Te Uru Rākau New Zealand Forest Service

Erosion processes for forest and harvest planning

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1 Background

The Erosion Susceptibility Classification (ESC) is a spatial database used in the National Environmental Standards for Commercial Forestry (NES-CF).

ESC is a screening tool of forestry activity status that is used for RMA planning. It sets out erosion susceptibility as low (green), moderate (yellow), high (orange) and very high (red) classes. These determine what level of RMA scrutiny a forestry activity will have.

The ESC does not include detail on the erosion types that provide the information used to rank individual ESC units.

The **purpose** of this guidance is:

- to support non-geologists involved in forestry, particularly harvest planners, afforestation planners, land purchasers, and council CME staff;
- to support better understanding of site-related plantation forestry erosion issues, by providing greater insight into the types and severity of land failure.

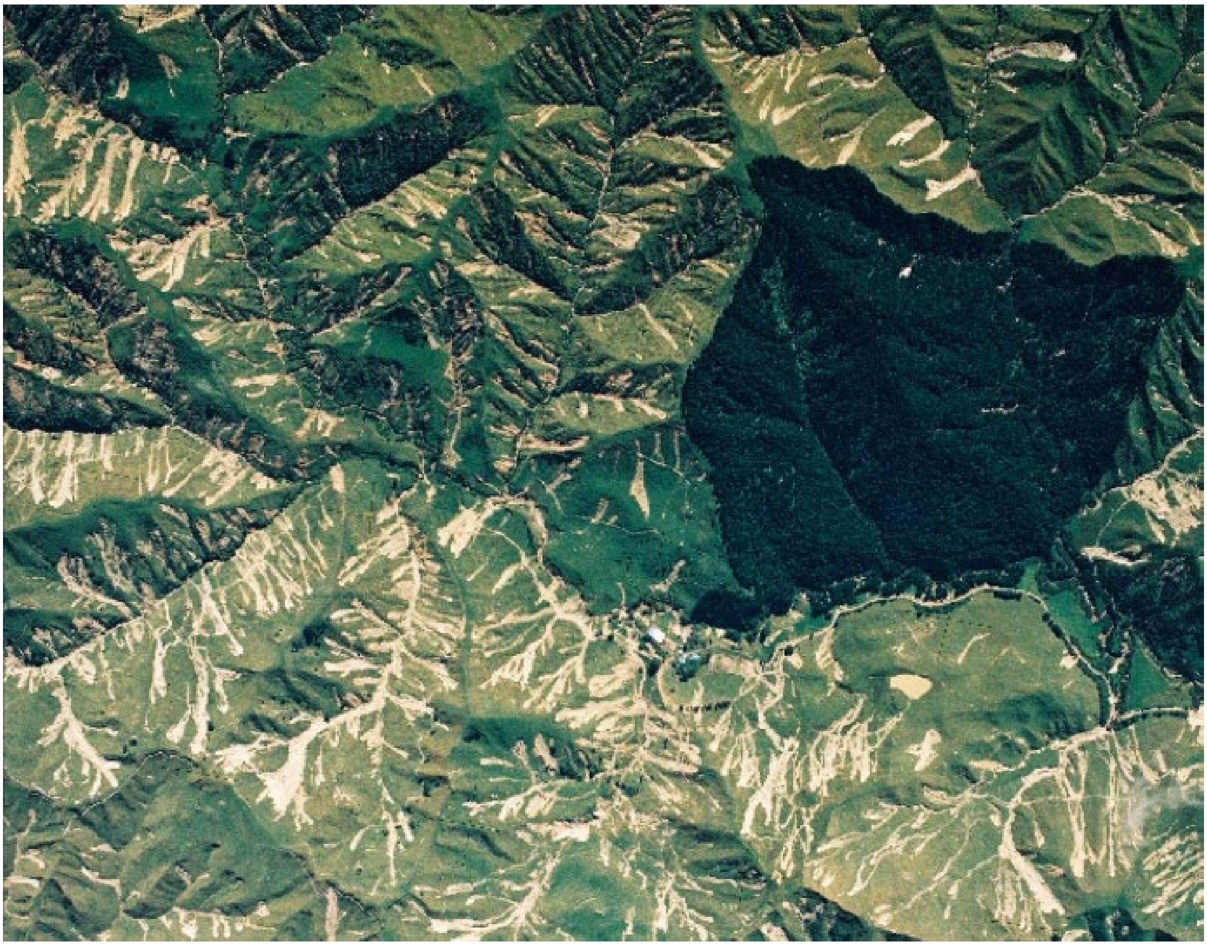


Image credit: Malcolm Todd. Severe shallow landslide erosion from the 2004 storm, inland of Whanganui, in “Learnings from ten years of hill country farm planning” 2018. Occasional Report No. 31. Fertilizer and Lime Research Centre.

This guide introduces the reader to common New Zealand erosion and mass-movement processes. Its intent is to be a very simple "knowledge is power" resource to assist foresters with their site risk management.

It sets out ways to use spatially-based information to find out more about erosion and mass-movement processes. This spatial information covers large parts of the country, and this guide will help you use the strengths of each type of spatial dataset to create a more complete picture of the erosion processes likely to be found in a forest.

It does not include recent research on the mechanics of failure and how trees and their placement affect this[1] as it is not a spatial database. Nor is recent work on shallow landslide modelling and the high-resolution landslide susceptibility maps as - in 2024 - these covered two regions only. References for these landslide susceptibility models from LiDAR-derived digital elevation models (DEMs) and landslide data are below[2].

2 Introduction

The ESC classes are derived from the New Zealand Land Resource Inventory (**NZLRI**) Land Use Capability (**LUC**) system. This presents data at a 1:50,000 scale and creates polygons of broadly similar erosion susceptibility.

You can get details of the erosion modes relevant to a forestry site by using the NZLRI extended legends in the form of spreadsheets, and bulletins, which provide a narrative approach. The failure type and its likely severity will give insights on their potential effects for planting, earthworks and harvesting.

You can use this information for planning, including to manage or reduce risk. Council staff can use this information to understand individual site risk and how it can be addressed through forestry practice.

You can enhance LUC insights into how the land is behaving with additional spatial data sources and on-site observations. For example, both LiDAR and aerial photos can give a detailed 3D picture of the ground surface and add significantly to what information LUC can offer about slope and its effects.

Figure 1 shows how the information in this guide relates to the ESC requirement in the NES-CF. Figure 2 shows the process for locating site specific information for specific LUC units, which is detailed in section 4.

This guide often uses plain English rather than the technical terms that geologists and natural hazards experts use. For example, "erosion" is used as an umbrella term for erosion and mass movement in many places.

[1] https://www.landcareresearch.co.nz/assets/Discover-Our-Research/Projects/STEC/wrap-up/knowledge-based-and-data-driven-erosion-feature-mapping.pdf and https://www.landcareresearch.co.nz/publications/innovation-stories/innovation-articles/getting-to-the-root-causes-of-soil-erosion-using-high-res-remote-sensing/ and https://www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/smarter-targeting-of-erosion-control/stec-news/lidar-data-enables-modelling-of-slope-stability-at-the-scale-of-individual-trees/

[2] https://www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/ and https://www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/smarter-targeting-of-erosion-control/stec-wrap-up/

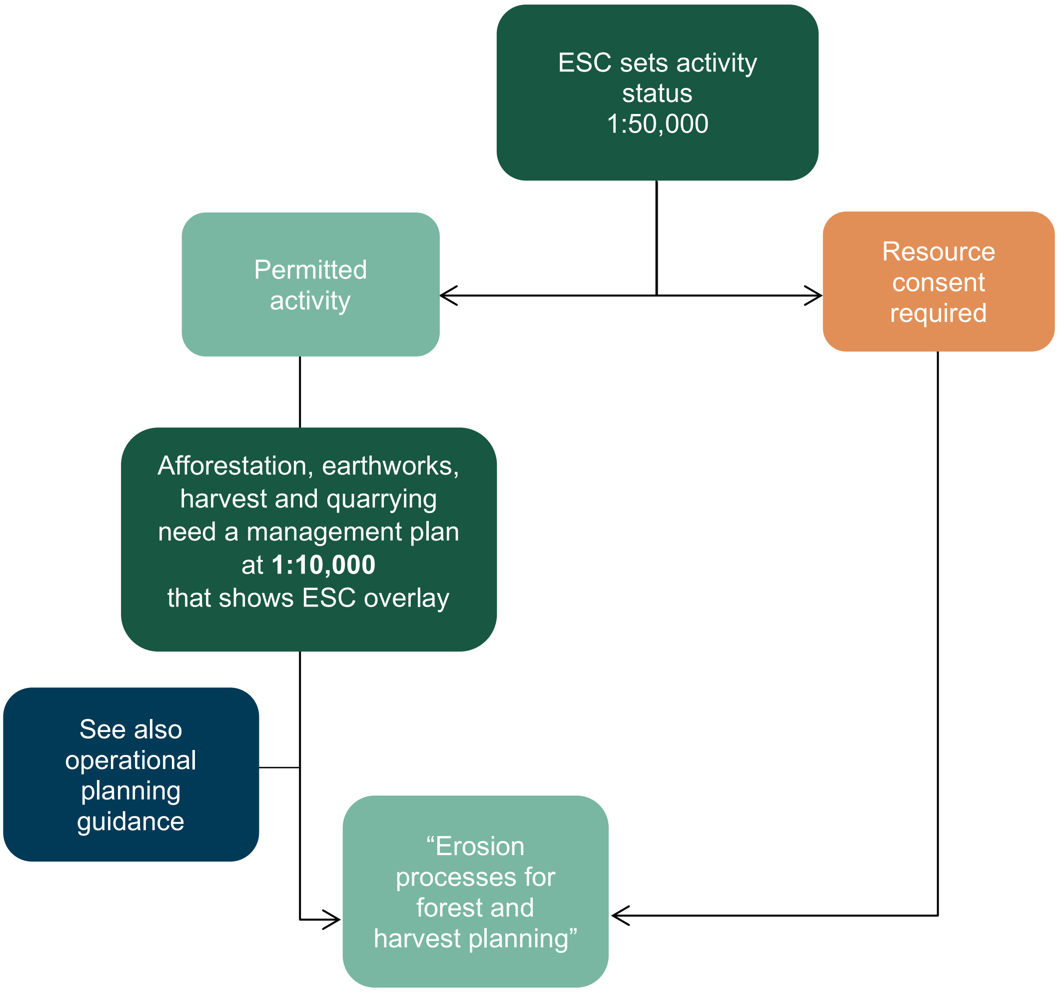


Figure 1: Using ESC in the NES-CF

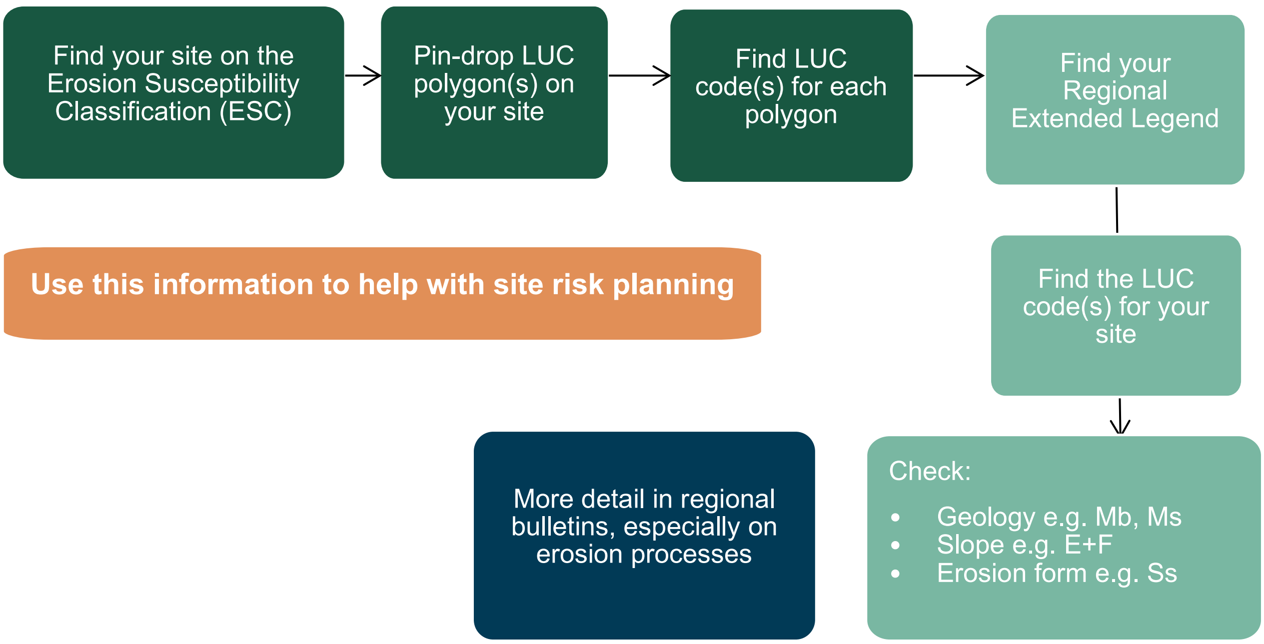


Figure 2: How to find out what sits beneath the Erosion Susceptibility Classification for an LUC unit

3 Understanding erosion to understand site vulnerability

Plantation forestry in New Zealand mainly uses *Pinus radiata*. This species will survive and thrive in many soil types, which makes site selection straight-forward from the perspective of tree survival.

But this forgiving nature does mean that deeper site risks, due to erosion susceptibility, can be overlooked. Beyond survivability it is important to ask:

- Will the site be able to hold trees to a harvestable age, and not fail mid-rotation?
- Will forest infrastructure hold together to support the harvest and a new rotation?

These questions require some understanding of the most likely type of failure and where on the site it is most likely to fail. If you recognise underlying land vulnerability at the **pre-planting** stage, you can avoid areas where site failure is more likely. If you understand the nature and scale of **erosion** and **mass movement**[3] and how they may affect the crop and harvest infrastructure, you may save money and avoid reputational damage over the long term.

This guidance first sets out some common site issues. It then provides information and links to some readily-available datasets, and advice on how to use them. These help to clarify which erosion forms are the most important on any particular site, and the way these are likely to play out over time. Using these insights with field observation, will support forest risk analysis and management.

4 Common erosion processes that lead to land failure

Much of New Zealand's land surface is geologically young, so erosive weathering processes are still very active. Production forests are often the land use choice where agriculture has proved unsuccessful - often because of erosion. Plantation forests are therefore already being put on more erosion prone sites than other primary production land uses. These trees *can* reduce erosion rates, or the areas affected, but they don't change the underlying type of erosive processes that are characteristic of the site. This means forest and landowners still need to manage the site based on its erosion forms. It is important to keep these in mind, particularly at harvest, but also when considering sound replanting boundaries.

Knowing the predominant types of erosion is helpful for those:

- Planting - to avoid sites or parts of sites that will not sustain a crop to maturity, and/or will produce an uneconomic crop that presents considerable difficulties to harvest;
- Planning infrastructure location - to avoid or correctly engineer for specific issues.

[3] Generally referred to from now on as "erosion"

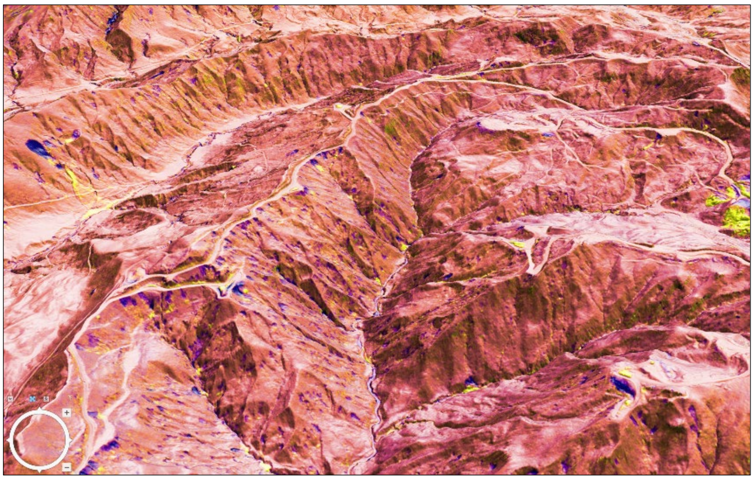
A simple way to get a sense of what erosion or mass movement is likely to happen is to look at the site (or an adjacent slope) under pasture.

Look at recent landslide scars, and at scars that have healed over.

This hill slope has shallow landslides (soil slips) initiating close to the change of slope at the top of the hill face. The runout of the landslide ends on the lower slope rather than moving off site.

LiDAR imagery[4] is a great way to see slip scars. It’s possible to see:

1. what has already failed;
2. what could still fail (such as parts of the slope where soil has developed but has not yet been subject to an erosion event);
3. what is very unlikely to fail (ridges and spurs).



This 3D LiDAR image includes a time series. The purple and yellow colours identify erosion and deposition that has occurred between the first and second LiDAR image runs. LiDAR analysis can categorise slopes or elevation changes.

Image credit Interpine, Tai Rāwhiti

[4] https://www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/smarter-targeting-of-erosion-control/stec-news/landslide-susceptibility-and-lidar/

When assessing how vulnerable a slope is to failure the type of boundary between the soil and the parent material is relevant. The site depicted on this page does not have an abrupt boundary between the soil and the parent material. This means trees can send roots down into the parent material, which will mitigate erosion severity as the roots provide mechanical reinforcement.

Trees will also reduce the amount and speed of water reaching the soil, reducing the risk of landslides.

Image credit "Above Hawkes Bay" - Southern Hawkes Bay Porangahau.

4.1 LANDSLIDES

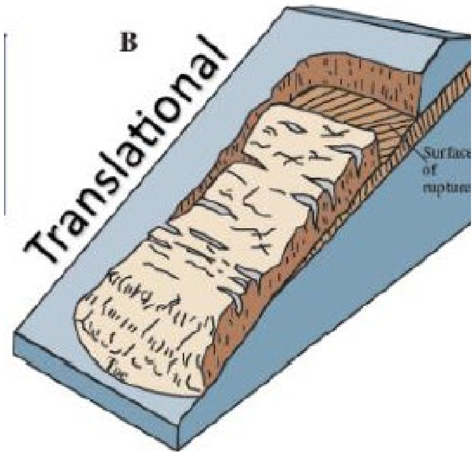
Landslide is an umbrella term for a range of mass movement processes that include:

- **shallow landslides** (NZLRI refers to this as "soil slip"). The presence of trees will considerably mitigate these compared to a grass cover ***unless there is a shear zone present***.
- **earth flows** (slow moving, mostly shallow);
- **slumps**. Large-scale rotational failures (creating a head scarp and often rubbly runout material).

Shallow landslides are a ***translational*** failure. The material on top slides off the material underneath, often as a result of lubrication of a shear zone in wet conditions.

A **shear zone** occurs where there is a (fairly) distinct boundary between a consolidated parent material below and the weathered material on top. Water can percolate through the top layer but not the bottom layer, so as it runs along the bottom layer it lubricates it. The weight of the top material and the lubrication causes the top layer to slide off.

If this landslide depth is greater than the tree roots, it will carry away the material on top of it, including trees. Earthflows are also mainly translational, as the main movement is basal sliding.



Based on Varnes 1978

P. radiata has a tap root and large lateral roots but it can only use these on sites where it can get its roots into the substrate. On a strongly consolidated substrate the tree can only perch on top.

Image credit GNS Photo GH2667 ***Shallow soil slides and flows*** *Mangawhero*[5]

[5] https://static.geonet.org.nz/info/reports/landslide/SR_2005-010.pdf

Image credit GNS ***Shallow soil slides and flows*** *(0.5 – 1m deep) Pohangina valley*[6]
The difference in susceptibility to shallow slips for forested compared to non-forested land is stark

Image credit GNS - ***Landslides*** *Mangamahu on Pliocene sandstone. Coalescing of debris tails has increased run-out distance*[7]

[6] https://static.geonet.org.nz/info/reports/landslide/SR_2005-010.pdf
[7] https://static.geonet.org.nz/info/reports/landslide/SR_2015-047_FINAL.pdf

4.1.1 Shallow landslide / soil slip

This failure type often occurs on **strongly consolidated sedimentary geologies**. These landforms hold a steep slope because of their degree of consolidation (unlike weakly consolidated sediments which lack the cohesion to do so). Because of this level of consolidation, weathering processes on these sediments have only managed to create a shallow soil. This is vulnerable to slipping off, particularly when water gets between the soil base and the underlying parent material – hence the colloquial description of "greasy-back". These strongly consolidated sandstones, siltstones and mudstones are derived from marine sediments and are widespread in the lower North Island.

Shallow landslide on a **consolidated substrate** is one of the few instances where a plantation forest doesn't mitigate the erosion issue. Failure on these skeletal soils can occur from mid-rotation through to harvest. Windthrown timber and lower volumes per hectare can compromise harvesting economics.

Trees (particularly tall, heavy, fast-growing trees) can aggravate this slope failure process. A tree can't put roots into the **consolidated substrate** so it perches on a shallow biscuit of roots.

If water gets under the root biscuit the exposure and lubrication of this shear zone and the weight of the tree on the steep hill sets off slope failure as shallow landslides. This can occur in rain and high wind, where the sway of the tree lifts the root plate[8]. The trees lose their footing and slide off the hill.

[8] https://www.youtube.com/watch?v=U03kVsVnKOw

Image credits (right and above) - John Douglas Sustainable Forest and Land

Management 2022 - inland Whanganui ***shallow landslide***

4.1.2 Debris flow

Shallow landslides fail initially by sliding, and they may stop on the slope. However, if they become channelised and the ratio of sediment to water reaches a flow threshold, they may transform into a debris flow. These are highly erosive. They generally occur on steep slopes so the speed and force of these failures can be immense. Their power means that anything in their path gets caught up and added to the flow. This water-laden mass of soil and fragmented rock includes riparian vegetation, crop/crop residue, as well as the soil that is scoured out of the channel. They form thick, muddy deposits on valley floors as they lose energy.

A shallow landslide at the top of a catchment, or instability created by infrastructure can trigger a debris flow. More debris flows are likely in high magnitude rainfall events, particularly where multiple soil slips enter streamlines and merge.

Channelised debris flows cut stream channels deeper and ream out the bed (rather than widening out the channel).

Because of their power, run-out can extend hundreds of metres - even kilometres -beyond the start point. Energy produced by stream gradient and flow depth determines runout distance. Debris flows will slow and stop when they lose energy – if stream gradient reduces (12 degrees or less) or they reach a fan and spread out so the flow depth reduces.

Debris flows are much more likely to cause damage off site than other types of landslide.

Image credit: GNS Stream channel scoured by sediment and woody debris-laden ***debris flow***[9]

Melton's Ratio[10] is an index of catchment ruggedness. It gives a useful indication of which catchments have the potential to generate debris flows and an estimate of their runout fans.

> The Melton Ratio (R) is equal to catchment relief (highest altitude minus lowest altitude in metres) divided by the square root of catchment area:
> $R = Hb / \sqrt{Ab}$ where Hb is catchment relief[11] and Ab is catchment area.

Catchments with a Melton Ratio > 0.5 are capable of generating debris flows. For these catchments likely run-out fans can be assessed for important features that may be affected by a debris flow, such as houses, bridges, and roads. Managing large harvest debris in stream channels that meet the > 0.5 threshold will help to reduce the potential risk from debris flows. Where possible, it is easier to keep channels clear of harvest debris than to prevent it from mobilising. However, slash catchers can prevent slash moving further down a channel. These may be built structures or growing trees, and will be most effective positioned where there is change in grade. This is where the velocity of a debris flow slows, and material starts to be deposited.

[9] https://static.geonet.org.nz/info/reports/landslide/SR_2013-044_Final.pdf
[10] https://static.geonet.org.nz/info/reports/landslide/sr_2019-034.pdf
[11] NZ Journal of Forestry Feb 2024 Vol 68, No. 4 Simon Smith, Rien Visser, Mark Bloomberg and Dave Palmer

*Image credit Geonet - **Debris flow** into Waingawa River, Wairarapa*

In a steep catchment during a significant rain event the initial soil and debris movement creates the momentum conditions for a debris flow.

On this site debris flow has been created by small slips above the road. Below the road a larger debris flow has been set off with contributions from roading infrastructure.

*Image credit GNS: **landslides** initiated off infrastructure, reaching stream channel*[12]

[12] https://static.geonet.org.nz/info/reports/landslide/SR_2013-044_Final.pdf

4.1.3 Earthflow

This failure mode is a feature of crushed sediments, usually mudstone or argillite. These sediments do not have the structural integrity to hold a steep slope; and can create large, slow-moving, slope failures, often at low slope angles. Reducing the water supply to these features can help stabilise or slow earthflows, by:

- not adding any more water to them, and actively directing all water away from the top of the feature;
- using trees for interception and evapotranspiration. This also makes flow more consistent;
- stabilising the toe (which is often being cut out by a stream).

Any roads that traverse these features are likely to continue to move, which will require regular expenditure on repairs and maintenance. Avoid tracking across them if possible.

These mass movement failures are found in Tai Rāwhiti on both crushed argillite and crushed mudstones and in Southern Hawkes Bay/ Wairarapa on crushed argillite. They are also present in parts of Northland where older volcanic material overlays weaker sedimentary material[13] (the geological version of a custard square).

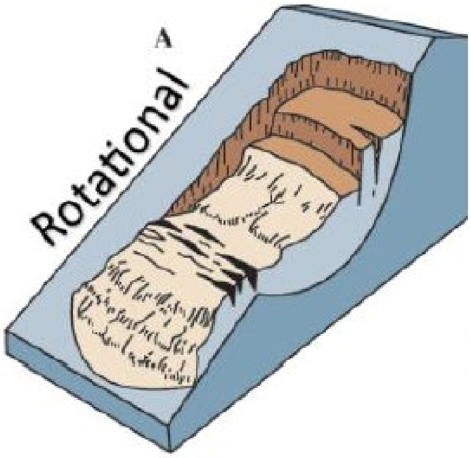
*Image credit GNS - **Earthflow** at Waingake, Tai Rāwhiti* [14]

These features are often quite fertile so they can grow good trees, but because they are on the move, the tree’s attempts to right themselves can result in a ‘hockey stick’ form at the base.

[13] The Northland allochthon
[14] https://static.geonet.org.nz/info/reports/landslide/SR_2006-022.pdf

4.1.4 Slump

In this **rotational failure mode** the landmass breaks away from the upper slope and creates a steepened scarp. The main slump block often breaks into a stair-step pattern of displaced blocks. The upper surface of these blocks can be rotated backwards and form ponds or swampy areas. Slumps are often activated by the removal of the toe of a slope, either from natural (often stream) or manmade processes (such as road construction). It is the removal of the slope's physical support that provokes this mass wasting event. Rain provides lubrication for the material to slide, as well as increasing the weight of the material.



Based on Varnes 1978

Mudstones in the lower central North Island are prone to slumping. The runout rubble can be planted with trees to reduce the likelihood of the slump reactivating. Trees intercept rain and reduce soil water by evapotranspiration, which keeps the soil moisture level down.

Infrastructure across the runout should be avoided if possible. Stabilisation techniques are similar to those for earthflows. Actively direct all water away, and plant trees to remove water through interception and evapotranspiration.

Image credit GNS - ≈200,000m3 ***rotational slide*** *Mangawhero. Head scarp 50m high, run-out almost 1km* [15]

Image credit GNS – ***Slump*** *Pohokura saddle, Waitara River, Whangamomona Group sandstone (Kiore formation)*

[15] https://static.geonet.org.nz/info/reports/landslide/SR_2005-010.pdf

4.2 FLUVIAL EROSION

Fluvial (water) erosion occurs where the erosive power of water chews away at land and removes it at a particle level. This is generally less of a problem in forest stands than it is for pastoral systems even after harvest because the roots and the slash usually provide sufficient surface roughness, meaning that water generally can't pick up enough force to create large problems. Fluvial erosion remains an issue of varying degrees on bare ground. In areas where gully erosion is the main issue, water control on bare ground (landings and roading infrastructure) is crucial.

Although in general fluvial vulnerabilities are lower than those of landslides, some vulnerabilities still exist. These are greatest where:

- the landscape is - by its nature - more vulnerable;
- the vegetative cover has been breached so that it can create a water channel down a slope, for some distance. For example, infrastructure or tracks from tethered harvesting.

The most vulnerable landscapes are those where parent material and soil is of highly sorted particles:

- sorted by wind (for example, loess);
- sorted by volcanic eruptions (for example, pumice); or
- sorted by water (for example, marine sediments).

Because particles are of similar size they don't compact well, as they can't lock or nest with each other. This means they are easily moved by water.

At the finest scale this is via sheet erosion, then through channel formation this becomes rill erosion (micro-channels) or gully erosion (large channels).

Image credit MWLR Les Basher – Gully erosion Kaingaroa/Taupo airfall tephra

In New Zealand the landscapes that are vulnerable include the air-fall tephra pumice country of the central North Island; loess (for example, Marlborough and Port Hills); unconsolidated sedimentary marine sands (for example, Whanganui area) and "rotten" granites which have poor internal cohesion (for example, Separation Point Granites in the Tasman District).

4.2.1 Gullying

Gullying occurs where bare land and water has formed a channel, which cuts down through the soil and substrate. This is the primary failure mode in the highly sorted materials discussed above.

Image credit NZFOA

Actions to minimise gullying include:

- controlling runoff, and never allowing large volumes to build up or gather speed;
- avoiding bare ground in overland flow paths;
- armouring water tables;
- reducing peak flood flows;
- stabilising margins;
- remediating bare earth vehicle tracks on steep slopes.

4.3 POST-HARVEST RESIDUES LEFT ON SLOPE

The examples of erosion above are of

- fast and slow **mass movement** failures, in which water and gravity act together to cause sections of the land surface to move;
- high-energy **fluvial erosion**, in which water is the main driving force.

Anything sitting on top of the mass movement failures will be carried downhill with them, so where there is concern about potential slash movement, such a site can be described as **susceptible**. The second related issue for the debris material that has moved from its original position, is whether the **connectivity** to water courses means it could be carried off site by channelised water flow.

The combination of **susceptibility and connectivity** helps identify whether that material could create a hazard, either directly or if it enters a waterway and travels further downstream. Where is it unlikely to move off the slope, or where surface and fluvial erosion are the dominant erosion processes, leaving vegetation on the cutover is good practice to intercept rainfall and reduce erosion.

5 Spatial databases for more information on site hazards

The erosion types and processes described above are found in various parts of the country. Publicly available spatial data sets can help identify which ones are most relevant in any particular place. This section gives some guidance on which type of failure may affect a site, and how to assess different parts of the slope for vulnerability. This will support decision-making on:

- whether and where to plant;
- where to locate infrastructure and what water controls should go where;
- the likely higher risk locations if slash is left on site.

This guidance can *inform* harvest planning, but it is not a harvest planning tool. It identifies on-site failure vulnerabilities, but not whether these are likely to move off site and have significant downstream effects on waterways or downstream infrastructure. Recent work by Manaaki Whenua Landcare Research (MWLR) on slip connectivity to stream networks will help more with this analysis, but at time of writing had coverage of two regions only.

5.1 EROSION SUSCEPTIBILITY CLASSIFICATION (ESC)

The NES-CF **Erosion Susceptibility Classification** (ESC) uses four levels to map susceptibility. It is at a scale of 1:50,000. The colour-code sets out increasing levels of erosion susceptibility as: green, yellow, orange and red. Orange indicates high erosion susceptibility and red very high erosion susceptibility for plantation forest.

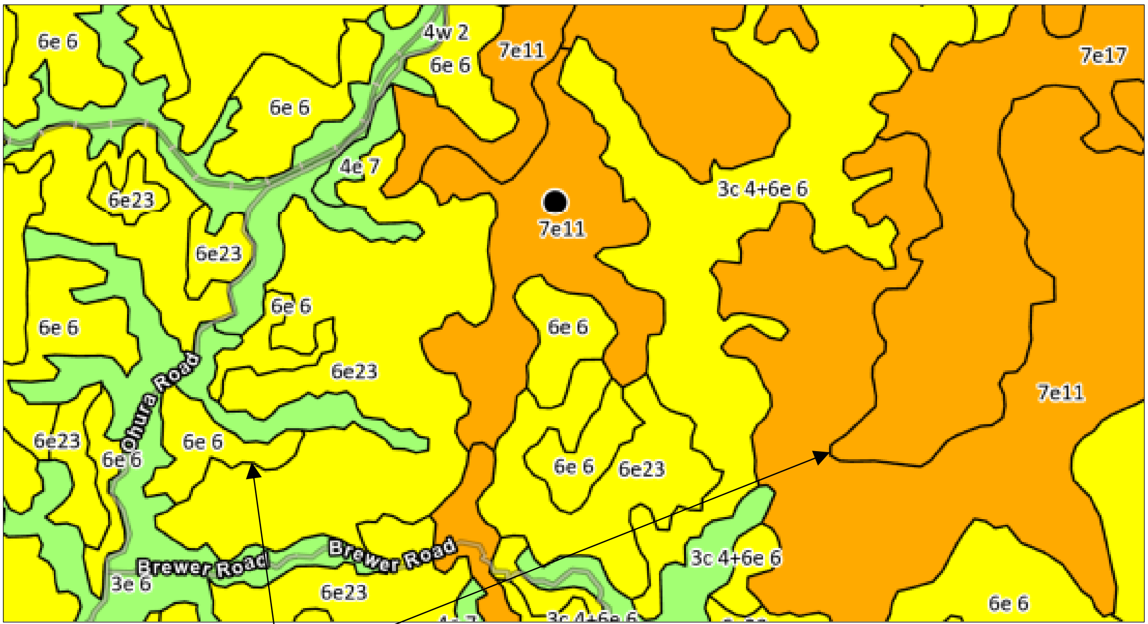


Image showing ESC colours and LUC boundaries.

Text and polygon boundaries within the ESC colours are of the underlying LUC units that the ESC relies on.

These “traffic lights” of the ESC are a simple gateway test, which indicate whether activities can proceed as permitted (providing they meet all the NES-CF standards) or are required to obtain resource consent. In this capacity it provides a simplified and high level assessment of on-site susceptibility to erosion.

The ESC uses data from the New Zealand Land Resource Inventory (NZLRI), hosted by MWLR[16]. The NZLRI provides much more information on the **nature** of the erosion susceptibility of a site, and its likely **scale** and **severity**. The ESC map unit boundaries follow the underlying NZLRI Land Use Capability boundaries, which are presented at a scale of 1:50,000.

[16] https://ourenvironment.scinfo.org.nz/maps-and-tools/app/Land%20Capability/lri_luc_main

This information is useful for both **infrastructure location** analysis and for planning **planting locations**, to be confident that a viable crop can reach maturity and that it can be harvested. However, to be truly useful at forest scale some further interpretation is required, so that a map created at forest scale (e.g. 1:10,000 to 1:5,000, as required by the NES-CF schedules)[17] is not just relying on data created at 1:50,000.

5.2 NEW ZEALAND LAND RESOURCE INVENTORY (NZLRI)

The NZLRI[18] is a spatial polygon-based database, developed mainly in the 1970/80s. Its original purpose was to provide guidance on land versatility and the nature of the main limitations for cropping and pastoral farming, so some translation is required to adapt it to the risks posed by short-rotation softwood regimes based (generally) on *P. radiata*. NZLRI uses spatial data on geology, soils and slope, and observation of erosion forms and severity under the vegetation present, to create polygons of areas that have a roughly consistent suite of these factors. These are then ranked. These Land Use Capability (LUC) units range from 1 which is extremely versatile with very few constraints, to 8 which has very severe to extreme limitations for all productive land uses. LUC only considers on-site vulnerability, not downstream risks. Section 4 below explains the LUC unit code in detail.

There are two key sets of information for each LUC map unit:

1 LUC classification, in which each LUC unit is expressed as a code that reflects the nature and severity of constraints on its use. The code is expressed as:
- a **number** from 1 to 8 (note older versions of maps/explanations use roman numerals e.g. 6 is written as VI)
- a **letter** signifying the main limitation from four options: **e**rosion, **c**limate, **s**oil and **w**etness, and
- a **second number** signifying its relative constraint within its class e.g. 4e3 is less erodible than 4e11.

2 A five factor inventory, the combination of which is used to determine which map unit most appropriately describes its overall susceptibility. The five factors are: parent material, slope, soil, vegetation and erosion.

NZLRI was mapped prior to the digital era, at the coarse scale of 1:63,360[19]. This has since been redone at 1:50,000. This means the NZLRI erosion typology is helpful for a broad brush site vulnerability assessment, but the scale should not be enlarged beyond the original mapping scale (this is a general rule for mapping biophysical factors).

More detailed site study (which is required for creating earthworks or harvest plans) is likely to come up with a slightly different result to the units that appear at 1:50,000, because more detail will be revealed on such things as slope angle. For example, in a steepland (Class 7 unit) at 1:50,000 there will be bits of a lower slope hill unit (Class 6 unit) that will only appear at a 1:5,000 scale. The most significant difference will be for **compound units**, where at 1:50,000 the scale restrictions mean a terrace and scarp system are mapped as one unit. The legend will describe it as [say] 3e4 + 6e11 but will not separately map the two. At a scale of 1:5,000 these can be disaggregated to show a terrace unit and a scarp unit, which will be treated differently for many forestry operations.

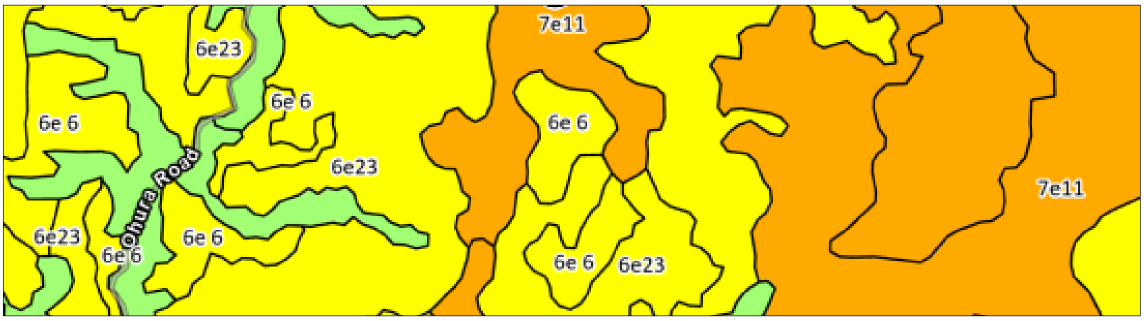
5.3 THE RELATIONSHIP BETWEEN LUC AND ESC

To decide which ESC category an LUC unit would go into, all LUC units were ranked according to their erosion or mass movement vulnerability ***in a plantation forest production context***. In some instances, this differs from the LUC ranking, which was originally done for agriculture. For example, both wind and fluvial erosion are far less likely to reach their potential erosion rating under forest than under pasture. This is reflected in their ESC rating. Most mass movement forms are also less likely to reach their potential erosion rating under forest, the exception being the skeletal soils on consolidated sediment, discussed in section 2.1.1.

[17] https://www.mpi.govt.nz/dmsdocument/32323/direct
[18] https://soils.landcareresearch.co.nz/tools/nzlri-soil/nzlri-development/
[19] Inch to the mile

The LUC units were then assigned into one of the four categories of the ESC. An expert group assessed LUC units on each ESC colour boundary, to confirm their ESC status.

Each ESC polygon has the same boundary line as an LUC polygon boundary. LUC polygons vary in size. At a 1:50,000 scale the smallest LUC polygon is about 8 hectares. An ESC polygon may contain several LUC polygons. On the image below ESC orange is all LUC unit 7e11 and yellow contains LUC units 6e6 and 6e23.



5.3.1 Potential erosion under a plantation forest regime

The LUC unit is an assessment of the capability of the land for any use. It identifies present erosion and potential erosion, the latter representing a worst case scenario in the estimation of the LUC mapper. Whether potential erosion is reached depends on the vegetation cover and land use practices.

Mature plantation forest exhibits about 10% of the erosion/mass movement[20] sustained by equivalent land under pasture[21], so it has a marked reduction in susceptibility. Clearcut plantation forest does have a "**window of vulnerability**"[22] for about 4 to 8 years out of 30 years of a rotation. This is the time during which the old crop roots have broken down, but the new crop has yet to reach canopy closure and fully inhabit the site with a protective root network. At times when full canopy is absent, the interception and re-evaporation that occurs in a forest is much reduced, making it more similar to its vulnerability under pasture cover. Although a clearcut regime has periods where erosion rates are similar to pasture, over the whole forest rotation a plantation forestry regime generally has a lower vulnerability than pasture. A continuous cover forest regime would have lower rates again.

The LUC explanations that accompany the maps provide some details about use of the land for agricultural production, and for production forests (for example, site index). This provides a useful insight into the relative value of the site for production forestry. These explanations are:

- the **extended legend** - a spreadsheet of 18 physical parameters relevant to the site;
- the **bulletin** - a report on the context of the landforms.

However, as LUC's initial purpose was to describe land versatility for *pastoral farming*, the LUC ranking for potential erosion levels are those that would occur under pastoral farming. For LUC units where erosion is the main constraint (most of them), this reflects the erosion severity *under pasture*. Thus, there are differences in LUC unit description of erosion types and severity that don't fully reflect whether the erosion potential is likely to be reached under a plantation forestry regime.

[20] Basher et al Lit. review and feasibility study for national modelling of sediment attribute impacts MWLR 2019
[21] Except in extreme events, in which case catastrophic failures can occur under any land cover.
[22] https://www.landcareresearch.co.nz/news/closing-the-window-of-vulnerability/ Phillips C, Betts, H, Smith HG, Tsyplenkov A 2024. Exploring the post-harvest 'window of vulnerability' to landslides in New Zealand steepland plantation forests. Ecological Engineering 206: 107300. https://doi.org/10.1016/j.ecoleng.2024.107300


Wairoa April 2023 post Cyclone Gabrielle, showing mass movement – shallow landslide (soil slip)

Potential erosion considers the frequency of erosion causing events (susceptibility) and predominant land uses/vegetative covers, both of which affect severity. On erosion-prone land, changing the vegetation cover changes the erosion potential. Erosion **susceptibility** is lower in plantation forest than pasture because tree cover moderates and reduces soil wetness, and provides root reinforcement for most of the production forest cycle, thus reducing conditions for land failure. Erosion may or may not be as **severe** (the area and/or depth of the effect is less) than would occur under pasture cover.

Often the recommended mitigation for erosion and mass movement is to plant trees. As a mitigation trees and forests can dramatically reduce the actual erosion and the likelihood of the site ever reaching potential erosion. For example, if the land is used for production forest the site vulnerability to wind erosion is generally very low. Even in the window of vulnerability after harvest, before the new crop has achieved canopy closure, surface roughness means that wind doesn't get a hold on the soil to cause erosion. Forest cover, and slash on the cutover after harvest, also significantly reduces fluvial erosion (sheet, rill, and gully). In most instances a plantation forest regime will mean that the potential erosion susceptibility depicted for the LUC unit is not reached, and often actual erosion will be reduced. Erosion susceptibility under forest generally follows the same ranking as the LUC.

However, there are some sites where planting fast-growing tall trees does not de-risk a site. The main example is skeletal soils with a shear plane, common on the strongly consolidated uplifted marine sediments in Tai Rāwhiti, Hawkes Bay, inland Taranaki, and Whanganui. Shallow landslide vulnerability here can stay high under plantation forest[23], because trees cannot put sinker roots[24] into the consolidated substrate and are thus balancing on a root "biscuit". In windy, rainy conditions, the trees are readily dislodged and fall over. This heightened vulnerability is reflected in the ESC category of these units.

The other factor that affects overall likelihood of reaching potential erosion levels is weather conditions during the window of vulnerability. During this time, when the root occupancy and canopy cover are less than 100%, the site has a different hydrological profile compared to what it would under full tree cover. The rank grass and weeds typical of recently harvested- to- immediately post-planted land may intercept and hold more water in the soil than pasture on similar terrain (which, if closely grazed, will have more overland flow). Extended wet periods in the early phases of the window of vulnerability increase soil weight (and thus propensity to fail). This is mitigated by the tree roots of the residual crop, however it does increase susceptibility compared to closed canopy forest[25].

[23] Observations by soil conservation practitioners: Trevor Freeman and Kerry Hudson (GDC), Ian Moore, Robin Black
[24] Sinker roots grow down from the lateral surface roots.
[25] Phillips et al, op cit., p.11 found in three study regions that rainfall-induced landslide density is greatest on land harvested 1-4 years before a landslide triggering event.

Stream morphology also changes post-harvest. With tree cover, the lower energy of the streams means they become wider and shallower. With no tree cover and greater flow, streams tend to cut into the stream bed, and streambank erosion occurs.

5.3.2 Risk reduction by understanding geomorphic vulnerability

To make sound decisions on planting location and siting of infrastructure an accurate characterisation of erosion vulnerability under a plantation forest regime is essential.

Consider the nature of the likely erosion and take steps to reduce the effects. These steps will vary with the type of erosion but would include:

- Reducing the erosive effect of water on the infrastructure through the use of water controls. This involves managing water energy to keep it low and slow;
- Avoiding loading active mass-movement features with extra weight and/or water from infrastructure itself, or from the infrastructure water controls;
- Smoothing the temporal distribution of risk over the estate to reduce the proportions of land at peak risk in any one year. For example, planning the harvest so that it is not all of the same slope aspect within a catchment, so that big rain events, arriving from a particular direction, may not affect all the slopes in the same way.

In a pasture situation the nature of erosion is obvious because grass cover can't hide it. It is much more difficult to detect on land covered with trees, which requires some close scrutiny of images of the site that can reveal more detail. For example, using aerial photos of the farmland prior to planting, or LiDAR that can capture ground contour. Assessing an aerial photo and/or LiDAR image *after* having checked the failure modes typical of that area can give a much more useful picture of likely vulnerabilities on the site.

The value of the standard-issue LUC maps is affected by:

1. **Scale**. LUC maps are at 1:50,000. Mapping sometimes inaccurately identifies susceptibility at this scale, which can lead to sub-optimal decisions. It doesn't pick out high susceptibility areas and may bundle lower susceptibility areas along with high susceptibility areas.
   As scale is refined, different units will appear, especially on complex landforms. For example, at 1:50,000 a slump may not be mapped as a slump and scarp, but at the mapping scale for forest operations (1:5,000 to 1:10,000) the two areas can be clearly identified and dealt with differently. Operational scale can therefore identify the genuine high-susceptibility areas.

2. **Map Error.** This can occur where a polygon boundary is not accurately matched to ground features (transcription issues) or where LUC has been wrongly ascribed. For example, in a compound unit the proportions may be different from what the unit as a whole describes. This will affect which base unit is used (for example, a choice between a terrace and a scarp). If the terrace proportion is greater, the unit will be categorised as terrace, generally LUC 1-4, thus under-rating some areas of higher susceptibility. If the scarp proportion is higher, the unit will be categorised based on the scarp, the LUC unit will be 6-8, thus over-rating some areas of lower susceptibility.

5.3.3 Process to refine map scale using existing technology

If scale or mapping issues appear to be misrepresenting the vulnerability levels on a site these are some steps to take:

1. List all the relevant LUC mapping units for the site. This includes those represented in the block, as well as any different units in the general vicinity of the block, as these may be represented in the block once you map at a finer scale. Slope is often a key indicator of the changes of capability, as it is often the factor that leads to greater mass movement vulnerability. Extra topographical detail, such as from detailed digital elevation models (DEM) and LiDAR will create more accurate information on slope and slope changes.

2. Use the NZLRI parameters set out in the extended legends to create LUC maps at an appropriate scale. More detail on how to do this is in section 4 below.
3. Assess whether mapping scale has resulted in any units containing elements that are not listed in the site's LUC units. In some areas this will be obvious, particularly at the boundaries of alluvial, colluvial, hillslope, or steepland soils. A quick assessment of slope compared to the different LUC units will allow you to identify the relevant unit.
4. Check whether any areas on your map don't fit within the recorded LUC unit description. For example, there may be a gut that at 1:50,000 is too small to get a rating of its own, or it may be described as a feature of a larger unit at 1:50,000 (possibly represented as a compound unit). However, at 1:5,000 it becomes an obvious feature of its own. There will usually be a unit that describes it in the wider vicinity of the block, that can be picked up on the **extended legend** or in the **bulletin.** This will describe the relationship between units of a "**suite**" - the family of landforms associated with that parent material. Each suite is likely to have one or more of a steepland, a hill and a plain unit, with diagrams explaining how they relate to each other. An example is depicted in the figure below.

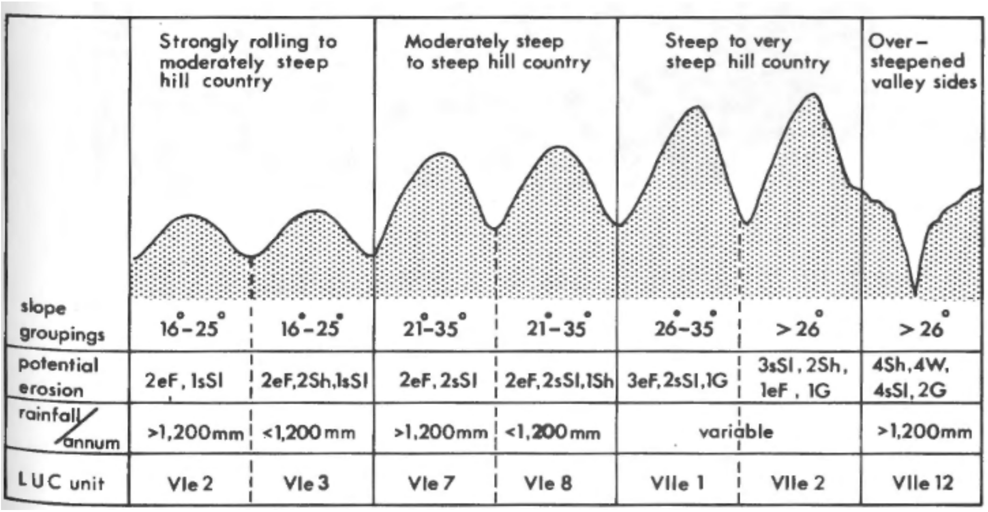


Figure 3: Relationship between hill to steepland LUC units for the mudstone and siltstone suite - Southern Hawkes Bay.

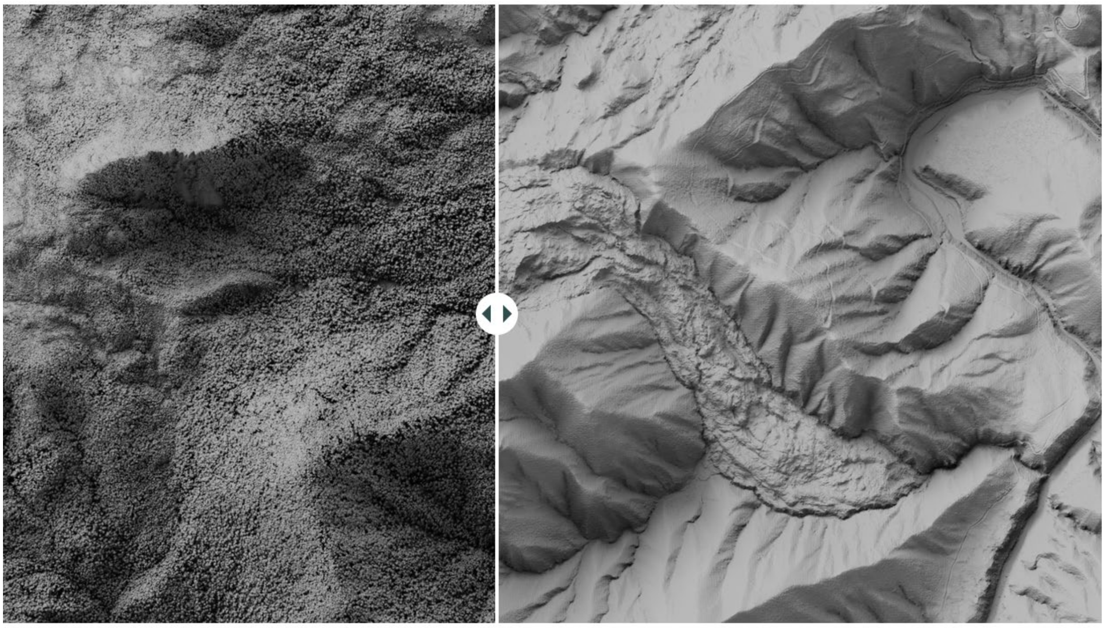
5.3.4 Process for re-checking the level of erosion susceptibility

1. Until about 15 years ago LUC classifications focused on pastoral land use. More recent LUC classifications should include forestry as a land use and should be correct in describing actual and potential vulnerability **under plantation cover**.
2. Check whether the refinement of scale to 1:5,000 resolves any instances where the ESC rating seems inappropriate. In some instances, LUC are classified as compound units merely because of scale issues.
3. Check the accuracy of your 1:5000 map against what it was originally assigned as in the ESC, taking account of the rationale for seeking reclassification, and an assessment of erosion vulnerability under forestry:
   a. **Forest crop vulnerability** to erosion or mass movement will generally be lower than that of pasture, especially on sand country. The exception is on very consolidated substrate that has a skeletal cover, in which case it may be higher than pasture, because the topsoil may slough off under the weight of trees;
   b. **Infrastructure risk** is lower on consolidated parent material. If the land itself can hold a steep slope then usually any earthworks on it will be relatively stable. However, infrastructure creates bare ground, making it more vulnerable to fluvial erosion (sheet, rill and gully erosion) compared to the crop area.

5.4 LIDAR AND SATELLITE DEM

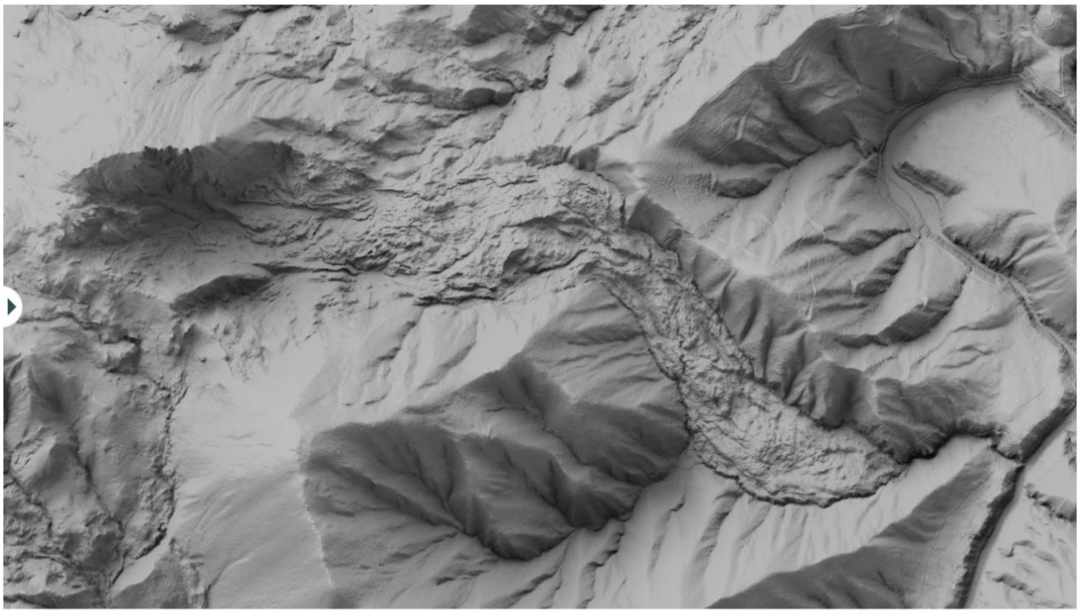
More recent datasets provide very valuable supplements to LUC. Chief among these is LiDAR[26], a remote sensing method that reveals in great detail the site slope and visible patterns of erosion and mass movement. Using LiDAR in conjunction with the NZLRI LUC units significantly enhances the picture.

LiDAR imagery at high resolution provides multiple points per square metre. If it is captured as bare earth LiDAR it shows the land surface, allowing you to "see through the trees" which can help you understand erosion processes that are usually obscured by tall vegetation.



Marlborough - Marlborough North LiDAR (2020)

The left of the image shows a semi-circular scarp, but it is hard to see the river of rubble that is coming out of it. The bare earth image on the right clearly shows the outflow. The bare earth image below shows the entire mass movement feature.



Marlborough - Marlborough North LiDAR (2020)

Land Information New Zealand (LINZ)[27] holds LiDAR for all regions except Otago and Manawatu-Whanganui. These two regions have satellite-derived Digital Elevation Model (DEM) data that has a

[26] Light Detection and Ranging
[27] https://www.linz.govt.nz/products-services/data/types-linz-data/elevation-data https://data.linz.govt.nz/data/?q=LiDAR

(coarser) resolution of 8m[28]. The 8m DEM has superior slope information to that in LUC, but doesn't reveal much about erosion features or form, unless it is large scale mass movement.

This data is publicly available at LINZ. Help on how to get access to it and software for interpretation is available.[29]

5.5 HIGHLY ERODIBLE LAND

Highly erodible land (HEL) is a model[30] indicating land that is very susceptible to certain types of erosion (landslide, earthflow, or gully). It uses a digital elevation model (DEM) to identify slopes, incorporate different erosion terrains and determine erosion thresholds based on these terrains. It uses land cover mapping from the Land Cover Database (LCDB), with a minimum mapping unit of 1 hectare, or the Woody layer, which has a minimum mapping unit of 0.1 hectare and is updated annually.

The HEL model identifies five classes of land vulnerable to erosion[31].

- High landslide vulnerability – delivery to stream (a connectivity risk)
- High landslide vulnerability – non-delivery to stream
- Moderate earthflow vulnerability
- Severe earthflow vulnerability
- Gully vulnerability

When land has protective woody vegetation with reinforcing roots it is not considered a risk as the HEL model regards the vulnerability to mass-movement erosion as being significantly reduced.

HEL is used as a national to regional scale, so gives broad indications of the type and level of vulnerability, rather than providing site specific detail at forest-scale. For useful insights into the most vulnerable period for plantation forest (post-harvest and prior to canopy closure by the next crop) the fundamental layer of HEL, prior to adding the vegetation mitigation layer, is more useful.

5.6 RADIOMETRIC/PHYSIOGRAPHICS

In some parts of the country[32] a Physiographics assessment uses satellite-derived radiometric data to identify erosion rates/severity as one of its inputs to assess water-borne contaminants. Its resolution is significantly greater than what LUC can offer. However, finding the erosion data involves looking at one of the inputs rather than being able to use the final output maps. It provides some interesting and useful insights in Northland.

5.7 SHALLOW LANDSLIDE MODELLING

Active research is underway on shallow landslide modelling and high-resolution landslide susceptibility mapping (including whether these connect to stream systems). The area is developing rapidly, but at time of writing only two regions have been modelled[33].

[28] https://data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012/
[29] https://linz.maps.arcgis.com/apps/MapSeries/index.html?appid=2552c3a5cee24f7b87806b085c3fee8a
[30] https://environment.govt.nz/assets/publications/Environmental-Reporting/Update-to-highly-erodible-land-and-estimated-long-term-soil-erosion-data-sets-for-environmental-reporting-2.pdf see pages 13-14 for graphics
[31] https://www.stats.govt.nz/indicators/highly-erodible-land-data-to-2022/
[32] As of October 2023 = Northland and Southland https://www.nrc.govt.nz/media/zrnpfc4p/physiographic-controls-over-water-quality-state-for-the-northland-region.pdf page 63 https://www.es.govt.nz/community/farming/physiographics/introduction-to-physiographics
[33] https://www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/ and https://www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/smarter-targeting-of-erosion-control/stec-wrap-up/

5.8 IN SUMMARY

As with all datasets and models, using more than one dataset will give a more accurate picture. It is crucial to refine the scale to be appropriate for the site, so that it usefully informs the proposed site management.

LUC relied on field mapping supplemented by checking aerial photographs and transposing that information onto base maps at a 1:50,000 scale. LUC denotes the main erosion type(s) at a board scale. For forestry infrastructure location and engineering, and for assessing slash movement risk the main value of LUC is in identifying the **type** of mass movement that will occur on that landform. Using LUC to identify the erosion form prior to looking at a LiDAR image makes that LiDAR image more meaningful, to more **precisely locate** erosion features. For example, discovering that the main failure mode is shallow landslide makes it easier to interpret what a LiDAR image is showing.

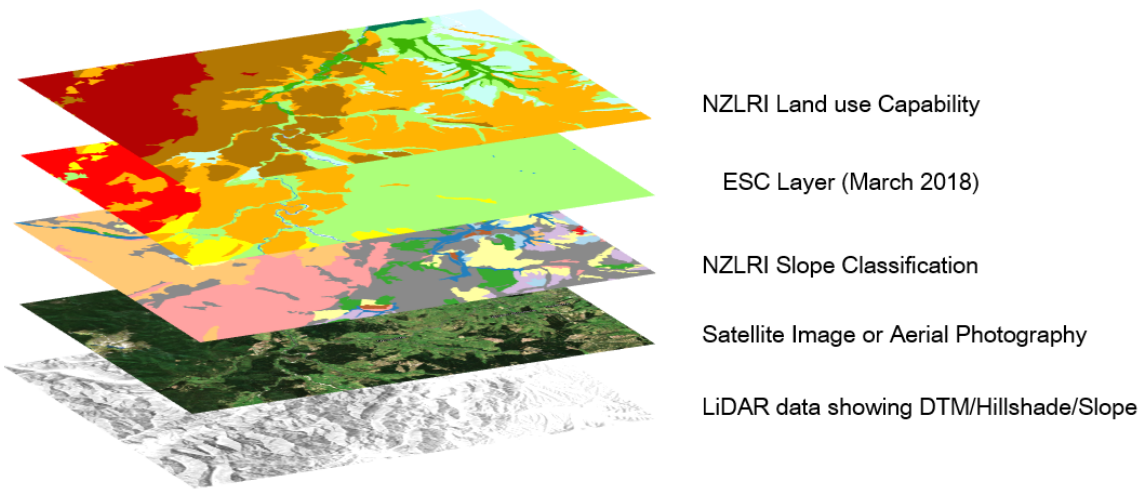
LUC estimates erosion **severity** through the LUC unit ranking (for example, LUC 6e14 is more severe than 6e4). It provides more detail on actual and potential erosion severity in the extended legend (See section 4).

LiDAR images show the existing erosion features. These can suggest likely locations of future failure points, particularly by someone with experience in landform interpretation.

Using two or three datasets give good insights into the nature of vulnerability and therefore appropriate mitigation techniques. For example. it's possible to see on:

- LiDAR the image of an erosion feature and slope, and erosion processes via time series in some areas;
- Physiographics, a relative intensity;
- Shallow Landslide Modelling, whether the landslide form connects to the stream network.

Different data sets combined to get results



If LiDAR and/or other databases show a different level of severity than that of LUC, it would be wise to give their representation some weight.

The LUC unit code alone (e.g. 6e14) gives a context and a relative susceptibility rating, however a further step, of using the extended legend, gives more information on the level and type of susceptibility.

To make the most of the NZLRI LUC data for plantation forest planning requires some understanding of the categories it uses for slope, erosion type, and parent material (broadly, geology). It also requires translating an assessment for pastoral farming into one that identifies the vulnerabilities relevant to plantation forests.

6 Using the NZLRI

The NZLRI can provide some useful insights into failure modes, so how do you find this information to use it?

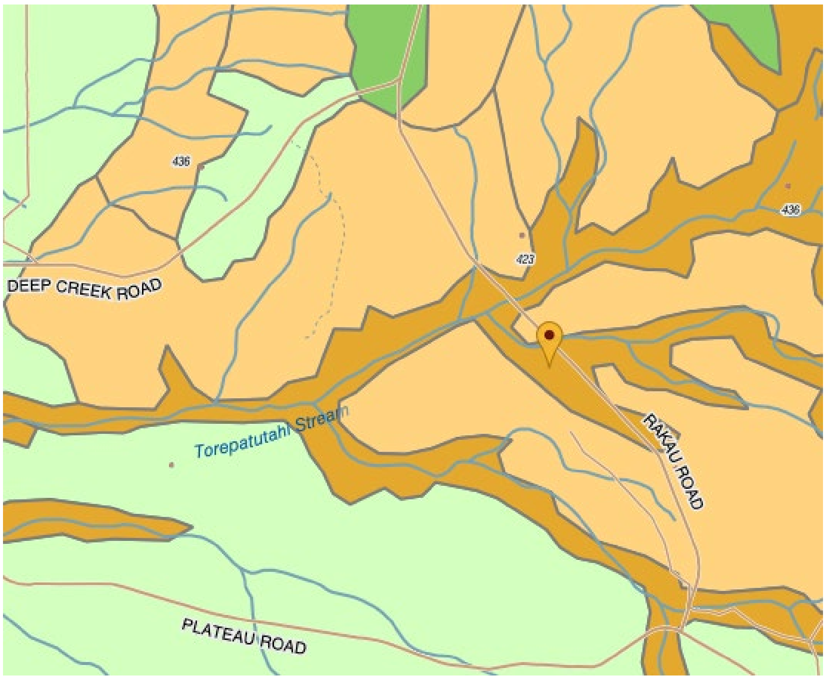
The LUC land mapping and classification system has two main components:

1. the map;
2. the detail of the classification that the LUC unit's "code" describes at high level, in its number-letter-number format.

6.1 INTERPRET THE INFORMATION THAT ACCOMPANIES THE MAP.

1. Gain access to the LUC map and its dataset at: https://ourenvironment.scinfo.org.nz/maps-and-tools/app/Land%20Capability/lri_luc_main

2. Identify the site of interest on the LUC map by entering an address or co-ordinates or dropping a pin.



3. One or more LUC polygons might be present on the site. Drop a pin for each LUC polygon present on the property you are interested in. A **Report Preview** pane pops up on the right of the screen for each pin.

   The example site above is in the North Island Central plateau. It has deep incised gullies (LUC class 7, brown) that are a result of volcanic material being eroded by water shortly after the eruptions and more recently as a result of pastoral land use. Water flowed over compacted grass, broke through the soil surface, with significant gullies the result.

   Each report preview summary presents information in the same order. Each word or phrase has a particular defined meaning:

Report preview

Land Use Capability

Dominant NZLUC Unit

nz7e-61

Description

Flat to rolling closely dissected terraces mantled with Taupo flow tephra up to 1000m asl with low fertility Pumice and Recent (yellow brown pumice) soils in moderate to high (1200-2400mm) rainfall areas subject to periods of moisture deficit and with a potential for very severe gully and streambank erosion, and severe sheet erosion.

Historical Regional Units

7e12 (Bay of Plenty–Volcanic Plateau)
7e16 (Northern Hawkes Bay)
7e19 (Taranaki–Manawatu)

The summary identifies:
slope,
then
parent material,
then
soil group,
then
rainfall, and lastly
the
erosion type and **severity**.

The three highlighted factors are particularly useful for forestry risk planning. The soil group doesn't add too much for this purpose – it reflects the parent material, and rainfall is of more interest for growing conditions.

Some further examples of report previews show North Island west coast sand country (left) and Whanganui hard hill country (right), highlighting the slope, parent material and erosion type and severity:

Report preview

Land Use Capability

Dominant NZLUC Unit

nz6s-4

Description

Flat to gently undulating sand plains and low dunes below 30m asl with free draining low to medium natural fertility sandy Brown and Gley (yellow brown sand) soils in moderate (<1200mm) rainfall areas with periods of soil moisture deficit and a potential for slight wind erosion.

Historical Regional Units

6s4 (Wellington)
6s4 (Taranaki–Manawatu)

Report preview

Land Use Capability

Dominant NZLUC Unit

nz7e-38

Description

Steep to very steep hills of consolidated sandstone and massive siltstone below 600m asl with Recent, Brown, Allophanic and Podzol (yellow brown earth) soils moderate to high (1200-2000) rainfall areas with a potential for severe soil slip erosion.

Historical Regional Units

7e17 (Gisborne–East Coast)
7e11 (Taranaki–Manawatu)

The process for getting more detail is explained below. Sections 4.1.1 - 4.1.3 explain how the three key factors of slope, parent material and erosion types are categorised.

6.1.1 Slope – NZLRI key

Slope is measured in degrees and is always described by dominant slope (see blue circles above), using specific terms for each slope range. “Flat to gently undulating” in the sand country example to the left is 0 - 3°. The hill country example “steep to very steep” is 26 - >35°. The steepness of a slope plays a part in mass movement, but the relationship is not always direct. It is important to keep the parent material in mind when assessing the role that slope plays in erosion. Some parent materials lack cohesion, cannot hold a steep slope, and fail at relatively low angles, for example, crushed mudstones. Others are stable even though they are very steep, for example, greywacke.

Slope Group	Slope angle (degrees)	Description	Typical examples
A	0–3°	Flat to gently undulating	Flats, terraces
B	4–7°	Undulating	Terraces, fans
C	8–15°	Rolling	Downlands, fans
D	16–20°	Strongly rolling	Downlands, hill country
E	21–25°	Moderately steep	Hill country
F	26–35°	Steep	Hill country and steeplands
G	>35°	Very steep	Steeplands, cliffs

Table 1: Slope groupings. From 3rd edition of the Land Use Capability Handbook 2009 at http://digitallibrary.landcareresearch.co.nz/digital/collection/p20022coll14/id/74

Forests are often planted on hill country with long slopes. Aerial photos, LiDAR or contour maps will reveal whether slopes are:

- **concave** – steeper at the top, with likely skeletal soil development in the top area of the slope. This may be too skeletal to sustain a crop to maturity (see Hawkes Bay photo next page);
- **convex** – rounder at the top with potentially more soil development but steepening into a gorge downslope. On these slopes there is a greater likelihood of parts of the slope being blind to a hauler operator, and of some of the crop being lost into the gorge (see inland Whanganui photo below).

These differing slope types mean that slope failure susceptibility may not be uniform for the entire length of the slope. It could be greater at the top for concave slopes and at the bottom for convex slopes. Whether the slope is convex, concave, or straight can be picked up by looking at topographic map contour lines, or on a GIS layer. This description is also usually covered in the bulletins.

Image credit – F Cunningham, Rayonier, Hawkes Bay.
Post Cyclone Gabrielle damage showing a concave slope – steeper at the top. In some instances, planting this upper slope may not be a good idea as any failure will also wipe out trees on the more productive lower slope.

For long concave slopes the runout from the slip may not reach flowing water, but in convex slopes if it reaches the slope inflection point, it almost certainly will. Therefore, any vegetation on top of slips on convex slopes will also end up in the stream channel. It is difficult to remove material from a confined channel so convex slopes have a higher risk of creating channel blockage in the form of debris dams than other slope types. Planting patterns should take this into account and should not extend over the inflection point.

Image credit - John Douglas Sustainable Forest and Land Management 2022, inland Whānganui

6.1.2 Parent material – NZLRI key

Parent material is a simplified explanation of the geology. Rock types are grouped according to their similar erosion susceptibilities and characteristics (orange underline in the examples above).

The parent material description concentrates on rock types that directly influence surface morphology. These are based on the dominant rock type for the area.

Igneous rocks			
1. Extremely weak to very weak igneous rocks			
Ng	Ngauruhoe tephra	Kt	Kaharoa and Taupo ashes
Rm	Rotomahana mud	Mo	Ashes older than Taupo ash
Ta	Tarawera tephra	La	Lahar deposits
Sc	Scoria	Vu	Extremely weak altered volcanics
Tp	Taupo and Kaharoa breccia and pumiceous alluvium	Ft	Quaternary breccias older than Taupo breccia
Lp	Pumiceous lapilli		
2. Weak to extremely strong igneous rocks			
Vo	Lavas and welded ignimbrites	In	Ancient volcanics
Vb	Indurated volcanic breccias	Gn	Plutonics
Tb	Indurated fine-grained pyroclastics	Um	Ultramafics

Table 2: Rock type symbols, names and prefixes used in the NZLRI rock type classification. From 3rd edition of the Land Use Capability Handbook 2009 at http://digitallibrary.landcareresearch.co.nz/digital/collection/p20022coll14/id/74

Large areas of the first category - **extremely weak to very weak igneous rocks** - have been used for plantation forests in the central North Island. This was originally because the land was unsuitable for pastoral farming due to mineral deficiencies. These rock types were often highly sorted as they fell from the sky during volcanic eruptions, so are very vulnerable to fluvial erosion - gullying, and tunnel gullying. That susceptibility is considerably reduced under forest cover, compared to pasture. Because LUC focussed on pastoral uses, the *potential* erosion severity for these deep unconsolidated ashes of the Waikato/Bay of Plenty is rated as severe to very severe. This is because pasture roots cannot hold them together in high intensity rain events, but under forest cover the actual erosion is slight. Erosion susceptibility will increase when the forest is harvested, however the landform is usually of low slope. Provided the bare ground associated with infrastructure is well managed to avoid creating high-energy channelised flow, erosion issues are generally low.

A large proportion of plantation forests planted on land considered too erosion-prone for pastoral agriculture are on the sedimentary rocks (Table 2 below), mainly on **Very compact (very stiff) to weak sedimentary rocks**. These are common in the North Island hill country of western Waikato, Taranaki, Manawatu-Whānganui, Wairarapa, inland Hawkes Bay, and Tai Rāwhiti.

The nine parent materials listed in Sedimentary 2 below - **very compact (very stiff) to weak sedimentary rocks** - have distinct mass movement failure modes, discussed in section 4.1.4. Understanding these failure modes helps identify what types of management risks are relevant for:

- planting, as to whether the crop is likely to reach maturity;
- infrastructure construction and maintenance;
- slash left on slope, should the slope fail.

Sedimentary rocks			
1. Very loose to compact (very soft to stiff) sedimentary rocks			
Pt	Peat	Cl	Coarse slope deposits
Lo	Loess	Gl	Glacial till
Wb	Windblown sand	Uf	Unconsolidated clays and silts
Af	Fine alluvium	Us	Unconsolidated sands and gravels
Gr	Alluvial gravels		
2. Very compact (very stiff) to weak sedimentary rocks			
Mm	Massive mudstone	Sb	Bedded sandstone
Mb	Bedded mudstone	Cw	Weakly consolidated conglomerate
Mf	Frittered mudstone	Mx	Sheared mixed lithologies
Me	Bentonitic mudstone	Ac	Crushed argillite association of rocks
Sm	Massive sandstone		
3. Moderately strong to extremely strong sedimentary rocks			
Ar	Argillite	Cg	Conglomerate and breccia
Si	Indurated sandstone	Li	Limestone
Gw	Greywacke association of rocks		

Metamorphic rocks			
Sx	Semi-schist	Gs	Gneiss
Sy	Schist	Ma	Marble

Table 3: Rock type symbols, names and prefixes used in the NZLRI rock type classification. From 3rd edition of the Land Use Capability Handbook 2009 at http://digitallibrary.landcareresearch.co.nz/digital/collection/p20022coll14/id/74

6.1.3 Erosion severity and type - NZLRI key

Erosion severity and type also have specific terminology (red circle in the examples above).
Erosion severity has 6 categories:

- negligible
- slight
- moderate
- severe
- very severe
- extreme

A formal analysis process is used to ensure that the categorisation process is standardised.

Erosion potential is made up of severity and susceptibility, and varies depending on with vegetation cover.

Erosion types, a function of lithology and climate, are:

- Surface erosion;
- Fluvial erosion;
- Mass movement erosion.

Table 4: Erosion types and symbols. From 3rd edition of the Land Use Capability Handbook 2009 at http://digitallibrary.landcareresearch.co.nz/digital/collection/p20022coll14/id/74

Category	Erosion types	Symbol
1. Surface erosion	Sheet	Sh
	Wind	W
	Scree	Sc
2. Mass movement	Soil slip	Ss
	Earthflow	Ef
	Slump	Su
	Rock fall	Rf
	Debris avalanche	Da
	Debris flow	Df
3. Fluvial erosion	Rill	R
	Gully	G
	Tunnel gully	T
	Streambank	Sb
4. Deposition	Deposition	D

Surface erosion severity is predominantly assessed as the surface area affected (depth is also considered for sheet and wind erosion). Surface erosion, especially via wind, does not feature as a risk to plantation forests, mainly because the surface roughness and root occupancy created by a forest means wind erosion does not get a hold.

Fluvial erosion is usually a feature of bare ground with low or no root occupancy. It is therefore a risk mainly from the bare ground created by infrastructure, rather than a risk to or from a standing crop.

For **mass movement,** factors specific to each mass movement process are also taken into account. For shallow landslides they include:

- areal extent;
- size of scars;
- volume of material removed;
- nature of rock and regolith (the weathered top layer, including the soil);
- slope angle and length;
- position on hill slope i.e. connectivity of debris tails with stream channels;
- likelihood of reactivation;
- likelihood of stabilisation if soil conservation measures are implemented.

The parent material information also gives insights into site fertility (for example, sandstones are less fertile than mudstones). This will be apparent in the site index information in the extended legend.

NZLRI also maps:

1. a dominant soil type, using units based on previous soil surveys;
2. vegetation cover, using a national classification.

These last two factors are of less relevance in a forestry situation. Soil reflects the parent material, but the parent material usually has the greater effect on the tree site index. The relevance of vegetation cover is that it indicates the difference between actual and potential erosion.

6.1.4 Sedimentary 2 rocks – common failure modes

This section takes a closer look at failure modes on sedimentary 2 rock types because they have had high erosion failure rates in agricultural use and plantation forest has often been regarded as a better land use on this vulnerable land. They are also a significant proportion of forested land. The list of the sedimentary 2 rock types is:

2. Very compact (very stiff) to weak sedimentary rocks

Mm	Massive mudstone	Sb	Bedded sandstone
Mb	Bedded mudstone	Cw	Weakly consolidated conglomerate
Mf	Frittered mudstone	Mx	Sheared mixed lithologies
Me	Bentonitic mudstone	Ac	Crushed argillite association of rocks
Sm	Massive sandstone		

Table 5: Rock types and symbols. From 3rd edition of the Land Use Capability Handbook 2009 at http://digitallibrary.landcareresearch.co.nz/digital/collection/p20022coll14/id/74

Massive sandstone and massive mudstone - Sm and Mm

Slopes on **massive sandstone** and **massive mudstone** are often steep or very steep. There is a high likelihood that a shear zone will readily develop, along which water can travel and lubricate the junction between soil and parent material.

On the steep parts of these sites there are risks that:

a. the crop will not reach maturity without portions of it being peeled off, because the roots cannot penetrate the massive sandstone or mudstone. Windthrow can create routes for water entry that continue to lubricate the shear zone;
b. post-harvest, before the replanted crop reaches canopy closure (the window of vulnerability), the additional weight of water in the soil creates conditions for shear zones to activate a slip.

Shallow landslides in these conditions will take all that is sitting on top of it, downslope.

Image credit - John Douglas Sustainable Forest and Land Management 2022, inland Whānganui

Image credit – Ian Moore 2024 Inland Whanganui Windthrown trees on very steep consolidated mudstone (papa)

Bedded mudstone, bedded sandstone, sheared mixed lithologies - Mb, Sb, Mx

Shear zones are also present where there are transitions between parent materials. Water can create weakness that leads to shear failure as it preferentially flows above the denser layer. It occurs where:

- there is a volcanic overlay on a sedimentary substrate, commonly found on hill tops of inland Taranaki/ Whanganui, and in the eastern Bay of Plenty; or
- there are distinct layers in bedded mudstones and sandstones.

Volcanic overlays can be thin and may result in shallow landslides being the main form of slope failure. Provided the underlying material is not massive, trees will be quite well anchored, but as with the shallow soils, slope failure can occur post-harvest with the increased water-holding that happens in soil in the absence of canopy closure. In that case the shallow soil layers may slough off, taking all that is on top of them as well.

Image credit – BOPRC[34] showing slope failure after a high intensity rainfall event at the interface of the volcanic material mantling the sedimentary rocks.

[34] *Operations publication July 2011, page 3*

In **bedded sedimentary rocks** the failure mode becomes more complex. Shear zones occur at the change of bed material. For example, where it changes from a coarse sand to a fine consolidated mudstone. In these cases the shear zones aren't at the soil/parent material interface, so not necessarily running parallel near to the surface. Most marine sediments have been tilted as they were uplifted, so the change in parent material will be different on different slope aspects. The hillslope may intersect them at an acute or at a shallow angle, and they will behave differently accordingly. Interbedded marine sediments (Mb, Sb) are found in inland Whanganui, Taranaki and Hawkes Bay and at the allochthons[35] of Tai Rāwhiti and Northland. Often their presence is marked by springs emerging partway up a hill. This is because water can percolate through the looser material, but once it reaches the more consolidated layers it can't, so it finds its way out to the surface. Where infrastructure, such as cuttings, go across these junctions several factors are likely to change, so when planning roads, tracks and landings be aware of the different angles of repose of the different layers (for example, those that can hold a steep batter and those that can't).

There may be pre-existing large erosion features in a forest such as earth slips and rotational failures such as slumps where this zone of weakness has already been activated. Adding infrastructure onto these features or cutting into them may add weight, supply further water to a shear plane, or intersect already weak junction points.

Being aware that these features are likely to be present, and using LiDAR to pinpoint any that are already active, provides useful information on where to avoid putting roads and landings, or where extra cost might arise, so that a road or landing can be designed and maintained to retain its integrity.

Frittered mudstone, Crushed argillite association of rocks – Mf, Ac

Argillite is older and denser than the frittered mudstone, having been formed earlier and compressed more, but both can have similar failure modes. Due to their lack of internal coherence the failure can occur as a slow flow, which can cover a large area. Once started these flows are difficult to stop, particularly if the toe is being cut out by a stream at the base. Argillite-based earth flows are relatively common on the lower North Island east coast. They can be very dry and hard to establish trees on, but when the trees are being harvested it's important to avoid adding significant amounts of water that could weight-load and/or lubricate the flow mass, as this can increase its activity. Make sure planned water controls will not add water to the flow mass (for example, no decanting earth bunds), and that they direct water away from land (for example, with channels and fluming).

Bentonitic mudstone - Me

The major issue here is that a layer of bentonite, which can be quite thin, can shrink and swell, and create a failure plane. Well known New Zealand examples of this type of failure are the Whaeo and Ruahihi canal collapses[36] and the landslide in the Dunedin suburb of Abbotsford.

Weakly consolidated conglomerate – Cw

A conglomerate has gravel sized (>2mm) fragments contained within a fine-grained matrix of sand, silt or clay sediments deposited by water (alluvial, fluvial) gravity (colluvial,) or ice (glacial). They have varying levels of consolidation. Weakly consolidated conglomerates include alluvial fans, scree, and glacial and colluvial deposits. Their main failure mode is rapid gully and fissure erosion, particularly during heavy rainfall events.

[35] **allochthon** is a large block of rock moved from its original site of formation, usually by [low angle thrust faulting]
[36] http://www.delahyde.com/tauranga/pagest/ruahihi_canal_collapse.html

Concentrated surface water will rapidly scour these unconsolidated sediments, transporting the debris downslope or downstream. Escalation of incised gully erosion, toe erosion or stream bank erosion over-steepens the gully walls, causing them to fall in. The clay cliffs at Omarama and the Pūtangirua Pinnacles in the Aorangi Ranges, Wellington are extreme examples.

Image credit Department of Conservation, Pinnacles Track, Wairarapa.

6.2 HISTORICAL REGIONAL UNITS – FOR MORE DETAIL

The NZLRI interactive map sets out the basic LUC information, as described above.

For detailed information on any LUC unit, including an example of where it's found, MWLR have on their website the Land Resources Portal that makes it easy to find the extended legends and bulletins for each region[37] by clicking on the relevant region[38]. Each region was mapped individually so there are differences in descriptions of LUC units. For example, a 6e1 unit in Bay of Plenty – Volcanic Plateau is on *ashes older than Taupo ash over welded volcanic rocks*, while a 6e1 unit in the South Island is on *limestone, with loess in places.* It is essential to check the correct regional information.

MWLR have also improved data search-ability, with many of the extended legends available as Excel spreadsheets. Digitising the hard copy bulletins has been challenging, so not all of them are searchable and you will need to check the table of contents and scroll to the right page[39].

NB: North Island region boundaries predate and are different from regional council boundaries. The South Island has always been one "region".

[37] https://lrp.landcareresearch.co.nz/resources/luc-regional-data/

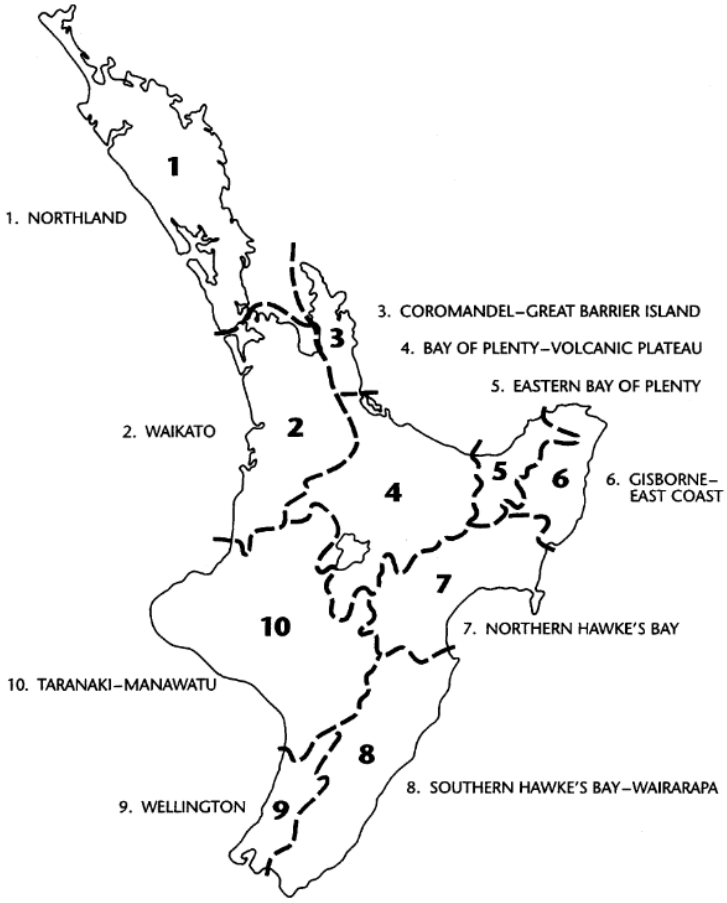
[38] the rationale for creating national units was to remove regional discrepancies in unit numbering, however in doing so some of the detailed description, including typical sites, is no longer presented up front.

[39] Northland, Taranaki are not yet searchable.

The Portal has very useful explanations and links to use the NZLRI and LUC. Links allow you to refer to:

- **Extended Legends** which list the LUC units from most to least versatile in a spreadsheet format with 18 columns of data. Foresters will find eight of these Excel columns most useful

- **Regional bulletins** which have the most detailed explanations of the regional context and the physical land resources in a book format. There will often be about a page of detail per LUC unit. Note that in the bulletins the LUC unit description convention is roman number/letter/Arabic number (for example, VIe11) rather than the Arabic/letter/Arabic (6e11) used in the national dataset. A bulletin search needs to use the roman/letter/Arabic format for the unit.



The bulletins generally present the Land Use Capability units in their suites. For example, eight parent materials (alluvium, sand, tephra and loess, mudstone, sandstone, limestone, argillite and greywacke) are covered as eight sections of the bulletin. A **suite** describes a family of landforms associated with a specific parent material, with each suite likely to have one or more of a steepland, a hill and a plain unit, with diagrams explaining how they relate to each other. For example, the sand suite below has a fore-dune, a mid-dune and an inland dune landform, which have different LUC units that reflect the gradual increase in capability.

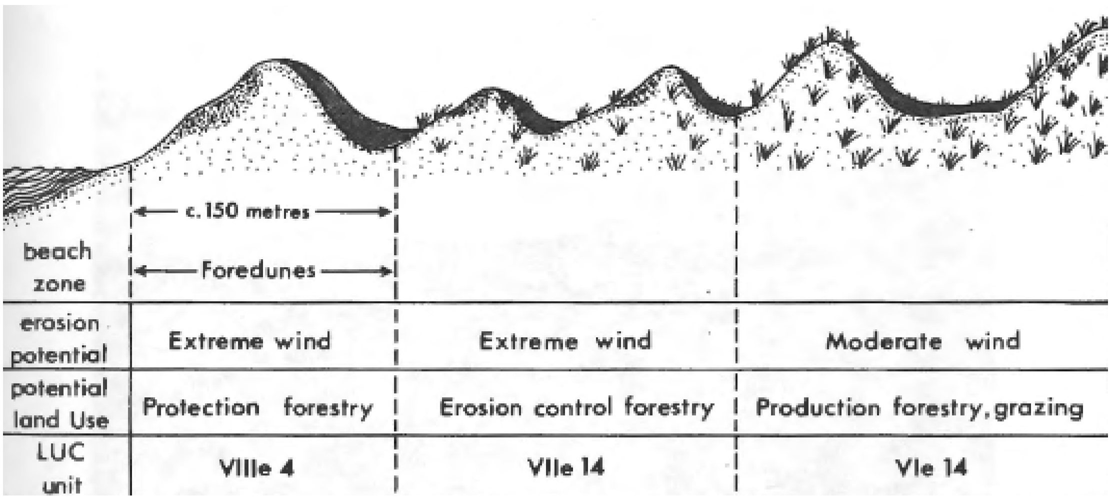


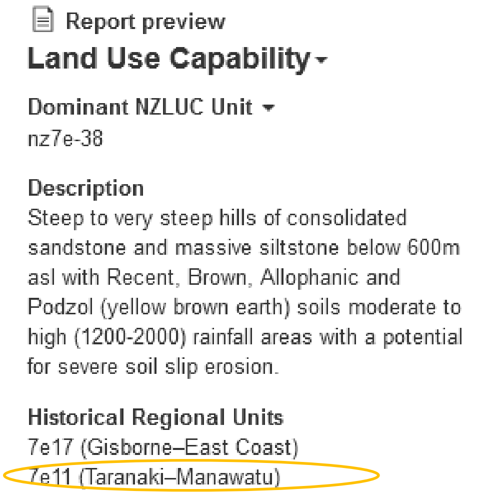
Figure 4: Relationship between LUC units on coastal dunes - Southern Hawkes Bay

6.2.1 Worked example using the extended legend and bulletin detail

For the Whanganui hard hill country example on page 29, clicking on Taranaki-Manawatu and searching for the historical unit 7e11 in the extended legend and bulletin would provide all the detail for that unit which is now named 7e-38.

STEP 1
Select the relevant region.
https://lrp.landcareresearch.co.nz/resources/luc-regional-data/#taranaki
This example uses legend 10, Taranaki-Manawatu

The material that MWLR holds for this region is the bulletin (1987), the original extended legend (1981) and the Excel file of the extended legend.



Report preview

Land Use Capability

Dominant NZLUC Unit

nz7e-38

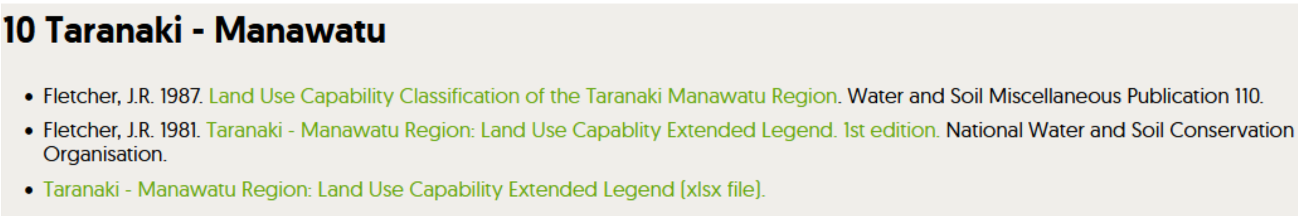
Description

Steep to very steep hills of consolidated sandstone and massive siltstone below 600m asl with Recent, Brown, Allophanic and Podzol (yellow brown earth) soils moderate to high (1200-2000) rainfall areas with a potential for severe soil slip erosion.

Historical Regional Units

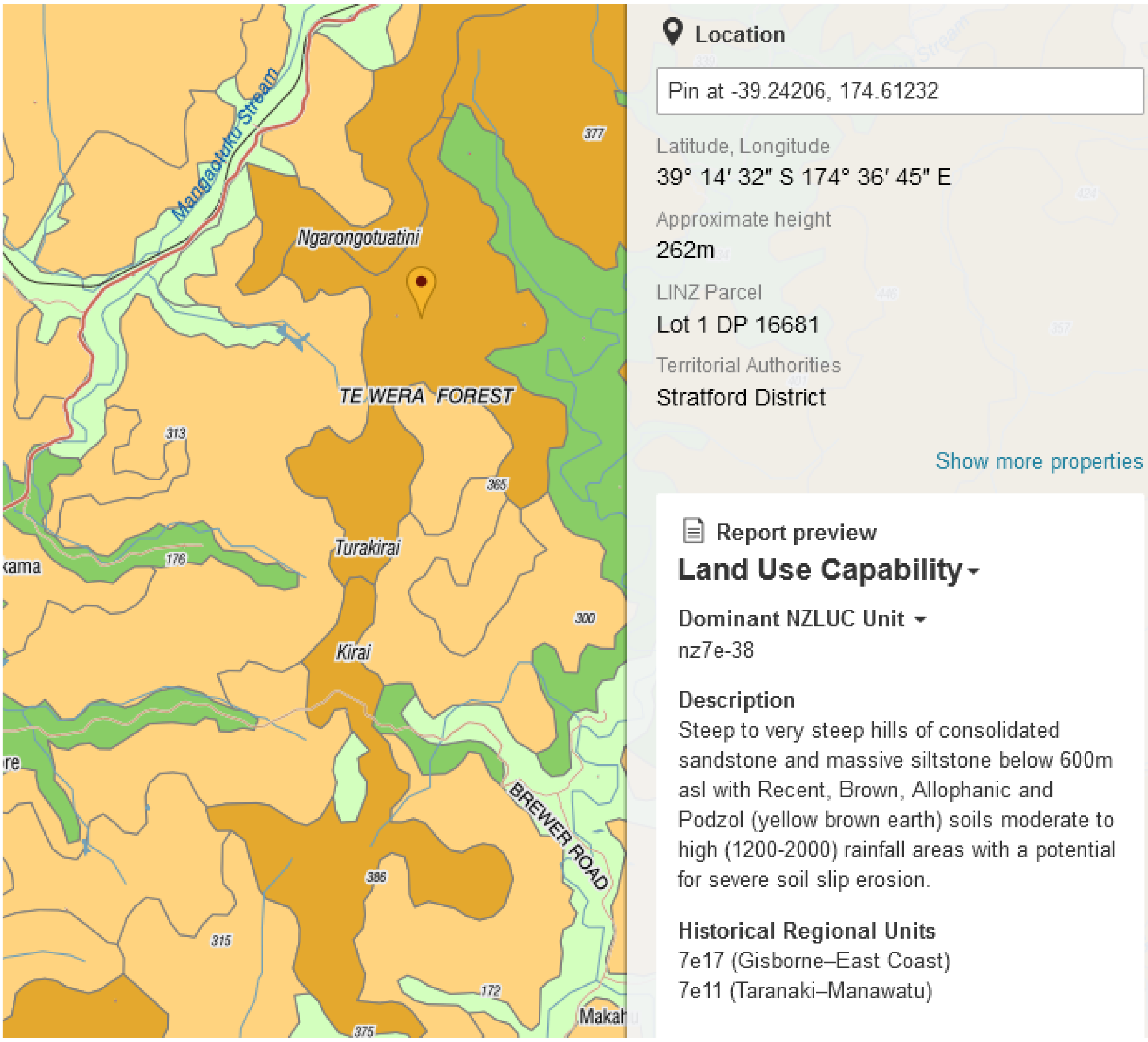
7e17 (Gisborne–East Coast)

7e11 (Taranaki–Manawatu)



10 Taranaki - Manawatu

- Fletcher, J.R. 1987. Land Use Capability Classification of the Taranaki Manawatu Region. Water and Soil Miscellaneous Publication 110.
- Fletcher, J.R. 1981. Taranaki - Manawatu Region: Land Use Capablity Extended Legend. 1st edition. National Water and Soil Conservation Organisation.
- Taranaki - Manawatu Region: Land Use Capability Extended Legend (xlsx file).



STEP 2
Open the Excel version of the extended legend and scroll down to 7e11

The **extended legends** present information in a table (with 18 columns).
For a forestry planning assessment, 5 columns are of most interest:

1. Unit description
2. Rock type
3. Rock type lithology symbol
4. Erosion present
5. Erosion potential

These generally speak for themselves. Looking at the **Rock type** lithology symbol, the **present and potential erosion**, and the description of the failure modes will help with recognising what features to look for on a LiDAR image, to assist with setting planting limits and for siting infrastructure. (The snip below has hidden all other less relevant columns, as you can see from the column headers)

A	B	C	J	O	P	Q	U	V	Z
Unit	area mapped (ha)	Unit Description	ential land	Slope	Rock Type		Erosion		Additional Comments
			P. rad SI				Present	Potential	
7e10	5150	Steep to very steep slopes with shallow, strongly leached soils developed on greywacke in the Ruahine Range. There is a potential for severe soil slip, debris avalanche, sheet and scree erosion	24-27	F, F+G	Greywacke	Gw	Slight soil slip. Nil to slight debris avalanche sheet and scree creep.	Severe soil slip. Nil to slight debris avalanche sheet and scree creep.	Steeper slopes generally unsuitable for forestry due to possible access, establishment and logging difficulties.
7e11	315350	Steep to very steep slopes of consolidated sandstone. Unit occurs predominantly in the King Country and inland Taranaki-Wanaganui districts where rainfall exceeds 1200mm p.a. There is a potential for severe soil slip and moderate debris avalanche erosion. Revegetation of soil slip and debris avalanche sites is slow. Earthflow erosion occurs on colluvial slopes	25-28	F, F+G.	Massive consolidated sandstone.	Sm	Slight to moderate soil slip. Slight sheet, debris avalanche and earthflow.	Severe soil slip. Moderate debris avalanche. Slight sheet and earthflow.	This unit has significant areas of siltstone alternating with predominant sandstone. Steeper slopes generally unsuitable for forestry due to access, establishment and logging

Table 6: Excerpt from the Taranaki - Manawatu Excel version of the LUC extended legend

STEP 3

In the **bulletin** the LUC units are grouped by geology and soil type, not rank order so searching requires using the table of contents to find “massive sandstone”. This reveals the following on page 174:

LUC unit VIIe11 (316,000 ha)—Figures 113, 114

VIIe11 comprises steep and very steep slopes on consolidated sandstone where the annual rainfall is between 1200 and 2000 mm p.a. Slopes are steeper and longer (approximately 150 m) than in LUC unit VIe23, and ridge crests are narrow and streams deeply entrenched. It is the most extensive LUC unit in the Taranaki-Manawatu region, and the dominant hill country LUC unit in much of inland Taranaki, the Waitotara River Catchment, Waimarino County and parts of the King Country.

There are severe physical limitations to pastoral and forestry use due to severe erosion hazards, steep and very steep slopes, and shallow infertile soils.

Typical soils include the steepland soils of the Whangamomona, Moumahaki, Timi and Otamawairua series. Sandstone bluffs with no soil development are recorded as bare rock.

Much of VIIe11 has not been cleared for farming and remains largely in indigenous forest. Pasture is primarily in areas with the best access. However extensive areas that were developed for farming have now reverted to scrub and fern. Pasture is the exclusive vegetation on map units covering only 3% of VIIe11 although grazing also occurs on another 22% that has pasture with forest or scrub. The remainder is recorded as forest (49%), scrub (15%) and forest-scrub (11%).

Physical land use constraints are demonstrated by the potentials for pastoral and forestry use. The average stock carrying capacity is 5 su/ha with a potential of 9 su/ha. Lower slopes have a medium suitability (SI 25–28 m) for *P. radiata* growth, but the steeper upper slopes are generally unsuitable for forestry because of access, establishment and logging difficulties. Difficult access is a major constraint to use. Numerous deeply incised gorges require expensive bridging and the cost of maintaining county roads is high.

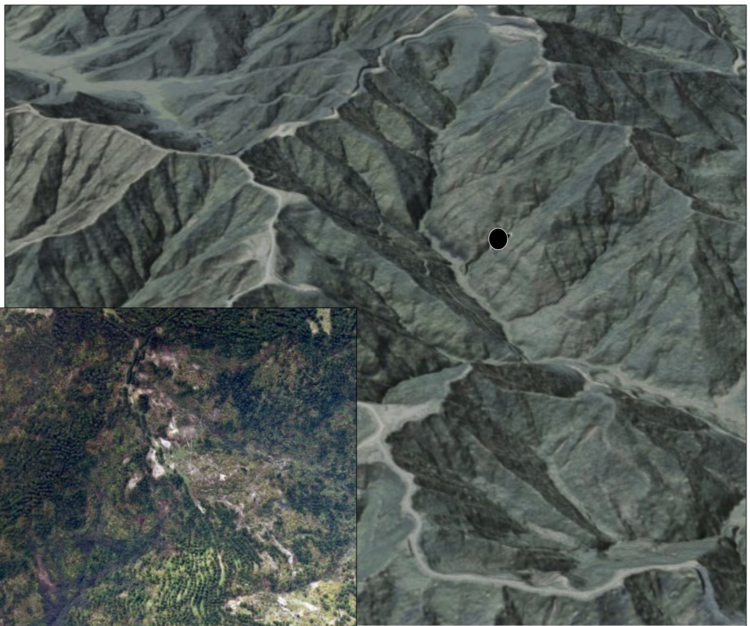
The unit has a potential for severe soil slip and moderate debris avalanche erosion. Eroded sites need to be oversown and topdressed, however establishment of vegetation on the low fertility sandstone can be difficult. Conservation trees, adequately protected from goats, cattle and possums should be open planted in areas most susceptible to erosion, and indigenous vegetation should be maintained on inclusions of Class VIII. There is also a potential for slight sheet erosion particularly when north facing sunny slopes are over-grazed. Lower colluvial slopes may have a slight earthflow potential particularly if undercut by streams.

STEP 4

Use the insights from the extended legend and/or the bulletin while checking the site using LiDAR imagery or satellite DEM to decide whether there are areas to avoid for:

- Planting, in order to avoid mid-rotation failure or areas of very low yield that will affect the overall economics of the whole block. The description above cautions against using the upper slopes (underlined in orange).
- Infrastructure locations. If the upper slopes are not planted and instead revert to scrub, how will this affect and constrain harvest options?

Aerial photo (below) and LiDAR (right) images



7 Further reading

Barringer J et al 2018. Use of modern technology including LiDAR to update the New Zealand Land Resource Inventory MPI Technical Paper No: 2018/51. Manaaki Whenua − Landcare Research Contract Report LC3091 for the Ministry for Primary Industries.

Basher L, Barringer J 2017. Erosion susceptibility classification for the NES for Plantation Forestry. Landcare Research Contract Report LC2744 for the Ministry for Primary Industries.

Harmsworth GR 1996. Land Use Capability classification of the Northland region. A report to accompany the second edition (1:50 000) New Zealand Land Resource Inventory worksheets. Landcare Research Science Series 9. Lincoln, Manaaki Whenua Press.

Harnett M et al 2020 Planting eroding hill country in the Hawke's Bay Region: Right tree, right place, right purpose. Scion contract report QT-7569 for Hawke's Bay Regional Investment Company Ltd

Lynn I et al 2009. Land use capability survey handbook: a New Zealand handbook for the classification of land. 3rd ed. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science.

Visser R et al 2018. Best practices for reducing harvest residues and mitigating mobilisation of harvest residues in steepland plantation forests. Enviro Link Contract 1879-GSD152 Prepared for: Dr Murray Cave, Gisborne District Council.

8 Useful links

Ministry for Primary Industries
Plantation Forestry Erosion Susceptibility Classification Risk Assessment Report for the NES-CF 2017
https://www.mpi.govt.nz/dmsdocument/19340/direct

Manaaki Whenua – Landcare Research
About land use capability
https://ourenvironment.scinfo.org.nz/help/land-use-capability

LUC and scale
https://lrp.landcareresearch.co.nz/topics/understanding-luc/luc-and-scale/

A risk matrix for storm-initiated forestry-related landslides and debris flows in the Gisborne region
Chris Phillips, Les Basher, Michael Marden MWLR for GDC Jan 2017
www.gdc.govt.nz/__data/assets/pdf_file/0025/12868/gdc-riskmatrix-for-storm-initiated-forestry-landslide-and-debris-....pdf

Geoscience Australia
What is Map Scale?
https://www.ga.gov.au/scientific-topics/national-location-information/topographic-maps-data/basics/what-is-map-scale

9 Glossary

Terms in common use can have a more tightly constrained meaning when used in natural hazard management. For example, a common use meaning of risk is "the possibility of loss or injury". It becomes much more tightly prescribed in natural hazard management to mean the likelihood and consequence.

Mass movement - natural geomorphic agents that shape landforms and redistribute sediment and debris to gentler terrain and water bodies. Gravity is always the primary driving mechanism, but may be supplemented by water. Earth movement by one or more of: falling, toppling, sliding, spreading or flowing.

Erosion - the geological process in which earthen materials are worn away and transported by wind or water. **Potential erosion** is the inherent predisposition of the land to erode and considers the frequency of erosion causing events (susceptibility), predominant land uses and vegetative covers (which affect severity).

Erosion susceptibility has two components,

- **predisposing factors** which determine the *inherent* susceptibility of a land unit to erode (such as slope and lithology), and
- **preparatory/mitigating factors** which respectively *increase or reduce* erosion susceptibility above or below this inherent level e.g. earthworks and forest canopy removal by clearfell (preparatory factors), and reinstatement of a forest canopy by tree planting/regeneration (mitigating factor).

Hazard - The probability of a particular threat occurring **in an area** within a **defined time period**. [40] **Hazard Maps** identify the spatial extent and intensity of potential hazards - the areas likely to be affected by specific natural events **within a given timeframe**. i.e. they have a predictive function. For landslide hazard probability assessment, these factors are relevant:

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

Risk[41] A combination of the occurrence of harm and the severity of that harm. Effect of uncertainty. Usually expressed in terms of **risk sources**, **potential events**, their **consequences** and their **likelihood (probability)** [42]. Erosion **risk**[43] = erosion **susceptibility** x **frequency** of triggering events x **consequences -** the nature of the downslope/downstream values affected by the erosion

Risk analysis should consider:

- the **likelihood** of events and consequences;
- the **nature and magnitude** of **consequences**;
- complexity and connectivity;
- time-related factors and volatility;
- the effectiveness of existing controls;
- sensitivity and confidence levels.

Susceptibility - the estimation of the **likelihood** of **spatial** occurrence of natural hazard evaluated on the basis of terrain and environmental conditions[44]. It measures the **likelihood** of a **natural hazard** occurring in a **specific area**, considering local environmental conditions and historical data. It doesn't predict when or how often hazards will occur but identifies *potential future locations* of such events.
Susceptibility maps identify areas prone to a particular type of hazard based on the **intrinsic properties** of those areas (slope, soil type, vegetation cover, hydrology, etc.) and indicate the relative likelihood of occurrence. **Landslide susceptibility** assesses the volume (or area) and spatial distribution of landslides that exist or may potentially occur in an area, including a description of potential landslide runout areas. Landslide risk as a measure of the **probability** and **severity** of an adverse effect to life, health, property or the environment[45] [46].

[40] https://www.gns.cri.nz/assets/Data-and-Resources/Download-files/MS-144-Landslide-Planning-Guidance_FINAL_25Jan2024.pdf
[41] https://committee.iso.org/sites/tc262/home/projects/published/iso-31000-2018-risk-management.html
[42] CDEM Act. ISO 31000:2018 (AS/NZS 2004)
[43] Bloomberg
[44] Brabb, 1985
[45] Corominas et al. (2015)
[46] https://blog.geoneon.com/en/blog/understanding-susceptibility-in-natural-hazards