Best practices for reducing harvest residues and mitigating mobilisation of harvest residues in steepland plantation forests.

Enviro Link Contract 1879-GSD152

Prepared for:
Dr. Murry Cave, Gisborne Regional Council

July 2018

Prepared by: Prof. Rien Visser,
With the support of: Dr. Raffaele Spinelli[1] and Dr. Kris Brown

School of Forestry, University of Canterbury, Christchurch, NZ
[1]IVALSA, CNR, Italy

1. Summary

Plantation forestry in New Zealand covers approximately 7% of NZ’s total land area with 28 million m^3 of timber expected to be harvested in 2018. The majority of timber harvest is from Pinus radiata (‘radiata’) plantation forests grown 25-30 years. Approximately 40% of the plantation estate is on steeper and or erodible terrain, driven mainly by the lower land values for forest conversion but also the benefits of stabilising erosion prone land with trees. The current preferred harvesting practice in New Zealand is larger scale clear-cutting, based on logistical and economic benefits, but also on planting regimes whereby whole catchment areas are planted in a short time-frame.

Although certainly not new, recent larger scale debris flow events with entrained harvesting residues has caused significant damage to downstream land use. This includes inundation of land with sediment and slash, damage to infrastructure including roads, bridges and homes, or the deposition of woody debris on beaches. A number of events have occurred in the Gisborne Region resulting in significant flooding, but also large scale deposition and damage from harvest residues on the regions’ rivers and beaches, coinciding with recent extensive harvesting within the catchments. Similar events have also occurred in Northland, Coromandel, Bay of Plenty and Nelson-Marlborough. These events are prompting Regional and District Councils to review the acceptability of current forestry practices and to identify opportunities for improvement.

The report focusses on the relationship between harvesting, harvest residues, and the best practices that help mitigate debris flow events and or the delivery of harvest residue. This report was commissioned to answer three primary questions:

1. **Wood Generated from NZ Harvesting Operations:**

The harvesting of radiata generates relatively large volumes of harvest residues, typically estimated to be 15% of the total volume. For an average stand with a volume of 500 m^3/ha, this equates to 75 m^3/ha of residues left on site post-harvest. Volume of harvest residues is particularly high in regions with poor market conditions for short and or small diameter logs, difficult terrain that both increases the level of stem breakage during harvesting and makes retrieving all stems from the site more problematic, but also in harvest areas with poor stand quality, such as those affected by prior storm damage (‘wind-throw’). For the higher production stands in the Gisborne region, and given the difficulty of the terrain, a reasonable harvest residue estimate would be 120m^3/ha.

As a general rule, when well spread out over the cutover harvest residues are beneficial to the natural environment. This includes recycling of nutrients from litterfall, and the armouring of the soil against surface erosion. However, if harvest residues are (a) left either in the waterway or floodplain, or (b) left on slopes susceptible to mass movement, then the residues can become entrained during a storm event and are at risk of moving off-site. While all harvest debris might be considered a nuisance, large woody debris is responsible for most downstream infrastructure damage and hence a focus for management activities.

Harvesting systems can be categorised as cut-to-length (CTL) or whole-tree harvesting (WTH). In CTL systems the stems are felled and processed in the stand. This means the residues are evenly distributed, and when placed in front of the harvester are pushed into the ground to minimise disturbance. In WTH the trees are felled only, the extracted to a processing area (called a landing) where they are delimbed, topped, and cut into logs. While some stem and branch breakage occurs during felling and extraction, the majority of the harvest residues are at the landing. In steep terrain, cable yarding systems are used for extraction, whereby CTL operations are not really feasible because of safety risk. While for WTH ground based systems there is the opportunity to at least carry some of the residue back into the forest, in steep terrain the majority of residues will be pulled to, and remain at the landing.

Recovering harvest residue for biomass products at the landing may not be profitable, but will reduce the accumulation of harvest residues, improve operational efficiency and increase post-harvest plantable area. Harvest residues can also be burned to the risk of debris movement, but there are both concerns around visual smoke pollution as well as managing smouldering fires. For operations on steep terrain, cut-to-length as a preferred harvest system is not feasible for both safety, but minimising felling breakage through improved felling and avoiding sweeping debris into gully’s during extraction where it cannot be retrieved are practices that minimise harvest residues.

2. **Site conditions and forest systems and practices that reduce/exacerbate woody debris generation, and the risk of its off-site movement, focusing on hauler operations in steepland country:**

Off-site movement of harvest residue can create a hazard to both the natural and built environment, as well as to subsequent forest operations. Three primary mechanisms for the off-site movement of woody debris are identified: (a) harvesting residues left in gullies, waterways or flood zones than can be flushed out during higher rainfall events, (b) large accumulation of harvest residues, such as birdnests around landings, then can collapse under their own weight over time, and (c) harvest residues on the cut-over that are entrained and mobilised by debris flows.

In steep terrain, felling around waterways can result in higher levels of stem breakage and subsequent cable logging harvest residues can be swept into gullies and waterways. Clearing this debris and placing it in a safe location as harvesting progresses is the most logical mitigation method. For whole-tree harvesting systems the majority of harvest residue will be generated at the landing. Post-harvest this debris can be burned or pulled back on to the landing, but this leaves a residual risk during the harvest period. As such, a preferred solution will be the recovery and or utilisation of residues during harvesting. This can include simply moving the material off-site to a stable location using bins, or developing an integrated biomass strategy.

Debris flows that entrain cut-over harvest residues are infrequent, but high risk events. Forestry activities such as clearfelling, building infrastructure, and creating soil disturbance are all activities that exacerbate the risk of slope failure and should be carefully managed. Restricting the size of clearcut, maintaining infrastructure standards, and setting limits on the level of soil disturbance are all pragmatic ways of mitigating debris flow risk.

Leaving harvest residue on the cut-over is complex and has conflicting goals. Leaving harvest residues has considerable benefit for recycling nutrients, but also for erosion control that will help stabilise the slope. For this, it is important the focus is on minimising the volume of large woody debris that creates the greatest hazard when mobilised

3. Guidance on harvest practices and post-harvest strategies that have the potential to reduce woody debris generation and the risk of mobilisation within planted forests:

The larger scale removal of forest vegetation ('timber harvesting' or 'logging') has an impact on the receiving environment. The biggest and most common concern is associated with the impact on water quality and steam habitat caused by accelerated erosion from harvesting disturbance. Because erosion can occur readily in even small rainfall events, these are extensively studied, well understood, and internationally forestry has relied on the concept of 'Best Management Practices' (BMPs) to mitigate or minimise impact from harvesting. BMPs develop over time, responding to both new research and operational experience to define workable solutions to a given issue. However, most BMP guidelines have an element related to harvest residue management.

The issue of larger volumes of harvest residues moving off-site is complex as they occur infrequently, and with a combination of steeper slopes, weaker or more erodible soils, and a larger rainfall events (or smaller event but with saturated soils). New Zealand has a number of documents that support best harvesting practices, but few collate, detail or set standards for minimising debris flow risk. Common BMPs will help maintain overall site stability, especially those related to infrastructure design and maintenance. Specific to debris flows, practices that minimise the risk of their occurrence, and or the severity of their impact are recommended and include (a) limiting the scale of clearcutting (b) use of streamside management zones (c) and avoiding accumulation of harvesting residue through higher utilisation of harvested timber.

2. Definitions

Note: These definitions are provided to help understand and differentiate between terms that are often commonly used, but sometime incorrectly. They are either from dictionaries, or as compiled from common harvesting terminology.

Woody Debris: This term is widely used to refer to material left behind after a harvesting operation. However, it is not necessarily a preferred term as the definition of debris is "scattered pieces of rubbish or remains" and as such has an immediate negative connotation. The woody material being left behind is neither rubbish nor evenly scattered. Especially post-harvest on steep terrain the material is typically concentrated either at the landing (/processing area) or swept into depressions along the slope. ***Large Woody Debris (LWD) / Coarse Woody Debris (CWD):*** Is also a well-established term and by common definition refers to logs, sticks, branches, and other wood that is larger than 10cm in diameter. It is frequently used when discussing the need for LWD in creating adequate waterway habitat, or for identifying a risk when an over-abundance poses a dam risk. ***Small (or Fine) Woody Debris (SWD):*** is a less used term, but simply refers to 'woody debris' that is smaller than 10cm in diameter, but larger than 1cm. Material less than 1cm is referred to as '***litterfall'***.

Harvesting Residues: should be the preferred term in the forest industry for material left on-site post-harvest. The definition for residue is "a small amount of something that remains after the main part has gone or been taken or used". As such it can refer to all material left on site after harvesting has been completed, but also recognise that it might still have value. The benefit of this term is that it includes merchantable stems and or logs left onsite, but excludes naturally downed woody material. ***Non-merchantable timber:*** This term refers to stem material left on site that does not meet the specification of any of the forest products being produced in the forest. For most operations this means it is smaller than a pulp log, with a small end diameter of 10cm (but can range from 8 to 15 cm depending on region), and a minimum length of 2.5m (but this can range from 2 to 3.5 m depending on region). ***Slash:*** (also called 'Brush') is defined as coarse and fine woody debris generated during logging operations, but it also includes material generated by wind, snow or other natural forest disturbances. In Europe slash usually just refers to the branches that are delimbed from the felled trees. For example, 'slash' is used in extraction corridors to reduce soil disturbance and compaction. ***Off-cuts:*** a specific type of slash whereby a segment of a stem that has a defect (i.e. large knots), and these will typically be larger than 10cm in length. NZ operations generate a large volume of off-cuts (1) radiata pine trees have many defects that are not preferred in our log grades (2). ***Sloven:*** a specific type of slash whereby a log (or stem) is trimmed to create a flush end. These thin segments will typically be less than 10cm in length. NZ operations tend to generate a large number of slovens as most stems will be cut flush at the butt end, and again either side of the stem break. Sometime also incorrectly called a '***biscuit'*** because of its shape, but that term technically refers to a small flat piece of wood used to join two larger pieces of wood together.

Biomass. Any woody material in a forest. Refers to both merchantable material and material left following a conventional logging operation. In the broad sense, all of the organic material on a given area; in the narrow sense, burnable vegetation to be used for fuel in a combustion system.

Debris Slide: “a mass of predominantly unconsolidated and incoherent soil and rock fragments that has slid or rolled rapidly down a steep slope when comparatively dry to form an irregular hummocky deposit.” ***Debris flows:*** “geological phenomena in which water-laden masses of soil and fragmented rock rush down mountainsides, funnel into stream channels, entrain objects in their paths, and form thick, muddy deposits on valley floors.” Note that ‘debris flows’ by definition includes ‘entrained objects’ which for forest harvested areas will include ‘harvesting residues’.

Landing: also called a skid, or a deck, is an area that is cleared in the forest where the stems and or logs are extracted to for processing, storage and subsequent loading onto trucks for transportation to market.

Cut-over: The forest area that has been clear-cut is referred to as a cut-over. This area excludes the landings and roading infrastructure.

3. Best Management Practices, Guidelines, and the NES

There are currently no dedicated guideline documents for reduction and or management of harvest residues with regard to downstream impacts. However, there are numerous document that support improved environmental outcomes associated with harvesting practices that include aspects of harvest residue management. These guideline documents are most commonly referred to Best Management Practices (BMPs) as they reflect a current state of knowledge. While BMPs were primarily developed to protect water quality (Aust and Blinn 2002), BMPs are often expanded to include maintenance of site productivity, with guidance for harvest planning, road construction and maintenance, minimizing soil disturbance from harvest operations, maintaining streamside management zones, and ensuring rapid revegetation following harvesting (Aust and Blinn 2002). BMP document can legitimately vary in content and detail as the accepted practices will reflect the environmental quality expectations of the region / state / country they are written for.

NZ National Rules and Guidance

National Environmental Standard for Plantation Forestry **(***shorted to* ***NES-PF*** *in this document***)** was enacted in 2017, to be implement by all Regional Councils as a minimum standard, in the form of rules that are expected to be adhered to from May 2018. http://www.legislation.govt.nz/regulation/public/2017/0174/latest/whole.html

Environmental Code of Practice (ECoP). (NZFOA 2008). Prepared for and published by the NZ Forest Owners Association, with expectation of compliance for its members. https://www.nzfoa.org.nz/resources/file-libraries-resources/codes-of-practice/44-environmental-code-of-practice/file

New Zealand Forest Code of Practice (FCoP) (Vaughen, et al, 1993). Developed at the Logging Industry Research Organisation in collaboration with both industry and Regional Councils, also to support best practice development to meet RMA requirements. It was referenced in multiple Regional Council plans as a reference for best practices to comply. Effectively superseded by the ECoP.

UN FAO Model Code of Forest Harvesting Practice (Dykstra and Heinrich 1996). Its overall purpose is to promote harvesting practices that will improve standards of utilization, and reduce environmental impacts. Provides guidance on how to develop national and or regional codes of practice, and links to United Nation initiatives such as the Convention for Climate Change, and Deforestation (Agenda 21). http://www.fao.org/docrep/V6530E/V6530E00.htm

Montana Forestry Best Management Practices (Montana DNRC 2015). Most US states manage their national obligation to protect water quality in forests using BMP guides that have quasi-regulatory status. As these documents are used in day-to-day regulatory inspections, they have typically developed into very professional well illustrated resources.

The Montana BMP guide is a nice example.
http://dnrc.mt.gov/divisions/forestry/docs/assistance/practices/finalbmp_versionforweb10_1_15.pdf

New Forest Management Approaches to Steep Hills (Amishev et al 2014). A report prepared for MPI that reviews national and international best practice in steepland plantation forests to understand and minimise the damage from post-harvest landslide and debris flows
http://www.climatecloud.co.nz/CloudLibrary/FRI30584%20New-Forest-Management-Approaches-to-Steep-Hills.pdf

New Zealand Regulatory Authority Forestry Guides

Under the RMA (1991), every council was expected to take an effects-based approach to managing land-use in its region base. The rules, conditions or guidance for forest harvesting operations (with or without resource consent) was often augmented with best practice guidance for various land uses. A number of the Councils produced their own separate forest practice guides, and examples include:

Bay Of Plenty - Erosion and sediment control for forestry operations guidelines (BOP 2013). A nicely detailed and presented guide, well aligned with the ECOP, but using regional specific information and photos to illustrate practices.
https://www.boprc.govt.nz/media/293804/erosion-and-sediment-control-guidelines-for-forestry-operations-2013.pdf

Northland Regional Council - Forestry Earthworks & Harvesting Guidelines for Northland. (2016). A good example of forestry companies collaborating with their Regional Council to compile best practice information.
https://www.nrc.govt.nz/contentassets/25ef0305a0e54171a99015d26e2f67e1/forestry-earthworks--harvesting-guidelines-for-northland---issue-2-june-2016-excl-app.pdf

Marlborough District Council – Environmental Guidelines: Forest Harvesting (2013). A modern guide with a strong focus on reducing woody material in waterways.
https://www.marlborough.govt.nz/environment/land/environmental-guidelines-forest-harvesting

Auckland Regional Council. TP223 - Forestry Operations in the Auckland Region A Guideline for Erosion and Sediment Control. (2007). This guideline has numerous erosion control standards and forestry companies are audited against the specifics.
http://www.aucklandcity.govt.nz/council/documents/technicalpublications/ARC-TP-223%20B%20-%20Header%20%26%20contents.pdf

Forest Infrastructure Guidelines

NZ Forest Road Engineering Manual (NZFOA 2011) – a comprehensive manual that covers many aspects from road design, but includes extensive information around best practices for minimising environmental impacts. It built on the LIRO (Larcombe 1999) manual. https://www.nzfoa.org.nz/resources/file-libraries-resources/transport-and-roading/484-nz-forest-road-engineering-manual-2012/file

NZ Forest Road Engineering Manual: Operator's Guide (NZFOA 2012) – a partner publication to the NZFOA Forest Road engineering Manual, this guide is pragmatic in that it primarily uses illustrations to provide guidance for both good and poor practice. The manual is designed for machine operators. https://www.nzfoa.org.nz/resources/file-libraries-resources/transport-and-roading/512-nz-forest-road-engineering-manual-operators-guide/file

Low Volume Roads Engineering: BMP Field Guide (Kellar and Sherar, 2003) provides a well-illustrated example of where to use and how to install BMPs. https://trrjournalonline.trb.org/doi/abs/10.3141/1819a-25

Other Relevant Guides
Most larger NZ forestry companies have developed either guides, rules or make education material available for their harvesting supervisors and harvesting contractors. Compliance with ECoP, Regional Council requirements, and more recently NES-PF rules, would be an expected part of most logging contracts.

PF Olsen - Practice Guide Workshop (2017). An example of education material where they have pulled together expertise and information (mainly in the form of presentations) that taught best practice workshops throughout all regions in 2017 and 2018.

Guide books specifically dedicated to harvest residue removal or reduction are typically guided by their regional need to reduce fire risk. As such the focus is often on fuel load reduction (smaller more readily combustible material) as compared to large woody residues that are a the greater risk for debris flows. However, these guides can provide a good overview of the varied methods including burning, chipping, piling and removal.

Brush Disposal Guidebook (2015) Manitoba Conservation, Canada. http://www.gov.mb.ca/sd/forestry/pdf/practices/brush_disposal_2005.pdf

As harvest residue movement is commonly associated with mass landslide events, it is worthwhile cross-referencing with non-forestry specific guides to support our understanding of debris flows.

Guidelines for Evaluating Potentially Unstable Slopes and Landforms. (OR-DNR- 2016. Developed by the Department of Natural Resources in Washington, this guide provide an excellent and pragmatic overview of unstable slopes, with a focus of forestry and forest practices. https://www.dnr.wa.gov/publications/bc_fpb_manual_section16.pdf

While this report focuses on the management of harvesting residues to minimise downstream impacts, considerable effort has been made to recover biomass either during harvest or post-harvest. This not only reduces post-harvest risk for debris flows with woody material entrained, but also fire risk and supports planting and or regeneration.

Guidelines for harvesting forest biomass for energy: A synthesis of environmental considerations. (Abbas 2011). A publication that reviews the requirements for a successful biomass recovery with regard to the environment. https://www.sciencedirect.com/science/article/pii/S0961953411003539

Good Practice Guide: Production of Wood Fuel from Forest landings (Visser, Hall and Raymond 2010). A publication support by the NZ Energy Efficiency Conservation Agency (EECA) to promote the use of renewable energy resources. www.forestenergy.org/openfile/227

Developing Streamside Management Guidelines for New Zealand Production Forestry. (Visser and Fenton 1994). A report prepared by the Logging Industry Research Organisation in collaboration with both Councils and Environmental interest groups that outlines the process of establishing specific SMZ protection measures.

Sustainable Forestry Initiative (2015). A US based accreditation programme that sets standards and rules for the plantation forest industry. http://www.sfiprogram.org/files/pdf/2015-2019-standardsandrules-web-lr-pdf/

4. Review of Harvest Residues from NZ Harvesting Operations

As part of the production forest management cycle, trees are harvested for economic gain to sustain the financial viability of the land use. Radiata Pine plantations are typically harvested between 25 and 30 years. National average stand volume at harvest is estimated to be 500 m^3/ha (from NZFOA 2017, derived from area and volume harvested), but are typically 650 m^3/ha or higher on professionally managed stands with good soils (Visser 2017). The merchantable volume, that is the volume converted to logs for sale, depends on the quality and characteristics of the trees in a stand, but also on the desired product mix (Hall 1999). Based on estimates from MPI National exotic forest description yield tables, an average of 85% of the total standing volume will be merchantable (Goulding 2005). This will range from 90% in good condition well-tended stands, down to 80% for untended stands on moderately steep terrain.

Figure 1: In this harvest operation, felled and delimbed stems are extracted to the landing for processing into logs. While the smaller harvest residues will be spread out in the cut-over, stem residues (off-cuts and slovens) from processing are discarded over the edge of the landing behind the processor.

Conversely, this means between 10 and 20% of the total standing volume is left on site post-harvest. As a national average this would be approximately 75 m^3/ha. For the Gisborne region, on most stands there is a higher volume at harvest (estimated to be 650m^3/ha), and given the difficulty of the terrain and poorer markets, it would be reasonable to estimate 100 to 125m^3/ha of residue left at harvest (Figure 2). For site specific information post-harvest, most companies will be able to reconcile their pre-harvest inventory survey with the documented volumes delivered by truck and hence estimate harvest residues.

Figure 2: In locations with poor markets for lower value logs, significant volumes of large woody debris is often discarded at the landing.

The accumulation of residues was identified as an important research topic area both in terms of environmental risk in steep terrain, but also as a post-harvest planting impediment, prompting the industry to support a number of LIRO studies in the 1990's. However, few studies have quantified the actual volume of radiata residues at landings in New Zealand. Hall (1993), in a study that included four different landings and with an average volume of logs of 6700m^3, found the average harvest residue located at the landing to be 1400m^3. This alone equates to 20% of the total volume, and as such corroborates the estimates presented above. In a separate study of 10 landings, Hall (1994) reported an average of 85 m^3/ha. left on the cut-over (split into 37 m^3/ha for branches and 48 m^3/ha. stemwood). Cable yarding landings had a much higher average residue percentage pulled to the landing, with 5.3% of the total volume, compared to 2.5% of the volume for ground-based harvesting systems.

Rocca (2014) completed cut-over merchantable harvest residue survey in the Gisborne region indicating an average of 11.7 m3/ha, ranging from 0 to 71 m^3/ha. This study showed a positive relationship between slope steepness and merchantable volume left in the cutover. Merchantable sized material accounted for 51% of the total volume on the cutover, 32% were pulp and 17% were short pulp. In a series of six ground-based case studies, Hall (2000) reported an average of 67 m^3/ha for cut-to-length and only 37m^3/ha for whole-tree harvesting systems in the cut-over. However, this study did excluded the volume of residues accumulated at the landing for the whole tree harvesting system.

Figure 3: Typical residues in the cut-over after extraction by a cable yarding system.

At a national level, Visser and others (2010) estimated that about 1 million tonnes of recoverable woody residue was generated from harvest in NZ (from a 20 million tonnes harvest), with about 25% of that being recovered for biomass. Similarity in the US, and estimated 66 million tonnes of harvest residues are left in the forest each year (McKeever and Falk 2004), but approximately 22.4 million recovered for biomass.

In-field measurement of post-harvest residues carried out by forestry companies only focuses on merchantable residues: that is any material left on site that could have made it to a log grade. There is a standard “Wagner Method of Waste Assessment” procedure using a line transect method to provide an accurate estimate of waste that is randomly distributed across the cut-over (Watson 1972). This can be used as part of the quality control process to ensure the contractor has retrieved all the merchantable volume from the cutover. The method can also be extended to account for all residues by reducing the lower threshold, and this has been completed for environmental survey type work (e.g. Ballie 1999). It does not enable an estimate of harvest residues left at the landing, which is typically piled. A survey of landing waste will typically rely on geometrical measure of log pile size and shape, and with a density factor converted into a log volume (Hardy 1996).

However, even though a segment of stem might meet a minimum merchantable specification, retrieving small diameter wood from the cutover will typically not be economic (McMahon 1998). The logging contractor will incur an expense much higher than the logging rate for retrieving that material, and in remote locations the forest owner will typically not recover the cost of harvest and transport on small diameter logs (Figure 4). As such, depending on region and company policy, a contractor may not be required to retrieve smaller merchantable stem wood from the cut-over. This is also supported by Hall (2000), who showed that the level of harvest residue left in the cut-over increases as the distance from the landing increases. In his study it increase from 35m^3/ha at 20m up to 55m^3/ha at a distance of 220m from the landing.

Figure 4: Setting chokers for a cable logging operation is physically very demanding work. In this scenario the choker-setter would not hook up the two larger pieces of woody debris in the photo (to the right and below his foot) as they have no economic value.

Most international literature reviewing harvest residue levels are linked to biomass recovery studies, where the volume of biomass available for recovery post-harvest will affect the feasibility of operating a biomass recovery system.

Ghaffariyan (2012 and 2013) looked at cut-to-length radiata harvests in Australia and found on average 98 t/ha based on six case studies, of which approximately 40% is stem wood (cull, offcuts). The percentage of branches (35%) and stem wood (38.2%) was higher than bark, needles and cones based on the fraction test of remaining slash. For tests on eucalypt, less slash remained after whole-tree extraction (no comparative study completed on pine). At one site in a southern Tasmania pine plantation, 238.7 t/ha of slash was reported for a CTL harvest method. The major reason for this high level of slash was linked with higher small end diameter specifications (10 cm), older trees (30 years), higher yield and stand quality. This does provide an indication that if we extend rotations to decrease the temporal risk, there is a potential for more severe consequences with much higher slash volumes.

Smethurst and Nambiar (1990) also surveyed residues post-harvest in Australian radiata after CTL and found 52 t/ha. Similarly Ghaffariyan and others (2015), in Australian radiata measured 144 t/ha (of which 45% was stemwood) after CTL, 102 t/ha (with almost no stemwood) after integrated harvesting. Spinelli and others (2014) in a study with Mediterranean pine showed CTL residues of 33 t/ha, compared to whole tree harvest of only 5 t/ha, suggesting whole-tree extraction reduces cut-over biomass release by a factor five. Spinelli and others. (2016) studied Spruce and hardwoods in cable yarding where the biomass retention after whole-tree harvest ranged from 20 to 50 t/ha. They also showed that whole tree harvest systems can be used to remove 10 to 70% of available residues, but much is left on site.

Hytonen and Moilanen 2014 in thinning Scots pine showed that whole tree harvesting reduces logging residues by half, with 7-15 t/ha. Cuchet and others (2004) from France studied the recovery of residue after CTL and showed that only about 50% of the residue was able to be recovered. This is consistent with Thiffault and others. (2014), where in a Boreal forests the mean recovery was also 50%. Overall whole-tree harvests yield higher recovery opportunities as the main losses are through stem breakage, compared to just branches and tops from CTL systems.

5. Site conditions and forest practices that reduce or exacerbate the risk of harvest residue off-site movement in steepland.

There are three primary mechanisms whereby harvest residues can be moved off-site during a rainfall event:

(a) Harvest residues are allowed to accumulate in a gully, waterway or its floodplain during harvest and are mobilised during a rainfall event. Residues might also be placed in a floodplain as part of stream cleaning, or if landings are constructed close to a waterway.

(b) Harvest residues are allowed to accumulate in a large pile on a steep slope, whereby the weight of the pile, typically with the gradual collapse of the soil underneath the pile, causes it to slide downslope and into a waterway. The most common scenario for this is the harvest residue 'birdnest' at the edge of a landing.

(c) Harvest residues (specifically large woody debris) is left on slopes, whereby an element of the harvesting process decreases slope stability and results in a mass erosion (debris flow) event that entrains the residues.

From a harvesting practice and management perspective, the first two are relatively easy to understand and these risks can be readily mitigated through good practice. The risk of harvest residue mobilising through debris flows is far more complex as it requires an understanding of debris flow triggers exacerbated by harvesting.

Note that the next section details recommended best management practices that will reduce woody debris, or mitigate the risk of off-site movement.

Harvest Residues accumulating in Gullies, Waterways or the Floodplain

The previous chapter detailed the volumes of harvest residue generated by harvesting of radiata production forests, but especially on steep terrain this residue accumulate in gullies, waterways and or the floodplain. During felling there are invariably higher levels of stem breakage from felling in broken terrain (Andrews 2015), and during cable yarding extraction logging slash can be swept down into lower lying areas. A study by Baillie and Cummins (1998) showed the scale of the problem, whereby they measured woody debris greater than or equal to 1 cm in diameter before and after harvesting, along a 100 metre stream reach, at 17 stream sites in NZ's pine plantation forests, ranging from Southland to Auckland/Coromandel. In their study, 287 m^3/ha of debris was measured in the stream channel when the harvest systems simply hauled across the stream channel, this was reduced to 104 m^3/ha when hauling back from the stream (gully to ridge extraction), compared to 48 m^3/ha with ground-based logging. Finally, post-harvest stream cleaning reduced the volume of woody debris to 15 m^3/ha.

Figure 5: Trees felled into a gully are difficult for cable yarder crews to extract. Tops and slash will typically also accumulate in such gullies.

The management of woody debris in waterways does have complexity: large woody debris is an integral part of stream habitat and has important ecological function (Ballie 1998; Tasmania LWD Manual 2014). Debris can also effectively forms traps for sediment resulting from harvest operations, reducing sediment delivery to the waterway. From an ecological perspective, both Ballie (1999) and Basher and others (2016) noted our incomplete understanding of the ecological effect of varying levels of harvest residues in the stream.

LWD can form small-scale log-jams that can fail, releasing large quantities of stored debris and sediment downstream. In survey of streams post-harvest, Baillie (1999) noted that log jam failure resulted in 38% debris flows, second only to landslides/slips (with 48%). The NES-PF lists primary reasons for removing debris that blocks or dams a water body as having a significant adverse impact by eroding river banks, effects on aquatic life, and damaging downstream infrastructure, property, or receiving environments, including the coastal environment.

In a survey of forest management companies for streams that require protection, Baillie and Cummins (1998) found that one of the main reasons for stream protection was to minimise debris dams. Collapsing natural log-jams have been implicated in one of New Zealand's worst debris-flow disasters, at Peel Forest in 1975. The risk of a larger wood debris dam collapsing can have large financial implications, with Thonon (2006) reporting on a scenario in the Fraser river, BC Canada, where the failure to remove the dam would result in costs 12 times the companies running cost.

However, not all large woody debris is equally at risk of movement when in a waterway. Abbe and Montgomery (2003) noted that woody debris dam 'architecture' can consist of different elements: key, racked and loose. Woody debris that is keyed, or embedded into the ground, is far less likely to mobilize. Rigon and others (2012) noted that large woody debris that has accumulated over time, which is typical of managed forests in the mountain basins of the European Alps, is much less likely to mobilise (by a factor of 2 to 10). Ballie (2015) highlighted the impact of LWD, as compared to branches, when mobilized and impacting other land users. The Tasmania LWD Manual (2014) states there is little evidence to support the argument that removing LWD reduces the frequency of floods or improves the capacity of rivers to carry floods, and that one option is to re-position LWD if it is detrimental to flow; logs perpendicular to the flow should be rotated.

Both the ECoP and the NES-PF have clear guidance on slash with regard to waterways. The ECoP states “ensure that slash is left in a position where it won’t be picked up by flood flows”. The NES-PF, as part of its permitted activity specification, states: “Slash from harvesting must not be deposited into a water body or onto the land that would be covered by water during a 5% AEP event”, or if it does occur, “slash from harvesting must be removed from a water body and the land that would be covered by water during a 5% AEP flood event”, with a caveat “unless to do so would be unsafe”. Specifically, the NES-PF adds that trees are to be felled away from water, and fully suspend stems when extracting across rivers more than 3 metres wide (see also section on Felling to minimise breakage).

The safety caveat in the NES-PF is important. Having workers remove harvest residues from gully, especially steep or incised gullies, can readily be considered a dangerous task. Sending machinery down into gully or waterways to remove harvest residues, while effective, can result in soil disturbance that destabilises the streambank, increasing the risk of bank collapse.

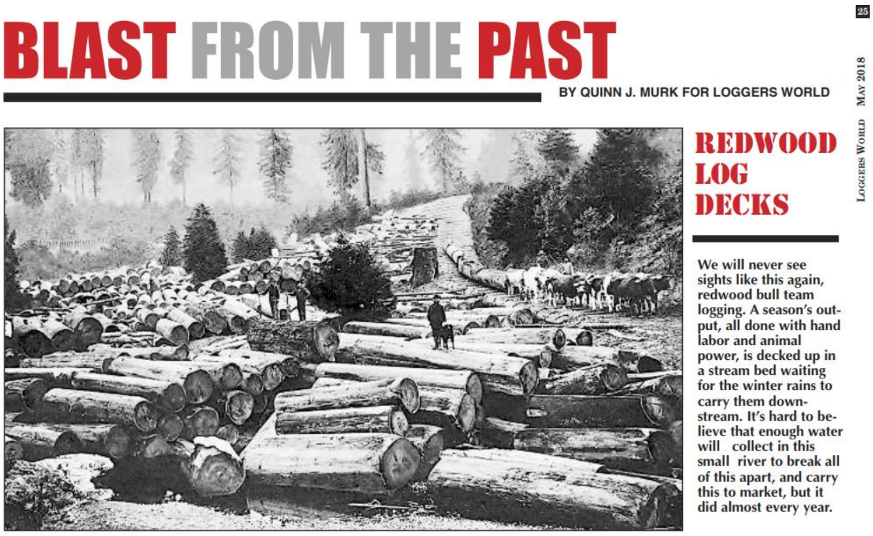
While removal of debris from the watercourse itself may be obvious and effective for stream ecology, in terms of the risk of debris material moving off-site there is also a need to understand not to store the recovered material in the floodplain region. The Gisborne District Council (Cave and Davis and Langford 2017) found that landings and logging slash located in floodplain areas was a main source of mobilised harvest slash in the 2017 Cyclone Cook event.

There are directional felling practices that can reduce harvest residue entering the waterway. Baillie and Kirk (1997) presented an evaluation of streamside felling techniques use in ground-based operations; whereby skidders and tractors are used to assist motor-manual operations in felling trees away from stream edges, and tree jacks are used for felling heavy leaning edge trees. They noted that for a high level of protection, the excavator was the most productive and safest method, followed by the skidder. Tree jacks and motor-manual felling were cheapest, but they cannot completely protect the stream from damage. For steep terrain, presence of the stream and heavy leaning edge trees increase the difficulty of felling using machinery.

For cable logging operations, Baillie (1997) studied the use of a ‘Batwing’ for cable-assisted directional felling. The Batwing is attached to a carriage or in place of the butt rigging and assists in felling trees against their natural lean. While this minimised the environmental impact of harvesting on the stream and riparian vegetation, it was also noted that an average of 4.7 minutes was required for each tree, and that if used with a standing tower and fixed skyline system a mobile tailhold is a requirement. It also creates a safety hazard with the proximity of falling trees to suspended ropes, but these could be managed by careful attention to scarfing, back-cutting, and wedging techniques so the tree fell in the intended direction when pulled over.

In Washington State, USA, there is a requirement to protect ‘Debris Torrent-Prone Streams’. The rule is to retain large standing trees in locations where they might slow debris torrent movement along debris torrent-prone streams with substantial or intermediate downslope public safety risk. While exacting requirements are left to the discretion of the State Forester, trees should be larger than 50cm in diameter breast height and be within 15m of the edge of the active channel along both sides of the stream. The caveat is that the trees left for this purpose do not pose a greater public safety risk because of windthrow.

One aspect to consider, as it relates to harvesting, is how over time we value and manage waterways: a relationship that continues to change over time. Less than 100 years ago, prior to readily available powered machinery, waterways and rainfall events were often used deliberately to facilitate the extraction of timber especially in steep terrain. Trees were felled towards waterways so that the logs could be floated downstream, and mills were often located on the edge or a river or lake to retrieve the logs. To improve log movement on smaller waterways, wooden dams that could be ‘tripped’ (i.e. collapsed for sudden release of water – also called ‘splash dams’) were built to flush logs felled into the gullies down to larger waterways. This practice was extensively used in the Pacific Northwest in America in the late 1800’s and early 1900’s, but also used in New Zealand with evidence of ‘splash dams’ in the Coromandel and Great Barrier Island that were built in the 1920’s.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BLAST FROM THE PAST

BY QUINN J. MURK FOR LOGGERS WORLD

LOGGERS WORLD MAY 2018

REDWOOD LOG DECKS

We will never see sights like this again, redwood bull team logging. A season’s output, all done with hand labor and animal power, is decked up in a stream bed waiting for the winter rains to carry them downstream. It’s hard to believe that enough water will collect in this small river to break all of this apart, and carry this to market, but it did almost every year.

Figure 6: This historical photo shows how historically, loggers would bring logs down into the floodzone and wait for winter rains to carry the logs downstream to sawmills (story, from Loggers World magazine May 2018).

However, the uncontrolled nature of those log drives, together with the resulting extensive waterway damage, meant the practice was all but abandoned by the late 1920’s. In the Pacific Northwest (PNW), there were also extensive flooding and debris flows attributed to the harvesting practices; caused by the scale of the clear-cuts and the collapsing of poorly constructed infrastructure. Over time, most countries have developed detailed protection measures for protecting both waterways and water quality.

In New Zealand, in 1991 waterways were given a special protective status under the RMA, and all Regional Councils identified natural waterway habitat and water quality as values requiring protection. For plantation forestry, the regionally specific guidance and rules varied considerably (Pendly et al 2015), and this was a primary driver for the industry to support the development of a National Environmental Standard (for Plantation Forestry, abbreviated NES-PF). Even with the NES-PF now enacted, the level of waterway protection from land use will continue to develop over time.

Felling and Stem Breakage

One of the reasons for the high volume of harvest residue in radiata plantations is the breakage of the stems during felling, and or during extraction. Because of the value loss implications, there have been many field studies on stem breakage. Although there typically still is merchantable stem wood in the broken top, the lower value and difficulty of recovering it leads to many tops being left in the cutover. Table 1 shows a summary of breakage studies (compiled by Andrews 2015), with breakage ranging from 70 to 99%, and the relative height at breakage of 70%. For a 30 metre, 2m^3 tree, this is a top of about 9m in length but only 10% of the volume (0.2m^3). These studies also showed that specific practices, such as felling across the slope and ensuring the tree does not strike rock, other stems, stumps, or undulating ground slope, minimised breakage. Factors that a faller cannot influence, such as the tree characteristics in terms of height, DBH, density are also correlated to breakage in the studies. Lambert (1996) noted that other reasons for stem breakage are not fully understood.

Table 1: Percentage of broken stems and relative break heights of NZ based studies in radiata.

Author	Location	Breakage	Relative Break Height
Manley (1977)	*Kaingaroa Forest*	*99.30%*	*67% (age unknown)*
Murphy & Gaskin (1982)	*Whakarewarewa Forest*	*99%*	*70% (age 41)*
Murphy (1984)	*Tairua Forest*	*73%*	*83% (age 43)*
Twaddle (1987)	*Kaingaroa & Kinleith*	*% unknown*	*66% (age 31)*
Lambert (1996)	*Kinleith Forest*	*84 – 100%*	*76% (age 25-30)*
Fraser et al, (1997)	*New Zealand*	*69%*	*67% (age 29)*

Andrews (2015) made a comparative study on stem breakage, comparing motor-manual and mechanised felling. The percentage of stems that broke once felled was 73%, 76%, and 94% for motor-manual, mechanized out of the stand, and mechanized into the stand felling respectively. These numbers support felling trees away from the stand. Felling in to the stand results in striking standing trees, and more stems break as it is difficult to fell through a gap in standing trees. Volume retention was not significantly different among the three different felling techniques: Mechanized Felling out of the Stand (94.5%), Motor-manual (93.7%), and Mechanized Felling into the Stand (91.9%).

Harvest Residues at Landings / Birdnests

As reported in the previous chapter, cable yarding extraction will concentrate harvest residues at the landing. Hall (2000) showed that on even relatively small landings, processing a total of 6,700 m^3, (harvest area approximate 12 ha.), 900 m^3 of harvest residue can accumulate at a single landing.

Figure 7: A typical steep terrain cable logging harvesting operation showing trees being extracted and processed into logs on the landing, whereby the harvest residue is discarded off the landing edge.

Once at the landing a solution for managing the residue is required. Since the risk of landing collapse has been recognized as a hazard, birdnests have typically been pulled back onto the landing (or other stable terrain) or burnt, and that is the recommended practices in the NZForRoadManual (NZFOA 2011). In terms of pulling back the harvest residue, the ECoP states that if not enough space is the landing for slash storage then it should be moved off-site (e.g. to another landing). The ECoP, as well as the PFOlsen Workshop Guide 2017, also highlight the need to maintain water and sediment control structures to prevent landing failure, and that a monitoring and maintenance schedule is required as landing failures can occur well after the harvest.

Hall (1993) reported on the use of a 20-tonne excavator pulling back birdnests at four landing locations. The results showed that on average it took the excavator 6.6 hours to retrieve 62% of the total bulk volume, and clear 55% of the total area covered by the birdnest. In terms of cost this equated to about $0.10/$m^3$ (1993 value). Restricting additional recovery was the boom reach of the machine at 7.3m. In terms of moving harvest residues off-site and or for delivery to a market if available, Hall (1995) describes the use of self-loading dump trucks or bin trailers as being feasible.

While burning of birdnests was common and recommended in the ECoP, it creates highly visible smoke with negative public reaction. As the harvest residues are typically embedded into the soil below, birdnest fires can remain alight for weeks, or even months, and run the risk of reigniting during dryer or windier periods. New fire restrictions for log piles over 3m in height requires stringent adherence to rules and equipment requirements. As such burning is no longer a preferred option in New Zealand. In other countries (e.g. Canada, USA) where pests such as beetles can propagate in decaying slash piles burning is still common.

Hall (1994) completed a brief study on using an air curtain to improve the burning of recovered harvest residue in a pit (approx. 5m square and 2.5m deep). Once alight and well established, the fire burned very hot and clean and was able to consume about 3.4 tonnes of woody material per hour.

Harvest residues can also be hogged or chipped to create a by-product with value (Hall 2000; Visser et al 2011), and is a recommended practice in the ECoP where it is economic to do so. One option is to hog, grind or chip the residues post-harvest for a fuel product. As the hogging process is relatively expensive, such an operation is only viable if the market is close with low transportation costs, or if the forest owners is prepared to subsidize the operation for the benefit of removing the residue and resulting fire risk.

Figure 8: An excavator with a rake, combined with a tub grinder, being used to remove LWD from a super-skid. The grinder produces a hog-fuel that is used by the local mill.

Integrated biomass harvesting systems refer to biomass 'residues' being converted to by-products as an integral part of the harvesting process. With a high value biomass market for fuel, European logging contractors will typically manage the slash as another separate product (Figure 9).

Figure 9: A European yarder system, showing the slash (just behind the yarder) being recovered and piled alongside the processed logs for subsequent grinding to make a biomass product.

Visser and others (2011) describe how non-merchantable logs, and or logs with very low value, can be stored on the landing for subsequent conversion into a quality firewood. For this to be successful the logs must be piled carefully to avoid contamination with dirt. Logs can also be moved to a central location for drying and subsequent chipping into a quality fuel chip. Quality fuel chips used for heating residential or commercial buildings can attract a high price.

Figure 10: Left - LWD harvest 'residue' being sorted and stacked by the logging contractor for subsequent conversion to firewood. Right - LWD carted from landings to a centralised location for drying and subsequent chipping into a quality heating product.

Harvesting activities that exacerbate the risk of debris flows.

For clarity, a brief description of debris flows is provided, and then harvesting activities that exacerbate debris flows are categorised into clear-felling, infrastructure and soil disturbance.

Debris Flows

As a general rule, debris avalanches and debris flows result from failure of a relatively shallow, cohesion-less soil mass on steep slopes as a consequence of surface loading, increased soil water levels, removal of mechanical support, or a combination of all three. Debris torrents are the result of debris dam failures. It is important to note that most landslides do not become rapidly moving debris flows. However, large initial landslides are more likely to result in large debris torrents, and small landslides can become large, rapidly moving debris flows and, particularly when they enter stream channels. Debris flows often move rapidly and can exceed 50 kph. They have the power to entrain both large rocks and stems. Some debris flows behave similarly to flash floods, except that they contain less water and more mud and debris (Oregon Forestry Dept. 2002)

The resulting debris from these mass movement processes may be deposited at the base the slope: such deposits supply small increments of sediment to the stream over long a period of time and may be much more important to sedimentation of stream gravels than the initial slug supplied during high flow periods, until vegetation cover is established (Figure 11).

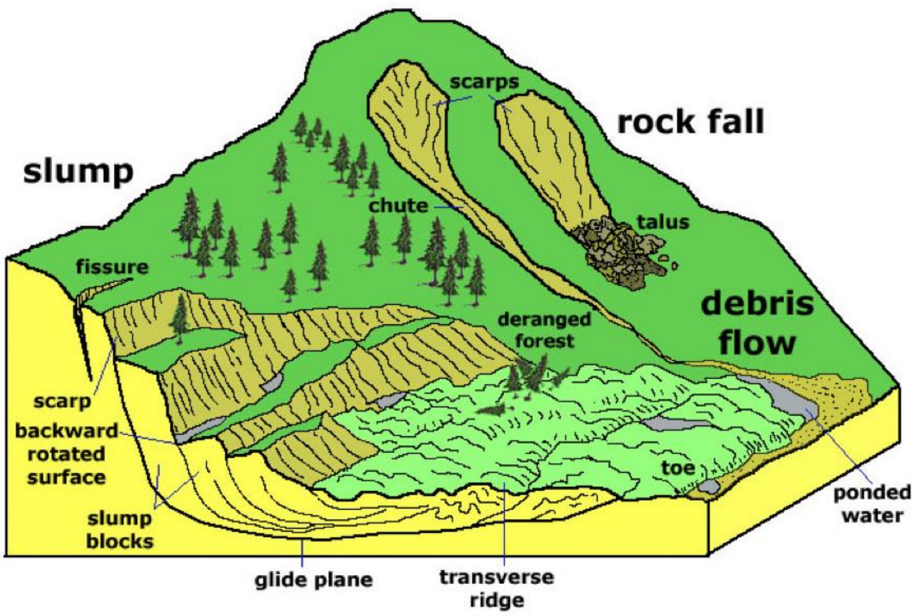

Figure 11: Geomorphic feature associated with landslides (Sourced from http://geologycafe.com/landslide/types.html).

Because of geologic processes, sites prone to shallow-rapid landslides are subject to these landslides, regardless of forest management (Washington State DEM 2013). If there is a high natural landslide hazard in certain locations, forest practices regulations can reduce the risk to people who are present in locations prone to shallow, rapidly moving landslides. The Washington State Department of Emergency Management notes that in the long term, effective protection of the public can only be achieved through the shared responsibilities of homeowners, road users, forestland owners, and state and local governments to reduce the number of persons living in or driving through locations prone to shallow, rapidly moving landslides during heavy rainfall periods.

Debris flows occur in a variety of mountainous settings worldwide (e.g. Hungr et al., 2005; Reid et al 2016), including steep forested slopes (e.g., Fannin et al 1993; Guthrie et al., 2010). Debris flows can occur naturally, and cannot be avoided entirely (Oregon 2013). This is supported by Raymond (2015) in an article entitled *"Crisis. What crisis? Maintaining our social license to harvest steepland forests"*, who stated that even if we're on top of our game with quantitative hazard identification, risk management, and BMPs in place, it is unlikely that landslides and post-harvest debris flows on steep erosion-prone land that is subject to intense rainstorms can be entirely avoided.

Even in an extreme storm event, only a small percentage of the landslide-prone locations will fail, but these landslides may affect a fairly large portion of the stream channel network. Channels where rapidly moving landslides have occurred in the past are likely to experience these landslides again in the future. Once landslide events have occurred, stabilisation is expensive.

In terms of mapping and planning for mass-erosion events, Basher and others. (2010) made a detailed comparison of the NZLRI, HEL and NZeem for use in mapping the land susceptible to mass movement affecting soil carbon stocks. They concluded that of the three different approaches used to define susceptibility to mass movement, potential erosion from the NZLRI provides the most robust and defensible definition. Bloomberg and others (2011) used potential erosion as shown in the NZLRI as the basis for the four category ESC system in the NES-PF. In terms of combining erosion classification with risk, using LiDAR based slope maps, Page and Jones (2012) provided a landslide susceptibility classification using four terrain stability class categories for the 2011 Ligar Bay event in the Nelson region (Table 2). However, in a review of science needs in terms of understanding the significance and management of debris flows, Basher and others (2016) suggested to develop improved terrain hazard zoning and risk management approaches for use at operational scales suitable for harvest planning.

Table 2. Landslide susceptibility classification using four terrain stability class categories (source: Page and Jones 2013)

Terrain Stability Class	Criteria	Interpretation
1	• Majority of slopes are <20°. • Slopes occur on or near ridges and spurs that are usually >50 m from streams, or are not contiguous with streams (e.g. drain onto fans). • No evidence of landslides.	Low likelihood of landslides following logging and road construction. Minor collapse of road batters.
2	• Majority of slopes are 20-45°. • Slopes are usually >30 m from streams, in basins with contributing area <50 m^2 • Evidence of occasional landslide activity.	Moderate likelihood of landslides following logging and road construction. A proportion of landslide sediment will be retained on slope.
3	• Majority of slopes are 30-45°. • Slopes are usually <30 m from, and contiguous with stream network, in basins with contributing area >50 m^2 • Evidence of landslide activity.	High likelihood of landslides following logging and road construction. Sediment and debris will enter directly into a stream.
4	• Majority of slopes are >45°. • Slopes are usually <30 m from, and lead directly into streams, in basins with contributing area >50 m^2. • Evidence of landslides entering the stream network.	Very high likelihood of landslides following logging and road construction. Landslides are often large and may contribute to debris flows/floods

Impact of Clearfell

Vegetation removal often has a negative effect on the stability of steep slopes (O'Loughlin 1995; Swank et al 2001; Phillips and Marden 2015). 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, illustrated in Figure 12 (based on Phillips et al 2012). This is supported by Andreoli and others (2007), who noted that the destruction of the root network caused severe slope instability, which in turn resulted in debris flows able to transport LWD into the stream, prompting the formation of massive valley jams. Tre roots also extra moisture and reduce slope loading, but also reduce pore pressure to create slope instability (Greenway 1987)

In New Zealand, 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, whereby it was reported that they are usually caused by storms with return periods greater than 20 years, though smaller events have occasionally caused problems (Amishev et al 2014).

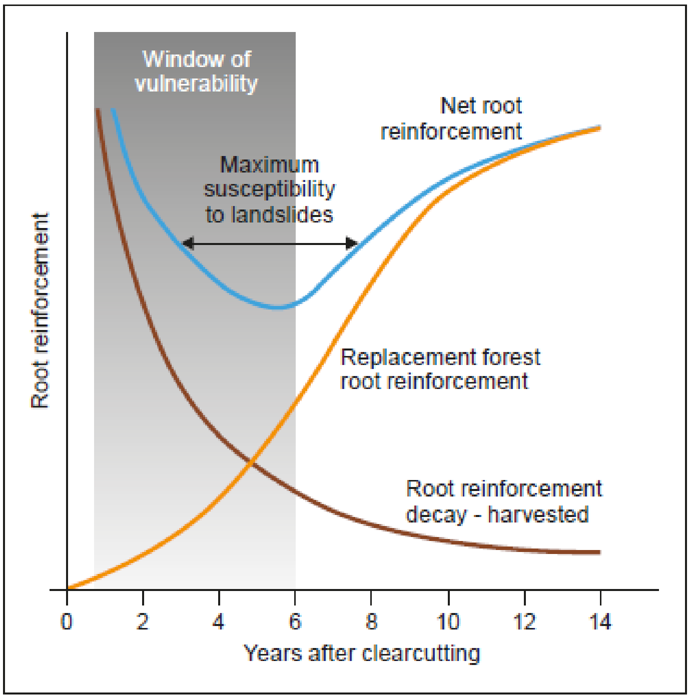

Figure 12: Typical changes in forest vegetation root strength after timber harvesting (from Phillips et al 2012).

In an Oregon Department of Forestry storm impacts study, higher landslide densities were found in stands that had been harvested in the previous nine years (as compared to forests older than 100 years), at least in three out of four study areas. Forested areas between the ages of 30 and 100 years typically had lower landslide densities than mature forest stands (over 100 years old). They noted that most existing research on the effects of forest removal on slope stability has focused on root strength. Imaizumi (2007) studied the effects of forest harvesting on the occurrence of landslides and debris flows in steep terrain of central Japan and concluded that debris flows associated with forest harvesting can cause much destruction, and that the influence of the timing of harvesting on these mass wasting processes needs to be assessed.

Land instability through vegetation removal is not unique to forestry; 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.

Infrastructure

Forest practices can alter the physical landscape and its vegetation, which can influence the stability of steep slopes (Oregon Forestry Dept. 2002; Fahey and Coker 1989; Fransen 1998). Roads and landings were regarded as primary sources of landslides in harvested forests that transformed into debris flows in a wide ranging review of harvest practices in the PNW and Alaska (Swanston 1974a, 1974b), noting that soil failures resulting largely from slope loading (from road fill and side-casting), over-steepened bank cuts, and inadequate provision for slope and road drainage. Marden and others (2006) stated that most research on erosion in New Zealand plantations has concentrated on effects of roading and associated mass-movement (landslide) erosion. For example, Coker and Fahey (1993) reported on road related mass movement; Coker and others (1990) reviewed the risk and prevention of landing failures; and, Langford and O'Shaughnessy (1977) showed the impact that poor roading and harvesting practices can have on stream water quality particularly in steep country with unstable or erodible soils.

Figure 13: Aerial Photo showing extensive soil disturbance form building roads and tracks (photo: Vince Udy, Waikato Regional Council)

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. Amishev and others (2014) reported that most failures originate on slopes within the cutover that have no connection to infrastructure. However, Brown and Visser (2017) still found that 50% of sediment breakthrough (where sediment entered waterways in a concentrated location) originated from roads, trails and tracking. Langford and O'Shaughnessy (1977) confirmed that the introduction of good practice prescriptions can markedly reduce these impacts.

Fransen and others (2001) reviewed 12 New Zealand studies of erosion from forest roads and found that surface erosion from roads at harvest times may increase sediment yield five-fold compared with that from pre-harvest ungraded and lightly used roads. Infrequent road-related mass movements are major sources of sediment within forests and overall yield up to seven times as much sediment to the waterways as simple surface erosion. Mass-movement erosion rates decline with road age.

A unique risk scenario for forest road infrastructure and woody debris is the construction of corduroy roads (Arnold and Gaddum 1995; NZFOA 2011). While such a construction technique is designed to prevent the collapse of roads, if such a road does collapse it will also introduce large woody debris into the environment (Figure 14).

Figure 14: Corduroy road, where logs are used to help support road construction on soft or unstable slopes.

Earthwork can be affected by relatively short return period rainfall events. Oregon Forestry Dept. (2002) recommend minimizing road-building to reduce risk, and that earthworks should completed as soon as possible so that the risk of being hit by an extreme storm event when the work is still in progress is minimized.

Landings in New Zealand are typically very large by international standards. A survey by Visser, Spinelli and Magagnotti (2010) showed the average landing to be 4,000m^2, ranging from 2,500m^2 up to 8,000m^2. The primary factors for driving landing size was the average daily production and number of log sorts, but the study also showed that landings increase in size during use. Landings on steeper terrain tend to be smaller, but that is also linked to those cable logging operations having lower daily production expectations and being required to cut fewer log sorts. Pushing a landing into a hillside requires larger cut and fill slopes. Larger landings, and or landings built on steep slopes, will have considerable cut and fill sections. As such minimising the landing size, with particular attention to fill slope, will minimise the risk of collapse.

Soil Disturbance from Harvesting

Harvesting can create significant soil disturbance in the cutover (Wallis and McMahon 1994; Marden and Rowan, 2015; Fahey et al. 2003; Marden et al., 2006). This disturbance leads not only to erosion, but in recently harvested forest area even smaller rainfall event are also know to create significant sedimentation and or debris flow events. Swanson and others (1976) found that 83% of debris flows in an Oregon study were triggered by hillslope slides. Amishev and others (2014) noted that now most failures originate on slopes within the cutover with no connection to infrastructure.

In terms of understanding, and helping predict the risk or erosion, Bloomberg (2011), using the Saunders and Glassey model, noted that erosion susceptibility is determined by two interacting factors. This is the *predisposition* (of a land unit) to erode, and *preparatory* factors. *"Predisposition to erode is an intrinsic quality of a land unit determined by soil type/lithology and topographic characteristics (slope, aspect, drainage pattern, slope position or landform element). A land unit with a specific predisposition to erode may be placed at greater likelihood of erosion by preparatory factors. Examples relevant to forestry are removal of forest cover by land preparation or harvesting, interruption of drainage patterns and earthworks which undercut, and/or create unstable surcharge on, previously stable slopes. Examples of natural preparatory factors include undercutting of toe slopes when rivers change their course."* Certain forestry regions in New Zealand have strong predisposition; for example Gisborne where the combination of soft rock geology, climate, vegetation clearance causes severe erosion and long-term damage to the productivity of rural land *(*http://www.gdc.govt.nz/erosion-management/*).* Even at the national scale, Bloomberg and others (2011) show that 33% of the current plantation estate is rated either high or very high as to land prone to severe erosion.

In terms of forestry studies, Pearce and Hodgkiss (1987) noted a 1.5-2 year return event caused significant erosion from a landing on steep slope, with sediment 3000 times higher than from adjacent undisturbed area. Phillip and others (2005) noted two 1.5-2 year return events on recently harvested areas on volcanic soil caused peaks in sediment yield, with 37% of total annual sediment recorded during these two events. In terms of level of disturbance, Marden studied the amount of surface (sheet) erosion ("slopewash") from cable logging sites. Deep disturbance areas comprised 9-15% of study areas, and contributed ~85% of total slopewash from all disturbed sites. Where deep disturbance sites (including the soil deposited by soil scraping) were connected to channels, these sites contributed to sediment loads in catchment streams.

Other broader factors to consider is parity with other land use; in that soil disturbance and overall that long term sediment yield from pastures is greater than from forested areas (e.g. Fahey and Marden 2008). Rainfall patterns are difficult to describe and predict, but a 50-year return period 1h storm will impact a cut-over differently compared to a 50 year 24h storm event

In terms of steep slope harvesting practices, some exacerbate the risk of soil disturbance. For example cable logging is done from ridge to ridge using North Bend or 'scab', which can cause scouring of hillslopes and sweeping of logging debris into stream channels if there is not enough deflection to at least fully suspend the log butt (Raymond 2015). Raymond notes that multi-span skyline systems using intermediate supports are a harvesting technique to manage the risk of landslides and debris flows on steep terrain by reducing soil disturbance. In pine plantations in Chilean steep terrain they use such systems, as well as permanently protected riparian areas, to avoid extraction of timber across or through waterways. As such it is possible to choose systems that are complementary to permanent, forested riparian areas. In New Zealand, a study by Harrill

(2014) showed a preference for motorised carriages to protect Streamside Management Zones (SMZs).

Figure 15: Cable logging across a gully system – if not enough deflection is available then extracting stems from the back face will sweep the logging slash into the gully system.

As forest operations shift to steeper slopes, they play an increasing role in initiation and acceleration of soil mass movements.

Harvest Residue on the Cut-over

Amishev and others (2014) surmised that 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. Basher (2016) summarizes the need to balance the benefits of using slash for erosion control (i.e. leaving in the cutover, spreading on skid trails, stabilizing gullies) for small and medium-sized rainfall events with the risk of a big debris flow during a larger.

While it makes little economic sense retrieve residue left on the cutover, taking all LWD from any slope at risk of debris flows will mitigate the risk of the debris moving off-site and causing downstream damage. Minimizing breakage during felling and extraction will also ensure that most stem wood is extracted to the landing where it can be more readily managed and secured.

Figure 16: A typical post-harvest photos of a cable logging operation, showing that the post-harvest residue is concentrated around the landing area.

The North American Sustainable Plantation Forestry Initiative (SFI, 2015), which is the primary certification scheme for pine plantation forests, specifically recognises that down woody debris is an integral part of the forest stand structure “Forest stand structure refers to a number of characteristics, including the physical arrangement of trees, snags, and down woody debris.

Learning from recent events

Whakatane, BOP

In 2011 there was a major event in the Whakatane area, Bay of Plenty, where approximately 5% of the affected area was forest area where debris was flushed out with subsequent sedimentation of the streams and risk to infrastructure due to debris build up (Douglas and Stokes, 2011). While pastoral catchment were also affected, they yielded water and mud. The event was triggered by extreme rainfall: with peaks >50 mm/h, 250 mm/24 h, in excess of 100-year storm event on soil already saturated by heavy rainfall the previous week. Saturation by prolonged rainfall is an important predisposing factor leading to mass movement, rather than simple erosion. The reported conditions were: Slopes >25°, lythology: Greywacke (highly indured sandstone with significant clay content).

For the forest areas, the reported damage was greatest on sites harvested within last 5 years, and worst if within last 2 years. The report details the different erosion types that contributed to the overall problem, including; sheet and soil slip, gully headward, debris avalanche, streambank erosion.

Report Recommendations

Earthwork construction: it noted that for that region the risk for extreme storm events is highest in Summer/Autumn, so earthworks should be planed accordingly. For the cutover itself, it also noted that the risk is increased if post-harvest regime is pastoral rather than new forest.

Planning: areas with slope > 25° be mapped, and the underlying geology in these areas identified. In erodible areas only partial harvest should be considered.

Harvesting: Slash was to be removed from the site (esp. large, such as slovens, logs >4 m SED 30 cm) and that slash was not to be pushed over the landing edge. It also highlighted the use of a stable excavated bench to put slash, or to simply burn the slash. For non-merchantable trees in the stand it was recommended they be poisoned and not cut-them-to waste. Slash racks should be build with railway irons and cables in fan areas (not across gullies),

Golden Bay, Nelson Marlborough

Bloomberg (2014) detailed the 2013 event in Golden Bay, Nelson Marlborough Region, where a 137 ha stand of radiata (on 213 ha catchment) on highly erodible and unstable Separation Point granite, with a 200-year return storm event delivered 450 mm of rainfall in a 24 hour period.

Report Recommendations

Earthwork construction: Consider restricting the main access road to a ridgeline location, with no side-cutting within the study area.

Planning: Spatial mapping of risk and exclusion of any new development in high-risk areas. Careful management of upstream catchments to minimise land-sliding and subsequent initiation of debris flows.

Slash: channel works to control and contain the debris flow as it moves across the fan, and build debris retention structures to trap coarse debris while allowing through flow of fine debris and water.

Harvesting: extract and store all biomass to a 10 cm SED and length >3 m from high risk areas.
Future Planting: Replant Class1 and 2 sites with Radiata, Class 3 with A. melanoxylon (longer rotations), and Class 4 with native species (for classification, see Table 2 on page 26 by Page and Jones 2013)

Cyclone Cook Slash Investigation, Gisborne

A report on cyclone Cook striking Tairawhiti is the Gisborne region (Cave, Davies and Langford 2017). Of particular interest is that the storm itself had a relatively low return period of 1 to 8 years, but that 80+ mm in a 3-hour period caused woody debris to mobilise. It also noted that some slash catchers failed or were damaged by the event. As part of their study, they investigated the composition of the woody debris with pine being approximately 70% of the total and the presence of freshly cut logs gave concern as to how forest harvesting contributed to exacerbate the resulting damage.

Report Recommendations

Earthwork construction: That roads and tracks are designed to minimize risk of failure, with side-casting avoided as much as possible, and that their erosion control structures mitigate the migration of sediment to the receiving environment using silt traps, settling ponds, bunding and silt fencing. That ridge-top landings are placed and constructed in such a way as to eliminate the risk of edge failure, and that they are designed for storage of slash.
Slash: That slash catchers are subject to rigorous engineering design. That the practice of storing slash on floodplains be discontinued and that the slash is either removed or protected from mobilization.

6. Harvesting practices and post-harvest mitigation strategies for reducing woody debris and the risk of mobilisation within planted forests.

In forestry, the concept of Best Management Practices has always relied on implementing multiple elements to minimise the overall impact of harvesting activities. There has never been a single solution to a specific problem and there will always be a risk of harvest residue leaving a catchment during larger storms, especially on highly erodible soils. Infrastructure and harvesting effects are difficult to avoid or eliminate and most often are minimised. Internationally, the most common concept for managing the adverse effects of infrastructure and harvesting is the application of best management practices (BMP’s).

BMP’s are considered a desirable standard of management, whereby the regulatory authority will accept unintended consequences (e.g. major erosion events) as a failure of the BMPs, not of the harvest operation.

- BMPs are effects based, that means BMP measures can vary according to both risk and potential effects (Hodges and Visser 2004).
- BMPs should contain enough detail where they can be readily assessed for both level of implementation and technical compliance (Yonce and Visser 2004).
- There must be an agreed process for departure from BMP’s where necessary to achieve environmental standards. The applicant can make a technical case for design or operational standards that are lower than those in the BMPs.
- BMP’s are ‘live documents’ with an agreed process for review and updating. As new information becomes available expectations and standards may be changed.

The authors recognise that there are few hard and fast rules for either infrastructure or harvesting that will best mitigate the risk of harvest residues moving off-site. We also note that the NES-PF has specific rules relating to slash and these are discussed in the previous section.

Planning

Planning and managing risks are often reported as being paramount with regard to harvest residue (Ballie 1999). Hazard refers to the inherent susceptibility of a given location to some event that could produce negative consequences (for example, the likelihood that a landslide or debris torrent will occur). Risk is the likely consequence associated with the occurrence of a hazard negatively impacting a valued resource (https://en.wikipedia.org/wiki/Return_period). Landslides can occur without having a significant effect on any resource, but the greatest perceived risk is typically that it poses a risk to people. So while the probability and magnitude of a significant rainfall can be calculated and are used to design elements such as stream crossing (culvert or bridge) design, determining the risk has to include an evaluation of the potential downstream impacts.

Specific practices that should be considered at the planning stage for minimising the risk of harvest resides mobilising include clearcut limit, use of streamside management zones (SMZs), choosing harvest systems that minimise soil disturbance.

Figure 17: A cable logging operation where every effort was made to clear the cut-over of LWD – leaving a very 'clean' site.

Criteria to determine site specific logging slash management strategies around streamside management zones would combine the value and importance of the waterway (Visser and Fenton 1993) and physical parameters such as the flow permanence (e.g. perennial vs. intermittent vs. ephemeral), catchment size and stream size (e.g. 1 m or 3 m wide) proposed by Baillie (1999).

Clearcut Limits

- ***For high risk catchments (orange or red in NES-FP), a move towards clear-cut limit of 60 ha. or 25% of larger catchments, should be introduced with an adjacency constraint of 3-4 years.***

Clear-cutting, also known as clearfelling, is a forestry/logging practice in which most or all trees in an area are uniformly cut down. It is a commonly accepted harvesting practice, with most certification schemes accepting it. Clearcutting as consistent with sustainable forest management principles in the right forest ecosystems. Clearcutting can accomplish the following: it mimics some of the natural disturbance dynamics of the forests (e.g., fire, wind blow downs, insects); it allows regeneration and rapid growth of certain tree species; it costs less, making forestry more economically viable, and it provides safer working conditions for loggers.

The issue with clearcutting is the scale at which it is implemented. Clearcutting larger catchment areas changes the hydrological response to rainfall events (Bosch and Hewitt 1982; Davie and

Fahey 2005. Many studies in forested catchments have shown that clearfelling a larger portion of the catchment will increase the hydrological response from a rainfall event (Hornbeck et al 1997; Swank et al 2001). Research cited in Sidle and Ochiai (2006) suggests that limiting coupe sizes and or partial harvesting are highly effective ways to reduce erosion susceptibility of forest lands. A rule-of-thumb is that harvesting more than 25% of a catchment will show a significant change in peak flood. This combined with the increased availability of harvest residues, and the movement of soil, combines to increase the risk of a debris flow.

Clearcut limits serve multiple functions, whereby initial restrictions will typically originate from hydrological impacts, further restriction based on ecological, wildlife or aesthetics value. In the US, their Sustainable Forestry Initiative (SFI 2015) certification, which is the most applicable to pine plantation forest management, limits average clearcut harvest areas to 120 acres (approx. 50 ha.). This clear-cut limit is similar as that for steep terrain in Washington, with in clearcut limits of 150 acres, but considerably lower in California with 40 acres (approx. 15 ha.). Interestingly this is larger than the clearcut limit for flat or rolling terrain with just 30 acres, reflecting the difficulty of planning forest operations on steep terrain (California Dept. of Forestry 2017). To put a 60 ha. clearcut limit into perspective, it would still be 150 days of continuous work for a cable logging crew producing 250 t/day.

Figure 18: Aerial photo of harvesting activity in California showing the clearcut size limit, adjacency constraints and the use of permanent SMZs.

There clearcut limits will typically also have adjacency constraints. These can be very pragmatic – for example in Washington the rule is: “For harvesting operations that remove all or most of the largest trees, operators shall ensure that no more than half the area of high landslide hazard locations on a single ownership within the drainage or hillslope directly above the affected structure or road are in a 0 to 9 year-old age class or with reduced canopy closure in other age classes”. For the SFI certification programme it is when the trees in the clearcut are 3 years old, or 1.5m high, then the neighbouring stand can be harvested.

In central Europe, Austria, with a large forest industry, legally restricts clearcuts to 0.5 ha. with an exemption allowing a harvest up to 2 ha. In comparison, in Germany and Italy in principle restrict all ‘clearcuts’, allowing only patch-cuts, thinning or single tree selection. This does results in higher harvesting costs (Spinelli et al 2015). For very high risk sites alternative management practices can be considered. Amishev and others (2014) suggested New Zealand forestry could also considering partial cut thinning operations to maintain continuous cover, but noting the need to change our current cable logging technology towards European-style yarding that is specifically designed for that purpose. They also suggested considering small coupe harvesting with adjacency constraints like in North America. 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. The other comment was to replant quickly and at higher density to obtain rapid cover.

Figure 19: European style forest practices, of longer-term rotations and smaller patch cut harvests results in very little soil disturbance during harvest.

Use of Streamside Management Zones

- **SMZs should be developed and implemented in all forested areas and protected during harvest.**
- **Sensitive catchment areas should ensure retention of large trees in the SMZs to help restrict the movement of large woody debris.**

Streamside management zones are a commonly used to mitigate the impact of harvesting (Basher et al. 2016; SEPA 2009; Borg et al 1988). Their primary purpose is both to preserve the aquatic ecosystem, but for forest harvesting also to minimise the delivery of sediment in to the waterway and thereby maintain water quality standards (Quinn 2005). Harding and others. (2000) reports “Maintaining a buffer of riparian vegetation throughout the forest rotation can avoid or reduce many of these changes in stream habitat due to clear-felling." Streamside management zones are most commonly not exclusion zones, and as such will differ by region in terms of width, required vegetation and or canopy cover, and restriction with regard to harvesting practice such as tree removal or equipment entry, and such an approach was promoted in New Zealand by Visser and Fenton (1994).

Figure 20: An aerial photo of a plantation forest (from Texas USA) showing SMZ that protects water quality. SMZ need not be no-cut zones, but enough vegetation remains to avoid direct harvesting impacts, to intercept erosion, and on steeper slopes mobilised harvest residues.

While much of the SMZ literature and guideline material focuses on water quality protection and keeping the impact of harvesting operations away from the stream edge (e.g. Keim and Schoenholtz 1999), there is also clear reference to keeping woody debris out of the waterway and that 'Buffer' strips can also slow down flood flows as well as providing bank stabilisation and habitat (Toews and Moore 1982). In the MPI report (Amishev et al 2014) recommended creating setbacks for the creation of riparian areas. In the Oregon rules for riparian buffers, the protection of 'Torrent-Prone Streams' are to reduce or eliminate woody debris loading. While many of the rules pertain to the actual felling and extraction practice, they aim to leave larger diameter trees to catch woody debris coming from the cut-over. There is a caveat in their rules with regard to not leaving trees that pose a greater public safety risk because of windthrow.

Much of NZ's steep slope plantation forests currently planned for harvesting was established in the 1970s and 80s and were planted to the stream edge. This is recognised as a legacy problem also facing other countries, for example Scotland. Streamside management zones are best established at time of planting, where consideration can be given to the type of vegetation suited to the area. Leaving a buffer strip of plantation gown radiata along a waterway may result in extensive wind-throw. Although there is no clear research outcomes that suggest wind-throw mobilises readily, downed large woody debris that is at least partially embedded into the terrain is considered stable.

Baillie (1999) reported that streamside management zones or riparian vegetation were used in only two cases to keep slash out of streams. However, Visser and Fenton (1994) suggested that just designating an SMZ and keeping logging machinery away from the streams edge can result in less slash in the channel from harvesting. While there are clear environmental benefits of SMZs, a study by Visser and McConchie (1993) showed that in catchments with a stream density of 40m/ha, a 20m buffer strip (either side, and assuming they would not be harvested) would account for about 5% of the forest area, and that to protect riparian vegetation during harvesting there would be a need for additional roads.

Commercial forestry (both plantation and native) in the Eastern USA all have SMZs as part of their BMPs. While they vary by state, a common design is 50ft (approx. 15m) on all intermittent streams, perennial streams, and perennial waterbodies with a requirement to leave 50% of the canopy. SMZ wider than 50ft are required for: steep slopes adjacent to the stream; long, continuous slope lengths leading towards a stream; highly erodible soils; soil areas with little or minimal groundcover that are near the waterbody, areas of intensive soil disturbance nearby the SMZ, and special waters, such as trout spawning or water supply (North Carolina Forest Service 2016).

Forestry in Australia, especially when harvesting native vegetation, has had SMZ requirements since the 1970s. Borg and others (1998) studied the effects of logging in stream and river buffers on watercourses and water quality in six catchments in the southern forest of Western Australia. All cut-over areas were regenerated to forest soon after logging. Their findings showed that reducing the width of river buffers from the usual 200 m to 100 m (3 trials), and or from the usual 100 m to 50 m (2 trials) had no effect on the watercourses or water quality. While making it clear that they were not advocating the complete removal of buffers because of the risk of damage to a watercourse, they did conclude that relatively wide buffers brought no benefit in terms of water quality, as long as logging is confined to the dry season, and all roads and tracks are built and drained properly and located away from the watercourses

The dominant forest certification system for plantation forests in the USA, the Sustainable Forestry Initiative SFI (2015) has a Performance Measure 3.2 also states that program participants shall implement water, wetland and riparian protection measures based on soil type, terrain, vegetation, ecological function, harvesting system, state best management practices (BMPs), provincial guidelines and other applicable factors. The required indicators include addressing management and protection of rivers, streams, lakes, wetlands, other water bodies and riparian areas during all phases of management, including the layout and construction of roads and skid trails to maintain water reach, flow and quality, and mapping of rivers, streams, and lakes.

Landing design

- **Minimise landing size on steep terrain to less than 3,000m², and ensure established best practices for fill compaction and drainage are implemented.**

Landings pose risks for debris flows, both with regard to mass soil movement and the harvest residues that accumulate at the landing edge. There is considerable generic guidance in the NZForRoadManual on 'Reducing adverse impacts of landing earthworks': including locate landings on stable sites; locate away from watercourses; prevent run-off onto landings or fill; always strip and remove organic material from the construction site; benching around landings will control slippages or other material from rolling down the cutover; use cut and fill or end-haul techniques on sensitive sites; avoid sidecasting; compact fill areas in layers to ensure stability (and also prevent water infiltration and weakening of the structure); always have good drainage away from the landing sites; slope landings away from fill batters by approximately 3%; avoid wet weather construction; allow sufficient time for stabilisation before use.

In terms of what constitutes a good of benched landing, the NZForRoadOpGuide (pages 24-27) shows how fill slopes that have been compacted in layers, no stumps in the fill; choosing a good landing location to minimise earthworks and ensure stability; compacting the landing surface and ensuring that the landing is sloped (i.e. 3% away from fill slopes). The PFOlsen Workshop Guide (2017) provides additional guidance on benching: it should be carried out on slopes between 20 and about 35 degrees, but benching does not work on slopes steeper than 35 degrees. The reason it doesn't work is because the fill slope would have to be steeper than 35 degrees (70%) to connect with the hillside and this this is too steep for a fill slope gradient, which is typically no greater than 1.5 to 1 (67%). The PFOlsen guide also recommends to remove all organic material from earthworks. The focus for water control is to control it in small amounts with berms, cross-drain culverts, cut-outs, ditches; and to reduce runoff velocity by controlling road gradient. Use fluming where applicable to move water below the fill slope and onto stable ground, and slash can be used to dissipate energy

There are alterative landing types for steep hauler country that could aid in better slash management. One is to build a split level landings which has advantages that include less earthworks, shorter batter slopes, and possibly improved deflection. It also provides for improved post-harvest recovery of slash and storage away from fill slopes. The other alternative is to use extraction pads for the yarder, and use a two-stage systems to extract to the timber to a larger landing, in a more stable location, for the processing (NZForRoadManual).

Best practices for harvesting

- **Set standards for acceptable levels of soil disturbance and cut-over harvesting residues, which should be 6% for all harvest areas, and consider reducing to 4% for high risk area.**
- **Provide mitigation measures for all deeply disturbed soil areas greater than 200 m^2 that are caused by harvesting practices.**
- **Consider choose harvest systems with integrated wood residue recovery systems.**

In principle, the goal is to choose harvesting systems that minimise both soil disturbance and slash generation. There is a strong preference on steep terrain cable logging over ground-based logging for minimising soil disturbance (Oregon Forestry Dept. 2002). Using skyline systems that extract uphill (gully to ridge) will help avoid slash accumulation in waterways (Ballie 1999). Improving deflection and ensuring ground-clearing will avoid scouring of the slopes during extraction across the cutover. As reported in the previous section, integrating biomass recovery at the time of harvest will mitigate most risks associated with both landing collapse, and the availability of harvest residues. However, post-harvest residue recovery around the landing will also remain acceptable in lower risk areas.

Figure 21: An excavator is used to 'feed' the motorised grapple extraction system. While an excavator can readily clean up the cut-over from all LWD, the risk is a greater level of soil disturbance.

Slash Traps

- **Construct Slash Traps designed to intercept harvest residue movement expected in a 20 year return period flood event.**

Barriers or slash traps have been used to prevent harvest residues from moving off-site. While Ballie (1990) reported that many New Zealand companies had a 'just leave it' approach to managing slash, Froelich (1971) reports on using barriers to reduce logging slash once it gets in streams in western Oregon. ECoP (NZFOA 2008) also talks about using slash traps downstream of areas where you can't do slash removal.

Slash traps are particularly suited to alluvial fan area below areas with a significant risk of woody residue mobilisation and debris flow generation (Amishev et al 2014). However, little information is currently available on the efficacy of slash traps and in his report on the Cyclone Cook event, Cave and others (2017) noted that many slash traps had failed. Basher (2016) called for studies to provide detailed designs of debris catching structures and to evaluate their effectiveness.

The NES–PF provides the following guidance on slash traps:

- ***Design***: Allow water to flow freely through structure; Height of structure no more than 2m above stream bed.
- ***Placement***: For catchments > 20 ha, structure must be outside the bank full channel width; Machine must be able to access for clearing/maintenance
- ***Inspection and clearance*****:** Traps must be inspected within 5 days of a *significant rainfall event that is likely to mobilise debris.* Must be cleared of debris within 20 working days of a 1-in-20 year flood event. Must be maintained to avoid river bed erosion and to ensure soundness of the structure
- ***Reporting***: Written report to the Council within 20 working days of construction and an annual report detailing cleanout/maintenance, performance, and any adverse effects.
- ***Where to put the slash*****?** Somewhere stable, above the 1-in-20 year peak water level.

While full engineering designs for larger scale slash traps are available (Huebl *et al* 2017), most NZ designs are simple structures with: railway irons linked and anchored by wire rope (Figure 22). Other low cost materials include eucalyptus poles, steel grid, a debris dam itself, and a heavy duty fishing net. More substantial structures can be designed for higher risk forested catchments, and like battery culverts for stream crossing, are designed to overflow in high rainfall events (Figure 23).

Figure 22: Left - Gisborne slash trap in a headwater stream using crossed railway irons embedded in the stream bed. Wire rope is wrapped around the railway irons and secured to radiata pine trees. Right - slash trap installed using vertical railway irons. Wire rope is threaded through the irons and secured either to mature trees or with deadmen (buried anchors).

Figure 23: A more substantial debris catcher ('Slash Rack') installed in a higher risk catchment (Photo retrieved from USDA NRCS)

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Appendix – Information Provided by Gisborne District Council

Background

Planted forests covering approximately 155,000 ha in the East Coast region of New Zealand, and provide an important financial and employment contribution to the local economy. A large proportion of these forests are on steep erosion-prone land, however, and subject to intense rainfall events. Large rainfall events have the potential to mobilise woody debris, particularly post-harvest residues (logging slash) on steep unstable land. Once mobilised this material can travel off-slope, migrating downstream beyond the forest boundary where is it deposited onto floodplains, river margins and beaches. This material can pose a risk to downstream infrastructure and receiving environments. Any logging slash deposits remaining within the catchment system will be at risk of re-mobilisation during future rainfall events.

While landslides or debris flows generated during high rainfall events are key processes for transferring post-harvest woody debris off steep slopes, a recent detailed assessment of a significant slash mobilisation event during ex-Cyclone Cook (April, 2017) by GDC indicated that other sources of logging slash, such as landings and logging slash located in floodplain areas, were the main contributors to this event.

The Gisborne District Council is seeking technical advice to improve their understanding on harvest systems and practices that generate or reduce logging slash residues, particularly for hauler operations on steep slopes. The review and assessment on woody debris generation during harvesting operations on steepland forests in New Zealand would assist the council in identifying those factors that have the potential to reduce woody debris generation in the East Coast region.

The project would involve the following steps:

- Complete a review on woody debris generation during harvesting operations in New Zealand
- Use this information, along with expert knowledge, to evaluate those site conditions and forest systems and practices that reduce/exacerbate woody debris generation, and the risk of its off-site movement, focusing on hauler operations in steepland country
- Provide guidance and advice to the council on harvest methods and practices and post-harvest mitigation strategies that have the potential to reduce woody debris generation and the risk of mobilisation within planted forests

Conclusions and recommendations for any further work

Linkages / Benefits:

The Gisborne District Council undertook a comprehensive review of a number of slash mobilisation events that occurred during ex-tropical Cyclone Cook 2017 and found that much of the woody debris comprised fresh cut logs, weathered cut logs with subordinate windthrow pine, willow and poplar. This project would complement previous work undertaken by Landcare on monitoring and reporting and the development of a risk matrix for landslides and debris flows generated within planted forests.

- The Gisborne District Council is seeking specialist advice on this topic as it is outside the technical expertise currently held within the Council and the scope is beyond council's 'business as usual'.
- This information is not readily available to the council and advice is needed to improve Council's understanding of the underpinning drivers of forestry practices that exacerbate migration of forestry slash and assist the formulation of consent conditions to mitigate the risks.
- School of Forestry has the expertise in harvesting systems and technologies, logging waste residues and management and woody debris dynamics in waterways and are available to undertake the work.
- Council is constrained from placing conditions on forestry companies as a result of the lack of access to empirical data and independent expert opinion to back up those conditions.
- New practice for forestry management is set by the NES for plantation forestry, however, this sets a minimum standard and does not necessarily assist for regions such as the East Coast where the geology and climate means that the environmental risks of forestry are considerably higher than the risks at a national level.
- The results of this project will greatly assist Council manage the environmental impacts of forestry harvest long term and may inform amendments to the NES over time.
- This project may assist other councils, for example Hawkes Bay Regional Council, who face similar issues.

Implementation

The overall expectation of this research is that it will be one of a series of building blocks that are being put in place to manage the long term environmental impacts of the "wall of wood" we know we will need to manage over the next decade.

The advice will be used by council staff to improve their understanding of tools available to mitigate environmental risk. We expect to engage with the forestry industry to reach a better understanding of the issues that this advice along with the other in-train advice grants.

This advice will support council to make more efficient and scientifically supported decisions on the impacts of forestry.