7.5 Landslide susceptibility mitigation

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Preamble: Landslide susceptibility describes the inherent properties of terrain which make it more or less susceptible to failure e.g., geology, slope angle, elevation, hydrological conditions, etc. It does not include the frequency of landslides, or the consequences (e.g., areas that may be impacted by landslides are not identified).

In practical terms the ‘landslide susceptibility mitigation’ attribute aims to reduce erosion from rainfall-triggered shallow landslides on land at high risk from this process by requiring councils to proactively define areas where susceptibility is high and then plan and monitor relevant mitigation such as soil conservation planting, afforestation and reversion.

It is not currently monitored nationally or regionally.

It would be difficult to focus specifically on this as an attribute as it risks being conflated with more general ‘measures’ of ‘erosion susceptibility’ and current progress towards reducing erosion in general. It (landslide susceptibility) varies widely across NZ making it less suitable as a national attribute, particularly for much of the South Island.

Landslide susceptibility is a specific subset of ‘erosion susceptibility’ which is a more encompassing term describing the susceptibility of land to some/all erosion processes, e.g., Highly Erodible Land (HEL – [1]; NZeem® [2]). Highly erodible land has been defined as land at risk of severe mass-movement erosion (landslide, earthflow, and gully) if it does not have protective woody vegetation”. ‘Erosion susceptibility’ has been, and continues to be incorrectly used, to cover landslide susceptibility, mass wasting (as in HEL), and any or all erosion processes.

Because landslide susceptibility is lumped with other erosion processes, it is difficult to assess the state of knowledge of this specific attribute, particularly its control, i.e., separate it from more general erosion control. However, our knowledge of rainfall-triggered landslides being the dominant erosion process in many parts of Aotearoa is well established [3] as are the significant impacts that arise from events that trigger landslides [4, 5].

A well-established woody vegetation cover can reduce the number and density of landslides triggered by storms [6, 7, 8]. Thus, vegetation is the main control measure for most erosion processes, including rainfall-triggered shallow landslides, and this is well understood [7, 8]. Our knowledge of land specifically susceptible to rainfall-triggered landslides across Aotearoa is not well-advanced, i.e., there are no national maps nor agreed approaches for producing such layers. Statistical landslide susceptibility models have been developed for several regions [9], and when incorporating LiDAR-derived digital elevation models, promise to provide high spatial resolution of shallow landslide susceptibility. These data-driven models are likely to be the most suitable approach for developing national layers.

If such an attribute were to be considered, the current state would need to be defined at a suitable scale. A 'response' indicator such as 'area of works/area treated' (planting, afforestation, reversion, soil conservation planting) would then need to be defined to provide evidence that land that was susceptible was being treated and progress was being made against a baseline state.

State of knowledge of 'Landslide susceptibility mitigation' attribute: Medium / unresolved

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Soil erosion is a wide-spread and long-standing issue in New Zealand [3, and many others]. Rainfall-initiated shallow landsliding is the key/dominant erosion process in many regions of New Zealand [3]. However, its occurrence and effects are episodic in both magnitude and spatial extent.

It affects ecological health through reducing soil depth and integrity at source locations and through the deposition of sediment in receiving environments. It can affect human health indirectly via mental well-being, being a recurring natural hazard that impacts livelihoods, infrastructure and communities. Knowledge and understanding of these impacts are not well correlated other than in a general sense.

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

Landslide susceptibility is an inherent property of the landscape. Geology, steepness, vegetation cover, historical and current land use, and the exposure to hydrological factors such as intense rainfalls determine a location's susceptibility to rainfall-triggered shallow landslides. Landslide susceptibility is often conflated with erosion susceptibility, i.e., all erosion processes combined.

Statistical models are used to determine the probability of one location's susceptibility over another e.g., [10]. Such models are data driven and require an inventory of where landslides occur and where they don't and how each point relates to rock type, vegetation cover, slope steepness, etc.

Impacts can be local or regional and depend on the characteristics of the triggering rainfall event (and/or antecedent conditions). The evidence is strong that rainfall-initiated shallow landslides are a key environmental and societal issue e.g., [3, 10, 11] as is the evidence that vegetation is the primary method to reduce most, but not all impacts [6].

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

In some places, susceptibility has temporarily reduced in the last 60 years as steep pasture covered slopes have been treated with soil conservation plantings, allowed to revert, or afforested [6, 12]. In other areas the opposite has occurred as susceptible land remains without woody vegetation.

Vegetation removal including forest harvesting, can increase landslide susceptibility [13].

Climate change projections suggest increasing storminess in many regions indicating more occurrences of rainfall-triggered shallow landsliding will occur [14, 15].

Impacts are only partially or temporarily reversible. In short timescales (years to decades), closed canopy woody vegetation will reduce local incidence of landslides for small to moderate rain events. At decadal to century timescales and in the most severe rain events (e.g., cyclones like Gabrielle, Bola, etc) geomorphic thresholds are crossed and many landslides will be initiated, including those under a woody vegetation cover. Further, soil will take centuries to rebuild and soil loss is not easily reversible. Vegetation, weeds, grass, colonisers will establish quickly, weeks to months across shallow landslide scars and on deposits (woody vegetation longer). Impacts of pasture production and forestry production of landslides are well known [25, 26].

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

This attribute (*sensu stricto*) is not routinely monitored.

In regions where it might be monitored, it is usually combined with other erosion processes such as 'highly erodible land', 'erosion susceptibility' or other proxies such as 'bare land'.

Where it might be monitored, the metric is usually the spatial extent of 'highly susceptible' land and how much of the 'worst' classes have been, or are being treated, by either soil conservation planting, afforestation or reversion.

There is no consistent methodology in use and no nationally agreed monitoring methodology.

Some Councils assess 'bare ground', or the proportion of LUC classes that have changing vegetation coverage, or similar approaches as part of SOE monitoring. Other councils may report how much is invested annually in soil conservation programmes, or poles planted etc. None of these approaches are focused on land that is specifically susceptible to rainfall-initiated shallow landslides.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

There are no major implementation issues for this attribute. While there is no consistent approach to assessment of land susceptible to rainfall-initiated shallow landslides and its treatment, remote sensing is clearly the most suitable approach for determining treated areas relative to a baseline state. As the baseline state does not exist, it is somewhat moot.

There is unlikely to be issues accessing private land unless there was a requirement for validation of remote-sensed information. Many remote sensing tools can provide resolution down to individual trees. The main barrier will be the cost of acquiring imagery and setting up automated processes to enable change comparisons. Another barrier will be the development of consistent and standardized data reporting, including systems and infrastructure to manage, store and report on monitored data.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

It is not being done routinely therefore hard to assess.

At least one regional council undertakes a 5 yearly survey of changes in "erosion status" assessed through remote-sensed imagery coupled with local records, while others assess bare ground on an annual basis as a proxy for 'erosion'. Some councils report on how many farms are treated with soil conservation works, others on the number of poles planted, etc.

If high resolution, cloud-free satellite imagery was regularly and cheaply available, algorithms could be developed to routinely assess different treatments, such as areas planted, counts of individual trees, etc. between one year and the next.

To date, most assessment of rainfall-triggered shallow landslides is manually done following a storm event and is therefore costly. Semi-and fully-automated approaches utilising satellite imagery for mapping landslides (or eroded area) are still in their infancy in NZ [16]. Separating shallow landslide erosion from other erosion types and the proportion of landslide-susceptible land treated or not, will be problematic.

The attribute would need to be monitored by consistent, spatial and standardised reporting of soil conservation work overseen by regional councils and/or central government to progress the evidence base that work is being done towards environmental improvement.

Some councils already report on assessments of proxies of erosion and the kinds and area of land treated with soil conservation plantings and are well positioned with data systems in place. Data standardisation across regional councils is likely to be achievable with direction, coordination, and funding.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

Land slide susceptibility risk is of high interest to Māori (see, e.g., [38], Hōretireti Whenua Sliding Lands programme, etc.), although I am not aware of any monitoring of this attribute being carried out by representatives of iwi/hapū/rūnanga. GNS are working with Ngāti Porou representatives to understand detailing learnings from recent landslide events, co-design a landslide response framework for hapū, iwi and the community, and enhance natural hazard preparedness and response in Kura Kaupapa Māori/schools. See https://www.gns.cri.nz/research-projects/sliding-lands/

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

Shallow landslide erosion is usually grouped with other erosion processes in a "general erosion assessment". It may or may not be correlated with the other listed land attributes.

During large rain events that initiate shallow landslides, gully processes are likely to be exacerbated particularly where shallow landslides transform into debris flows and are channelised within a gully or stream. In this situation, toe slope removal may initiate mass failure. Alternatively, in the absence of landslides being connected to gullies, concentrated runoff in the gully may scour the toe slopes resulting in 'streambank' failure (mass failure), i.e., in certain conditions there is a feedback loop between channel and slope.

Shallow landslide erosion is usually lumped with other erosion processes, e.g., gully erosion, surface erosion, and even bank erosion in assessments of erosion. In the LUC/Land Resource Inventory the key/dominant erosion process for that polygon is described along with its severity, e.g., in LUC as Ss soil slip, Da debris avalanche, Df debris flow [17], along with secondary erosion processes. In the NES-CF ESC, erosion processes are combined within one of 4 erosion susceptibility classes (the ESC is based on the national LUC).

Part B—Current state and allocation options

B1. What is the current state of the attribute?

Current state of landslide susceptibility is not well understood at the national scale. Understanding is not advanced enough for this to be used as an indicator.

Some North Island Councils (Gisborne, Hawkes Bay) have recently acquired high-resolution shallow landslide susceptibility layers derived from statistical landslide susceptibility models [10, 18, 19].

To be used as an indicator would require further development of statistical landslide susceptibility models that incorporate different geological rock types and empirical data from South Island regions before a national layer could be derived. Once a national layer was available, the areas deemed to be most susceptible could be monitored (annually or 5-yearly) to determine how much land had been 'treated' or was under a permanent tree cover relative to a starting baseline.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

I am unaware of the existence of natural reference states for this attribute.

Removal of the original indigenous forest increased the susceptibility of the landscape to erosion (of many processes) across the motu. We no longer have a natural system - it is highly modified - vegetation was removed, cities were built, hydrological regimes were changed etc. Consequently, susceptibility to erosion from all processes has likely increased - by how much by when it is difficult to know as we start getting into broader landscape evolution concepts which operate over much longer time frames 10^2 to 10^4 years (e.g., [26]). Assessments in lakes and estuaries and flood plains of sediment build up as being a proxy for erosion that span 10s to 100s to 1000s of years provides a glimpse of this but it relates to all erosion and is therefore an estimate of what natural erosion might have been [27-29].

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

I am unaware of any existing numeric or narrative bands for this attribute.

Globally, landslide susceptibility models (and their outputs) are routinely developed to inform landslide hazard and risk assessments [26]. The aim of landslide susceptibility analyses is to assign different likelihoods for landslide occurrence and classify different spatial locations in different susceptibility levels. However, practical uses of susceptibility analyses are often limited by large uncertainties and inconsistencies of various input data, and difficulties to understand the different susceptibility maps based on numerous methods [26-27]. Thus, it is important to have sufficient empirical data from landslide inventories to underpin these approaches. These data are more commonly available in the North Island than South Island.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

I am unaware of thresholds or tipping points that specifically relate to effects on ecological integrity or human health.

'Tipping points' exist but in a general sense. These are more correctly described as geomorphic thresholds and embody concepts of magnitude and frequency, and they are difficult to quantify.

Thresholds will vary from region to region, i.e., there is no 'one-size-fits-all' which is why we see different responses in different places to the same 'size' rain event.

The annual recurrence interval of a storm that will initiate shallow landslides is likely to vary by an order of magnitude across New Zealand.

Large storms/events such as Cyclone Bola and Gabrielle do have significant effects on ecological integrity and human health. We do not know enough to suggest what the minimum recurrence interval of an event will be that will result in 'significant' effects on ecological integrity, either locally, regionally, or nationally.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Although uncertain, lags and legacy effects are likely to be present for this attribute.

Vegetation removal creates a period in which landslide susceptibility increases. Typically, this is from a few years up to several decades.

The original clearance of indigenous vegetation off steep hill country 150 years ago clearly demonstrates this. Conversely, planting/reversion will with time reduce susceptibility on land prone to shallow landsliding for the smaller to moderate-sized events. Tree planting and reversion are the key treatments for such land.

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

As noted above, there are current studies underway within GNS that are exploring how mātauranga Māori informs landslide risk. In addition to discussing this attribute directly with iwi/hapū/rūnanga, there is likely to be tikanga and mātauranga Māori relevant to informing bands, allocation options, minimally disturbed conditions and/or unacceptable degradation in treaty settlements, cultural impact assessments, environment court submissions, iwi environmental management and climate change plans, etc.

Anecdotally, many iwi do not like pine forests or exotic trees as mitigation options for reducing shallow landslide susceptibility, preferring native forest [39].

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

The relationship between erosion-prone land (including land that is susceptible to rainfall-triggered shallow landslides) and vegetation cover is well understood and has been for decades [11, 22, 23].

Past approaches have often been to afforest significant areas of marginal pastoral farmland with exotic pines to treat multiple erosion processes including land susceptible to rainfall-initiated shallow landslides. Alternatively, wide-spaced soil conservation plantings of poplars and willows is used where pastoral farming continues. Increasingly, planting of natives such as manuka, managed reversion, and permanent forestry are also seen as additional options [28, 29].

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

All Regional and Unitary Councils have or have had soil conservation or land management programmes that aim to reduce the amount of erosion (and sediment) in their regions. However, the size, scale and cost of these programmes varies widely. In some regions there is not enough resource available to treat the current state of erosion.

Afforestation, soil conservation planting, and reversion are the primary treatment methods.

C2-(ii). Central government driven

Current and past initiatives have been directed towards erosion control, e.g., East Coast Forestry Project, One Billion Trees, Hill Country Erosion Fund.

Central government funding is the primary source of funds for regional erosion control. It may be delivered through local government and/or iwi/NGO/catchment/industry initiatives.

C2-(iii). Iwi/hapū driven

Landslide risk and mitigations to prevent these occurring is of high interest to hapū/iwi, especially in the areas severely impacted by Cyclone Gabrielle (e.g., the GNS - Ngāti Porou partnership study outlined above. Iwi planning documents such as Environmental Management Plans and Climate Change Strategies/Plans may contain policies/objectives/methods seeking to influence erosion outcomes for the benefit of current and future generations.

C2-(iv). NGO, community driven

Unknown.

C2-(v). Internationally driven

Unknown.

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Not managing this attribute and erosion in general, would result in further losses to ecological integrity (sedimentation in rivers, wetlands, hydro dams, estuaries and oceans), reduced clarity in freshwaters, woody debris impacts of bridges, etc. It would also result in the degradation of hill country soils leading to reduced productivity [24, 25].

Increased erosion may also lead to a decline in farmer well-being and could lead to the further demise of rural communities and those who live in highly susceptible/erosion-prone areas, e.g., East Coast Māori communities.

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

North Island hill country farming communities are the most likely to be affected as this is the area where rainfall-induced shallow landsliding is more common [3]. Farming is marginal on many hill country properties [30]. If there were further requirements to plant more trees on farms it could make some properties uneconomic and lead to further rural decline. The Beef & Lamb and forestry sectors are linked, in a general sense, with soil loss and erosion, including rainfall-induced shallow landsliding, and their management, including social license to operate [31].

Horticulture on floodplains in Gisborne, Hawkes Bay and other regions are also impacted by erosion in catchments expressed as increased flood risk and sedimentation on flood plains (e.g., [32, 33].

Manawatu, Whanganui, Wairarapa, Hawkes Bay, East Coast, Northland, Te Tau Ihu, etc., are regions prone to rainfall-induced shallow landslides on steeplands (e.g., [1], [18]).

When a storm occurs cannot be predicted, nor can its spatial extent (other than in a near-time weather forecast). Thus, how often and where a locality is impacted becomes a matter for natural hazard and risk assessment. Current research by GNS, NIWA, and Manaaki Whenua Landcare Research is aimed at improving this, though there are no near-term national products available.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Climate change is projected to result in more storminess and thus more rainfall-triggered landslides [15].

Many hill country areas currently under pasture will require more trees to ameliorate landslide risk. Better classes of land could consider a change to silvopastoral systems (e.g., [34, 35] while the most susceptible parts of the landscape will require a permanent tree cover.

The challenge will be to embrace the diversity in NZ's landscapes and match land-use to both land capability and susceptibility to provide a mosaic of use and cover at a finer spatial scale than is seen today [36].

Large-scale afforestation with exotic species on the most landslide-susceptible terrain will merely repeat the failures of the past, e.g., slash issue (https://www.landcareresearch.co.nz/news/living-with-nature-for-a-sustainable-future/).

The pace of transition needs to increase faster than the perceived, modelled, or real changes arising from climate change [15].

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