Te Uru Rākau New Zealand Forest Service

Slash risk management handbook

Te Kāwanatanga o Aotearoa
New Zealand Government

This Handbook has been developed under contract and with the assistance of a Technical Advisory Group.

Publisher
Te Uru Rākau – New Zealand Forest Service
Ministry for Primary Industries
PO Box 2526, Wellington, 6140
New Zealand
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www.mpi.govt.nz

ISBN No: 978-1-991285-97-3 (online)

ISBN No: 978-1-991285-98-0 (print)

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Introduction

Forestry slash is tree waste left behind after commercial forestry activities. This Handbook is aimed at helping users – forest managers, contractors, council staff, landowners – to understand and manage forestry slash risk.

Forestry slash can improve forests by providing habitat for terrestrial and aquatic plants and animals, nutrients for the soil, and protection from rain while a new forest crop is establishing.

Forestry slash can also cause damage when it is mobilised, especially when it enters waterways. This can cause damage to property and infrastructure, community safety, and the environment. Note – land instability is the main reason for slash mobilisation.

This Handbook is not regulatory guidance, and it is not designed to be used for resource consent conditions. This information can help you to make decisions about the management of slash risks.

Scope

This Handbook covers the management of slash risks across the forestry cycle, particularly:

- afforestation;
- harvest planning;
- harvesting operations;
- post-harvest rehabilitation;
- post-harvest replanting.

It also covers windthrow and options to manage it.

This Handbook does not cover the financial, commercial, public (cultural, social, and political), reputational, compliance, and legal risks of slash.

Purpose

This Handbook provides you with options and tools to consistently manage slash risks on all land types in New Zealand by:

- Answering common slash questions – *what, where, when, how,* and *why*.
- Assisting in the identification of potential high-risk areas and identifying management options.
- Explaining how risk reduction principles can be used in afforestation and pre-harvest slash management planning.
- Informing you about common slash management situations.
- Informing you about health and safety requirements.
- Identifying options that may be appropriate for replanting areas that are highly vulnerable to slash mobilisation.
- Identifying worker health and safety risks related to slash, particularly when working on high-risk cutovers and near waterways.

Handbook layout

This Handbook uses a risk management framework, which identifies, assesses, and manages risk. The layout reflects the Australia and New Zealand Risk Management Standards.

Chapters 1-3 provide an overview of slash risk and management, causes of slash mobilisation, and risk assessment, including:

- ✓ Definitions of key terminology.
- ✓ Which forestry activities cause slash.
- ✓ Where commercial forestry slash is a risk
- ✓ Why slash risk management is important.
- ✓ When slash retention is beneficial.
- ✓ What factors can cause slash to mobilise.
- ✓ Steps to identify forestry site factors that cause slash to mobilise.
- ✓ How forest management decisions can change slash risks.
- ✓ How to assess potential consequences from slash and their likelihood of occurring.
- ✓ How to assess slash mobilisation risk levels.
- ✓ Health and safety risks associated with slash management.

Chapters 4-6 provide information on managing slash on landings, high-risk cutovers, and near waterways:

- ✓ What makes slash accumulate on landings.
- ✓ How to calculate the estimated slash volumes coming to a landing.
- ✓ Options to manage slash on landings.
- ✓ Options to manage slash risks on landings at pre-harvest planning, during harvest operations, and post-harvest phases.
- ✓ What is a high-risk cutover.
- ✓ How to estimate the volume of slash on a cutover.
- ✓ How to manage slash on a high-risk cutover at planning and during operations.
- ✓ What windthrow is, and potential management options.
- ✓ Why waterways can create slash mobilisation risks.
- ✓ How to use the River Environment Classification (REC) system to help identify waterway size..
- ✓ Options to manage the slash risks near waterways during harvest planning, harvest operations, and post-harvest rehabilitation.
- ✓ Different types of slash retention structures.

Chapter 7 sets out some catchment level forest harvest approaches for very high-risk sites where the management approaches set out in preceding chapters are not enough to manage very high slash risks.

Chapter 1
Overview of slash and risk management

In this chapter, you will find out:

- ✓ Definitions of key terminology.
- ✓ Which forestry activities cause slash.
- ✓ Where commercial forestry slash is a risk.
- ✓ Why slash risk management is important.
- ✓ When slash retention is beneficial.

Definitions of key terminology

This chapter defines several key terms used in the Handbook. Some of these terms will be discussed in more detail in relevant chapters. A more comprehensive list of terms is in the *Glossary*.

Slash

The definition is from the National Environmental Standards for Commercial Forestry (NES-CF):

> *Slash is tree waste left behind after commercial forestry activities.*

"Harvest residues" is another term used to describe the organic waste material generated from forestry harvest activities.

Woody debris

Woody debris describes all sources of dead wood, whether natural or man-made, including fallen trees, logs, branches, twigs, bark and root balls. It includes material such as toppled and fallen trees, unrelated to any forest activity. Woody debris occurs in all forests and on land uses that have trees and other woody vegetation. Slash is an example of man-made woody debris.

Erosion

Erosion refers to the wearing away and movement of soil and rock by natural forces such as wind and water. There are many types of erosion, but this Handbook principally discusses mass movement erosion, such as landslides, debris flows, earthflow and soil slip.

Landslide

Landslide is a term used to describe a number of mass movement processes, including rock fall, shallow soil slip and deep rotational slope failure.

Debris flow

Debris flows occur when intense rainfall events on steep slopes activate fast-moving landslides containing large quantities of sediment, water, and wood, that can be channelized into waterways before terminating on flatter downstream areas.

Riparian area

A strip of land that extends along the edge of a stream, river, lake, or wetland. These areas are a transition zone between the edge of a freshwater body and the upslope terrain, so they contain a mix of aquatic and terrestrial characteristics.

Risk

This Handbook describes risk. It also identifies landscape features or events that contribute to risk. A hazard is something that has the potential to cause harm. Slash is a hazard because it can potentially harm the environment, property, and people's health, and safety.

Risk is made up of the likelihood that a hazard could harm something or someone and the consequences if it does happen. It includes an element of uncertainty, especially with natural hazards so assessments of risk will vary in possible outcomes. Without a hazard, there is no risk. The level of risk is the magnitude of a single risk or the combination of associated risks.

Which forestry activities cause slash?

The commercial forestry cycle includes:

- **Afforestation and replanting** establishes or renews a forests. These activities do not cause slash, but they can be used to put mitigations in place to reduce future harvest slash risks.

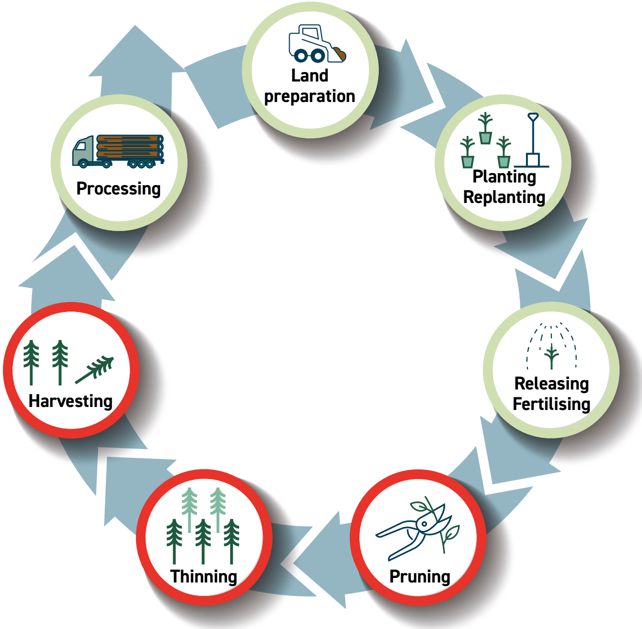
- **Pruning** removes the lower branches of a tree to create knot-free wood. Pruning creates small volumes of slash that are unlikely to create a risk because pruned branches are small, light, and trapped within the growing forest.
- **Thinning to waste** selectively fells forest trees, these felled trees remain on the ground where they decay. The removal of smaller size and lower quality trees, provides space for the remaining trees to grow with less competition for sunlight and nutrients. Thinning to waste causes slash that is unlikely to create more than a low risk because the trees are young, light, and trapped within the growing forest.
- **Harvesting** is the activity of felling trees, extracting trees, thinning tree stems for extraction and sale or use (production thinning), processing trees into logs, or loading logs onto trucks for delivery to processing plants. Harvesting is the forestry activity that causes the most slash and risk associated with this.

Where does slash accumulate at harvest?

The three areas in a forest where slash will commonly accumulate are:

On the landing

Landings are extraction sites where trees are typically processed into logs, sorted, stockpiled, and loaded onto trucks for distribution to markets. They are also called skids, pads, dumps, processing, or hauler sites.



Red circled activities generate slash in the forestry cycle.

On the cutover

A **cutover** is a clearfelled area of forest. During harvesting, the forest is progressively cleared of trees which are extracted to a series of landings.

Near waterways

Slash “near waterways” includes slash in or over the waterway as well as slash in the floodplain and riparian area.

Larger waterways that drain areas of cutover forest are more likely to transport slash within and beyond the forest boundary than smaller waterways.

How does slash create risk?

The greatest risk from slash occurs when it mobilises and is transported within or beyond the forest boundary.

Most risk comes from slash that is mobilised from:

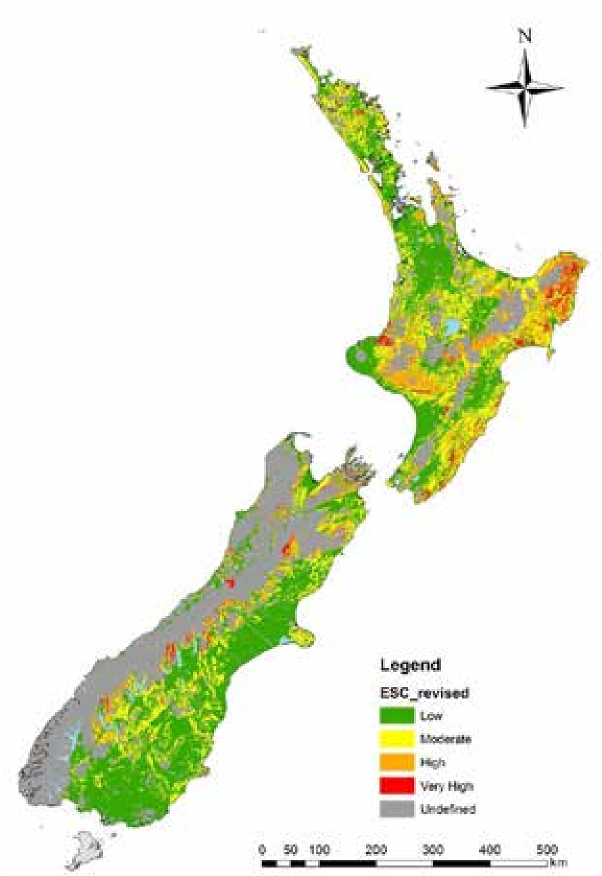
- Landings where slash management or storage is not adequate to stop it entering waterways.
- Steep cutover slopes that are prone to erosion causing landslides and debris flows.
- Waterways transporting slash off-site during periods of increased stream flow where it could adversely affect:
  - Downstream environments (e.g. waterways and coastal habitat).
  - Infrastructure within or downstream of the forest, (e.g. roads and bridge)s.
  - Downstream neighbours and communities, e.g. safety, property, water, access, or impact on recreation.

Slash can also create fire risks and risks to the health and safety of forestry workers. These risks are covered in later chapters.

Where forestry slash is a risk

Risk of adverse impacts from slash varies across New Zealand. Most of New Zealand's commercial forests are on terrain where the slash risk from landslides is low.

The map shows the Erosion Susceptibility Classification (ESC) (MPI, 2017). This shows much of New Zealand has low or moderate erosion susceptibility. The slash mobility risk for these areas is generally low or moderate. Orange and red ESC zones are the most vulnerable land which have high or very high erosion susceptibility respectively. The slash mobility risk in these ESC zones is generally high or very high.



In some regions, including Gisborne (Tairawhiti), there are large areas of ESC red zone land that need a higher level of slash management.

The ESC is one tool to inform slash management decisions. It has a mapping scale of 1:50,000 but assessing risk requires a finer scale map. There are other tools available which can be used to enhance understanding of erosion susceptibility such as LiDAR and the Land Use Capability(LUC) extended legends.

Risk is variable

Factors contributing to forest slash risk can differ significantly between forests and operational locations within a forest e.g. topography, land stability, climate. The risk of slash mobilisation will also vary over time. For example, on high-risk cutovers the likelihood of slash mobilisation decreases as the trees grow. With increasing age, trees intercept increasing amounts of rainfall and remove larger quantities of water from the soil. This keeps the soil dryer for longer periods. With increasing soil-root reinforcement, landslides are less likely to occur, and slash remains on slope and decays over time.

For forest managers working on easier, less erodible land the slash management approach may be less complex to reflect lower risk. Forest managers working on higher risk, more erodible land may require carefully targeted controls to lower the slash risk.

Is slash the same as woody debris?

Commercial forestry operations need to manage slash, but woody debris is generated across most land uses. It can be difficult to identify the difference between slash and other woody debris once it is in a river. There are methods to categorise and describe different forms of woody debris. Categorising the woody debris typically incorporates age class, species, whether it has been cut or is broken, and whether it has any processing marks on it.

Not all woody debris with saw cuts is slash. Non-slash woody debris often needs to be cut next to water to provide access, reduce health and safety hazards, for overall streamside management and for slash risk mitigation strategies. In the context of streamside management these decisions may have been entirely appropriate. Conversely, slash can have broken ends where it has smashed as the tree is felled or extracted.

Why slash risk management is important

Slash management may be required by law and where there is risk of it adversely affecting people, property, and the environment.

On lower-risk sites, less management may be required. For example, large areas of the Central North Island are on flat land or easier slopes, and connectivity to waterways presents little risk. On higher-risk sites, such as the Marlborough Sounds and some of the North Island's steep hill country, slash will require careful management.

Management plans

Management plans at all levels could contain:

- identification of slash risks;
- chosen risk management options;
- reasons why options were selected;
- steps taken to avoid or mitigate the risks;

These two stems were left in a river which was otherwise cleaned out. The proximity of the landing and the ease of extraction indicate they weren't slash but windthrow.

A slash choked culvert is an example of poor slash management practice near a waterway.

- resources required to implement the plan;
- performance measures;
- monitoring and reporting;
- timing and responsibilities;
- who approved the plans.

A variety of forestry management plans can be used to document the slash risk management process. These management plans may be found in:

- Forest valuation, forest modelling or forest planning documents that give the overarching goals for the forest. These strategic level goals include details in company policies, procedures and operational documentation, including contracts.
- Harvest planning documents, which provide tactical level management.
- Afforestation and replanting planning. For example, managing setbacks or deciding not to plant some areas of the forest in a standard commercial crop such as *Pinus Radiata*.
- Maps, work prescriptions, and monitoring plans and checks done by the contractor and the forest manager. These document operational level management.

Weather events increase slash risk

Weather events can cause slash to move outside the boundary of the forest in a major storm.

Research shows that where a weather event is severe enough or part of a sustained weather pattern, there is no land cover on higher risk slopes that will prevent slope failure (e.g. Phillips et al., 2018). Sites prone to shallow, rapid landslides remain subject to these landslides regardless of land use. This is because the causes of the landslides are inherent in the landform, and soil erosion is a natural part of earth processes.

Inadequate slash management and water control caused the landing failure.

When slash retention is beneficial

Slash is beneficial when it is stored where it cannot mobilise, and the slash volume remaining on the cutover is appropriate for the site.

Slash protects the soil against surface erosion by creating a protective layer until the ground cover vegetation re-establishes. Decaying slash provides food for invertebrates, then birds, and our prey birds, supporting a diverse ecosystem. As it breaks down, it helps to maintain, create, and improve soil quality. This is because slash is organic material which contains stored nutrients. Most of a tree's nutrients are in the branches and needles, so retaining these on the slope adds to the nutrients available for the next crop.

Slash in waterways can trap and store sediment and organic matter providing food, refuge, and breeding sites for a wide range of aquatic organisms such as aquatic plants fish, insects and birds, depending on the amount and location in the stream channel.

Plan, Do, Check, Act

The **plan, do, check, and act** process is a helpful way to regularly check whether assessed risk, and the practices and mitigations put in place to manage risk are appropriate and effective.

Using the plan, do, check, and act process helps reduce some risks by linking these actions:

- **Plan:** those who plan operations – the forest manager, harvest planner and the contractor or foreman – must understand the hazards and manage the risks when determining whether to afforest, harvest, or replant the harvested areas.
- **Do:** operational tasks to reduce slash problems are included in operational documents and clearly explained to those doing the work.
- **Check:** the contractor, the forest manager, and the council ensure operations meet requirements. Evidence gathered through monitoring can be used to demonstrate that acceptable standards were followed. Checks also provide opportunities for improvement.
- **Act:** If something goes wrong or changes need to be made, these happen on time and are done correctly.

Chapter 2
What causes slash to mobilise?

In this chapter, you will find out:

✓ What factors can cause slash to mobilise.
✓ Steps to identify forestry site factors that cause slash to mobilise.
✓ How forest management decisions can change slash risks.

What factors can cause slash to mobilise?

Key factors that increase the risk of slash mobilising off the land are high landslide risk and exposure to high rainfall events. Connectivity to waterways increases the risk of slash mobilising downstream.

Many forests have a low or moderate risk of slash mobilising. For example, forests on stable geology, areas with lower rainfall, flat or rolling ground with few or no waterways. These areas may still contain small, isolated areas with higher risks.

The following diagram shows factors that can contribute to risk of slash mobilisation and the potential harm when it does.

Factors that contribute to a slash mobilisation risk (e.g. slash transported through erosion or waterways)

Site characteristics	**Geology**	Rock and soil type
	Catchment	Catchment characteristics, e.g. size, stream network, stream size and steepness Slope attributes, e.g. length, steepness and aspect
	Climate	The storm frequency-return interval The amount of rainfall The rainfall intensity and duration
Management decisions (that may compound the amount of slash or the underlying site and climate risk)	**Strategic**	The total harvest area The clearcut size How rapidly the forest is harvested
	At harvest planning	The location of roads and landings, (e.g. to improve harvesting effectiveness) How the harvest is sequenced, (e.g. managing for wind) The selection of the logging system, (e.g. ground base or hauler) The approach to harvesting near waterways, e.g. haul away from the waterway or ride to ridge The harvest method, e.g. highlead or skyline extraction
	During and after harvesting operations	Choice of harvest manager, supervisor, and contractor Choice of machinery and equipment Post-harvest site rehabilitation, e.g. type, quantity, and quality Timing and quality of maintenance

Factors that could contribute to slash mobilisation risks.

Identifying site factors that cause slash to mobilise

The factors to consider in identifying significant site risks include:

- geological factors;
- climatic factors;
- catchment factors;
- potential off-site slash mobilisation effects.

Step 1: Identify geological factors

Geology, tectonics, and terrain features like slope length and steepness, slope aspect, and the thickness and composition of the material over rock influence the overall stability of slopes and the type of erosion process most likely to occur during storms, (e.g. shallow landslides, rotational slumps, gully erosion, and earthflows).

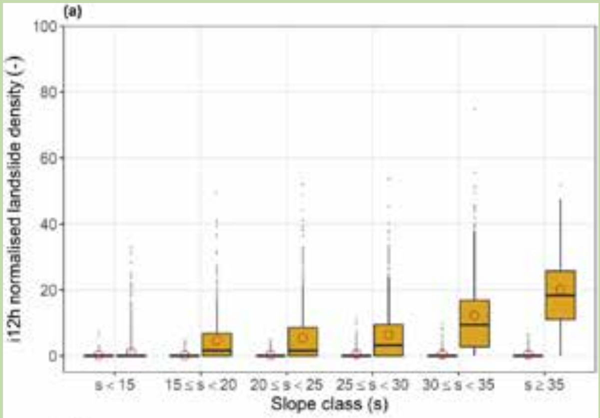
Slash that is distributed across the cutover is unlikely to trigger or increase the likelihood of slopes to failure (see Chapter 4 on the increased weight of slash piles on landings over time). Heavy rainfall triggers slope failure in the form of landslides that will catch or carry any slash on the slope, and deposit it and the sediment into waterway channels.

Geological factors on sites, that can influence the level of risk of slope failure and landslides include the:

- Proportion of the forest with steep and highly erodible slopes.
- Slope aspects that are repeatedly affected by storms, (e.g. east facing slopes).
- Presence of existing, large-scale erosion features – such as gullies – within a forest.
- Composition of the underlying bedrock, (e.g. sedimentary, metamorphic, or volcanic).
- Zones of weakness affecting the strength of the bedrock, (e.g. bedding planes and faults).
- Composition, depth and degree of weathering of surface materials, (e.g. soil, volcanic ash, loess, and colluvium).

Tools that can be used to assess the risk of slope failure include LiDAR and digital terrain models. These can be complemented by local experience to assess the likelihood of different intensities of storm events causing landslides and debris flows.

Research supports the strong link between increasing slope and the incidence of landslides.



Variation in landslide densities (based on a normalised maximum 12-hour rainfall intensity) for pasture (brown box) and forest (green box) cover across a range of slope classes (Smith et al., 2023).

Note – At the time of publication, New Zealand does not have a national-level terrain risk model that is sufficiently detailed to accurately predict the probability of slope failure.

Landslides

Landslides can mobilise slash, but most do not contribute sediment and slash to waterways. Only landslides connecting with a waterway will deposit sediment and slash in the stream channel.

Landslide is a term used to describe mass movement erosion processes, including rock fall, shallow soil slip and deep rotational slope failure.

Shallow landslides are most common in New Zealand hill country, and are usually triggered during storm events. For example, in areas with weak sedimentary geology such as Tairawhiti, Hawke's Bay, Wairarapa and Whanganui.

Slope failure can occur within the surface layers of weak sediment and rock, or where these surface layers meet the underlying (and impermeable) bedrock. This occurs when soil moisture levels are high for extended periods.

Slope failure can also occur deep within the bedrock which is below the tree's rooting depth. These deep-seated landslides account for some of the slips within maturing (closed canopy) commercial and indigenous forests.

The influence of forest age and harvest on landslide risk

Soils under a closed forest canopy (where neighbouring tree branches touch) are less likely to have rainfall-induced landslides than similar soils under pasture, young pines before canopy closure, clearcut harvest sites, and scattered, regenerating scrub. A closed canopy forest helps increase slope stability and leads to a significant reduction in erosion.

The reasons for this are trees:

- Intercept rainfall, some of which evaporates back into the atmosphere.
- Extract moisture from the soil as they grow (transpiration).
- Mechanically reinforce the soil through their roots, particularly once roots of adjacent trees overlap.

Evaporation and transpiration reduce the amount of water in the soil, so that soils remain drier for longer.

The effectiveness of *P. radiata* forests in mitigating the impact of large-magnitude storms against landslides is well documented. For example, during Cyclone Bola in 1988, areas under closed canopy indigenous forest and exotic plantations older than eight years were 16 times less susceptible to landslides than pasture (Marden & Rowan 1993).

An example of the effectiveness of a closed canopy of exotic forest in protecting slopes against storm-initiated landslides. Landslides affected an estimated 80 percent of the pastured slope.

When weather events bring extreme volumes of rainfall, such as during Cyclones Hale and Gabrielle in 2023, they can undermine the ability of old-growth indigenous forests and older commercial forests to remain anchored to slopes.

Comparisons of the number of landslides resulting from storm events for different vegetation types show little difference in the protective value of closed-canopy forest species, either exotic or indigenous.

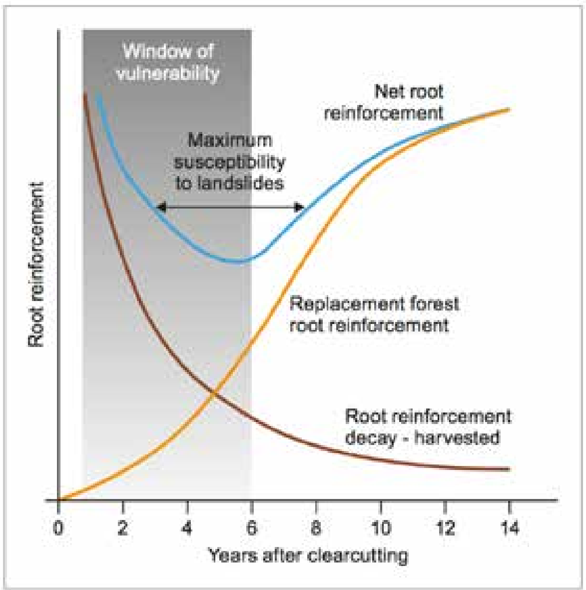
Post-harvest areas are more vulnerable to landslides than forested areas.

Forestry land behaves similarly to land under pasture when it is harvested, and the tree roots have decayed and no longer provide reinforcement. This is because the risk of landslides is driven by the underlying geology for both land uses as the forest land is no longer protected by mature trees.

In some cases, forest soils can be less compacted than farm soils. This may increase their vulnerability as they have greater water-holding capacity.

During storms, tree root reinforcement may provide the difference between landslides occurring or not, especially when soils are at or near saturation. Where root reinforcement is lost (usually around 2-3 years after harvest), old slips can reactivate, and new ones occur. If a storm with an Average Return Interval (ARI) of greater than 20 years occurs in the first eight years after harvesting, many locations have a high probability of landslides where this is risk naturally occurs in the landform.

The "window of vulnerability" diagram shows the potential for increased likelihood to landslides because of changes in the land cover. The length of the "window" will vary depending on slope steepness, geology, species, and silviculture.



From Phillips et al. 2012

Debris flows and debris dams

Debris flows are a type of landslide. Debris flows occur when intense rainfall events on steep slopes activate fast-moving landslides containing large quantities of sediment, water, vegetation, and wood. These can be channelled into waterways before ending on flatter downstream areas. Debris flows can be very destructive, for example the downstream damage from debris flows in Cyclone Gabrielle.

There is not enough information to accurately predict where debris flows could likely form or potentially become a risk. However, the location of previous landslides and debris flows can indicate where future failure could occur.

A **debris dam** is created when enough sediment and woody debris accumulates to dam a waterway. Typically, debris dams are formed in narrow and deeply dissected small (1st and 2nd order) waterways (refer to Chapter Six).

When a debris dam fails, the debris flow increases in speed as it travels down the waterway and may strip the waterway and banks of all vegetation, increasing the volume of sediment and woody debris. The steepness of the stream, the distance debris travels, and the nature of the receiving floodplain affect the level of destruction. Generally, waterways become wider downstream as steepness decreases, so stream energy is reduced. As a result, this is where a significant proportion of the sediment and woody debris in the flow is deposited.

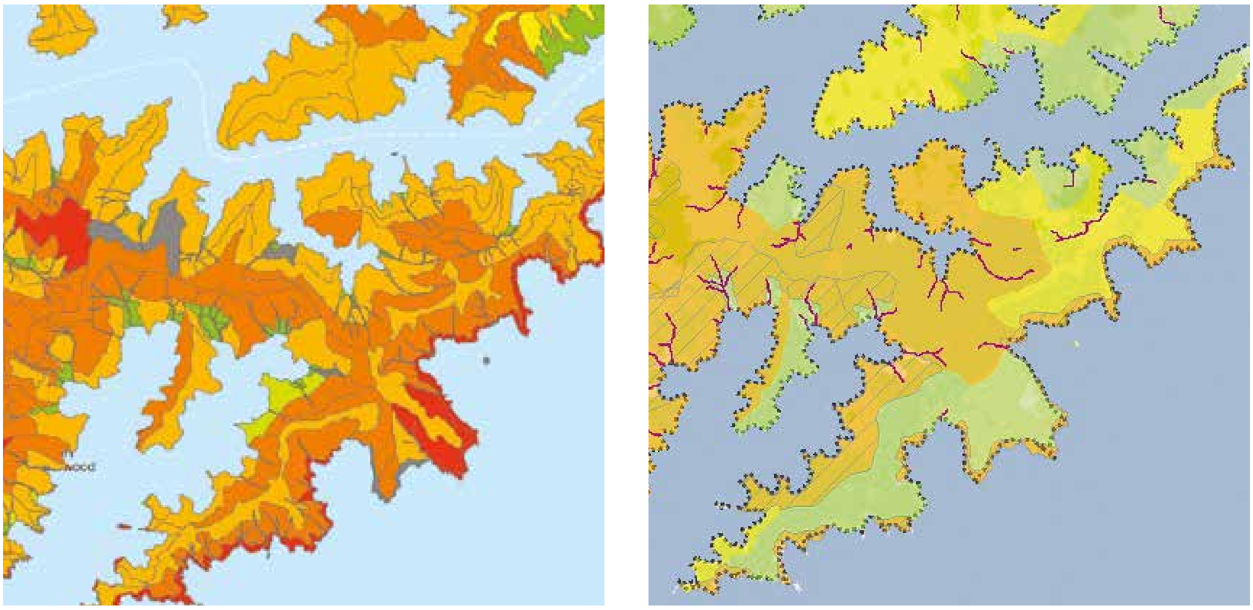
Left: a rapid shallow landslide.

Right: The aftermath of a debris dam/flood that started several kilometres upstream. The bridge deck was never found. The waterway's bed and banks were polished.

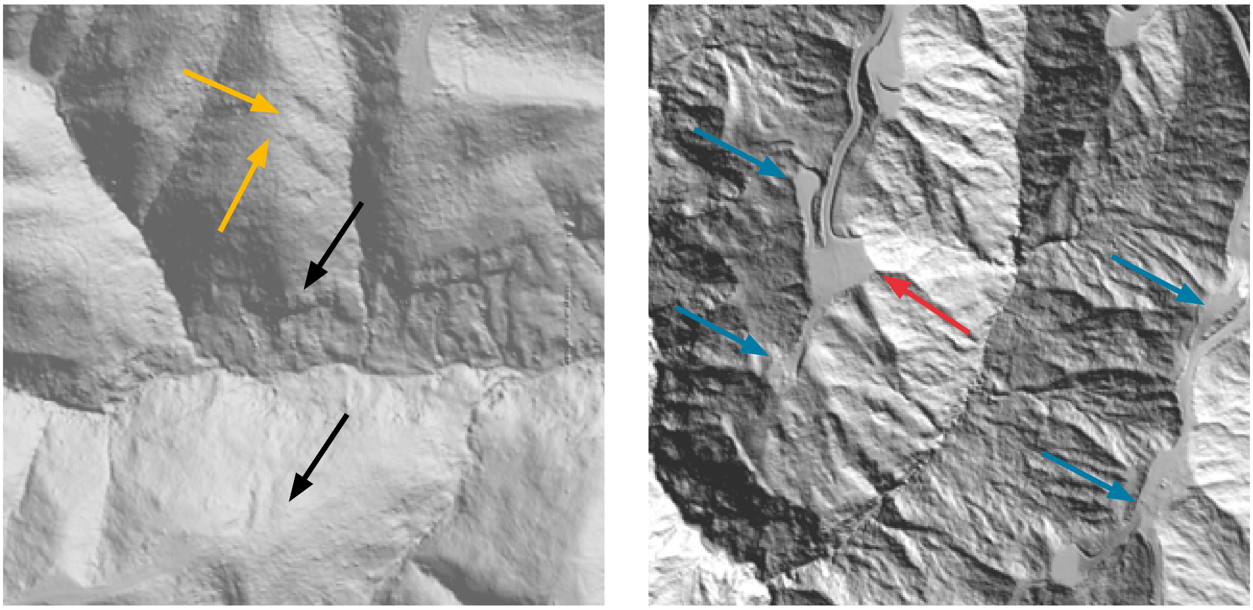
Tools to identify terrain and slope stability

The Erosion Susceptibility Classification (ESC) is a high-level indicator of erosion susceptibility, which will assist in assessing a location's slope stability. The New Zealand Land Resource Inventory (NZLRI) is the underlying dataset for the ESC. The NZLRI includes a series of extended legends that give much more detail on the underlying geology of a site and the type and severity of erosion. They are mapped at a 1:63,360 scale or at 1:50,000 in some regions. This scale means they can only provide an indication rather than very accurate site-specific information. In some regions, the council has detailed 1:10,000 scale mapping available. Expert LUC mappers can map at this scale (or finer) for any site.

LiDAR (Light detection and ranging remote sensing) is another tool that is available in some regions. LiDAR can provide a very detailed mapping of the land even when it's covered with mature trees. Land Information New Zealand (LINZ) and councils are expanding their publicly available LiDAR data. New technologies, including drone imagery that provides 3D surface models, and LiDAR time-series data are also rapidly evolving.



These two images of Port Underwood, Marlborough, show NZLRI LUC (left) and ESC data for the area (right).



LiDAR clearly shows the different landforms and erosion features. Left: The rim rock band shows land sliding below it (black arrows), and on the slope rollover (mid-slope failure) near the top of the slope (yellow arrow), some additional slipping which is common in this landform. Right: This challenging country is covered entirely with recent erosion features. The forest manager has used small pads (blue arrows) and a processing landing in easier country (red arrow) to limit earthworks for harvesting. The LiDAR was flown after infrastructure was put in place and before harvesting.

With LiDAR, aerial and satellite imagery, Geographic Information System (GIS) datasets, and field visits you can:

- create hill shade, slope, and aspect coverages;
- analyse the site-specific data for landslides. (e.g. whether they are widespread and deep, or scattered and shallow);
- view photo imagery, especially old aerial photos, to see past evidence of slips;
- use the mapping tools to look at features on neighbouring farmland. If it is in similar country, look for the number of slips and how recently they occurred;
- In addition, you can contact the regional council as they may have additional resources. You can also seek expert assistance, if necessary.

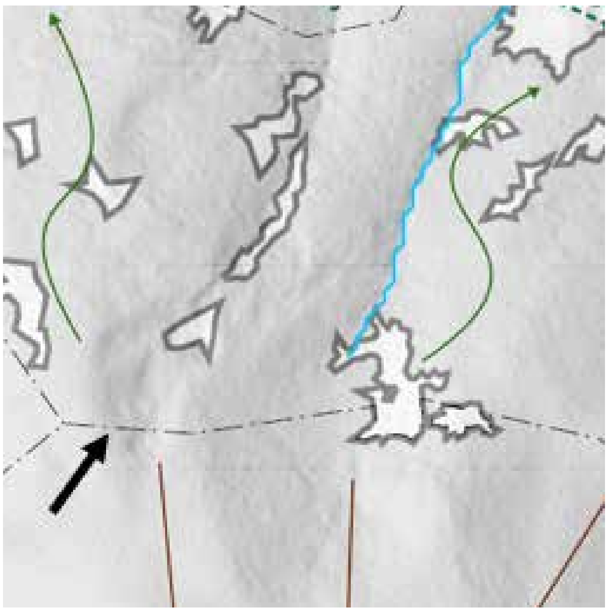
The checklist at the end of the chapter can be used to identify the location risks of forests.

Step 2: Identify climatic factors

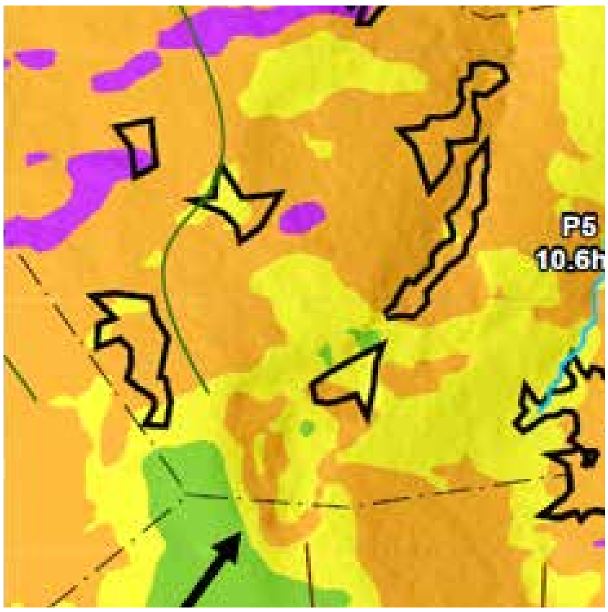
Geomorphologists agree that where a weather event is severe enough or part of a sustained weather pattern, some parts of the landscape are naturally more susceptible to landslides than others. This is independent of vegetation species, density, and maturity of vegetation, and of the standard of land management practices.

Landslide and rainfall data collected after storm events across many regions identified the rainfall factors (intensity, amount, duration) required to trigger landslides, particularly for shallow landslides. The relationship between landslides and rainfall is better understood in regions most frequently affected by storms. Mapping tools and modelling can help identify which areas have a greater risk of landslide.

Rainfall events can have a significant impact on slash risks especially after harvesting. Increased rainfall intensity, frequency or duration contribute to increased risk, because water is the most common trigger for landslides, particularly in forests that have natural high erosion susceptibility. Infrequent, high-magnitude storms can be responsible for the most serious slash risks. Forests with less intense rainfall and/or a lower erosion susceptibility are less likely to have landslides.



The shaded relief generated from LiDAR (left) identified small slips on this steep face (black arrows).



The slope mapping (right) also derived from LiDAR data, shows additional slope details. Yellow is 25-35 degrees, orange 35-45, and purple is over 45 degrees.

Rainfall depth, duration, and frequency

The NIWA High Intensity Rainfall Design System (HIRDS) (**https://hirds.niwa.co.nz/**) rainfall surfaces dataset provides rainfall depth, duration, and frequency for all of New Zealand. This data can be interpreted by an experienced user to better understand an individual site.

In the HIRDS rainfall data for a Marlborough site (below), scattered landslides are known to occur if there is 120-150 mm of rainfall in 24 hours. The HIRDS data suggests a return period of no more than 2-5 years for this rainfall intensity. This timeframe could be less if the soils are already wet. This could indicate there is the chance of at least one landslide event during the "window of vulnerability". The greater the average return interval (ARI), the greater the expectation of landslides, e.g. a 20-year storm would create more landslides than a 10-year storm.

Regional councils may have additional information on the rainfall conditions that could cause landslides.

Return period (years)	Rainfall Duration						
	10 min	30 min	1 hr	6 hr	12 hr	24 hr	48 hr
Annual	7–8	13–15	19–23	51–65	71–92	94–122	118–153
2	8–9	14–17	21–25	56–71	78–100	103–134	129–167
5	10–11	18–22	27–33	73–93	101–130	134–173	168–216
10	12–13	22–26	32–39	86–109	119–153	158–204	197–254
20	14–16	25–30	37–45	99–126	138–177	182–235	227–293
50	17–19	30–35	47–54	118–150	164–210	216–279	269–347
100	19–21	34–40	50–61	133–169	184–237	243–314	303–391

HIRDS rainfall data for a Marlborough site measured in mm. NIWA.

Step 3: Identify catchment factors

A catchment is the basin that captures water that flows or drains into a waterway, lake or wetland. Catchments can be any size, depending on the terrain. Within a catchment there are often sub-catchments.

The risk of slash mobilisation increases:

- With the increasing size of the waterways. Greater flow means more energy to transport slash.
- With the increasing density of streams nearby. This increases the proportion of the catchment slopes that are in close proximity to waterways, the likelihood that landslides will connect with the waterway, and the number of waterways available to transport slash.
- When steep waterway banks are present, (e.g. incised waterways). Slash is difficult to retrieve from these waterways.
- As the gradient of the stream increases. During flood events, a steeper gradient stream creates more energy to transport slash.
- Where there are short, steep faces, due to the increased risk of landslides generating on these slopes and the proximity to waterways.

Step 4: Identifying potential off-site slash mobilisation effects

When slash is mobilised, it can be transported considerable distances. Slash mobilisation within and outside the forest boundary can affect:

- downstream activities (e.g. other land users, neighbours, communities);
- infrastructure, (e.g. culverts, roads, and bridges, recreational areas);
- receiving downstream ecosystems such as lakes, wetlands, and coastal areas. In marine environments, wood in salt water floats and becomes rot-resistant due to the salt.

The checklist at the end of the chapter covers off-site risks.

Shallow landslides on the East Cape. Steep, broken terrain, shallow soils, intense high rainfall, numerous waterways, and short harvest faces create high slash mobilisation risks.

Bedrock failure in mid-rotation forest created a debris avalanche in Hawke's Bay. Both images are post-Cyclone Gabrielle 2023.

How forest management decisions can change slash risks

Management decisions across the forestry cycle could assist in lowering the risk of slash mobilisation on higher-risk sites. This could include:

- Afforestation (new forest) and replanting.
- Harvesting decisions at a:
  - whole of the forest, or catchment, level;
  - harvest planning level;
  - operational management level, including post-harvest rehabilitation.

Afforestation and replanting decisions

Decisions made at planting have long-term implications for slash management. When establishing a forest, applying current information to plan for foreseeable harvesting slash issues is an active risk management approach.

Forest management includes deciding initial and final tree stocking and other silviculture (tree tending) requirements. Initial tree stocking can influence the length of the "window of vulnerability" i.e. higher stocking means a shorter time until canopy closure. Silviculture can greatly change tree form and size. For example, stand stocking rates affect tree diameter and branch size, which affects the amount of slash produced at harvest.

If establishing a forest on farmland, a high-level indicative harvest plan could be used to highlight any areas likely to be difficult to harvest and manage slash. Considerations could include deciding if these areas are better left unplanted or planted as indigenous forests. Planning now, may give you more options if intentions change over time.

Replanting is an opportunity to reduce the risks from slash that you might have experienced in your last harvest. What areas might be harvested differently? Are some areas worth retiring into another land use? These questions could be informed by a harvest manager or other harvest experts.

Species selection can affect future slash risk, particularly on high-risk sites for landslides and slash mobilisation. You may consider the suitability of different species and their site preferences and potential survival rates, as well as future markets opportunities and current limitations. For example, establishing coppicing species such as eucalyptus and redwoods in strategically important locations means that root decay at harvest is significantly reduced, because these species can grow again from the felled stumps. This may reduce the length or intensity of the window of vulnerability.

Strategic harvesting decisions

A forest manager's strategic or "big picture" harvesting decisions can reduce the slash risk on high erosion risk sites. Factors that affect strategic slash risk include:

- Catchment harvesting strategies.
- Scale of harvest. The larger the harvest area the greater the volume of slash.
- Length of time taken to harvest an area.
- Harvest timing, (e.g. summer or winter logging).
- The opportunity to spread the harvest across a mix of age classes, (e.g. if catchment location, scale and intensity influence strategic risk).
- Harvest area size on higher-risk sites where slash may mobilise because of landslides. The entire harvested area is unlikely to fail, but a larger area represents larger cumulative volumes of slash which may pose a risk.

Forest managers may have conflicting strategic demands to balance, along with slash risks, including:

- health and safety;
- broader environmental factors, (e.g. managing erosion, sediment, and biodiversity);
- regulatory requirements;
- market supply requirements, (e.g. forestry machinery and domestic processing capacity restricts log size);
- production rates, (e.g. moving crews between forests can be time-consuming and non-productive, and harvesting crews prefer consistent work);
- rotation length, and the size and age class distribution of the forest, (e.g. a forest planted over the course of a year may only have a five-year harvest "window" before the wood becomes too large to process);
- economic return.

Smaller forests and economically marginal forests may have fewer strategic options, for example, many hill country forests are not located near ports or domestic markets.

Harvest planning decisions

Harvest planning is important to improve or maintain productivity, quality, health and safety, and environmental outcomes.

The harvest plan could identify ways to reduce slash and risks from slash. This could reduce the need to make additional operational decisions once the slash is produced.

Harvest planning could consider:

- Identifying areas with a high risk of slash mobilisation e.g. short steep unstable faces in close proximity to waterways.
- Slash storage capacity on processing landings and end-haul sites.
- How the harvesting system will address any slash management requirements.
- Opportunities to haul away from, rather than haul across, waterways.
- The approach used for log extraction across waterways to reduce slash loading of the waterway and riparian area, (e.g. full suspension, partial suspension, riparian corridor vs unconstrained extraction).
- Methods to reduce felling breakage through felling technique, machinery choice, and stem presentation.

Steep slopes and windthrow on shallow soils on consolidated mudstone contribute to this cutover's challenges. The woody material remaining is unmerchantable. Adverse weather events could lead to landslides and debris flows, mobilising slash and windthrow. The five-year-old trees in the background show evidence of this previously happening.

Operational management decisions during harvest

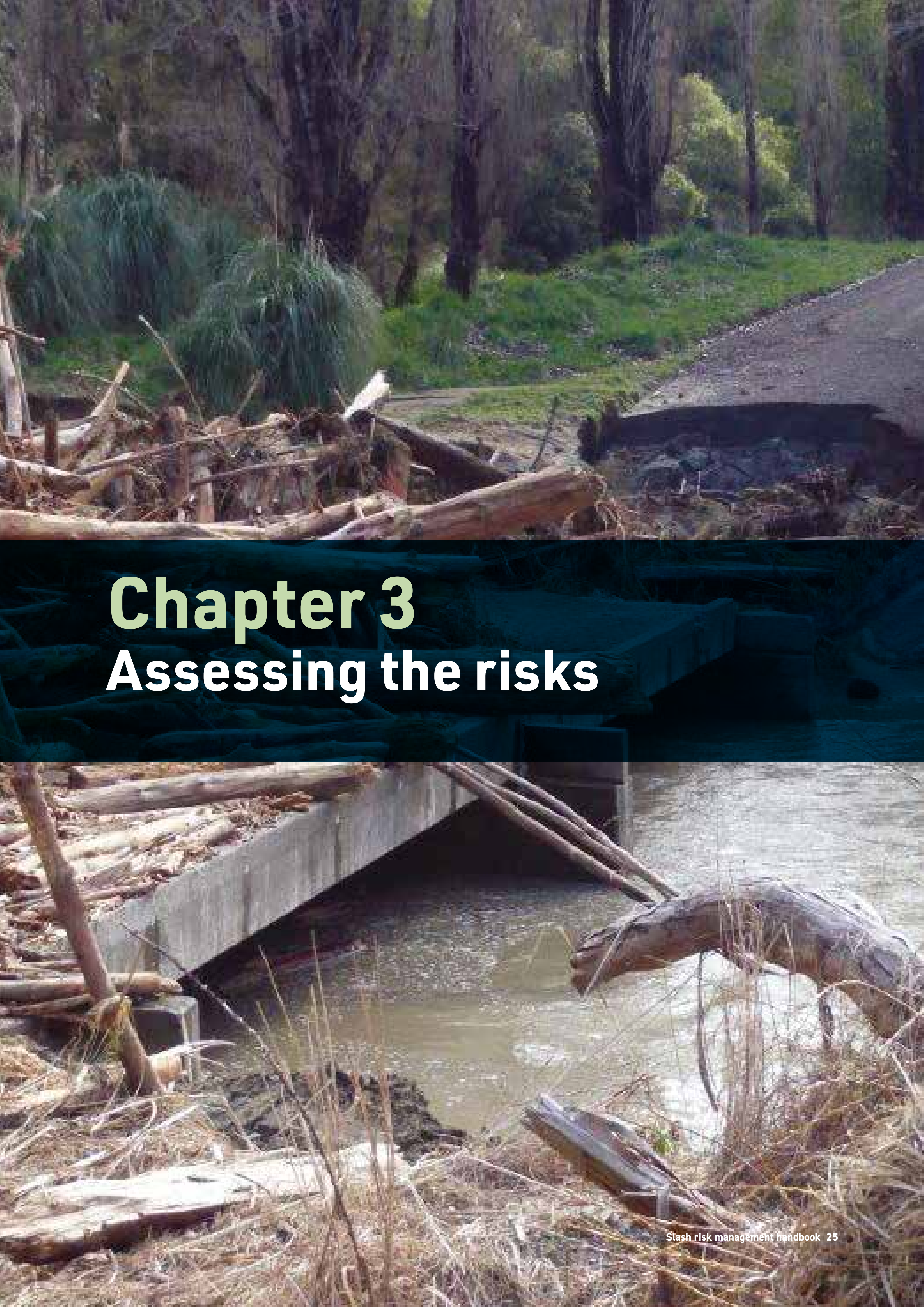
Operational management includes supervising harvesting progress and ensuring that changes are made if the harvest plan needs revision. Operational risks because of slash accumulating and potentially mobilising could be created by:

- Felling and extraction machinery that does not match the terrain or tree size, (e.g. not enough height) (a swing yarder rather than a tower).
- Little involvement of the forest manager and contractor during harvest planning, and in the content of the final job prescription.
- Not recognising and/or not adequately addressing a slash risk before or as it arises.
- "Normalising" slash risks due to over-familiarity with difficult harvest conditions, or not anticipating or understanding the level of risk.
- Little supervision by the forest manager or contractor and limited operational checks.
- Not prioritising slash management.
- Rehabilitation of tracks and landings not being completed promptly.
- Too much slash, (in size, density, or presence) for the risk profile of the site, is left in the cutover or in rivers.
- Inexperienced or trainee crew making decisions without appropriate support from experienced persons.
- Not following agreed operational procedures.

Assessing the consequences of slash is discussed in detail in Chapter 3.

Checklists for managing what causes slash to mobilise

Identify site and climate factors that may contribute to a high slash risk		✓ Yes × No ? Not sure
Geological factors	Steep country, with slopes > 30 degrees?	
	Slopes that steeply roll over (convex), or changes in slope angle, especially mid-slope or near waterways?	
	Long and steep faces. (A landslide can generate a lot of energy over distance).	
	Is there broken country with many gullies? This often includes short faces.	
	Evidence of weak rock? (e.g. bedding plane dipping downslope, soft sedimentary rocks).	
	History of previous landslides and terrain risks evident in LiDAR, photos, or field visits.	
	Are shear zones visible, (e.g. between rock and soil)?	
	Do some aspects get more rain or stay wet, (e.g. south facing)?	
Land classifications	'Is the Erosion Susceptibility Classification orange or red?	
Climate	Detailed LUC mapping or LUC extended legends show high risk, (e.g. 7e land)	
	High rainfall area?	
	Does the area have regular and intense storms?	
	Is the area known for windthrow-generating winds?	
	Is there a history of storm events triggering landslides and debris flows?	
Closeness to water and mobility	Forest is within a dense river network of many waterways?	
	Forest or harvest block is near a major tributary that could disperse slash widely?	
	Steep stream gradient?	
	Erosion-prone riverbanks?	
	Do terrain and climate together create high energy ephemeral or intermittent waterways in 1 in a 20-year event?	
	Is the forest near the coast or outstanding or sensitive receiving environments (e.g. lakes, wetlands)?	
	Rivers with incised channels and non-accessible gorges?	
Catchments	Is harvest in a single catchment?	
	Is the harvest area a significant proportion of a catchment?	
Proximity to offsite slash impact risks	Potentially affected productive land users are nearby, e.g. farms?	
	Neighbours and the community are close to the forest?	
	Infrastructure vulnerable to slash is close, e.g. culverts and some bridge abutments?	
	Slash could mobilise and affect recreational areas?	
	Slash could mobilise and affect sensitive downstream ecological areas?	



Chapter 3
Assessing the risks

In this chapter, you will find out:

✓ How to assess potential consequences from slash and their likelihood of occurring.
✓ How to assess slash mobilisation risk levels.
✓ Health and safety risks associated with slash management.

Understanding the factors that could cause slash mobilisation and the potential adverse effects enables better risk assessment. A good risk assessment will help determine how to manage these risks effectively.

Assessing risk: consequences and likelihood

Risk combines the consequence of something occurring with the likelihood of it happening.

- **Consequence** is the outcome of an event that affects objectives.
- **Likelihood** is the probability or chance that the thing will occur.

The likelihood of an adverse slash event is low or negligible in most parts of New Zealand because the risks for slash mobilisation are either absent or minimal. Undertaking a process to assess risk can help you identify areas of low and high risk on a forestry site.

Assessing each harvest area at the right scale is important. Different parts of a forest are likely to have different combinations of factors that influence slash mobilisation.

For completeness, any analysis of risk needs to include an assessment of the potential offsite consequences if slash mobilises.

Risk perception

People's risk perception is highly variable. For example, a forester who has seen slash mobilisation incidents may assess the risk more conservatively than someone without first-hand experience.

Managing slash on steep harvesting sites near to waterways or infrastructure may become second nature to those frequently operating in those forests, but it is a learned skill.

How to assess slash mobilisation risk levels

A five-step process could be used to assess slash risks:

Step 1: Assess potential consequences.

Step 2: Assess likelihood.

Step 3: Assign slash risk levels.

Step 4: Develop options to manage slash mobilisation risk.

Step 5: Assess whether mitigation measures will reduce the level of risk.

Step 1: Assess potential consequences

The potential consequences of slash mobilising from an operational area of the forest could be assessed by identifying whether the slash could:

- reach a waterway;
- leave the forest boundary; and
- with a volume of material that will cause downstream impacts.

Field surveys, assessment of maps and aerial photos, local knowledge, discussions with neighbours and the community, and information from the Regional Council could identify potential off-site effects of slash mobilisation.

The following diagram outlines potential consequences when slash is mobilised in sufficient volume both on- and off-site.

Note the ESC rating only considers on-site risks of erosion susceptibility.

Slash clean-up can be time-consuming and challenging as the slash cannot safely be removed until ground conditions dry out.

Slash mobilisation consequenses

Outside the forest boundary

- **Affects neighbours and the community** damage to other land users, houses, property access, fences, agriculture and horticulture, water supply, and restricts water activities, e.g. swimming, boating, and access
- **Damages infrastructure** e.g. roads, bridges, culverts, communications, power and water
- **Impacts receiving environment** e.g. rivers, lakes, wetlands, and coastal environments
- **Creates costs** e.g. clean-up, repairs, legal proceedings, fines
- **Creates community stress and loss of trust, and wastes time**

Inside the forest business

- **Damages the forest's infrastructure** e.g. roads, bridges, culverts
- **Creates loss of production** e.g. time to open up access and fix the damage
- **Impacts receiving environment** e.g. rivers, lakes, wetlands and coastal environments
- **Adds significant costs inside and outside the forest** e.g. repairs, clean-up, legal proceedings and fines
- **Creates legal and environmental certification non-compliance which has widespread impacts**
- **Damages forest manager and contractor social and environmental "licence to operate"** e.g. community and client trust

Consequences of slash mobilisation

Cumulative effects

Individual slash risks can combine to create greater risks. This can be managed by assessing slash risks both individually and collectively. For example, slash practice on cutovers or landings combined with steep terrain could lead to worse consequences than similar practices on less steep terrain.

Impact of slash in a waterway

Mobilised slash affects recreation in coastal areas.

Cumulative consequences of a 500 m debris flows: landing failure (blue arrow), debris flow pathway (red arrows), slips from tracks (yellow arrow), and heavy cutover slash loadings on steep, erosion-prone soil. The tail of the debris flow is in the foreground. Heavy rain was the catalyst.

Assessing potential consequences using risk indices

Risk indices are scores linked to broad classes of consequence. These classes relate to the scale of the potential consequences of an incident.

A common consequence class scale uses the following descriptors:

1 – Insignificant

2 – Minor

3 – Moderate

4 – Major

5 – Extreme

6 – Catastrophic

Each consequence class needs to be clearly defined to ensure that a consistent risk assessment is applied. For example, a major consequence could be large volumes of slash ending up on a neighbour's property.

Step 2: Assess likelihood

Risk indices are also the most common method for assessing likelihood. A common 6-class likelihood system uses the following descriptors:

1 – Negligible

2 – Unlikely

3 – Possible

4 – Likely

5 – Almost Certain

6 – Certain

Likelihood classes must be defined and assigned a timeframe. For example, "certain" could be defined as within the next three years, within the "window of vulnerability" or occurring over a forest rotation.

Step 3: Assign slash risk levels

This table is an example of a commonly used traffic light risk matrix. It combines two risk indices, consequences, and likelihood. These are helpful as they represent complex situations in a simple way.

Although the traffic light approach is widely used in forestry[1] and other industries, there are many different risk assessment methods. Techniques already in use in commercial forestry include: field surveys, checklists and classifications, brainstorming, scenario analysis, Structured "What if?" analysis (SWIFT), Fault tree analysis, bow tie and Cost Benefit Analysis. Each technique has advantages, and many work well in combination.

Step 4: Develop options to manage slash mobilisation risk

The risk management options available to forest managers include:

- Removing the risk at source, (e.g. not storing slash around a landing or burning the slash; removing slash from high-risk cutovers).
- Changing the likelihood of a mobilisation risk, (e.g. ensuring all slash is removed from a watercourse and its floodplain).
- Reducing the risk of mobilised slash moving off-site and further downstream (e.g. slash traps within the forest boundary, or collaborating with neighbours to construct slash retention structures outside the forest boundaries).
- Accepting the slash risk, (e.g. doing nothing or meeting the minimum actions required).
- Avoiding the risk by deciding not to start or continue with a slash-causing activity, (e.g. not harvesting an area).
- Considering outcomes beyond harvesting to reduce future risk may require potential replanting mitigation strategies.

Step 5: Assess whether mitigation measures will reduce the level of risk

Forest managers and landowners might have different risk tolerance levels when deciding how to best manage the risks associated with slash mobilisation.

Assessing mitigation at a strategic level

Where risk of slash mobilisation is very high, risk mitigation can be more effective when it covers the whole of the forest site at a strategic level. This might differ from evaluating mobilisation risk during harvest planning and operational activities. For example, for sites with a very high risk of landslides, the identification of mobilisation risk during the planning and operational management of replanting could change the decision on whether or not to replant.

Some strategic factors that may affect whether mitigation measures could manage risk include:

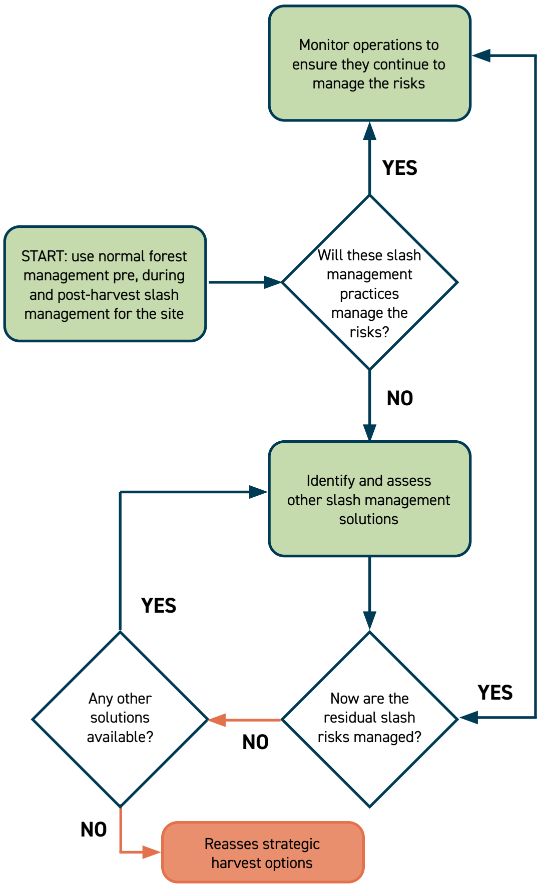
- Harvesting scale, (e.g. harvesting large contiguous areas).
- Harvesting duration or timing, (e.g. rapidly harvesting large areas may increase risks). Time of year may increase risks.
- Suitability of harvesting machinery (e.g. the type of machinery is suitable for the site and terrain for the site).
- Level of supervision, monitoring, and reporting.

Concequences	Likelihood: 1 – Negligible	2 – Unlikely	3 – Possible	4 – Likely	5 – Almost Certain	6 – Certain
6 – Catastrophic	Medium	High	Extreme	Extreme	Extreme	Extreme
5 – Extreme	Medium	Medium	High	High	Extreme	Extreme
4 – Major	Low	Medium	Medium	High	High	Extreme
3 – Moderate	Low	Low	Medium	Medium	High	High
2 – Minor	Low	Low	Low	Low	Medium	Medium
1 – Insignificant	Low	Low	Low	Low	Low	Medium

A consequence/likelihood matrix (risk matrix/heat map) showing acceptability based on ratings class.

1 Australian and New Zealand Standard AS/NZS IEC 31010:2020 Risk management - Risk assessment techniques.

The following process diagram can be used to assess whether mitigation measures could be effective, (e.g. on the landing, on cutovers, or near water).



Will the slash mitigation measures manage the risk?

How long should mitigation measures be maintained?

Mitigation measures are more effective when they are consistently applied, maintained, and monitored until the risk is gone or reduced to an acceptable level. On higher risk sites, this can involve checking on post-harvest rehabilitation for several years to ensure it is still performing. How long mitigation measures could need to be maintained will depend on the site's slash risk characteristics and will need to be decided on a case-by-case basis.

Example: Risk management outcomes – coastal North Island

The forest in the picture below adjoins a state highway with culverts, has neighbouring houses and farmland, and a regionally significant wetland and estuary. Significant natural areas (SNAs) are within the block, along with several threatened species, archaeological sites, and numerous indigenous remnants. Slash mobilisation could have effects on all these factors. The site's steep terrain provided good deflection (easier harvesting) and flattens off on the lower slopes, which helped reduce slash mobilisation risks.

The forest manager's mitigation measures reduced potential mobilisation risks. They included:

- burning processing slash at landings;
- removal of most large slash from the cut-over;
- riparian management zones having minimal disturbance (corridor extraction).

Above: The landing, cutover and waterway risks are minimal on a high-risk site. Slash on landings has been burnt (green arrows). Almost all large slash was removed from the site. Riparian vegetation along the waterways is undamaged (grey arrows), except for a few examples of narrow skyline corridors to bridle otherwise inaccessible harvest areas (white arrows). Cutouts on the roads provide ongoing water control (yellow arrows).

Health and safety risks associated with slash management

Health and Safety at Work Act

The purpose of the Health and Safety at Work Act 2015 (HASWA) is "to provide a balanced framework to secure the health and safety of workers and workplaces by, [among other things], (a) protecting workers and other persons against harm to their health, safety and welfare by eliminating or minimising risks arising from work".

The person responsible for health and safety under HASWA is the Person Conducting a Business or Undertaking (PCBU). The PCBU has a "primary duty of care" to ensure the safety of workers, and anyone affected by their work in the workplace[2]. Harvesting contractors and forest managers as businesses are both PCBUs with an explicit duty of care for safety of workers and other persons.

Many duties under HASWA apply "so far as is reasonably practicable". This means doing what is reasonably able to be done to ensure people's health and safety under the given circumstances. Something is "practicable" if it is possible or capable of being done. "Reasonably" does not mean doing everything humanly possible to manage a risk. It means doing what others would reasonably do in the same situation.

A council compliance, monitoring, and enforcement (CME) officer is not responsible for the work site and is not a PCBU. If they consider slash needs to be removed when the expressed reason to leave is to meet PCBU obligations under the HASWA due to concern about the safety of extraction, they need to ensure that their advice does not interfere with forestry managers and their contractors' HASWA obligations.

Forest harvest contractors should do their own risk assessments as PCBUs. Where a decision is made to leave slash in situ because it is unsafe to remove it, the decision and the reasoning should be documented and communicated with the forest manager. This documentation should be made available to CME staff so that any reliance on the safety exemptions is clearly understood by all parties.

2 Section 36 Health and Safety at Work Act 2015.

High risk slash removal areas

The areas of greatest slash removal risk are on the cutover and near or in waterways. Eliminating or minimising risks to forestry workers require particular attention to sites with:

- wet and slippery areas;
- steep or slippery slopes;
- geologically unstable slopes that may not sustain multiple machinery passes;
- slopes with downhill hazards or terrain traps such as bluffs, and gullies;
- confined spaces, (e.g. gullies, narrow and incised waterways);
- multiple logs in piles, possibly under tension.

Although it was common in the past for workers to enter waterways on foot, the forest sector now views this as an unacceptable risk in most situations given the safety risks of working and lifting in wet, muddy, confined conditions. Where excavator-based machines with felling/cutting heads can reach the waterway, these can be used to place slash outside of the stream zone and can be highly productive while eliminating health and safety risks associated with manual labour. For example, a safe weight for manual lifting would be no more than 25 kg without assistance whereas a machine can lift an average tree (about 2,000 kg).

In the past, workers manually attached logs (or slash) using a wire strop, or chain to a cable hauler or ground based machine for extraction: "breaking out". It is very high risk with no room for error. There have been many incidents related to breaking out, including fatalities. The sector now strongly favours mechanised forestry harvest.

Significant risk factors of manual breaking out are trees or debris sliding down the slope, or rocks falling and hitting the worker. The steeper the slope or more unstable the ground the greater the risk. This is also the terrain most at risk of slash mobilisation. The usual method of eliminating this risk is to mechanise breaking out, and use a grapple, which removes the person from the risk.

Harvesting grapples are not designed to pick up small pieces of slash as they physically cannot close up enough to grab a small diameter piece. Multiple small pieces may be grabbed from a pile, but they can drop out on the inhaul, potentially creating additional health and safety risks.

Where slash is being managed at the same time as harvest the procedures used should be included in harvest risk assessment. Where a slash clean-up operation is carried out after normal harvest is complete the forest manager/crew must carry out a risk assessment before starting the work, to determine what is reasonably practical and safe to do.

Above: The hauler operator is removing slash from a waterway beside the line of trees in the distance. The screen shows the view from a camera mounted on the grapple, which provides a very close operational view. The operator must switch constantly between the camera view and the wider view outside the cab window to bring the slash to a landing. On sunny days the glare from the camera's protective box can make it hard for the operator to see the grapple.

Chapter 4
Managing slash on landings

In this chapter, you will find out:

✓ What makes slash accumulate on landings.
✓ How to calculate the estimated slash volumes coming to a landing.
✓ Options to manage slash on landings.
✓ Options to manage slash risks on landings at pre-harvest planning, during harvest operations, and post-harvest phases.

Landings or processing sites are where slash accumulates and is a risk. Landing design and layout are beyond the scope of this Handbook.

What makes slash accumulate on landings?

Landings are harvest extraction sites where the trees are typically processed into logs, sorted, stockpiled, and loaded onto trucks for distribution to markets.

During the log making process, wood not suitable for logs becomes processing slash, also referred to as residues. Processing slash includes sections of the tree that are broken, defective, or of insufficient diameter to be made into a saleable log, or bark. Most of the slash on a landing is processing slash. Other sources include woody debris such as extracted windthrow, incidentally damaged indigenous trees or dead timber brought to the landing. Some slash, including binwood and other harvesting residues can be used for boiler fuel, wood pellets and other products if a market exists. The amount of slash left on a landing increases if there is no market for it.

Slash put over the side or on the edge of a landing is commonly called a "**bird's nest**".

What contributes to the amount of slash on landings?

The following contribute to the slash volume on landings:

- Wood resource:
  - higher volume stands;
  - lower quality stems (poor form, defects);
  - unpruned trees (more branches).
- Terrain:
  - broken terrain increases felling and extraction breakage;
  - poor deflection when hauler harvesting increases breakage.
- Management decisions.
- The size of the harvest setting area.
- The space available on landings for slash storage, and its location on the landing.
- Whole tree extraction creates more slash on the landing (though less on the cutover).
- Felling and cable/grapple extraction plans affect rates of stem breakage.
- Pulling windthrow and/or small-dimension wood.

Large volumes of harvesting residues can be generated on landings with small harvest areas.

How to calculate the estimated slash volumes coming to a landing

Depending on the tree form and log cut even relatively small harvest areas can generate large volumes of slash at a landing. A high-producing harvesting crew could generate 50 to 75 m^3 of slash daily. This would require a storage area of about 4 m x 4 m x 4 m.

Slash volume can only be estimated as the components in the slash calculation vary across the harvest area. Having an idea of the amount of slash coming onto a landing will help you develop a landing slash management plan.

- Calculate the slash volume likely to be generated based on the area harvested, the size of the wood resource, stem breakage rates, and residue supply commitments.
- Add other sources of woody debris, such as windthrow extracted (with or without a root ball).
- Multiply by a bulking factor. A slash pile doesn't stack well and has a lot of air gaps.

The following formulas (Harvey, 2022) can be used to determine the volume of harvesting residue and bulking factors to estimate storage space required:

- Landing residues are about 6 percent of Total Recoverable Volume (TRV), or about 35 tonnes/hectare.
- Average bulking factor is 0.25 t/m^3. Each tonne of slash takes up about 4 m^3.
- Average bulk on a landing of slash per hectare harvested = 170 m^3/hectare.

The formula to determine how much space is needed to store harvested slash is:

V = ((A x TRV x S) + (A x O)) x B

Where:

V = Total slash volume, bulked up (m^3)

A = Setting area (ha)

TRV = Total recoverable volume (t/ha)

S = Proportion of the TRV expected as harvesting slash, e.g. 0.06

O = Other woody debris volume e.g. windthrow pulled, (t/ha)

B = Bulking factor, e.g. 4 m^3/t

Example

A 10-hectare hauler setting has a TRV of 550 t/ha, an estimated 6 percent processing slash and non-merchantable slash extracted to meet regulatory thresholds.

V = ((10 x 550 x 0.06) x 4

V = (330) x 4

V = 1,320 m^3 (approx. 21 m x 21 m x 3 m)

Therefore, 1,320 m^3 of storage area is needed for slash disposal. Storing slash in piles over 3 m high is a potential fire risk (particularly if soil is mixed in the slash reducing air voids and promoting composting), so the required area is approximately 21 m x 21 m x 3 m. This requires an area of 441 m^2 to store the slash.

This example uses average values. When calculating for a specific site check whether the 6 percent average volume generated applies to the harvest operation, and whether windthrow is pulled.

A bulking-up factor is needed because the slash has many air gaps.

Options to manage slash on landings

There are several options for managing slash on landings. These include:

Permanent slash storage

Permanent, stable, and safe slash storage sites could be:

- on a natural feature that can contain the slash, (e.g. a natural bench, low gradient slope (< 5°) or depression);
- within a purpose-built engineered slash retaining structure, (e.g. a slash bench or end-haul site);
- stockpiled on the landing after post-harvest rehabilitation;
- stored on stable forestry tracks;
- a combination of these options.

Assess the geology, soil, slope stability, and construction standards of a proposed storage site. If the harvest planner lacks the necessary assessment skills, you can consider seeking expert advice to assist you.

Secure and stable sites:

- are beyond areas threatened by floods or high storm flows or where slash could roll or slide into rivers;
- have adequate underlying rock layers/strength to support the slash;
- are not located on an old landslide, slump, gully head, or other erosional feature. Land should show no sign of instability. Look for butt-sweep (hockey stick shaped) trees as a sign the land may be slowly moving;
- have no evidence of water flowing or water-logged ground. Look for water-adapted vegetation such as sedges or rushes;
- are not in, or where slash could enter, riparian management zones, significant natural areas or archaeological sites.

Slash around the landing's edge poses little risk in easier terrain if it is not sited adjacent to a waterway where it could be mobilised during a flood. On steep, landslide-prone country, it may be difficult to store all slash in a permanent and stable location around the landing. Alternative storage locations may need to be found.

Temporary slash storage

Temporarily storing slash where it can be recovered by excavator post-harvest, is a good way to maintain operational flexibility on a landing.

Common forms of temporary slash storage are:

- Slash pushed over the landing edge in designated locations, The amount of slash pushed over or built up on the edges of the landing is a forest manager's decision.
- Slash benches may also be used temporarily if made safe. For example, a track is installed in the bench to stop slash from rolling downslope (see further information on slash benches below).
- Log retaining structures to contain slash.
- On the edge of the landing.
- Incorporated into the landing surface with machines working on top of it.
- Any combination of these options.

Often a combination of temporary and permanent storage is used to manage slash on landings.

Slash benches

Slash benches are often non-engineered side-cast access tracks required to install the anchors (deadmen) that secure the hauler. They can also be designed or modified to contain slash.

Slash benches on steep terrain for permanent slash need to be structurally capable of holding the weight of the slash. Side-cast fill has no structural integrity. On a 25-degree slope, side cast fill has limited resistance to sliding. On slopes over 35 degrees, it is likely to fail.

General practice for slash benches was to be in-sloped, drained, and bunded (rather than out-sloped). This means slash could be trapped by the bench and not roll or slide off it. However, effective water control on in-sloped benches cannot be guaranteed. Stormwater can soak through the fill, as the slash restricts water from being channelled and directed from it, increasing the risk. All slash benches require careful design and location.

The compacted slash bench was built during landing construction. The natural ground slope is 30 degrees (black line) which should hold the slash, but the bench could create additional erosion and slash risks if not adequately drained.

A permanently stable off-site slash storage location has collected slash from several landings. The slash piles are no higher than three metres to reduce fire risk. The slash is stored about 3 metres from the edge of the landing to keep it back from areas of fill.

The in-sloped side cast track was built after landing construction and has no soil compaction. Some slash from the harvest operation will collect in the bund. Stormwater will likely soak through because there is no drainage, potentially weakening it to failure point.

Processing slash is mulched on a landing.

Carting away/Off-site storage

If there is insufficient room on a landing, the harvest planner may need to consider options for carting slash away as it is generated to a permanently stable off-site location.

Mulching and chipping

Mulching and chipping reduce the size of the slash to small chunks, which removes most mobilisation risks and significantly increases the speed of decomposition. This material may be spread over disused landings, or along road margins for erosion control. Some forest managers use the chip material for road surfacing on temporary roads, offsetting the cost of using quarried rock.

Above: Two-stage harvesting separates extraction from processing. This eliminated all harvesting residue at this pad.

Planning for centralised and two-stage processing almost eliminated landing slash, significantly reduced landing size (orange arrows), and removed a potential fire risk in this highly erosion-prone and summer-dry hill country.

To manage the risk of potential fire, avoid leaving large piles of chipped material on-site, as it will reach very high temperatures as it composts. It holds substantial amounts of water which will increase overall weight and there are minimal air pockets to help dissipate heat.

Two-staging

Separating logging from log processing is a method called **two-staging**. It is widely used on more challenging terrain and is an option that can assist with managing slash on landings. The hauler sits on a pad or reduced-size landing, and processing is on an adjacent smaller landing. The aim is to put the hauler on the optimal log extraction site with the processing landing constructed at another site suitable for earthworks and slash storage. The slash can be shifted by a grapple skidder, bulldozer, or off-highway truck if the distance requires it. For operational efficiency you may want to consider the distance/time between the extraction pad and the processing landing.

A central processing site is an extension of two-staging where tree stems from multiple pads are processed.

Burning

The main benefit of burning slash on landings is the rapid and inexpensive removal of large volumes of slash. Under optimal conditions the bulk of the slash is burnt in the first 12 hours. Uncontrolled fires can create safety, health, environmental, and property risks as:

- Fires can get out of control and jump planned fire boundaries.
- Smoke can affect neighbours.
- Fires can remain alight for weeks or months and may reignite during drier or windier periods.

When managed well and risks controlled, burning effectively removes large volumes of landing slash.

During and after a successful burn

Why is slash presentation important?

Well managed slash leads to the fire burning quickly, consistently, and completely, making it easier to manage. Harvesting contractors preparing landing slash for burning could:

- Minimise soil and mud getting into the slash pile. Stack the slash rather than heaping and pushing.
- Ensure no non-wood products are in the slash (e.g. wire rope).
- Mix up small and large slash to make the slash distribution more consistent.

Burn plan

Planning and safely carrying out a slash burn requires a high level of fire management, a skilled and trained team and specialist equipment. For example, post-burn thermal imaging to identify elevated ground temperature, as fires may burn underground before they appear at the surface.

The burn plan sets out when and how to burn and describes the resources and equipment needed to manage the burn. Each fire or group of fires requires its own specific plan.

Above: Well-presented slash, free from soil or mud, containing a mix of slash sizes to assist in a consistent burn.

Good management and a skilled team lead to a successful burn.

Carrying out the burn

- Check the Fire and Emergency New Zealand (FENZ) fire season rating. A permit is required during a restricted season, and burning is not allowed during the prohibited season.
- The regional council may also have rules for discharges to the air.
- Discuss the burn plan with the forest manager so they can decide on it.
- Understand the local weather patterns, the weather leading up to the burn, and the following days. Rain within 24 – 48 hours after light-up is a useful safety net.
- Consider what could go wrong, (e.g. burning slash rolling downhill, embers crossing into a gully or a hard-to-access opposite face).
- Know how fire weather indices affect burning.
- Burn when seasonal conditions are suitable. It is useful to ensure any deep-seated burning is over before dry, windy conditions prevail.
- Only light fires after meeting the burn plan's light-up requirements.
- Consider burning before pre-plant spraying, as the cutover vegetation will still be green/ contain moisture.
- Actively choose the time of day to light the fire. For example, lighting up in the early morning maximises daylight hours but after 1 pm allows more confidence of the weather conditions. Lighting up as the day cools into the evening also reduces spot fires. This is site and weather dependent.
- Burn only well-presented landing slash to avoid a poor burn or a deep-seated fire as wood burns under the soil.
- Have people on-site at all times, with sufficient resources to control the burn.
- Work with stakeholders and keep them informed, including neighbours.
- Keep FENZ involved or informed so they know what is happening and how to contact the burn team. They are then less likely to roll out resources unnecessarily if the public reports a fire via 111.

Additional resources on fire management are listed in the Bibliography.

Fires in forests are challenging and expensive to contain. Burning landing slash requires careful management to avoid unintended consequences.

Managing slash on landings

Slash risks on landing sites can be managed:

- at pre-harvest planning;
- during harvest operations;
- post-harvest.

Forest managers have many existing systems that incorporate and document these three aspects. For example, within earthworks and harvesting contracts, Standard Operating Procedures (SOPs), monitoring checklists for all phases, and the operational prescription and maps.

Managing slash on landings at pre-harvest planning

Slash can be hard to manage, especially in steep hill country and where large volumes are coming to a landing. Identifying any slash management risk upfront via a management plan before harvesting starts is preferable to addressing the risk during a harvesting operation.

A landing slash management plan can:

- Estimate the quantity of slash likely to be produced at the landing.
- Identify, plan, and map safe and stable temporary and permanent slash disposal areas, either on- or off-site.
- Ensure processing operations can be carried out safely and efficiently.

- Incorporate slash structures as part of the landing design and construction, (e.g. slash benches).
- Designate and map "No-Go" slash zones where slash may not be placed or stored.

There are trade-offs to be made between managing slash on the cutover and on the landing. For example, operational safety for crews versus long term safe storage, and the immediate operational costs of slash management versus the uncertain risks of a slash incident in the future.

Managing slash on landings during harvest operations

The forest manager and the harvesting contractor usually agree on a slash management plan and the operational prescription before starting the job. If variations are required, document the changes and act on them quickly.

Slash location and placement on landings

Slash control on landings, especially on higher-risk sites, can include:

- Keeping slash to the designated areas and out of No-Go areas.
- Ensuring that machines have unrestricted access to slash areas.
- Monitoring storage space. If it is likely to be exceeded, decide on an alternative site. Get approval from the forest manager to amend the plan.
- Checking slash is stable and fully occupies the storage area. It may need to be shifted or reworked as needed.
- Managing the amount of slash on the edge of landing fill. Saturated fill can weaken and potentially fail. The additional weight of too much slash can increase this risk. Slash absorbs water over time, increasing its weight.
- Keeping slash retrievable if it is in a temporary location.
- Not overfilling benches by keeping at least 1m of the bench visible.
- Keeping the size and location of the bird's nest manageable.
- Limiting or restricting the use of slash to increase the landing's working area as this may lead to over-steep bird's nest faces.

The bird's nest's angle is less than 45 degrees, and the volume is retrievable. However, the slash shouldn't have been put there because it is on a steep, landslide-prone slope. Post-harvest removal of this slash is essential.

The bird's nest's angle is too steep, and it is not on a bench. The slash may fail due to its mass on an uncompacted fill.

- Keeping the slash clean. Don't mix dirt with the slash, as it reduces water movement, binds it together, increases fire risk, and adds weight to the slash.

Water control

It is important to maintain landing and slash disposal site drainage in an operative condition. This can stop slash and the supporting soil from getting waterlogged, leading to potential landing failure.

Stormwater management can be included in the forest monitoring and maintenance plan.

Maintain stormwater controls around slash areas by:

- Directing water away from slash storage areas.
- Reinstating stormwater controls if operations damage them.
- Removing any slash that is blocking or could block landing water controls.

Managing fire risk

Fires can start from fine materials (needles and twigs) composting. Fire may occur after rain, as the water helps the composting process create heat. Fires can also begin in dry, windy, and hot locations if there's a spark. Mixing dirt with the slash reduces water movement, binds it together, increases fire risk, and adds weight to the slash.

To reduce fire risk when planning slash location and storage you could:

- Keep slash piles to less than 3 metres deep.
- Ensure no wire rope, metal or other rubbish is left in processing slash as they increase fire risk.
- Separate fine material and soil from bulk slash to reduce spontaneous combustion risk.
- Immediately report slash piles that show evidence of steam or smoke to the forest manager.

Managing slash on landings post-harvest

Once harvesting is complete, the landing slash should be stored in a permanently stable and safe location. The aim is to leave the landing with minimal risk from slash or fill failure.

Landing rehabilitation needs to be effective for about seven years, the time it usually takes for slash to break down. This will vary according to moisture, temperature and whether it is in contact with the ground. Good slash management and water control by the harvesting contractor can assist in preventing slash management problems that need solving during the rehabilitation work.

Not all aspects of post-harvest landing rehabilitation can be carried by the harvesting contractor if they don't have the right equipment to shift slash effectively. In these cases, the forest manager may contract in some-one else to complete the work.

Most landings will need some slash rehabilitation. On easier land, if the environmental risk is low, pulling slash back onto the landing to maximise planting area is often sufficient.

On higher-risk land more may be required. An option to minimise the amount of rehabilitation required is to managing issues as they arise.

Left: The slash over the side of the 45-degree face (green line) was in a No-Go zone and out of reach, making retrieval impossible. The option to cart it away should have been identified during harvest planning.

Right: Landing failures often generate debris flow and landslides. The image looks 400m down an eroded gully created from this landing failure.

Left: Even small slash volumes in the wrong location can trigger landslips. Slash above an eroding gully head triggered this slip.

Right: This debris flow was initiated at the landing (black arrow). Stormwater was being drained into a pocket bench that failed.

Left: Uncontained slash spills 50 m below the landing, ending on a track next to a permanently flowing river. The landing was used to store what was reachable (blue arrow).

Right: Poor landing drainage collapsed the landing fill.

When should post-harvest rehabilitation occur?

Landing rehabilitation is usually completed within one month of the harvesting contractor leaving the site unless more urgent preventative actions are required. Rehabilitation timing should be prioritised according to erosion and slash risks.

Weather and ground conditions may affect the timing of the work as rehabilitation is difficult and often unsuccessful if the ground conditions are wet.

The forest manager cleaned off the landing surface and re-installed water controls but decided not to shift the slash. The slope is 20-degrees and there is a low residual risk of slash failure and environmental risk. The pile was deemed permanently stable.

In this highly erodible geology, a high landing and slash rehabilitation standard was needed. The image, taken during a cyclone, shows the effectiveness of good water controls.

Rehabilitation requirements

Landing rehabilitation is required where the predominant slopes are greater than 20 degrees or where other risks are present, such as risk to the receiving environment if a bird's nest fails, or where the terrain is potentially unstable (e.g. earth flows).

The amount of rehabilitation needed can depend on the:

- Size and location of the landing. Landings in erosion-prone locations that are constructed with large fills need rehabilitation to manage mass-movement risks.
- Condition of the landing surface, (e.g. ponding, deep rutting, or shedding water into fill or into erosion-prone areas).
- Quantity and stability of slash. The more slash to shift, the more work that may be required.
- Amount of slash that must be removed from unstable or temporary locations.

Rehabilitation can include:

- Creating cross-fall or drainage back towards the landing's 'hard' or non-filled areas.
- Removing unstable slash from the landing edge or other temporary storage sites so that the ground is visible on the landing edge through any remaining slash:
  - Use an excavator (or long-reach excavator).
  - On landing edges, move thickly built-up processor-generated bark back to solid ground.
  - Place the pulled-back slash and bark on the landing about 4 m back from the landing edge, preferably on the landing's hard surface rather than on the fill.

Installing drainage to control stormwater. Make sure perimeter drainage is in place and working by:

- Building berms around the landing edges to channel water to selected drainage locations. Construct the berm on top of the soil and not the slash.
- Out-sloping landing edges only where sufficient cover is in place to prevent scouring or soil consists of low erodible soils/rock; water must be able to drain freely off the skid without scouring or ponding.
- Checking and reinstating drainage around benches and other permanent slash storage sites as necessary.
- Taking slash offsite if it still poses a risk, (e.g. not in a long-term stable position).

Before: The bird's nest posed a risk to several houses below the landing. Slash should not have been initially put there. Major tension cracks indicated the fill was close to failure.

After: The risk of slash collapse was addressed by removing the bird's nest. A bench was constructed for an excavator to access the lower slash.

Left: A well-constructed berm suitable for a high rainfall area effectively channels water to a sediment trap. Out-sloping is an alternative, especially where berms would need ongoing maintenance or could lead to landing edge instability through water seepage.

Right: The temporarily stored slash has been placed within reach of a long-reach excavator so it can be retrieved.

Left: This landing was not rehabilitated and had a bird's nest failure four years after harvest.

Right: Tension cracks on the edges of landings can indicate minor fill settling or they can be the precursor of a potential failure. Relocate slash from the landing edge onto the hard surface before the crack. Install water controls to stop water getting into the crack and further lubricating that structural weakness.

After rehabilitation, this slash was left in a high-risk location. The excavator could not reach all the debris, and a burn to remove what was left was only partially successful. Landslides have occurred 20m on either side of the remaining slash (black arrows). The landslides triggered a debris flow that went to the gully floor (red arrows).

Checklists for managing slash on landings

Checklists for managing slash on landings		✓ Yes ✕ No ? Not sure
Pre-harvest slash management planning	Have slash volumes been estimated for slash storage areas?	
	Do all landings have safe and permanently stable slash disposal areas ?	
	Are off-site slash disposal sites required? If so, have these been identified?	
	Have temporary slash storage areas been identified and mapped? Is slash readily retrievable from these locations (e.g. with an excavator)?	
	Have slash structures been included in the landing design and construction?	
	Have "No-Go" slash zones been identified and mapped?	
	Does the contractor's prescription adequately cover slash management?	
Evaluating whether a slash storage area is safe and stable	Do the sites avoid old landslides, slumps, gully heads, or other erosional features?	
	Are there signs of slope instability such as existing slips, or tree movement like butt sweep that could indicate a site is not stable?	
	Is the site away from waterways or where the slash could roll or slide into the water?	
	Is the planned slash storage location on hard ground? Does it avoid uncompacted fill?	
	Are there signs of wet ground, (e.g. wet, swampy with sedges or rushes)?	
	Is the site located well away from indigenous vegetation, archaeological sites, or other restricted areas it could enter?	
	Are potential storage areas on a slope less than 20 degrees?	
Checking slash on landings during harvest operations	Is the slash stored in approved locations as required in the harvest plan?	
	Is the slash clean and not mixed with dirt?	
	Has slash been used to increase the landing's working area on non-approved sites?	
	Is storage space still adequate? Are there any anticipated storage problems?	
	Is slash on temporary storage sites still retrievable?	
	Are slash benches visible and not overfilled?	
	Is there slash that needs to be shifted or reworked at the storage areas?	
	Are water controls being maintained around slash to prevent water from entering areas with slash?	
	Has slash been cleared slash away from locations where it could block landing water controls?	
Additional landing controls for heavy rain	Are stormwater controls suitable for the anticipated rainfall around slash areas?	
	Do stormwater structures direct water away from fill, or if over fill, are they flumed or rock armoured?	
	Is all slash put in the designated locations? If not, is there an action plan to move it to approved areas before the heavy rain?	
Checking and sign-off of slash specific landing rehabilitation requirements post-harvest	Has the unstable slash been pulled back from the landing edge or removed from other temporary storage areas to a permanent site?	
	Has slash and bark been pulled about 4 m back from the landing edge, preferably on the landing's hard rather than fill? Is the ground visible through the remaining slash?	
	Is the drainage working around slash benches and other permanent slash storage sites?	

Chapter 5
Managing slash on high-risk cutover

In this chapter, you will find out:

✓ What is a high-risk cutover.
✓ How to estimate the volume of slash on a cutover.
✓ How to manage slash on a high-risk cutover at planning and during operations.
✓ What windthrow is, and potential management options.

High-risk cutovers need careful planning and operational controls to manage slash risks effectively.

What is a high-risk cutover?

The cutover is the land area the trees have been harvested from. A high-risk cutover is one which:

- is likely to slip or move under certain conditions (usually landslides and debris flows); and
- this movement would carry slash to a waterway, and off-site during flood events; and
- create moderate to major downstream impacts for communities, infrastructure, property, and the environment.

Removing slash from the high-risk areas of the cutover can reduce the slash mobilisation risk. High risk areas include:

- gullies with headwall;
- slope-breaks known to trigger slips;
- areas near/within ephemeral gullies that could intercept landslides or debris flow and channel them into waterways.

How to estimate the volume of slash on a cutover

Post-harvest slash volumes are measured to confirm they meet the forest manager's or regulatory requirements to remove slash. Remote sensing and machine learning are rapidly delivering alternatives to measuring slash volume through field assessments.

Line Intersect Sampling Method

The most common sampling method used to measure slash volumes is the Line Intersect Sampling method, similar to the Wager Waste Assessment. This sampling methodology has been used since the 1970s in New Zealand to calculate harvest residues on cutovers. It is still being used to measure slash on some sites and for research purposes (e.g. Harvey 2022).

$$V = \frac{\pi^2 \sum d^2}{8L}$$

The formula to calculate slash per hectare is:

V = volume per hectare (m^3/ha)

d = the diameter (cm) of each piece of slash intersected by the transect

L = the length of the transect line (metres horizontal)

Interpine Innovation has detailed information on the method at **interpine.nz/29-cutover-residue-assessment-using-line-intercept-sampling/**.

Typical hill country cutover slash loading with more slash lower on the slope. Slash often rolls or is "swept" downhill during extraction.

Measurement issues

Resource consents or regulations may require the removal of slash of a certain size from the cutover. It can be challenging to assess whether the quantity of slash on the cutover meets size or volume criteria, especially on steep and broken land.

- Many harvest settings are up to 500 m wide. Visually assessing the site without walking or flying a drone over the cutover is impossible.
- Walking steep slopes to manually measure slash is slow, difficult and labour-intensive. It presents health and safety risks due to steepness, thin soils, bluffs, and hazards from the residual slash. There are significant consequences if a person falls onto the slash or down the slope. Walking without putting in sampling plots provides no validation.
- Drones can be used to provide visual assessment of the harvest setting from a distance. Drone imagery will require additional technical assessment to determine individual slash dimensions and a cumulative volume.
- Sampling error can be significant because slash is not randomly distributed across a cutover. This makes statistical analysis of a size threshold difficult.

Forest Managers can assess the value of using a formal physical measurement process over other methods based on site and safety risks. A visual assessment (including with a drone) may work for experienced operators and lower-risk sites. Remote sensing technology and analytics may be more useful on higher-risk sites.

Managing slash on high-risk cutover

For forest managers with high-risk sites, slash management can reduce, but not remove slash risks, given the site risk. The primary risk drivers are landslides and debris flows (refer to Chapter 2)

For effective slash management on high-risk areas of cutover consider including the following steps:

Planning

Step 1: Identify high risk cutover.

Step 2: Assess risk and management options.

Operational

Step 3: Manage harvest operations.

Step 1: Identify high risk cutover

A high-risk cutover is prone to landslides or debris flows which provide the conduit to move slash. The factors that determine this are:

- geology and soils prone to mass-movement failure;
- high-intensity storms and high-intensity peak flows in catchments;
- proximity to waterways.

Offsite factors that increase risk include the forest's connectivity and proximity to downstream features such as roads, bridges, houses, beaches, water supplies and ecologically sensitive receiving environments.

"High-risk cutover" excludes slash in or close to rivers, as these are discussed in chapter 6.

The slopes of this high-risk cutover are prone to landslides and debris flows. There is a large slash loading, and a major river immediately downstream.

Step 2: Assess risk and management options

Forest managers use a range of pre-operational planning and operations systems. These include contracts, SOPs, operational prescriptions and maps, and monitoring checklists. These documents usually set out how risks will be managed.

When preparing the harvest plan, you could collaborate with the earthworks or harvesting contractor to consider all slash management options before finalising the harvest design layout.

As part of the harvest plan, consider doing a slash accumulation and mobilisation risk assessment:

- Are there stand factors that are likely to increase the amount of slash created and remaining on the cutover (e.g. large trees, older-aged stands, lower quality/unthinned stands, large areas of windthrow)?
- Are there areas of irregular or broken terrain likely to create poor deflection, reduce tree suspension and increase felling and extraction breakage (e.g. gullies that could trap slash)?
- If slash on the cutover were to move, where would it end up?
- Are there parts of the slope that present a higher risk than others?

To reduce the amount of slash left on high-risk cutovers, you could plan to:

- Reduce the risk of windthrow during earthworks and harvesting, (e.g. by opening the block to maximise opportunities to create wind firmer boundaries where possible).
- Reduce extraction breakage and slash accumulation by:
  - improving deflection and suspension where practical;
  - selecting machinery for the site and terrain, (e.g. using a tower rather than a swing yarder if it improves the harvesting outcome);
  - using a harvesting system method that managed the risks for the site, (e.g. bridle rather than highlead difficult areas);
  - reducing tree extraction across a slope in broken, heavily dissected country;
  - harvesting away from rivers.

Almost no slash was left on the cutover on this high-risk site. All landing slash was carted offsite. The decision not to establish the lower slopes in commercial forest creates a large risk mitigation buffer between the cutover and the major river in the shadows.

Step 3: Manage harvest operations

Operational cutover slash management aims to create less slash through felling and extraction methods, limiting slash in the difficult-to-access areas of the cutover, and removing slash as the operation progresses. A well-prepared management plan, a skilled harvesting contractor, and good operational supervision are important for achieving the plan for high-risk cutovers.

Removing all slash on a cutover is not possible, and potentially unsafe on many sites. Slash can be ‘swept’ downslope during extraction, especially when hauling a back face and during downhill extraction. Harvesting machines may not be capable of extracting the swept slash from gullies. The gullies may not be machine-accessible, or access is restricted (e.g. because of different ownership of the adjoining property).

Managing slash during harvesting operations

Aim to create less slash through good felling and extraction

Factors that guide the felling pattern include the landing location, topographical constraints, proximity to waterways, and the direction the trees lean.

Felling breakage could be reduced by:

- Using machine felling where possible for greater directional control to limit felling and extraction tree breakage, and to align trees with the extraction direction. Note that greater use of machinery may increase the amount of soil disturbance on the cutover.
- Using skilled felling operators if manually felling as it can be more difficult to precision fall on steep slopes as felled trees are more likely to slide.
- Using fixed-head felling machines over 'dangle head' where feasible for less stem breakage. (Fixed-head machines aren't generally suitable for trees beyond a 2-tonne piece size).
- Controlling tree felling and placement to:
  - Fell across rather than directly downslope.
  - Limit, where possible, striking rocks, other stems, windthrow, or stumps.
  - Reduce felling across broken terrain.

Extraction breakage could be reduced by:

- Using machinery, harvest system and carriages that suit the harvest area.
- Presenting stacks of felled trees in areas of improved lift (this may also improve the extraction costs and reduce environmental effects).

Mechanised harvesting options that can assist with extracting slash from the cutover, include:

- Hauler harvesting with fixed or rotatable grapple tongs. Tongs can have limitations when they cannot adequately grab the slash.
- Quick hitch slash-specific tongs that fit onto log extraction systems to improve slash removal.
- Specialty carriages for skyline capable yarders that assist with slash removal.
- Specially developed helicopter-mounted grapples have been used in some circumstances where slash mobilisation risk is very high. Helicopters have limits on the weight they can lift, and operational conditions that limit safe use, (e.g. deep gullies and windy conditions).

Where a risk analysis indicates that leaving slash on the cutover will create less environmental impact than removing it, or it is the appropriate health and safety response, the forest manager could discuss this with the council compliance officer and record the outcome of the discussion.

Left: Limited lift has resulted in gouging and soil removal of the intermediate ridge.

Right: A low residual slash cutover achieved by good terrain, little windthrow, and a capable contractor with the right harvesting machinery.

Managing production and cost pressures

Extracting small pieces of slash is expensive. Production and cost pressures may lead to shortcuts or take the focus away from slash management. For example:

- Extracting slash reduces production, and the slash takes up valuable space on the landing.
- Extraction of tree heads and other smaller slash is cost-negative to the contractor, and their harvesting rates may not reflect the forest manager's slash removal standards.
- Slash removal requirements must match machinery, terrain, and safety requirements, (e.g. can the grapple carriage access a deeply incised gully face or retrieve smaller pieces of slash)?

Left: Harvesting machines operating on steep slopes can fall and present trees in a way that reduces the likelihood of stem breakage during felling and extraction.

Right: Gully heads with steep headwalls are prone to failure. This cutover shows an example where only a light residual slash was left on the cutover (yellow arrow).

Left: An advantage of mechanised harvesting over manual harvesting is reduced breakage. A winch-assisted felling machine directionally falls trees and bunches them aligned in the direction they will be hauled to a landing.

Right: Low volumes of evenly distributed slash.

Windthrow

Windthrow describes trees toppled or snapped during high winds. Foresters also include 'dead and down' trees from landslides, waterway bank collapse, and natural tree mortality in this definition.

Windthrow generated through roading and harvesting activities and windthrow that naturally occurred before these operations started, have different characteristics and management options.

Pre-harvesting windthrow can be indiscriminate and extensive (hundreds of trees/hectare). In some instances, it can account for a significant volume of the timber remaining on slopes. Areas where it can commonly occur are:

- Along river margins, especially where there are minimal riparian management zone setbacks. Waterway banks may collapse at any time during a forest rotation, leading to trees toppling into the river.
- Along incised gullies and steep bluffs and associated with particular geologies, (e.g. scattered windthrow is common where there are shallow soils with hard bedrock underneath). A tree can only grow a shallow root system, so it is prone to tipping in strong winds.
- In forests subject to gale-force winds, which may be more prevalent at higher elevations.
- In the same areas over successive rotations.

Pre-harvest plantation windthrow along with indigenous vegetation caused by wind and bank collapse.

Pre-harvest windthrow often has no economic value unless the tree fell immediately before harvest. Any value can depend on the quantity, severity, and type of damage to the tree, its age, and whether rapid access to the windthrown area was possible.

It would be hard to determine whether this windthrow was pre-harvest or triggered by the harvesting operation.

In some areas of New Zealand, windthrow incidence can rapidly increase with age, generally as the trees reach their mid-20s. This incidence is caused by wind, steepness, and geology induced toppling. Forest managers may decide to fell the harvest areas at a younger age to decrease the risk of windthrow.

Harvest windthrow can occur once roading and harvesting activities start because these activities open the forest to the wind. Trees can blow over or snap in strong winds along road edges, at new landings and at the felling face. In some locations it can be common.

Roads and landings are not usually built next to waterways, so the direct windthrow risk to water from these activities is low compared to pre-harvest windthrow.

Severe pre-harvest windthrow on slopes and along the waterway. This cutover has an extremely high residual volume of pre-harvest windthrow. As the windthrow was non-merchantable, it wasn't extracted.

Managing windthrow

Planning options that may reduce windthrow

Minimising windthrow at roading and harvest can avoid costs. Damaged, leaning, snapped stems, and trees with root balls create health and safety risks during extraction, which slows production. Returns are reduced because logs have lower value or are unmerchantable. Replanting costs are higher due to additional land preparation and access issues.

You may reduce windthrow during earthworks and harvesting, by:

- Considering the wind risk when opening up the block.
- Reducing the number of partially logged areas that could channel wind.
- Keeping road line clearance limits narrow, to restrict wind funnels (existing road networks seldom generate windthrow because trees next to the roads are wind-firm).
- Harvesting into the prevailing wind, if feasible.
- Planning for wind-firm setting boundaries, e.g. do not leave boundaries of un-harvested forest on wind-exposed ridges.

Managing windthrow on very high-risk sites

Where safe to do so, windthrow needs to be managed on very high-risk sites vulnerable to landslides, earthflows, and debris flows to avoid it being remobilised into waterways, where it may cause impacts on- and off-site of the forest.

Windthrow removal requires sound planning and a detailed risk assessment because:

- Health and safety risks are high on steep hill country, especially for machine operators. For example, windthrow often requires root ball removal onsite, as trees are too heavy to extract otherwise. Severed root balls are a risk for harvesting and replanting crews because they can roll.
- Windthrown trees are under tension, which makes them less predictable when cut.
- Variability in the soundness of wood may lead to stem breakage (and potentially rolling/sliding) during hauling.
- It can rapidly make harvest areas uneconomic because extraction is slower and average log returns are generally much less.

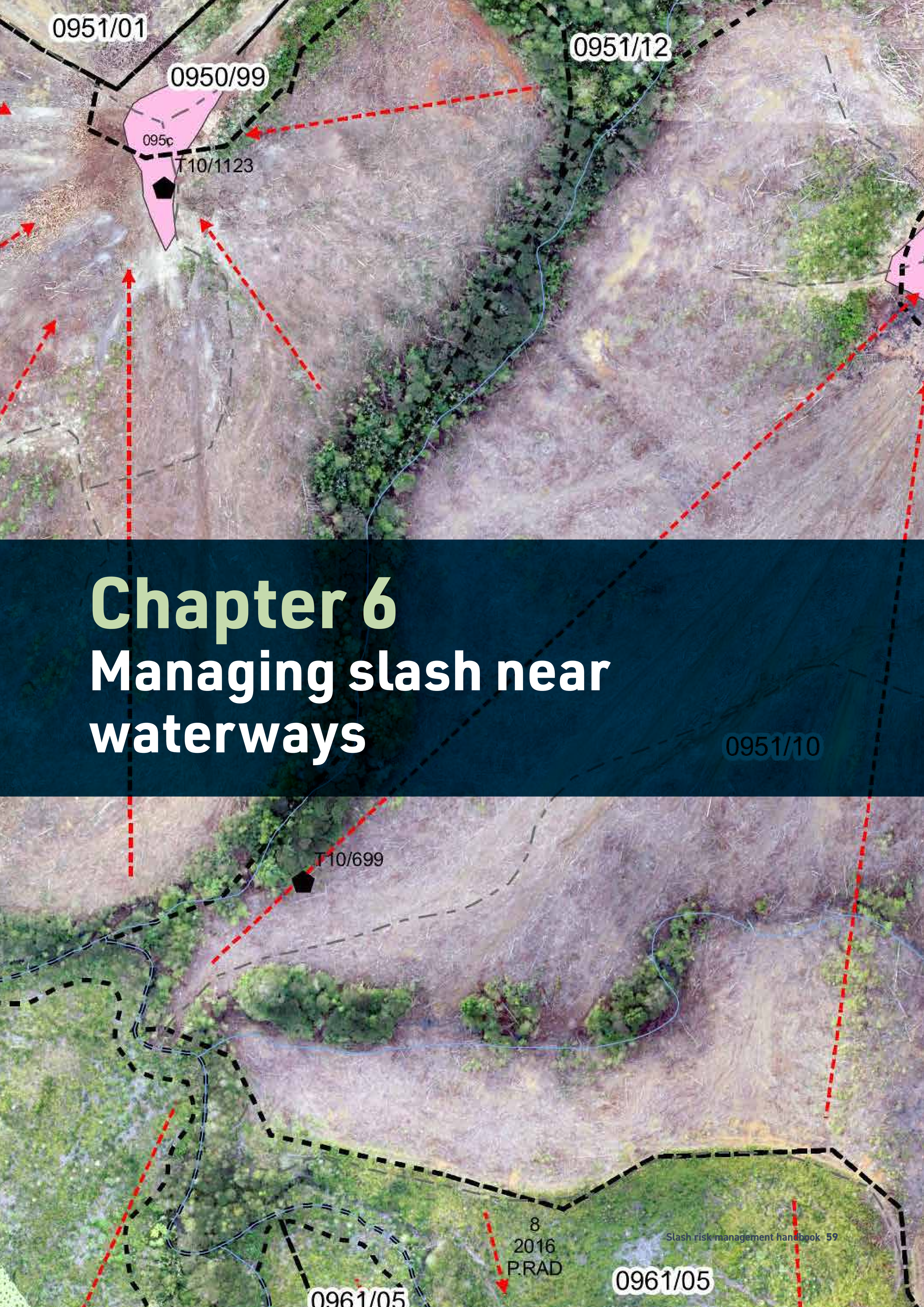
Management options could include:

- Removing all or some of the windthrown trees from high-risk sites to the landing.
- Shifting windthrow from high-risk sites to a part of the extraction line with a lower assessed risk.
- Leaving windthrow where it has fallen especially where the health and safety risks of removal are too great.

An example of harvesting-generated windthrow. The logging crew harvested a wide road line salvage strip cleared for road construction up to the top of a ridge exposed to gale force winds. Ground-based machines can easily salvage this windthrow.

Checklists for managing slash on high-risk cutover

Checklists for managing slash on high risk cutover		✓ Yes × No ? Not sure
Pre-operational planning on high-risk cutovers	Does the plan meet the regulatory slash management requirements, company policies and procedures, and industry best practices?	
	Have specific sites with increased risk been identified within the harvest area, and plans developed to reduce the slash issues in these locations?	
	Is the harvest block planned with the most appropriate felling and harvesting machines if choice impacts on slash retrieval?	
	Has the plan excluded harvesting areas due to unacceptable health and safety or environmental risks?	
	Does the site require a minimum slash extraction size?	
	If there is ground based extraction, have track location, operational management, and rehabilitation been adequately planned to maintain slope stability?	
	Does the plan consider ways to reduce felling breakage, (e.g. how the block is opened up, or the use of fixed-head felling machines)?	
	Have the impacts of poor deflection and broken terrain been assessed for the slash risk?	
	Does the plan include ways to reduce extraction breakage?	
	Is there a plan for windthrow management if leaving it in situ significantly increases overall woody debris mobilisation risk?	
	Have potentially affected neighbours and community been advised of the harvesting and the prevention and mitigation measures included in the plan?	
	Does the contractor's work prescription cover slash requirements on the high-risk cutover?	
Contractor checks for high-risk cutover	Are the crew meeting the forest manager's slash requirements, (e.g. within the contract, prescription, and map)?	
	Do tailgate meetings cover slash management on the cutover, including felling and extraction breakage?	
	Does the foreman check that slash volumes meet management requirements in hard-to-extract areas?	
	Have any harvesting plan changes that affect slash on high risk cutovers been approved by the supervisor before actioning?	
	Have any areas of slash left due to H&S risks been clearly written up, explaining the reasons, in the tailgate or felling notes?	
Supervisor checks for high-risk cutover	Are the harvest plan's slash management requirements clear?	
	Are the slash requirements within the contract, prescription, and map being followed?	
	Is the crew recognising and reacting to a slash problem before or as it arises?	
	Do slash volumes meet regulatory and company standards?	
	Are there indications that the crew is "normalising" the slash risks due to over-familiarity?	
	Are the production target and prescription requirements realistic for slash retrieval?	
	Is slash assessment included within formal operational monitoring?	
	Are regulatory requirements being met?	
Evaluating risks of harvesting generated windthrow	Is the area known for winds that cause windthrow?	
	Are the implications of roading, earthworks and harvesting on windthrow clearly understood? For example, do road line clearance limits consider the effects of windthrow?	
	Does the infrastructure construction-ahead position take advantage of wind direction, (e.g. harvesting into the wind)?	
	Do specific areas require partial or full windthrow removal?	
	Have harvest settings been scheduled with wind impact taken into consideration?	
	Has the implication of extracting windthrow with root balls attached been evaluated and documented compared to leaving the slash in situ with less soil disturbance?	



Chapter 6
Managing slash near waterways

In this chapter, you will find out:

- ✓ Why waterways can create slash mobilisation risks.
- ✓ How to use the River Environment Classification (REC) system to help identify waterway size.
- ✓ Options to manage the slash risks near waterways during harvest planning, harvest operations, and post-harvest rehabilitation.
- ✓ Different types of slash retention structures.

Managing slash mobilisation risks around floodplains, riparian areas or in waterways, along with slash risk reduction at the landing and on high-risk cutovers will help reduce overall slash mobilisation risks.

Protecting waterways

Woody debris is a natural part of a forested stream system. New Zealand research shows that low to moderate slash loading in smaller-sized, lower energy streams benefits aquatic biodiversity by providing habitat and food sources, and moderating water temperature. But large quantities of slash can block or dam a waterway, with significant effects if mobilised.

Waterways need to be protected during forestry operations, particularly harvest.

- Harvesting machinery can damage stream banks and beds, impact riparian management zones, and affect aquatic ecology. However, machinery may need to operate near waterways to fell and extract trees and to retrieve slash.
- Slash in a waterway can cause damming, erosion of riverbanks, impact aquatic life and create downstream damage to infrastructure or the receiving environment.
- Slash outside the waterway but within a flood zone is at risk of mobilisation.

Why waterways can create slash mobilisation risks?

Slash "near waterways" includes slash in or over the waterway as well as slash in the floodplain and riparian areas.

Slash can enter waterways by rolling and sliding down hillslopes during harvest operations, and via landslides and debris flows. Slash near waterways can be a major contributor to the overall slash mobilisation risk, (e.g. flood events that pick up any additional slash in the stream channel, floodplain, or riparian management zones).

Slash and other woody debris can also form debris dams in waterways. If these fail, they can release large quantities of stored debris downstream (refer to Chapter 2).

Landslides are a primary driver for slash in rivers.

Health and safety risks near waterways

There are health and safety risks to workers removing slash from waterways at harvesting or post-harvest rehabilitation, particularly on steeper and less accessible terrain.

In steep forest environments waterways can be small, narrow, and difficult to access. The slopes beside them can be steep and slippery, and sometimes covered with permanent vegetation which needs to be protected.

Felling and extracting trees on steep terrain next to waterways and the margins around them is difficult as they tend to slide or fall downhill. Refer to Chapter 3 on assessing health and safety risks and the Health and Safety at Work Act.

Riparian management zones

A "**riparian management zone**" refers to a specific setback width from the edge of a water body, (e.g. river, stream, lake, or wetland, where activities are usually restricted or may be allowed under certain conditions to minimise potential effects on the ecosystems of water bodies and the riparian vegetation). Riparian management zones are sometimes called streamside management zones, or riparian strips, areas, and setbacks.

Riparian management zones may help trap slash and other woody debris so that it is not swept or moved into the river. A riparian management zone's effectiveness in intercepting slash can depend on the size of a flood event, slope steepness and stability, riparian vegetation type, and width.

Riparian management zones may be damaged or destroyed in large floods, and landslides and debris flows. They can be effective in trapping slash in flatter areas where the flood velocity slows, and the sediment and slash start to drop out. A wider riparian management zone will likely intercept more slash than a narrow one, but this will be site specific. For example, a wider zone on a steeper site may provide a wider channel for slash and debris to move through, which may be more damaging than a narrower zone.

The slash in the gully below this cliff is inaccessible to people and machines.

Left: A post-harvest intermittent waterway showing the legacy of planting through the waterway 25 years earlier.

Right: This perennial waterway's riparian management zone setback can be seen after the pre-plant aerial spray.

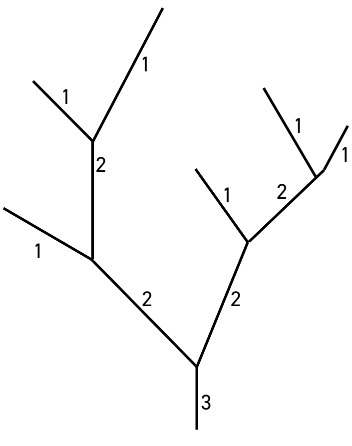
These two images show where the forest managers have kept as much of the indigenous riparian strip for these intermittent waterways intact as possible during ground-based harvesting.

The River Environment Classification system

The size and potential flow of a waterway are factors affecting the risk of slash mobilisation.

The River Environment Classification (REC) is a nationally recognised river classification system. It summarises every segment of New Zealand's river network.

REC uses a stream order classification, which gives numerical positions of a tributary or section of a river. Headwater streams are assigned an order of 1. When two tributaries of the same order meet, the order increments by one for the next section downstream. If two stream sections meet where one section has a higher order than the other, then the next section downstream has the same order as the highest upstream section (refer to the diagram below).



A higher order stream will usually carry more water than a lower order stream. Given this, it carries a greater risk of slash mobilisation and transport. Other factors that influence the energy and volatility of water flows in any stream, such as gradient and hydrology, also need to be considered when assessing slash mobilisation risk.

Stream mapping scale

The REC is scale dependent. The national coverage is at 1:15,000 and based on a 30 m digital elevation model.

Forest managers often use a 1:5,000 scale with high-resolution LiDAR contour data, so the scale and resolution may identify additional river sections. The User Guide can be found at **https://data.mfe.govt.nz/layer/51845-river-environment-classification-new-zealand-2010-deprecated/**.

New Zealand Topographical maps generally show permanent and some intermittent waterways. On occasion they also show watercourses where none are flowing (e.g. the central plateau). The mapping scale may be too coarse to indicate ephemeral waterways.

Measuring flood probability

Annual Exceedance Probability (AEP) is the probability of a particular size of flood flow occurring in a single year. For example, a 5 percent AEP flood flow has a 5 percent, or a 1-in-20 probability of occurring in any one year.

Annual Return Interval (ARI) is the average number of years between floods events of a certain size. For example, a 20-year ARI event would happen on average every twenty years.

AEP and ARI provide a probability that an event will occur, based on past experience. They are not predictive – it is possible to have a 5 percent AEP event in a single year, and then the following year.

Regional Councils usually have rainfall and river level data available, often through their websites, and NIWA can supply HIRDs data (refer to Chapter 2). However, the HIRDs estimates are generally easier to interpret and more accurate for larger rivers than the smaller 1st and 2nd REC order rivers more common in forests.

Left: The slash and other woody debris (poplar) are stacked outside of the REC class 2 waterway, and three years after harvest, it has not moved. It is not known what size flood event would mobilise this slash or whether the stability is a result of good luck or good management.

Right: The slash is stacked too close to the class 2 river.

The slash was not removed from a short section of the river when logging across this perennial waterway.

Left: Slash, including entire stems, remaining in the ephemeral gully post-harvest.

Middle: The slash is stacked within the waterway.

Right: This landing (yellow arrow) was built immediately next to a river, and the slash was pushed into and not extracted from the waterway.

Left: The ephemeral waterway was completely modified first as an extraction route then during excessive slash removal.

Right: These stems should have been removed during harvesting.

Managing slash risk near waterways

Understanding a river's size, energy, and storm response will help identify gullies and waterways that could collect or contain hard-to-extract slash that also has a risk of mobilisation.

Slash may move slowly through a river system, progressively moving downstream with each high-energy flow event, thus having an ongoing impact for years.

These sites may have some of the following features:

- Short, steep terrain above waterways. The steeper the terrain, the greater likelihood that slash will migrate to waterways during tree extraction.
- Steep and incised banks. These collect slash and make retrieval difficult.
- Larger and higher energy waterways to transport

Left: The operational challenges of removing slash increase in complexity from easy rolling ground-based harvesting

Right: to hauler extraction in steep, bisected country with inaccessible and incised rivers.

slash, especially those with direct connectivity to vulnerable downstream areas.

- Evidence of risk or a known history of landslide and debris flows. (e.g. past landslide scars, waterways with debris deposited on and above their flood plain).
- A high density of streams. The greater the number of streams within or near a harvest site the greater the cumulative quantity of slash that will need to be managed near waterways.

During harvest planning

In the harvest plan, you could include options that reduce the amount of slash near waterways within the overall harvest design layout by:

- Using the right harvest system and harvest machines for the job, especially where the slash is at high risk of entering waterways. For example, ridge-to-ridge logging can substantially increase waterbody slash loading when the slash is swept or dragged downhill.
- Identifying on the harvest plan any high-risk slash areas and No-Go zones near waterways for machines. Identify any areas where slash cannot be retrieved.
- Planning to maximise retrieval of slash near waterways. Where the risks of retrieval are high you may consider whether some trees are better left unfelled (balancing this risk with risks of windthrow discussed in chapter 5).
- Where possible, identifying slash storage areas that will keep slash above the flood zone, especially in non-machine accessible and steep banked rivers.
- Considering ways to manage the potential mobilisation of slash where on-site mitigation does not lower risk to acceptable levels. For example, use a slash retention structure downstream if this is consistent with a risk-based assessment.

Consider whether authorisation from the council is required before disturbing or operating a machine on the riverbed.

During harvest operations

Slash removal near waterways can be difficult and sometimes ineffective.

Keeping slash out of waterways in ground-based mechanised operations can be easier than in hauler operations, as the terrain is less challenging, and the machines have more control over felling and extraction. Slash removal is also easier.

Consider the following operational management ways to manage slash risks near waterways:

1. Operational prescriptions and maps

- Have a clear operational plan for managing slash near or in waterways.

2. Supervision

- The contractor and supervisor are clear about slash removal requirements and agree on the slash management aspects of the plan.
- The forest manager agrees and signs off any plan changes affecting slash volumes near waterways.

- The contractor does regular self-audits of slash near waterways.
- The forest manager regularly audits the contractor and their audits.
- A photographic record of slash management activities is kept.

3. **Felling and extraction**

- Limit tree breakage during felling and extraction near waterways.
- Consider leaving higher stump heights along the edges of waterways where slash extraction is difficult to provide natural "guardrails" for slash outside the flood zone. Consider whether these may create barriers for machines and traps for hauler lines and logs.
- Leaning trees are often difficult to fell and extract. Use mechanised felling to reduce leaning trees from falling into waterways, if possible. Excavator-based machines with felling/cutting heads can better place slash outside a flood zone.
- Avoid trimming or heading near waterways.
- Avoid damage to riparian vegetation, or if unavoidable, limit the impact. Preserving riparian vegetation where possible will maintain shade, habitat, and erosion control.
- If available, use designated corridors to limit the zones where trees are extracted over/through waterways.
- Avoid extracting trees down waterways.
- Where possible extract directly across the waterway.
- If practicable, maximise deflection to improve lift when hauling across waterways and keep the stem butts raised above the waterway.
- Consider extracting other woody debris near waterways on very high-risk sites.
- Remove the slash on each line shift. Going back for slash requires double handling and additional machinery movements.
- Ensure health and safety risks are managed where manual extraction is the only option, including where machines cannot place slash above a flood threshold, (e.g. incised gullies).

The area in the image was shovel-logged uphill instead of hauling across the waterway.

Post-harvest rehabilitation

Post-harvest rehabilitation can manage slash near waterways when it was not removed during harvest.

Decisions on rehabilitation can include:

- How far slash should be moved from a waterway to avoid it being caught in a flood flow. This could be informed by rainfall patterns, previous flood levels and storm risk.
- Removing slash from the waterway sooner rather than later. Where the risk of slash mobilisation is high, slash removal should start straight after harvest, before forecast heavy rain or periods of increased storm frequency.
- Using the right machine for rehabilitating the waterway, (e.g. placing the slash outside the flood zone).
- Removing slash to reduce cumulative risk that is rated as high.
- Limiting machine passes over the same ground. The more track movements, the greater the disturbance to the riverbank or bed.
- Not operating machinery during the fish spawning season, in the riparian management zone near a waterway.

Post-harvest weather events may introduce new slash into waterways, (e.g. via landslides or debris flows or remobilise existing slash in or near waterways). Monitoring waterways after storm events will identify when additional slash needs to be removed from waterways.

Different types of slash retention structures

Slash retention structures catch slash that could migrate out of a catchment. They are not a substitute for good on-site management but can be part of a broader slash management strategy. Slash traps, slash nets, and living slash traps are potential options.

Slash traps

Slash traps, also called debris traps, are generally constructed in the channel. Depending on the site, they work well in smaller catchments up to a few hundred hectares. Resource consent may be required.

Their effectiveness is through experience rather than engineering analysis. There is no "approved" standard for their design, but rather some basic construction principles. Most slash traps use railway irons driven into the ground at regular spacing (approx. 2m) with a single or a series of wire ropes threaded through the iron and anchored into the streambanks. The anchors are generally "deadmen" (buried logs) or stumps. This makes them cheap and quick to install.

Their functional limit can be unpredictable because:

- calculating an expected debris load from a storm event is not possible;
- they are at risk of failing in larger flood events. A failure can mean the sudden discharge of the trapped slash;
- they can fill up rapidly during periods of high rainfall.

Slash traps should not be used if they will:

- alter the natural alignment of the river;
- change the river gradient by creating a weir because debris has built up behind the structure;
- cause erosion of the banks and bed of a river;
- adversely affect downstream properties.

Slash trap design and location

When developing a slash trap, some factors to consider could include:

- Designing to allow water to flow freely through the structure and allow for fish passage.
- Locating to maximise slash capture without overloading the design. This may be outside the riverbed. They can still be very useful here, as they can capture the flows overtopping the banks on the outside bend of a river in high flow situations.
- Locating in a low gradient reach of the river, where the combined energy of water and the weight of debris on the trap will be minimised during peak flows. This helps to minimise the chance of structural failure.
- Locating where it can be machine-cleared of slash and debris.
- Providing a site adjacent to a large flat area above flood flow level for storage of debris the trap intercepts. A close site will reduce the cost of maintaining the slash trap.
- Positioning at right angles to the river or stream. If there is a natural bench, slightly angle the trap downstream to aid in capturing the slash.

For larger catchments consider having them designed by a Certified Professional Engineer (CP Eng) to incorporate engineering and hydraulic design. Design requires Producer Statements (PS1 to PS4) to be lodged with the relevant Regional or Unitary Council. A risk assessment can be used to determine where they may be appropriate. Consider whether a series of slash traps (two or more) would be a better solution than one. Documenting design, construction, and location, including with photos can be helpful to track effectiveness.

For more information on the design of slash traps see the New Zealand Forest Owners Forest Practice Guides.

Slash trap maintenance

Maintenance could include:

- Inspecting the trap regularly, particularly after rainfall which is likely to mobilise debris. The cumulative impact of many small events may also be sufficient to fill a trap.
- Maintaining the trap to avoid riverbed erosion and ensure the structure's soundness.

Slash nets

Slash nets are effective at trapping slash and other woody debris but are not common in New Zealand.

Slash nets are designed to allow water to pass through even as slash is trapped. During a flood additional slash and debris is able to over-top the net once the net is full. Slash nets require engineering design and installation sign-off. The slash net is constructed above the waterway, so no modification to the waterway bed is required.

Left: The slash trap was designed to direct slash onto the floodplain. Instead, it failed due to a weak anchor.

Right: The slash trap should not be constructed across a major waterway.

Left: Bridges are usually sited at the narrowest waterway width. Constricted waterway sections may also bottleneck or accumulate slash.

Right: This slash trap is a non-engineered structure in a large catchment (>1000 hectares). It will likely fail in a significant event because it won't withstand the volume of debris and water that such a large catchment could generate and deliver.

A railway iron/cable debris trap anchored by stumps in a catchment <20 hectare.

The Hawke's Bay slash net.

Living slash traps

Living slash traps are strategically located trees designed to trap slash and other woody debris.

Species such as poplar, eucalyptus, pine or willow can be planted in a herringbone pattern on either side of the waterway for the next harvest. These species grow into mature trees relatively quickly and have excellent root systems. Poplar and willow are very tolerant of "wet feet".

Purpose-designed and planted living slash traps need about 20 years to establish. If there are no established living slash traps for the upcoming harvest, existing crop trees could be used if planted to the waterway banks. The trees must be kept post-harvest until the new forest has been established, and slash mobilisation has reduced to a low risk.

The relative merits of live or installed slash traps will vary by site and region depending on geology, topography, and growing conditions.

When selecting a location for a living slash trap you could consider the following:

- Identifying mature crop trees parallel and immediately adjacent to the waterway that can be left post-harvest.
- Living slash traps are likely to be most effective where the waterway velocity reduces, usually in the lower catchment area or at a significant grade change.
- Having multiple living slash traps in the upper catchment if the risk of slash mobilisation is high.

Example: slash net, northern Hawke's Bay

The slash net was installed and maintained under a Hawke's Bay Regional Council (HBRC) resource consent. Since installation it has successfully captured slash and other woody debris mobilised by rainfall-induced landslide events.

Resource consent conditions included:

- Inspection every three months and within five days of significant rainfall events (defined as >50 mm/24-hour period).
- Clear accumulated debris
- Installation under strict parameters to limit the environmental impact, including provision for ongoing fish passage.

Forest manager to submit an annual report detailing maintenance frequency and clearance of the slash net, including photos and any observations of blockages to fish passage, disturbance of the waterway bed or banks, or damage to downstream property or infrastructure.

Left: An incidental living slash trap. Mature trees planted along the waterway banks can trap mobilised slash. However, the slash was not easily retrievable, so it can be mobilised in future storms.

Right: A living slash trap planted post-harvest for the next rotation's harvest in about 20 years.

Checklists for managing slash near waterways

Checklists for managing slash on waterways		✓ Yes × No ? Not sure
Contractor checks for managing slash near waterways	Are the crew meeting the forest company's slash requirements near waterways, (e.g. within the contract, prescription, and map)?	
	Do tailgate meetings cover slash management near waterways, (e.g. felling and extraction breakage near waterways to reduce the slash needing removal)?	
	Is the foreman visually checking that the slash is removed to the approved standard before each line shift?	
	Have any plan changes that affect slash in or near waterways been approved by the supervisor before action?	
	Have any slash not been cleared out due to H&S risks been clearly written up, explaining the reasons within the tailgate, or felling notes?	
Supervisor checks for managing slash near waterways	Are the harvest plan's slash management requirements clear?	
	Are the slash requirements within the contract, prescription, and map being followed?	
	Is the crew recognising and reacting to a slash problem before or as it arises?	
	Do slash volumes meet regulatory and company standards?	
	Are there indications that the crew is "normalising" the slash risks near waterways due to over-familiarity?	
	Are the production target and prescription requirements realistic for slash retrieval out of waterways?	
	Is waterway slash assessment included within the manager's formal operational monitoring?	
	Are regulatory requirements being met?	

Chapter 7
When very high mobilisation risk remains

In this chapter, you will find out:

✓ Some catchment level forest harvest approaches for very high-risk sites where the management approaches set out in preceding chapters are not enough to manage very high slash risks.

As Chapter 2 outlines, underlying land instability is the primary trigger for slash mobilisation. In the past, some forests were planted on erosion-prone land to stabilise erosion, including on land that was highly erodible under pasture. Harvesting those forests re-exposes the underlying land and its risks. This can significantly increase landslide and slash mobilisation risks. Leaving the forest to grow on without harvesting may not be a good solution.

Chapter 3 provides ways to assess the slash mobilisation risks and works through a method to assess the consequences and likelihood of the slash mobilisation risk, and the possible residual risks after mitigation measures are completed.

Chapters 4, 5 and 6 set out a range of options and practices that can be used to address slash mobilisation risks. For some sites multiple practices may be required. If, after considering or trying these options, you find that the slash risk remains very high to extreme, you may consider alternative land management options. This chapter provides a high-level introduction to some of these options. It is only one part of the much larger subject of land management, which extends well beyond managing the risk of slash mobilisation.

Addressing a complex problem

This chapter is silent on the suitability of any specific approach because every site or catchment is different. Land management approaches need to reflect the site's or catchment's individual characteristics.

Catchment constraints

Catchment constraints limit the overall area that can be harvested over a specified period, typically as a percentage of the catchment. They are used in some New Zealand plantation forests. Catchment constraints generally use area exposed and time periods to manage the effects of scale and intensity of harvest on hydrology. For example, harvesting not exceeding a third of any catchment greater than 250 hectares in a rolling 5-year period.

The size of the catchment where a constraint is considered, and the other land uses within it are important. Larger catchments are likely to have many different land uses.

During storm events, flood conditions can generate landslides, sediment, woody debris (including slash) and non-woody debris across all land uses. In catchments with a large amount of commercial forestry, slash may be a higher proportion of debris mobilised than those with a smaller proportion of commercial forestry.

Clearcutting large catchment areas may change the hydrological response to rainfall events, as trees no longer provide evaporation and transpiration, so soils can become wetter when exposed to rainfall.

Vulnerability to erosion and landslides also increases in this period.

No research is yet available to clarify whether harvesting a catchment over a short period exposes it to greater slash mobilisation risks than harvesting over an extended period. Research results would be highly dependent on when severe storms, if any, hit the project areas. The harvesting exposure risk is unknown because the future location, timing, and intensity of storms are unpredictable. The risk becomes one of assessing probability. For example, is it better to harvest over a short period, leaving a greater percentage of the catchment exposed to slash mobilisation risks? Or cut the area over a longer timeframe, recognising that extends the exposure time to storms, albeit on a smaller harvested area?

There are potential costs associated with a change in a planned harvest regime once a forest is planted. Where slash mobilisation risks are very high, there may be strategic advantages to harvesting over multiple years to help spread out the area replanted. The intention is over multiple rotations to spread the age class distribution over a rotation.

Clearfell limits (coupe harvesting)

Coupe harvesting refers to setting limits on harvest area.

Clearfell limits restrict the maximum area that can be clearfelled in any one operation and are often combined with a limit on how soon any adjoining area can be harvested.

Clearfell limits are widely used in commercial forestry internationally (Visser, 2018), with a variety of rules and purpose. Not all forests, or areas within a forest, have similar risks, even in similar terrain, so clear objectives and site-specific assessments are important.

In New Zealand, the purpose of self-imposed catchment and clearfell limits has been erosion and sediment control. In other countries, the purposes often originate from hydrological, ecological, wildlife, or aesthetic values.

Clearfell limits are identified as one of the key strategies for minimising the risk of debris mobilisation in the Eastland Wood Council Good Practice Guide for Catchment Management developed for plantation forests on the East Cape of the North Island. It also highlights the opportunity to identify specific areas in a catchment to defer for harvesting. This can include headwater segments of the catchment that are most at risk of mobilisation, as deferring harvest will allow the lower reaches of the catchment to "green up/ re-establish in vegetation".

A significant effect of clearfell limits is the increased risk of post-harvest generated windthrow. This is because coupe boundaries may no longer follow logical edges, and the increase in roading and associated earthworks potentially increase the risk of unstable land.

Adjacency constraints (green-up rules)

Adjacency constraints or "green up rules" are intended to ensure clearfell limits are not simply a series of continuous smaller harvests. For example, in Oregon, in the United States, clearcuts are limited to about 50 hectares (120 acres), with adjacent areas in the same ownership not allowed to be clearcut until the trees on the original harvest site are well-established, usually at about age four. This tends to create a checkerboard look when viewed from above, though different rules and landscapes will produce different effects.

Continuous-Cover Forestry

Continuous-cover forestry is a management regime that involves selectively harvesting or thinning trees to maintain a continuous forest cover. This means there is no "window of vulnerability" for the forest. This has been suggested as an option at high-risk sites (Amishev and others (2014)).

Left: New Zealand harvesting is characteristically clearfell harvesting, often over hundreds of hectares.

Right: Aerial imagery of harvesting activity in California, USA, showing the clearcut size limit, adjacency constraints and the use of permanent riparian management zones.

Left: This sensitive catchment has council-imposed green-up and clearfell size rules. Three-year-old trees are in the background.

Right: This Northland forest shows evidence of green-up provisions and headwater catchment constraints (white arrows).

Some small forest areas in New Zealand are managed under continuous cover. This harvest model suits high-value species and boutique forestry on easier terrain. Harvest systems and machinery differ from those used for clearfell harvest.

It would be difficult to implement this approach for an existing forest planted for clearfell harvest. For example, issues such as windthrow, managing forest age structure, sourcing machinery, creating harvest access, and economic viability. Also, the predominant commercial species, *P. radiata* is not a shade-tolerant species, so an uneven age class within a forest area would result in suppressed or dead trees.

Transitioning an existing forest planted for harvesting to continuous cover may be extremely challenging. There are multiple considerations requiring significant input from a range of experts. For example, continuous-cover forestry for *P. radiata* would consist of small forest clearcuts, requiring a significantly different economic model and silvicultural management.

What happens if harvest is not possible?

In some instances, the instability of the land and the consequential risk of slash mobilisation may make continued use of the land for plantation forestry non-viable. This may be because the:

- post-harvest residual risks are deemed too high, regardless of harvesting mitigations, given the risk of the location and landform;
- cost/benefit analysis showing that the required slash mobilisation risk mitigation, in conjunction with operating costs, make the forest or harvest area marginal or uneconomic;
- risks of slash mobilisation mean the social license to operate is not forthcoming.

Post-harvest slash risks could apply to discrete, localised, and highly vulnerable steeply incised gullies where slash cannot be retrieved.
This risk may also apply to larger-scale landform features such as steep, slip-scarred, highly erosion-prone faces.

Alternative forestry practices may include:

- transitioning certain areas to a permanent or continuous-cover indigenous forest;
- re-planting all or part of a harvested area in long-rotation, higher value species, including both introduced and indigenous species;

- re-planting with coppicing tree species, which regrow from tree stumps, so the existing network of roots remain alive to maintain soil stability, (e.g. redwoods and eucalyptus).

Changing species and silvicultural practices may improve the hydrological and mechanical reinforcement properties of the soil during the post-harvest "window of vulnerability". For example, reactivated landslides may need species that provide a better option for soil stabilisation than the existing crop provides. These might be exotic or indigenous, though options are often limited. Many species will not be viable on highly erosion prone sites. This Handbook does not assess the suitability of individual species.

Not harvesting may increase long-term risk

Generally, it is best to harvest the existing crop if it can be done safely. Leaving large areas of plantation forest unharvested on high or extreme-risk sites is unlikely to be the best long-term risk management solution. This includes leaving crop trees near waterways at high-risk sites, where the forest was planted up to the stream edge. If left, the trees will increase in size and become more likely to topple into the waterway, creating greater risk of off-site movement of woody debris.

Unintended Consequences

The options for managing slash mobilisation where standard mitigation will not lower risks to tolerable levels are complex. They span social, environmental, and economic factors. For example, in areas where unstable land is making forestry harvest a significant challenge, other primary production options have often proven unsustainable. Identifying sound solutions that meet social, economic, and environmental goals is challenging.

The sites where standard mitigation will not achieve a positive outcome are some of the most unstable terrains in New Zealand. No land cover can prevent slope failure, especially during severe weather events, or a sustained high rainfall weather pattern. Sites prone to shallow-rapid landslides remain prone, regardless of land use, because the causes of the landslides will remain.

Introducing catchment constraints, clearfell limits and adjacency constraints, could mean the projected age at harvest creates extraction and marketing challenges. This is because the logs are too large for standard equipment and mills to process them. Large areas of forest on vulnerable land were established over a short period as a means of stablising the land. This means that there is a harvest window of about ten years. For example, a 5000-hectare forest would require clearfelling at a rate of 500 hectares a year. If harvest restrictions reduce this rate, then the forest remaining after the 10-year harvest window is not suitable for harvesting or processing machinery.

The most significant unintended consequence is these forest areas will not be logged. This may leave the land subject to greater environmental and downstream risk in future weather events if land under whole forests fails. There may also be major knock-on effects for regional economies and employment.

Another significant unintended consequence of leaving forest areas is increased risk of post-harvest windthrow. This is particularly important where there is a combination of:

- forests or harvest areas in areas known for strong winds, (e.g. equinox gales);
- the geology and soils predispose the trees to toppling, (e.g. shallow ash over mudstone);
- the trees grow faster and are larger at felling age due to growing conditions, genetics, or silviculture;
- the trees have been grown-on because of clearfell limits.

Left: The tipping forces of these trees pop the root plates off the consolidated mudstone, leading to large volumes of fallen stems before harvest. Shallow soils, heavy rains, 45-degree terrain, and old and tall trees all help make them slide, fall, or blow over. On current projections, this country is certain to have a significant landslide triggering storm event with a 10-year return period.

Right: A shallow landslide has transported mature trees down into the river. Retrieving these trees will be difficult, dangerous and possibly unachievable. This area will likely be unplantable when adjacent slopes are replanted in subsequent rotations.

Glossary

Afforestation: In this handbook, this refers to the planting and establishment of forestry trees on land that has not been planted before in forest.

Annual Exceedance Probability (AEP): The probability of a particular size of flood flow occurring in a single year.

Annual Return Interval (ARI): The average number of years between flood events of a certain size. Also known as the annual recurrence interval.

Aspect: The compass orientation of a slope.

Bedding planes: The surface that separates one layer of sedimentary rock from another layer of sedimentary rock.

Bedrock: The hard, solid rock beneath surface materials such as soil and gravel.

Bench: A ledge cut into natural ground to contain fill, or a step cut into a batter to make it more stable.

Bin wood: Short pieces of stems removed from the forest in bin trucks rather than a standard logging truck.

Bird's nest: Slash put over the side or on the edge of a landing.

Bridle: A term used in hauler logging to help extract trees that are not directly under the ropes. This enables less accessible wood to be pulled, especially where the ropes cannot be shifted underneath them.

Butt sweep: A curve in the base of the tree or log.

Catchment: The basin that captures water that flows or drains into a waterway, lake, or wetland.

Clearfell: Harvesting all the trees within a given area.

Colluvium: Loose, unconsolidated sediments deposited at the base of hillslopes.

Commercial forestry: In this handbook, commercial forestry refers to the activity of growing trees for harvest.

Consequence: A consequence is the outcome of an event affecting objectives. An event can lead to a range of consequences. A consequence can be certain or uncertain and can be positive or negative. Consequences can escalate through knock-on effects (AS/NZS ISO 31000 2009 Risk management principles and guidelines).

Continuous-cover forestry: A management regime that involves selectively harvesting or thinning trees to maintain a continuous forest cover.

Coppicing species: Tree species that grow new shoots from their stumps after they have been felled.

Coupe harvesting: Setting limits on the size of a clearfell harvest within the larger harvest area.

Cutover: A clearfelled area of forest.

Dangle head: A type of felling head that dangles from the end of the felling machine's boom freely rotating rather than being fixed. See fixed head definition also.

Deadmen: Solid objects, usually logs, buried in the ground to form an anchor for a logging machine.

Debris dam: A dam created when enough sediment and woody debris accumulate to dam a waterway.

Debris flow: A type of landslide. Debris flows occur when intense rainfall events on steep slopes activate fast-moving landslides containing large quantities of sediment, water, and wood, that can be channelised into waterways before terminating on flatter downstream areas.

Deflection: The amount of sag in the cable logging machine's lifting rope when extracting trees.

Earthflow: Earthflows are a type of landslide that can occur on less-steep slopes. A large slope failure of soil and weathered, crushed rock, saturated with water, that flows downhill under the pull of gravity. Earthflows typically have a bulge at the bottom of the slope.

End-haul site: An off-site disposal area where excavated material is transported to during operations such as road construction and quarrying.

Ephemeral waterway/gully: An ephemeral waterway is where the water only flows during and immediately after rain. An ephemeral gully is the channel created by ephemeral flows.

Erosion: Erosion refers to the wearing away and movement of soil and rock by natural forces such as wind and water.

Excavator: A tracked, turntable-mounted, boom-equipped machine with specialised attachment to perform tasks. In forestry, excavator machines can construct roads, fell and cut trees into logs, and load log trucks.

Faults: In geological terms a fault is a fracture or zone of fractures between two blocks of rock.

Fire season: A period of time when certain fire requirements or restrictions apply to lighting fires in the open air. New Zealand has three types of fire season: open, restricted and prohibited.

Fire weather indices: A general index of fire danger for the rural areas of New Zealand. Six components relating to fire risk are used to calculate the Fire Weather Index. The indices cover areas such as the depth and dryness of the litter on the ground, the weather conditions and how the fire is likely to behave.

Fixed head: A fixed felling head is attached to the end of a boom on a felling machine.

Forest modelling: A forest model is a computer representation of the forest and how it grows. Modelling is a way to analyse different management options, e.g. options around how much forest area is available to harvest, and where, over time.

Forest valuation: The process of determining the value of the forest.

Full suspension: A cable logging term to describe when a log or tree is entirely lifted above the ground when hauling it to a landing.

Geographic information System (GIS): A computer system for capturing, storing, checking, and displaying data related to positions on the Earth's surface. GIS can show different kinds of data on a single map, such as streets, buildings, and vegetation.

Geomorphology: The study of relief features of the earth.

Grapple: Tongs that are used to pick up logs and slash on both ground-based and cable-logging machinery and log loaders

Ground-based harvesting: Harvesting carried out using wheeled or tracked harvesting machines.

Harvesting: Felling, thinning, or extracting trees, and including processing trees into logs, and loading logs onto trucks for delivery.

Hauler: A harvest machine that uses cables to extract felled trees from the stump to the landing.

Headwater catchment: Headwaters are the source of a stream or river. A catchment is the area of land that feeds rainfall or spring-fed water into the stream or river.

Highlead: A type of cable logging system.

Infrastructure: Refers to fixed, long-lived structures such as, roads, landings, buildings, bridges, culverts, and river crossings.

Intermittent stream/waterway: Streams that cease to flow for a period of time each year.

Landing: An area of land where logs or tree lengths extracted from a forest are accumulated, processed and loaded for removal. Also known as a skid.

Landing fill: Soil or aggregate placed, and usually compacted to raise and/or level the surface of a landing.

Landslide: Describes a number of mass movement erosion processes, including rock fall, shallow soil slip and deep rotational slope failure.

Land Use Capability: The Land Use Capability system categorizes land into eight classes according to its long-term capability to sustain one or more productive uses based on physical limitations and site specific management needs. Productive capacity depends on physical qualities of the land, soil and environment.

LiDAR: (Light detection and ranging) is a remote sensing method used to examine the surface of the Earth. It is commonly used to make high resolution maps, and it can "see through" vegetation to the ground below, highlighting any hidden landscape features, such as slip scars.

Line shift: Shifting the cables of a hauler system across the slope into a new position while the hauler machine remains in its position.

Living slash traps: Strategically located trees designed to trap slash and other woody debris.

Mass movement: A process of erosion which involves the movement of large amounts of rock or soil down slopes under the force of gravity.

Mitigation: The process or result of making something less severe, dangerous, painful, harsh, or damaging.

Practicable: Possible or capable of being done.

Processing slash: During the log making process, wood not suitable for logs becomes processing slash, also referred to as residues.

Pruning: Removing the lower branches of a tree to create knot-free wood.

Rehabilitation: A process to restore harvesting infrastructure once harvesting activities are complete, e.g. to control erosion and slash risk on a landing, road or track.

Replanting: The planting and growing of commercial forestry trees on land less than 5 years after commercial forestry harvesting has occurred.

Risk: A risk is the effect of uncertainty on objectives. An effect is a deviation from the expected and can be positive or negative. Objectives can have different aspects such as financial, health and safety and environmental goals. Risk is often expressed in terms of a combination of the consequence of an event and the associated likelihood of occurrence (AS/NZS ISO 31000 2009 Risk management principles and guidelines).

Riparian area: Refers to a strip of land that extends along the edge of a stream, river, lake, or wetland. These areas are located in a transition zone between the edge of a freshwater body and the upslope terrain, so they contain a mix of aquatic and terrestrial characteristics.

Riparian management zone: A specific setback width from the edge of a water body (e.g. river, stream, lake, wetland) where forestry activities are usually restricted, or may be allowed under certain conditions, to minimise potential effects on the ecosystems of water bodies and the riparian vegetation. Riparian management zones are sometimes called streamside management zones, strips, or setbacks.

Setting: An area of forest that is harvested to an individual landing. A setting can be the harvested area, or several settings may make up the harvest area or "block".

Shovel-logging: A method of moving logs from the cutover to the landing or road. The machine moves across the setting or harvest area, grabbing logs/trees within reach and swinging them around to drop them closer to the extraction area.

Slash: Slash is tree waste left behind after commercial forestry activities.

Slash trap: Means a structure set in a river, on the bed of a river, or on land to trap slash mobilised by water. Also called a debris trap.

Standard Operating Procedure (SOP): Instructions compiled by an organization to help workers carry out routine operations.

Stem: A single tree in a plantation forest.

Swing yarder: A specialist cable log hauling machine configured like a crane and capable of swinging around on its base.

Thinning to waste: Selectively felling smaller size and lower quality trees to improve the future forest, where the felled trees remain on the ground and decay.

Tower hauler: A type of cable log hauling machine that has a pole (the tower).

Two staging: The physical separation of stem extraction from log processing. Often a grapple skidder or an off-highway truck transports the extracted stems to the log making area.

Tree stocking: The number of trees per hectare.

Waterway: Natural channel system carrying flowing water or surface water permanently or intermittently in the course of a year (e.g. stream, river, ephemeral stream, intermittent stream)

Windthrow: Trees toppled or snapped during high winds. Often the definition includes trees that have fallen through stream bank collapse or other non-wind generated processes.

Woody debris: Describes all sources of dead wood, whether natural or man-made, including fallen trees, logs, branches, twigs, bark and root balls.

Yarder: A harvesting machine that uses a system of cables to extract logs from the stump to the landing.

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data-niwa.opendata.arcgis.com/datasets/hirds-v4-rainfall-depth-surfaces-new-zealand

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www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/smarter-targeting-of-erosion-control/#programme-updates

Fire management

FOA/FFA website for Rural Fire Guidelines
www.nzfoa.org.nz/resources/file-libraries-resources/fire/831-rural-fire-guidelines-managing-the-risks/file

Fire Emergency NZ (FENZ) website for permits and whether vegetation fires are permitted.
fireandemergency.nz

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