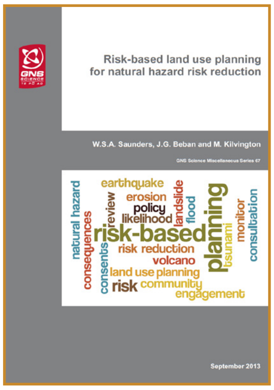
APPENDIX 3 NATURAL HAZARD PLANNING GUIDANCE AND LITERATURE

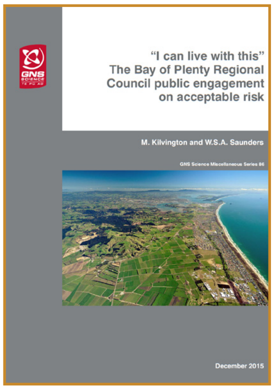
This guidance is part of a suite of natural-hazard- and climate-change-related guidance for decision makers, planners and policy analysts, as shown by the following titles:

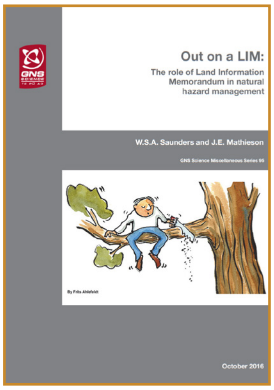


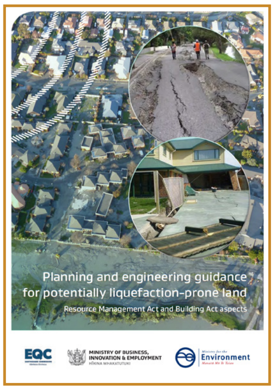


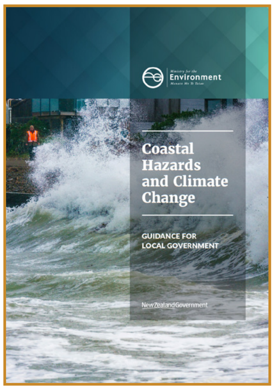


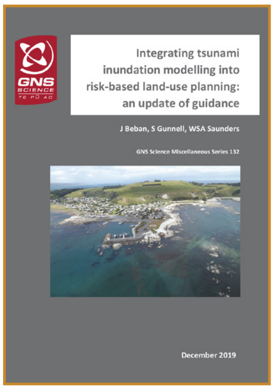












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26 Note that an updated version of this guidance is expected to be published in early 2024. The interim guidance (Bell 2022) is also noted in this list.

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