

Plantation Forest Harvesting and Landscape Response – What We Know and What We Need to Know



Bartons Gully, inland of Ruatoria. The upper slopes have been retired from farming with the help of MAF's East Coast Forestry Project. Photo courtesy of Randolph Hambling

Experienced scientists in Landcare Research's Erosion and Sediment Processes team – **Chris Phillips**, **Michael Marden** and **Les Basher** – expose the gaps in our knowledge regarding landscape responses to forest harvesting in New Zealand.

In New Zealand, barely a year goes by without a storm causing damage to a plantation forest from landsliding (i.e. shallow landslides (soil slips), debris avalanches, debris flows, earthflows, slumps). And commonly in association with landsliding there are downstream effects arising from trees or slash being deposited in rivers, on beaches, or on land adjacent to forests. These storms seem to have increased in recent years or at least reporting of them has, with significant events reported from the Bay of Plenty, Auckland Region, Nelson, and Marlborough. It is also likely that more go unreported at a regional level that may be reported within a forest as an "environmental incident". Ironically, many of our plantation forests were established on erosion-susceptible locations in steeplands, with the purpose of controlling erosion.

The fact that many of these forests have moved from a protective function to one of production has not been without consequences; some of which have been relatively severe.

We know that mature plantation forests provide protection against erosion (landsliding and surface erosion) and in particular against landsliding. In general terms, the on-site benefits of planted forests for erosion control are well-understood. These include a reduction in shallow landsliding, reduced rates of earthflow movement, reduced gully erosion and the retention of soil (Marden & Rowan 1993; Phillips & Marden 2005; Marden 2005). Off-site benefits include a reduction in the amount of sediment delivered to fluvial and coastal ecosystems, and improvements in

water quality and stream habitat in mature forests (Quinn *et al.* 2004). Reducing the effects of future floods may be another key benefit (Blaschke *et al.* 2008).

However, when forests are harvested, landsliding risk increases. Whether that risk is fully realised is usually related to the incidence of storms in the years following forest removal. Landsliding and the mobilising of slash and debris from slopes into and through stream networks can have disastrous effects both within and beyond the forest boundary (e.g. Phillips & Marden 2011). Sediment yield also increases in the few years after harvesting but then drops to pre-harvest levels even in the absence of large storms (Fahey *et al.* 2003; Phillips *et al.* 2005; Marden *et al.* 2006).

The aim of this opinion piece is to briefly review plantation forest harvesting and landscape response in New Zealand. More importantly however, in order to improve on-ground management and forest management policy development in the future, we suggest areas for further investigation where our knowledge is limited.

Forests and slope stability – how it works

The role of vegetation and in particular that of trees in improving slope stability is well recognised. Forest vegetation provides two major benefits to the stability of slopes (e.g. Greenway 1987; Norris *et al.* 2008). Firstly, root systems reinforce soil, and secondly, trees modify soil moisture by reducing rainfall inputs through interception and the withdrawal of moisture through transpiration processes. Both these factors reduce the potential for slopes to fail. Species composition, tree spacing and age influence the nature and magnitude of these processes.

Root morphology, architecture (depth and spread) and root tensile strength contribute to soil reinforcement by creating both lateral and vertical reinforcement. Roots also bind soil particles at the ground surface to reduce the rate of surface soil erosion that may otherwise lead to undercutting and instability of slopes.

The contribution of roots to site stability is related to the rate at which roots grow and occupy the soil (Phillips *et al.* 2011). Generally, the morphologies of root systems and individual roots are closely determined by the soil physical conditions, particularly stoniness, site and soil drainage conditions, depth to water table, bedrock conditions or the strength and permeability of strata.

Slope stability analyses of forested hillslopes show

that the stress-strain behaviour of soils with tree roots is quite different to that of soils without roots (fallow soil). Soils with tree roots have the ability to undergo larger shear displacements before failing than soil without roots (Ekanayake *et al.* 1997) and confirms why tree roots are considered to be a major contributor to soil strength and slope stability in the zone where roots are present (O'Loughlin & Ziemer 1982; O'Loughlin 1985; Phillips & Watson 1994). Thus for many New Zealand hill country situations where soils are thin and slopes are steep, the root reinforced soil layer(s) are critical to slope stability. With many creeping landslides such as earthflows, the presence of roots can act as a reinforcing layer that possesses relatively high lateral (tensional) strength as well as enhanced compressional shear strength (O'Loughlin & Zhang 1986). The lateral extent of this reinforced layer is highly dependent on tree density.

Slope failure (landsliding) is a natural geomorphic process in all steepland landscapes. Its rate is governed by key controlling factors like climate, topography, geology, soils, etc. Landsliding tends to occur after a triggering event, such as heavy or prolonged rainfall (Glade 1998; Crozier 2005) but earthquakes, volcanic eruptions, and undercutting of slopes by construction activities or by fluvial erosion are also triggers. While rainfall intensity and duration are the main triggering factors for shallow landslides and debris flows, prolonged wet periods may also reactivate other mass movement features such as deep-seated slumps and earthflows (Zhang *et al.* 1993).

A natural forest exists in "balance" with landscape processes to create a spatial pattern of slopes with a range of thresholds (or potential for failure), most of which only get exceeded in extreme storm events. These thresholds are dynamic and change with time as soil weathers, slope hydrology changes and trees come and go. Minor failures will still occur in forests with lower frequency events but these are related to locations where specific local conditions are "ripe for failure", i.e. they are close to the threshold for failure, for example where root reinforcement is low such as in a large gap between trees. Thus any landscape has different levels of "ripeness" or potential for failure both in time and space.

In contrast, much of New Zealand's pastorally-farmed hill country does not have the benefits that trees provide to slope stability unless soil conservation trees are present. As a consequence, many grassed steepland landscapes are more susceptible to landsliding and the threshold conditions for failure are generally lower than for a similar slope that has trees on it. Historically, those landscapes were once forested and have been extensively transformed over the last 150 years. They all bear the scars of slope adjustment

by successive phases of landsliding that have resulted in significant reduction of the soil's natural capital (Rosser & Ross 2011). It is perhaps interesting to observe that pastoral farmers, many of whom farm in very erodible landscapes, get a lot of sympathy (community, regional, and central government) when their properties are heavily affected by landsliding (and often financial support to re-establish farming). In contrast, foresters tend to get blamed (or fined) for what are essentially similar levels of landscape response and are continually being asked or required to manage better!

Forest harvesting – what happens when the trees are removed

Just as we know how trees work to enhance slope stability, we also know what happens when we remove a forest, particularly when it is clear-cut. Timber harvesting changes the two mechanisms that provide stability (hydrological and mechanical) and in turn changes the threshold conditions for failure across the landscape. As a consequence, plantation forests located on steepplands are more prone to shallow landsliding for several years following harvesting than at any other time in the forest growing cycle. Removal of trees allows soil moisture conditions to be wetter for longer (loss of interception capacity of canopy and evapotranspiration). Also, once trees are removed, roots slowly decay and soil reinforcement is reduced and is not fully compensated for by the replanted trees for several years following planting. The result is a period often referred to as the “window of vulnerability” (Fig 2) in which soil/slope/geomorphic conditions are such that even without a “big” trigger such as a severe rain storm, some mass movements are highly likely to result. If a severe storm was to occur, then the degree of damage/landsliding would be elevated because a wider range of slope threshold conditions will be met.

The length of time between the death of trees and the onset of root decay is also species dependent. Radiata loses half its tensile strength in 15 months compared with the more than 30 months native trees will take (Phillips & Watson 1994). The nature of the hazard that exists is also related to the density of trees in the landscape before harvesting and the stocking rate of the replanted forest. Thus during storms when hillslope soils are in a vulnerable state, reinforcement from tree roots may provide the critical difference between stable and unstable sites, especially when soils are partly or completely saturated. Worldwide, the period of maximum landslide susceptibility following harvesting has been suggested as being about 3-15 years after logging and this has been confirmed in catchment-scale simulations of slope

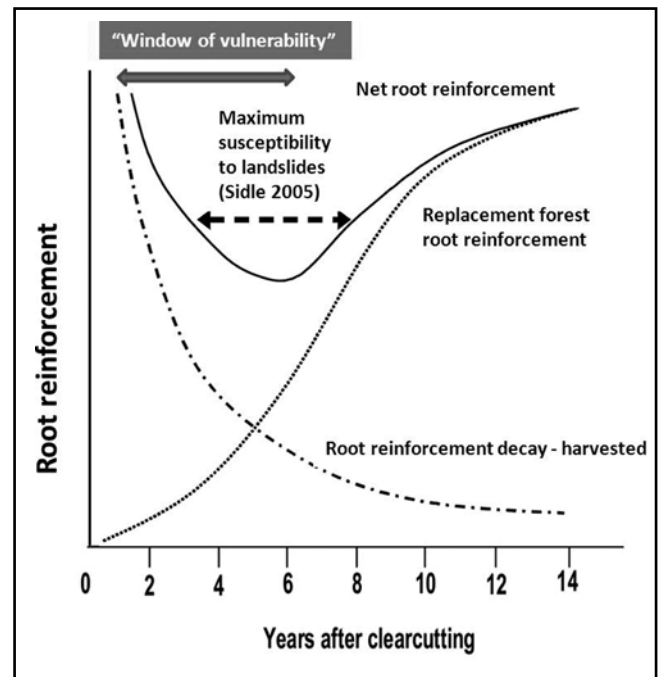


Fig. 2 An example of typical changes in forest vegetation root strength or root reinforcement after timber harvesting. Initial curves from O’Loughlin (1985) and Sidle (1991, 2005) and modified by Watson and others. Net root strength or reinforcement is the sum of the decay and recovery curves. The window of vulnerability for New Zealand plantations is estimated to be in the period 1-6 years after harvesting, but is species and density dependent.

stability (e.g. Dhakal & Sidle 2003). However, based on our observations in New Zealand, we suggest the period of maximum susceptibility is between 1 and 6 years following tree removal though this will vary depending on site conditions, tree density and other factors.

The connection between forest cover and initiation or reactivation of deep-seated landsliding is less clear than with shallow landslides. However, any land use or management practice that alters hydrological pathways could potentially influence deep-seated landsliding activity (Sidle *et al.* 1985; Phillips *et al.* 1990; Marden *et al.* 2008). In general though, the duration of rainfall events or the occurrence of long wet periods are contributory factors to the reactivation of deep-seated landsliding (Zhang *et al.* 1993).

The effect of logging systems *per se* probably has a minor direct impact on slope stability compared with the more significant effects of clear-cutting and earthworks associated with road and landing construction. However, systems that require more slope disturbance by way of more earthworks, tracking, etc. are likely to increase the potential for slope instability.

Increases in soil moisture following logging that may increase landslide and debris flow activity are poorly documented. However, at Mangatu Forest, where soil moisture conditions have been monitored through a harvest cycle and into the next rotation, there appeared to be a correlation with increased movement of earthflows that were marginally stable under mature trees. These observations show that the soil water store tends to “fill up” and soils remain wetter for longer in the years following tree removal, approaching conditions similar to slopes under pasture. Water tables do not lower to pre-harvesting levels until several years following tree removal and new forest growth.

Roads are an integral part of forested landscapes managed for timber production. The critical concerns related to hillslope stability are the length of roads in steep terrain, the cutting of roads at mid-slope locations, water control, recognition of highly unstable landscape features (i.e. terrain stability analysis), overall road design, layout and construction considerations, maintenance, and life of the road.

Because mechanical slope stabilisation is generally not economically feasible along most low volume roads and tracks, landslide prevention can be partly achieved by road location and construction methods that recognise erosion hazard.

Studies worldwide have shown that roads increase landslide erosion by about two orders of magnitude compared with undisturbed forest land (e.g. Fahey & Coker 1989; Coker & Fahey 1993; Fransen *et al.* 2001). There have been no recent studies in New Zealand on the impacts of roads on erosion. However, attention to location, design and construction in recent years in New Zealand – arising from drivers such as the FCOP, FSC, and company EMS – has seen a dramatic improvement in both the quality and performance of roads and earthworks particularly in the corporate forest sector. However, in some localities and in smaller operations, problems still persist and landscape responses are much the same as would have been found in parts of New Zealand in the 1970s, or that are currently occurring in developing countries (Sidle *et al.* 2004). An update and impending release of the 1999 LIRO Forest Road Engineering manual is likely



Severely eroded hill country in inland Tokomaru Bay. Retired from farming under MAF's East Coast Forestry Project. Photo courtesy of Mike Marden

to contribute to further improvements in erosion and sediment control (Brett Gilmore pers. comm.).

Forest landings are a special case of earthworks in forests. Once considered a key source of sediment generation through mass failure (e.g. Coker *et al.* 1990), the location, construction, stabilisation and management of landings are now much improved.

How has forest management affected landscape response?

In the last few decades, forest managers have been on a continuous environmental improvement cycle driven largely by market access systems such as Forestry Stewardship Council (FSC), but also because of increasing “societal expectations” often reflected in resource consent conditions. With respect to erosion, these approaches have to a greater or lesser degree seen major changes in attitude, understanding, and implementation on the ground. This is particularly so for “corporate forestry” interests, because they tend to be the ones who adopt these accreditation schemes. This has resulted in better environmental outcomes in

general, except in the most severe storms. Where the effects of these storms have been assessed, they have all significantly exceeded established design criteria used in road and landing construction, i.e. they were “extreme” events. In cases where these severe storms occur and they correspond with periods in which large parts of a forest estate have been recently harvested or are in age classes less than about 6-8 years, then the landscape response can be dramatic. The question remains, can anything further be done to reduce these effects?

We have also seen forest management respond to the erosion issue in terms of the way logging systems are used and in improved harvest planning. Most steeplands are now cable-harvested instead of ground-based thus minimising the amount of roads and tracks and slope hydrology disruption. Similarly, landings are sited with careful consideration of the potential hazard they might create and are often of minimal size to allow for reduced risk of potential failure, or are large and located on stable sites (super skids). These changes point to lessons having been heeded from the past.



Studies worldwide have shown that roads increase landslide erosion by two orders of magnitude compared with undisturbed forest land. Totaranui Access after the December 2011 storm. Photo courtesy of Gerry Draper.

Riparian buffers and set-aside areas are now becoming the norm rather than the exception, particularly in relation to the transition from one rotation to the next, when such decisions can be made and future problems avoided. However, there still exists the potential for more to be done here. In many situations avenues to make “better” decisions on future land use are not being made because of contractual or other factors. For example, we understand that many Crown Forest Licences have conditions that require the licence holder to re-stock harvested areas when for some parts of a forest leaving land to revert might be a more suitable and sustainable option, i.e. because it was difficult or costly to harvest, or with the type of land, it makes more sense to allow reversion. Conversely, forest companies are also unlikely to give up “productive” land without some form of compensation.

Perhaps one lesson that may not have been heeded is the planting (re-planting) density issue in steeplands. Recommendations in the early days for steepland forests were for high stocking numbers – greater than 1250 and up to 2000 stems per hectare (spha). In recent years there has been a move towards lower stocking rates, often well below 1000 spha. This has the effect of widening the window of vulnerability outlined in Fig 1 and increasing the potential risk for landsliding to occur in the post-harvest, early-regrowth period of the rotation. While some crude conceptual attempts have been made to evaluate planting density, there is a need to revisit this issue with climate change predictions suggesting there are likely to be more extreme rainfall events in the future (NIWA 2008).

What still needs to be known?

While we know a great deal about how forests work to control erosion and what happens when forests are harvested, more information is needed to help the forest industry make on-going and continuous improvements in environmental performance and meet increasing societal expectations of land users. The additional avenues for further investigation involve collection of new data and aggregation of existing data to better understand the hazard of erosion to plantation forestry, as well as modelling. Without data, modelling efforts, no matter how sophisticated, are limited in their usefulness.

While modelling offers a bright future, the priority need is more empirically-based and can broadly be described as hazard analysis. What are needed are modern tools (GIS, LIDAR, remote sensing, etc.) and new data brought to old approaches, i.e. terrain stability assessment (e.g. Phillips & Pearce 1986). Recent examples that are beginning to address this need include the approach used to create the foundation

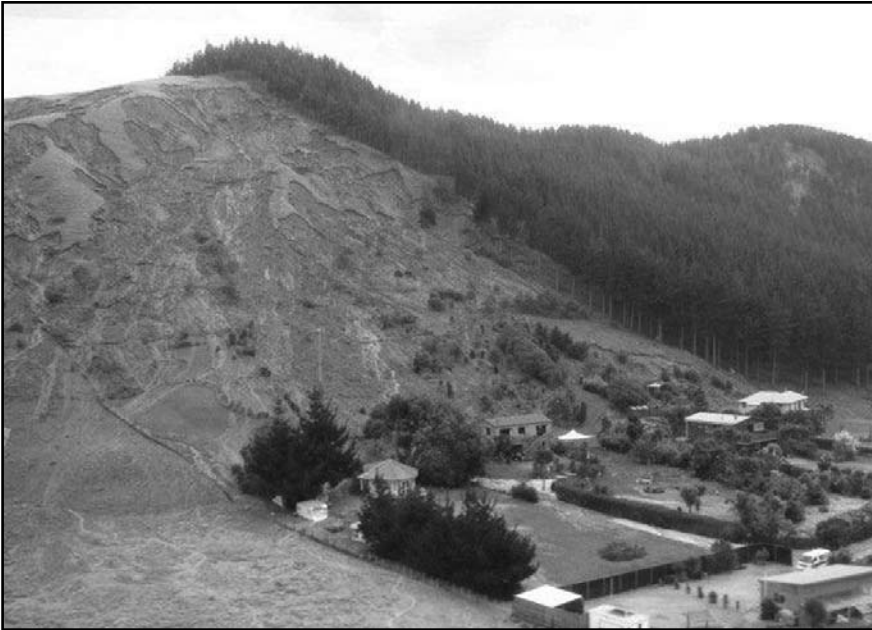
for the NES for plantation forestry (Bloomberg *et al.* 2011) and the development of a national sediment-generation-yield model - SedNetNZ (De Rose & Basher 2011).

Another priority mixes aspects of process understanding with spatial terrain information to create hazard-risk profiles for various landscapes that can then be calibrated with environmental monitoring information. We suggest this approach will yield the best results in the short to medium term. However, successful application is contingent upon using terrain indicators that are closely linked with the processes that control slope stability. An analogy relates to past efforts to predict sediment yield from forested catchments, with many previous models focused on surface erosion rather than the dominant sediment-generating processes such as landslides and debris flows.

There is also a need to understand the interactions of vegetation with slope stability at large scales and over long periods. To better understand this it is necessary to evaluate slope stability in relation to the temporal and spatially-distributed attributes of catchments (Sidle 2005). This can be done by applying distributed, physically-based slope stability models at the catchment scale (Dhakal & Sidle 2003). However, these models require substantial data inputs to characterise variable soil and site conditions – many of which are not available. We suggest it is unlikely that these approaches will find favour in New Zealand in the near future due to the lack of data to run them, i.e. they are nice to have but difficult to do accurately.

To be able to construct or improve model performance for sediment yield, risk reduction, hazard mitigation, forest productivity, ecosystem services etc., there are a number of specific data or information needs for forests in different terrains throughout New Zealand. These include:

- Regional information on landslide density and slope relationships and landslide density and rainfall thresholds.
- Information on the effectiveness of management practices on erosion (sediment generation within the forest and sediment yield beyond the forest gate) – e.g. culvert spacing, earthworks, storm damage.
- Wood and slash management from harvesting – what do you do, can it be managed cost-effectively and can the downstream impacts be lessened?
- Improving erosion susceptibility mapping at both regional scale and forest management scale. This would build on the current NES mapping but would bring modern



Shallow landslides in April 2011, Hawkes Bay. Note the minimal landslide damage to the adjacent stand of exotic forest. Source of photo: unknown.

quantitative GIS-based approaches using the best available physical resource data describing the fundamental controls on erosion hazard (e.g. slope data from the national DEM or LIDAR, climatic data from the extensive NIWA database, rock type and structural data from the GNS QMAP maps and database, soil map unit and property data from Landcare Research databases). It would also require incorporation of the wealth of erosion process understanding that is available from many parts of the country (e.g. Basher *et al.* 2008), and might include some form of quantitative hydrological and slope stability analysis.

- An adequate level of understanding of how different species reinforce soils, i.e. information on growth rates and root site occupancy for different regions and different soil types in order to determine how important lateral root reinforcement is compared with vertical anchoring.
- Recording storm damage information in a consistent and comprehensive way, i.e. beyond descriptions and photographs to obtaining measured data on landslides, their slope position and aspect, nature of contributory factors such as roads, etc.). Currently there is sparse information and each forest company manages this differently in their EMS – so there is no national overview. The New Zealand plantation forest industry should investigate the establishment of a national recording system to capture information relating to storm damage within forests so that the true nature of “the problem” can be assessed and generic and/or local threshold conditions for landsliding determined and the key driving

factors for the level of damage assessed. This system should also extend beyond the plantation forest estate so the magnitude of the problem for plantation forestry can be put in a wider land use context.

- What happens at larger scale and when land uses become mixed, i.e. at what scale can forest removal (or establishment) be measurable in terms of landscape and hydrological response in a mosaic of other land uses?

Other avenues of investigation relate to land use planning questions concerning the long-term future of production forests that are on land with a high erosion hazard. Are some forests in the wrong place and are the risks posed at harvest and beyond so high that consideration needs to be given to a change in land use? Retirement issues, lease agreements, set-asides, widths of riparian buffers are all part of that conversation. The adversarial approach of the RMA often limits opportunities to engage in rational and logical conversation about some of these issues. Maybe there is a need to have more open and frank discussions around these issues – e.g. Crown Forest Licence rules and obligations. These discussions need to be part of a wider debate about future land use options for our erosion-prone steplands.

We don't know what the future will look like but we are told that climate change will have increasing impacts on our land use and management (e.g. NIWA 2008). Our view is that under climate change, extreme (low frequency, high magnitude) events are likely to be of increasing concern for the forest industry resulting in a change in the rates and possibly the relative importance of different processes causing significant shifts in regional vulnerability compared to today.

Further, we also suggest that in the future current forest management and erosion control methods may need to be modified.

Conclusions

Plantation forestry on New Zealand steeplands exists largely due to historical reasons. Many forests were established in erosion-susceptible locations to control erosion. The fact that many of these forests have moved from a protective function to one of production has not been without consequences; some of which have been relatively severe. There is still a sizeable risk of future problems as many of our plantation forests are on slopes over 20 degrees, and in many places deemed to be at risk from landsliding (shallow landslides (soil slips), debris avalanches, debris flows, gullies and earthflows).

Over the last 30 years, progress has been made in improving our understanding of landscape response through the forest growth and harvesting cycle. In addition, forest management has improved and many practices that contributed to undesirable consequences several decades ago are now less prevalent. Improved attention to infrastructure design and construction has largely been responsible as has improved understanding and on-ground management of risk within the industry.

Our understanding and management of the risk associated with high intensity, low frequency storms and their local nature have perhaps received less attention. Identifying areas of greatest risk to the environment from these events (within and beyond the forest) and formulating management strategies to deal with this has, in our view, not kept pace with other gains by the sector. Managing the "window of vulnerability" either by identifying areas of high risk and taking appropriate action such as retirement, choosing longer-rotation species, increasing stocking rates, planned reversion, and retaining larger buffers (to act as slash traps) between harvest/production areas and streams are but some ways of managing this risk.

There is a clear need, however, to understand more so that forest managers can make additional gains in their environmental performance and meet the increasing demands of future markets for their products.

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