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Manatū Ahu Matua

# New Forest Management Approaches to Steep Hills

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# Contents

# Summary

## PROJECT AND CLIENT

- Scion, Landcare Research and the University of Canterbury reviewed national and international best practice in steepland plantation forests to understand and minimise the damage from post-harvest landslide and debris flows;
- The work was funded by MPI under the Sustainable Land Management and Climate Change programme (contract no. FRI30584).

## OBJECTIVES

The objectives of the project were the identification of silvicultural and harvesting techniques to manage post-harvest erosion impacts from landslides and debris flows on high risk sites. By 2013, knowledge about silvicultural and harvesting techniques for use on high risk sites will have been transferred to forest managers providing them with a broader range of options for managing the risk of erosion from landslides and debris flows on such sites.

The specific objectives of the work were to:

- Review information on the nature of the steepland forest harvesting problem, definition of erodible steepland terrain, the benefits of forestry, current forest management and harvesting practice, economics of production on steep terrain, mechanics of slope stability, drivers for erosion problems;
- Identify innovative approaches to steepland forest management and harvesting locally and internationally;
- Focus on forest infrastructure, silvicultural and harvesting systems, hazard identification and offsite management options.

## METHODS

- Review national and international literature, including unpublished literature;
- Develop a company questionnaire and undertake field visits and interviews with forest companies and regional councils;
- Complete an overseas study tour to Chile, Germany, Italy and Switzerland;
- Present results at end-user workshop and collate feedback;
- Complete a report on findings.

## RESULTS

- The issue of post-harvest landsliding and debris flows in which significant amounts of woody residue are transported off-site has been highlighted in the media in recent years and attracted attention from the general public and regulatory agencies;
- This phenomena is not new and similar issues arose following the original forest clearance when New Zealand was settled; in the 1970’s and 1980’s when scrub was cleared under schemes to expand agriculture or establish forests; and when beech forest was cleared on the West Coast in the 1970’s;
- Many plantation forests were planted to control erosion, particularly shallow landslides on erosion-prone steeplands and hill country in the North Island;

- Forests provide protection against shallow landslides through the combined processes of root reinforcement of soils and by modifying slope hydrology;
- There is a period following harvesting when the landscape is at risk from events that cause shallow landslides and debris flows, termed the “window of vulnerability”. Typically this is 4–6 years long depending on factors such as planting density and storm event characteristics;
- Post-harvest landslides and debris flows that transport large quantities of woody residue have been recorded in Northland, Coromandel, Bay of Plenty, Gisborne-East Coast, and Nelson-Marlborough. They are usually caused by storms with return periods greater than 20 years, though smaller events have occasionally caused problems;
- Interpretation of the literature indicates that it is unlikely that post-harvest landslides and debris flows on steep erosion-prone land subject to intense rainstorms can be entirely avoided;
- Historically roads and landings were regarded as primary sources of landslides in harvested forests that transformed into debris flows. However, attention in recent years to better infrastructure design and construction implemented through improved training and the use of codes of practice and guidelines has seen these sources decline in significance. Now most failures originate on slopes within the cutover that have no connection to infrastructure;
- A number of approaches are used by the forest industry to minimise the incidence of debris flows and accumulation of woody material that may get incorporated into debris flows including: employing different harvesting approaches in areas identified as having a high risk; minimising the size of bird’s nests on landings, pulling harvested trees away from riparian areas; creating setbacks in riparian areas; and scheduling harvest operations;
- Internationally, steepland forests where landslides and debris flows occur tend to be regarded primarily as protection forests with timber production a secondary benefit.

## CONCLUSIONS

- About one third of the New Zealand plantation forest estate is located on erodible steeplands with many of the forests having originally been planted as protection forests. For most of the forest rotation these forests provide a high level of slope stability and reduce erosion from landsliding and other processes.
- When forests are harvested, landsliding risk increases considerably. There is a long history of landslides and debris flows associated with rainstorms following forest harvesting in New Zealand, especially in Northland, Coromandel, Bay of Plenty, Gisborne-East Coast, and Nelson-Marlborough. These events also occur in pastoral farmland and indigenous vegetation. The trigger for these events is rainstorms typically with a >10–20 year annual recurrence interval.
- The hill country and steeplands were often planted for reasons other than timber production (AGS and ECFS) and they are now considered almost exclusively as timber producing forests. As ground based machinery become increasingly dangerous and less productive to operate on steep terrain (> 45% slope); cable extraction of stems still remains as one of the only viable options for harvesting.
- In the past roads and landings were significant contributors to post-harvest erosion. Although not well quantified it appears that improvements in forest engineering have substantially reduced the incidence of landslides associated with roads and now most originate on the clearfelled slopes.

- In NZ, a variety of harvesting systems is used, but they are largely typified by hauling from ridge to ridge using skyline systems or variant thereof to maximize reach with minimum roading (a major source of erosion and sedimentation) and to maximize deflection and hence payload and productivity. Most of the machinery is based on relatively old American technology.
- Because of the rigging configurations most frequently used in New Zealand, during harvesting operations, the so called “sweeping” occurs where broken tops and pieces from the felled trees are swept into the gully bottom leading to substantial accumulation of woody residue in these places.
- It will not be possible to completely avoid slope failures and debris flows following harvesting. The future focus should be on improving risk assessment and management, and implementing best management practices to reduce the incidence and consequences of these events. This may involve a combination of use of on-site landslide hazard zoning in planning forest replanting, and off-site management to reduce the consequences of landsliding and debris flows. The forest industry should also develop a consistent approach to dealing with the consequences should an event occur.
- Many regional councils have developed Erosion and Sediment Control guidelines for forestry operations while the forest industry has developed an Environmental Code of Practice for Forestry Operations and a Road Engineering Manual. These largely focus on erosion and sediment control for forest infrastructure and provide less guidance on how to best manage the clear felled slopes. Some companies have started to develop operational level hazard identification and risk management approaches to try and better manage the risk of landsliding, woody residue mobilisation and debris flows. Further work is required to develop improved quantitative hazard identification and risk management methods that can be widely applied.
- Under the current situation, there are a number of strategies that can and are being employed increasingly by industry that will assist in reducing the risk at the margin.
- Incorporation of woody residue into landslides is a major contributor to the off-site effects of debris flows from forests. Management of post-harvest woody residue is complex with a balance needed between retaining woody residue for its beneficial effects and avoiding the adverse effects in large storm events.
- Riparian setbacks, unless they were very wide, are likely to have limited impact in reducing the effect of landslides and debris flows.
- Slash traps have been recommended to manage the offsite effects of woody residue mobilisation. They require a method for identifying alluvial fans below areas with a significant risk of woody residue mobilisation and debris flow generation and preliminary research has identified a possible method that needs to be more widely tested. Little information is currently available on the effectiveness of slash traps.
- Overseas, as a result of previously denuding their mature forests, some countries had suffered severe erosion, flooding, and debris-flows and their governments have implemented plans to replant erosion prone land primarily for protection. In Europe, the majority of steep terrain forests have been there for many generations and no intial forest establishment cost is considered. The roading network has been largely in place for the same reasons and the costs sunk.
- Alternative management practices that might be considered are:
    - Partial cut thinning operations to maintain continuous cover
    - Small coupe harvesting
    - Uphill extraction from gully to ridge
    - Improved harvesting methods (less breakage and ground disturbance)
    - Greater utilisation of woody biomass to reduce woody residue on site’
    - Substantial debris-capturing structures

- If change of species is contemplated then critical mass is required in the market – large amounts of successfully established plantations in relatively compact transport radii for other species to be considered.
- Any additional requirement and effort that may lead to reduced landslide or debris flow risk in New Zealand steep landslide susceptible areas would likely increase the cost of the delivered logs making forest plantations unsustainable in such areas. On current costs and current overvalued rural land prices, plantation forestry cannot meet the hurdle return of about 8% normally required by overseas investment capital. It is particularly important to point out the significance of discounting and discount rates when considering change of species, longer harvesting rotation periods and partial cutting regimes (greater amount costs incurred for roads and infrastructure built up front and carried over extended periods).
- The current commercial investment model for plantation forestry is all about achieving a rate of return and without certainty in achieving that investors would likely be deterred from investing in forestry in such areas. Under this model there will likely be no new afforestation in steepland areas of New Zealand so areas that are subject to the ongoing risks of the effects of large scale erosion will have to face the consequences of that (i.e., floods, debris, productive land inundation, and redundant infrastructure, e.g., stop banks, bridges, and beds’ aggradations, etc.

## RECOMMENDATIONS

- There is an urgent need to collect national data on the occurrence of post-harvest storm-induced landslides and debris flows, rainfall and any forest management conditions (i.e. roading or landing related) that triggered them, what was affected, and what the costs were to remediate any damage caused;
- Understanding the nature of the risk associated with the window of vulnerability and the steps taken to reduce it are key to providing a sound basis for forest planning and regulation;
- Regional landslide thresholds should be established from knowledge of past events and from company records. These rainstorm-geology-steepness-landslide threshold relationships are required to provide consistent quantitative assessment of risk for different regions of New Zealand;
- Terrain hazard zoning or risk management approaches should be investigated to assist forest managers and harvest planners to minimise the risk of landslides and debris flows during the post-harvest window of vulnerability. This information would then assist both forest managers and owners understand this additional element of their forests’ risk profile and also assist regulators by providing a more evidence-based approach for setting policy and consent conditions/rules for the forest industry;
- Since it is not possible to entirely avoid slope failures and debris flows following harvesting even with risk management and good management practices in place, the forest industry should develop a consistent set of protocols to deal with the consequences should an event occur. This could include rapid response and help with clean-up operations, proactive communication with neighbours and the media, and implementation of remediation plans for any infrastructure that is damaged. Many forestry companies will already have some of these activities included as part of their environmental management systems (EMS);
- Given the amount of steep land that is classed as erosion-prone that is without a tree cover, there is a clear need to establish more trees or maintain/replace existing

tree cover on New Zealand's erosion-prone hill country landscapes to minimise the occurrence of shallow landslides and debris flows.

- There is a need to test possible "future forests" on steep erosion-prone land for their potential to reduce the incidence of landslides and debris flows. At this stage there are no suitable models for doing this, and development of such tools should be seen as a priority.
- There is a requirement to develop systems to efficiently harvest in a way to minimise the impact of large clearcuts.

# Introduction

MPI contracted Scion, Landcare Research, and University of Canterbury to review national and international best practice in steepland plantation forests to understand and minimise the transport of logging residue[1] from post-harvest landslide[2] and debris flows. The projects' problem statement was:

*Some current harvesting practices on steep erodible hill country in New Zealand may lead to significant environmental, social and economic costs if one or more severe storms occur in the first 3 to 5 years after harvest (regardless of whether the land is replanted in plantation crop, left to revert to pre-existing natural forest or converted to pastoral farming). If landslides occur after harvest, there is often an associated loss of soil natural capital on-site and mobilise sediment and woody debris into debris flows that leave the forest boundary causing damage to downstream infrastructure.*

To improve management of this problem the project team reviewed the scientific literature to identify practices that can be used to reduce harvesting impacts, surveyed forest companies and regional councils to identify innovative approaches to managing this problem, and used an overseas study tour to collect information on international approaches to steepland forest harvesting that may be relevant to improved harvesting practice in New Zealand.

# Background

In recent years there have been a number of incidents where extensive landsliding has mobilised woody residue during or after forest harvesting operations and caused debris flows which have affected houses, roads and bridges downstream of forests. These events have occurred in many parts of the country including coastal Bay of Plenty (a series of events from 2005 to 2012), Coromandel (March 1995), Gisborne (a series of events from 2000 to 2012), Northland (2009), Tapawera (May 2010), Marlborough (December 2010), and Golden Bay (December 2011). Concern about these events is not new with Baillie (1999) reporting 80 incidents of debris flows from production forests in the period 1994 to 1998.

In several cases these incidents have featured on national television and in newspaper headlines, and they have often been followed by many letters to the editor in newspapers complaining about the consequences of forestry operations on steep erodible hill country. Forestry companies have responded by developing more detailed environmental impact assessment and erosion and sediment control planning approaches, and by assisting with clean-up operations. Similarly regional councils have looked more closely at the environmental impacts of forest harvesting and many have developed erosion and sediment control guidelines, previously largely applied to urban earthworks, specific to forestry.

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[1] There are several terms to describe the material left behind on slopes and in the channels after forest harvesting. These include logging residue, post-harvest woody residue, woody debris, and slash, In this report, we use the short form "woody residue" to refer to post-harvest woody residue left as a result of forest harvesting operations.

[2] This term includes a range of failure types, including debris slides, debris avalanches and complex slide-flow failures (Varnes 1978). It is used as a generic term to include all these types of failures

These events have not been restricted to plantation forests with the debris flows at Matata in the eastern Bay of Plenty in May 2005 a notable example of similar effects occurring from an indigenous forest catchment. The transformation of storm-induced shallow landslides into debris flows is also recorded from pasture–covered hillslopes in many regions (e.g. Hancox 2003, Hancox and Wright 2005a, b). In these situations however, the debris usually lacks the woody materials observed in debris flows arising from forests but the consequences to infrastructure and housing can be similar (e.g. at Paekakariki, Hancox 2003, southern Hawkes Bay 2012).

Landslides also have significant impacts on site productivity with similar consequences for both plantation forest and pastoral land uses. Pasture-covered hillslopes lose 20% of dry matter production in the long-term on land that has slipped (Rosser and Ross 2011) and forests lose 26% of total stem volume per hectare (Dean and Heron 1998). While the total amount of sediment generated may in many cases, be larger from pasture hillslopes (because they have higher numbers of landslides), the presence of wood in a debris flow has more potential for damaging infrastructure such as fences, bridges, roads and houses.

Forester denies flooding liability

[redacted]

**A hand would be nice:** Ron Tye surveys neighbour Clare James' property on the Tapawera-Baton Rd after floodwaters carrying mud and logs damaged houses and closed roads in the Wangapeka area, near Tapawera.

Photo: MARTIN DE RUYTER

Figure 1: Press cutting from after the May 2010 storm at Tapawera (Nelson Mail).

Figure 2: Photograph of post-harvest logging residue deposited in a river bed.

Harvesting and re-establishment of existing forests is increasingly focussed on steep lands because many of these forests are reaching maturity reflecting past forest investment periods, and contributing to a significant increase in national wood volume from steepland forests. In addition there is considerable opportunity to expand the forest estate as many steepland areas have or are becoming marginal in terms of continued pastoral production because of the impact of a long history of erosion (Davis et al. 2009, Watt et al. 2011). These forests will be essential for maintaining New Zealand’s carbon balance, environmental integrity and export earnings. However, with increasing concerns about risks from extreme weather events, and the impact of climate change on the frequency of extreme events, managing steepland forests in erodible hill country in an environmentally, economically and socially acceptable manner poses significant challenges. It also has implications for on-going and future forest investment.

As a consequence, in the 2012 round of the Sustainable Land Management and Climate Change programme in Theme 2 (Mitigation of agricultural and forestry greenhouse gas (GHG) emissions) MPI sought a forestry project to “develop new harvesting approaches for risk mitigation and hazard management on steep hill country”.

The request for proposals suggested new options need to be developed to maintain forestry on steepland sites, with two areas of possible focus:

- improving harvesting and engineering practises through, for example, use of new harvest planning and engineering technologies such as LiDAR; different harvest regimes – coupe size; riparian buffers, and particularly woody residue management; and
- different forest management approaches such as continuous cover, higher value or mixed species, coppicing species or retirement.

The challenge is to develop approaches that are both economically viable for forest owners and environmentally effective. Scion in association with Landcare Research and University of Canterbury bid a 3-year programme “New forest management approaches for steep hill country”. The programme was funded for 1 year to complete a literature review of harvesting techniques, plantings and how best to use steepland for forestry.

## Objectives

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## Extent of erodible hill country

Plantation forestry is located on a variety of terrain, only some of which is prone to erosion. The current total area of forest estate, define as land mapped as Exotic Forest or Harvested Forest in the Land Cover Database (version 3, released in 2012 and based on 2007-08 satellite imagery) is 1.9 m ha - of this 1.72 m ha is managed exotic plantation forest estate (New Zealand Forest Owners Association 2012). The area with significant erosion risk can be derived from the erosion susceptibility classification developed by Bloomberg et al. (2011) for the proposed National Environmental Standard for Forestry. This classification used potential erosion severity data from the New Zealand Land Resource Inventory to derive erosion susceptibility classes. The land prone to severe erosion lies in the high and very high classes (Fig. 3). This amounts to 0.6 m ha or 33% of the current plantation estate. It is concentrated in Northland, Bay of Plenty, southern Waikato, Gisborne, eastern Wellington, Nelson and Marlborough regions (this distribution largely matches the reported occurrence of landslide/debris flow problems). Davis et al. (2009), using a different approach to the classification of erosion-prone land, suggest there is opportunity for a further 0.34 to 0.61 m ha of erosion-prone land to be afforested.

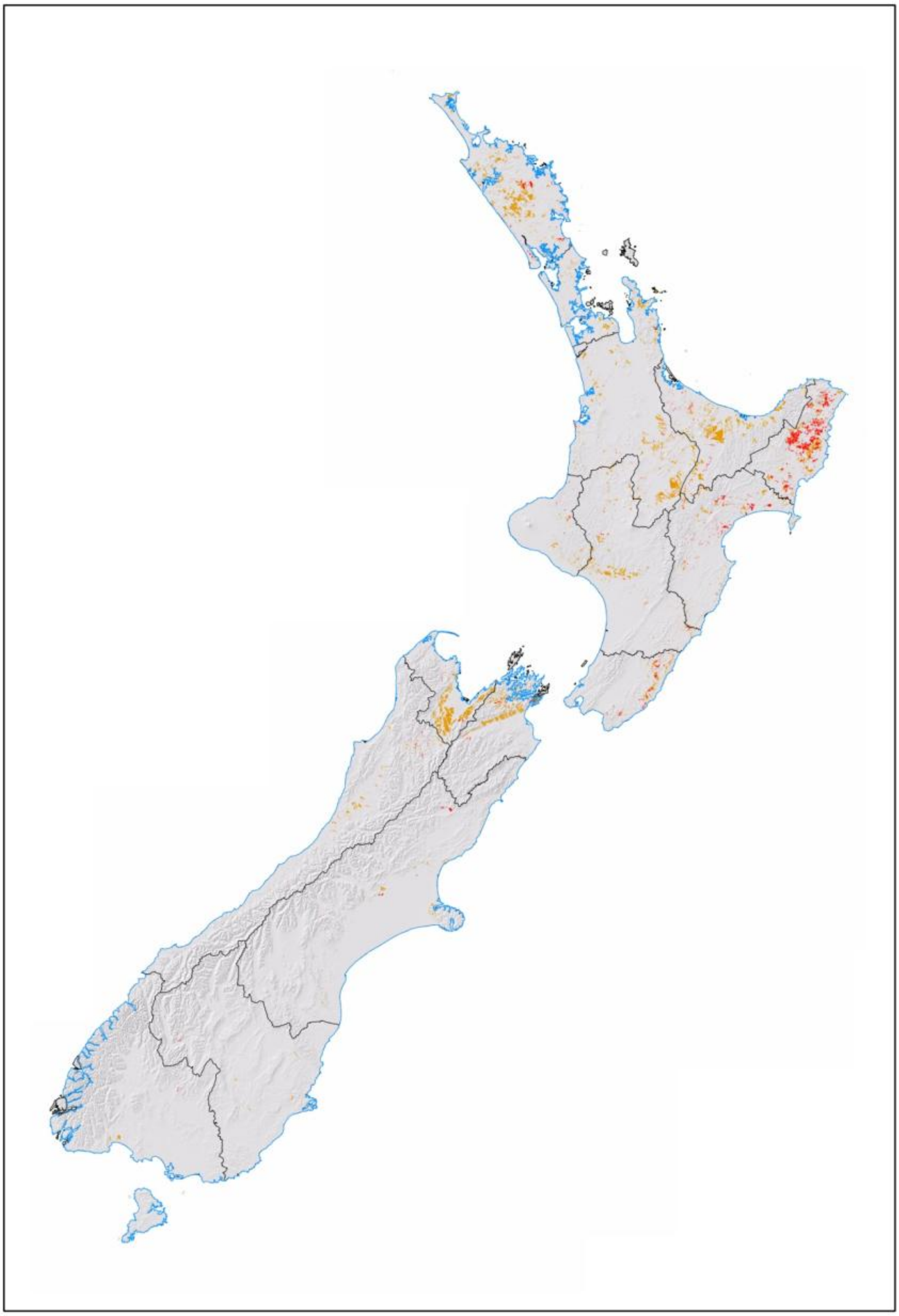

Figure 3: Map of the distribution of the high (brown) and very high (red) erosion susceptibility classes (Bloomberg et al. 2011) for the current plantation forest estate.

Ninety percent (1.5m ha) of the exotic plantation area comprises radiata pine (*Pinus radiata*), with Douglas fir (*Pseudotsuga menziesii*) accounting for 107,000 ha (6%), Cypress 10,000 ha (0.6%) and the remainder of the estate made up of Eucalyptus 22, 000 ha (1.4%) other exotic softwood 13,000 ha (1.4%) and exotic hardwood species 13,000 ha (0.7%). (New Zealand Forest Owners Association 2012)

## Benefits of forests

In New Zealand, plantation forests have been widely used to prevent or control erosion (McKelvey 1992, O'Loughlin 2005). They were established in many steepland areas where erosion risk is high, including Northland, Coromandel, Bay of Plenty, Taranaki, Gisborne-East Cape, Nelson and Marlborough. Many of these forests were originally planted as protection forests after pastoral farming had failed because of both erosion and soil fertility problems (Poole 1960, Olsen 1970). Initially it was not certain that these planting would survive the harsh environmental conditions let alone produce useable timber and they came to be known as 'conservation forests'. However, encouraged by good growth rates and tree form, new establishment and tending practices were introduced. Thereafter, management of these forests changed from maintaining trees for erosion control and soil conservation to improving timber quality and production with many of these earlier forests latterly referred to as protection/production forests (New Zealand Forest Service, 1986).

Realising their commercial potential these forests were subsequently reclassified as production forests while continuing to acknowledge the importance of their dual protection function. In recent years there has been a significant increase in forest harvest activity throughout New Zealand much of which is occurring in erodible steeplands.

### PLANTATION FOREST EFFECTS ON SLOPE STABILITY

The benefits of planted forests for erosion control are well-understood and include reducing rates of shallow landsliding, (Fig. 4) slowing earthflow movement, and reducing rates of gullying and surface erosion (e.g. McKelvey 1992; Marden and Rowan 1993; Zhang et al. 1993; O'Loughlin 1995, 2005; Marden 2004; Phillips and Marden 2005). Other benefits of mature forests include a reduction in the amount of sediment delivered to freshwater and coastal ecosystems, and improvements in water quality and stream habitat (Quinn 2005, Parkyn et al. 2006). Reducing the effects of future floods may be another key benefit (Blaschke et al. 2008).

Figure 4: Contrast in shallow landslide damage on pasture and closed canopy exotic forest. Following storm April 2012, inland Wairoa. Photo courtesy of P. F. Olsens, Gisborne office.

The greatest benefit of plantation forests is in reducing shallow landsliding, the most common and extensive form of mass movement in New Zealand (Basher in press). The presence of tall, closed-canopy, woody vegetation typically leads to a 70–90% reduction in the amount of landsliding during large storm events (e.g. Phillips et al. 1990, Hicks 1991, Marden et al. 1991, Marden and Rowan 1993, Bergin et al. 1995, Fransen and Brownlie 1995, Reid and Page 2002, Hancox and Wright 2005a, b, Dymond et al. 2006). The extent of reduction also depends on factors such as:

- Slope steepness: increasing reduction with increasing slope angle;
- Underlying rock type: greatest reductions are on the most erodible rock types;
- Rainfall: decreasing reduction with increasing storm rainfall.

Forest cover also reduces rates of earthflow movement (Fig. 5) with movement rates being one to three orders of magnitude lower under forest than pasture (Zhang et al. 1993).

Figure 5: Active earthflow complex before (left) and after (right) reforestation. Rates of downslope earthflow movement declined by an order of magnitude within the period of a rotation of pines ~27-years (Marden, 2004).

Reforestation has been highly effective in reducing the number of gullies and overall rate of gully erosion in the Gisborne-East Cape region (Marden et al. 2005, 2008, 2011, 2012) (Figs 6 and 7).

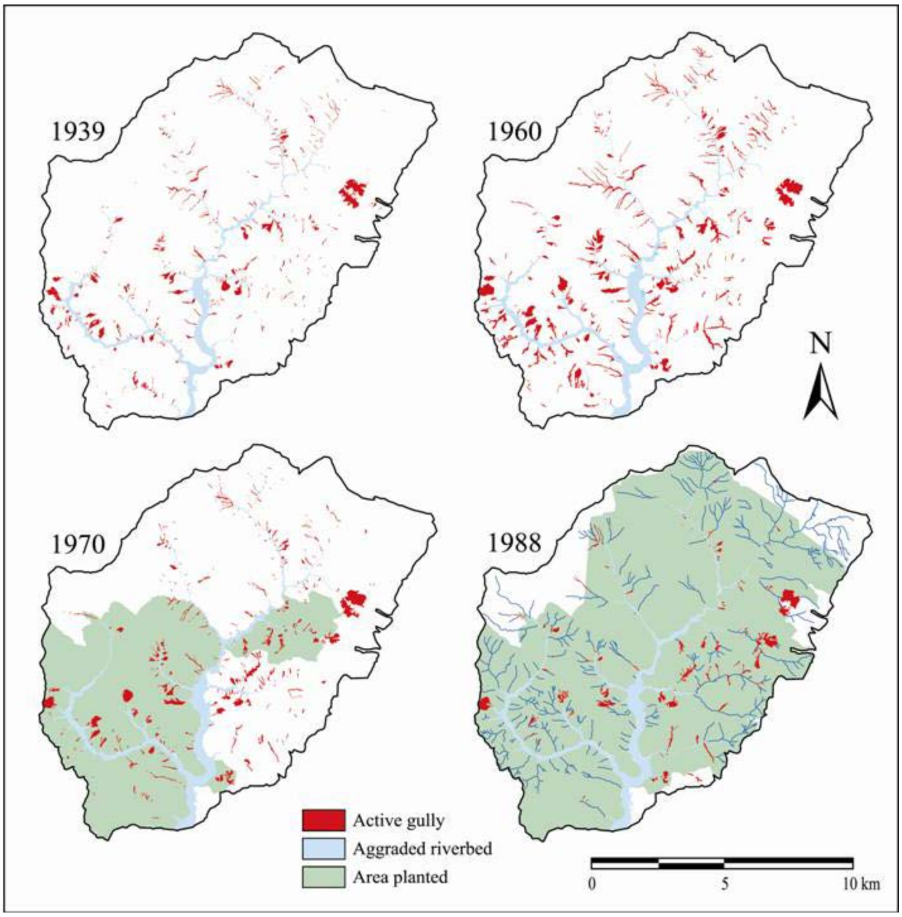

Figure 6: Reduction in gully numbers with consequent reduction in sediment yield before, during and at the completion of reforestation in Mangatu Forest (Marden et al., 2005).

The ability to stabilise gullies with trees is highly dependent on gully size and shape at the time of planting, with an 80% chance of success for gullies < 1 ha and little success once gullies exceed 10 ha (Fig. 6).

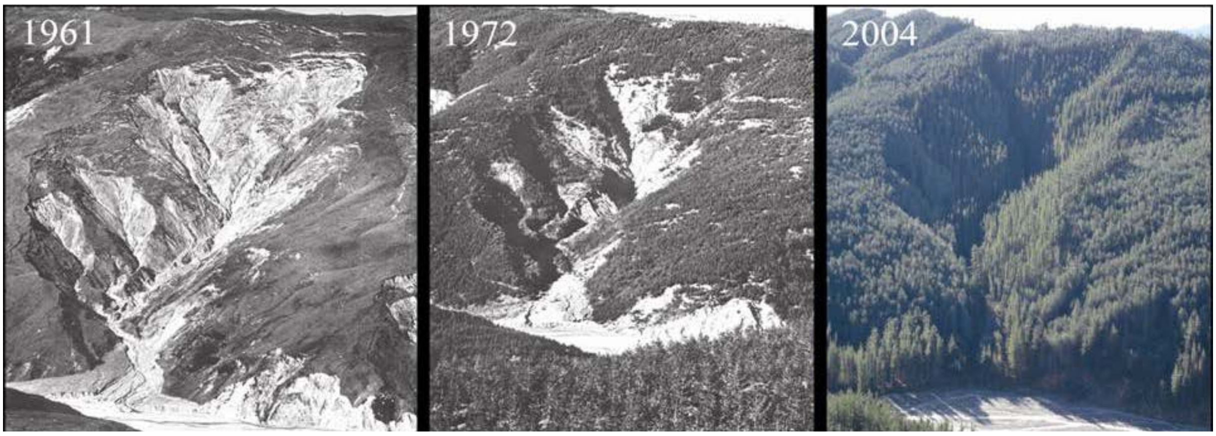

Figure 7: Severely degraded gully stabilised by planting exotic pines (from Marden et al., 2005). For scale, the elevation difference between stream level and the ridge at the head of this gully is 280 m.

The reduction in erosion associated with mature plantation forests is also evident as reduced sediment yields (compared to other vegetation types) at small catchment scale. In much of the published data small pine forest catchments yield 50–80% less sediment than pasture catchments (Dons1987, Hicks 1990, Fahey and Marden 2000, 2003, Eyles and Fahey 2006, McKergow et al. 2010).

## MECHANICS OF SLOPE STABILITY: FOREST IMPACTS ON SOIL STRENGTH AND SOIL WATER

The mechanisms underlying the influence of trees on slope stability[3] are well understood (see O'Loughlin 1995, 2005, Watson et al. 1995, Phillips and Marden 2005, Phillips et al. 2000 2012). The reduction in erosion (landsliding as well as earthflow movement rates, gully expansion and surface erosion) is attributable to two sets of factors (hydrological and mechanical) that influence both below-ground and above-ground processes:

- Mechanical;
  - tree roots mechanically reinforce slopes by providing shear resistance via root tensile strength and adhesion to soil particles which increases soil strength;
  - large roots may also penetrate deeply and anchor to firm strata supporting the soil mantle;
  - tree roots also bind soil particles at the ground surface reducing surface erosion.
- Hydrological;
  - Trees have a major effect on water balance by reducing rainfall inputs through interception and the withdrawal of moisture through transpiration processes (see Rowe et al. 2002). Measured interception losses range from c.20-50% of rainfall (Phillips et al. 2000). Tree roots extract soil moisture and reduce pore-water pressure, a major driver for slope instability, preventing pore water pressures exceeding critical thresholds likely to trigger slope failures (Greenway, 1987);
  - Trees have a permeable organic surface layer which can affect infiltration rates, moisture holding capacity and permeability. In the Waikato infiltration rate of soils under pine forest was an order of magnitude higher than soils under pasture (Taylor et al. 2008);
  - Tree roots and stems tend to increase surface roughness which can increase infiltration and reduce the velocity of surface runoff.

The effectiveness of a planted forest cover in preventing slope failure is both age and density dependent, with closed canopy and mature stands affording the highest level of slope protection (Hicks 1991, Marden et al. 1991, Bergin et al. 1993, 1995, Marden and Rowan 1993, Phillips et al. 2000). Species composition, tree spacing and age influence the nature and magnitude of the hydrological and mechanical effects of trees (Phillips et al. 2012). 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 (Fig. 8). Soils with tree roots have the ability to undergo larger shear displacements before failing than soil

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[3] This largely refers to the effect on shallow landsliding.

without roots (Ekanayake et al. 1997) and explains why tree roots are considered to be a major contributor to soil strength and slope stability (O'Loughlin and Ziemer 1982, O'Loughlin 1995, Phillips and Watson 1994). Thus for New Zealand hill country where soils are thin and slopes are steep, the root reinforced soil layer(s) are critical in reducing the incidence of shallow landslides.

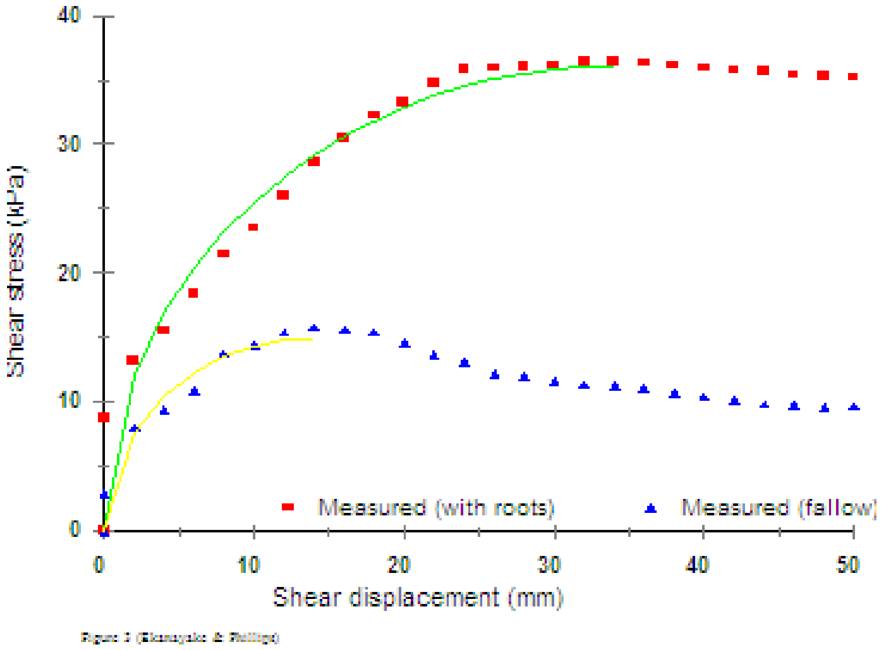


Figure 8: Shear stress-displacement curves for soils with roots of 2-3-year old radiata pine and soils without roots (Ekanayake and Phillips, 1999).

# Current forest management practice in New Zealand

## SPECIES

Radiata pine (*Pinus radiata* D.Don) is arguably one of the most profitable crops that can be grown over much of New Zealand (Maclaren 1993). It grows faster over the first 20-30 years than any other conifer in New Zealand, rapidly forms a closed stand and maintains a high rate of stem production. Radiata pine performs well over a wider range of New Zealand sites than almost any other exotic tree species, and almost wherever it succeeds it greatly outperforms all other conifers (Maclaren 2004). Productivity of radiata pine tends to fall markedly as annual rainfall drops below 1000 mm and 500 mm is often too low for commercial planted forests. High rainfall, however, increases the risk of foliage diseases (Burdon and Miller 1994). Radiata pine is very resistant to drought and moderately resistant to frost, but can be easily damaged by strong winds or wet snow. However, the climatic risk for this species can be categorised as low (Turner et al. 2008). Overall radiata pine suffers less from pests and diseases than most of the leading alternative candidate species for planted forests in New Zealand (Table 1). Radiata pine has a wide range of market uses. It is satisfactory or excellent in products as diverse as plywood, framing timber, barn-poles, reconstituted boards, newsprint, mouldings and furniture. The versatility of the species implies that market risk is low (Turner et al. 2008).

Table 1: Characteristics of some alternative species for commercial plantation forestry in New Zealand (Maclaren 2004). Growth range shown and maximum MAI achieved for that species.

| | **Radiata Pine** | **Douglas-fir** | **Redwoods sempervirens giganteum** | **Cypresses lusitanica macrocarpa** | **Eucalyptus spp** | **Indigenous** |
|---|---|---|---|---|---|---|
| Growth MAI m$^3$ha$^{-1}$yr$^{-1}$ | 24 to 38<br>52 | 13-16 | 20-30<br>55 | 11-20<br>36 | 20-38 | Varies |
| Climate risk | Low | Low | Medium – Frost, drought | low | Medium - drought | Low |
| Site requirements | >1000 mm<br><800 m NI<br><300 m SI | >1000 mm<br><950 m NI<br><800 m SI | Moist soils<br><500 m NI<br><400 m SI | Moist soils<br><600 m NI<br><400 m SI | Ash-cooler parts<br>Frost free | varies |
| Pests diseases | Largely controlled | Swiss needle-cast | low | Medium canker | Great risk | low |
| Market risk | Low | Low | medium | Very low | Medium | low |

Douglas-fir can produce large volumes of timber but is considered to be a late developer compared with radiata pine. A typical rotation age for Douglas-fir is around 45 years compared with 27 years for radiata pine. Volume-growth in Douglas-fir is relatively slow for the first part of the rotation until about age 30 years (Maclaren 2004). Douglas-fir grows well over most areas that receive moderately high rainfall (1000 to 1500 mm annually) and the growth is generally best on moist, free-draining, uncompacted soils. In general, Douglas-fir is often the best species for more moist areas of high country due to its tolerance to snow and lower winter temperatures (Miller and Knowles 1994). Drought is probably the most serious climatic threat for Douglas-fir before canopy closure; thereafter it is remarkably drought-tolerant. For Douglas-fir, the main disease of concern is Swiss needle-cast fungus. This disease parasitises the needles of Douglas-fir and may cause chlorosis and premature defoliation of older needles. The loss of productivity due to Swiss needle-cast has been reported to be at least 25% and in extreme cases even 40% (Miller and Knowles 1994). As global (mainly Pacific) markets for Douglas-fir are enormous and Douglas-fir supply from North America is quite likely to drop due to environmental issues, market risk for Douglas-fir can be considered low (Turner et al. 2008).

There are two redwood species that are of interest to New Zealand: coast redwood (Sequoia sempervirens) and giant sequoia (Sequoiadendron giganteum). Coast redwood is long-lived and grows taller than any other conifer in the world (Maclaren 2004). Coast redwood seems to thrive best in sheltered inland localities such as valley floors, gully bottoms and river flats with deep, fertile, moist but well-drained soils, relatively high humidity, and reasonably high, well-distributed rainfall. It has done particularly well on such sites in the northern half of the North Island (Knowles and Miller 1993). It is especially sensitive to climate and site factors when young (vulnerable to out-of-season frost, drought and wind). Coast redwood is also badly affected by drought, especially in the summer, as it has no root hairs or tap roots. For these reasons, climate related risks can be considered medium. Redwoods are generally healthy species and have a high degree of immunity to fatal attacks by fungi or insects. Markets for redwood are currently very limited and demand is mainly concentrated to California. Another factor that might pose a problem in the market is poor durability of New Zealand-grown redwood (Turner et al. 2008).

Out of all cypress species, C. macrocarpa and C. lusitanica currently hold the greatest commercial potential. On fertile, sheltered sites in New Zealand C. macrocarpa readily attains a top height of 30 m, and diameters exceeding 50 cm, within 40 to 45 years (Knowles and Miller 1994). Cypresses need moderately fertile, moist soils and prefer mild climates and reasonably sheltered sites up to altitudes exceeding 600 m. C. macrocarpa survives in a wide range of New Zealand climates and tolerates annual rainfall ranging from 500 mm to 2000 mm and thrives in cooler parts of both islands. It generally does best on fertile lowlands but is intolerant of poorly drained soils and is apt to be short-lived on very dry soils. C. lusitanica generally requires 1000-3000 mm rainfall and best sites are suggested to be those where humidity is constant. Assuming each species is planted in its appropriate sites, the climatic risk is low. The most significant disease of cypresses in New Zealand is cypress canker. Overall, the risks from pests and diseases are considered to be medium, although proper siting with appropriate species should lower the risk further (Knowles and Miller 1994). Market risk can be considered to be lower than for radiata pine, owing to high, unsatisfied demand. There is also a large export potential as a naturally durable timber species (Turner et al. 2008).
The potential radiata pine-like growth rates of the faster-growing eucalypts and their wood and utilisation properties have made them attractive to growers on a wide range of sites. Eucalypts have been widely planted in New Zealand, and have frequently grown well, although species performance and growth have very often been patchy and unpredictable (Maclaren 2004). There are hundreds of species of eucalypts divided into two primary groups planted in New Zealand, the Ash Group and the Stringybark Group. Matching site to the climatic and soil factors of the natural range of eucalypt species are likely to bring the best results. In general, however, eucalypts do best in free draining soils and frost free areas due to sensitivity of seedlings to frosts, particularly out of season frosts (Miller et al. 1994). As many eucalypts are also susceptible to drought and fire, climate risk for eucalypts can be considered medium, although this is species dependent (Miller et al. 1994). Eucalypts in general are at great risk from pests and diseases. The physical proximity of New Zealand to Australia means that more pests and diseases will arrive naturally, usually through extreme wind-flow events. Market risk is considered to be medium as eucalypt sawlogs pose many conversion problems. Pulp prices are low and both sawn timber and pulp are facing fierce global competition (Turner et al. 2008).

## SILVICULTURAL SYSTEMS, COST OF PRODUCTION, ROTATION LENGTH

Almost exclusively, the silvicultural system of choice in New Zealand plantations follows establishment, thinning (production or thin-to-waste) and clearcutting the final crop at its rotation age. For radiata pine, there may be different stand regimes based on site fertility and terrain roughness, location to markets and roading networks, personal goals of different owners and managers. Key regime variables include:

- Land preparation and releasing techniques;
- Initial stocking and type of planting stock;
- time of pruning (if pruning is desirable);
- final length of pruned log;
- intermediate yield (production thinning);
- time and intensity of thinning;
- final crop stocking;
- rotation age (Maclaren 1993).

Some of these have significant influence on landscape response to high rainfall events. Radiata pine incurs the lowest establishment cost compared to all the other alternatives (Table 2). Depending on the topography, soil conditions, vegetation, size of the area to be treated and other factors, site preparation is usually mechanical, hand, burning, grazing or chemical (Maclaren 1993).

Table 2: Silvicultural costs ($/ha) and costs of production at rotation age of some alternative species for commercial plantation forestry (overall) in New Zealand (Turner et al. 2008).

| | Radiata Pine | Douglas-fir | Redwoods sempervirens giganteum | Cypresses lusitanica macrocarpa | Eucalyptus spp | Indigenous |
|---|---|---|---|---|---|---|
| Cost per tree | $0.40 | $0.40 | $1.70 | $0.60 | $1.00 | $3.00 |
| Planting costs (yr 0) | $1,153 | $1,393 | $2,193 | $1,350 | $2,022 | $6,248 |
| Release costs (yr 1) | $261 | $261 | $261 | $300 | $280 | $248 |
| Release costs (yr 2) | $261 | $261 | $261 | $0 | $240 | $248 |
| Release costs (yr 3) | $0 | $0 | $0 | $0 | $0 | $248 |
| Release costs (yr 4) | $0 | $0 | $0 | $0 | $0 | $248 |
| Total establishment costs for the base regime | **$1,675** | **$1,915** | **$2,715** | **$1,650** | **$2,542** | **$6,744** |
| Base regime stocking (sph) | 900 | 1400 | 800 | 1000 | 992 | 1000 |
| Logging and Cartage ($/tonne) | $45 | $45 | $45 | $45 | $45 | $45 |
| Age | 28 | 50 | 38 | 40 | 25 | 70 |
| Revenue (In gate - $/tonne) | **$ 80** | **$ 90** | **$ 127** | **$ 117** | **$ 85** | **$ 700** |
| Yield(tonnes)/ha | 560 | 580 | 620 | 700 | 460 | 522 |

Numerous studies have shown the importance of rotation age to increasing the level of growing stock for a given site and stocking (Maclaren 1995). In commercial forests this is determined mainly by economic considerations (Chang 1983); the prices of timber and carbon and the discount rate; but also by the desire to maximise the yield of high-value timber. There is no standard rotation age for radiata pine in New Zealand, however, it is rare for stands to be sold when they are less than 25 years old and few managers will deliberately plan for rotations in excess of 35 years (Maclaren 1993). Similarly for alternative species, there is no standard rotation age for a commercial plantation, but the same considerations should be taken into account. There is no regulatory restriction on the size of the final clearcut area where all trees are removed as part of one harvesting operation.

# Forest harvesting in New Zealand

## SPECIFICS OF CABLE HARVESTING

Since 90% of the planted production forest estate in New Zealand is radiata pine the focus of this section will focus on this species. Nearly 700,000 ha were planted during an establishment boom in the 1990's. Some of these forests may be economically unviable to harvest due to steep terrain, extensive infrastructure requirements, small tree size, and where the harvest and transportation costs exceed the market value of the trees. This is likely to be of greatest concern when these 1990's planting reach harvest age in the 2020-2030 decade. The New Zealand forestry sector, supported by the New Zealand Government, has identified steep country harvesting as the key bottleneck in achieving greater profitability in forestry. Steep country forests already contribute more than 40% of New Zealand's annual log harvest, and this is forecast to rise to over 60% in coming years (www.ffr.co.nz). Harvesting and transport costs are 40-60% of the delivered costs of logs, yet little research has been done in this area in New Zealand since the late 1990s when the former Logging Industry Research Organization

(LIRO) was disestablished. Present harvesting methods on this terrain, such as cable logging, have changed little in 50 years (www.ffr.co.nz). Depending on factors not limited to but including small payloads, high fuel consumption, poor communication and organization, slope, and adverse weather, these operations can be costly and hazardous to workers on the ground (Amishev 2011).

Cable logging practices date back centuries in Europe, but modern cable yarding practices were developed in the late 19th century. Modern cable logging with integrated tower yarders (referred to as haulers in New Zealand) was introduced into plantation forestry in the 1950’s with the development of diesel powered yarders, and have continued to be the preferred method of extracting timber on slopes limiting conventional ground based equipment around the world (Kirk and Sullman 2001). Cable yarding is also preferred due to its’ environmental benefits over ground based yarding, because the partial or full suspension of logs results in reduced soil disturbance (McMahon 1995; Visser 1998).

All cable systems have common requirements for planning and implementation (Studier and Binkley 1974):

- Landings are required and must meet minimum standards to ensure safe and productive operation (Figure 9);
- Anchor points for guylines (supporting lines for the yarders) and skylines must be available or created (Figure 9);
- Deflection (the vertical distance between the chord and the skyline) must be adequate for maximising payload and productivity (Figure 10).

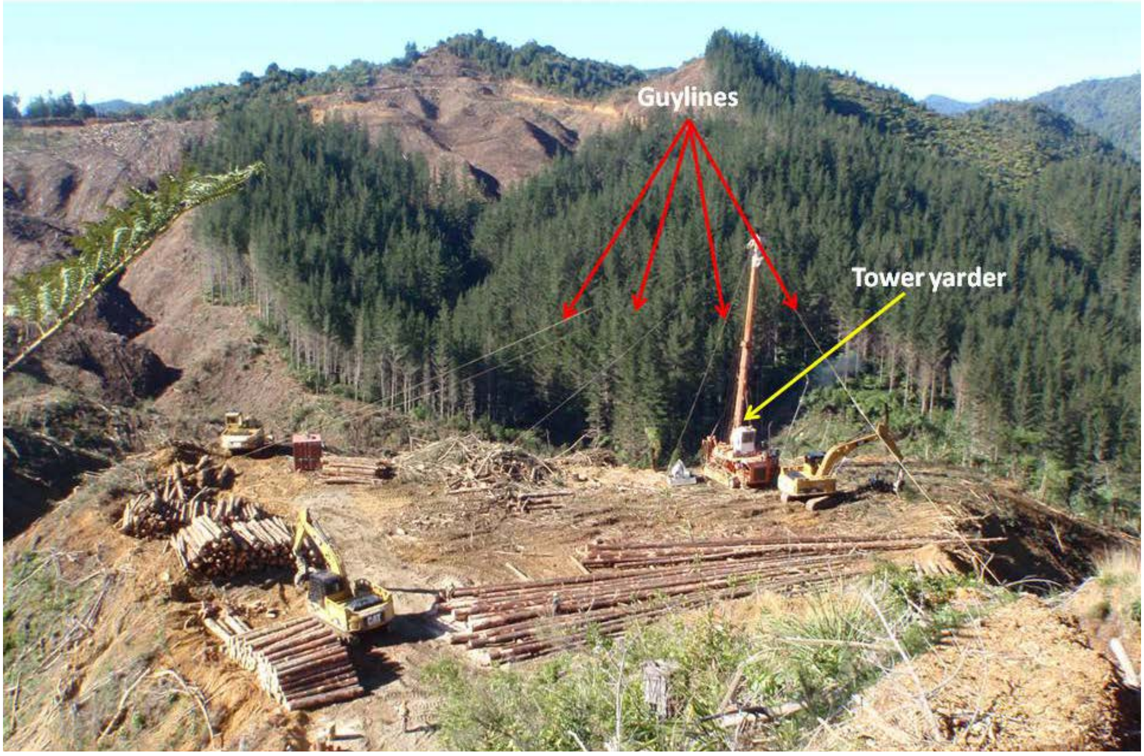


Figure 9: A tower yarder operation and landing in the Eastern Bay of Plenty, New Zealand.

Alternatives, such as modified ground-based equipment and helicopters exist for the extraction of timber on steep slopes. Helicopters are not often preferred due to their high rate of fuel consumption and expensive operating costs. Modified ground-based equipment are limited in their application due to their short economic yarding distance and their difficulty in traversing rough terrain.

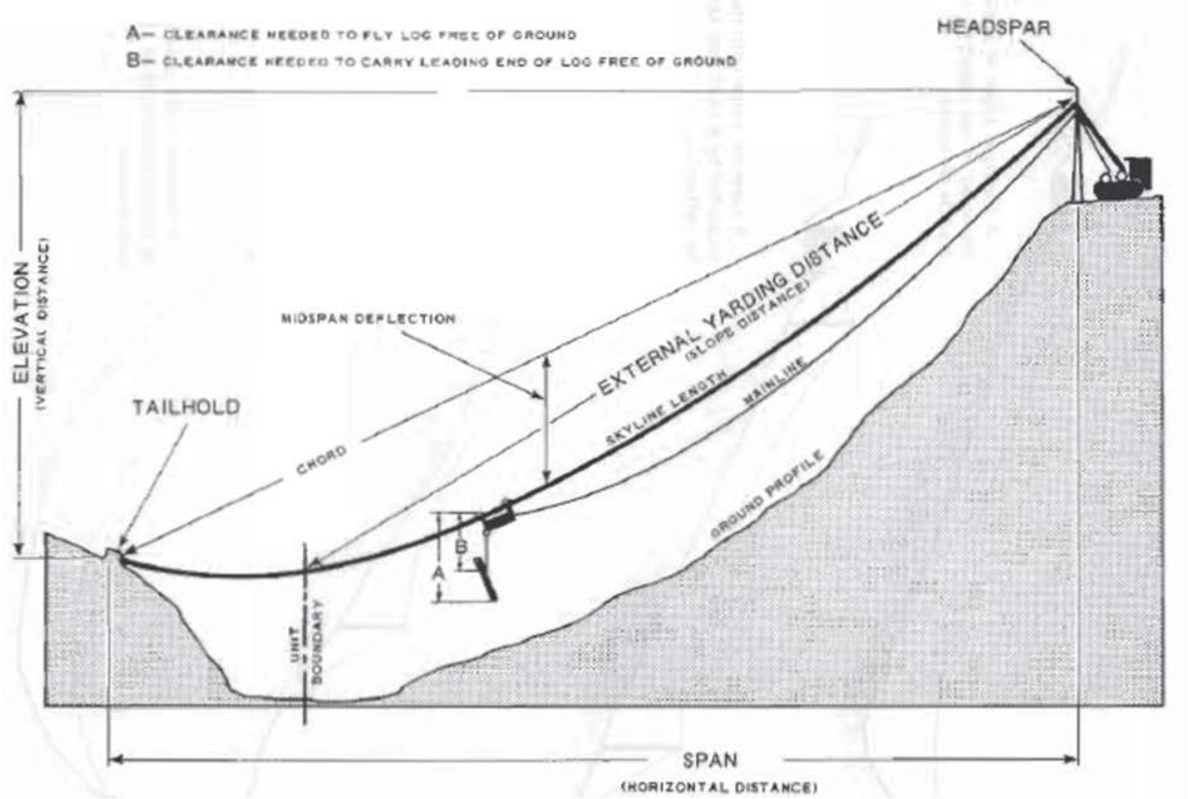
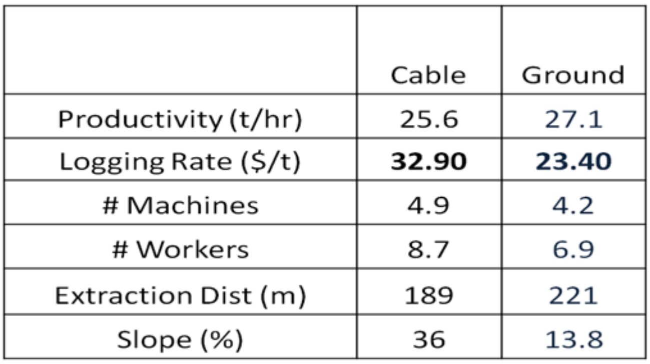


Figure 10: A profile of a single-span skyline showing the concepts of (midspan) deflection, yarding distance, clearance for full (A) and partial (B) suspension (Studier and Binkley 1974).

## CABLE HARVESTING VS GROUND-BASED HARVESTING

Cable systems harvesting is inherently different than ground-based logging – terrain is usually much steeper, typically broken and deeply incised (Figure 9). Construction of adequately sized landings is difficult and expensive and the subsequent processing on smaller landings into many log sorts/sizes and dealing with the woody residue is an issue. At similar stocking (stems/ha), tree size, log sorts and scheduled working hours per day, harvesting rates are very different between ground-based harvesting methods (generally limited to 22% slope) and cable harvesting (Visser 2012) as is labour requirement (Table 3).

Table 3: Comparison of cable and ground-based operations (Visser 2012).



| | Cable | Ground |
|---|---|---|
| Productivity (t/hr) | 25.6 | 27.1 |
| Logging Rate ($/t) | **32.90** | **23.40** |
| # Machines | 4.9 | 4.2 |
| # Workers | 8.7 | 6.9 |
| Extraction Dist (m) | 189 | 221 |
| Slope (%) | 36 | 13.8 |

The same ongoing benchmarking study revealed an interesting trend in terms of harvesting/logging rates for the past 3 years (Visser 2012). Although logging rates have increased for ground-based operations by 12%, it is important to evaluate this increase relative to input costs. Figure 11 shows the logging rate trend over time. It also shows the Producers Price Index that has increased by 6.8% for the same period. Some of this increase has been explained by the increase in wind-throw and road-lining operations. In comparison the cable yarding logging rate has decreased by 2% over the three-year period.

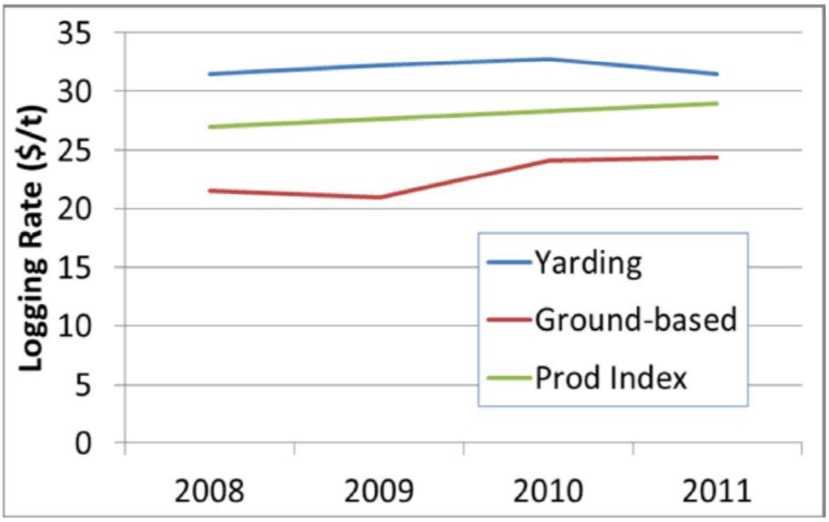


Figure 11: Logging rate trends from 2008 to 2011 for ground-based and cable yarding operations (Visser 2012).

Cable logging as it is practiced in New Zealand differs in several respects from how it is practiced elsewhere. The reasons are various, but the nature of *Pinus radiata*, the value of the wood recovered, features of New Zealand’s terrain and climate, and the reliance on plantation forestry, are all factors (Liley 1983). Evanson and Amishev (2010) have investigated new equipment development options to push the limits of ground based machinery on steep terrain. However, as ground based machinery become increasingly dangerous and less productive to operate on steep terrain (> 45% slope); cable extraction of stems still remains as one of the only viable options for harvesting. There are more than 300 cable logging crews in New Zealand of which approximately 200 are towers and 100 are swing yarders. A cable harvesting crew typically comprises a yarder as the primary extraction machine, several workers and other equipment for felling the trees, processing (log-making), sorting and loading. Depending on the type of yarder used, the number and type of machines and the number of crew members, the daily cost for a cable harvesting crew ranges between NZD $8,000 and NZD $12,000. This is why system productivity is of paramount importance in cable logging operations, as increasing productivity typically result in lower logging rate costs ($/ton or $/m3) (Visser 2009) which in turn are the key drivers for how a crew operates. Studies in forest operations in New Zealand have quantified various systems production rates, and even compared production rates of different systems and equipment side by side over the same terrain and stand conditions (Bell 1985; Douglas 1979; Evanson 1990).

## CABLE HARVESTING SYSTEMS IN NEW ZEALAND

Harrill and Visser (2011) reported that 49% of surveyed cable logging practitioners used the North-Bend rigging configuration in their operations, followed by scab skyline (22%) and shotgun (19%) (Figure 12). More than 70% of survey participants said they had used Scab, Highlead, North Bend (Figure 13) and Shotgun within the last five years. All of these rigging configurations tend to pull the trees with only one end slightly suspended in the air while yarding and the rest of the tree dragged on the ground because of insufficient clearance (Figure 10). This usually results in increased ground disturbance and when deflection is poor these configurations lead to significant gouging of the terrain. Less than 25% said they had used any of the other rigging configurations that usually provide greater lift for the yarded trees, including either motorized carriages or mechanical slack pulling carriages, or grapples within the last 5 years.

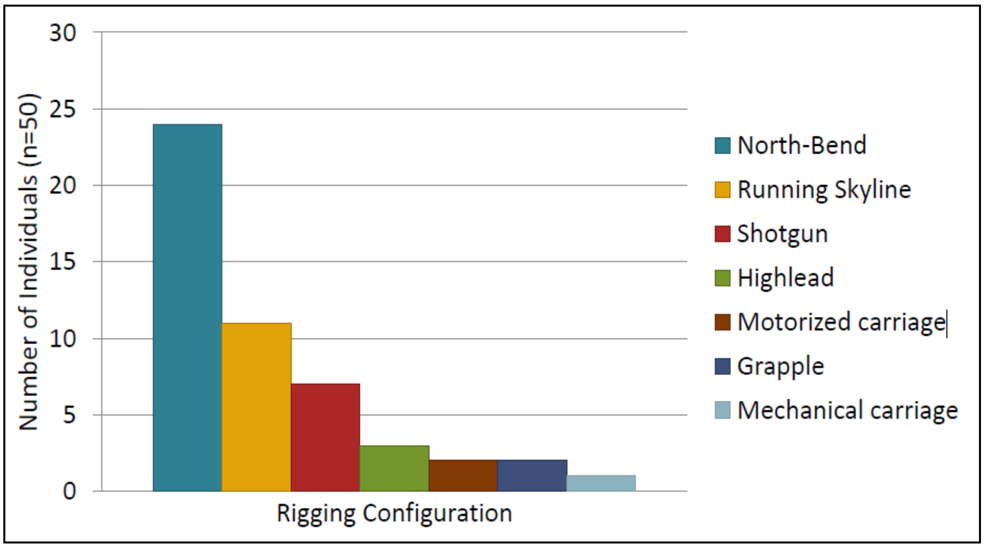


Figure 12: Most frequently used cable logging rigging configurations in New Zealand (Harrill and Visser 2011).

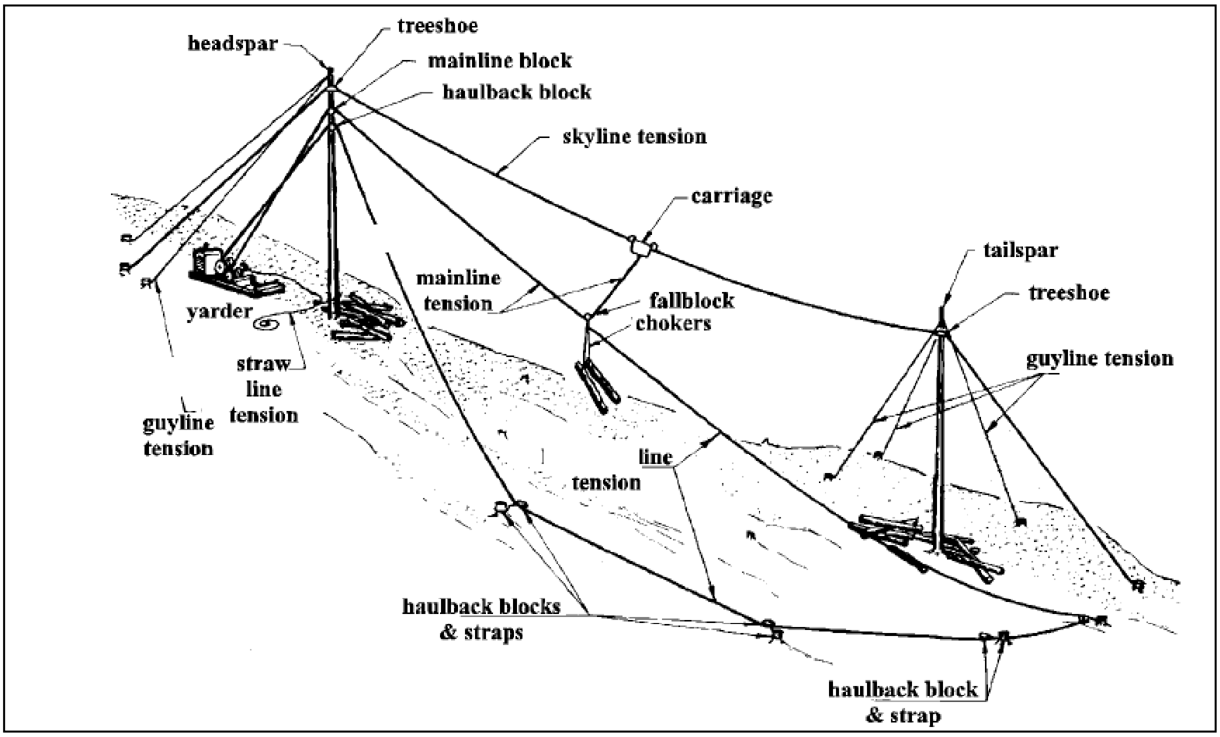


Figure 13: A schematic of North-Bend cable logging rigging configuration.

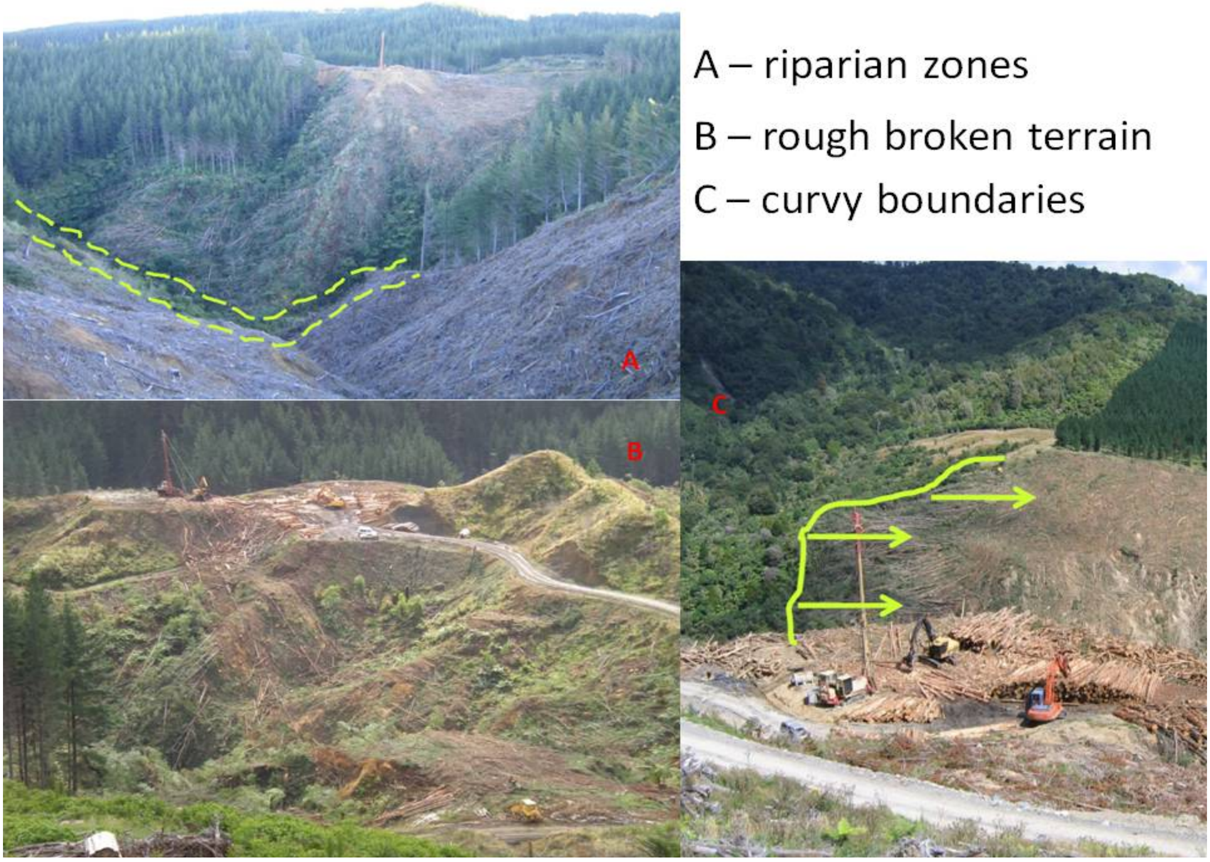


Figure 14 a, b, c: Some of the more common challenges for harvesting forest plantations on steep terrain.

New Zealand forest plantations on steep terrain present several challenges for harvesting crews, some of which are the presence of riparian zones around perennial water courses, rough broken terrain and often curvy uneven boundaries that harvesting crews need to keep away from during operations (Figure 14). These most frequently used rigging configurations are usually employed in conjunction with a slightly modified excavator/bulldozer as a mobile tailhold instead of a properly rigged tailspar (Figure 12). The mobile tailhold is beneficial in terms of faster line shifts and increased system productivity. In order to achieve suitable deflection for maximising payload and hence system productivity, cable harvesting crews in New Zealand almost exclusively use the “ridge-to-ridge” setup where landings are located on a ridge-top and the mobile tailhold is located on the next ridge across a gully bottom (Figure 14 A, C) and often across several smaller gullies (Figure 14 B). Thus the whole area between the two ridges is harvested and extracted at once. After all trees from one corridor are extracted, the mobile tailhold is shifted several meters along the ridge and anchored to form the next corridor for tree extraction. When extracting trees from the opposite (to the yarder) face of the gully, they are pulled across the gully bottom (often through riparian vegetation if there is a riparian streamside zone) and extracted up to the landing. During this process, the so called “sweeping” occurs where broken tops and pieces from the felled trees are swept into the gully bottom leading to substantial accumulation of woody residue in these places. This phenomenon is clearly shown by Hall (1999) who found that most of the residue comprised of unmerchantable stem wood and large branches and that cable operation residue tended to be concentrated in gullies (Figure 15) and around landings (birdsnests).

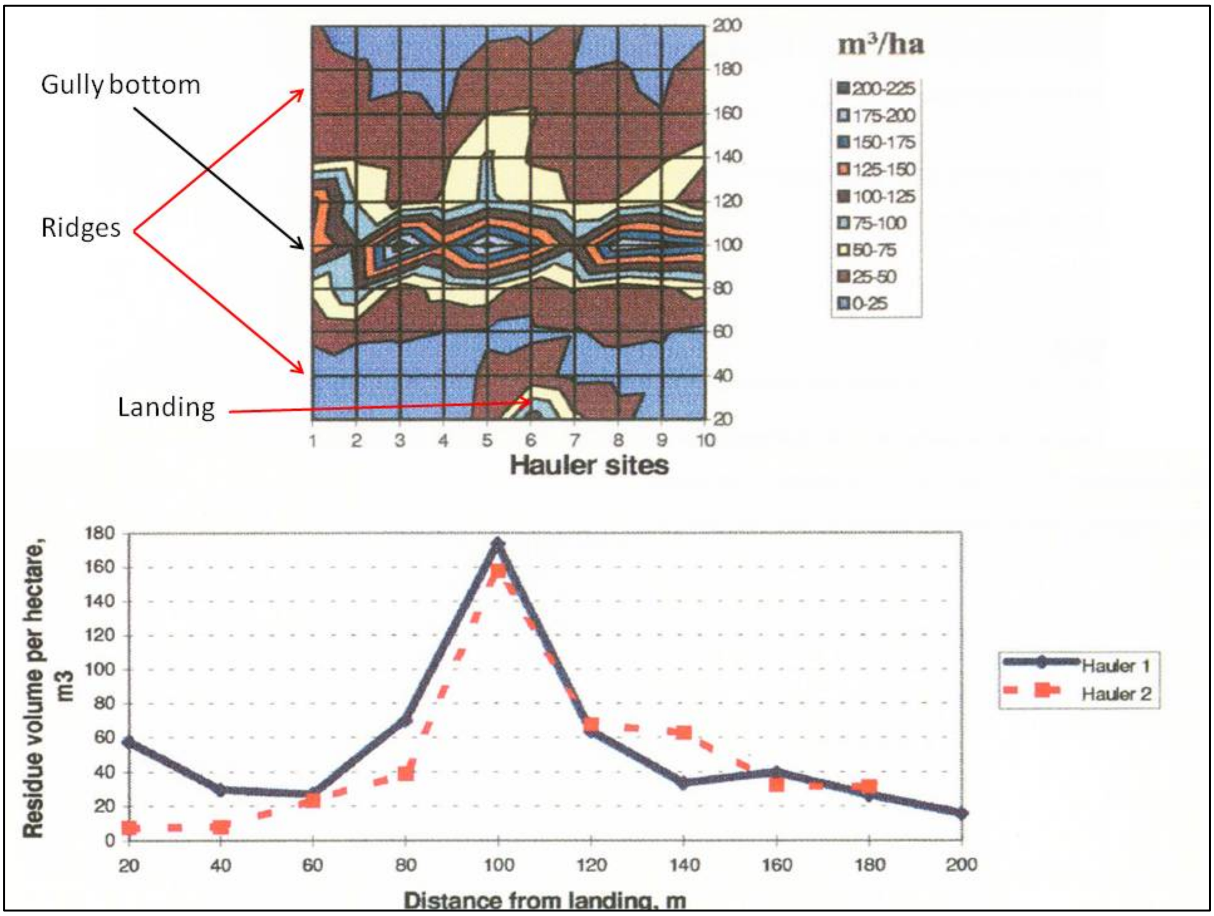


Figure 15: Residue distribution and volume for “ridge-to-ridge” cable harvesting settings (each grid line represents 20 m) (Hall 1999).

## Economics of production on steep terrain (net return to grower)

Radiata pine has clearly been the choice for forest plantation establishment in New Zealand for the last few decades because of various factors. It has been one of the most profitable crops to be grown in New Zealand and compared to other species alternative continues to be the most appealing for investors achieving the highest rate of return (> 7%) on investment (Figure 16). This is a crucial characteristic of New Zealand plantation forestry model, including plantations on steep terrain. Plantation forests are a private investment, often committed by an overseas entity, and as such they are expected to make a commercial rate of return. Discounting and discount rates therefore are an important consideration for any investor before any commitment of financial assets is made. This is very different to many other forestry models practiced over most of Europe and parts of the US.

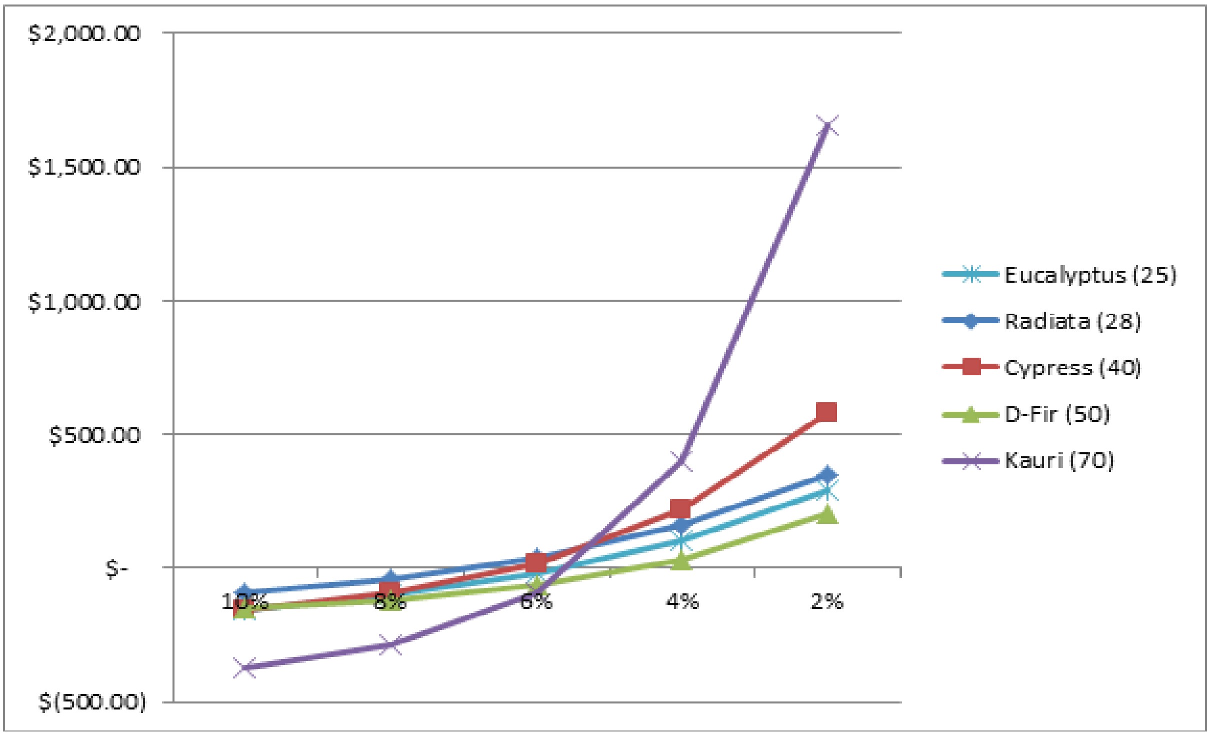


Figure 16: Influence of discount rate (x-axis) and rotation length (in parentheses) on Land Expectation Value (y-axis) ($/ha).

The influence of rotation length and discount rate are significant. Although some of the alternative species achieve greater revenues at harvest, the longer rotation age reduces the net present value compared to radiate pine. Until investment economics becomes a secondary consideration in deciding the species of choice for plantation forestry, radiata pine will continue to be the preferred option. Additionally, there is significant amount of research and development into improving radiata pine genetic pool further strengthening the argument for choosing this species.

Two decades ago Maclaren (1993) stated that forestry in New Zealand had the potential to “make New Zealand one of the richest countries per capita in the world” with rates of return (over and above inflation) of 7-9% and that prices were expected to rise further still. Looking at the past trends (Figure 17), however, reveals a different picture. Log prices have not risen, they have been trending downwards. Pruned logs have dropped from consistently above $200/m3 in the late 1990’s to firmly below $150/m3 in the past 5 years. The other grades have followed similar trends with the exception of pulp which has maintained its price over that period. On the other hand cost parameters have been increasing steadily over the years – labour, equipment, diesel.

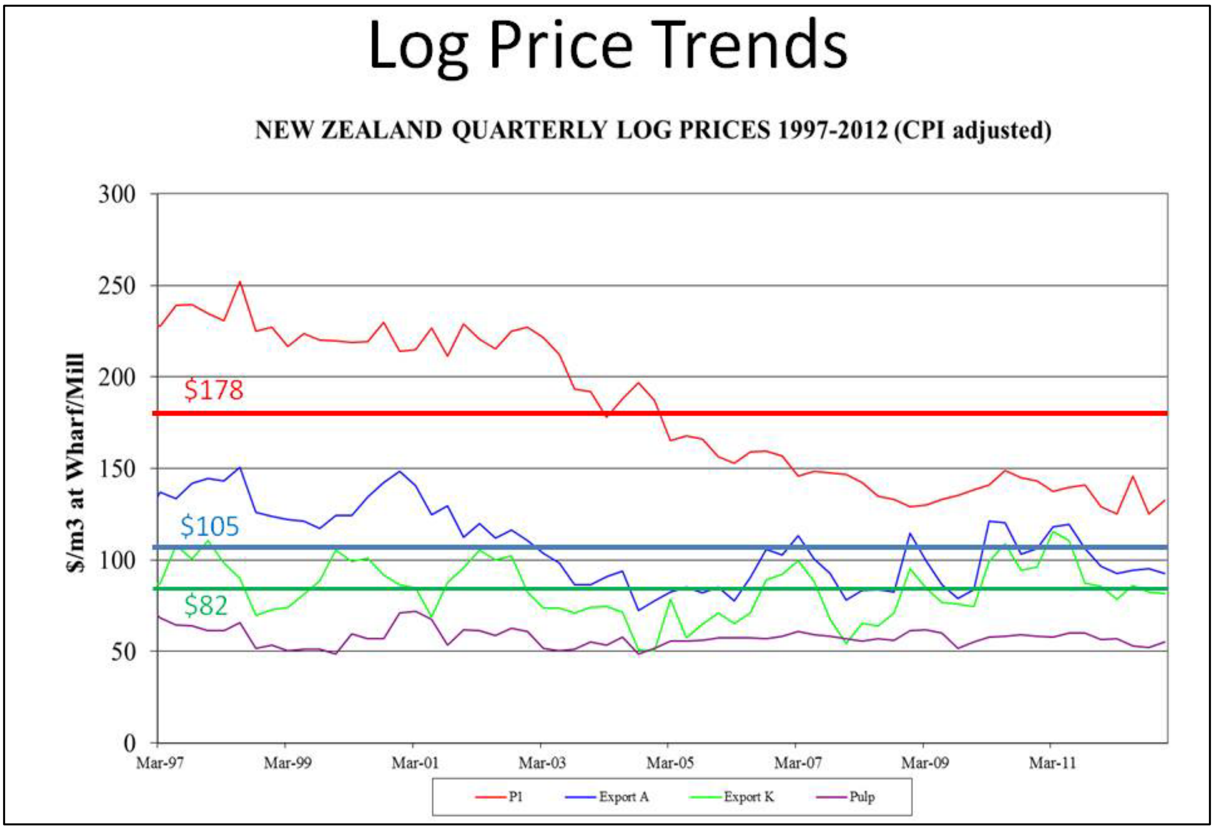


Figure 17: Trends in log prices over the past 15 years (pruned, export and pulp products).

In recent years, forestry has moved to steeper and more difficult terrain with associated higher roading and landing construction costs because of competition from other land uses on flat land. Some regions in the country are more difficult than others and the East Coast/Hawkes Bay (ECHB) region tends to have the highest harvesting costs in the country ($33.20/tonne) compared to the South Island (SI) at $26.70/tonne or the rest of the North Island (RNI) $25.30/tonne (Visser 2012). Breaking down the regional data by harvesting system showed a similar trend for ground-based operations, whereas cable yarding costs were lower in the SI region (Table 4).

Table 4: Regional logging rate breakdown by extraction system (Visser 2012).

| **Extraction System** | **ECHB** | **RNI** | **SI** |
|---|---|---|---|
| Tower Yarder | 35.50 | 33.70 | 29.00 |
| Swing Yarder | 32.00 | 31.85 | 27.90 |
| Grapple Skidder | 28.65 | 20.70 | 23.35 |
| Cable Skidder | 30.85 | 23.90 | 29.45 |
| Forwarder | 30.10 | 20.95 | 26.55 |

The ECHB region is also one of the regions with great concentration of land that is highly susceptible to erosion and landslides. A large proportion of forest plantations in the region are located at more than 100 km from a port or mill further increasing the transporting costs. Looking closely into the cost structure of delivering logs to a mill or wharf from the ECHB, the three major components include harvesting, roading and transport making up more than 85% with management, establishment, land rental etc accounting for less than 15%. These proportions can vary between regions and establishment in the Central North Island (CNI) for example tends to be more expensive than ECHB (Figure 18).

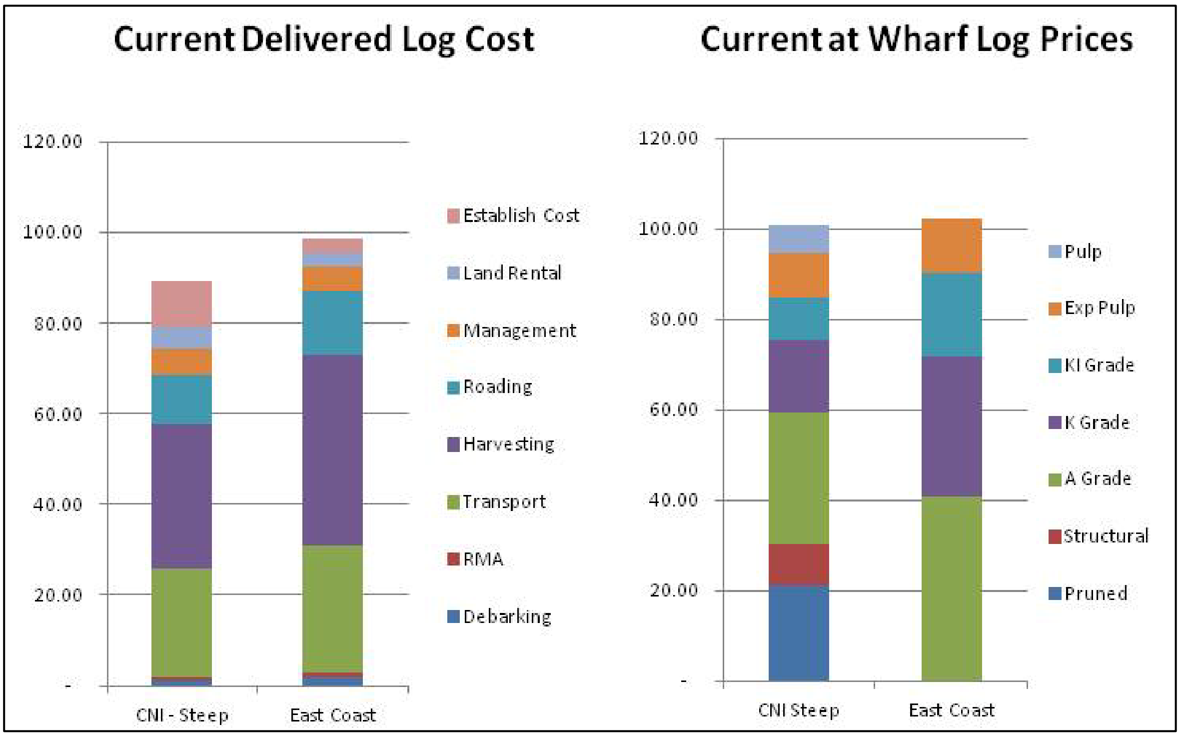


Figure 18: Current (2013) delivered log costs vs wharf log prices for steep terrain forests in Central North Island (CNI) and East Coast of New Zealand.

The market prices for New Zealand radiata pine logs over the last few months have been higher than the average in the last 5 years. Just recently, some of the forest management companies “are making a return” on ECHB forest stands in quite a long time. This is more likely to be a short-lived “spike” in prices seen several times before (Figure 17). If we compare these current costs to a long-term average price for logs, then the return for the forest grower from forests located greater than 100km from market in the ECHB is negative (Figure 19 A). And if we compare delivered log costs at a projected diesel price of $1.60/l, then even forests from the steep areas of the CNI will struggle to make a return for the forest grower (Figure 19 B). Such economic situation provides very little if any flexibility in terms of practices or regulations that would add to the cost of the delivered timber. Any additional requirement and effort that may lead to reduced landslide or debris flow risk may likely increase the cost of the delivered logs making forest plantations unsustainable in such areas. In the same instance, harvesting operations in these forests generates huge cashflow into the local economies and to walk away from these forests would have massive implications on local unemployment and the local economy.

This holds true for current as well as future forest plantations on steep erodible land that is unsustainable under pastoral regime. Harrison et al (2012) looked at whether or not it is economically viable for a potential investor to purchase land under the Future Forest Scenarios and afforest into perpetuity. The future forest scenarios highlighted non-arable land classes in New Zealand that have limitations under perennial pasture vegetation. Three scenarios were outlined according to erosion limitations, these ranged from slight to extreme erosion (2.9 million ha), moderate to extreme erosion (1.1 million ha) and severe to extreme erosion (0.7 million ha). The forestry regimes modelled were for a pruned, structural, biomass and solely carbon regime. The results show that, based on their assumptions:

1. Many of the 2.35 M ha[4] of future forest scenarios in New Zealand are not economically viable for a forest grower to plant, when the cost of purchasing land is factored in and a typical forest valuation discount rate of eight percent is used and a carbon price of NZ$8.
2. Although biomass and carbon regimes face lower costs than pruned and structural regimes, there are very few situations where, under their pricing assumptions, they are economically viable (Table 5).

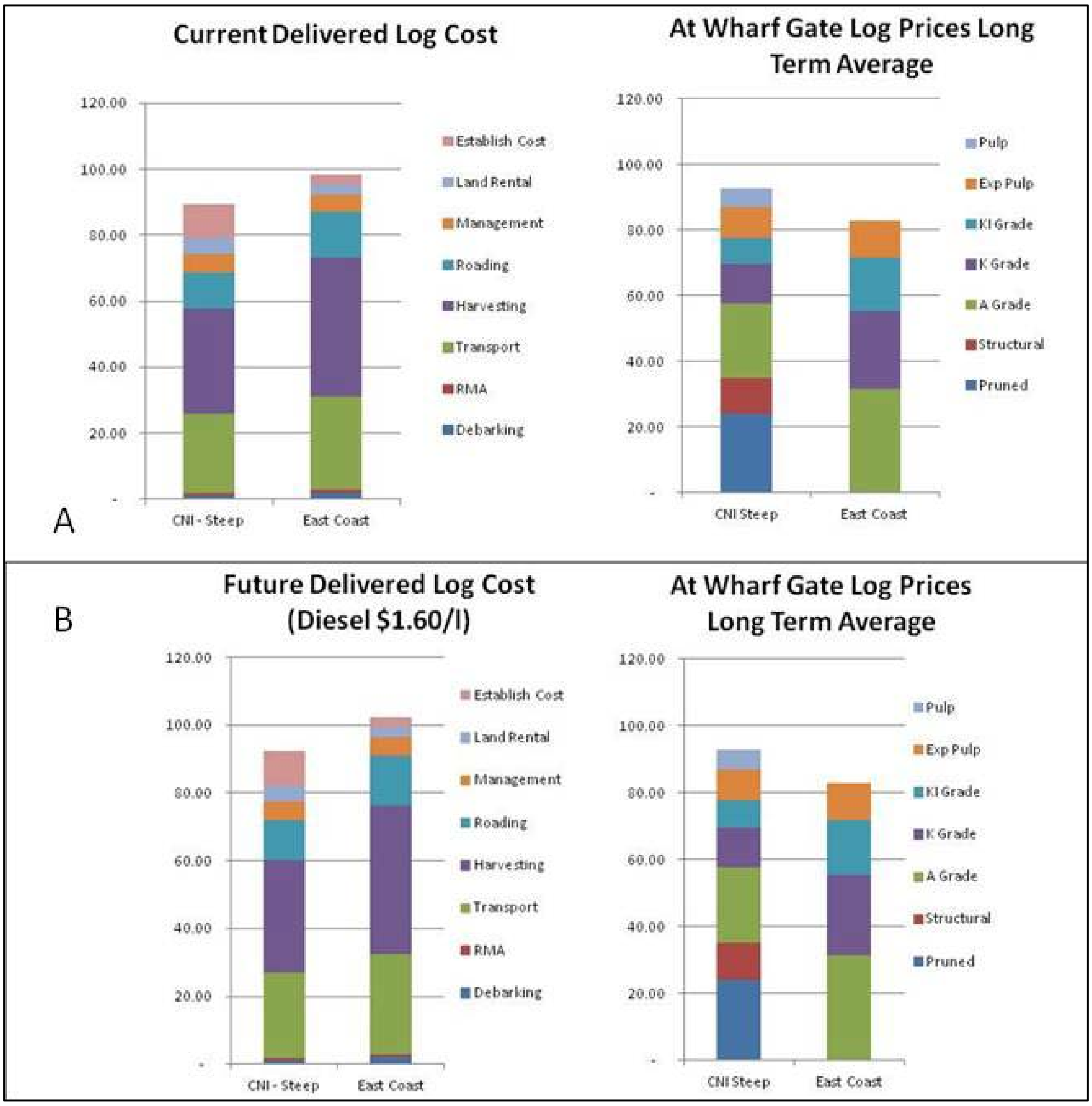


Figure 19 a, b: Current (2013) delivered log costs vs longterm average wharf log prices (A); and projected future delivered log costs vs longterm average wharf log prices (B) for forests in the high erosion susceptible steepland of the Central North Island (CNI) and East Coast of New Zealand.

It is important to understand that these results are based on specific assumptions and data around product prices, forestry costs, and discount rates, among others and do not account for possible future changes to this data (i.e. the price for carbon/timber may go up or down in the future). It therefore should not be used for small scale planning but rather as a regional and national strategic level planning tool to investigate variations in viability across regions and nationally (Harrison et al 2012).

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[4] This differs from the 2.9M ha mentioned above because many areas of future forest that occurred on New Zealand’s outlining islands were excluded as were any forest areas under 1 hectare in size. The reason being that commercial forestry would be uneconomic due to the added cost of transporting raw materials and timber to and from these islands by boat. Furthermore areas under 1 hectare are not eligible for carbon credits under the New Zealand Emissions Trading Scheme.

Table 5: Future Forest (FF) area in New Zealand and viable areas of forestry under four forestry regimes and two discount rates (Harrison et al 2012).

| | Viable Area (ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pruned | | | | Structural | | | |
| Total FF Area (ha) | 4% Discount rate | % Area of FF viable | 8% Discount rate | % Area of FF viable | 4% Discount rate | % Area of FF viable | 8% Discount rate | % Area of FF viable |
| 2,350,008 | 923,541 | 39 | 149,306 | 6 | 1,111,720 | 47 | 334,461 | 14 |
| | Carbon | | | | Biomass | | | |
| Total FF Area (ha) | 4% Discount rate | % Area of FF viable | 8% Discount rate | % Area of FF viable | 4% Discount rate | % Area of FF viable | 8% Discount rate | % Area of FF viable |
| 2,350,008 | 18,878 | 1 | 0 | 0 | 7,362 | <1% | 0 | 0 |

# Forest harvesting effects on slope stability and erosion

Forest harvesting has a wide range of potential effects on erosion processes and slope stability. These range from direct effects of disturbance (e.g. by soil scraping, road and landing construction, disruption of natural slope flow paths) to indirect effects such as the change in water balance caused by removal of trees. The major erosion response to forest removal is an increase in landsliding but there is also an incease in earthflow movement and surface erosion. These processes can act as points of reactivation of sediment production especially where associated with roads and forest infrastructure. Marden et al. (1992, 2012) show how the removal of forest and subsequent deterioration of the root network increases off-slope sediment yields from reactivated earthflows. Similarly there is an increase in surface erosion rates immediately post-harvest when the ground surface is highly disturbed and bare ground is extensive (Marden and Rowan 1997, Fransen 1998, Marden et al. 2006, 2007).

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 and tracking, or cause widespread deep soil distubance are likely to increase the potential for slope instability.

It is also important to note that it is impractical to address the long-term effect of forest management strategies on erosion, sedimentation, and the resultant downstream damage experimentally because to do so would require studying large watersheds for at least several decades (Ziemer et al. 1991). Data on many of these effects tends to be derived from opportunistic studies following storm events or by simulation modelling.

## SHALLOW LANDSLIDES

When forests are harvested, landsliding risk increases. Tree removal changes the two mechanisms that provide stability (hydrological and mechanical) and in turn changes the threshold conditions for slope failure (eg Nettleton et al. 2005). Plantation forests located on steeplands are more prone to shallow landsliding for several years following harvesting than at any other time in the forest growing cycle (O’Loughlin et al. 1982, Marden and Rowan 1995). The severity of erosion following harvest is a function of climate (frequency of storms, storm rainfall amount and intensity, areal extent of storms), slope steepness, soil and geological characteristics, and time since harvesting. The impacts relate to both the increase in soil disturbance as a result of earthworks associated with roading and landing development, and to the creation of large clearfell areas with exposed soils, modified slope hydrology and root cohesion.

Landsliding and the mobilising of slash and debris from slopes into and downstream channels can have severe impacts within and beyond the forest boundary (e.g. O'Loughlin and Pearce 1976, Collins 1988, Hicks 1991, Marden and Rowan 1993, Clapp 1999, Phillips et al. 2005, 2012, Douglas et al. 2011, Gray and Spencer 2011). As a consequence sediment yields also increase in the few years following harvesting but then drop to pre-harvest levels, typically within 2 years (Hicks and Harmsworth 1989, O'Loughlin et al. 1980, 1982, Fahey et al. 2003 Phillips et al. 2005, Marden et al. 2006, Basher et al. 2011).

In Northland, Hicks and Harmsworth (1989) found sediment yield increases at storm event scale up to 100 times and that the harvesting period produced 70% of the total sediment load through the entire forest cycle. At Pakuratahi near Napier, sediment yield increased by an order of magnitude during and following forest harvesting but the increase only persisted for 2 years (Fahey et al. 2003). In three small to moderate-sized (6–24 km2) catchments on weathered granite in Nelson, sediment yields over a 7-year period were on average about 5 times higher in catchments being harvested than from mature pine catchments (Basher et al. 2011). At storm-event scale, yields were up to 15 times higher in the harvested catchments. The extent of this increase in erosion and sediment yield is dependent on many factors but it generally increases with storminess (storm frequency, amount and intensity of rainfall), the erodibility of the underlying rock types, and with slope steepness.

The reasons for the decrease in slope stability are related largely to the removal of trees causing soil moisture to be higher for longer (largely due loss of interception capacity of the tree canopy). Also, once trees are removed, the roots slowly decay and the reinforcement they give to soil is reduced and is not fully compensated for by the replanted trees for several years following planting (Fig. 20). This phenomenon is particularly pronounced in 'soft wood' tree species like Pinus radiata (Ekanayake et al. 1997; Ekanayake and Phillips 2002). This results in a period, referred to as the 'window of vulnerability', in which slope stability is reduced and if a significant rain storm coincides with a recently harvested area, then mass movements are highly likely to result. The window of vulnerability between rotations for New Zealand plantation forests is estimated to be 2–3 years after harvesting (O'Loughlin et al. 1982, Marden and Rowan 1995) until canopy closure of the next rotation (~year-8), but is species and density dependent (Phillips et al. 2012; see Fig. 21). The length of time between the death of trees and the onset of root decay is species dependent with Pinus radiata losing half its tensile strength in 15 months compared with more than 30 months for native trees (Phillips and Watson 1994). The density of trees in the landscape before harvesting, the stocking rate of the replanted forest and the species that is replanted also have significant effects on root reinforcement by affecting site occupancy by roots, root reinforcement and canopy closure (Kelliher et al. 1992, Watson et al. 1999, Phillips et al. 2000). Figure 21 illustrates differences in relative root reinforcement for kanuka and Pinus radiata at 3 different stocking rates. 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 at or near saturation.

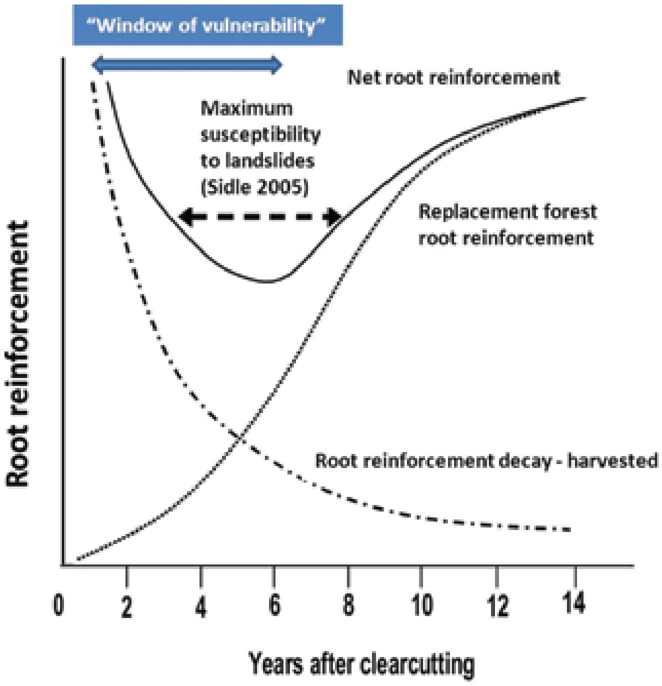

Figure 20: Typical changes in forest vegetation root strength or root reinforcement after timber harvesting. Initial curves from O'Loughlin (1985) and Sidle (1991, 2005) and modified by Watson et al (1999). Net root strength or reinforcement is the sum of the decay and recovery curves. The window of vulnerability for New Zealand plantations is estimated to be the period 2-3 years after harvesting until canopy closure of the next rotation (~ year-8),, but is species specific and density dependent.

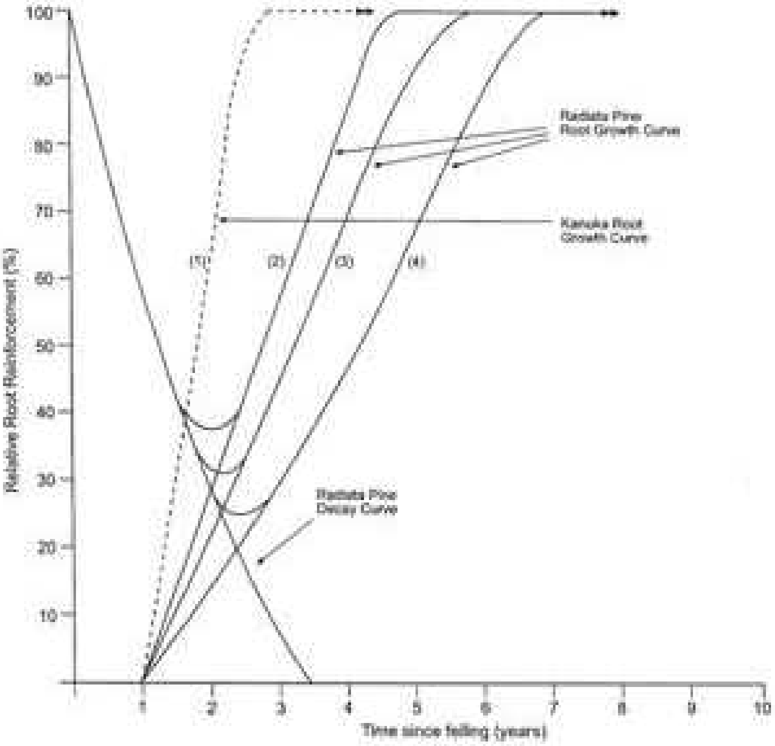

Figure 21: Comparative model of relative root reinforcement changes after clearfelling (at year 0) and planting (at year 1) of kanuka and radiata pine. Growth curve (1) represents an initial natural kanuka establishment density of 16 000 stems ha-1. Growth curves  (2), (3) and (4) represent initial radiate pine planting densities od 1250 stems ha-1 (a recommended slope stabilising regime), 800 stems ha-1 (a commercial forestry regime) and 400 stems ha-1 (an agro-forestry regime), respectively (Watson et al., 1999).

### ROADING AND EARTHWORKS

Forest harvesting involves a considerable amount of earthworks as roads, tracks and landings are constructed, bridges and culverts are installed, and large numbers of trucks and other equipment use the road system. This gives rise to considerable soil disturbance, alterations to natural slope hydrology and has the potential to cause severe erosion both at the time of construction and post-harvest as roads and landings are decommissioned. The main 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 during and post-harvest, and life of the road (Phillips et al. 2012).

Studies worldwide have shown that roads can be the major source of sediment from plantation forests (e.g. Chappell et al. 2004, Wemple et al. 2001, Sidle et al. 2004, 2006). Most New Zealand studies on harvest-related impacts recognise the significance of roads, tracks and landings as sediment sources (Fahey and Coker 1989, 1992; Mosley 1980, Pearce and Hodgkiss 1987, Smith and Fenton 1993, Fransen, 1998). In New Zealand roads can increase landslide erosion by about two orders of magnitude compared with undisturbed forest land (Coker and Fahey 1993, Phillips et al. 2012) and can generate significant surface erosion (Fahey and Coker 1989, 1992, Coker et al. 1993). The first forest road erosion studies in New Zealand were initiated in the early 1970s when fish (Salmo trutta) deaths were associated with excessive erosion and sedimentation from forestry roads and firebreaks in the Nelson region (Graynoth 1979, Mosley 1980). Throughout the 1980s and 1990s a series of studies of forest road and landing-related erosion were carried out in the Nelson, Marlborough Sounds and Coromandel (reviewed in Fransen et al. 2001). It was concluded that:

- Infrequent road-related mass movements are major sources of sediment within forests;
- mass-movement erosion rates decline with road age, but may increase to earlier levels when upgraded for harvesting activities;
- road mass erosion rates are up to three orders of magnitude greater than surface erosion rates.

Poorly constructed landings can also be major source of sediment (Pearce and Hodgkiss, 1987). Coker et al. (1990) concluded that landings could be prone to mass movement in high rainfall areas of New Zealand and suggested a series of measures to reduce the potential for failure. These included measures at the time of landing construction (full benching of fill slopes, end hauling of spoil if necessary, removal of large woody debris before fill is deposited) and post-harvest (managing drainage, reduction of woody over-burden, and replanting of sidecast fill slopes).

There have been few recent quantitative studies of erosion as a result of roads and landings but recent storm damage assessments have generally concluded that little of the damage was caused by poorly constructed roads and landings (e.g. Basher 2010, Douglas et al. 2011, Philips and Marden 2011, Ngapo 2012).

## Climatic drivers of landslides and debris flows

### STORMS AND RAINFALL

Landslides, and associated debris flows, triggered by rainstorms are a nation-wide problem in New Zealand (Glade 1998). They are triggered by intense individual storms or small rainfall events after prolonged wet periods leading to high antecedent soil moisture conditions. They are commonly small localised events but occasionally of regional or broader extent (e.g Cyclone Alison March 1975, Cyclone Bola March 1988, Manawatu-Wanganui February

2004). The occurrence of rainfall events capable of triggering landslides varies greatly in time and space (Glade 1997) and the impacts depend partly on vegetation cover (Glade 2003). Historic incidence of landslide-causing rainstorms are summarised in Harmsworth and Page (1991), Hicks (1995), Glade (1997, 1998), and Page (2008). Less information is available on the incidence of debris flows associated with landslides. Baillie (1999) lists 80 events in plantation forests between 1994 and 1998 where debris flows occurred. These were mostly concentrated in Northland, Auckland, Coromandel and Nelson-Marlborough, with smaller numbers in the central North Island, East Coast and Hawkes Bay.

Hicks (1995) summarises the number of mass movement events over a 70 year period for different parts of New Zealand, with a focus on the Gisborne-East Coast area (Fig. 22). In this area he suggests that the average recurrence interval for landslide-causing storms, based on historic occurrences, ranges from 2.6 to 5.9 years. Similarly Glade (1997, 1998) carried out a comprehensive analysis, using historical landsliding and rainfall information, of the frequency and magnitude of landsliding in New Zealand and its relationship with climatic characteristics. He plots the regional frequency of recorded landslide-triggering rainstorms (Fig. 23) suggesting it ranges from more than one storm every two years (Northland, Wellington, north Westland, north Otago) to less than one storm every 10 years (southern central districts of the North Island, south Otago, central Marlborough). He also identifies apparent temporal clustering of landslide-inducing rainstorms (with high activity in the 1940s and 1970s–1980s). There has also been a high frequency of events in recent times, with significant events in the Bay of Plenty (Douglas et al. 2011,Phillips and Marden 2011), Gisborne (2002, 2011),Hawkes Bay (2011), Nelson (Basher 2010, Page et al 2012) and Marlborough (Gray and Spencer 2011).

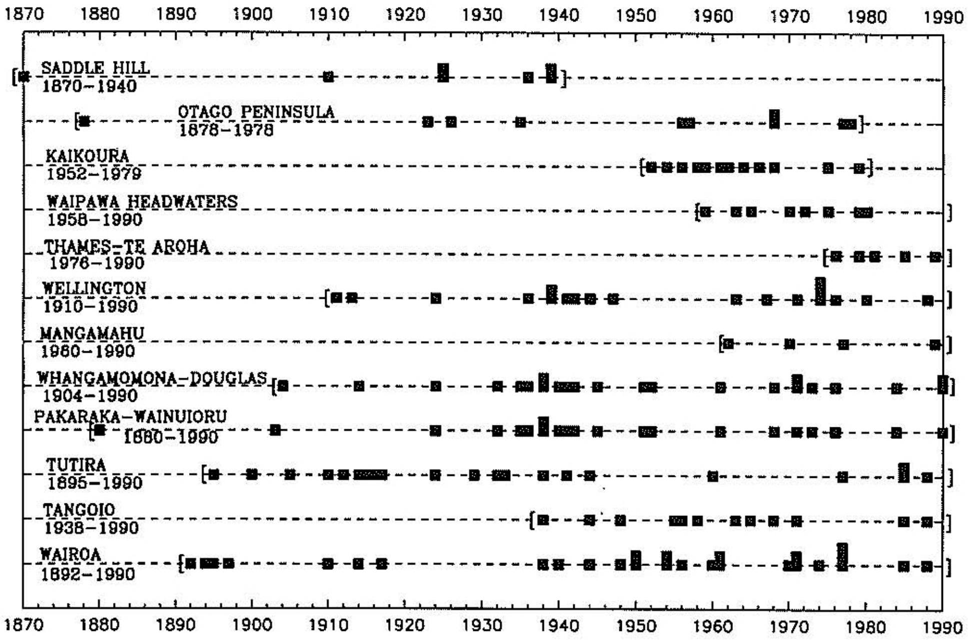

Figure 22: Dates of widespread mass movement in various districts of New Zealand (from Hicks 1995)

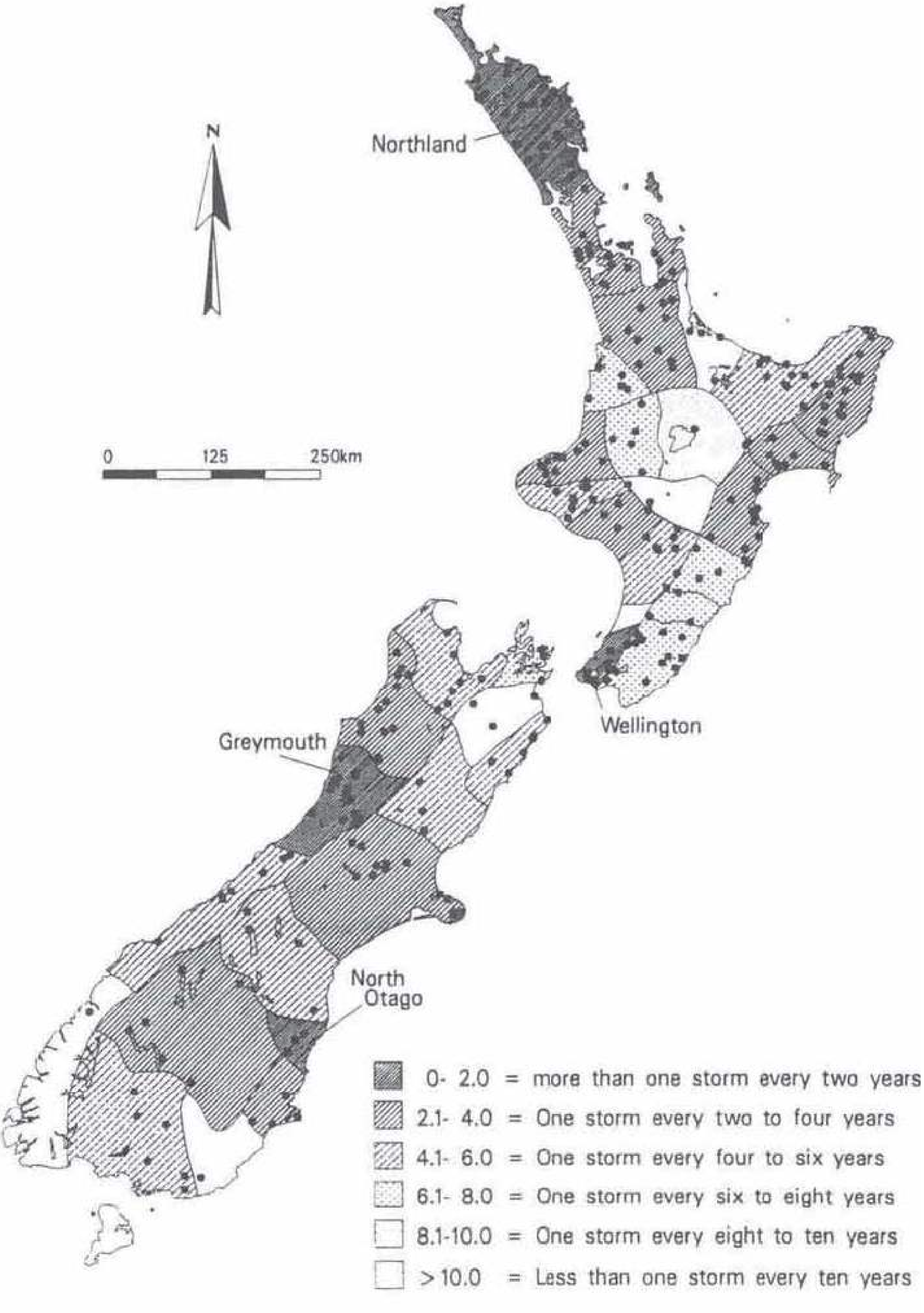

Figure 23: Regional frequency of recorded landslide-triggering rainstorms in New Zealand. Points are locations of recorded events (Source: Glade 1997, 1998).

However, Glade (1997, 1998) notes that his results in part reflect the limitations of the available data sources which do not necessarily record all landslide events nor do they include all storm events that did not produce landsliding (e.g. he shows Fiordland as having very low frequency of landsliding). Despite the frequency and intensity of landsliding in New Zealand there is no comprehensive system for recording storm damage and landslide information. Glade and Crozier (1996) and Phillips et al. (2012) comment on the issues this raises for identifying relationships between land use/management practices and landsliding, determining whether there are any temporal trends in the incidence of landsliding, and developing improved hazard and risk analysis approaches to underpin land (including forest lands) management policy and practice. Some information is recorded in the NIWA Historic Weather Events (HWE) Catalog (http://hwe.niwa.co.nz/) and the New Zealand Landslide Database (NZLD) held by GNS Science. The HWE Catalog provides a comprehensive list of storms that have caused landsliding but includes no quantitative data on landsliding extent or frequency. The NZLD provides quantitative data but focuses on large events that typically have caused damage to life or property.

Landsliding is typically triggered when a rainfall threshold is exceeded. There have been several attempts in New Zealand to define rainfall thresholds using empirical relationships based on annual rainfall (Omura and Hicks 1992, Hicks 1995), storm rainfall (Reid and Page 2002), hydrological records of large floods (Kelliher et al. 1995), daily rainfall (Glade 1997), daily rainfall and antecedent moisture conditions (Crozier and Eyles 1980, Glade 1997, Glade et al. 2000) or a combination of daily rainfall, antecedent moisture conditions, water loss through drainage, soil water storage and evapotranspiration (Crozier 1999; Glade 2000). Hicks (1995) argued that the threshold for triggering mass movement varied greatly (a) between sites, given the same rainfall and antecedent conditions, and (b) at a site, depending on antecedent soil moisture, intensity and duration of rain and therefore development of simple thresholds for landsliding are difficult. Glade (1997, 1998) compared landslide occurrence with total storm rainfall, maximum daily rainfall and maximum hourly rainfall and showed that there is a wide range probability of occurrence of landsliding and these storm parameters, and highlighted the importance of antecedent conditions as a strong influence on landsliding.

Most landsliding events have their greatest impact on pastoral farmland but there are also many recorded instances of landsliding affecting plantation forests and indigenous forest. In a plantation forest the worst damage occurs in the early post-harvest period (see earlier text). Table 1 provides a list of reported storms where landsliding has occurred in forests. This list is necessarily incomplete because of the lack of systematic recording of landslide-related storm damage information referred to earlier. However, it shows that:

- storm damage to both indigenous and plantation forests has a long history of occurrence and that recent events need to be considered in this context;
- landslides can and do occur in young plantation forests, harvested forests, indigenous forests, scrub and pastoral steeplands;
- most of the storms and their impacts have been local in extent with a few notable exceptions (March 1975-Cyclone Alison, December 1980 - East Coast, April 1982 – East Coast, July 1985 – East Coast, March 1988 – Cyclone Bola, July 1992 – Manwatu, February 2004 – Manawatu Wanganui);
- in most landslide-causing events storm return period (where those estimates are available) is typically more than 10–20 years, however there have been instances of significant damage in more frequently occurring storms (Cormandel in April 1983, Nelson in July-August 1990, Marlborough in November 1994).

Many of the largest events (especially the regional events) are caused by extra-tropical cyclones that bring high storm rainfall totals and high rainfall intensities.

## Table 6: List of storms in which damage to forests is mentioned in published papers or internal reports.

| Date | Region | Site | Rainfall (max) | Return period (yr) | Forest cover | Extent | Debris flows mentioned | Source |
|---|---|---|---|---|---|---|---|---|
| Dec-62 | Wellington | Rimutaka Range | 200 | | indigenous forest | local | | Cunningham and Arnott (1964) |
| Feb-66 | Auckland | Hunua Ranges | 200 | 10-50 | indigenous forest | local | | Pain (1971), Selby (1967, 1976) |
| Apr-66 | Wellington | Eastern Hutt hills | 125 | 10 | indigenous forest | local | | Jackson (1966) |
| Dec-76 | Wellington | Stokes valley | 250-300 (12 hr) | >100 | indigenous forest | local | | McConchie (1980) |
| Mar-75 | Marlborough, Hawkes Bay | Coastal Marlborough ranges, NE Ruahine Range | 600 (Cyclone Alison) | >100 | indigenous forest | regional | | Bell (1976), Bowring et al. (1978), Grant et al. (1978) |
| Dec-80 | East Coast | | 580 (8 days) | | infers forest affected | regional | | Phillips (1988), Kelliher et al. (1995) |
| Apr-81 | Coromandel | Thames-Te Aroha | 1000 (3 days) | 15->50 | indigenous | local | | Salter et al. (1983) |
| Apr-82 | East Coast | | 220 (3 days) | | infers forest affected | regional | | Kelliher et al. (1995), Phillips (1988) |
| Apr-83 | Coromandel | Tairua | 195-260 | 2 | post-harvest | local | | Pearce and Hodgkiss (1987) |
| Feb-85 | Auckland | Hunua Ranges | 260 (1 day) | 50 | post-harvest, mature pine, indigenous forest | local | | Barton et al. (1988) |
| Mar-85 | Hawkes Bay | northern Hawkes Bay | 100-250 | >30 | infers forest affected | local | | Harmsworth et al. (1987) |
| Jul-85 | East Coast | | 290 (2 days) | | | regional | | Kelliher et al. (1995), Harmsworth et al. (1987) |
| Feb-86 | Taranaki | Eltham | 200 (3 days) | | indigenous forest | local | | Pain and Stephens (1990) |
| Mar-88 | East Coast | | up to 900 (5 days, Cyclone Bola) | >100 | post-harvest, mature pine, indigenous forest | regional | | East Cape Catchment Board (1988), Marden et al. (1991), Phillips (1989), Phillips et al. (1989, 1990), Hicks (1991, 1992, 1995), Kelliher et al. (1995), Marden and Rowan (1993), Bergin et al. (1993, 1995), Page et al. (1999), Trustrum et al. (1999), Reid and Page (2002), Liebault et al. (2005) |

| Date | Region | Site | Rainfall (max) | Return period (yr) | Forest cover | Extent | Debris flows mentioned | Source |
|---|---|---|---|---|---|---|---|---|
| Mar-90 | Taranaki | Makahu | 200 | | mature pine, indigenous forest | local | | Hicks (1990) |
| Jul Aug 90 | Nelson | Golden Downs, Motueka west bank | 87-212 (4 storms) | <5 | | local | | van de Draaf and Wagtendonk ((1991), Coker and Fahey (1993) |
| Jul-92 | Manawatu | Pohangina, Puketoi Range | 150 | 10-50 | mature pine | regional | | Hicks et al. (1993) |
| Nov-94 | Marlborough | Marlborough Sounds | 240 (6 days), 133 (24 hr) | 1-5 | | local | | Phillips et al. (1996) |
| Mar-95 | Coromandel | Whangapoua | 150-200 | 20-50 | | local | | Marden and Rowan (1995) |
| Jan and March/Apr-96 | Hawkes Bay | Mohaka | 420 and 265 | >50 | 2 | local | | Phillips and Marden (1996) |
| Dec-98 | Coromandel | Ohui | 150-200 | 5-10 | | local | | Phillips and Marden (1999) |
| Feb-04 | Manawatu-Wanganui | | Up to 225 (2 days) | >100 | mature pine, indigenous forest | regional | | Hicks and Crippen (2004), Hancox and Wright (2005a, b) |
| May June 2004 | Nelson | Greenhill | 90 | | | local | | Hewitt (2004) |
| May-05 | Eastern BOP | Matata | 300 mm | >100 | indigenous forest | local | | McSaveney et al. (2005) |
| Oct-05 | Gisborne | Tolaga Bay- Te Puia Springs | 200-385 (2 days) | 40-85 | post-harvest, mature pine | | | Beetham and Grant (2006) |
| Jul-06 | Eastern BOP | Houpoto | | | post-harvest | local | | Hancock Forest Management (2010a) |
| Apr-08 | Eastern BOP | Waiotahi | 240 | | | | | |
| Feb-09 | Eastern BOP | Houpoto | 150 | | post-harvest | local | | Hancock Forest Management (2009) |
| Apr-09 | Eastern BOP | Houpoto | | | post-harvest | local | | Hancock Forest Management (2010a) |
| Jun-10 | Eastern BOP | Houpoto | | | | local | | |
| Jul-10 | Eastern BOP | Omaio, Waiotahi | | | | local | | |
| Aug-10 | Eastern BOP | Omaio | 500 (3 days) | | post-harvest | local | | |
| Oct-10 | Eastern BOP | Houpoto | 200mm | | | local | | Hancock Forest Management (2010a), Douglas et al. (2011) |

| Date | Region | Site | Rainfall (max) | Return period (yr) | Forest cover | Extent | Debris flows mentioned | Source |
|---|---|---|---|---|---|---|---|---|
| May-10 | Nelson | Middle Motueka valley | 200 | >50 | post-harvest, mature pine | local | | Hancock Forest Management (2010b), Basher (2010) |
| Dec-10 | Marlborough | North bank Wairau to Pelorus | 150-250 | 50-100 | post-harvest, mature pine, indigenous forest | local | | PF Olsen (2011a) |
| Jan-11 | Eastern BOP | Taneatua, Tuhoe, Wiotahi (Cyclone Wilma) | two events (240 mm, 260 mm) | | post-harvest, mature pine, indigenous forest | local | | P F Olsen (2011b), Douglas et al. (2011) |
| Apr-May 2011 | Eastern BOP | Omaio, Hopotu, Tuhoe | 280 mm Houpotu Apr 2011 (80 yr) | | post-harvest, mature pine | local | | P F Olsen (2011c), Phillips and Marden (2011) |
| Dec-11 | Nelson | Pohara, Takaka, eastern Nelson hills | 250-660 mm (3 days) | up to 600 yrs | post-harvest, mature pine, indigenous forest | local | | Hancock Forest Management (2012a), Page et al. (2012) |
| Sep-12 | Eastern BOP | Wiotahi | | | | local | | P F Olsen (2012) |

## EFFECTS OF CLIMATE CHANGE

Climate change is projected to result in changes in rainfall patterns and intensities. Tait (2011) summarises the latest climate change projections for New Zealand and Basher et al. (2011) review the likely impact on erosion processes. Annual rainfall is projected to increase by 5–15% in the west and south of the country and decrease by 2.5–7.5% in the east and north (Figure 24). The annual pattern of rainfall change is dominated by the changes in winter and spring, with projected changes to rainfall in summer and autumn being less significant and quite different to the annual pattern (being wetter in the east, drier in the west). These seasonal rainfall differences are related to the projected changes to the seasonal windflow patterns over the country.

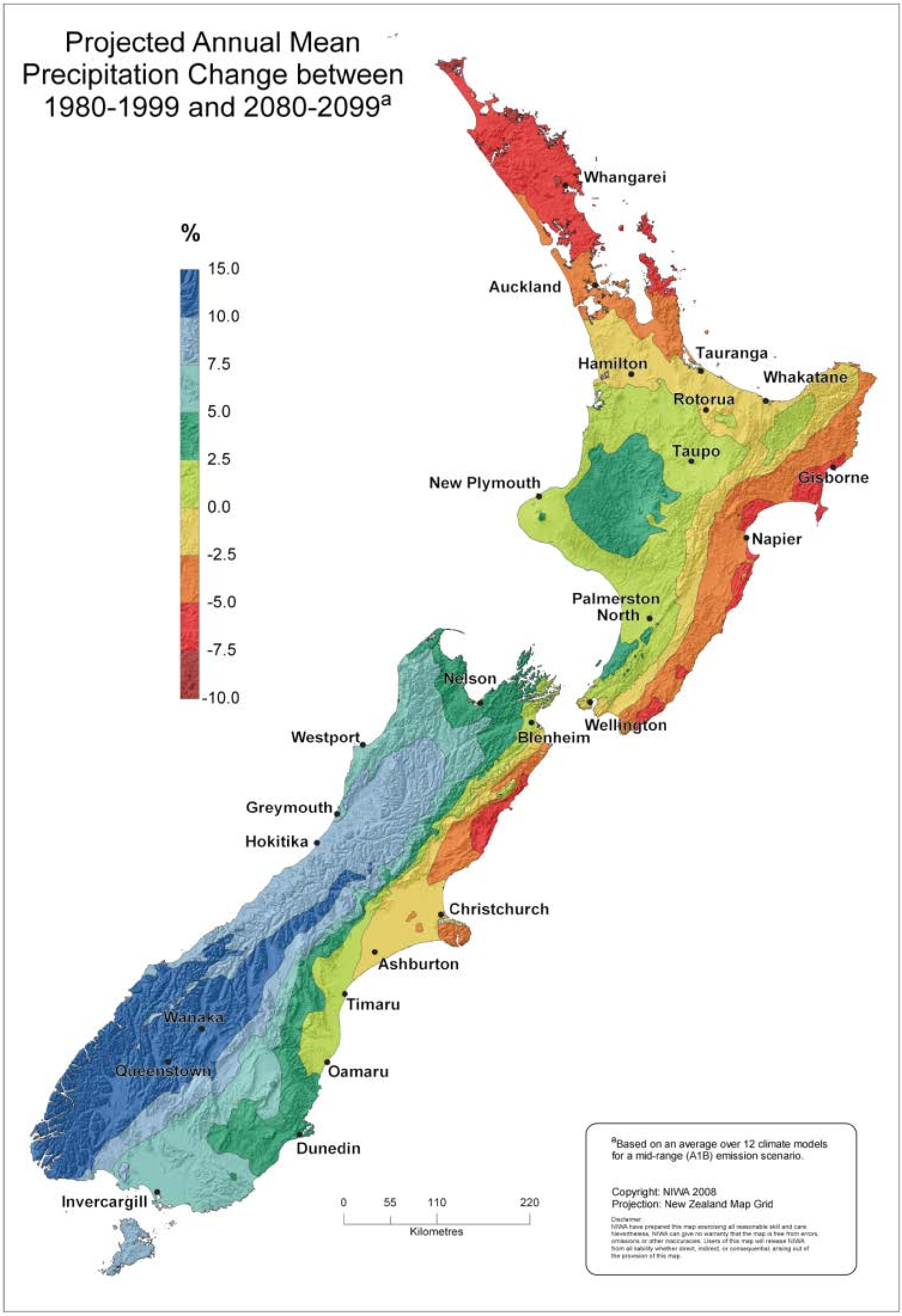

Figure 24: Projected mean annual precipitation change (%) between 1980–99 and 2080–99 (based on the average from 12 downscaled General Circulation Models and the A1B emission scenario) (Source: MfE 2008).

Climate change is expected to lead to increases in the frequency and intensity of extreme rainfall that causes landsliding, especially in places where mean annual rainfall is also expected to increase (Tait 2011). Increases to extreme rainfall for New Zealand of approximately 8% are projected for each 1°C increase in temperature - mean annual temperature increases are predicted to be (average of all global climate scenarios) 0.9°C by 2040 and 2.1°C by 2090. This results in the present-day 24-hour extreme rainfall with a 100-year average recurrence interval (ARI) being projected to occur about twice as often in most places by 2080 to 2099 (based on the average of 12 GCMs and the A1B emission scenario), compared with 1980 to 1999. The projected increase in the 24-hour 100-year rainfall is shown in Figure 25. Several tools can be used for predicting the effect of global warming on heavy rainfalls (Tait 2011), the simplest of which is incorporated into NIWA's High Intensity Rainfall Design System (HIRDS, http://hirds.niwa.co.nz/) and provides a method to predict changes in rainfall intensity-frequency-duration statistics for any location in the country. It uses a scaling factor by which rainfall is adjusted for each 1°C of temperature change (Table 7).

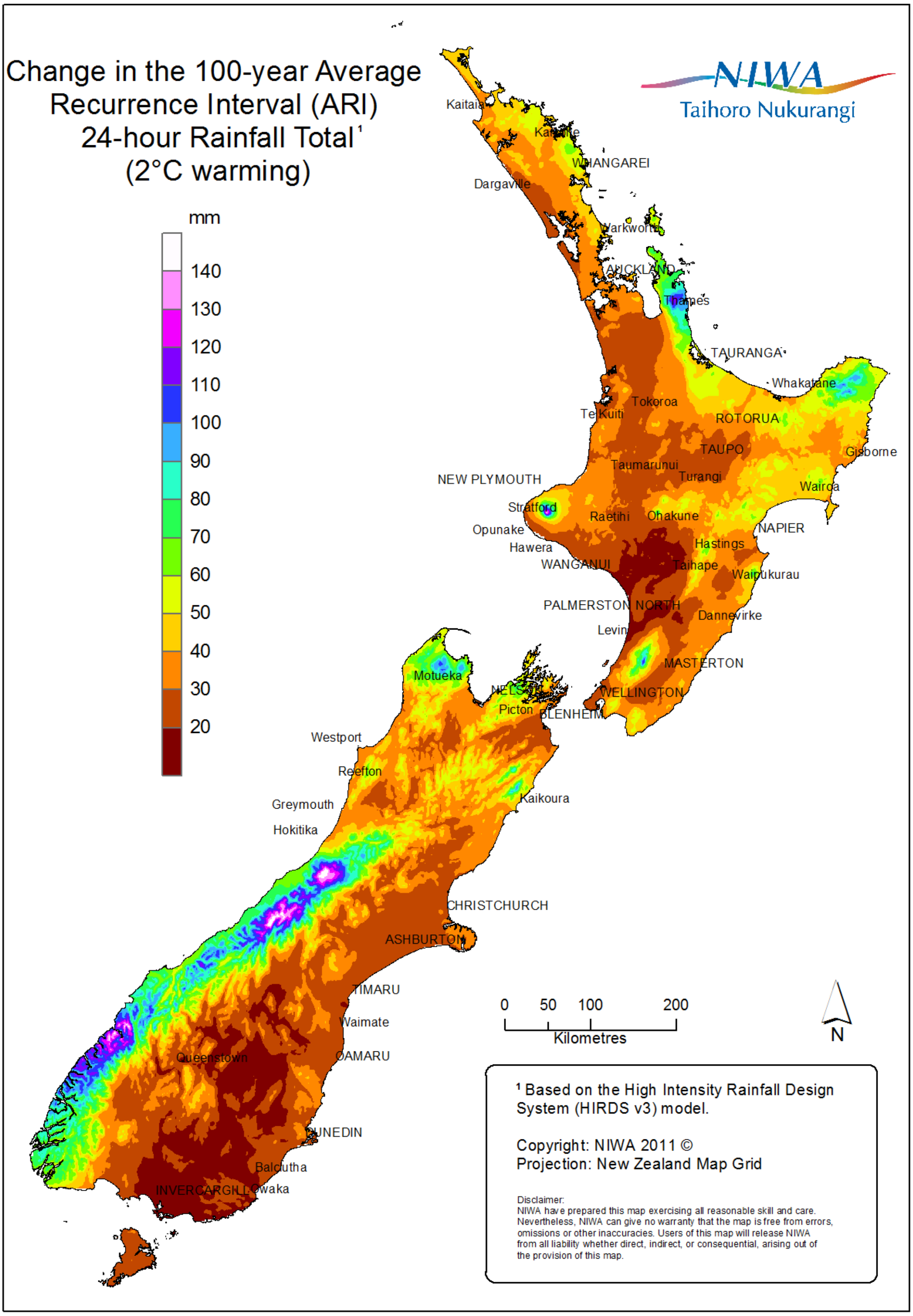

Figure 25: Difference between present-day and future (2°C warmer) 100-year Average Recurrence Interval 24-hour-rainfall totals (Source: HIRDS v3 online at http://hirds.niwa.co.nz/).

Currently NIWA predicts that heavy rainfall intensities will increase even where annual rainfall decreases, although they do note that the results are more reliable for wet areas and that changes in dry areas may be more complicated. In examining historical extreme rainfalls

Griffiths (2006) observes that between 1930 and 2004 there has been an increase in extreme rainfalls in the west of both islands but a decrease in the east. This was strongly related to changes in annual rainfall and stronger westerly circulation, rather than temperature warming (during this period New Zealand-averaged air temperature increased c. 0.9°C).

Basher et al. (2012) suggest the most significant effect of climate change on erosion is likely to be on rates of shallow landsliding, but effects on earthflows, gully, streambank, sheet and wind erosion are also likely. For most erosion processes incidence of storm rainfalls will be critical, although for some, increased temperatures and lower rainfalls in the north and east of the country will tend to counteract the effect of increased storm rainfalls by lowering antecedent moisture conditions. The areas most susceptible to increased erosion (landsliding, earthflows, gully and sheet erosion) are the soft rock hill country of Taranaki, southern Waikato, Manawatu-Wanganui west of the Ruahine Range, Otago, South Canterbury and inland Marlborough.

Table 7: Factor of percentage adjustment per 1°C to apply to extreme rainfall, for use in deriving extreme rainfall information for screening assessments (Source: MfE 2008).

| | ARI (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| Duration | 2 | 5 | 10 | 20 | 30 | 50 | 100 |
| < 10 min | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| 10 min | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| 30 min | 7.2 | 7.4 | 7.6 | 7.8 | 8.0 | 8.0 | 8.0 |
| 1 h | 6.7 | 7.1 | 7.4 | 7.7 | 8.0 | 8.0 | 8.0 |
| 2 h | 6.2 | 6.7 | 7.2 | 7.6 | 8.0 | 8.0 | 8.0 |
| 3 h | 5.9 | 6.5 | 7.0 | 7.5 | 8.0 | 8.0 | 8.0 |
| 6 h | 5.3 | 6.1 | 6.8 | 7.4 | 8.0 | 8.0 | 8.0 |
| 12 h | 4.8 | 5.8 | 6.5 | 7.3 | 8.0 | 8.0 | 8.0 |
| 24 h | 4.3 | 5.4 | 6.3 | 7.2 | 8.0 | 8.0 | 8.0 |
| 48 h | 3.8 | 5.0 | 6.1 | 7.1 | 7.8 | 8.0 | 8.0 |
| 72 h | 3.5 | 4.8 | 5.9 | 7.0 | 7.7 | 8.0 | 8.0 |

Tait (2011), quoting Mullan et al. (2011), suggests that because of a poleward shift in cyclone tracks under a warmer climate it is likely there will be a reduction in the number of extra-tropical cyclones over the North Island and to the east of the country in winter. However, there may be an increase in summer over the Tasman Sea. Mullan et al. (2011) also suggest cyclone intensity is likely to decrease over New Zealand. The changes in extra-tropical cyclone frequency and intensity are critical to predicting the effects of climate change on regional landsliding events.

## Erosion and sediment control in forest management

In general, the principles for erosion and sediment control (E&SC) in forests are the same for any land use. Most of the practices and understanding relating to E&SC have been derived from managing urban developments, especially road and earthworks activities. These include:

- Keep disturbed areas small and time of exposure short;
- Control erosion at source;
- Install perimeter controls;
- Retain sediment on site;
- Protect critical areas;
- Inspect and maintain control measures;
- Establish the new crop as soon as possible.

Some of these principles are more applicable to earthworks than management of clearcuts, and they do not deal directly with the issue of woody residue management.

## CODES, GUIDELINES, AND CURRENT PRACTICES

Since early studies of erosion caused by roads and landings (see section 7.4) and recognition of the importance of good engineering practice to minimise the environmental effects of soil disturbance there have been considerable improvements in construction of forest infrastructure. Because mechanical slope stabilisation is generally not economically feasible along most low volume gravel roads and tracks, erosion prevention can be partly achieved by road location and construction methods that recognise erosion hazard (Phillips et al. 2012).This has been greatly assisted by the preparation of an Environmental Code of Practice for Forestry Operations (E-CoP) and a Road Engineering Manual specifically written for forest roads. Some companies are starting to develop erosion hazard assessment approaches that allow identification of areas of high erosion susceptibility to be avoided or managed more carefully (e.g. Hancock Forest Management 2010a, 2012b).

The E-CoP was first prepared in 1990, revised in 1993 (Vaughan et al. 1993), and revised and upgraded in 2007 (NZ Forest Owners Association 2007). It provides a set of rules for best environmental practice (BEP), guidelines for additional considerations to be used where safe and practicable to do so, and general guidance with background information on the relevant BEP. It includes sections on BEP for earthworks and waterway crossings as well as harvesting and slash management and guidance on how to avoid the adverse effects of forest operations (including exposure of bare ground, changes in runoff, and compaction of soils).

In addition a Road Engineering Manual was first produced in 1999 (Logging Industry Research Association 1999) and substantially upgraded in 2011 (Gilmore et al. 2011). This provides a comprehensive guide to planning and constructing forest roads and associated infrastructure, and their maintenance. There are sections on:

- locating, designing and laying out roadlines;
- road and landing construction;
- pavement design and construction;
- stream crossings;
- water, erosion and sediment control;
- road maintenance, including maintenance of erosion and sediment control measures.

It provides detailed design guidelines and is extensively illustrated with pictures and diagrams to show how to follow the written description of all practices. It has a strong focus on practices that can be used to avoid, remedy or mitigate adverse environmental effects and is specifically designed for forestry operations and written by foresters with extensive practical experience. It gives close attention to preventing direct runoff of water from freshly harvested sites into important waterways by promoting careful design of roads including careful placement of any bridges and culverts, retention of a screen of live vegetation alongside any streams and use of logging systems which have least impact.

In addition some companies have produced specific guidelines for managing the effects of forestry activities, primarily infrastructure, in their estates. For examples:

- Hancock Forest Management have a guide (Hancock Forest Management 2010c) for operations around waterways that provides a classification of waterway and riparian values, a risk rating of streams, and guidance about how to manage proximity of earthworks and machine disturbance to streams, protection of riparian vegetation, and slash management around streams;
- Nelson Forests have a Granite Management Plan (Nelson Forests 2009) to provide specific guidance for management of forestry operations on the highly erodible

> Separation Point granite. This specifies how to choose landing sites and their allowable size, the types of trucks to be used on steep roads, road construction (including widths, corner radii, metal depth and size, cut-and-fill), track construction, water control, culverting, response to rainfall events, maintenance of roads and landings, revegetation of earthworks, measures for waterway protection. It also covers the reestablishment regime. This plan has been updated 5 times since it was first produced in 2001. stream crossings.

Regional councils have also begun producing erosion and sediment control guidelines (ESC) for forestry operations. These are generally based on similar guidelines for urban earthworks with some modification to forestry operations, and are largely based on guidelines initially produced by Auckland Regional Council. Forestry specific guidelines have been produced by Northland (Northland Regional Council 2012), Auckland (Dunphy et al. 2007), Bay of Plenty (Environment BOP 2000), Hawkes Bay (Shaver 2009 and Wellington (Greater Wellington Regional Council 2006). The focus of these guidelines is mostly on managing the effects of earthworks required for forest infrastructure.

Thus there is considerable detailed guidance on minimising the erosion and sedimentation resulting from earthworks and forest infrastructure. While there have been no recent studies in New Zealand of the impacts of roads and landings on erosion Phillips et al. (2012) suggest attention to location, design and construction in recent years in New Zealand – arising from drivers such as the E-CoP, Forest Stewardship Council certification, and company environmental management systems – has seen a dramatic improvement in both the quality and performance of roads and earthworks particularly in the corporate forest sector and it is considered likely that infrastructure makes less of a contribution to erosion and sediment generated from forest harvesting operations than it previously did. While there is limited quantitative data to support this view recent analyses of impacts of large storms at Tapawera in Nelson (Basher 2010) and Houpotu Forest in coastal Bay of Plenty (Phillips and Marden 2011), and post-harvest sediment generation in Coromandel (Phillips et al. 2005, Marden et al. 2006) and Hawkes Bay (Eyles and Fahey 2006), do suggest that most sediment is generated from clear-felled areas rather than infrastructure. Ngapo (2012) also concludes forest harvest planning has progressed in the last 30 years and currently is of a very high standard compared with normal practice in the early 1980s as is earthworks construction and erosion and sediment control techniques.

One of the key issues with all the guidelines is the choice of a storm return period used in design calculations. The ARC guidelines use a 20 year return period (expressed as 5% AEP) for diversion channels and bunds, temporary watercourse diversions, 100 year return period for emergency spillways for sediment ponds, and culverts should pass ‘as large a storm as possible’. The NZFOA Roading Manual suggests culverts be designed to carry the 50 year flow, bridges the 100 year flow, and that roads should have a 50 year design life.

Pendly (2012) found that prescriptive codes of practice require more background information and may require more options to increase flexibility. Forestry companies may need to educate relevant staff on best engineering practices to increase awareness and the utilisation of some overlooked practices. Fully monitoring compliance is a very time-consuming process which may be beyond the resources of forestry companies and councils. Collecting compliance data across New Zealand may allow the success of changes to regulatory systems and regional compliance differences to be quantified.

## WOODY RESIDUE MANAGEMENT

Woody residue management is regarded as a key issue because it is the combination of coarse woody residue left behind after harvesting with soil and regolith generated from landsliding that is a major contributor to the development of debris flows that cause the most severe off-site and downstream damage (Baillie 1999, Basher 2010, Douglas et al. 2011, Ngapo 2012). The woody residue is produced from breakages during felling and extraction, and from trimming and processing operations. Concentrations of woody residue typically occur around streams (as a result of difficulties with directional felling away from streams and hauling across streams), and around landings (where trees are trimmed and processed for loading out). Little work has been done on the source areas for woody residue (i.e. the relative contribution of bird's nests associated with landings, woody residue deposited in streams, and woody residue that is widely dispersed over clear-cuts) that causes downstream problems. (Douglas et al. 2011). In the 80 events analysed by Baillie (1999) it was estimated 48% of the debris was sourced from landslides and 38% from in-stream log jams and debris dams, with the remainder from landing failures and road collapses.

Hall (1999) found that average residue volumes were approximately 30 to 50 $m^3$/ha and most of the residue comprised of unmerchantable stem wood and large branches. Hauler residue tended to be concentrated in gullies and the ground-based systems tended to have slightly higher volumes as distance from the landing increased. Using a survey method, Hall McMahon (1997) found that of 869 hauler landings, 45% had significant birdsnests after logging and in 1996 a total of 24 birds nests were reported as collapsed. Baillie et al. (1999) reported that post-harvest volumes of woody debris in streams averaged 289 $m^3$/ha and increased three fold on average over pre-harvest levels. About 1/3 lay in-stream or on the floodplain and the most significant change in woody debris characteristics after harvest was size distribution. Bank scuffing from felling and log extraction during harvest operations was the most common channel bank disturbance after harvest.

Woody residue (or slash) management is covered in the E-CoP (NZ FOA 2007) which describes both:

- the benefits from woody residue
  - provides surface cover that helps protect against soil erosion and sediment discharges;
  - decaying woody residue returns nutrients to the soil and hosts a range of biota from fungi to invertebrates which contribute to processes of soil formation and nutrient redistribution, and assist growth of the following crop;
  - some woody residue in streams improves habitat (provides cover and shade for native fish and young trout, increases stream turbulence, provides food and substrate for macro-invertebrates).
- the risks from woody residue mobilisation
  - collapsed woody residue piles can trigger mass movement;
  - can form debris dams in streams which are prone to collapse and cause severe damage downstream;
  - extensive woody residue in streams can obstruct fish passage, restrict habitat and breeding, and impact on oxygen levels in water as it decomposes.

Thus there is a balance to be achieved between retaining woody residue for its beneficial effects (see Baillie 2011) and avoiding the adverse effects, especially in large storm events. The focus in the E-CoP is on managing woody residue and wood debris to avoid adverse environmental effects, especially surrounding landings ('birds nests') and waterways and the guidance is quite general. It suggests planning for adequate woody residue disposal sites, removing woody residue to a biofuel plant if possible, pulling back or burning landing woody residue where 'birds nests' are on unstable or potentially unstable ground, using directional felling to minimise the amount of woody residue deposited in streams, removing as much woody residue as possible from intermittent streams, moving woody residue beyond the reach of flood flows, and using downstream debris traps. The section on earthworks also notes no woody residue should be incorporated in steep fill batters (i.e. on roads and landings). No guidance is given on management of slash on the clear-cuts. The Road Engineering Manual (Gilmore et al. 2011) also recommends the use of logging slash and woody debris as a filter for water and sediment in sediment control structures. Slash management plans can be prepared as part of the consent process for forest harvesting.

Similarly ESC guidelines focus on woody residue on landings and around waterways with less attention given to managing the effects on the clear cuts. Several have very little comment on woody residue management other than very general statements about how to manage residue (Auckland, BOP, Hawkes Bay, Wellington).

The Northland Regional Council ESC guidelines (Northland Regional Council 2012) do provide specific guidelines for the management of woody residue risk and an example of a woody residue management plan/checklist. Woody residue management risk for streams considers: climate and the likelihood of high intensity rainfall events; topography and soil stability; catchment size, permeability and likelihood of flooding; proximity and importance of downstream infrastructure both internal and external to the forest, e.g. houses, fences, culverts, bridges, water intake structures etc.; water body ecological values – species present and their rarity; proximity of the site to neighbouring boundaries, state highways or public roads; proximity of trees to the margin of the water body or on steep slopes above the water body; evidence of historic or recent landslide activity. It is also assessed in relation to stream characteristics using a stream classification system. This is used operationally by Hancock Forest Management who have developed a specific woody residue mobilisation risk analysis for Houpoto Forest which has recently had a high number of landslide and debris flow incidents (see Terrain Stability Mapping section, Fig. 29).

Techniques for managing woody residue around streams include back pulling trees where practicable, corridor pulling through a water body using south bend or mechanised carriage systems, no trimming, or heading in or over a water body, fell first row of edge trees across water body (to bridge valley floor) to provide bank protection of the water body, cutting of woody material within a water body channel and placement on adjacent banks, stable wood (i.e. windthrow) can be left in the water body, slash traps may be used if this can be done without damming the river. For landings the following practices are recommended to minimise instability of birdsnests: placing of slash on formed benches (to be undertaken prior to commencement of harvest); if lack of storage for slash is identified at the site, trucking of the slash should be considered; water controls to manage water away from fill faces and control water outlets to original ground; pull slash back from fill areas; burning of woody residue where appropriate).

After storm events in 2010 and 2011 EBOP have also provided more specific recommendations regarding identification of areas at risk of woody residue mobilisation and woody residue management (Douglas et al. 2011):

- high risk land was identified from;
- underlying geology, soils and erosion type (largely done from Land Use Capability unit);
- topography (all slopes >26º on land types considered high risk).
- use of the following for woody residue management;
- physical removal of woody residue from the at-risk harvest sites, particularly large diameter material such as logs longer than four metres with a small end diameter of 30 cm, large slovens and intact tree heads. The pushing of woody residue from skid sites into areas with a high likelihood of underlying failure on very steep slopes should not be carried out. If there is a requirement to dispose of woody residue in this way, it should have as much organic material removed from it and be placed on a stable excavated bench which should not be overloaded by ensuring that it is visible;
- burning to eliminate woody residue from steeply incised gullies;
- poisoning of standing trees that cannot be harvested;
- trapping of woody residue below at-risk sites using slash racks or standing trees on alluvial fans;
- partial harvesting of at-risk land.

# Riparian management

Riparian buffers have been promoted as a primary measure for mitigation of the effects of a range of land use practices, including forest harvesting, on streams and water bodies. These buffers provide many biophysical functions such as stream bank stability, filtering of sediment and contaminants from overland flow, shading for temperature and nuisance aquatic plant control, woody debris inputs, cover and spawning habitats for fish species, and denitrification and nutrient uptake from shallow groundwater.

There is strong evidence to support their effectiveness for a number of these functions (eg. Gilliam et al. 1992; Collier et al. 1995; Quinn et al. 2004; Quinn 2005) however a question remains as to their effectiveness in removing sediment or preventing sediment from entering waterways in steep country as any overland flow tends to quickly become concentrated and follows well-defined flow paths that can traverse a riparian buffer without interacting with it, especially for landslides and debris flows. In less steep localities, filtering of contaminants such as sediment from overland flow can be an important function of the riparian zone. To be effective, the zone needs to:

- slow the flow of surface runoff, enhancing settling of particulates; and/or
- increase infiltration into the soil, enhancing filtration of particulates.

These filtering and settling functions are enhanced by the zone having flat topography, dense ground cover of grassy vegetation or litter under riparian forest that increase surface roughness, and soil characteristics that increase hydraulic conductivity. The function will be compromised if the surface runoff is channelised, so that runoff passes rapidly through the riparian area with little time for settling of particulates or infiltration into riparian soils. The likelihood of surface runoff occurring increases with rainfall intensity, slope length, slope angle and convergence of flows, and decreases with infiltration rate.

Apart from several studies that have focused on freshwater habitat and water quality effects of riparian buffers within forests there has been no published work that we could find that has looked at the trapping efficiency of riparian buffers for managing sediment associated with landslides and debris flows in steep erodible forested hill country.

A riparian Decision Support System for plantation forestry was explored and developed in the 1990’s but for various reasons did not get completed or widely used. Its main achievement was to bring much of the knowledge of riparian zones within forests together to improve general understanding (Collier et al 2001) and lay the groundwork for future studies such as those carried out in the Coromandel (e.g. Quinn et al. 2004).

Forestry and regulatory staff highlighted several issues concerning the use and value of riparian management as a way to deal with the debris flow-woody residue issue. Within the forest and agriculture sectors there is a generally accepted view that riparian buffers or stream side management zones have value and can contribute to improvements in water quality, biodiversity and wider ecosystem health. However, in consulting the forestry sector during the course of this project, there appeared to be a lack of uncertainty on the exact benefits of riparian buffers and their role in the forest and what sized buffer or set back was required to be effective for different functions. Setting aside land for riparian buffers also comes at a cost to the forest owner including loss of productive land, creation of potential weed issues, issues at harvesting (eg. leaning or tipped trees growing into the buffer) and requirements to pull away from riparian buffers as part of regulatory controls.

In summary, some issues and knowledge gaps remain:

- not one size fits all if one were to translate current science understanding of riparian performance into forest management
- in discussions with the forest sector, the issue of what kind of management is really needed in headwater environments where landslides and debris flows initiate was repeatedly raised.

- there seemed to be a general understanding that sediment runoff should not be discharged from roads into streams or ephemeral streams, hazard avoidance approaches should be utilized to minimize debris flows, and there were comments from a forest manager that by and large 10 m buffers looked pretty effective and why do we need to go wider.
- how to match management to the local situation rather than continue to go down the current path of one-size-fits-all regulations, BMPs and guidelines which often take a worst case scenario which for many situations is overly protective.

The connection between riparian zones and debris flows is complex and less well understood. Evidence from New Zealand and overseas suggests riparian zones may be either positive or negative in terms of trapping woody residue in debris flows. The width of the zone, its location in the fluvial system, slope and stream gradients, stature of vegetation within in it, may determine if the buffer traps or adds to the debris flow. In many situations riparian failures occur which add to the overall mass of the debris flow and contribute to the channel and near stream areas being “reamed out”.

## Off-site management options

Northland Regional Council and Environment BOP recommend the use of slash traps to manage the offsite effects of woody residue mobilisation (Douglas et al. 2011, Northland Regional Council 2012) and this practice is also recommended in the E-CoP. (NZFOA 2007). There is no published detailed design of these measures, nor is there any assessment of their effectiveness.

Slash traps would typically be located on alluvial fans below areas with a significant risk of slash mobilisation and debris flow generation into streams (Douglas et al. 2011). Slash racks are usually constructed using railway irons and wire rope driven into a floodway area where slash can accumulate. They should not dam streams. Trees (either existing or planted) on alluvial fans can also be used to contain woody residue during extreme rainfall events. A structure would have to be constructed in the floodway to guide the woody residue into the trees when the stream was in full flood.

In a “normal” flood situation slash racks work well to trap woody residue but in a large storm in which many landslides are triggered they may pose an additional risk to property downstream. Should a large debris flow occur upstream of such a structure with the potential to overwhelm and incorporate trapped woody residue into the flow, the erosive capacity of the flow will be increased.

Experience from countries that experience debris flows in steeplands suggest that in general terms, debris-flow risk can be reduced by:

- preventing woody residue from entering a stream channel;
- trapping woody residue on a hillside, in the channel or in a debris basin before it reaches developed property; or
- distributing or diverting woody residue on the alluvial fan away from structures.

Woody residue can be trapped using sediment fences/traps on slopes, check dams in channels, and debris basins on alluvial fans. Debris flows can also be diverted away from critical areas such as buildings by diversion banks.

Structural measures such as check dams are widely used in many parts of the world to control or limit the effects of debris flows and there is a well-established literature on their use and design (Takahashi 2007). Most of these are very costly and are used where infrastructure protection is paramount, such as in highly populated areas or where infrastructure such as motorways could be in the path (eg Mizuyama 2008, Volkwein et al. 2011). These include various forms of check dams, concrete structures, steel grates, wire nets, debris flow breakers (similar to a cattle stop). These structures are common in Japan and in the European Alps where the nature of the hazard has been recognised for centuries and management has similarly been in place for many years.

## Hazard assessment including debris flows

Much of the damage caused by landsliding and debris flows occurs during infrequent high-magnitude storms (>10–20 year ARI). Thus a key approach for forest management is to analyse this risk and design management approaches that aim to minimise it. A number of approaches have been tried both in New Zealand and overseas.

### TERRAIN STABILITY AND LANDSCAPE HAZARD MAPPING IN NEW ZEALAND

Terrain stability mapping was pioneered in New Zealand in the late 1970s and 1980s when awareness of erosion issues in protection-production forests was just beginning. Maps were compiled at scales between 1:30, 000 and 1:25, 000 for parts of the New Zealand Forest Service estate of ‘conservation forests’ located primarily in the East Coast region (Gage and Black, 1979; Phillips and Pearce, 1984a, b, 1986,). The system was based on analysis of age and composition of the underlying rocks, presence or absence of volcanic air fall ash (tephra) of known age, current erosion, and landscape morphology. Eight classes of terrain were identified (see Fig. 26):

1. Stable surfaces on Tertiary rock.
2. Stable surfaces on older rock.
3. Very deep slumps on Cretaceous-Paleocene rock.
4. Older flows and moderately deep slumps on Cretaceous-Paleocene rock.
5. Younger flows and moderately deep slumps on Cretaceous-Paleocene rock.
6. Active flows, slumps and eroding gullies[5].
7. Debris fans and floodplain accumulations.
8. Stream terraces and dissected fans.

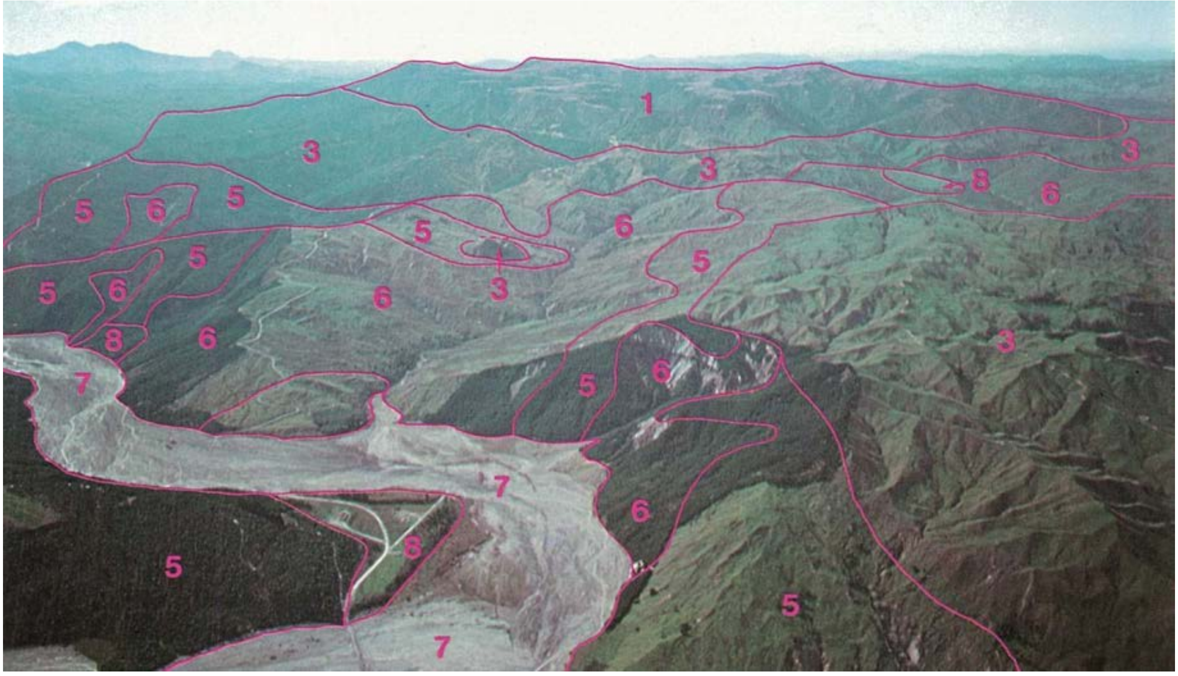

Figure 26: Terrain stability zoning in the south-eastern part of Mangatu Forest (Pearce 1977).

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[5] Classes 1 to 6 represent decreasing slope stability, classes 7 and 8 are depositional landforms.

The earliest example of this style of mapping was for an area where the landscape morphology is dominated by earthflow and deep-seated slump failures. Here, shallow landslides tend to be restricted to small isolated patches of steep terrain or convex riparian slopes and in this terrain are not considered to be a significant hazard and therefore pose little risk. Qualitative rather than quantitative assessments of the potential for slope failure were based on the physical geomorphic attributes of the type and 'recentness' of predominantly mass movement failures and their relationship to the lithologic age of the underlying geology. Slope hazard assessments of the likely reactivation of mass movement following harvest were not considered and no risk assessments were undertaken at this time.

However, in later years as harvesting moved to forested areas located in the steeper and more dissected terrain associated with Tertiary-aged lithologies, the marked increase in the incidences of landslide failures associated with harvesting in this terrain led to an improved awareness of the vulnerability of the landscape within this geological terrain to shallow landslide failure. With this has come the realisation that such failures have recently resulted in severe off-forest damage to infrastructure and sensitive environments such as streams and estuaries. The potential for further instances of off-forest damage as a consequence of forest-related activities is increasing as forests in this terrain mature. In turn this has led to the resurgence in use of terrain stability maps (where they exist) in these areas as part of the input into harvest planning.

A simpler scheme was developed for Westland hill forests separating the landscape into production areas that could be clear felled, production areas that require selective logging, and protection areas. This classification used evidence of current and past erosion, slope and geology as criteria to define the classes. In both cases the assessment was field-based, site specific with maps at semi-detailed scale (typically 1:30,000) and designed to be used operationally for forest management. The maps were used at the time, especially for harvest planning, but the system was shelved at the time of NZ Forest Service restructuring (Phillips et al. 1989). Interestingly Pearce (1977) commented that a landscape zoning scheme like this needed to be developed urgently for all New Zealand plantation forests if it was to be useful for management of plantation forests – 35 years later recent erosion events suggest the need remains.

Internationally and nationally, terrain mapping, terrain stability mapping and terrain assessments are a key input to risk management planning concerning landslide hazards. In some instances they are somewhat narrowly focussed on the hazard of landslide initiation following forest-harvest activities but not on the likelihood of landslide impact. Landslide runout distances are not often considered and in other cases a separate analysis is undertaken to evaluate the travel distance of a landslide, and hence the likelihood of sediment entering a stream (Maynard 1987, Hogan and Wilford 1989). In addition, risk levels assigned to alluvial fans, despite their periodic vulnerability to run-out sediment from landslides initiated within forest areas, tend to be underestimated.

In New Zealand there remains a need to provide landslide hazard information at the planning stage of forest activities to professionals in the forest industry and at a scale suitable for use at the operational level.

Recently MfE proposed a National Environmental Standard (NES) for Plantation Forestry. A key component of the proposal was the use of erosion susceptibility to define the regulatory status of forestry activities. An erosion susceptibility classification (ESC) was developed by Bloomberg et al. (2011) using potential erosion severity data from the New Zealand Land Resource Inventory (NZLRI) as shown in Table 8 with options for 3 or 4 classes (Department of Conservation estate was exclude from the analysis). This analysis provides a broad national overview of erosion susceptibility (Fig. 27) but is limited by the resolution of the underlying data (1:50,000 scale at best) and lack of clarity about the description of potential erosion in the NZLRI.

Table 8: Relationship between potential erosion severity and erosion susceptibility class (ESC) (Bloomberg et al. 2011).

| Potential erosion severity | Three class ESC | Four class ESC |
|---|---|---|
| 0=negligible | 1 | 1 |
| 1=slight | 1 | 1 |
| 2=moderate | 2 | 2 |
| 3=severe | 3 | 3 |
| 4=very severe | 3 | 4 |
| 5=extreme | 3 | 4 |

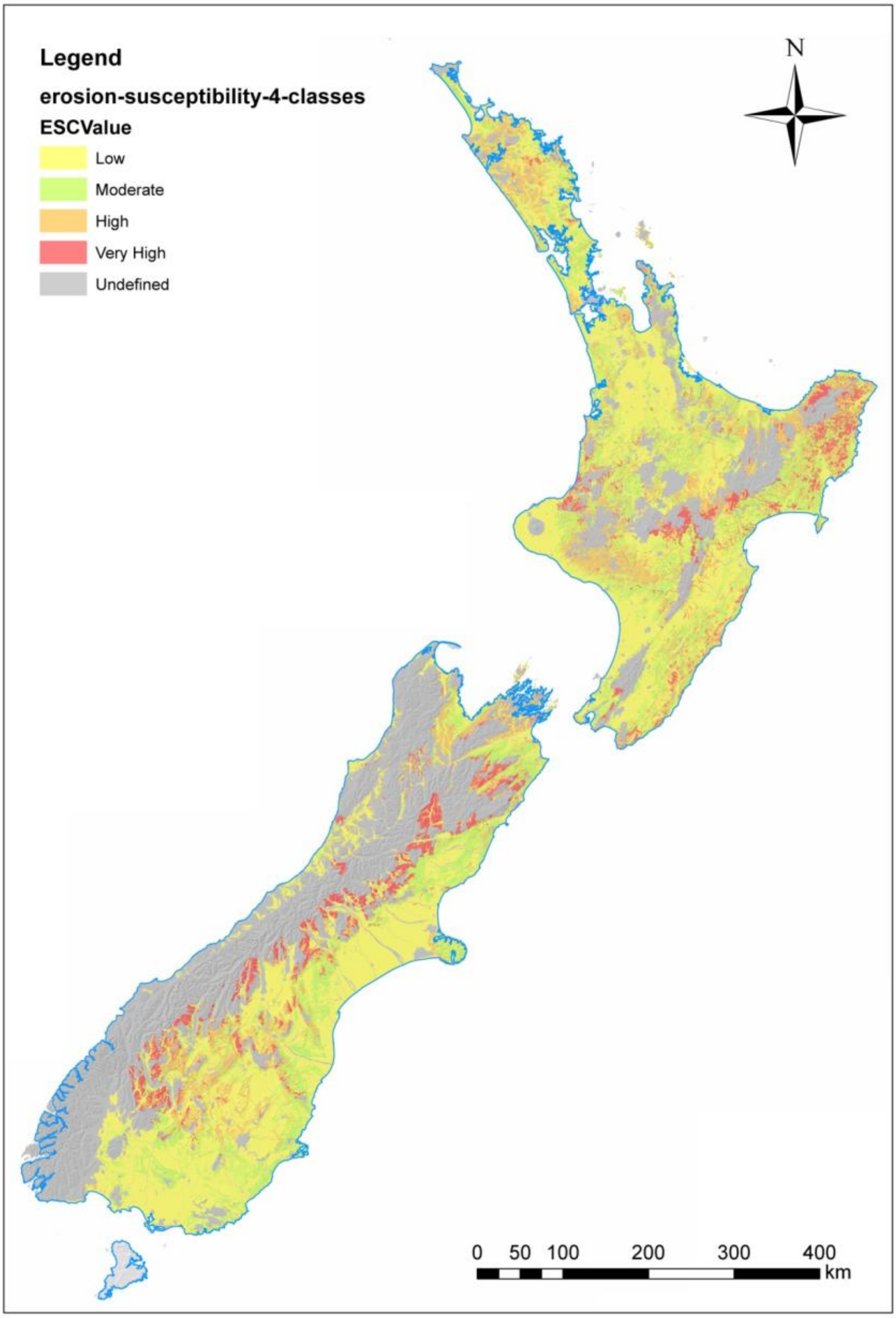


Figure 27: Erosion susceptibility based on the analysis prepared for the NES for Plantation Forestry (Bloomberg et al. 2011).

Future Forests Research and Scion have been exploring a modelling approach to provide a fine spatial scale mapping tool for assessing post-harvest landslide risk (Harrison et al. 2012).

Two methods have been evaluated:

- using a factor of safety analysis of slope stability implemented in the SINMAP (stability index mapping) model (Pack et al. 1998);
- an empirical model based on nonlinear regression between probability of landsliding and rainfall, soil, slope and vegetation factors.

Probability of slipping = R x S x V x A
Where; R = rainfall effect = max(Rain-R_threshold, 0)
S = soil/slope factor
V = vegetation cover factor
A = aspect adjustment = 1 + g x cos(Aspect - f)

This model has been developed using empirical data from the Pakuratahi and Tamingimingi catchments in Hawke's Bay and is currently being tested for other areas with data on landslide distribution and frequency. It is also being explored as an operational tool by P F Olsens (Fig. 28)

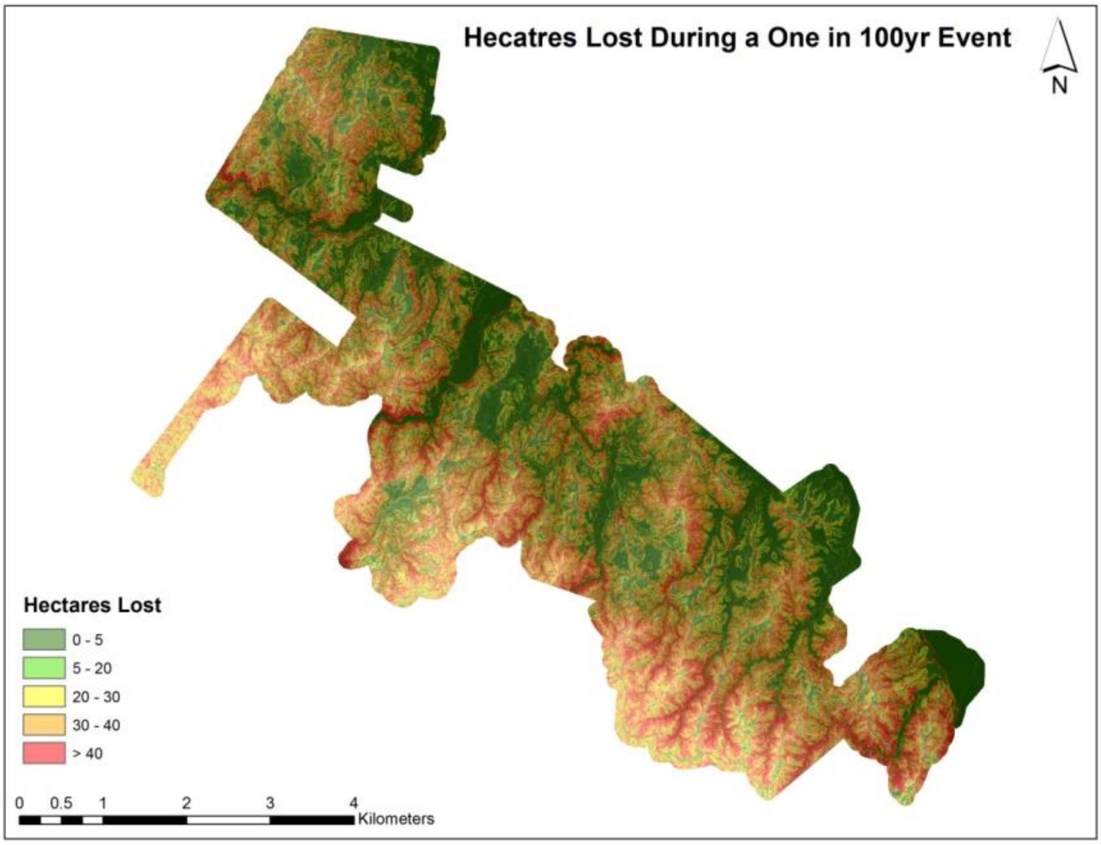


Figure 28: Map of prediction of landsliding during 100 year storm using the Harrison et al. (in press) landslide model (courtesy of PF Olsens Ltd).

Hancock Forest Management have developed an alternative approach based on identifying risk categories from slope, geology, soils, erodibility, erosion processes and potential for residue storage. Figure 29 illustrates the application of this approach to Houpoto Forest.

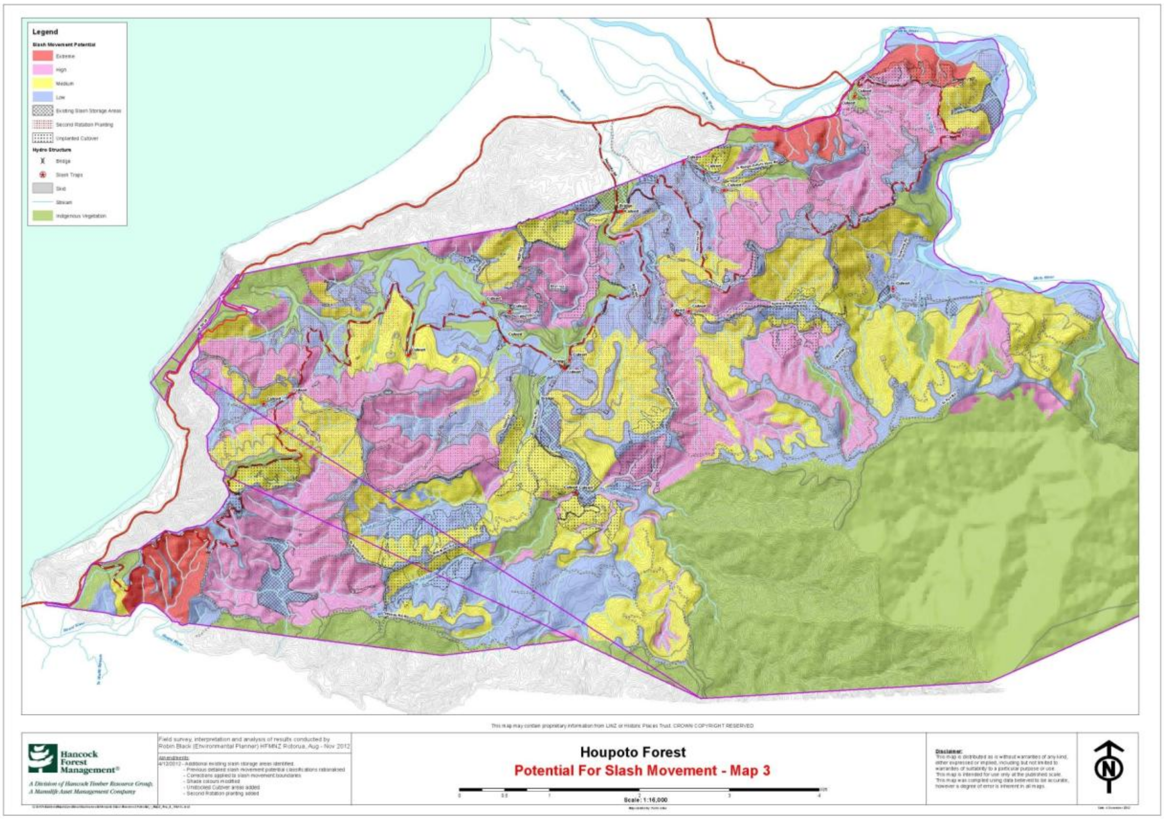


Figure 29: Map of Houpoto Forest showing risk of slash movement (courtesy of Hancock Forest Management).

Debris flows delivering large volumes of sediment and woody residue are one of the key hazards for plantation forestry in erodible steeplands. Welsh and Davies (2010) developed and tested a method for identifying alluvial fans susceptible to debris flow hazards. They assessed a number of morphometric variables that have been identified as capable of identifying and differentiating debris-flow and non-debris- flow basins and their respective fans including:

- basin area
- Melton ratio (R; an index of basin ruggedness; equal to basin relief divided by the square root of basin area)
- watershed length WL; (the planimetric straight-line distance from the fan apex to the most distant point on the watershed boundary.

After preliminary trials R and WL were selected as combining ease of use with adequate discrimination (Table 10). The approach was tested on 18 Coromandel streams and 18 other streams in New Zealand and found to perform quite well with the notable exception of two streams that have $R < 0.30$ but have produced debris flows (one of these was at Matata, the location of large debris flows in 2005). This approach was also tested on catchments in Separation Point granite in Golden Bay that were hit by the exceptional December 2011 storm that generated large debris flows (Page et al. 2012). Again it was possible to distinguish debris flow from non-debris flow catchments from the combination of R and WL, but the threshold values were different from the Welsh and Davies study. Page et al. (2012) suggest the method does work, but threshold values need to be developed for different geological and terrain types.

Table 9: Combinations of Melton ratio (R) and watershed length defining susceptibility to debris flows (Welsh and Davies 2010).

| | R | WL (km) |
|---|---|---|
| Conventional fluvial processes | ≤0.30 | >2.7 |
| Watersheds prone to debris floods | 0.30 – 0.60 | |
| Watersheds prone to debris flows | ≥0.60 | ≤2.7 |

## INTERNATIONAL LITERATURE ON LANDSCAPE RISK MANAGEMENT/HAZARD IDENTIFICATION

Much of the published literature on this topic comes from studies in the Pacific Northwest of the USA (especially Oregon and British Columbia) where landslide frequencies associated with areas of felled forest are up to thirty four times higher than natural background rates (Rood, 1984). Sidle et al. (1985) maintain that timber harvest is the primary factor responsible for this difference. This review is restricted to tools/models attempting to predict potential landslide risk (and associated debris flows or debris torrents) resulting from forest activities and specifically to the risk of natural slope failure (i.e. excluding incidences of failures associated with road and landing construction). However, some of the international studies also include gullies because landslides frequently occur on the steeper slopes associated with gullies and landslides within a gully often develop into a debris flow (Millard et al. 2007).

There is also a much larger body of literature on landslide hazard and risk assessment that is available but not included in this review (e.g. Glade et al. 2005; van Westen et al. 2006).

Shallow landslide activity is usually governed by topographic controls on shallow groundwater flow convergence. Quantitative attributes that influence the initiation of failure, typically expressed as a deterministic or probabilistic measure of the factor-of-safety, include site attributes (soil depth and ground slope), material attributes (angles of shearing resistance, soil cohesion or apparent cohesion as a result of a root network) and groundwater attributes (typically an assumed slope-parallel depth of flow) (Fannin et al. 2005).

The availability of Digital Elevation Models has led to considerable interest in the development of models that incorporate geographic Information Systems (GIS) technology, thereby quantifying topographic attributes that control slope stability (Montgomery and Dietrich 1994, Wu and Sidle, 1995, Pack 1995). A common feature of all methods is the coupling of a hydrological model that describes the groundwater flow regime, with the infinite slope stability model that describes the factor of safety e.g. SINMAP (Pack et al., 1998). Uncertainty can be incorporated through use of probability density functions for the input parameters. Such methods require calibration, and are most confidently implemented in conjunction with other terrain stability mapping techniques. Ideally, the methods are suited to calibration against a set of data that capture known landslide activity, with the intent of then applying them to other areas of terrain where data on landslide activity are sparse or unavailable (Fannin et al. 2005).

Slope instability screening tools have been developed to assess landslide risks associated with the harvesting of natural and steep slopes. Some of these tools are semi quantitative (e.g. HAZONE) and use landslide frequency data and landslide area to assess sediment delivery to streams. Others are GIS-based models of inherent landform characteristics (e.g. SLPSTAB) that utilises slope geometry derived from DEMs and climate data. The authors of these models claim that “The utilization of slope stability screening tools by geologists, land managers, and regulatory agencies can reduce the frequency and magnitude of landslides” (Whittaker and McShane 2012). While both approaches have reasonable success in identifying high landslide hazard areas, incidences of landsliding were not picked up in areas identified as low hazard. Importantly, the reasoning given was that i) landslides initiated in low hazard areas may have resulted from a variety of site specific factors that deviated from assumed modelled values ii) from the inadequate identification of potentially unstable landforms due to low resolution DEMs or iii) from the inadequate implementation of state Forest Practices Rules.

A severe limitation with empirical techniques, given the dependence of prediction on an adequate database of field observations for model development, is the uncertainty in applying them in new areas that are likely to differ from that used in model development. In addition, while they work best in simple terrain with shallow soils they do not work well for deep-seated landslides, or where the topography is significantly more complicated than captured on the DEM (Schwab and Geertsema 2010).

## INTERNATIONAL APPROACHES TO LANDSLIDE HAZARD ZONATION/TERRAIN STABILITY MAPPING

The move of forest harvesting onto steep terrain in British Columbia coastal forests in the 1960s-1970s without a systematic method for the identification of unstable terrain or downslope risks associated with forest harvesting had devastating results (Schwab 1988, Hogan et al 1998). The increase in incidence of landslides associated with forest –related activities and the need for a formal process to identify areas of greater and lesser risk led to the development of slope stability hazard mapping or terrain stability mapping. A basic requirement was that the information needed to be presented in a form that could be easily interpreted for forest and environmental management planning.

In the early days of development, reconnaissance level field and aerial photography inventories of existing, active and formerly active (old) landslides in environmentally sensitive areas provided qualitative and semi quantitative data on which the zoning and hazard evaluations of landslide occurrence were based. Mapping was generally at a scale of 1:50,000. The technique involves identifying individual landslides and stratifying them by ‘activity levels” based on criteria including: i) mapping drainage boundaries upslope of landslides ii) slope angle, aspect  and changes in slope angle iii) position on slope iv) effects of other geomorphic processes e.g. bank undercutting v)nature of regolith vi) bedrock geology etc.

Risk evaluations are then assigned to landslide ‘activity levels’ with landslides or concentrations of landslides with the highest risk (i.e. deemed to be active) being assigned to the most sever hazard level terrain. Conversely, landslides areas of minimum risk of failing are assigned to the least hazard level terrain. Risk also takes into account the potential for activated landslides to affect off-forest assets or sensitive environments.

The more recent development of high resolution aerial photography, DEMs, LiDAR, multi-spectral satellite imagery and GIS-based analyses of landslide inventories has in some respects simplified the data collection and mapping processes. In addition, these new techniques have facilitated the incorporation of more and better quality data, both qualitative and semi-quantitative. While improving the reliability of the mapping, the use of these new techniques has not diminished the requirement for detailed on-site verification of identified hazards by field inspections. Detailed terrain stability mapping is often undertaken at a scale of 1: 20,000.

The basic rule in the application of terrain stability/zonation principles is that any forest management activity (e.g. harvesting) which increases the groundwater or surface water entering landslide-prone terrain or potentially unstable slopes, increases the risk of failure or reactivation.

The provision of terrain stability maps at the planning stage of forest activities has through the awareness and avoidance of unstable terrain been credited with improved forest practices on steep, potentially unstable terrain (Fannin et al. 2005). The identification of physical landscape indicators of instability, both present and past, require  experience and professional judgement. The terrain stability maps are derived from these indicators through professional interpretation. This type of mapping and evaluations derived from it are site specific and cannot be transferred to other parts of the same type of terrain where indicators of slope stability will be different and a similar data gathering exercise and interpretation would be required.

## Silvicultural options for plantations on erosion-susceptible land in New Zealand

Approximately 1/3rd of New Zealand's plantation forest estate is on erosion-susceptible lands. While plantation forest effectively mitigates erosion on these lands, there is a "window of vulnerability" to erosion after clearfelling and before the replanted crop begins to occupy the site. This report investigates alternatives to large clearfelling coups for New Zealand plantation forests, as a way of eliminating or at least reducing the "window of vulnerability." These alternatives can be divided into two categories:

1. Alternative clearfelling systems.
2. Continuous cover or permanent forests.

Alternative clearfelling systems can mitigate the effects of clearfelling by using longer rotations, small-coup harvesting, and/or use of coppicing species. All these are silviculturally feasible, but have drawbacks. Longer rotations have a marked negative effect on the economic return from plantations, unless there is scope for significant income from carbon credits. Small-coup harvesting entails higher logging costs with no compensating increase in log revenue. The use of coppicing species is constrained by the lack of a site-tolerant coppicing species with potential for commercial wood production in New Zealand.

Continuous cover ("permanent") forests avoid the "window of vulnerability" since they are not clearfelled at any time in the life of the stand. Continuous cover forests are not invulnerable to erosion, and landslides can occur in fully forested catchments (Blaschke et al. 2008). Notwithstanding, continuous cover forests may be an option where:

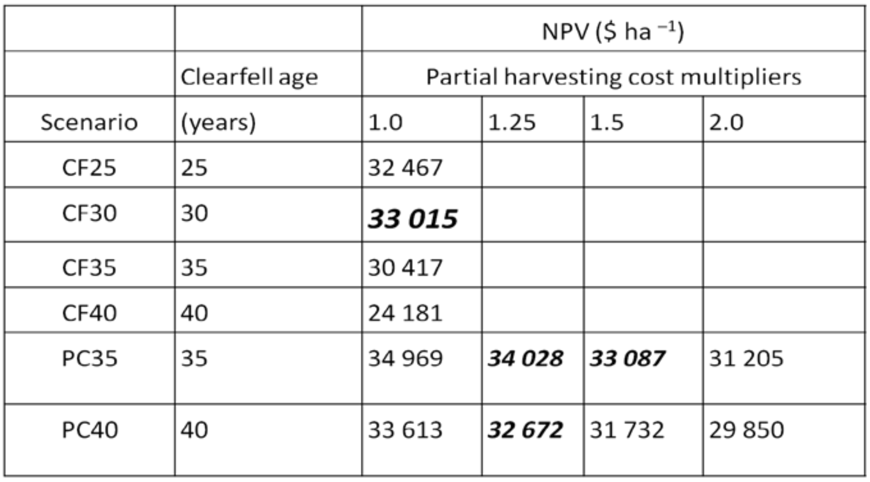
- erosion susceptibility is high;
- forestry is the preferred land use but;
- clearfelling creates an unacceptably high risk of landslides.

Continuous cover forests can be divided into those where managed for timber harvesting, and those where no timber harvesting takes place. For forests where no timber harvesting takes place, carbon forestry is the most likely alternative revenue from the forests. However, high establishment costs and relatively slow growth mean that planting of native species or long-rotation exotic species such as Douglas-fir for permanent carbon forests is likely to be uneconomic. An alternative is to plant species that grow rapidly and generate a high amount of carbon credits early in the rotation, but questions remain about the resilience and longevity of fast-growth species on erosion prone sites.

On suitable sites natural regeneration of native forests can be an effective low-cost way of creating a permanent forest. For forests where timber harvesting takes place, this must be a partial or selection harvest in order to maintain a permanent forest cover. Although seldom used, partial cutting has nonetheless been applied to radiata pine stands in New Zealand, both in the past and at present. Flexible diameter limit cutting involves selecting and harvesting dominant trees within a stand for processing, and in doing so releasing the competitive pressure on the surrounding trees so that they take advantage of the additional growing space until the next selective harvest occurs (Miller and Smith 1993). Flexible diameter limit cutting is similar to the technique employed at Woodside Forest in Canterbury, where trees are selected for harvesting above a diameter limit of 60cm. The rationale for this flexible diameter limit cutting is that by extracting only the larger, higher quality trees and leaving the smaller trees to grow larger before eventual harvest, a return on investment can be achieved similar or greater than clearfelling. The economic theory of flexible diameter limit cutting is well established (Klemperer 1996). Although costs of partial harvesting are higher than costs of clearfelling, flexible diameter limit cutting can lead to an increase in the on-ride value of the harvested logs—therefore flexible diameter limit cutting of established radiata pine sites on erosion-susceptible land may be able to absorb some of the additional cost entailed in partial harvesting. Dickson (2003) used GroMARVL (Gordon, 1991) to show that a partially-harvested radiata pine stand could be economically grown to at least 40 years before clearfelling. Key results were that:

- The predicted log mix produced using partial harvesting contained a much higher proportion of large valuable logs than what was produced from the clearfelling at ages 25 and 30;
- NPV's for clearfelling and partial harvesting options were calculated for partial harvesting costs using arbitrary multipliers of 1.25, 1.5 and 2 times estimated clearfell costs (Table 10). Note that for Woodside Forest partial harvesting costs are 25% greater than expected clearfelling costs for the same stand (John Wardle (pers. comm.).

Table 10: NPV for clearfelling and partial harvesting scenarios. Source: Dickson (2003)



| | | NPV ($ ha $^{-1}$) | | | |
|---|---|---|---|---|---|
| | Clearfell age | Partial harvesting cost multipliers | | | |
| Scenario | (years) | 1.0 | 1.25 | 1.5 | 2.0 |
| CF25 | 25 | 32 467 | | | |
| CF30 | 30 | ***33 015*** | | | |
| CF35 | 35 | 30 417 | | | |
| CF40 | 40 | 24 181 | | | |
| PC35 | 35 | 34 969 | ***34 028*** | ***33 087*** | 31 205 |
| PC40 | 40 | 33 613 | ***32 672*** | 31 732 | 29 850 |

The partial harvesting cost multipliers markedly reduced the NPV's for all partial harvesting scenarios, in particular when partial harvesting costs were multiplied by two. Assuming a partial harvesting cost multiplier of 1.25, partial harvesting twice and then clearfelling at age 35 or 40 results in similar NPV's to the clearfell scenario with a rotation of 30 years and superior NPV's to the clearfell scenarios with a rotation of 25, 35 and 40 years. More shade-tolerant species such as Douglas-fir may be more suited than radiata pine to partial harvesting, but radiata pine is the species likely to be planted on the most erosion-susceptible plantation forest lands, which are mainly in the North Island—and it has the silvicultural capacity to be managed on a partial-harvesting basis. While residual crop damage is always a risk factor in partial harvesting, experience of Woodside Forest has shown that with careful directional tree felling and log extraction, it has been kept to a low level (J. Wardle, pers. comm.) However, the case for partial harvesting on erosion-susceptible land may founder on three operational considerations.

- For first-rotation stands which do not have established harvest roads, significant additional road costs will occur—since diameter-limit partial harvesting may require roads that service an entire large catchment to be constructed, in order to access all trees as they reach target diameter and are harvested. The cost of the road may have to be carried for a long period before sufficient harvest volume is generated to pay for it. Road cost is less of an issue for second or third-rotation forests, where existing roads may only require renovation to be suitable for logging traffic;

- Secondly, shifting and set-up costs are a significant part of the cost of harvesting, especially in steep terrain and with large piece sizes, where large haulers are required which require time to take down, shift and set up;
- Finally, on steep terrain where hauler logging is required, partial harvesting becomes a technically demanding operation. Skyline corridors must be opened in the standing forest to allow inhaul of logs, and the scattered distribution of harvested trees requires either pre-bunching or lateral slack-pulling from a skyline carriage (Visser and Stampfer, 1998). Current NZ research into feller-buncher machines capable of traversing steep slopes may solve the problem, at least in part (R. Visser, pers. comm.).

Other silvicultural strategies for mitigating the risk of erosion during the “window of susceptibility” are:

- Harvesting over longer rotations, either with radiata pine or a slower-growing species such as Douglas fir. - Species such as Douglas-fir and coast redwood are longer-lived and appear to be more windfirm, and are silviculturally suited to longer rotations. Some of the disadvantages of these species were described above (site requirements, economic performance over longer periods, climatic and pest risks);
- Small-coupe clearfelling. - Small-coup (~1 ha) clearfelling on unstable terrain seems a logical way to spread the risk of an erosion-triggering storm event occurring during the “window of vulnerability” across a range of sites and to substantially maintain the protective effect of forests at a medium-size catchment level (O’Loughlin, 2005). Operational and/or economic objections to small coup harvesting are similar to those for partial harvesting, since capital costs of roads for first-rotation forests, and costs of operation shifts and set-up are higher compared to large-coup clearfelling. In order to achieve the desired effect of reducing the “window of susceptibility” a common practice in North America is the spatial and temporal arrangement of harvesting operations where “adjacency constraints” are in place. These constraints prevent a stand from being harvested before all adjacent stands are well established and “free to grow” which usually means having well developed root systems as well;
- Use of coppicing species or mixed species. - The advantage of coppicing species is that the root-reinforcement effect of trees is retained after clearfelling, although the “umbrella effect” is lost until the canopy re-establishes itself. This system has received little attention in New Zealand plantation forestry, although coppicing willows and poplars are widely used on farms for erosion control plantings in moderately erosion-susceptible pastures (Wilkinson, 1999). Coast redwood is often mentioned as a candidate species for this type of silviculture in New Zealand plantations. There are no examples of coast redwood being managed under a clearfell/coppice system in New Zealand, although it is widely reported in the natural range of this species in California (O’Hara et al. 2007). If change of species is contemplated then critical mass is required in the market – large amounts of successfully established plantations in relatively compact transport radii for other species to be considered.

# International study tour

As part of the review, a party of 4 people with different background and expertise (erosion processes scientist, forest engineering scientist, harvest systems researcher and an industry representative with environmental management background) completed an overseas study tour in early April. There were 4 countries identified as relevant to the project objectives: Chile (similar terrain, forestry practices and species), Germany, Italy and Switzerland all of which have steep terrain, advanced forest harvest and engineering technology, yet different silvicultural systems and hazard planning processes. In each country a similar protocol was followed – a standard questionnaire was presented to our host organisations and discussions were held followed by field visits to relevant sites.

## CHILE

In Chile the two biggest forestry companies were visited (Arauco and Forestal Mininco) in two distinctly different regions of the country. The problem of significant landslides and debris flows did not exist in any of the regions we visited. They do have sensitive soils, similar to New Zealand (weathered granites similar to Separation Point) as well as steep and broken terrain. Although annual rainfall (1200 to 1900 mm/yr) was comparable to some regions in New Zealand, extreme events in rainfall may be 60 mm/24 hrs. Some of the observed practices were:

- A lot of effort in good roading and landing construction practices to reduce sediment into waterways; aim to reduce the road density per area;
- LiDAR is being used extensively for planning and reconciliation purposes;
- They exclusively use multi-span harvesting systems with intermediate supports (Figure 30 a, b, c). Only “gully-to-ridge” harvesting setup is used and no extraction through riparian zones which are a permanent feature and are protected;
- High utilisation of woody material and little roundwood residue left behind – birds nests mainly branches and no mud incorporated into them;
- Strong efforts in reducing impact on soil disturbance during harvesting – in some places trees were felled across the slope to create a protective “corduroy” and extract trees on top of that; no aerial herbicide application and blanket dessication before planting.
- They have regulatory clearcut restrictions in place (500 ha) and companies have self-imposed restrictions of 200 ha;
- Management plans for each forest is prepared and in place well in advance of operations, and there is larger number of regulatory staff.

Figure 30 a, b, c: Chilean harvesting: “gully-to-ridge” setup around riparian zones (A); an intermediate support jack (B); a birdsnest of woody residue made up mainly of branches (C).

## GERMANY

In Germany the state owned forest management office ForstBW landesbetrieb was visited in the Southwest region of the country in the Black Forest. The aea has thin soils over sandstone or granite bedrock which can be fragile. Annual rainfall was approximately 2200 mm/yr in that region with rare extreme events of 60 mm/24 hrs. The terrain is steep to very steep with an extensive roading network in place. Some of the observations include:

- Any forest over 80% slope is exclusively for watershed protection and recreation and timber harvesting is secondary;
- Continuous cover forestry is the silvicultural system of choice with partial or selective tree harvesting using sophisticated cable logging as well as ground based equipment (Figure 31 a, b, c, d). Some of these machines have state-of-the-art engineering technology for semi-automation and ergonomic comfort for the operator;
- State-owned research and development centre with own harvesting crews for trialling new equipment and systems;
- Very low labour requirements in these types of harvesting operations as well as landing space requirements;
- Great effort is put into soil conservation and any heavy equipment in the forest follows designated tracks with branches and tree tops laid on top of the soil before traversing the terrain;
- Ongoing research trials to quantify impact of harvesting systems on erosion.

Figure 31 a, b, c, d: German harvesting: “gully-to-ridge” cable harvesting corridor (A); a truck mounted yarder with an integrated processor arm (B); a tethered wheeled (C) and tracked (D) harvester-processor. I note this looks like very easy terrain apart from perhaps A

## ITALY

In Italy the state owned forest management office for the provincial forest of Trento was visited in the Northeast region of the country in the Alps. They have thin soils over Porphiric bedrock or Dolomites which can be fragile. Annual rainfall ranged from 1200 mm/yr to 1800 mm/yr in the region with extreme events occurring relatively frequently the largest one of which was recorded at 700 mm in 7 hours. Terrain is steep to very steep with an extensive roading network in place. Some of the observations include:

- Any forest over 80% slope is primarily for watershed protection and recreation and timber harvesting are secondary forest uses;
- Social and cultural aspects of forests recognized and valued;
- Continuous cover forestry is the silvicultural system of choice with small coupe harvesting (Figure 32 a, b, c, c). Any larger clearcuts only for sanitary purposes to prevent disease outbreaks;
- Mainly multi-span harvesting with the use of intermediate supports;
- Huge effort in storm water control and debris flow control;
- Natural regeneration primarily chosen with small areas planted if necessary;
- Focused management on flood protection;
- Generous subsidies from EU initiatives for uptake of newer, safer and more productive harvesting equipment.

Figure 32 a, b, c, d: Italian observations: "edge-effect" cable harvesting (A); a substantial debris capturing structure (B); partial cut opening to enable natural regeneration (C) and cable harvesting corridor (D).

## SWITZERLAND

In Switzerland the state owned forest management office for Canton of Lucerne was visited in the Central region of the country in the Alps. The area has thin soils over granite bedrock which can be fragile. Annual rainfall ranged from 1800 mm/yr to 2200 mm/yr in the region with extreme events occurring relatively frequently. Debris flows have occurred regularly in the history of the region and the Swiss are very aware of this issue. Terrain is steep to very steep and in addition to debris flows avalanches, rock falls and floods are identified hazards. Some of the observations include:

- Any forest over 80% slope is primarily for watershed protection and recreation and timber harvesting occurs as a secondary income source. In addition, a standardized science-based approach is followed to identify areas of forests that are crucial in providing protection from a natural hazard and delineate them as protected;
- Social and cultural aspects of forests recognized and valued;
- Continuous cover forestry is the silvicultural system of choice with small coupe or corridor harvesting (Figure 33 a, b, c, d). Any larger clearcuts only for sanitary purposes to prevent disease outbreaks;
- Mainly multi-span harvesting with the use of intermediate supports;
- Extensive research into risk assessment, tree root development and characteristics;
- Focused management on slope stabilization through species selection.

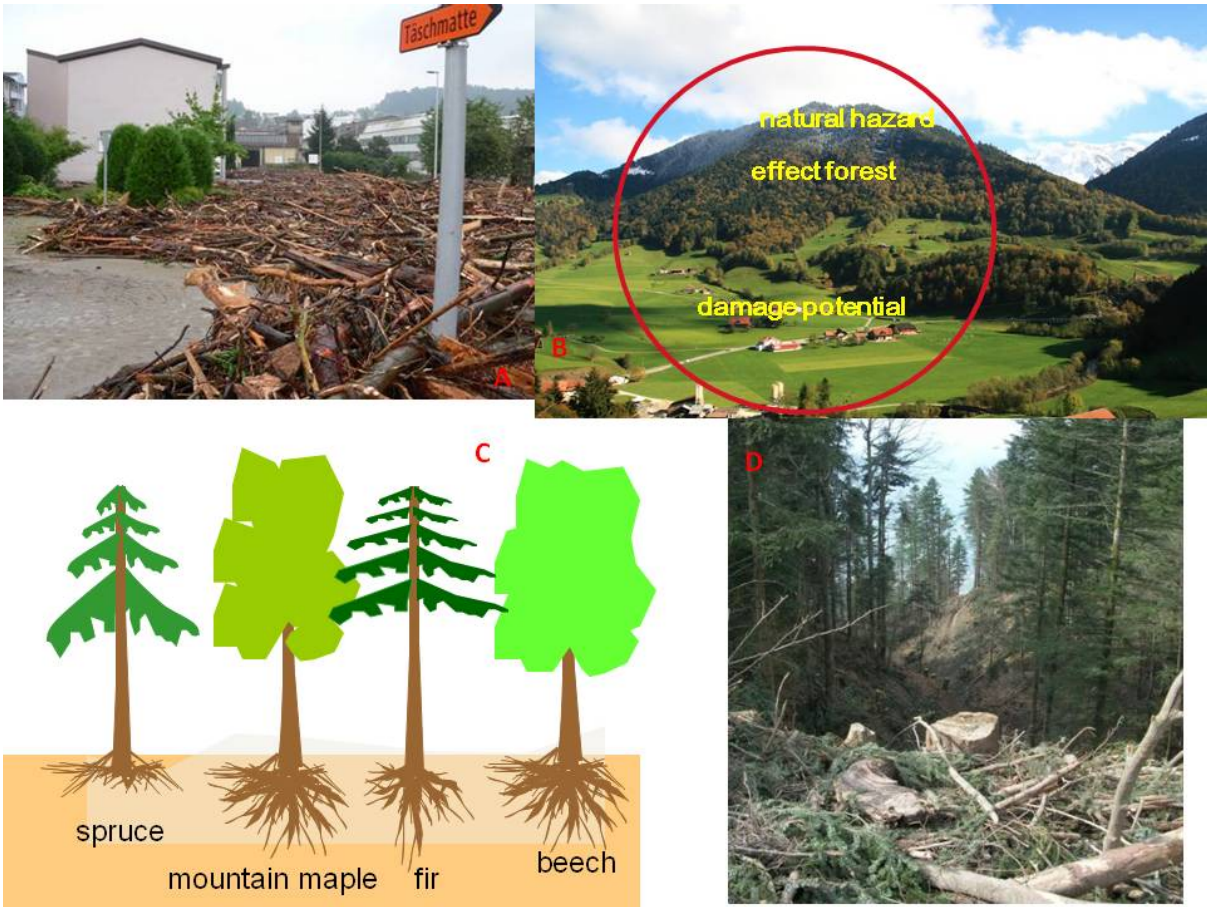


Figure 33 a, b, c, d: Swiss observations: Debris-flow in a major city (A); approach identifying protected forest (B); understanding of tree root characteristics (C) and cable harvesting corridor (D).

## KEY LEARNINGS

The overseas study tour provided the opportunity to acquire a better understanding of the problem and the way those countries dealt with it. Generally the European forestry situation is that:

- The forests are all basically their native forests. They have existed “free”, there are no costs of establishing and growing the forest thus there has been no investment capital tied up in “creating the forest”. Making a profit is thus purely a cash flow driven calculation;
- Harvesting the forests over very many years (generations) plus two world wars has led to extensive creation of at least “primary roading” - the networks have been established and the costs sunk. Other than maintenance and new small shunts to access parts of the total landscape, the capital infrastructure is covered and again doesn’t come into the equation. Also most forests are part of a very big picture which is largely that of a near normalized forest (continual annual production).
- Very low rates of return are accepted and sometime zero or negative remain acceptable because of the other values attributed to the forest - a very different situation to NZ. On top of that there are many “in-built” subsidies and incentives in these areas to provide or add to the services created by the forest and in some cases in publicly owned forests the wood value simply defrays the magnitude of the costs of providing the other services.

In relation to the issue of shallow landslides and debris flows, some of the key points were:

- Clearfelling substantial continuous areas does not necessarily cause landslides and debris flows – in Chile clearcut areas of 200 ha had no history of widespread landlides and debris flow problems; they simply did not experience intense rainfall events such as those frequently measured in New Zealand;
- On the other hand, if intense rainfall events occur, even continuous cover mature forests do not provide ultimate protection against landslides and debris-flows – Italy and Switzerland experienced such events on a "regular" basis.
- Protecting the soil and minimising disturbance during harvesting and other in-forest operations seemed to result in improved erosion and sediment yields and seen as good practice by the public and regulatory authorities;
- Multi-span skyline systems and permanent protected riparian areas with mature trees were economically feasible in Chile using radiata pine and clearfelling as systems of choice. These would likely be seen as good practice by the public and regulatory authorities in New Zealand in highly landslide susceptible areas of New Zealand as well as provide reduced soil disturbance and debris-flow capturing capabilities (several workshop participants in New Zealand shared the view that mature trees can successfully act as debris-flow capturing structures at the right locations).
- Wide-spread "blanket" herbicide application (desiccation) is not practiced in those visited countries. Thus even when clearfelling larger areas, there is a continuous occupancy of live plant roots in the soil providing continuous root reinforcement and evapotranspiration and possibly resulting in gradual build-up of soil organic matter.
- High utilisation of woody material results in reduced amounts of woody residue left on site and in vulnerable positions for potential mobilisation and forming of debris-flows. Even with clearfelling and "birdsnesting" the lack of larger roundwood material and no incorporated mud in those birdsnests seemed to be crucial in preventing them from failure.
- Continuous cover of mature forests provided sufficient protection in areas previously experiencing flooding, severe erosion and debris-flow problems. Some tree species develop "better" root systems for providing improved slope stability than others and research is needed in New Zealand to investigate those differences.
- Good understanding of high-risk areas and thresholds through risk-assessment systems is vital in decision making for mitigating the risk of debris-flows. Such understanding would result in better informed management and evaluation of alternatives – economically and technically; substantial debris capturing and retention structures are expensive and careful consideration of their location and size is crucial in achieving the greatest impact.

## Alternative options for plantations on erosion-susceptible land in New Zealand

### PARTIAL CUT THINNING OPERATIONS TO MAINTAIN CONTINUOUS COVER

Continuous cover forestry helps to reduce landslides and associated debris flows due to the inception of heavy rain and tree root structures giving strength to soil. Both Germany and Switzerland practice continuous cover forestry with selective tree harvesting while Italy employed small coupe harvesting thus maintaining continuous forest cover over the large-scale landscape. Both countries have at some stage during the previous century denuded much of their forest lands for economic benefit. As a result both countries had suffered severe erosion and flooding and Government has implemented plans to replant erosion prone land primarily for protection. Today those forests are being harvested in a manner that leaves much of the forest intact. Steep country is harvested in narrow corridors with cable systems often over intermediate supports. Low volumes per hectare are taken during any one year's harvest. The objective of such harvesting is to ensure not only continuous cover but also that the remaining forest resembles as near as possible the natural forests. Switzerland in particular had researched and understood which trees provided the best root structure for soil strength. This research used in conjunction with LiDar was allowing soil strength mapping to identify high risk areas of the forest (density of trees and the expected interaction of trees roots). In Germany the steep country harvesting approach was similar but was focused on reducing sediment yield from the forest.

This approach is possible in New Zealand but would not relieve the immediate problem (near future) of debris flows. Forest instability in relation to wind damage is increased by thinning late and forest managers will try to thin prior to the age of 12 for this reason. Removing some trees at maturity could result in an increase in wind damage susceptibility (reference?). The volume extracted in anyone year would therefore need to be low to avoid reduced forest stability, how low would require trials to be developed. The implications of a continuous cover approach to forest management and the associated restriction on harvest volumes on forest profitability would be significant. To harvest the same volume from a forest area would require a greater network of roads. A huge investment in additional road construction would be required for a short period of time which would result in many steep country forests being non-profitable until such a time when the road network was in place. Harvesting small volumes would also have a negative impact on harvesting cost, again how much impact would need further investigation.Eventually, after successive thinning operations the whole area would be clearfelled to ensure the trees do not grow too old and degrade as a result. At clearfell the same period of exposure/vulnerability to storm events causing mass soil movement and associated debris flows would still exist and therefore the risk is the same, just delayed. While continuous cover could help in moderate storm events, it may not help in the severe storm events (>250mm/24hours?). The underlying risk of moving to such a regime would be the requirement for large investment in forest road construction and the potential environmental impacts of building more roads for a short to medium time horizon.

## SMALL COUPE HARVESTING

Reducing the size of clearcuts could reduce the severity of landslides in any one catchment. The study tour visited the mountainous regions of Trento in Northern Italy and specifically the Fiemme and the Fassa Valleys. The forested area of the region was large. The Fiemme valley for instance produced only 100,000 $m^3$ of sawlog per year, barely enough to keep local sawmillers supplied with logs. This regions harvest came from small 500 $m^2$ coupes. Small coupe harvesting and in some cases corridor harvesting came about by the need to maintain a homogeneous landscape with no large visual breaks; however the area did suffer from windthrow events which resulted in much larger areas of harvest. Wind damaged areas were harvested to avoid insect infestation. The small coupes were in most cases left to naturally regenerate due to the cost of replanting. There was no evidence of landslides from these coupes although the region had a history of landslides and debris flows. Many of the streams and rivers in the region had structures to capture debris, some of which were over a century old.

Small coupe harvesting methods have been used in New Zealand in the past. In the Bay of Plenty region for example Stanley forest, at the time managed by Tasman Forestry, obtained one of the first 10 year consents for harvesting incorporating the Wainui Stream catchment which flows directly into Ohiwa harbour. The 350 hectare catchment was harvested over a 10 year period. No neighbouring coupes were harvested in successive years. To harvest in such a way the roading infrastructure was built 5 years in advance of harvesting in one year and the forests productive volume was reduced to approximately 1/10th of what it could have been based on age class. With the eventual sale of the forest to overseas investors the new owners wanted to cut the maximum level possible on an age class basis which resulted in large clearcut areas. Currently PF Olsen Ltd in their higher risk coastal forests of eastern Bay of Plenty is now using a coupe style of harvesting to try and reduce the number of landslides and consequent debris flows.

The downside of small coupe harvesting is a greater network of roads are required to be built in the short term and maintained for longer which has major implications on net stumpage and in marginal forests such as those in the eastern Bay of Plenty or the east cape region of Gisborne could well result in negative stumpages, until such a time as the roading network is in place. A change from current transport systems (i.e. to purpose built transport systems for steep country low quality roads) could negate the need for expensive road construction, however further investigation of such systems would be required. A change to in-forest transport systems would impact the whole supply chain.

## UPHILL EXTRACTION FROM GULLY TO RIDGE

Baillie (1999) reported that for cable harvesting operations, planning to maximise the use of skyline systems, carriages, and gully to ridge extraction were commonly cited by respondents as a means of minimising entry of logging slash into streams. Full or partial suspension of loads across the stream and directional felling (cross-slope, back from stream edge, directly across with full stem extraction) were the most common practices used during harvesting. Uphill extraction from gullies to ridge reduces the amount of woody debris being swept into gully bottoms when extracting trees across gullies. Reducing the amount of debris in gully bottoms reduces the risk of that debris being mobilised in storm events. The Chilean cable harvesting operations were all uphill extraction and rarely were trees extracted across gully bottoms. Forests in Chile have substantial riparian areas, mostly in gullies. These riparian areas were fully protected and at no time could harvest extract through or over them. Restricting extraction to the near face often results in limited deflection and therefore limits the amount of volume capable of being extracted per cycle. In Chile the lack of deflection was an issue for all cable harvesting operations. Intermediate supports to keep the skyline off the ground were always used to overcome the deflection issues. Using intermediate supports allowed gully to ridge extraction and avoided any need to damage riparian areas. Intermediate support trees did not need to be topped in Chile making the rigging-up time quick.

In New Zealand intermediate supports are not often used due to the rig up time, the need to top the tree, the lack of carriages capable of operating over intermediate supports, the lack of skills to rig intermediate supports and the reduced payload that are consistent with intermediate support systems. More common in New Zealand is to track into a difficult area to site the hauler and then 2-stage the trees back to larger processing areas using skidders and bulldozers. This harvesting method results in more earthworks but more productive extraction. To move harvesting operations to gully to ridge extraction without the use of intermediate supports requires a solution to the deflection issue. With a move to gully to ridge systems without intermediate supports there is still a need to anchor the skyline on the opposing face invariably through standing trees to obtain suitable deflection. Rigging-up through standing trees increases the time to rig-up and therefore can result in lower productivity and thus higher cost. Research into alternative cable harvesting systems to provide solutions for deflection limited areas is currently underway as part of the Future Forest Harvesting Research programme. However more research is required to develop higher productivity systems using intermediate supports. The downside of gully to ridge harvesting is a greater density of roads and the environmental impact this could have and the lower productivity as a result of reduced deflection.

## CHANGE/IMPROVE HARVESTING METHODS

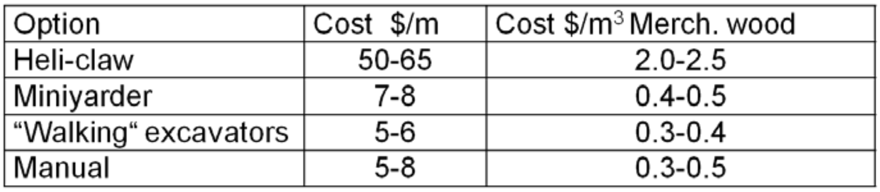
If clearfelling of large areas is to continue as a silvicultural regime of choice then harvesting methods will have to be changed in the areas most susceptible to landslides and debris flows leaving the forest boundary. In order to reduce the risk of woody residue getting mobilised into debris flows and causing damage downstream the most logical approach is to reduce the amount of woody residue left on site or at least in vulnerable areas. There are two ways of achieving this: continue current practices and clean up after harvesting is finished, or reduce the generation of woody residue and waste by either reducing breakage during felling and extraction.

Breakage during the tree felling process on steep slopes can be reduced by directionally felling the trees across the slope or uphill. With manual felling this poses many difficulties and safety hazards. Mechanical tree felling wherever possible should assist in achieving this goal. In order to reduce breakage during extraction probably the best alternative would be to fully suspend trees and avoid collisions and log drag – with the current systems used in New Zealand deflection would not be sufficient to achieve that. Any of these practices would most likely reduce productivity and thus increase the cost of harvesting on steep slopes.

Woody residue cleaning from streams is an important issue for the industry. Current methods can be difficult, hazardous, ineffective and expensive. Burning is an option that has been practiced before, and is certainly permitted in some regions of the country. Due to fire danger, air quality concerns and timing burning may not be effective or even permitted. Amishev (in press) presented some potential options and based on simple cost calculations (Table 11) there may be more effective and safer methods for removal of slash from streams. An assessment trial should be conducted involving one of these “walking” excavators to investigate their suitability for removal of slash from streams and gullies on steep terrain. There are some issues to be considered:

- Despite their light weight (less than 10 tonnes) regional council consents would be required for machines working in streams;
- In very steep areas, access may be limited, even for these machines which can be equipped with a winch;
- In steep V-shaped creeks they may not be able to reach above flood level.

Table 11: Options for slash removal from streams compared to manual removal (Amishev, in press).



| Option | Cost $/m | Cost $/m$^3$ Merch. wood |
|---|---|---|
| Heli-claw | 50-65 | 2.0-2.5 |
| Miniyarder | 7-8 | 0.4-0.5 |
| “Walking“ excavators | 5-6 | 0.3-0.4 |
| Manual | 5-8 | 0.3-0.5 |

## GREATER UTILISATION OF WOODY BIOMASS TO REDUCE WOODY RESIDUE ON SITE

Removal and utilisation of available volumes of biomass does not seem to be cost-effective under current biomass pricing and renewable energy policies and current extraction systems (Ximenes et al., 2012). In New Zealand, there are “barriers to the utilisation of forest harvest residue resources” such as cost, quality, and security of supply (Hall 2009). A 57% increase in the value of bioenergy is required to enable bioenergy to compete directly with pulp and paper and particle board manufacturers. A market for biomass harvesting residues on sites that require stacking and windrowing would directly save $500/hectare (Ximenes et al., 2012). Current markets are not expected to change in the short term (1-3 years), however in the medium term (4-10 years) projected growth in the demand for bioenergy and biofuels is likely to be sufficient to make it cost-effective (Ximenes et al., 2012). According to Childerstone (2012) the New Zealand wood energy market is showing good prospects and potential savings of up to 3x the costs can be made by the use of woody biomass in chip form compared with LPG, diesel and electricity in Dunedin. He describes that there are two principle wood chipping businesses in the region, sourcing residue after harvest operations and supplying chip fuel for local commercial boilers. Both businesses rely on European made chippers.

## SUBSTANTIAL DEBRIS CAPTURING STRUCTURES

The overseas study tour observed many debris trapping structures in beds of streams as these were used extensively in Italy. Due to the lack of flat land in northern Italy many towns were built on flood plains. To reduce the impact of floods on these towns, flood protection structures had been built. The northern Italy region understood that they couldn't manage storm events or stop landslides or debris flows and therefore protected their towns with flood control and debris capturing structures. All the debris capturing structures could be accessed with excavators to allow maintenance. Most of the observed debris structures were clearly performing their objective of reducing water velocity which was reducing the ability of water to carry sediment or debris. One site viewed in northern Italy was capturing thousands of tonnes of sediment annually and any associated debris. The downside of these structures was they were impassable to fish. Fish were liberated in areas of the streams used for fishing. Flood control and debris capturing structures would be applicable to the New Zealand forest situation. Debris capturing structures such as check dams or debris traps could be designed and built for minimal cost but in some forests would need to be substantial. A drawback to such structures in the resource consent process required to be undertaken prior to any works beginning. Regional councils would need to agree that placing debris in waterways is not an offence but a risk associated with forestry in steep country, as long as the risk is minimised through good management.

## PUBLIC VS PRIVATE BENEFIT FRAMEWORK

The problem with landslides and debris flows from steep forested land is by no means a new phenomenon in the New Zealand landscape – natural indigenous forests and exotic plantations alike. It is a complex issue requiring action from all involved stakeholders – private industry, government and the public as a whole.

In regards to exotic plantations, in many situations the location of steepland forests is distant from processing and export facilities and that has a significant implication for total costs. Also the hill country and steeplands were often planted for reasons other than timber production (AGS and ECFS) and they are now considered almost exclusively as timber producing forests. Large areas of unsustainable land under current pastoral farming regime would probably require some form of future forest establishment. If investors are to be brought in for that, they would need maximum certainty that they will get to harvest any tree crop they plant. Such forests/plantations would provide the benefit of avoided erosion and flooding and debris-flows as well as recreational values to the public. For the private owner, however, this may not be economically feasible.

The Public Private Benefits Framework (PPBF) (Figure 34) describes the common approach for interpreting the relationship between public and private benefits (Engel et al 2008; Pagiola and Platais 2007) and expands to identify the appropriate policy mechanism for encouraging more sustainable outcomes based on this relationship ( Pannell 2008; Pannell 2009). Policy choice is made through a consideration of the likely net public and private benefits that may arise from land use changes. The current practice is indicated at the zero-zero point of the framework. This is because the framework is designed to evaluate projects that seek to move people away from the current practice. In fact, by setting the zero-zero point to current practice, the framework allows us to analyse whether the private land owner involved will be made better or worse off from a land use change, and whether the public will be made better or worse off. The various potential combinations of public and private benefits from a land use change generate a number of situations that lend themselves to specific policy instruments.

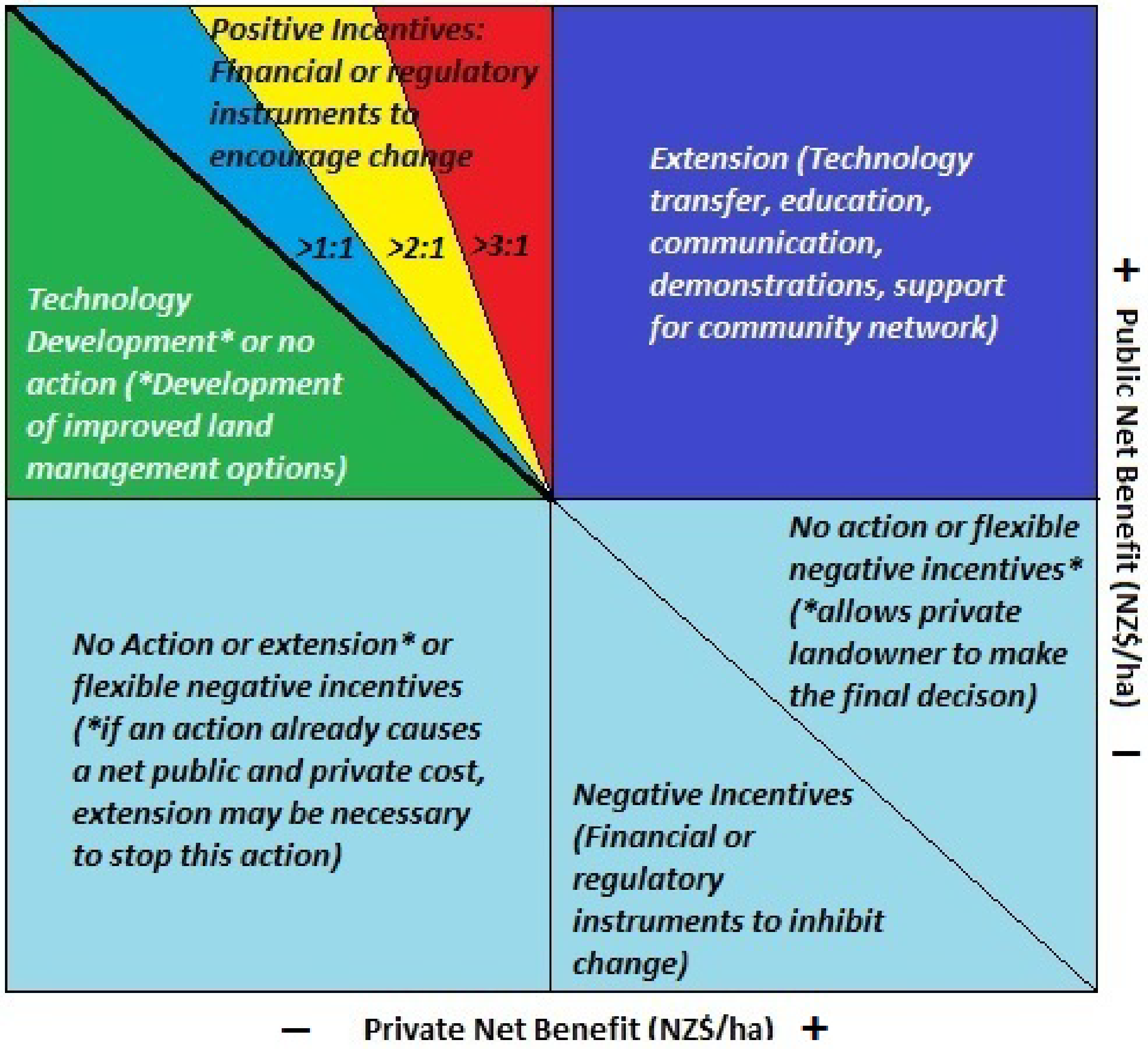


Figure 34: The Public Private Benefits Framework for identification of appropriate policy mechanisms (Pannell 2009).

# Discussion

In steepland plantation forests the worst storm-related damage occurs post-harvest. There are few examples of studies that have quantified the extent and type of landslide damage on harvested slopes or have endeavoured to relate the damage to slopes harvested at different times. Even fewer reports have attempted to quantify sediment volumes generated by different erosion processes during a single storm event (e.g. Marden and Rowan 1995).
Most post-harvest storm damage assessments are by company personnel and consist of a file note containing photographs and brief descriptions of the damage. A number of storm damage assessments carried out in recent years by independent consultants have attempted to establish relationships between the type and location of damage to site factors including geology, slope angle and aspect, to stand age and density and to infrastructure using observational and photographic data only (Phillips and Marden 1996, 1999, 2011; Basher 2010). At present the paucity of good quality quantitative data collected in a methodical and consistent way precludes establishing robust relationships between rainfall characteristics and on-site factors

that may alleviate or exacerbate the severity of damage sustained to a forest during extreme rainfall events.

Assessment of the literature indicates that post-harvest landslides and debris flows on steep erosion prone land subject to intense rainstorms cannot be avoided entirely. Historically roads and landings were regarded as primary sources of landslides in harvested forests that transformed into debris flows. However, attention in recent years to better infrastructure design and construction implemented through improved training and the use of codes of practice and guidelines has seen these sources decline significantly. In most situations, landslides occur on slopes within the cutover that have no connection to infrastructure.

The unique combinations of soil accumulation/weathering, time, and other factors contribute to a locality's pre-disposition for failure at a certain threshold condition. The marginal stability (factor-of-safety) of that locality may exist while the tree is growing but falls below the conditions for failure once the tree is removed. Failure is then imminent when conditions reach those critical for failure. This explains why small shallow landslides are observed in the first year following tree removal in conditions that are not related to rainfalls of high annual recurrence intervals. If a storm with an ARI of greater than 20 years occurs in the first 8 years after harvesting, then many localities have a high probability of failing. This is similar to the landscape response in pasture-covered landscapes on similar geology and slope steepness. How many landslides have the potential to transform into channelized debris flows is unknown and likely to be difficult to predict, but there is an urgent need to improve our predictive ability.

As it is not possible to completely avoid slope failures and debris flows following harvesting even with risk management and good management practices in place, the forest industry should develop a consistent set of protocols to deal with the consequences should an event occur. This could include rapid response to clean-up, proactive communication with neighbours and the media, implementation of remediation plans for any infrastructure that is damaged. Many forestry companies will already have some of these activities included as part of their environmental management systems (EMS).

Based on what was observed in the countries visited during the benchmarking study tour, there seems to be the potential for at least two possible trajectories for future forests that have a production element on steep erosion-prone land. One sees a continuation of the current "corporate" forestry model of mostly larger-scale "mono-cultural" commercial plantation forests. The other could see the development of smaller-scale forests that might be managed as continuous cover forests (single or multiple species), multifunctional forests (ecosystem service forests), or approaches similar to many farm forestry activities seen in many parts of New Zealand. In the second "type" of forest there is likely to be more species diversity with "forests" or groups of trees occupying landscape niches within a pastoral agricultural system that target land not directly suited to pastoral agriculture. The wood produced could be high value single trees for specialist markets or for use on the farm itself. Harvesting would likely be on a single tree or group section basis and in many cases the timber would be sawn on the property. This type of forestry would not require substantial investment in roading or earthworks and may be able to use smaller less capital-intensive forms of harvesting technology. A further possibility exists for land that has a high risk of debris flows. Areas identified as being of high risk of landslide-debris flows on steeplands could be "abandoned" and allowed to revert to scrub and or native forest. Weed control and some management may be required for this option to succeed.

Whichever forest "type" is followed, there is a clear need to establish more trees or maintain/replace existing tree cover on New Zealand's erosion-prone hillcountry landscapes to prevent or minimise the occurrence of shallow landslides. However, these types of forestry may not meet the economic criteria for commercial plantation forests and may require incentivising at least initially to target the most critical areas within a region, something like Horizons approach with its SLUI programme or the East Coast Forestry Project.

There has been no research in New Zealand evaluating the likely effectiveness or economics of alternative silvicultural or harvesting options for steepland forests. This can only be assessed through a modelling approach as has been used overseas. Dhakal and Sidle (2003) modelled the impact of different management practices (four sequential clearcuts and partial cuts with variable rotation lengths with or without leave areas and with or without understorey vegetation) on landsliding. Partial cutting produced fewer landslides and reduced landslide volume by 1·4 to 1·6 times compared to clearcutting. Approximately the same total landslide volume was produced when 100 per cent of the site was initially clearcut compared to harvesting 20 per cent of the area in successive 10 year intervals; a similar finding was obtained for partial cutting. Vegetation leave areas were effective in reducing landsliding by 2 to 3 times and retaining vigorous understorey vegetation also reduced landslide volume by 3·8- to 4·8-fold. This type of modelling provides a guide to the best alternative for minimizing landslide occurrence in managed forests but needs to also be combined with economic analysis.

## Conclusions

- About one third of the New Zealand plantation forest estate is located on erodible steeplands with many of the forests having originally been planted as protection forests. For most of the forest rotation these forests provide a high level of slope stability and reduce erosion from landsliding and other processes.
- When forests are harvested, landsliding risk increases considerably. There is a long history of landslides and debris flows associated with rainstorms following forest harvesting in New Zealand, especially in Northland, Coromandel, Bay of Plenty, Gisborne-East Coast, and Nelson-Marlborough. These events also occur in pastoral farmland and indigenous vegetation. The trigger for these events is rainstorms typically with a >10–20 year annual recurrence interval.
- The hill country and steeplands were often planted for reasons other than timber production (AGS and ECFS) and they are now considered almost exclusively as timber producing forests. As ground based machinery become increasingly dangerous and less productive to operate on steep terrain (> 45% slope); cable extraction of stems still remains as one of the only viable options for harvesting.
- In the past roads and landings were significant contributors to post-harvest erosion. Although not well quantified it appears that improvements in forest engineering have substantially reduced the incidence of landslides associated with roads and now most originate on the clearfelled slopes.
- In NZ, a variety of harvesting systems is used, but they are largely typified by hauling from ridge to ridge using skyline systems or variant thereof to maximize reach with minimum roading (a major source of erosion and sedimentation) and to maximize deflection and hence payload and productivity. Most of the machinery is based on relatively old American technology.
- Because of the rigging configurations most frequently used in New Zealand, during harvesting operations, the so called “sweeping” occurs where broken tops and pieces from the felled trees are swept into the gully bottom leading to substantial accumulation of woody residue in these places.
- It will not be possible to completely avoid slope failures and debris flows following harvesting. The future focus should be on improving risk assessment and management, and implementing best management practices to reduce the incidence and consequences of these events. This may involve a combination of use of on-site landslide hazard zoning in planning forest replanting, and off-site management to reduce the consequences of landsliding and debris flows. The forest industry should

also develop a consistent approach to dealing with the consequences should an event occur.

- Many regional councils have developed Erosion and Sediment Control guidelines for forestry operations while the forest industry has developed an Environmental Code of Practice for Forestry Operations and a Road Engineering Manual. These largely focus on erosion and sediment control for forest infrastructure and provide less guidance on how to best manage the clear felled slopes. Some companies have started to develop operational level hazard identification and risk management approaches to try and better manage the risk of landsliding, woody residue mobilisation and debris flows. Further work is required to develop improved quantitative hazard identification and risk management methods that can be widely applied.
- Under the current situation, there are a number of strategies that can and are being employed increasingly by industry that will assist in reducing the risk at the margin.
- Incorporation of woody residue into landslides is a major contributor to the off-site effects of debris flows from forests. Management of post-harvest woody residue is complex with a balance needed between retaining woody residue for its beneficial effects and avoiding the adverse effects in large storm events.
- Riparian setbacks, unless they were very wide, are likely to have limited impact in reducing the effect of landslides and debris flows.
- Slash traps have been recommended to manage the offsite effects of woody residue mobilisation. They require a method for identifying alluvial fans below areas with a significant risk of woody residue mobilisation and debris flow generation and preliminary research has identified a possible method that needs to be more widely tested. Little information is currently available on the effectiveness of slash traps.
- Overseas, as a result of previously denuding their mature forests, some countries had suffered severe erosion, flooding, and debris-flows and their governments have implemented plans to replant erosion prone land primarily for protection. In Europe, the majority of steep terrain forests have been there for many generations and no intial forest establishment cost is considered. The roading network has been largely in place for the same reasons and the costs sunk.
- Alternative management practices that might be considered are:
    - Partial cut thinning operations to maintain continuous cover
    - Small coupe harvesting
    - Uphill extraction from gully to ridge
    - Improved harvesting methods (less breakage and ground disturbance)
    - Greater utilisation of woody biomass to reduce woody residue on site’
    - Substantial debris-capturing structures
- If change of species is contemplated then critical mass is required in the market – large amounts of successfully established plantations in relatively compact transport radii for other species to be considered.
- Any additional requirement and effort that may lead to reduced landslide or debris flow risk in New Zealand steep landslide susceptible areas would likely increase the cost of the delivered logs making forest plantations unsustainable in such areas. On current costs and current overvalued rural land prices, plantation forestry cannot meet the hurdle return of about 8% normally required by overseas investment capital. It is particularly important to point out the significance of discounting and discount rates when considering change of species, longer harvesting rotation periods and partial cutting regimes (greater amount costs incurred for roads and infrastructure built up front and carried over extended periods).
- The current commercial investment model for plantation forestry is all about achieving a rate of return and without certainty in achieving that investors would likely be deterred from investing in forestry in such areas. Under this model there will

likely be no new afforestation in steepland areas of New Zealand so areas that are subject to the ongoing risks of the effects of large scale erosion will have to face the consequences of that (i.e., floods, debris, productive land inundation, and redundant infrastructure, e.g., stop banks, bridges, and beds' aggradations, etc.

## Recommendations for future investigations

There is an urgent need to begin to collect data on the occurrence of post-harvest storm-induced landslide-debris flows, rainfall and any forest management conditions (ie. roading or landing related) that triggered them, what was affected, and what the costs were to remediate any damage caused. This needs to be carried out as part of a consistent national monitoring programme with clearly set methodology and criteria and a simple process to record this data and report at both a regional and national level.

Establishing regional landslide thresholds from knowledge of past events and from company records could begin to be assessed, but to be effective in the long term will need additional data from a national monitoring programme outlined above. These rainstorm-geology-steepness-landslide threshold relationships are required to provide consistent quantitative assessment of risk for various regions of New Zealand where the issues are known and for regions where climate change predictions indicate future risk. This would then assist both forest managers and owners understand this additional element of their forests' risk profile and also assist regulators by providing a more evidence-based approach for setting policy and consent conditions/rules for the forest industry.

There is also a need to broaden the survey questionnaire used in this project to other forest companies and regional councils to obtain further data to gauge the national size of the problem and elucidate any mitigation measures being used that have not already captured.

Further investigations into suitable terrain hazard zoning or risk management approaches suitable for use at operational scales in New Zealand's landscapes should be developed to assist forest managers and harvest planners understand both the risk of landslide-debris flows and to help target suitable counter measures. Low-cost countermeasures should also be investigated.

Utilising information obtained from above should then be used in developing appropriate user-oriented tools and/or models that could provide a higher level of refinement and focus for defining critical conditions for specific local areas and accurately incorporate the effects of tree root reinforcement (eg SoSlope – Schwarz and Cohen 2011). These tools could begin to test alternative "future forests" for their ability to minimise landslides and debris flows.

Future research on silvicultural systems should focus on:

- Methods to promote and manage natural regeneration of indigenous forests on highly erosion-susceptible land;
- Methods to manage fast-growth species (radiata pine, eucalypts, acacias) as permanent forests which are resilient to disturbance, so that they can maintain enough biomass to be viable as permanent carbon reservoirs;
- More accurately characterising the site requirements of coppicing species such as redwoods and eucalypts, so that they can be successfully used on suitable erosion-susceptible sites;
- Further work in developing high production multi-span harvesting systems;
- Further research into partial-harvesting techniques for steeplands. This would include:

– The feasibility of machine felling and pre-bunching on steeplands, to facilitate extraction along skyline corridors while retaining an intact canopy;
– Growth and yield models for individual or group-selection silvicultural systems.

- Undertake detailed hypothetical economic modelling of an existing large forest to understand the true financial and commercial implications of new silviculture, harvesting techniques, species change. What are the key drivers that affect the return and by how much. Investigation into the ways those (extra) costs compare against the benefits provided by the forests vs competing land use models.

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# Appendix 1: Milestones

| | **Milestone description** | **Due date** | **Invoice GST excl** |
|---|---|---|---|
| **Milestone 1** | Provide a framework of the final report detailed methodology within one month of signing contract. | 21Jan 2013 | $15,000 |
| **Milestone 2** | Scope for review of national and international approaches for risk mitigation developed and information sources identified. Scope approved by MPI. | 28 Feb 2013 | $45,000 |
| **Milestone 3** | Interim findings from the review are presented at stakeholder workshops and feedback is collated. Structure of review document approved by MPI. | 15 May 2013 | $150,000 |
| **Milestone 4** | Review of best practice and possible mitigation options is completed. Draft report independently peer reviewed | 20 June 2013 | $45,000 |
| **Milestone 5** | Final report completed and submitted to MPI | 30 June 2013 | $45,000 |
| **Total** | | | $300,000 |

# Appendix 2: Overseas tour itinerary and questionnaire

03 and 04 April 2013 – visited Forestal Mininco in Los Angeles and Concepcion, Chile
05 and 06 April 2013 – visited Arauco in Valdivia, Chile
09 April 2013 – visited Forst BW in Forbach, Germany
10 and 11 April 2013 – visited Trento Forest Service in Trento, Italy
12 April 2013 – Forest Management of Canton of Lucerne in Bern, Switzerland

## International study tour of forest companies/state-regional forest owners

### Project Problem Statement

*Some current harvesting practices on steep erodible hill country in New Zealand may lead to significant environmental, social and economic costs if one or more severe storms occur in the first 3 to 5 years after harvest (regardless of whether the land is replanted in plantation crop, left to revert to pre-existing natural forest or converted to pastoral farming). If landslides occur after harvest, there is often an associated loss of soil natural capital on-site and mobilise sediment and woody debris into debris flows that leave the forest boundary causing damage to downstream infrastructure*

To improve management of this problem we will review the scientific literature to identify practices that can be used to reduce harvesting impacts, survey forest companies and regional councils to identify innovative approaches to managing this problem, and use an overseas study tour to collect information on international approaches to steepland forest harvesting that may be relevant to improved harvesting practice in New Zealand.

## Questions to be posed

### Recognition of problem

Is post harvesting landsliding and movement of woody debris from your forests a problem?
If so

1. Where (which regions of the country)

2. What experience have you had with this problem? Why was it a problem? Who was impacted?

3. Are the sources of woody debris mainly from:
   ☐ - natural forest (with/without some management)
   ☐ - plantation forest
   ☐ - failed landing/birdsnest
   ☐ - mobilised midslope woody residue
   ☐ - debris left in perennial/ephemeral water courses
   ☐ - other

4. What is the root cause of the landslides
   ☐ - natural extreme rain event
   ☐ - failed infrastructure (roads and infrastructure)
   ☐ - midslope/clearcut soil saturation and failure
   ☐ - concentrated runoff due to clearcut size
   ☐ - heavy machinery on steep slopes
   ☐ - other

5. What degree of engineering design goes into infrastructure (road, landing and stream crossing) design? Are runoff models available for flood design in steep headwater streams and what are

the design parameters – Q10, Q20, Q50? Are stream crossings required to pass debris flows (not stop them)?

6. Is peer-review required and is engineering sign off required by an in-house or independent suitably qualified forest engineer, or can a forester or technician do this work?

7. What qualifications are required of the person doing harvest planning? are foresters required to hold professional registration?

8. Are log sales done on a stumpage basis to third party log buyers or to independent harvesting contractors?

9. When the land owner has his own log supply chain or wood processing plant, is harvesting undertaken by in house (company) crews or by independent contractors?

10. In the cases of infrastructure related damage:
    ☐ - How much do you attribute to contractor “performance” or not following procedures?
    ☐ - How much do you attribute to contractor inexperience/lack of understanding?
    ☐ - How much do you attribute to insufficient on-site supervision by forestry personnel?
    ☐ - Would greater on-site supervision help to alleviate the problem?

11. AWhat is the land tenure on which you operate: State lease or rental (volume or area based tenure, duration of lease, annual rental), leased from indigenous peoples (ditto), private freehold nature or other.

12. Are harvest planning and forest infrastructure (road bridge landing & stream crossing) development costs deductible from rental, capitalised in year of expenditure or amortised over the life of the (road/bridge) asset?

13. What is the nature of regulatory regime under which forest roads are constructed and harvesting undertaken (prescriptive or effects based)

14. What is the impact of regulation on private land values and private property rights? Do regulatory takings occur (i.e. is land rendered unable to be used or tree crops unable to be harvested? What is the economic impact of this on land owners?

15. What role do Codes of Practice or Engineering manuals have in forest road construction, harvesting and slash management? What is the design storm or run-off event that these Codes aim to cope with (1 in 10, 1 in 50 year event?). Who developed these Codes, who provides operator training and supervision and what is the industry uptake?

16. Are there incentives, directives or subsidies to remove harvest residues to feed into bioenergy supply chains?

17. How are wind-thrown areas of forest managed and are logs salvaged? Are there tax or other incentives offered to recover wind-thrown logs when it is not economically viable to recover the wind thrown logs.

18. How are worker health and safety issues managed in relation to wind throw? Are wind thrown areas left because it judged too dangerous to send workers in to salvage logs? Who makes that Professional judgement on trade-off between Health & Safety and Environmental issues.

19. How are residual risks managed when residential or industrial development has occurred on fans or in flood plains downstream of forests zoned or scheduled for harvest? Is upstream land use constrained because of downstream land development?

20. How often do these events happen? Typically what is the recurrence interval of events that cause problems?

21. Do you keep any form of records of these events?

22. Where you required to do any remediation? What kind?

23. Were you fined/prosecuted?

**Managing the problem/risk**

1. Do you currently do any risk assessment to manage this problem?

2. Do you use a regional approach or a site-specific approach? What factors do you take into account and where do you derive the data to do this?

3. Do roading, harvesting, and silviculture personnel responsible for environmental compliance have equal input into risk assessments? ☐ - Yes
   If not, is part of the problem poor communication within the company or other?

4. Do you prepare an erosion and sediment control plan to specifically manage this problem? What do you use to guide preparation of this?

5. Do you undertake a risk assessment specifically of the potential for landslides mobilising debris flows? What do you use to guide preparation of this?

6. Do you put in place specific controls to reduce the risk of debris flows leaving the forest boundary? If yes, what are they? What techniques do you use?

7. If you use debris traps to manage the off-site effects of sediment and woody debris, how do you locate and design them?

8. Do you apply different silvicultural techniques to mitigate the problem?

9. What else do you do on a day-to-day basis to mitigate the problem?
10. How well is erosion and sediment control planning translated into practice by roading and harvesting crews? Is there a need for better training of these personnel?
11. Do you consider past problems when developing replanting strategies? If so, how?
12. Do you think the type of machinery and harvesting systems currently used are appropriate for the terrain in your region?
13. If not do you think this is contributing to post-harvest problems particularly slash management and the destruction of existing riparian set backs
14. Are you using any innovative harvesting systems to reduce the wood debris on the slope? What makes them special?

**Legislature/governance**

1. Are there national or local rules/legal requirements to manage site specific risks? If not what other source of reference material do you consult?
2. What additional information would help you better manage this risk?
3. Is there sufficient guidance about how to best manage residual woody debris?
4. Is there any guidance about where to establish and how to best manage riparian areas?
5. Are riparian setbacks obligatory in your forests?
6. Does your company/state/forest actively promote riparian setbacks or retirement options?

# Appendix 3: National industry and council interviewee list and questionnaires

PF Olsen,
Hancock Forest Management,
Jukken Nissho,
Ernslaw One,
Hikurangi Forest Farms,
Environment Bay of Plenty,
Gisborne District Council

## Problem statement

*Some current harvesting practices on steep erodible hill country may lead to significant environmental, social and economic costs. Postharvest, associated landslides cause loss of soil natural capital on-site and mobilise sediment and woody debris into debris flows that leave the forest boundary causing damage to downstream infrastructure*

To improve management of this problem we will review the scientific literature to identify practices that can be used to reduce harvesting impacts, survey forest companies and regional councils to identify innovative approaches to managing this problem, and use an overseas study tour to collect information on international approaches to steepland forest harvesting that may be relevant to improved harvesting practice in New Zealand.

## Questions - companies

### Recognition of problem

Is post harvesting landsliding and movement of woody debris from your forests a problem? If so

24. Where (which regions of the country)

    ______________________________________________

25. Are the sources of woody debris mainly from:
    ☐ - failed birdsnest
    ☐ - mobilised midslope woody residue
    ☐ - debris left in perennial/ephemeral water courses
    ☐ - other ______________________________________

26. What is the root cause of the landslides
    ☐ - failed infrastructure (roads and infrastructure)
    ☐ - midslope soil saturation and failure
    ☐ - concentrated runoff due to clearcut size
    ☐ - heavy machinery on steep slopes
    ☐ - other ______________________________________

27. In the cases of infrastructure related damage:
    ☐ - How much do you attribute to contractor inexperience?

    ______________________________________________

    ☐ - How much do you attribute to insufficient on-site supervision by forestry personnel?

    ______________________________________________

    ☐ - Would greater on-site supervision help to alleviate the problem?

    ______________________________________________

28. How often? Typically what is the recurrence interval of events that cause problems? Do you keep any form of records of these events?

    ______________________________________________

    ______________________________________________

29. What experience has your company had with this problem? Why was it a problem?

    ______________________________________________

    ______________________________________________

## Managing the problem/risk

15. How do you currently do risk assessment to manage this problem?

______________________________________________________________

16. Do you use a regional approach or a site-specific approach? What factors do you take into account and where do you derive the data to do this?

______________________________________________________________

______________________________________________________________

17. Do roading, harvesting, and silviculture personnel responsible for environmental compliance have equal input into risk assessments? ☐ - Yes

If not, is part of the problem poor communication within the company or other?

______________________________________________________________

18. Do you prepare an erosion and sediment control plan to specifically manage this problem? What do you use to guide preparation of this?

______________________________________________________________

______________________________________________________________

19. Do you undertake a risk assessment specifically of the potential for landslides mobilising debris flows? What do you use to guide preparation of this?

______________________________________________________________

______________________________________________________________

20. Do you put in place specific controls to reduce the risk of debris flows leaving the forest boundary? If yes, what are they? What techniques do you use?

______________________________________________________________

______________________________________________________________

21. If you use debris traps to manage the off-site effects of sediment and woody debris, how do you locate and design them?

______________________________________________________________

______________________________________________________________

22. Do you apply different silvicultural techniques to mitigate the problem?

______________________________________________________________

______________________________________________________________

23. What else do you do on a day-to-day basis to mitigate the problem?

______________________________________________________________

______________________________________________________________

24. How well is erosion and sediment control planning translated into practice by roading and harvesting crews? Is there a need for better training of these personnel?

______________________________________________________________

______________________________________________________________

25. Do you consider past problems when developing replanting strategies? If so, how?

______________________________________________________________

______________________________________________________________

## Legislature/governance

7. Do you use the NES to manage site specific risks? If not what other source of reference material do you consult?

    ______________________________

    ______________________________

8. What additional information would help you better manage this risk?

    ______________________________

    ______________________________

9. Is there sufficient guidance about how to best manage residual woody debris?

    ______________________________

10. Is there sufficient guidance about where to establish and how to best manage riparian areas?

    ______________________________

11. Are riparian setbacks obligatory in your forests?

    ______________________________

12. Does your company actively promote riparian setbacks or retirement options?

    ______________________________

13. Do you believe current recommendations for setbacks are adequate?

    ______________________________

14. Are there differing opinions between harvesting and environmental staff concerning the value/role of riparian setbacks?

    ______________________________

15. Does your company regard riparian setbacks within commercial forests as temporary (allowed to be trashed during harvesting) or the beginnings of moving towards a permanent feature within these forests?

    ______________________________

16. If your forests are leased are you financially penalised or constrained by lease agreements in implementing additional setbacks and/or exploring retirement options because of diminishing net stocked area?

If so

- ☐ - Maori
- ☐ - Crown
- ☐ - Other

______________________________

17. Is renegotiation of the lease or compensation options worth exploring?

    ______________________________

### Questions - councils

How common is post harvesting landsliding and movement of woody debris from forests in your region?

In which areas is it a problem?
- A specific geologic terrain
- High rainfall areas
  - Particular NES category

Is the scale of NES mapping inadequate for setting site specific sediment control, harvesting, re-establishment guidelines
If so give specific examples

Would you like forest companies to provide more detailed mapping of site specific hazards, proposed riparian set backs and slash-extraction locations when applying for consents

Have you developed erosion and sediment control guidelines specifically for forestry?

Do you have specific guidelines for management of residual woody debris and riparian set backs?

Does Council regard riparian setbacks within commercial forests as temporary (allowed to be trashed during harvesting) or the beginnings of moving towards a permanent feature within these forests

Does Council consider current recommendations for setbacks to be adequate?

How would you generally rate forest companies performance in managing the risk of post harvesting landsliding and debris flows?

Do you have sufficient in-house resource to adequately/regularly monitor forest activities and compliance?

What additional information would help you and foresters better manage this risk?

Do you think the type of machinery and harvesting systems currently used are appropriate for the terrain in your region?
If not do you think this is contributing to post-harvest problems particularly slash management and the destruction of existing riparian set backs

# Appendix 4: Workshop agenda

New forest management approaches to mitigate the risk of post-harvest landslides and debris flows in erodible hill country

Date: Wednesday, 8 May 2013
Venue: Wellington Airport Conference Centre
Time: 9.45 am – 3.00 pm

## AGENDA

| | | |
|---|---|---|
| *9.45 am* | *Welcome, Coffee* | |
| 10.00 am | **Introduction, Project Background, the Issue** | **Tim Payn** |
| 10.25 am | **Understanding the Issue - History**<br>– Land Clearance to Reforestation<br>– Benefits of Forests | **Chris Phillips** |
| 10.45 am | **Understanding the Issue**<br>– Why We Get Landslides<br>– Why Trees Reduce Erosion<br>– Window of Vulnerability<br>– Climate Change Projections | **Chris Phillips** |
| 11.05 am | **Steep Country Harvesting**<br>– Current Practice<br>– Economics | **Spencer Hill** |
| 11.15 am | **Current forest management practice**<br>– Silviculture<br>– Harvesting and Roading<br>– Environmental management | **Dzhamal Amishev** |
| 11.30 am | **National Review – Industry and Regional Council Surveys** | **Dzhamal Amishev** |
| 11.45 am | **National Review – Silvicultural Options** | **Mark Bloomberg** |
| 11.55 am | **International Study Tour**<br>– Issue<br>– Relevant Management practices<br>– Take-home messages | **Spencer Hill** |
| 12.30 pm | LUNCH | |
| 1.15 pm | **Recommendations and Implications**<br>– Existing Forest Estate<br>– New Plantings on Steep Erodible Land | **All, Discussion** |
| 2.00 pm | **Knowledge Gaps and Needs** | **Chris Phillips** |
| 2.15 pm | **Pannell Framework for Policy Mechanisms** | **Luke Barry** |
| 2.20 pm | **Issues for Policy Makers**<br>– Discussion | **Peter Weir** |
| 2.50 pm | **Wrap up** | **Kit Richards**<br>**Tim Payn** |
| 3.00pm | **Meeting Close**<br>– Next Steps<br>– Report/Presentations access<br>– List of Contacts | |

# Appendix 5: Workshop feedback

## New Forest Management Approaches to Steep Hills

### Workshop feedback summary

A workshop titled ”New forest management approaches to mitigate the risk of post-harvest landslides and debris flows in erodible hill country“ was held in the Wellington Airport Conference Centre on Wednesday, 8 May 2013. A total of 56 people from industry, regional councils, MPI and other institutions confirmed their attendance. Starting at 10 am, the project team presented the following topics with main results from the review that was undertaken:

1. Understanding the Issue – Chris Phillips.
2. Steep Country harvesting economics – Spencer Hill.
3. Current forest management practice and National review – Dzhamal Amishev.
4. Silvicultural options – Mark Bloomberg.
5. International study tour – Spencer Hill.
6. Issues for policy makers – Peter Weir.
7. Knowledge gaps and needs - Chris Phillips.

Discussion was open to all attendees on key learnings from the presented material, as well as, new ideas for forestry models of the future. Feedback forms were distributed to all attendees to provide their thoughts on the workshop, as well as, any other comments they might have. A total of 24 completed forms were collected after the workshop.

Asked about the most useful presentations, the answers identified “Understanding the Issue” and “International Study Tour” as most useful, followed closely by “Issues for Policy Makers”. On the other hand, “Current Forest Management Practice” and “Silvicultural Options” were voted as being of least value.

The majority of the workshop attendees found the event to be very good or exceeding their expectations (58%), about a third of them were satisfied, and 13% expected more (Figure 1).

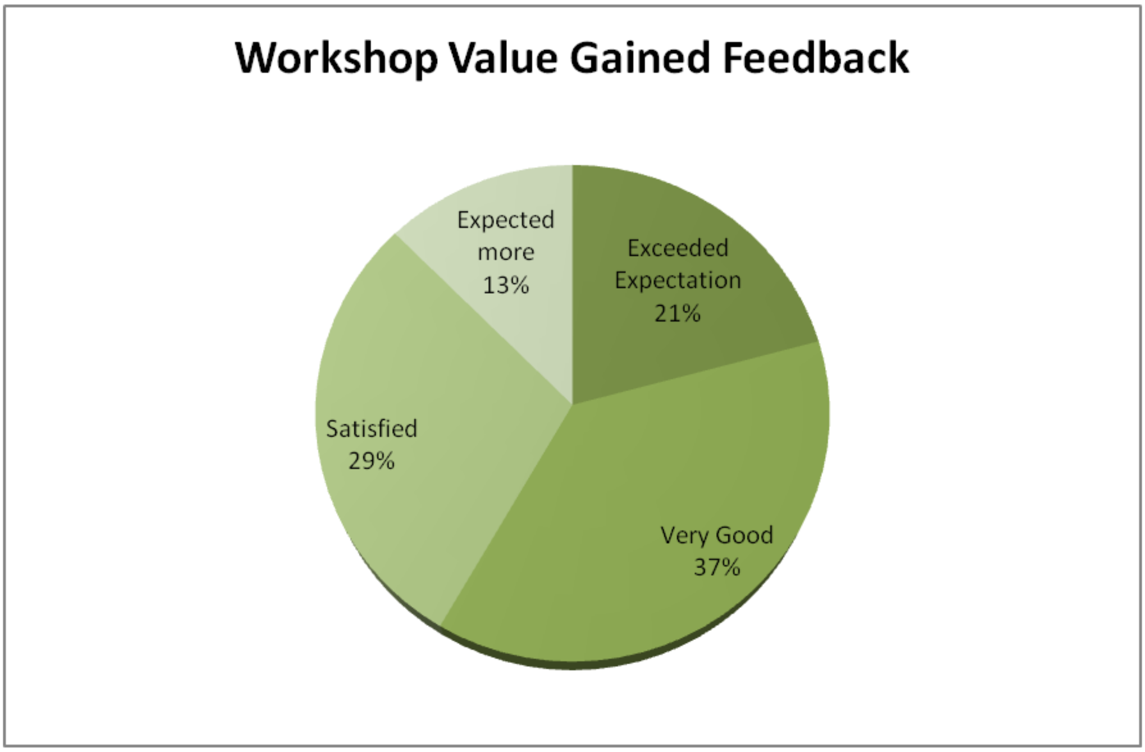


Figure 1. Summary of feedback results on value gained from the workshop.

One of the comments that several attendees shared was the need for more discussion time – of the problem, of the key learnings from the review, and of new ideas / suggestions / initiatives. This is a valid point given the limited time of a single workshop and the amount of information that needed to be presented. There are several ways to follow up on this and give people the opportunity to voice their ideas or comments on the topic:

1. Set up a “discussion forum” online where people can access this and add their inputs.
2. Follow-up mini-workshops, possibly in the main regions where the problem is present the most.
3. Invite comments via email to all attendees.

Any of those would require additional time and additional funding, since the current budget does not accommodate such expenditures.

Some of the comments from the feedback forms are included below:

“Environmental hazard/risk identification and assessment needs to be taken seriously. Training/assessment/auditing is needed.”

“Less time on recapping and more time on sector discussion of problem.”

“Demonstrate what good risk management looks like - find high risk site and demonstrate options and recommended actions.”

“Need a balance with presentations from MPI and Councils. Again, another workshop of "council/government bashing" and a lost opportunity to build bridges. Would have liked a "tool box kit" of ideas for risk management. Great networking opportunity.”

“Need more time for discussions.”

“Field trips always make them more interesting. Maybe more info on what hill country operators are doing currently.”

“Complete a study within NZ of some of the talked about harvesting systems that other countries undertake to see how they go within the NZ terrain and skill set.”

“Start earlier - more discussion time, time for suggestions of new initiatives. Discussion of how existing ideas were working.”

“Well organised, excellent workshop, key now is how to keep momentum on this through FFR or other.”

“How significant is this problem really! Needs some perspective I think. The issue in my view is not the serious problem perceived. We need good practical information to deal with the specific problem.”

“Plenty of visuals, pictures, graphs. Want to be on the discussion list, great learning day.”

“This workshop covered much more than management approaches to mitigate the risk of post-harvest landslides. It could be better to formalise this, more would attend. Converting the wall of wood into a non-declining yield - needed to retain confidence in forest investment on erodible hill country among other things. Excellent workshop.”

“It was really well presented and managed. Environmental management needed more discussion. I think that at times the discussion topic "landslides and debris flows" was lost in other discussion topics.”

“Provide some solutions or a few more part-solutions. Less negative, more solution-based. Loss of sediment not related to catastrophic events. I was hoping for some solutions for sediment loss causing loss of habitat in waterways. Many of the arguments raised the major issues which have resulted from a National government.”

“More workshops would not necessarily need to improve but would need to evolve what has occurred, e.g. further developing scenarios for alternative harvesting.”

“How do we get people engaged and trained in new harvesting techniques and establishment models. How do we get the ball rolling, government funded training/technology unit (LIRO +). Lots of talk about technology - none really applied in NZ. WHY? Interesting how little government control in comparison to other countries. Need to look at what we want 100 years from now, then work back.”

“Must be progressed - findings answered/pursued.”

“Less rush, more discussion. A great lead in.”

“Like to see some "lower level" workshops where the various options available e.g. residue burning vs on-slope trimming vs mechanical removal of residue. Stuff to stop the debris flows, not just how to manage them once they have occurred. Expected some discussion on practical ways to stop/minimise debris flows. Info presented was good stuff, but missed what I had expected - e.g. comparisons of ways to prevent residues on landings getting into waterways, etc.”

“Small group breakouts to brainstorm issue could have thrown up some fresh ideas/thinking rather than hearing sort of the same stuff as previously. I got most value from comments from the floor in relation to the presentations.”

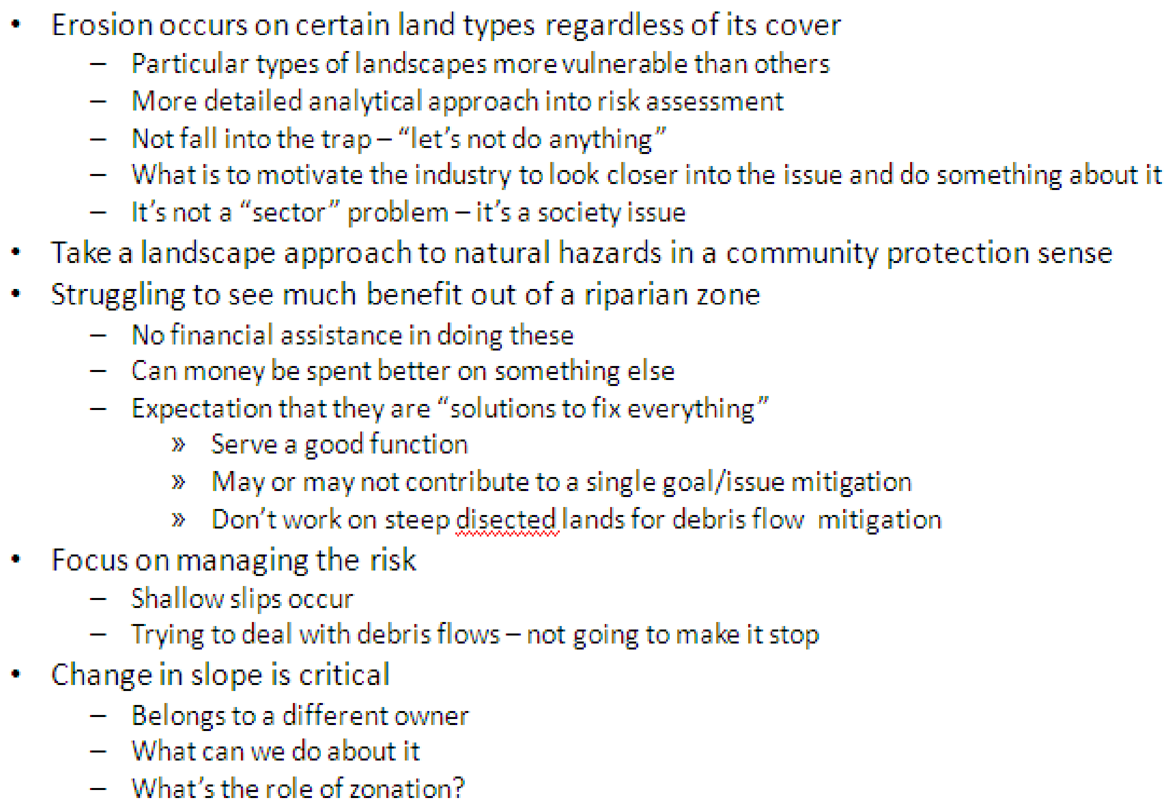
“More information on possible systems to mitigate issues.”

“Perhaps a study into the quantification of the ecosystem services forests provide in terms of avoided erosion and otherwise, as this was a point raised throughout the workshop.”

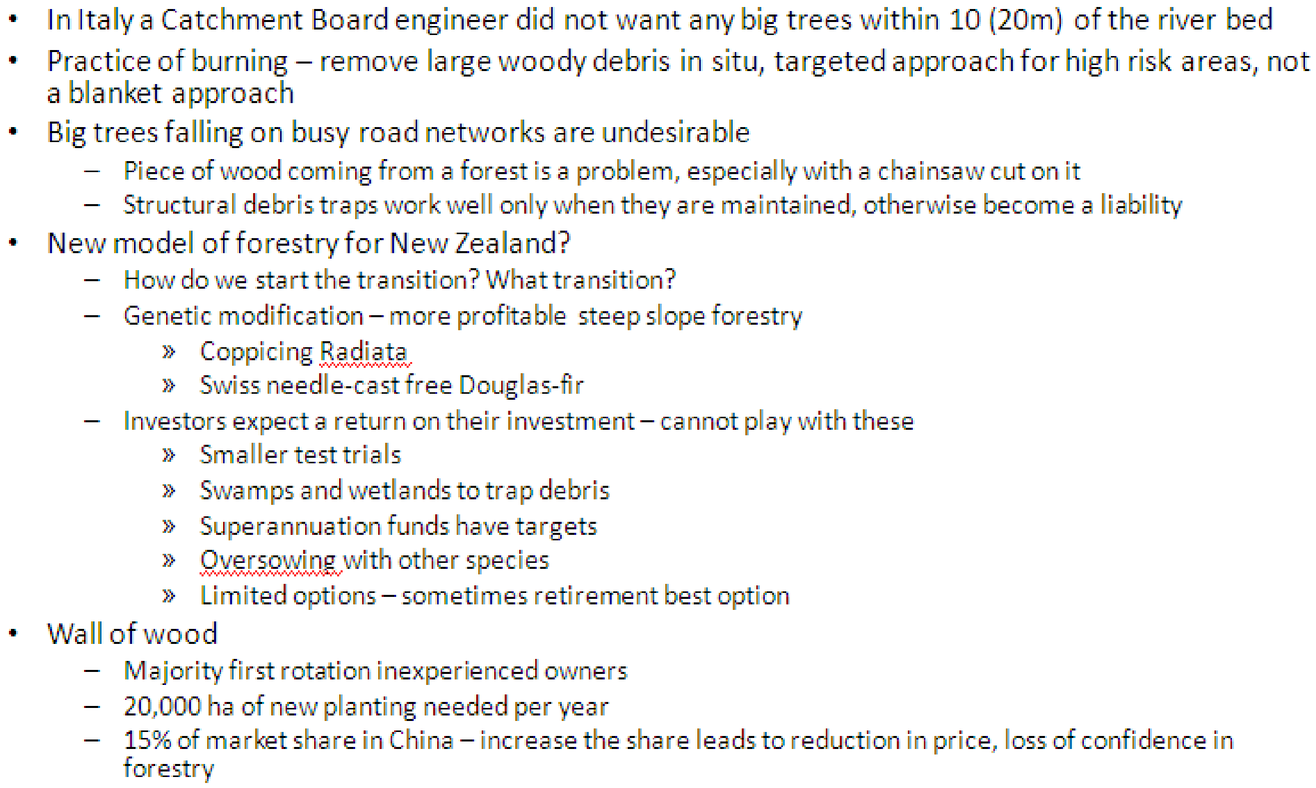
“More on answers - what are people doing that are producing results - more emphasis at "top of cliff stuff".”

“More focus on forest management and harvesting approaches, technologies, practices and opportunities to improve viability on steep terrain. Less emphasis on regulation and subsidies - not that these are not to be debated, but seemed out of scope with the project.”

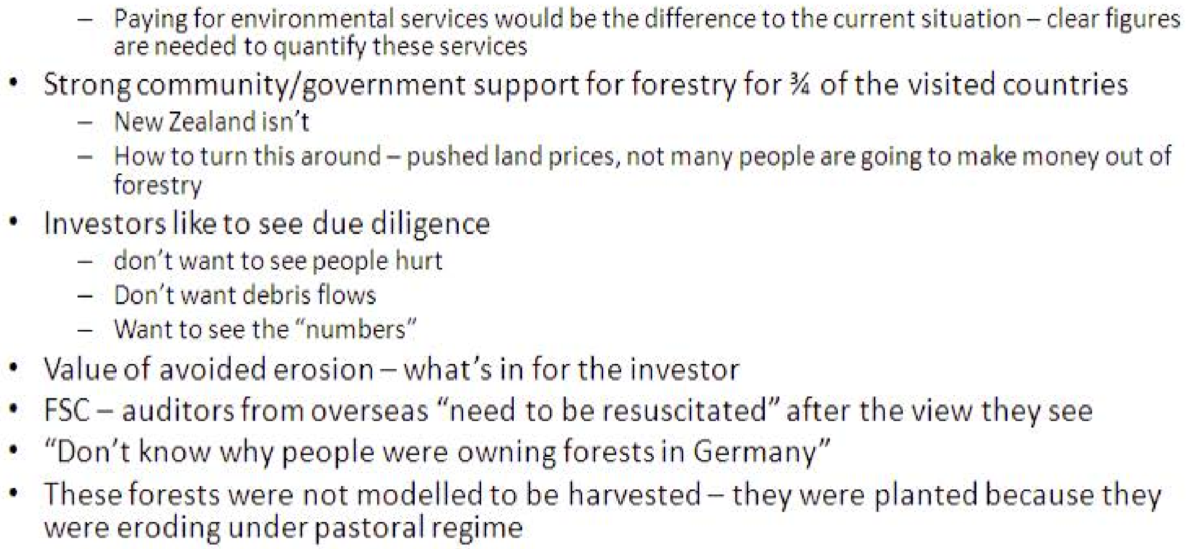
# Appendix 6: Workshop participants' comments



- Erosion occurs on certain land types regardless of its cover
  - Particular types of landscapes more vulnerable than others
  - More detailed analytical approach into risk assessment
  - Not fall into the trap – "let's not do anything"
  - What is to motivate the industry to look closer into the issue and do something about it
  - It's not a "sector" problem – it's a society issue
- Take a landscape approach to natural hazards in a community protection sense
- Struggling to see much benefit out of a riparian zone
  - No financial assistance in doing these
  - Can money be spent better on something else
  - Expectation that they are "solutions to fix everything"
    - Serve a good function
    - May or may not contribute to a single goal/issue mitigation
    - Don't work on steep disected lands for debris flow mitigation
- Focus on managing the risk
  - Shallow slips occur
  - Trying to deal with debris flows – not going to make it stop
- Change in slope is critical
  - Belongs to a different owner
  - What can we do about it
  - What's the role of zonation?



- In Italy a Catchment Board engineer did not want any big trees within 10 (20m) of the river bed
- Practice of burning – remove large woody debris in situ, targeted approach for high risk areas, not a blanket approach
- Big trees falling on busy road networks are undesirable
  - Piece of wood coming from a forest is a problem, especially with a chainsaw cut on it
  - Structural debris traps work well only when they are maintained, otherwise become a liability
- New model of forestry for New Zealand?
  - How do we start the transition? What transition?
  - Genetic modification – more profitable steep slope forestry
    - Coppicing Radiata
    - Swiss needle-cast free Douglas-fir
  - Investors expect a return on their investment – cannot play with these
    - Smaller test trials
    - Swamps and wetlands to trap debris
    - Superannuation funds have targets
    - Oversowing with other species
    - Limited options – sometimes retirement best option
- Wall of wood
  - Majority first rotation inexperienced owners
  - 20,000 ha of new planting needed per year
  - 15% of market share in China – increase the share leads to reduction in price, loss of confidence in forestry



  - Paying for environmental services would be the difference to the current situation – clear figures are needed to quantify these services
- Strong community/government support for forestry for ¾ of the visited countries
  - New Zealand isn't
  - How to turn this around – pushed land prices, not many people are going to make money out of forestry
- Investors like to see due diligence
  - don't want to see people hurt
  - Don't want debris flows
  - Want to see the "numbers"
- Value of avoided erosion – what's in for the investor
- FSC – auditors from overseas "need to be resuscitated" after the view they see
- "Don't know why people were owning forests in Germany"
- These forests were not modelled to be harvested – they were planted because they were eroding under pastoral regime