MARLBOROUGH DISTRICT COUNCIL

MITIGATING FINE SEDIMENT FROM FORESTRY IN COASTAL WATERS OF THE MARLBOROUGH SOUNDS

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Mitigating Fine Sediment from Forestry in Coastal Waters of the Marlborough Sounds

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Photo courtesy of Rob Davidson

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Cover photo *- Courtesy of Peter Hamill, Marlborough District Council*

Summary

In 2015, Marlborough District Council (Council) received a report of damage to a significant ecological marine site in the Marlborough Sounds (Sounds) from sedimentation caused by plantation forestry activities.

A review of scientific literature was undertaken to identify the causes and consequences of adverse effects from forestry in the Sounds. These effects include the smothering of seabed habitats by fine sediment, and discolouration of the water column, particularly in areas of low current flow in the Sounds. The ecological impacts observed included damage to sensitive biogenic (or 'living') habitats and a decline in fish numbers.

Plantation forestry is currently a permitted activity in most of the Sounds. However, the effectiveness of forest harvesting and earthworks practices, and the existing regulatory regime, in mitigating fine sediment deposition into coastal waters has been widely questioned over the years. Water column and seabed impacts were first identified in the late 1970s and further research occurred in the 1980s and 1990s.

Over a dozen scientific papers and reports from the Sounds were examined in this review, along with literature from elsewhere in the country. The review was informed by comments from Landcare Research scientists, and their analysis is included in full within the document. In addition, hydrodynamic modelling of sediment resuspension thresholds was done by the National Institute of Water & Atmospheric Research (NIWA) to identify areas of the Sounds susceptible to settlement once sediment enters coastal waters.

This review highlighted that generation of fine sediment associated with forestry harvesting is inevitable no matter how many, and how stringent, the controls. In part, this is due to the periodic occurrence of high intensity rainfall events, and the nature of the underlying lithology and soils in the Sounds. Fine sediment production is also a function of the periodic removal of forest cover and the gradual decay of root systems, which predispose soils to greater erosion risk. The susceptibility of soil loss by erosion is most pronounced in the 5-8 year interval between the decay of harvested tree root systems and the establishment of the next tree crop and/or seral plant species. This is the so-called 'window of vulnerability' to erosion.

This report discusses a number of options that attempt to reduce the transfer of fine sediment into coastal waters during this window. These options should be viewed as an integrated set of methods to mitigate sediment originating from different sources. This is because no mechanism on its own will be effective. The options include: a range of setbacks from the shoreline for replanting; controls on replanting on slopes over 30°; and a requirement for stricter engineering standards for forestry related earthworks, such as roading.

These controls are considered within the context of the proposed National Environment Standard (NES) for plantation forestry, currently being revised following public consultation. It is recommended Council proceed with developing its own rules due to the importance of the Sounds, the uncertainty around the final outcome of the NES, and in acknowledgment that the NES does not address the issues identified in this report.

In summary, a number of options are evaluated for improving soil conservation and water quality, and thereby helping to maintain indigenous biodiversity within the Sounds. The most likely to be effective are:

i. **Replanting setbacks from the shoreline**: 30 metres (m), 100 m, <u>or</u> 200 m.

ii. **Replanting setback for permanently flowing streams directly coupled to the sea**: 5 m for streams less than 3m in width; and 10 m for steams equal to, or greater than, 3m in width.

iii. **Replanting controls on steep slopes**: A mandatory Replanting Management Plan identifying areas at high risk of erosion which require retirement and implementation of buffers, such as gully heads and steep ephemeral gullies. A similar Plan would be required for afforestation.

iv. **Replanting requirements to reduce the window of vulnerability**:

   a) Replanting of areas harvested within 12 months of harvest.

   b) Replanting in excess of 1000 stems/hectare.

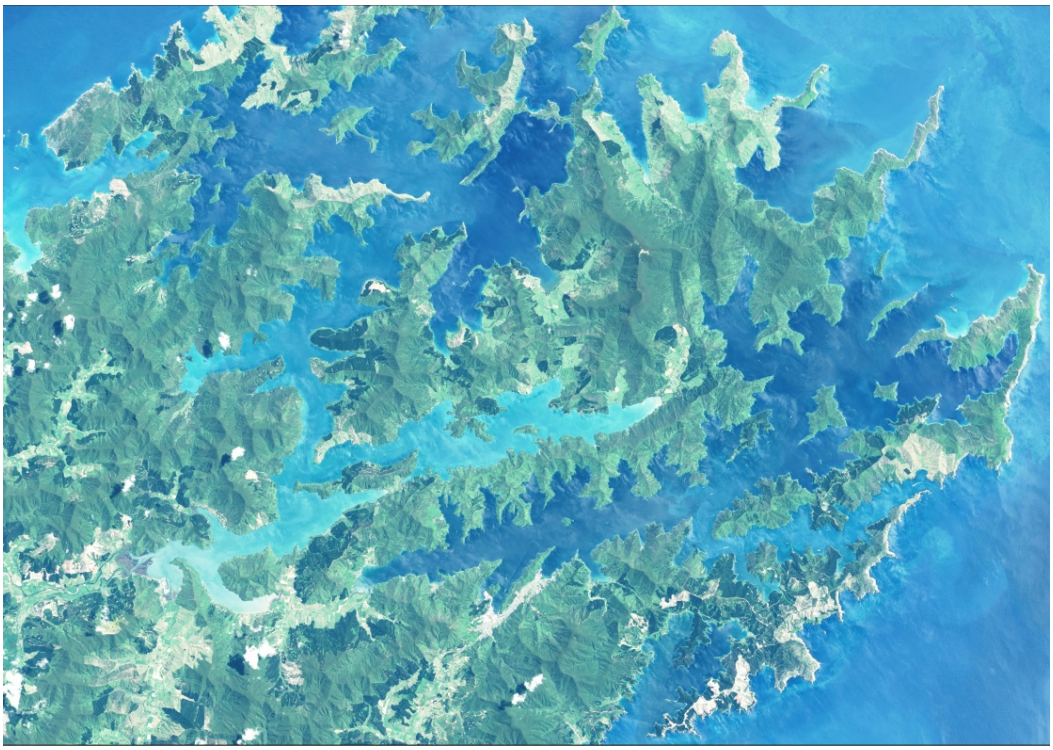
v. **Harvest controls**: Remove all woody material >100 mm diameter and > 3metres in length from gullies (>5000m^2 or 0.5 hectare) as soon as practicable, but no later than 1 month, after harvest.

vi. **Earthworks requirements**:

   c) All road design, construction, and maintenance to be certified by a Chartered Professional Engineer (CPENZ) for land stability, and effective erosion and water control.

   d) All areas of loose fill (soil) to have a grass cover established within 12 months of being created unless covered by natural revegetation.

Contents



The Marlborough Sounds from space *– 28 November 2015. Courtesy of Ben Knight, Cawthron Institute.*

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Scope and Structure of this Report

The report has been produced to assist in the ongoing development of the Marlborough resource management planning framework. It forms part of the 'Review' component of the continuous 'Review-Plan-Do-Monitor' resource management planning cycle.[i]

The scope of this review is focused on evaluating regulatory mechanisms that seek to reduce the amount of fine sediment deposition into coastal waters. It is therefore centred on regional responsibilities under the Resource Management Act 1991 (RMA) for soil conservation, water quality, and maintenance of biodiversity.

The structure of the report is set out as follows:

1. Extent of forestry in the Sounds and the current regulatory regime.
2. Ecological effects of fine sediment on coastal ecosystems.
3. Behaviour of fine sediments in coastal waters and water quality.
4. Factors predisposing forest soils to erosion in the Sounds.
5. Mechanisms to mitigate erosion after harvesting.
6. Proposed National Environment Standard (NES) for forestry applied to the Sounds.
7. Options for setbacks, slope controls, forestry earthworks, and post-harvest vegetation cover.
8. Review of options by Landcare Research.
9. Concluding remarks.
10. References and Appendices.

Section 1 outlines the extent and location of forestry and the current regulatory regime. Sections 2-5 provide an analysis of the causes and consequences of fine sediment production and transfer into coastal waters. This is derived from a review of published scientific literature on forestry-related activities in the Sounds. Table 1 provides an overview of this research, which is discussed in more detail within these sections.

This collective body of work shows that forestry-related activities increase the incidence of soil erosion, land slips, discolouration of the water column, and smothering of seabed habitats. The transfer of fine sediment into coastal waters also increases the extent and depth of muds (fine silt and clay) covering the seabed, but impacts on shallower intertidal areas can vary depending on the strength of currents and exposure to winds.

The susceptibility to the settlement of fine sediment within different parts of the Sounds is also discussed. This analysis has been informed by hydrodynamic modelling undertaken by the National Institute of Water & Atmospheric Research (NIWA). NIWA assessed the potential for fine sediments to settle onto the seabed, or to be re-suspended into the water column and dispersed. The analysis found that sediments will settle close to shore in most areas of the Sounds, due to the location of forestry predominantly above slow flowing bays.

Therefore, most of the Sounds will be susceptible to fine settlement deposition rather than dispersal, which means that regulatory management tools can be generically applied. This is important because the NES does not in its current form enable effects on sensitive receiving environments to be effectively managed. The likely failure of the NES to protect the ecology of the Sounds is discussed in section 6.

The review of the research in Table 1 was supplemented by studies elsewhere in the country. This provided a sufficient body of evidence on which to formulate sound management options, which are outlined in section 7. These options have been reviewed by Landcare Research scientists with experience in forestry impacts on soil and landform stability throughout the country. Their review is discussed in section 8, and it is included in full within Appendix 3. In Section 9, concluding remarks are made about the need for increased regulatory controls, given the national significance and importance of the Marlborough Sounds.

The report does not contain an economic analysis of the options presented. Although, there was an economic analysis of different harvest methods and sediment yields in 1991, and the figures are well out-of-date, it does offer a potentially useful framework which could be repeated.[ii] Similarly, there was an economic evaluation done in 2003 of a forest landscape management model, which sought to value a range of options that mitigate adverse effects on the environment over the forestry life-cycle.[iii]

These studies would be useful inputs into a contemporary analysis. This should include an exploration of the impact on ecosystem services of these options, in terms of the value of improved ecosystem processes from less fine sediment deposition into coastal waters and improved maintenance of biodiversity as a result. There may be the opportunity to seek such advice through the Government's Envirolink information transfer fund.

Table 1: Overview of scientific studies on forestry identified as occurring in the Marlborough Sounds since the 1970s. The full citations are in the Reference list.

Year	Author(s)	Type	Location	Summary
1979 & 1980	O'Loughlin	Scientific paper	Bay of Many Coves, QCS	Compared water quality between harvested and non-harvested areas. Sediment loads up to 13,000ppm from streams in harvested vs 30ppm in non-harvested. Laboratory tests to show sediments clump and settle on contact with seawater, due to high fine clay content.
1981	Johnson et al.	Scientific paper	Bay of Many Coves, QCS	Compared seabed below harvested and non-harvested areas. Found seabed smothered below harvested area, but was healthy and diverse below non-harvested areas. A photo comparison is in Appendix 1 (Fig. A1a).
1985	Laffan & Daly	Scientific paper	Sounds-wide	Characterised lithology and soils and identified the degree of weathering varied with altitude. Discussed the causes of superficial and deep seated landslides related to soil weathering, soil depth, and altitude.
1985	Laffan et al.	Scientific paper	Sounds-wide	Soils between coastline and 200m more highly erodible as more weathered, and produce most fine sediment after tree harvest/removal. Advised skyline & helicopter logging be investigated to reduce extent of earthworks.
1985	O'Loughlin	Report	Bay of Many Coves, QCS	Identified 'window of vulnerability' as harvested tree roots decay and replanted root networks. Management options made to reduce both the window and land-slides as clay-rich Sounds soils prone to land-sliding.
1987	Lauder	PhD thesis	Sounds-wide	Investigated the formation of coastal landforms, sedimentology, and sediment delivery to the Sounds.
1991	Murphy et al.	Report	Sounds-wide	Analysed different harvesting methods on sediment yields and economic costs and returns for three different forest blocks in the Marlborough Sounds.
1992	Sutherland et al.	Report	Sounds-wide	Report for development of coastal plan. Summarised information on natural processes and hazards in the Marlborough Sounds. Identified slope stability issues related to topography, lithology, and soil development.
1992	Fahey & Coker	Scientific paper	Tory Channel	Examined effects of forestry roads on fine sediment production into coastal waters. Estimated quantities of fine sediment to be up to 200 tonnes entering local embayments annually, thereby affecting water quality.
1993	Coker at al.	Scientific paper	Tory Channel	Quantified fine sediment from frequent logging truck movements, which produced 10 times the sediment after rainfall compared to background levels. Advised trucking and other heavy traffic be delayed after rainfall
1994	Coker	Master of Science thesis	Tory Channel	Reviewed the factors causing sedimentation in the Sounds from forest harvesting. Used a case study of a forest above Onepua Bay to suggest best practices.
1996	Phillips et al	Scientific paper	Tory Channel	Examined land-slides after 1994 storm. Found shallow soils in gullies on slopes >30° slipped and became debris flows with logging waste. Forestry has ongoing erosion risk due to steep slopes, weathered clay-rich soils, high-intensity rainfall, and coupling of land to sea.
1998	Fransen et al.	Scientific paper	Tory Channel	Looked at storm effects on seabed in Onepua Bay below a harvested block and a native forest. Found fine sediment increased far out into the bay at both sites. Less sediment close to shore below harvested area, due to hydrodynamics and wind exposure differences.
2003	Davidson & Richards	Report	Tory Channel	Baseline study of three estuaries in Tory Channel. Hitaua, Deep and Ngaruru Bays. All three were relatively unaffected by forestry at that time.
2015	Davidson & Richards	Report	Tory Channel	Identified Hitaua estuary smothered by fine sediment from a slip on a harvested area, high above the bay.

1. Extent of forestry in the Sounds and the current regulatory regime

The total area of forestry in the Sounds is approximately 17,440 hectares (ha) (Table 2). The largest contiguous concentration of production pine forestry (forestry) in the Sounds is in the Port Underwood and Tory Channel areas (Figure 1). In Pelorus Sound, there are a number of forestry blocks around the coastal margins of Mahau Sound, Kenepuru Sound, Hikapu Reach, and Crail and Clova Bays. There are also large forestry plantings around Croisilles Harbour. In addition, but not considered in this report, are extensive areas in the catchments feeding into the Pelorus Sound, such as the Rai, Wakamarina, and Pelorus.

Table 2: Area of plantation forestry in the Marlborough Sounds derived from the Land Cover Database 4 (2012).

Geographical Area	Area of forestry (ha)
Port Underwood	3288
Queen Charlotte & Tory Channel	5070
Pelorus Sound (including Anakoha, Forsyth & Admiralty Bays)	7091
Croisilles Harbour	1140
Tasman Bay	423
d'Urville Island	428
Total	**17440**

Forestry in the Sounds is currently regulated under the Marlborough Sounds Resource Management Plan (MSRMP).[1] In addition, the provisions of the NZ Coastal Policy Statement (NZCPS) apply. The relevant policies to this report are briefly summarised below.

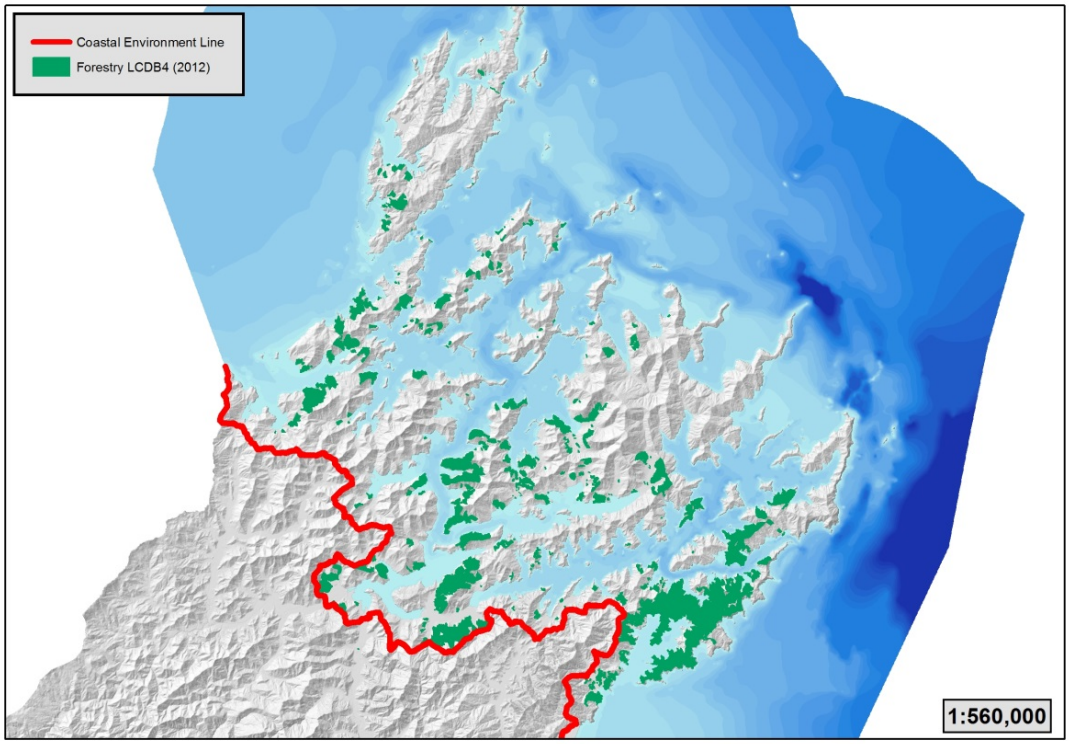


Figure 1: Map of existing production forestry in the Sounds from the land cover data base (LCDB 4). The red line is the Coastal Environment Line identified for the review of the Marlborough Resource Management framework.

[1] The MSRMP is available on Council's website: http://www.marlborough.govt.nz/Your-Council/RMA.aspx

The NZCPS has two objectives that are directly relevant to forestry in the Sounds: Objective 1: Ecosystem Integrity, and Objective 6: People and Communities.

Objective 1 sets out the requirement to safeguard and sustain marine and intertidal ecosystems. This includes water quality and benthic habitats. The NZCPS also recognises that use and development of the coastal area is needed for social, economic and cultural wellbeing. However, this is couched in the context of ensuring that habitats for marine resources are protected, and not compromised by activities on land.

There are specific policies which require significant effects on biodiversity to be avoided, remedied, or mitigated (Policy 11), and sedimentation from plantation forestry harvesting to be controlled (Policy 22).

The current MSRMP categorises forest harvesting and replanting as permitted activities under Chapter 36 (Rural Zone). Land disturbance associated with forestry earthworks is generally a discretionary activity in the Sounds, as the area of land disturbance typically exceeds the permitted activity standards of >1000m^3 on land with a slope angle of >20° and <35°.

There is no current setback from the shoreline for replanting in the MSRMP.

The permitted standards for land disturbance are usually carried through into consent conditions, when the activity triggers the volume and slope thresholds. These were designed to minimise erosion and the accompanying production and deposition of fine sediment, and included:

- No increase in suspended sediment by greater than 20%, as measured by the 'black disk' method.
- No woody material >100 mm diameter to be left in any permanently flowing river or in the sea.
- All land disturbance sites to be stable when subject to a storm event of probable return frequency of 10% or less.

In addition, there are controls on the gradient of side cut excavations, culverts and water tabling, batter and side-cast stabilisation, direction of run-off to stable land areas, river crossings, and riparian disturbance.

However, the application of these rules has been unsuccessful in preventing large pulses of sediment from regularly entering coastal waters, and resulting in the smothering of benthic habitats. For example, the storm that smothered Hitaua Bay in 2012 was subject to a storm event of return probability of <10% (1 in 5 years).[iv]

There are a number of interacting reasons for this, such as: the underlying lithology and soil erodibility; the window of vulnerability following harvest and the reestablishment of the next crop's root network; high intensity and/or prolonged rainfall events; adequacy of existing coastal and riparian setbacks; planting and harvesting in ephemeral gullies and on slopes >30°; and poor road construction and maintenance practices (Figure 2). These are discussed in the following sections. Firstly, though, the literature on known ecological effects of fine sediment deposited into coastal ecosystems is summarised.

Figure 2: Instability of fill areas after road construction in Pelorus Sound 2012. Source: Marlborough District Council.

2. Ecological Effects of Fine Sediment on Coastal Ecosystems

Benthic[2] reef, sand and mud habitats in sheltered and exposed coastal waters are the most highly threatened marine environments in New Zealand.[v] An expert review in 2012 assessed that the foremost threat to these habitats is increased sedimentation from changes in catchment land-uses.[vi]

Excessive sedimentation can smother benthic habitats and thereby change ecological composition by killing and displacing macrofauna.[vii] The effects of fine sediment on the benthos can also: increase turbidity and reduce light transmission in the water column and thereby affect photosynthesis; change biogeochemical gradients and cause negative effects to benthic microalgae; clog fish gills and the feeding parts of sediment-dwelling filter-feeders; and cause chronic effects on macrofauna physiological condition and behaviour.[viii]

It is worth noting that sedimentation from landslides and soil erosion is a natural process, which coastal ecosystems have adapted to assimilate over time. However, what has changed since human settlement in the Sounds is the rate of sedimentation caused by changes to land use practices, such as gold mining, land clearance, farming, road construction, and timber harvesting.[ix] Sedimentation rates into the Pelorus Sound have risen dramatically in the last 150 years compared to the previous 1000 years.[x]

The effects of sediment on the seabed were first documented in 1981 in Queen Charlotte Sound (QCS).[xi] The seabed close to Farnham Forest comprised few species within the fine-textured, muddy sediments, which instead contained buried bark and tree detritus. In contrast, in nearby areas unaffected by the forest harvest, coarser textured sandy sediments hosted a diverse array of shellfish, urchins, anemones, starfish, and tubeworm colonies (Fig. A1a - Appendix 1). There was also greater fish abundance in the control areas.

More recently, intertidal species disappeared from the estuary in Hitaua Bay, located within a side bay of Tory Channel, following a large sedimentation event.[xii] This site was monitored in 2015 as part of the Council's ecologically significant marine site programme. The estuary now has a cover of fine sediment which has been attributed to a slip associated with forestry earthworks. The sedimentation was likely caused by a mid-slope failure in 2012 after rainfall of a 1 in 5 year return interval (Figs. A1b-A1g - Appendix 1).

A 2003 baseline study of Hitaua estuary described it as: "a relatively high quality intertidal and shallow subtidal environment…rare in the Marlborough Sounds" (Fig. 3).[xiii] Estuaries provide many ecosystem services and benefits, such as: nursery grounds for young fish, shellfish beds, habitat for wading birds, contaminant processing, nutrient cycling, cultural values, and recreation opportunities.[xiv] Healthy estuaries in the Sounds mainly comprise sand and shell substrate with seagrass and cockle beds. However, many now have a greater mud (fine silt/clay) component which has been attributed to land use impacts.[xv]

Figure 3: Hitaua Bay estuary, Tory Channel 2003. Note the shellfish on rocks. Photo: Davidson Environmental Ltd.[xvi]

[2] In this report, benthic, seafloor, and seabed are used interchangeably.

3. Behaviour of fine sediments in coastal waters and water quality

The behaviour of fine sediments upon entry into the water column has been characterised as follows:

"Terrestrial sediment is washed into the aquatic environment as a result of runoff from the land, river and stream erosion and landslides. Small rivers draining small and steep catchments make disproportionately large contributions to sediment, and most sediment enters the estuary during storm events. In estuaries, this can result in sediment loads that, for short periods of time, are orders of magnitude higher than average. The sediment is mostly in the form of fine silts and clays – highly charged particles which flocculate on contact with seawater and are rapidly deposited. When sediment concentrations are very high, however, high-density turbidity currents that flow along the bed of the estuary can be created. Regardless, the net result is the smothering of estuarine and marine sediments. The smothering is easy to detect as the chemical nature of terrestrial sediments, particularly the presence of iron-rich minerals, gives them a distinctive yellow-orange color, clearly distinguishing them from adjacent marine sediments.[xvii]

The deposition of clay-rich soils from the Sounds occurs rapidly upon contact with seawater according to laboratory tests.[xviii] These tests, done on Kenepuru series soils which underlie many forestry areas in the Sounds, showed rapid flocculation and settlement of suspended sediment[3]. The conclusion drawn from that study was that sediment from coastal erosion is likely to settle out in close proximity to the shoreline, due to the chemical reaction of charged clay particles reacting with seawater.[xix]

The other mechanism for sediment clearance from the water column is the strength of the longshore tidal currents.[xx] In areas of relatively fast flow, such as within the main channel of Tory Channel[xxi], sediments are more likely to be suspended and widely dispersed. In slower flowing side bays, the bottom stress from tidal current action can be below a typical resuspension threshold of 0.1 newton m^2 (0.1 pascal) for clay-rich sediments resulting in settlement onto the seabed.[xxii] Therefore, the deposition of eroded sediment on the seabed depends somewhat on the hydrodynamics at a bay- and reach-scale.[4]

Figure 4: Hitaua Bay Estuary, Tory Channel 2015. Note the yellow colour of the sediment, reflecting its terrestrial origin. Photo: Davidson Environmental Ltd.[xxiii]

Broad-Scale Dynamics

To investigate this, and to assist Council with this report, NIWA conducted simulations of near-seabed current speed using the recent Queen Charlotte and Pelorus hydrodynamic models[xxiv, xxv] as well as their own Port Underwood model.[5] Figure 5, Figure 6, and Figure 7 show the bays where settlement is more likely to settle after deposition into coastal waters (the dark blue colour in each map).

In QCS, only the main stem of Tory Channel has sufficiently large flow velocities to re-suspend and disperse fine sediment (Fig. 5). There is some forestry directly above the main channel on the Arapawa Island side, where powerful tidal currents will scour and remove sediment into QCS or out into Cook Strait. All other areas, including Onepua, Hitaua, Bay of Many Coves, and East Bay where most forestry is situated in QCS (Fig. 1), the flow is insufficient to prevent sediments from settling in relatively close proximity to the shore.

[3] Flocculation is defined by the International Union of Pure and Applied Chemistry as: "a process of contact and adhesion whereby the particles of a dispersion form larger-size clusters." https://en.wikipedia.org/wiki/Flocculation#Term_definition

[4] Hydrodynamic models simulate the movement of currents, winds and tides.

[5] There is no current profile data for Croisilles Harbour held by NIWA sufficient to undertake this exercise.

This is a similar situation in Port Underwood where there are extensive plantation forests fringing almost the entire coastline (Fig. 6). Flows are below the resuspension threshold in the whole area of the harbour. This situation also applies to the majority of coastal locations in the Pelorus, such as Mahau Sound, Crail and Clova Bays, and sheltered bays off Hikapu Reach (Fig. 7). There are some exceptions in parts of Hikapu Reach, where current flows are likely to be sufficiently strong to re-suspend sediment and disperse it away.

However, the majority of forestry blocks in the Sounds are situated above low flow current areas. This is likely to also be the case for Croisilles Harbour, where there is no hydrodynamic modelling available. Although strong winds may winnow out sediment close to shore within some bays, the majority of sediment will settle out in relatively close proximity to where it enters the sea.

Overall, when considering the distribution of forestry and the modelled current flows, there is little justification for devising specific rules for different areas of the Sounds. Therefore, having one set of rules for the whole Sounds Environment area (red line in Figure 1) will assist in developing a clear and simple regulatory regime that is easy to understand, and provides industry and the community with certainty across the Sounds.

In accepting this approach, it is acknowledged that as the modelling is at a broad scale, it will not pick up areas within sheltered bays where current flows may be higher, due to localised sub-surface topography and wind exposure.[xxvi] However, the cost and practicality of doing this is prohibitive.

Fine-Scale Dynamics

The hydrodynamic variability at a local scale may explain why sediment depositional patterns after storms can vary, even within a generally slow flowing bay.[xxvii] The recovery of the benthos also varies in time and space depending on the winnowing action of wind and tides on the redistribution of fine sediment. This was identified in a study in Onepua Bay in Tory Channel, where impacts on the seabed after a storm in 1994 were greater at the head of the bay where logging had not occurred, than in mid-bay below a logged area.[xxviii] The results of the study were confounded by the differences in nearshore current flows between the sites.

Nevertheless, this study demonstrated that the deep bottom mud habitat spread shoreward at the mid-bay logged site, even as fine sediment cleared from the near shore areas. In addition to the accumulation of more sediment to existing offshore mud habitats, pine needles and woody material were also deposited on the seabed up to 100 metres (m) offshore, to a depth of 10-12 m.[xxix] It was noted that further accumulation of fine sediment onto the soft mud in the offshore areas (> 200 m distance from shore) may occur after logging. Moreover, although there was some recovery of species richness and abundance recorded after the storm, the offshore habitats were already impacted and altered by the previous effects of land use.

What this study clearly showed was that large storms generated widespread landslides. These storm events have been shown elsewhere to deliver proportionately the most sediment to the stream network.[xxx] For example, another study in the Sounds showed that the volumes of sediment entering the sea from harvested areas after heavy rainfall were significantly higher than unlogged areas. [xxxi] Sampling done after heavy rainfall in 1978 quantified suspended sediment concentrations greater than 13,000 ppm in a small stream draining a logged site at Farnham Forest, compared to 30 ppm in a stream in a nearby unlogged area.

Impacts on water quality are therefore greatest at the time of harvesting and during the ensuing period before the establishment of the next crop's root network. This is known as the 'window of vulnerability' due to the incidence of soil erosion during this phase of forestry.[xxxii] Outside this period, when the canopy is closed and the forest soils are relatively undisturbed, water quality is comparable to native forests.[xxxiii]

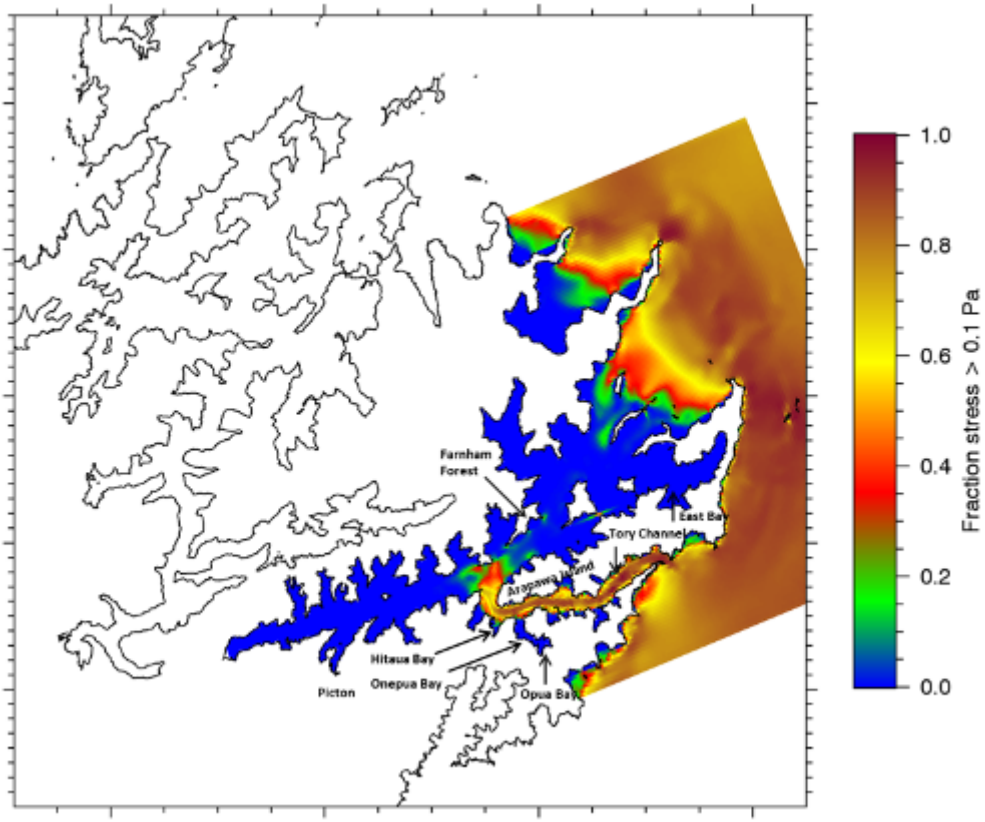


Figure 5: Areas within Queen Charlotte Sound and Tory Channel where bottom stress from current action is likely to be below a resuspension threshold of > 0.1 Pascal (Pa) based on existing hydrodynamic models. Source: NIWA[xxxiv]

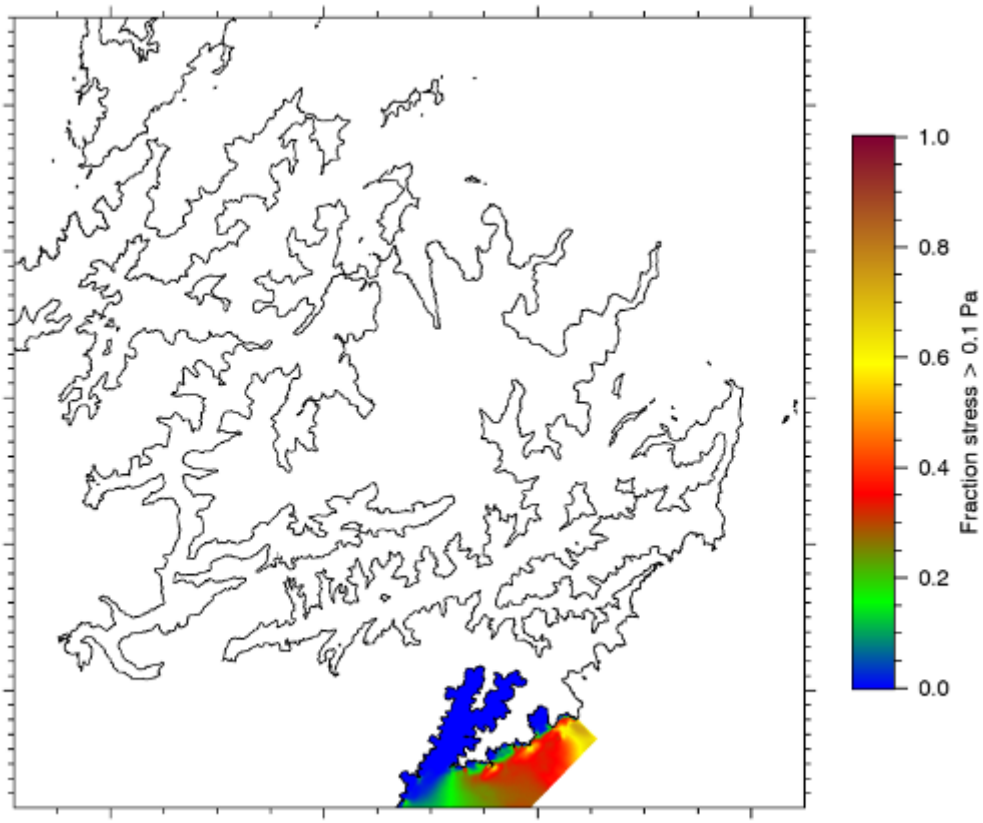


Figure 6: Areas within Port Underwood where bottom stress from current action is likely to be below a resuspension threshold of > 0.1 Pascal (Pa) based on existing hydrodynamic models. Source: NIWA.[xxxv]

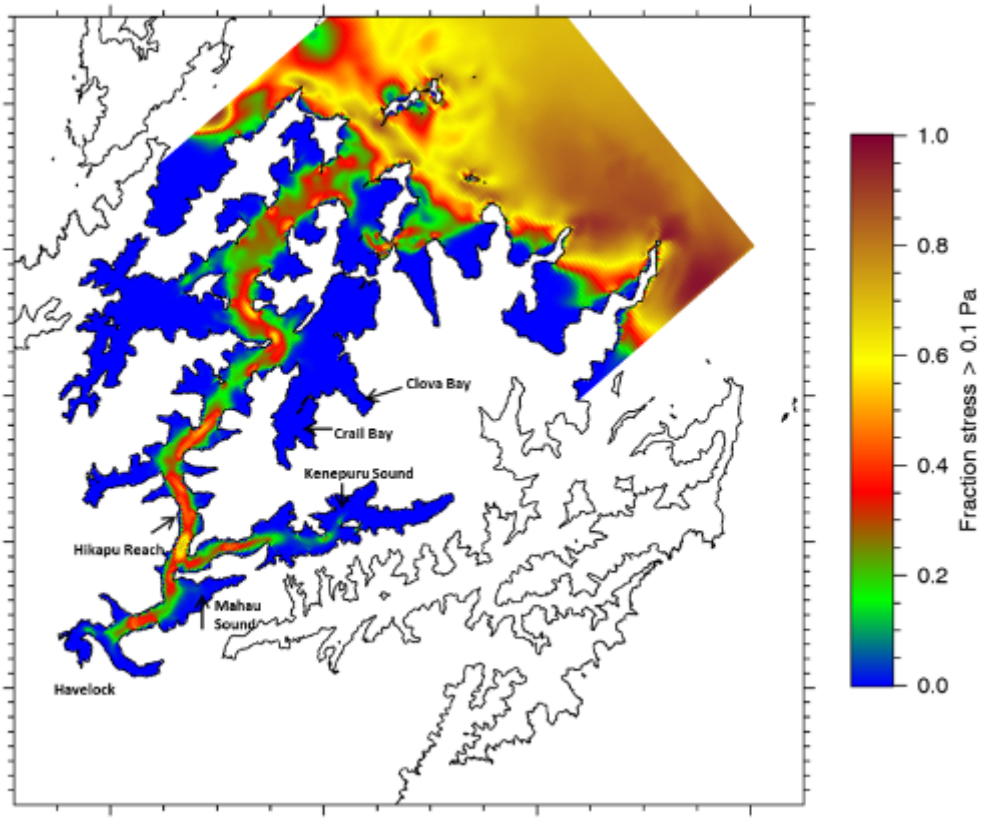


Figure 7: Areas within Pelorus Sound where bottom stress from current action is likely to be below a resuspension threshold of > 0.1 Pascal (Pa) based on existing hydrodynamic models. Source: NIWA.[xxxvi]

4. Factors predisposing forest soils to erosion in the Sounds

Forestry in the Sounds is generally on steepland yellow-brown earth soils, which are prone to slips, and sheet and rill erosion once the vegetation cover is removed.[xxxvii] These soils are derived from greywacke and schist, and are primarily silt and silty-clay loams with up to approximately 45% clay, formed by weathering of the parent material and some loessal deposition[xxxviii] (see Appendix 2 for general soil descriptions).

Soils between the shoreline and 200 m elevation in the Sounds are generally clay-rich, highly weathered, and therefore prone to erosion.[xxxix] Soil mantles (regoliths[6]) are generally thicker at these lower altitudes and likely to yield more fine sediment than less weathered and thinner soils at altitudes above 200 m.[xl]

Under high rainfall intensity, considerable run-off into coastal waters occurs from erosion and land-sliding where hillslopes are directly coupled to the coast.[xli] For example, an intense storm between the 5th and 10th November 1994 resulted in widespread landslides in the Sounds, including within plantation forests. Landcare Research scientists identified eight landslides in a recently harvested forest above Opua Bay, Tory Channel.[xlii] All landslides were below 200 m elevation in gully depressions in steep slopes (often over 30°).

Soil erosion also occurs at higher elevations under heavy rainfall. The shallow soil mantle sits over weakly weathered rocks, which can slip under high rainfall due to relatively shallow shear planes between the thin soil and bedrock.[xliii] In two storm events that hit Farnham Forest in 1983, the slopes on which the landslides occurred were in the range of 30° to 40° in areas harvested 1 to 3 years prior to the storm. [xliv]

The susceptibility to erosion in recently harvested areas is also related to the decay of harvested tree roots.[xlv] Roots loose much of their soil holding strength a year after logging, leading to greater susceptibility

[6] Regolith is defined as a mantle of soil and weathered rock covering solid rock (https://en.wikipedia.org/wiki/Regolith).

to soil erosion until the roots of the new crop take hold 5-8 years after replanting. In the Sounds, multiple shallow landslides occur even in moderate storms on slopes over 30° during this window.[xlvi] These landslides can turn into debris flows or avalanches as they pick up logging debris (Fig. 8),[xlvii] which intensify the scouring in ephemeral streams and gully areas, and can end up in coastal waters.

It is worth noting that outside this window, storm damage and erosion in plantation forests can be comparable to, or less, than other land uses, depending on the storm path and slope.[xlviii] Storm-initiated slope failures following a major storm in the Coromandel occurred mostly in indigenous forests. However, sediment generation rates were greatest in pine forests harvested three years prior to that storm.[xlix] This was also the case in the December 2010 storm in Marlborough which caused widespread slips and erosion.[l]

Managing the window of vulnerability is problematic in a clear-fell system, as opposed to coupe harvesting (smaller clusters of trees).[li] This is because greater amounts of sediment are produced in a clear-fell system, due to the area of bare soil exposed. In addition, there is a buffering effect from surrounding trees left in a coupe system which can contain sediment runoff somewhat.

The loss of evapotranspiration from widespread tree removal causes soils to become more waterlogged and prone to slipping under heavy rainfall.[lii] Therefore, it is important that the window of vulnerability is not prolonged by any delay in replanting, and sufficient seedlings are planted to hasten the establishment of a root network to hold erodible soils.[liii]

Other forestry activities that result in fine sediment being deposited into coastal waters include: runoff from freshly cut batters and fill areas, and the frequent movement of logging trucks and the machinery along roads, tracks, and landings.[liv] The volumes can be significant following the construction of new roads and landings, with one study in Tory Channel estimating about 200 tonnes of fine sediment could enter coastal waters per annum from a 60 km network of roads and tracks.[lv]

In summary, there are a number of interacting factors which lead to fine sediment production and deposition under commercial forestry. Potential regulatory methods to mitigate these are discussed in the next section. This then leads to a discussion of how well the proposed NES deals with these issues. Section 7 then outlines a range of options for mitigating soil erosion and improving water quality in the Sounds. These are reviewed by Landcare Research scientists, including one who has had research experience in the Sounds.

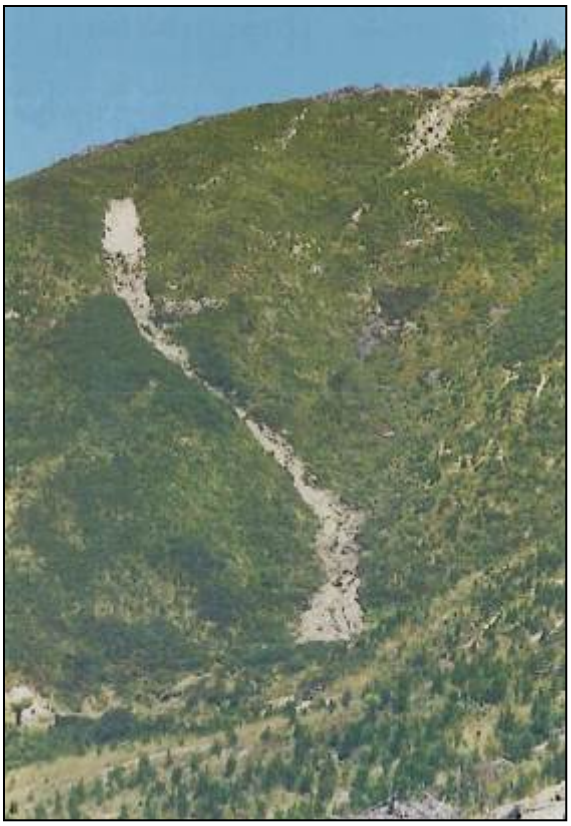


Figure 8: Landsliding and debris flows on shallow soils Tory Channel (from Phillips et al. 1996: Fig 3b. p29).

5. Mechanisms to Mitigate Erosion after Harvesting

The literature summarised in the previous sections illustrate that any one mechanism on its own not will be sufficient to reduce soil erosion and sediment deposition in the Sounds. A number of possible approaches are outlined below, which should be considered in an integrated way. These are not the only options available (for example, moving to coupe- instead of clear-felling which is not being advanced at this time), but represent a range of reasonable measures that target different causes of sediment generation.

It is worth noting that long-term monitoring of the effectiveness of these measures is desirable. However, this is likely to be expensive[7]. It is also relevant to consider that in sheltered, poorly flushed embayments, recovery of the seabed habitats may be slow without some form of active restoration. This is because the mud-inundated seabed may be a persistent ecosystem state that is difficult to shift without intervention, especially if sediment inputs continue to arrive from high-intensity rainfall events under climate change.[lvi]

i) Setbacks from the shoreline

Setbacks provide a protective buffer to help reduce soil erosion and sediment deposition entering coastal waters (Figure 2). In the absence of studies nationally about the effectiveness of setbacks around coastlines, ongoing monitoring would be advisable should these be implemented.

The benefit of implementing setbacks is that a permanent vegetation cover will protect the erosion-prone, highly-weathered soils between the shoreline and up to 200 metres elevation.

In the Sounds, setbacks will quickly be colonised by gorse and seral plant species due to the adequacy of rainfall that assists natural regeneration.[lvii] There are likely to be visual landscape effects from gorse covered coastal margins for several decades following the implementation of setbacks. There may also be weed issues in these setback zones, such as boneseed and wilding pines[lviii], which will require active control programmes. This may be a situation for Council to consider a complementary non-regulatory approach to management to assist landowners to manage weed issues within setbacks, or in any other retired area.

ii) Setbacks from permanently flowing streams coupled to the coast

Riparian protection in the form of setbacks along permanently flowing waterways would also lessen the incidence of soil erosion by protecting bank stability.[lix] An extensive root network of shrubs or large trees in riparian slopes will reduce, but not prevent, the initiation of soil slips in these margins.[lx] There will also be benefits to instream ecology by maintaining low light levels and natural temperature ranges.[lxi] This is because deforestation reduces stream shading and increases instream water temperatures, which affects the composition of the biota. A continuous vegetation cover also provides habitat for native fauna.

Riparian margins as little as 10 metres wide are effective in reducing organic material input into waterways; however, riparian protection may in of itself do little to reduce overland sediment flow into waterways in large storms.[lxii] Planted riparian areas in steepland forests also do not prevent debris avalanches, although they reduce the incidence of slope failures.[lxiii] Therefore, management controls on steep slopes are required to keep a continuous vegetation cover in areas at high-risk of erosion, such as steep gullies and gully heads.

iii) Slope controls

Most forestry in the Sounds is on slopes >30°. Currently forests are planted in a range of landforms from the shoreline up to the ridge line in many places. The benefit of regulating replanting in steep and erosion-prone areas such as gully systems is to minimise slips after high intensity storms. This can be done in a blanket way based on a slope rule, or an altitude band, or where the slope inflection changes from concave (gentler slopes) to convex (steep slopes) [lxiv] (Fig. 9). However, this practice has not been widely adopted (Fig. 9).

Episodic storm events have been shown to be the most important process for generating landslides and delivering the greatest amount of sediment into the network of streams and gullies which lead to the coast.[lxv] This means that the removal of harvest debris from riparian areas and ephemeral gullies will assist in

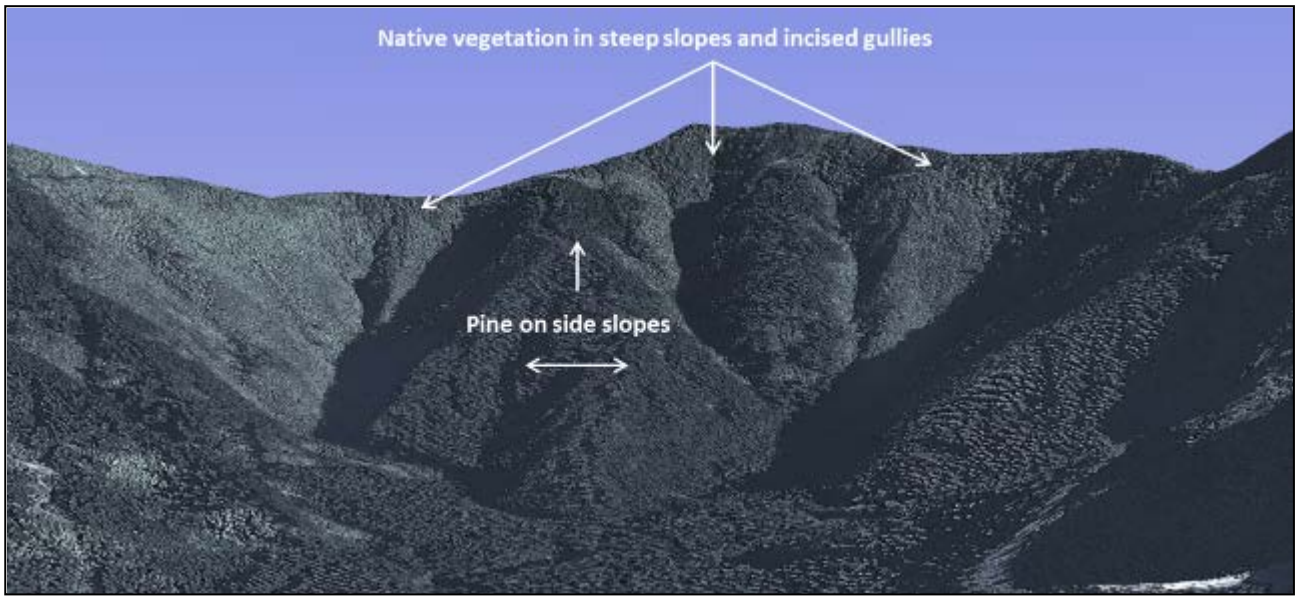
[7] This is the sort of land-sea environmental sustainability issues that fit with the core purpose of a number of Crown Research Institutes. E.g., NIWA: https://www.niwa.co.nz/about/scp. Landcare Research: http://www.landcareresearch.co.nz/about/our-core-purpose Scion: http://www.scionresearch.com/__data/assets/pdf_file/0006/30786/SCION-Statement-of-Core-Purpose-SCP-Nov-2010.pdf. They also fall into the purview for strategic research within the Our Land & Water and Sustainable Seas National Science challenges.

mitigating the damage from flood flows under intense rainfall. Reducing the amount of woody debris entering coastal waters will also reduce navigation hazards from floating semi-submerged logs.

Each forest block has different landform configurations, making the application of blanket replanting rules challenging. In contrast, a replanting management plan would enable a case-by-case approach to be taken. This mandatory plan would give practical effect to slope controls, identify landforms at high risk of erosion requiring retirement such as gullies, and ensure that coastal and riparian setbacks are properly implemented.

A property-specific replanting management plan would also provide assurance to Council that appropriate erosion mitigation is in place, and enable forest owners to maximise their crop within local topographical and soil constraints. Examples of areas that should be excluded from replanting are in Appendix 1 (Figs. A1j & k).

This would potentially drive innovation in the forestry sector in terms of landscape management, both for afforestation and replanting.[lxvi] It would also support the need for a risk management framework that can be applied at the property-scale, which Landcare Research scientists describe as: "*a fit-for-purpose landslide/debris flow susceptibility methodology at an operational scale and improved understanding of the magnitude and frequency of triggering events*."[lxvii]



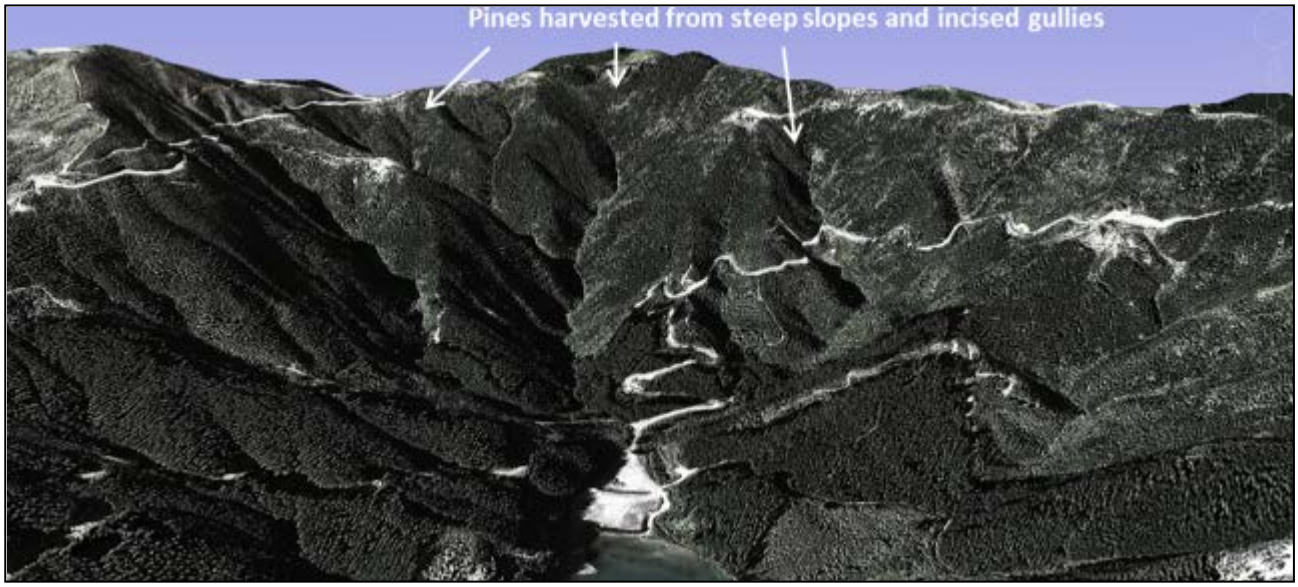


Figure 9: Example of erosion management by retirement of a steep convex slopes and gullies with native bush in Port Underwood (top). No retirement with planting to ridge line in steep gullies and convex slopes above Tory Channel (bottom).

iv) Replanting requirements

There are some straightforward measures that can be taken to reduce the window of vulnerability, such as replanting as soon as practicable.[lxviii] It has also been recommended that a minimum number of stems be required to be replanted to hasten the establishment of an interlocking root network.[lxix]

v) Harvest controls

Current harvesting techniques centred on up- or down-hill cable hauling tends to sweep tree branches and tops into gullies (Mark Spencer, Council Environmental Protection Officer, *pers comm* 14 October 2015). This material causes adverse effects on water and habitat quality, and can also get caught up in debris flows and avalanches, worsening the effects by scouring out more soil as the increasing mass gathers momentum, and ends up in the sea.[lxx] Prevention or removal of this material from permanently flowing and ephemeral gullies would minimise this risk.[lxxi] Slips can occur in storms that are less intense than 1-in-10 year return interval, such as the 1 in 5 year event that recently smothered the Hitaua Bay estuary.[lxxii]

vi) Earthworks controls

Roads, tracks and landings generate fine sediment due to the cut and fill of forestry earthworks.[lxxiii] These effects can be exacerbated if poorly constructed (Fig. 2 & Fig A1b in Appendix 1). Those photos reflect that the standard of earthworks construction is variable. As the Sounds are of national significance (ecologically, culturally, and visually), there is a compelling argument that consistent management is required. Accordingly, earthworks should be engineered to a high standard and certification provided that this has occurred.

Post-earthworks management should also be uniformly undertaken. One measure to reduce the fine sediment from fresh earthworks is to sow down fill areas in grass seed to create a continuous cover. This may only be needed where there was no evidence of rapid natural colonisation by seral plant species.

It is also desirable that loose fill is end-hauled to a location where it is at no risk of run-off reaching coastal waters. This is what currently occurs elsewhere.[lxxiv] However, there may be some locations in the Sounds where this may not be practically achievable, such as in small isolated blocks on steep hillsides. Therefore, it is not advanced as a generic option at this stage, but could be considered for individual resource consents.

6. Proposed National Environmental Standard (NES) for Plantation Forestry applied to the Sounds

The proposed NES[lxxv] does not currently deal well with managing forestry-related activities where these activities affect sensitive receiving environments, such as coastal or estuarine environments.[lxxvi] However, the NES does acknowledge that coastal areas may require more stringent management.

Council has called for further detail on the circumstances under which local authorities will have the ability to utilise more stringent rules to protect coastal values. The Ministry for Primary Industries is currently considering Council's and other submissions. For example, Gisborne District Council, which also has widespread soil erosion issues after forest harvesting, has submitted that there is no ability in their view for Councils to be more stringent in relation to meeting the requirements of the NZ Coastal Policy Statement.[lxxvii]

Council also expressed concerns about whether the effects of harvesting operations and earthworks in steepland soils would be appropriately managed in the NES, given the high erodibility of Marlborough's soils.

Therefore, it is recommended Council proceed with adopting its own rules due to the uncertainty around the finalisation of the NES, and in acknowledgment that the proposed NES is unlikely to address the issues identified in this report. This is a view shared by a number of other Councils on the proposed NES.[lxxviii]

7. Options for setbacks, slope controls, forestry earthworks, and post-harvest vegetation cover

A range of options have been developed to build on the recommendations of a Council report into the impacts of a powerful storm in December 2010. That report called for: "*management practices which minimise soil loss and debris accumulation in channels may help* [to] *reduce the effects of erosion during large storm events and at the very least be beneficial when lesser magnitude storm events occur in future*".[lxxix]

The options set out below have also been informed by Council's non-regulatory guidance on minimising sediment and protecting native vegetation from forest harvesting, which was published in 2013.[lxxx] These illustrated guidelines offered practical examples of how to undertake forest earthworks and harvesting for better environmental outcomes. However, the guidelines do not cover setback distances and slope controls, although they set out effective and complementary operational methods of reducing soil erosion if followed.

The options set out below have been crafted in a way that would not result in a radical change to the industry. For example, several studies in the Sounds have recommended reducing the area allowed to be harvested; either in coupes[lxxxi] or in altitudinal bands in different years.[lxxxii] Whilst these may have merit, the practicalities and benefits have not yet been explored in a comprehensive way within the scientific literature. Similarly, the planting of coppicing species in areas at risk of erosion has yet to be widely adopted or studied.

7.1. Setback Options

A case study approach is taken to demonstrate what setback and slope options may look like. One location was selected in the Pelorus Sound (Yncyca Bay[8]) and one in Queen Charlotte/Tory Channel (Onepua and Opua Bays). These were chosen because there is an existing 100 metre (m) setback above Yncyca Bay, and Onepua/Opua Bays contain extensive forests within the largest concentration of forestry in the Sounds.

i) Replanting setbacks from the shoreline:

30 metres: The proposed NES requires a 30 metres setback (roughly equivalent to one tree length) from the shoreline for replanting (and afforestation).[lxxxiii] This distance is likely to be insufficient to prevent slope wash during the window of vulnerability. This is because setback vegetation is likely to be damaged by pine trees immediately above the setbacks being felled downhill. The downed trees will also be dragged out of the setback area, potentially also damaging the vegetation. The vegetation will recover in time. However, its effectiveness to intercept slope wash will be reduced during the vulnerability window, as it is no longer intact.

100 metres: This distance is selected for two reasons. First, the existing setback in Yncyca Bay is anecdotally referred to as an example of a desirable setback distance in the Sounds. Second, to clearly distinguish it from a 30 m setback in terms of an adequate difference in distance to determine environmental benefits, than a lesser distance of say 50 m.

200 metres: This is based on the literature review which identified that the zone of the most highly-weathered, clay-rich and erodible soils in the Sounds is located between the shoreline and 200 metres elevation. The concept is that a 200 m setback would keep this zone under a continuous and undisturbed vegetation cover, thereby eliminating this as a diffuse source of fine sediment, and buffering the coast from sediment generated during harvesting uphill.

Figure 10 shows what the setbacks would look like in Onepua and Opua Bays from Google Earth. Figure 11 shows what a view of the setback from the water, as if viewed from a boat. Both are approximations and indicative only. Figure 12 and Figure 13 illustrate this for Yncyca Bay in Pelorus Sound. There are addition examples in Appendix 1 for Kahikatea Bay in QCS and Kenepuru Sound in the Pelorus (Figs. A1h and A1i)

[8] Pronounced "In-sigh-ka"

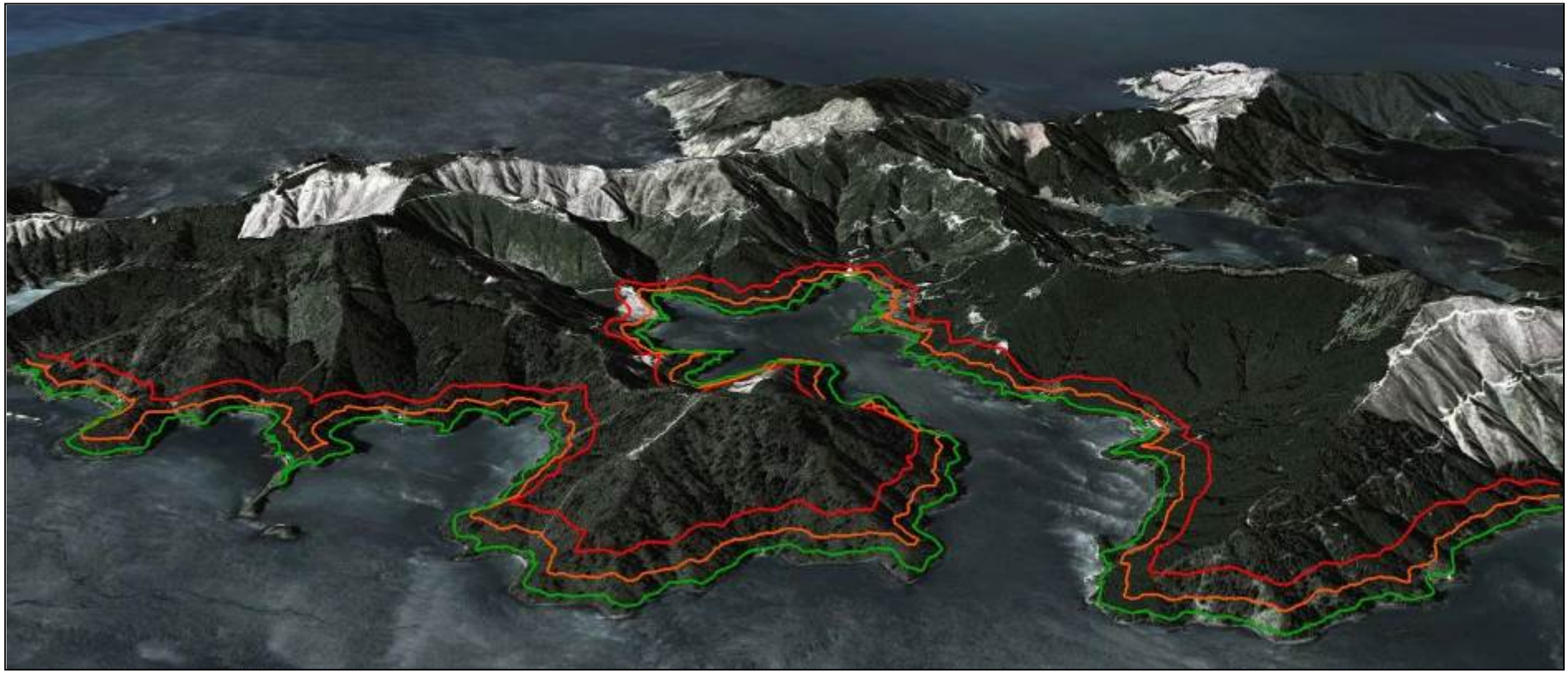


Figure 10: Proposed setbacks in Onepua Bay and Tory Channel: 30 metres from shoreline is the green line; 100 m is in orange; and 200 m is in red.

Figure 11: Setback options from a sea surface perspective (indicative only) for Onepua Bay.

Figure 12: Setback options from a sea surface perspective (indicative only) for Yncyca Bay.

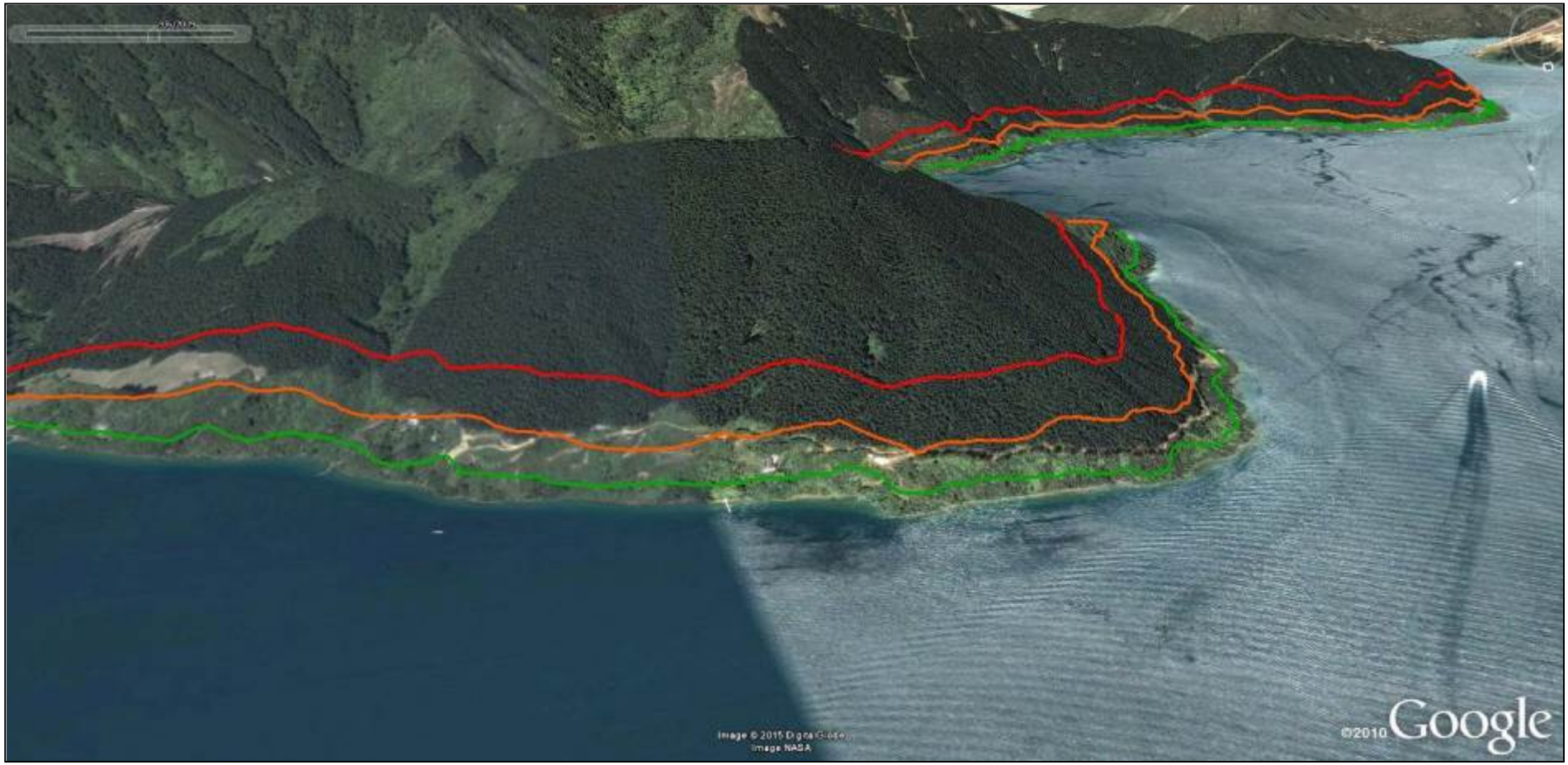


Figure 13: Proposed setbacks in Yncyca Bay, Pelorus Sound: 30 metres from shoreline is the green line; 100 m is in orange; and 200 m is in red.

ii) Replanting setbacks from permanently flowing streams coupled to the sea:

The proposed NES identifies a setback of 5 metres (m) from a perennial (permanently flowing) river or stream <3 m channel width; and 10 m for ≥3 m width. The aim of these setbacks is to reduce the risk of future harvesting or earthworks causing sedimentation.[lxxxiv]

A minimum of 10 m has been suggested in the scientific literature for the effectiveness of riparian setbacks for limiting the input of organic matter, reducing nutrient loads, and protecting bank stability from harvesting.[lxxxv] Setbacks reduce the amount of sediment from diffuse sources, but may not be as effective in buffering concentrated loads from slips and debris avalanches.[lxxxvi] This is pertinent to the Sounds given the steepness of the land and flow paths of permanently flowing waterways. Most forestry in the Sounds is on slopes >30° and a large amount is planted on slopes >35° (Figure 14, Figure 15, Figure 16, Figure 17). Plantings are often very close to water courses (e.g., Figure 9), resulting in a risk to bank stability and erosion under high rainfall.

There is a lack of scientific literature available to confidently recommend departing from the proposed NES setbacks for permanently flowing streams.[lxxxvii] It should be noted that setbacks will be left for vegetation to naturally regenerate. There may be weed issues such as wilding pines colonising the riparian areas, as for coastal setbacks.[lxxxviii]

7.2. Slope Controls

iii) Replanting controls on steep slopes:

In devising options for steep slopes, a digital elevation model was used to identify slopes over 30° and 35° in both case study areas. Figure 14 and Figure 15 show the spatial coverage of these different slope angles in Yncyca Bay.

Slopes over 30° and 35° are interspersed with gentler slopes throughout the landscape from the shoreline to the ridge tops. This makes it difficult to devise any rule that can be easily and practically be interpreted on the ground. A similar situation occurs in in Onepua Bay where steep slopes are also interspersed among extensive areas of more gentle slopes (Figure 16 and Figure 17).

Clearly any generic prohibition of replanting based on slope angle will have a severe impact on forestry in the Sounds. This would also be the case for any rule based on altitude (e.g., restrictions over 400 m).

One approach is to target particular landforms for replanting restrictions, based on their performance under high intensity rainfall, such as ephemeral gullies on slopes over 30° or 35° angles. The aim would be to reduce the number of slips that cause debris flows and avalanches by not replanting them after harvest, and thereby retaining a permanent vegetation cover. This is because slips mostly originate within ephemeral gullies and on convex slopes where there are thin soils on weakly weathered bedrock.[lxxxix]

Prohibiting replanting in these areas could significantly mitigate one of the major sources of fine sediment production into the sea. However, given the difficulty in distinguishing on the ground where slope angles change over short distances, as illustrated by the maps in Figures 14-17, compliance becomes difficulty to determine. Therefore, this option is not preferred.

The alternative is to make all replanting on slopes over 30° a discretionary activity. The benefit of requiring resource consent is that the applicant and Council can work together towards a property-specific solution, which takes into account the property's unique topographic features. This would require a mandatory Replanting Management Plan.

The Replanting Management Plan would be submitted for Council approval prior to replanting. It would identify high risk areas (such as incised gullies and gully heads) requiring erosion management and mitigation measures, such as retirement and setbacks. This would involve a joint inspection with Council to view the areas to be replanted and those areas to have setbacks and those steep gullies to be retired.

Examples of possible areas excluded from replanting are shown in Appendix 1 (Figures A1j-A1k). These are shown for indicative purposes only, but serve to illustrate the concept for gully heads requiring retirement and riparian buffers for steep and/or incised gullies. A similar plan would be required for afforestation.

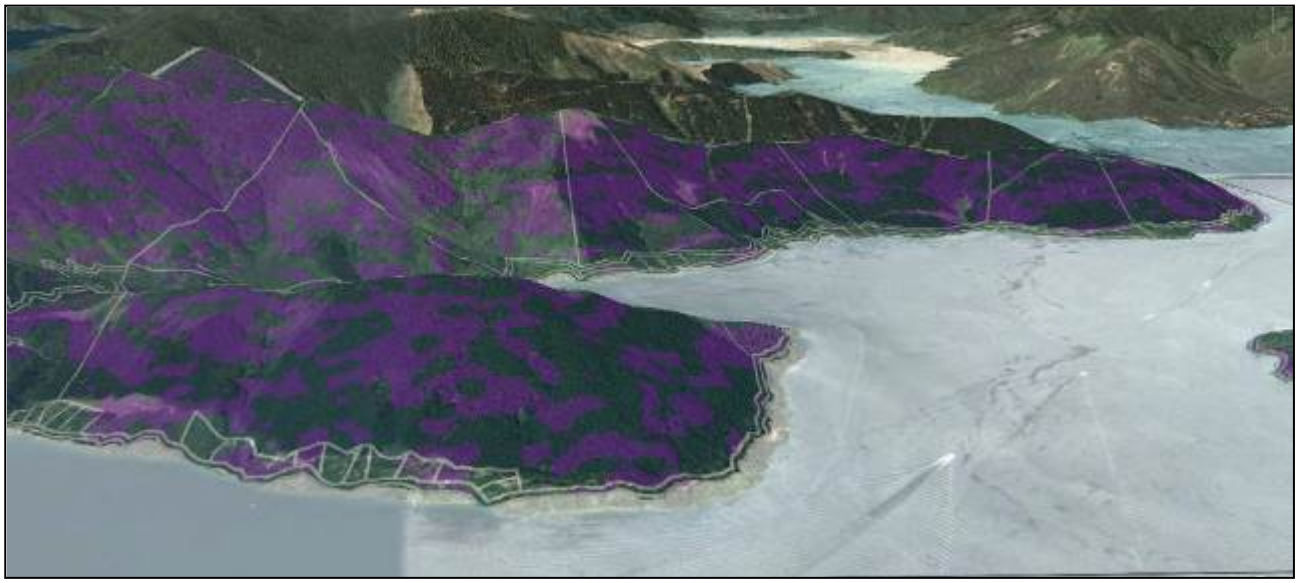


Figure 14: Digital elevation model showing modelled slopes over 30° (purple shading) in Yncyca Bay, Pelorus Sound.

Figure 15: Digital elevation model showing modelled slopes over 35° (pale green shading) in Yncyca Bay.

Figure 16: Digital elevation model showing modelled slopes over 30° (purple shading) in Onepua Bay (background) and Tory Channel in foreground.

Figure 17: Digital elevation model showing modelled slopes over 35° (pale green shading) in Onepua Bay.

7.3. Post-harvest vegetation cover

iv) Replanting requirements:

The following two options are designed to ensure that the window of vulnerability is not prolonged. The reasons for this, with reference to the scientific literature, are outlined in section 4 on pages 9 and 10.

a) *Replanting of areas harvested within 12 months of harvest*; and/or,

b) *Replanting in excess of 1000 stems/hectare.*

Should there be no intention to replant, and the area is left to naturally revegetate, Council may need to consider the role of a non-regulatory approach to manage wilding pine and noxious weed regeneration, in partnership with the landowner.

7.4. Harvest controls and earthworks requirements

v) Harvest controls:

The requirement is the removal of all woody material (>100 mm diameter and > 3 metres in length) from all gullies over 5000m^2 (0.5 hectare) as soon as practicable, and no later than 1 month, after harvest. This should significantly reduce the severity of damage from debris flows and fine sediment entering the sea. The reduction of woody material entering coastal waters will also have benefits for navigational safety.

There is no realistic and practical method for this to be done over a particular slope angle or altitude, given the difficulties in delineating these in the field, as shown in Figure 14, Figure 15, Figure 16 and Figure 17.

The adoption of this requirement will present a challenge to existing harvest methods. However, the industry is currently required to remove all woody material of >100mm diameter in permanently flowing streams. Hence, there will be cost implications for extending this to ephemeral gullies; however, good managers will preventatively minimise these costs with careful planning and efficient operations. The industry is also looking to innovate to meet health and safety requirements, so the timing may be opportune.

vi) Earthworks requirements:

It is evident from Council's compliance monitoring that the standard of road and track construction is variable across the Sounds.

An example from Pelorus Sound, where fine sediment will continue to discharge into the water for years to come, has been shown in Figure 2. The quality of earthworks design and implementation is also likely to have contributed to the magnitude of the slip which smothered Hitaua Estuary.

The Sounds have been described as the 'Jewel in Marlborough's Crown' by Council. High standards associated with any land use activity are required to protect this iconic part of the country. It may now be time to lift the bar for forestry-related activities. Accordingly, the following two options would contribute to minimising soil erosion and preventing slips from poor practices:

a) *All road design, construction, and maintenance to be certified by a Chartered Professional Engineer (CPENZ) for land stability and water control efficacy*; and/or

b) *All areas of loose fill (soil) areas to have a grass cover established within 12 months.*

Both these options will also incur additional cost to industry, and also for Council in monitoring. However, it could be said that the natural ecosystems of the Sounds are currently bearing a disproportionate share of these costs.

8. Review of options by Landcare Research

Landcare Research scientists recently peer reviewed the report for scientific accuracy[xc] and their review is included in full in Appendix 3. Their summation of the report overall was that:

> *"In general terms, the MDC report is a fair and detailed assessment of the current state of the effects of forestry on sediment generation and delivery in New Zealand, and on how it might be mitigated."*
>
> *There are, however, omissions in the science-based data referenced in the MDC report that we have included, and that may have material bearing on some of the erosion-mitigation options suggested in that report."*

The omissions relate to scientific studies done elsewhere in New Zealand, and not the Sounds. This was to be expected given the focus on this report was on the Sounds, and was not an exhaustive review of all the literature. Therefore, the Landcare Research peer review undertaken by two experienced scientists, both with over 25 years' experience, was relied on to highlight any gaps in the analysis and management options in this report. These have now been addressed and are summarised along with the response in Table 3.

Overall, Landcare Research support the contention of this report that individual regulatory measures will not be effective in reducing all sources of sediment, and need to be considered as part of an integrated package. They also agree that fine sediment can only be mitigated and not prevented, given the steepness of the Sounds, the erodibility of soils, high intensity rainfall events, and plantings in high risk areas prone to slips.

Table 3: Summary of Landcare Research scientists comments on the draft report, along with a response as to how these were addressed in the final report. The Landcare Research peer review is included in full in Appendix 3.

Option	Landcare Research commentary	Response and how included in report
Coastal setback distances	Intuitively greater setbacks are better, but lack of research available to evaluate effectiveness of different distances. Setbacks likely to be effective in reducing sediment runoff from diffuse overland sources. May not be effective in holding back concentrated loads from slips & debris flows. Restricting forestry practices in weathered soils below 200 m could significantly reduce sediment availability and mobility.	No changes required in report. The need for setbacks acknowledged by Landcare. Mitigating the effects of mass failures can be partially done by retiring steep gully heads and removing logging debris from gullies, which will reduce slip severity. Studies show that soils in Sounds between shoreline and 200 m elevation are strongly weathered & highly erodible.
Riparian setback distances	The comments above also apply. In addition, reference is made to a 5 metre setback distance from a Master of Science thesis in 1994 (Coker). Coker suggested this where stream channels are well-defined (generally below 200 m contour). Effectiveness of setbacks depends on type of vegetation, its stature & density, local slope conditions, the mechanisms by which sediment regenerated and delivery pathways.	The option of a 5 metre (m) setback has been considered in light of the proposed NES. The NES has replanting and earthworks setbacks of 5 m for permanently flowing streams less than 3m in width, and 10m for streams greater than 3m width. The proposed NES setbacks are now reflected in the options. The ecological science of vegetation succession after disturbance shows that seral (early colonising) plants are shaded out by taller species over decades. A more complex structure also develops.
Replanting Management Plan	Supportive of this. Agree that 'blanket' rules based on slope steepness or altitude are not optimal. The development of a risk analysis tool that can predict where slips are likely to occur and be generically applied is some way off. This could include terrain stability mapping based on erosion susceptibility.	No changes made. Implementation of a Replanting Management Plan (previously called a Plan to Minimise Erosion) will enable property-specific erosion mitigation, and include risk analysis. A plan for afforestation is also necessary.

Option	Landcare Research commentary	Response and how included in report
Replanting requirements to reduce window of vulnerability	*a. Replant within 12 months of harvest.* Support this to reduce the risk of storm-initiated landsliding. The Sounds subject to intense storms. *b. Plant in excess of 1250 stems per hectare*. Whilst acknowledging that this is a valid erosion mitigation measure, suggested this needs to be balanced with other factors, such as producing more slash and logging waste which can get into waterways.	No changes required in the report. Revised down to 1000 stems per hectare as agree that a balance needs to be struck. Dense plantings prevent an erosion-buffering ground-cover and understorey from developing. More slash is produced which can be carried by slips
Remove all woody material >100 mm diameter from gullies >5000m^2	Supportive as an effective means of minimising risk. Gully heads have traditionally contributed the greatest sediment load to streams and to the Sounds, as they are steep sided and are the main conduit of water.	Added in a definition of minimum size of gully; i.e., 5000m^2 for practical implementation. This enables different shapes of gullies to be treated in a similar way for removal of logging waste.
Certification from CPENZ engineer	Unsure whether certification by professional engineers is necessary, as their experience is that significant improvements have generally occurred.	Given that Council staff periodically see unsatisfactory practices which result in preventable sediment discharge into the sea, stricter standards are justifiable.
Sow grass cover over loose fill within 12 months	Question whether this would be effective as even long-vegetated areas of fill can fail. Suggest end-hauling of loose fill to a safe site would be more effective in reducing fine sediment.	Acknowledge that grass seeding of loose fill is not always successful, and even good seed strike will not prevent failure. However, retaining this option will help to keep a focus on sediment mitigation. End-hauling of loose fill may not be practically done in all forestry blocks. It could occur where practicable to do so.
Limiting the size of harvested areas within forestry blocks	Landcare Research suggested that this option be considered so that there is less area of bare soils exposed at any one time.	This seems like a reasonable approach. However, there is a lack of recent studies on the costs/benefits of this. It may be impractical and financially prohibitive for small, isolated blocks in the Sounds. Perhaps it could be a future option if benefits can be clearly demonstrated by a future scientific study if industry and science funders agree that it is a priority.
Alternative species to pine	Landcare Research suggested that another option be considered for gully heads and other erosion prone areas. This is the planting of alternative harvestable species that coppice, so that permanent root networks stabilise erosion-prone soils.	There is insufficient information as to whether forestry companies are trialling this elsewhere, and the benefits of doing this on slope stability and prevention of slips. In addition, there is still the issue of logging debris in gully heads from coppiced species which can mobilise in intense rainfall events. Hence this option is not advanced at this time.
Map areas for high potential hazard for contributing sediment in the Sounds	Landcare Research suggested that the Sutherland et al. 1992 study of soil instability and hazards at the 1:50,000 scale could be used as a basis for identifying areas of different landslide/debris flows at <1:10,000. Landcare suggest that this sort of geomorphological-based terrain stability zoning approach could be an alternative to generic setbacks, and matched to the scale of activities.	The Sutherland study was not ground-truthed. However, it was adopted in the current MSRMP (Volume 3) as an indicative hazard layer requiring investigation for any consent application. It is unlikely to remain as a planning tool. This showed the distribution of potential hazards is Sounds-wide, and included part of a number of areas where forestry is sited. The approach suggested by Landcare is likely to require significant resources with an uncertain outcome, in contrast to the generic setback options.

9. Concluding Remarks

Forestry is a permitted industry in the Marlborough Sounds and provides jobs and social benefits to the community. Like all industries, it evolves with new technology and increasing awareness of its effects on the wider environment. As new knowledge becomes available, again like all industries, it must adapt to ecological and social concerns for it to retain its social licence to operate within the community.

The environmental effects of forestry on coastal water quality and benthic habitats in the Sounds were first identified in the late 1970s and have again recently been highlighted in Hitaua Bay estuary. Something needs to change, as these issues keep recurring and are likely to be causing ongoing negative effects to marine life. If the Sounds ecosystems are in good health, they provide a range of benefits including greater fish and shellfish abundance. These spill over into economic benefits from increased recreation and tourism.

Plantation forestry covers over 17,400 hectares in the Sounds (Fig. 1). There is a mosaic of different aged forest blocks spread throughout the Sounds, meaning that there will be regular and ongoing harvesting over the next 30 years.[xci] The impacts of erosion and sedimentation will continue, and mitigation measures will need to be implemented to ensure that forestry-related activities are consistently well managed.

Widespread soil erosion and fine sediment production, particularly after heavy rainfall, are caused by a number of interacting factors. This report has shown that sediment runoff into coastal waters is caused by a combination of intense rainfall events, the underlying lithology and topography, the removal of forest cover and the gradual decay of root systems, all of which predispose soils to greater erosion risk.

A number of options have been outlined to reduce the susceptibility to erosion in the interval between the onset of decay of harvested tree roots after harvest, and the establishment of the next crop's root network. These options will constrain the industry somewhat with additional costs, and impose a greater regulatory burden on Council as well. Any cost/benefit analysis of the options should include non-market valuation of the benefits to ecosystem services of reducing sediment into coastal waters, and the cost of not doing so.

The mandatory requirement of a Replanting Management Plan is probably the most important change that can be made. This will have the effect of driving innovation in land management. This was first floated a decade ago, with a joint exploration of the concept by Wrightson Forestry Services (now PGG Wrightson) and Council. That report, "The Next Crop", remains instructive in terms of landscape design and economics.

It is worth stating too that these options have not been constructed as a 'Trojan Horse' to force forestry from the Sounds. This is illustrated by the supportive peer review of the report by Landcare Research scientists who have decades of experience in the causes and management of soil erosion and sedimentation.

It is also important to note that these measures either implemented solely, or in combination, will not prevent fine sediment and woody debris from entering coastal waters. The community will need to accept that there will be an ongoing level of adverse environmental effects from forestry. However, the corollary is that these should be minimised where practicable, and operations will need to be carried out to the highest possible standards that are reasonable to achieve. This includes stricter standards for forestry earthworks.

Monitoring and research of the options selected by Council for its resource management framework will be required to understand how effective these measures will be over time. Ideally, this would be done in a collaborative way with industry, the Ministry for Primary Industries, and Crown Research Institutes, given the national importance of the Marlborough Sounds. This research could also explore whether there are practical and effective interventions to restore seabed habitats, and the benefits of doing so.

Finally, it is recommended that Council proceed with determining how it wants to regulate forestry in the Sounds within its resource management framework. This is because the proposed National Environment Standard for Plantation Forestry (NES) does not currently afford the iconic Marlborough Sounds the protection they require. In addition, it may be some time before the NES emerges back into the public domain, following submissions, which are currently being considered by central government.

Sharing this report with central government may assist them in clarifying the ability of Councils to adopt more stringent regulations for coastal environments in the NES. This is because the NES is likely to have a seminal influence on whether the Sounds can be sustainably managed now and for future generations.

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[lxxviii] Other Council's concerns are referred to in Marlborough District Council 2015. *See also* Gisborne District Council 2015.

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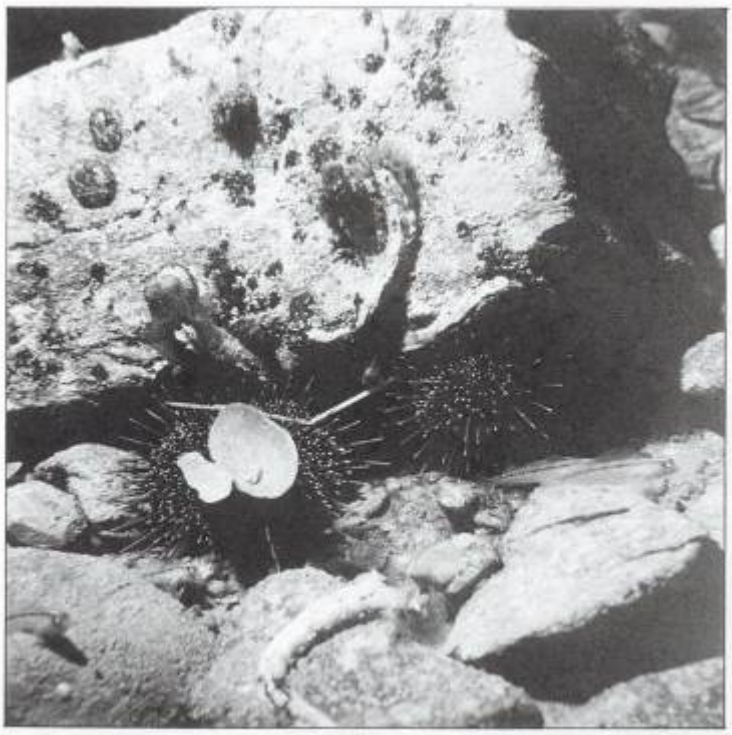
Appendix 1

A thick layer of muddy sediments and tree detritus adjacent to a log marshalling area in Milton Bay, Marlborough Sounds
Photo: *M. Bradstock*



Sandy and shelly sediments in a bay adjacent to an unlogged area. Note the marine life
Photo: *M. Bradstock*

Figure A1a: Photos from a 1981 survey of the seabed in Milton Bay, Queen Charlotte Sound (Photos by Mike Bradstock within Johnson et al. 1981. The Saw, the Soil, and The Sounds. *Soil & Water* Aug/Oct).

Figures A1b-1c: Possible cause of fine sediment deposition in Hitaua Bay, Tory Channel. Photo 13 April 2012**.**

Figures A1d-1e: Sediment plume after slip 13 April 2012. Note the sediment plume is confined to the inner bay, and had not cleared two weeks later.

Figures A1f-1g: Stream at head of Hitaua Bay in 2003 (left) & 2015 (right). Note increase in fine sediment in 2015.

Figure A1h. Setback options from a sea surface perspective (indicative only) for Kahikatea Bay.

Figure A1i. Setback options from a sea surface perspective (indicative only) for Kenepuru Sound entrance.

Figure A1j: Gully heads and gullies excluded from replanting; illustrative example for areas 200 metres above shoreline. This block has not been replanted since the last partial harvest in 2012 and is in pasture grass as at November 2015. Note the slip in the centre gully that occurred after harvest, shown by the blue arrow.

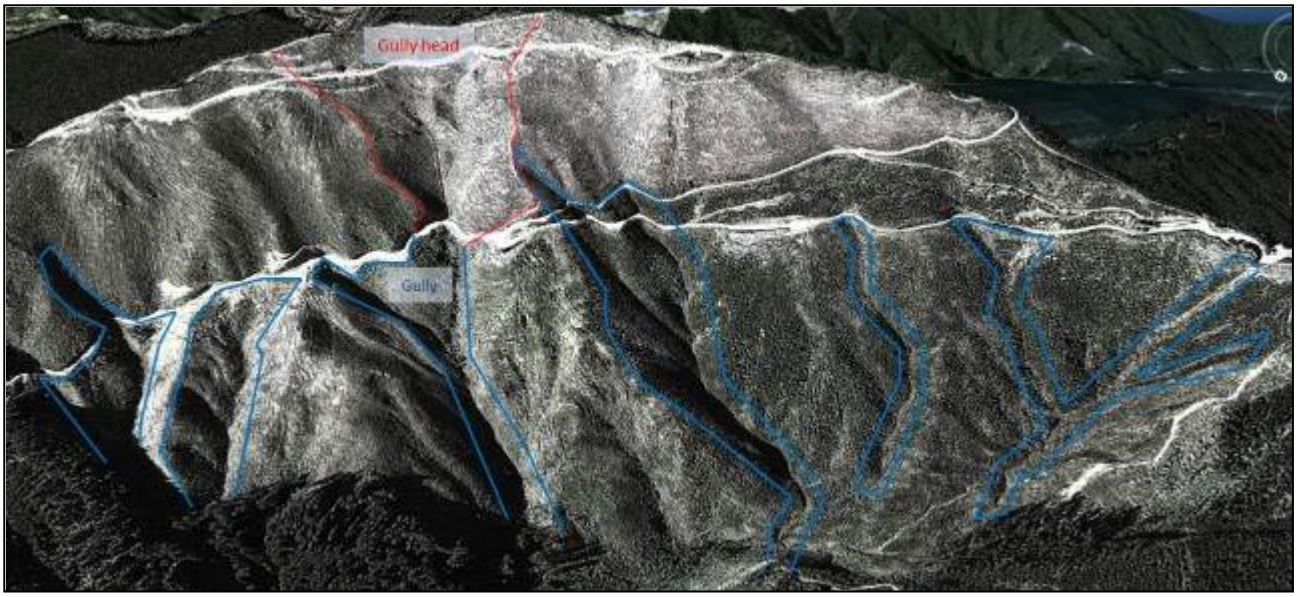


Figure A1k: Gully heads and gullies excluded from replanting; illustrative example for an area above Tory Channel that includes shoreline.

Appendix 2

General Survey of the Soils of South Island, New Zealand. DSIR Soil Bureau Bulletin 27. Wellington. 1968

Anakoha Soils (Class 42a) Subschist and greywacke. Mostly silt loams. Liable to slight sheet and scree erosion on very steep slopes (p240)

Arapawa Steepland Soils (Class 41). Silt loam, schistose greywacke. Liable to sheet and slip erosion (p238). "Hygrous Lowland Yellow-Brown Earths occur on steep lands and hills in…Marlborough…They are formed mostly on deep slope deposits and are commonly of stony silt texture. On higher slopes and very steep slopes along entrenched streams soils are shallow with some rock outcrops. The soils of the Nelson-Marlborough region are more weathered than those further south,,,Conversion of large areas of hill and steepland soils of this kind from tussock grassland to closely grazed intensively developed pastures may create serious hydrological problems in the lowlands. It is almost certain that run-off will increase greatly and there may also be a danger of increased sheet, gully, and slip erosion under pasture. It might be advisable to combine forestry use with grassland to offset these problems." (p40)

Kenepuru Steepland Soils (Class 47a): Greywacke and subschist (deeply weathered at low levels). Mainly silt loams and stony silt loams. Liable to sheet erosion and slips where inadequate plant protection (p248). Hygrous to Hydrous Lowland Yellow-Brown Earths (p40-41). These soils are of low nutrient status and on unstable steep slopes are liable to erode when forest is cleared. In parts of Marlborough Sounds erosion followed by clearing of forest, and later, as the small reserves of nutrients were depleted, the soils reverted to fern, scrub, and second growth. They should either remain in protection forests or be used for exotic forestry, for which they are well suited; but care would be necessary in harvesting forest crops because of erosion risk" (p41)

Opouri Steepland Soils (Class 47b): Shales, sandstones, and slates, slightly calcareous in places (deeply weathered on low-lying sites with patches of red weathering). Mostly silt loams and stony silt loams. Liable to sheet erosion and slips on very steep slopes (p250) - see description for Kenepuru oils as also Hygrous to Hydrous Lowland Yellow-Brown Earth.

Composition of Lowland Yellow-Brown Earths (p37): "Lowland yellow-brown earths are widespread in those parts of the South Island where rainfalls range from about 40 to 80in. [1-2 metres] per annum. Under these rainfalls soil moisture is normally at or near field capacity and it is uncommon for the soils to dry out. Where drainage of the soil is impeded or where winter rainfall is high, these souls may have a moisture status above field capacity during wet weather. This surplus soil moisture status above field capacity is called hydrous and leads to temporary pugging and some surface gleying in topsoils. However, in lowland yellow-brown earths hydrous conditions are not widespread, the hygrous state being more typical. Most of these soils of this group were formed under forest, but some were covered with scrub or tall tussock at the time of European settlement. The soils are formed on a variety of unconsolidated deposits derived from greywackes, schist, granite, sandstones, mudstones and reside from decalcification and weathering of limestones and calcareous sandstones. Small areas of soils are formed on these rocks in situ. Loess derived from schist and greywacke rocks is the most extensive soil-forming deposit…Profile features vary according to parent material, stage of weathering and leaching, slope, and the kind of vegetation under which the soil has formed. Soils formed on fine textured sediments such as siltstones may have coarser structure, firmer consistence, and poorer drainage than the modal soils, and older more weathered soils (mainly in Nelson and Marlborough) may have appreciably heavier textured subsoils indicating translocation of clay from the topsoil…The clay content of lowland yellow-brown earths on loess is not appreciably higher than in adjacent yellow-grey earths [18-22% - higher in wet soils p23], but the kinds of clays are different due to the influence of climate on weathering."

Appendix 3

Landcare Research scientific peer review of the report, 13 November 2015

LANDCARE RESEARCH
MANAAKI WHENUA

13 November 2015

Dr Steve Urlich
Environmental Science & Monitoring Group
Marlborough District Council
15 Seymour St
Blenheim 7201

Dear Steve

***Mitigating fine sediment from forestry in coastal waters of the Marlborough Sounds: options for determining plan rules*. Prepared by Dr Steve Urlich, Environmental Science and Monitoring Group, Marlborough District Council.**

Please find attached our assessment and comments on your report as requested under urgency via Envirolink Advice Grant 1626-MLDC 110.

We have amended the draft version of this review to incorporate your request for clarification of a number of points (Email dated 29 October 2015).

This is the final version of this review, however, if there is anything else we can assist with in the future, please get back in touch.

Yours faithfully

Dr Michael Marden
Scientist
Landcare Research, Gisborne

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A review of *Mitigating fine sediment from forestry in coastal waters of the Marlborough Sounds: options for determining plan rules.* (Prepared by Dr Steve Urlich, Environmental Science and Monitoring Group, Marlborough District Council.)

Reviewed by Michael Marden & Chris Phillips

Landcare Research

Executive summary

- MDC asked us to review a document that proposed several options for mitigating sediment delivery to the Sounds from forestry.
- A literature assessment and the author's experiences inform our commentary.
- In general terms, the MDC report is a fair and detailed assessment of the current knowledge state of the effects of forestry on sediment generation and delivery in New Zealand, and on how it might be mitigated.
- There are, however, omissions in the science-based data referenced in the MDC report that we have included, and that may have material bearing on some of the erosion-mitigation options suggested in that report.
- We have specifically not commented on the relationship of any suggested rules in relation to those in the proposed NES for Plantation forestry as we are "conflicted", having on-going work for MPI in revising the erosion susceptibility classification that underpins the NES.
- We are not overly optimistic that any significant monitoring and research associated with any future implementation of these options as suggested in the MDC report would be supported via National Science Challenges or by Core funding via Crown Research Institutes.

Key points

- While there is little scientific evidence available to evaluate whether the sediment trapping efficiency of the different setback options proposed for coastal setbacks (30 m, 100 m or 200 m) and for permanent streams (10 m, 20 m) improves with increased setback width, there is however general consensus that setbacks are ineffective in trapping sediment generated by mass failures but are likely to be effective in reducing sediment derived from diffuse sources by surface processes.
- There is also consensus that the effectiveness of any proposed buffer or setback will largely depend on the type of vegetation, its stature and density, the local slope conditions, the mechanisms in which sediment is generated, and the potential for delivery pathways to cut through or bypass such buffers.
- Landslides and debris flows are inevitable in the Marlborough Sounds and we support the requirement for a Plan to Minimise Erosion. While our ability to determine exactly where landslides and debris flows will occur is currently poor, it is possible to broadly zone land in terms of its risk of erosion by terrain stability zoning, and we suggest that this should be an integral part of the PME.

- We suggest that increasing the planting density above 1250spha would not necessarily result in significant additional contribution to slope stability.
- Alternative species (exotic and indigenous) especially coppicing species such as eucalyptus or redwood, and/or species with a longer rotation could be considered for slopes with the highest sensitivity to forest harvest practices and/or for areas identified as having the highest risk of slope failure, such as the steepest parts of gully heads.
- Retirement and reversion should be considered as an option for the most at risk sites such as gully heads.
- The requirement for the removal of woody material >100 mm diameter and 3 m in length from stream channels is a practical approach to manage the risk of slash mobilisation in gullies and streams.
- We concur with consideration being given to limiting the size of harvest coupes and spatially separating cutover so that areas clearfelled in successive years are not contiguous.
- Engineering standards for roads and earthworks need to be improved, at least to the standards outlined in the New Zealand Forest Road Engineering Manual Operations Guide, but this may not necessarily require certification by professional engineers.

Scope of review

We were approached by Dr Steve Urlich of the Environmental Science and Monitoring Group within Marlborough District Council (MDC) to undertake a review of a document 'Mitigating fine sediment from forestry in coastal waters of the Marlborough Sounds: options for determining plan rules'. The MDC document and this review will be presented to Councillors of the Marlborough District Council's (MDC) late in October 2015.

In agreement with Dr Urlich, the intention of this review is not to revisit the literature cited in the MDC report but rather to provide experiential feedback specifically on:

(i) replanting setback options for coastal shorelines, and for permanently flowing streams directly coupled to the Sounds.

(ii) replanting controls on steep slopes and alternative mitigation options

(iii) harvest controls, and

(iv) earthworks requirements

While we specifically review mitigation options proposed for forests in the Marlborough Sounds, much of our commentary is equally relevant to many other New Zealand exotic forests, especially those that were initially established as 'conservation forests' on erosion-prone hill country.

This review does not include discussion of the off-site impacts of the past and/or current sediment contribution on the marine environment within the Sounds as this has previously been well-documented.

General setting

As outlined in the MDC report, the topography in the Marlborough Sounds consists of a high proportion of short steep slopes that fringe the Sounds shoreline. Slopes adjacent to permanently flowing streams are equally short and steep with few places where within-channel storage of sediment might be retained. Additionally, given the high probability of storm events capable of triggering slope failure and generating high stream flow, much of the clay-rich sediment is entrained as suspended sediment thus a high proportion of sediment delivered to these streams is conveyed directly to the Sounds. The MDC report acknowledges that it will not be possible to completely avoid landslide failures or the occurrence of debris flows as they are part of the continuing cycle of landscape adjustment (Bloomberg & Davies, 2012). However, as forestry is a land use that results in the complete removal of the forest vegetation cover, with concomitant ground disturbance every 3-decades (at harvest), the mitigation of sediment generation and its conveyance to the Sounds, either directly from slopes bounding the coastline or indirectly via stream channels, needs to be minimised.

From as early as the 1970s, concerns have been expressed over inadequacies in plantation development planning and implementation in areas of steep hill country previously not used for intensive forestry. Issues highlighted over this period have included:

(i) insufficient effort to establish the types, extent and frequency of existing "natural" erosion processes considered critical to the design and placement of forest infrastructure

(ii) a lack of geomorphic/pedologic understanding of how the landscape might respond to forest development, and its' associated harvest practices, especially in relation to roads and landings, and

(iii) inadequate consideration of the provision, design and management of riparian buffers for various types of waterways, and different types of topography (O'Loughlin 1977).

Recent published articles reiterate on-going concerns associated with pre-and post-harvest forest management practices in steepland areas (Phillips et al. 2012; Marden et al. 2015; Basher et al. 2015; Payn et al. 2015; Baillie & Rolando 2015) though the scientific evidence upon which these opinions are made are sparse as investment in research related to these problems has been low for many decades.

The design and implementation of effective mitigation efforts is reliant on having a clear understanding of the processes, both natural, and as a consequence of forestry practice, responsible for the generation and mobilisation of sediment, and of the transport pathways between where the sediment is generated (i.e. source(s)) and the receiving waterbody.

Attempts to reduce the sediment contribution from areas of harvesting to the Sounds will therefore require consideration of different mitigation options for:

(i) slopes located immediately adjacent to and fronting the Sounds waterline

(ii) slopes within gully heads and adjacent to stream channels, and

(iii) sites of earth disturbance, both as a consequence of harvesting, and the result of road and landing construction.

1 Replanting setbacks

The literature supports the viewpoint that riparian buffers are ineffective in trapping sediment generated by mass failures, and as concentrated load, such as occurs when debris avalanches occur during storm events (Dillaha et al. 1989; Daniels & Gilliam, 1996). Previous research has shown that episodic, storm-initiated landslides are the single most important sediment-generating process, providing the primary mechanism for mobilising and delivering most sediment to the stream network. This was most evident during a storm in Whangapoua Forest in 1995 when ~91% of debris avalanches and ~51% of soil slips (cf. 40% of landslides initiated during the 1981 Thames-Te Aroha storm reported in Salter et al. (1983) and, 50% at Otoi during an event in 1985 reported by Harmsworth et al. (1987) tracked sediment and debris through standing forest and into stream channels (Marden & Rowan 1995). Furthermore, storm events commonly initiate slope failures within riparian areas and these can also potentially contribute significant sediment and woody debris to the stream network.

The general consensus from the scientific literature suggests that buffers in steep terrain are likely to be effective in reducing sediment derived from diffuse sources by surface processes such as slopewash (Schlosser & Karr 1981; Cooper et al. 1987; Daniels & Gilliam 1996). Their effectiveness, however, is dependent on the erodibility of the soils, density and type of groundcover vegetation, and diminishes as the ratio of un-vegetated to vegetated area decreases, and as slope length and storm intensity increases. Importantly, poor land management practices can also reduce their sediment trapping effectiveness (Magette et al. 1989; Dillaha et al. 1989).

Within a forest setting, riparian areas have been promoted as an effective means of reducing the delivery of sediment to streams (Quinn et al. 1993) and the instream impacts from harvesting operations (Graynoth 1979). Where ground cover vegetation has remained intact after harvesting, slope wash-transported sediment may be effectively filtered, however, the delivery of sediment to the receiving environment will be highly dependent on the coupling of source areas to the stream network (Marden et al. 2006, 2007). Our observations indicate that slope rather than buffer width is a greater determinant on whether sediment mobilised by slope wash and by runoff actually reaches the stream network, though there are few studies that have actually assessed this.

1.1 Replanting setback options from the shoreline

Intuitively it would be expected that the wider of the proposed setback options for coastal setbacks (30 m, 100 m or 200 m as suggested on page 13 of the MDC report), would be expected to have greater sediment trapping efficiency than the narrower options, however there is little scientific evidence available to evaluate this. Where there is an existing buffer of non-exotic forest vegetation between the Sounds coastline and stands of exotic forest, it makes sense to retain it intact. However, as the dominant vegetation appears to be gorse it is probable that the understorey groundcover is sparse or absent, and so these buffers are likely to have limited effectiveness. In the longer term, natural reversion by native species under the gorse nurse-crop may eventually provide a more desirable sediment trapping outcome, as would the creating of light-wells and the under-planting of indigenous species within these buffers.

The effectiveness of any proposed buffer or setback will largely depend on the type of vegetation, its stature and density, the local slope conditions, the mechanisms in which sediment is generated, and the potential for delivery pathways to cut through or bypass such buffers. However, we re-iterate the point that irrespective of buffer width it will not be possible to completely mitigate the risk of sediment being mobilised through buffers to enter the Sounds either directly or indirectly via stream channels. There is, however, no quick-fix means of improving their sediment trapping effectiveness.

Importantly, restricting forest-related practices in areas identified as 'high risk' (previously identified in the MDC report as occurring below ~200 m) could significantly reduce sediment availability and mobility thereby reducing the reliance on the sediment trapping effectiveness of buffers to reduce the possibility of fine sediment reaching the shoreline. Similarly, improvements in forest-related practices in areas identified as 'low risk' could potentially negate the need for buffers as the replacement crop would in effect be considered as performing the role of a riparian buffer (Maclaren 1993)

1.2 Replanting setback options for permanently flowing streams directly coupled to the Sounds

It would also be expected that the wider of the two streamside buffer options (10 m or 20 m) for streams directly coupled to the Sounds, as suggested on page 17 of the MDC report, would have greater sediment trapping efficiency than the narrower buffer. However, once again there is little scientific evidence available to evaluate the efficacy of streamside setbacks of different widths for trapping/filtering slope-derived sediment across different environments in New Zealand, particularly in steep, forested landscapes (Fransen 2000). Additionally, the functions of riparian buffers change with stream width. Stream width and stream order increase in a predictable manner with increasing basin area (Hack 1957). As streams widen progressively downstream, the role of the riparian vegetation in shading and aquatic productivity increases. Similarly as discharge increases, the impact of streambank vegetation on sediment transport and water quality becomes less important. The relationship of other functions of riparian vegetation, such as creating bank stability and channel complexity, remain (Hicks & Howard- Williams 1990). Thus for streams within forested areas of the Marlborough Sounds Coker (1994) suggested a 5 m setback where streams had well-defined channels (generally below the 200 m contour), and where channels were less well defined (generally above the 200 m contour), and presumably upstream of the majority of gully heads, that the planting of forest species to the stream edge be permitted. For the latter locations, and as suggested by Maclaren (1993), the replacement crop would in effect be considered as performing the role of a riparian buffer.

While acknowledging the intent of presenting slope-based rules is an attempt to minimise erosion, we concur with the view in the MDC report that given the complexity of differences in the susceptibility of different landform units, 'blanket-style' rules based on slope alone may be difficult to interpret and implement.

It must also be accepted that irrespective of the presence of a buffer, its width or the type, density and age of the vegetation cover, slope failures triggered during storm events are inevitable, and for reasons stated earlier it will not be possible to eliminate all sediment delivery from forest areas to the Sounds at all times as acknowledged in the MDC report.

2 Replanting controls on steep slopes

Natural slope failure in the Marlborough Sounds is dominated by two forms of mass movement that include shallow landslides (earthslides) and debris avalanches. Slopewash and rilling are also recognised as processes capable of mobilising sediment, especially from areas of bare ground disturbed during the harvest operation, and from natural slope failures bare of vegetation.

Harvested slopes are vulnerable to mass movement failures the most common of which are likely to be in the form of shallow landslides (earthslides) or debris avalanches. The former tend to be small in size (area and depth) and the material generated by them tends not to have a long run-out distance (debris trail). Thus unless such failures are likely to occur within close vicinity to stream channels or on steep slopes grading directly to the shoreline, material generated by them is more likely to remain on slope than reach the channel. However, the amount of sediment generated and its travel distance will depend on the erodibility of the slope materials, slope steepness and length, distance of the failure relative to the stream or shoreline, and if present, the extent, composition and density of the groundcover vegetation downslope of the point of failure. The intensity and duration of rainfall following a slope failure may also be a determinant for material to be re-mobilised and delivered to the stream network.

As debris avalanches are generally associated with steeper slopes, they tend to be larger than earthslides in areal extent, the volume of material generated by them is considerably greater, and in the majority of cases the bulk of the mobilised sediment is transported and deposited directly into a stream channel. Where slopes within areas of standing mature forest, whether indigenous or exotic, have a history of debris avalanche failure, forest type makes little difference in preventing their initiation or to the amount of sediment delivered to streams because these processes, and their consequences, can also be seen in the steeplands of the conservation estate.

Slopewash (also known as sheetwash) is not generally considered to be a significant sediment generating and transportation process on clearfelled sites (excluding tracks and landings, and earthworks) because the volumes of material mobilised, relative to other sediment generating processes is small, because areas of ground disturbance produced during harvesting are spatially scattered, and because bare areas tend to be separated by areas where the ground vegetation has remained intact (Marden et al. 2006, 2007). The distance that coarser-grained (sand and pebble) sediment is able to be transported by slopewash is thus limited by slope morphology and the density and composition of the groundcover vegetation with much of the remaining sediment trapped on-slope. Conversely, fine sediment (clays and silts) carried in suspension are more likely to travel further and in larger quantities than coarser-grained sediment. However, the amount of sediment generated and its travel distance will similarly depend on the erodibility of the slope materials, slope segment steepness and length, rainfall intensity and duration, permeability of the soil, and the extent, composition and density of groundcover vegetation. It is likely that sediment generated and transported by slopewash would only reach a permanent stream or the Sounds if it was generated within a few metres of the receiving environment, or should slopewash become a concentrated flow (e.g. rilling) in which case its sediment load would likely bypass any vegetative trapping mechanism such as a buffer. Thus sediment generated and entrained as concentrated flow is able to mobilise

larger quantities of both coarse and fine-grained material which can be transported further than is possible by slopewash. However, as is the case for slopewash-transported sediment, travel distance will depend on slope segment angle and length, permeability of the soil, the extent, composition and density of groundcover vegetation, and the volume and velocity of the flow.

To slow the rate of sediment generation and its mobility by slopewash and rilling, newly harvested slopes are commonly oversown with introduced grasses (Marden et al. 2006, 2007). In small-scale basins (ephemeral), forested riparian buffers may reduce the amount and travel distance of sediment generated by diffuse surface slopewash and concentrated flow (Schlosser & Karr 1981; Peterjohn & Correll 1984; Cooper et al. 1987; Daniels & Gilliam 1996). However, unless such buffers include a significant proportion of dense groundcover vegetation they will not effectively reduce sediment input into streams by either slopewash or rilling, thus buffers with no or limited groundcover vegetation will be ineffective for improving stream water quality (Dillaha et al. 1989b; Daniela & Gilliam 1996; Smith 1992), particularly within larger basins.

On slopes less steep than those present in the Marlborough Sounds, the generation and mobilisation of sediment off-slope can be effectively reduced by the construction of slash barriers in combination with practices to encourage rapid vegetation cover (e.g. oversowing) thereby minimising the expectation of riparian buffers as the last line of defence for filtering sediment. However, slash barriers also pose a risk if placed across steep slopes susceptible to landslides as such barriers can be breached by landslide failures, or debris can be incorporated into the failed material creating a debris flow (channelised or not). Given that the forested slopes in the Marlborough Sounds area exceed 30°, this mitigation option may be of limited use only, such as, as a second line of defence between forest cutover and a vegetative buffer at the base of slopes.

Elsewhere in New Zealand, where exotic forest has been established specifically to control erosion and the risk of reactivating erosion during the post-harvest period is considered high, restrictions have been put in place to limit the proportion of a catchment/watershed that can be harvested in any 5-year period. Indeed, O'Loughlin (1980) recommended that for a forested area in the Marlborough Sounds that the upper slopes of watersheds be harvested first then the lower slopes 5-years later to enable the upper slopes to develop a stabilising vegetation cover. This allows the tree cover on the area harvested earliest to become established and attain near-canopy closure before harvesting commences within the remainder of the catchment/watershed thereby potentially ameliorating flood flows and any potential reactivation of erosion during periods of heavy rainfall. In support of this option, the most critical period or window of vulnerability between rotations seems to be between 5-8 years after re-establishment. This is based on examination of landslides caused by Cyclone Bola in 1988 (Marden et al. 1991, Marden & Rowan 1993), and from root growth and site occupancy studies (Watson & O'Loughlin 1990). There appeared to be no difference in the extent of landslide damage caused by Cyclone Bola within individual age classes up to 6 years after planting, with most damage occurring in stands less than six years old and least damage occurring in stands over eight years after planting, and no difference in the extent of landslide damage within individual age classes older than eight years old. Additionally, at a density of 1250 stems per hectare, it takes about 4 years for lateral roots of adjacent trees to begin to approach each other and almost 6 years for the vertical roots to penetrate to a depth of 1.5 m (Watson et al. 1987).

These data indicate it is highly desirable that the re-planting of steep slopes must be as soon as is feasible in order to reduce the risk of storm-initiated landsliding. The Marlborough Sounds will continue to be subjected to rainstorms that initiate landsliding and erosion, thus to delay re-establishment will only increase the period of risk of sustaining such damage, both on-site and off-site. However, even if trees can be established immediately following removal, there is still the likelihood of slope failures in small to moderate events. This is because varying threshold conditions for failure exist across the landscape at any one time. As soon as the trees are removed, those sites that might have failed in the previous 20–30 years become susceptible to even the smallest rain events as the combined effects of evapotranspiration and interception loss by the tree canopy result in wetter soils and lower soil shear strength. With time, the roots also decay resulting in lower soil strength. This phenomenon of post-harvesting landslides resulting from small events with an average return interval (ARI) of <1–2 years has been observed in several places in New Zealand. While there have been no published studies in New Zealand that document these observations, the scientific literature on magnitude-frequency of events that contribute to landscape response suggest that even in the absence of a large storm (ARI > 20 years), the cutover slopes will still produce some mass movements. Our ability to determine exactly where those places are is currently poor, but it is possible to broadly zone land in terms of its risk of erosion as suggested in the MDC report with a requirement for a Plan to Minimise Erosion (PME). However the MDC report does not outline what they would require for a PME.

Currently there is no tool or process for assessing this risk (Basher et al. 2015), though aspects are being considered as part of an MBIE research programme. Nonetheless, it is possible, using a combination of old (stereoscopic analysis of aerial photography that pre-dates planting) and new (LiDAR, GIS, slope stability tools) technology, that the type and location of geomorphic responses during and following major storm events might be anticipated at forest block scale with reasonable certainty, i.e. hazard zoning. With climate change scenarios predicting a certain increase in the frequency and intensity of landslide-triggering events, an indication of the potential geomorphic response would equip harvest planners with the knowledge required to design a harvest strategy that aims to avoid, or is at least cognisant of, the most vulnerable areas at times of greatest risk from the impact of storms. This might involve a modelling (e.g. Harrison et al., 2012) or terrain stability zoning approach (e.g. Gage and Black 1979, Hancock Forest Management, 2010). The methodology is proven both overseas and domestically, and improvements to forest management practise based on a terrain stability zoning approach has been credited with reducing the incidence of mass movements (Fannin RJ, Moore GD et al. 2005). Indeed, a number of forest companies throughout New Zealand have begun to produce their own risk management maps, or hazard identification processes. In the Marlborough Sounds, Coker (1994) quotes a recommendation by O'Loughlin (1980) who considered that the most pressing research and planning requirements related to the future protection of foreshores and sea-water quality needed "an appraisal of forested areas to delineate those with a high potential hazard for contributing sediment, such as old landslide areas, poor drainage, present instability, susceptible soils and geology, and slopes over 35". This was subsequently undertaken by Ron Sutherland on behalf of the Marlborough Regional Council. At 1:50 000 scale, perhaps this attempt could be used as a starting point for identifying areas of different landslide/debris flow susceptibility at a scale more applicable for planning at an operational level (< 1: 10 000).

We also suggest that such a geomorphological-based terrain stability zoning approach would provide a better evidence base in the planning, design and composition of riparian set back options more appropriately matched to the scale and proximity of different operational activities (e. g. roading, size of harvest coup) relative to stream and coastal margins. Furthermore we suggest that this becomes a requirement of a resource consent application to harvest. Additionally, this should be accompanied by controls to minimise machine-related ground disturbance upslope of the setback, improvement in the design and construction standards of roads and landings, the adoption of slope controls to (i) mitigate sediment generation (e.g.by oversowing), (ii) reduce the amount and availability of woody debris (e.g. its removal from cutover and from 'at-risk' ridge-top landings), (iii) afford longer term protection to protect the most at-'risk sites' (e.g. by suggesting the use of alternative species, both exotic or indigenous, or a retirement strategy. ,and (iv) consideration of the vegetation composition of riparian buffers most likely to provide effective trapping of fine-grained sediment. If implemented well, this combination of slope controls would potentially reduce the volume of woody debris reaching a permanent water course, and thus the frequency of its removal (where practical to do so and without causing additional disturbance) from streams.

3 Replanting requirements

The MDC report (page 19) suggests that the replanting of harvested areas could be increased to more than 1250 stems/hectare (spha) to ensure that the "window of vulnerability" is not prolonged. It is general forestry practise to re-establish plantings on harvested areas as soon as it is practical to do so, and to plant more trees than are required for the final crop. This ensures that the site will be fully occupied even if some trees die at an early age. It is now unusual to plant more than 1000 spha in a direct regime for a final stocking of 200 to 350 spha, and in recent years there has been a trend towards lower stocking rates, often below 1000 spha. This has the effect of widening the window of vulnerability and increasing the potential risk for landsliding in the early stages of the post-harvest period (Phillips et al. 2012). This would be the case should the planting density requirements be reduced for areas of harvested steepland terrain, and for areas of new forest establishment within the Marlborough Sounds.

Conversely, higher establishment stockings are generally only prescribed if the site is harsh, infertile, weed infested or has a history of past or current erosion, giving a wider choice of final-crop stocking options to be decided later in the rotation (Maclaren 1993).

While increasing the stocking density reduces the length of the period of vulnerability, densities of greater than 1250 spha have historically been prescribed only for areas where erosion was considered to be extremely severe at the time of planting. Here, initial stocking rates as high as 1500, 2000 and 2200 spha were considered essential to counter tree losses, for modifying the hydrology (by rainfall interception and de-watering of the soil), and to hasten the rate of soil-root reinforcement sufficiently to slow the rate of downslope displacement of deep-seated slumps and earthflows (Zhang et al. 1993), and to slow gully incision and expansion (Marden et al. 2005). In these cases, and over the course of a rotation of *P. radiata,* this treatment option proved successful.

Furthermore, Kelliher et al. (1992) suggest that increasing the planting density to in excess of 1250 spha, as a means of reducing the 'period of vulnerability', should be based on an assessment of the erosion susceptibility of the site in question, and be considered only for those sites deemed to be most susceptible to erosion. In addition, and based on the modelling of the time (years) required for roots to reach full root occupancy and for canopy closure to occur, the difference in the length of the 'period of vulnerability' between planting 1250 spha and 1500 spha, for example, is less than 6-months.

It is apparent from the photographs of forested slopes provided in the MDC report that tree survival of past plantings has been high, and that the planting density (assumed to have been 1250 spha) has indeed provided a level of protection commensurate with forested areas on similarly erosion-prone terrain elsewhere. It is suggested therefore that increasing the planting density would not necessarily result in significant additional environmental benefit but may in fact result in negative impacts at harvest.

In summary, for forestry stands planted and maintained at high stockings the environmental benefits include:

- Earlier canopy closure
- Earlier and greater soil-root reinforcement
- Lower risk of storm-initiated landslides
- Probably a lower incidence of wind snap
- Better weed suppression
- Longer rotation (required to achieve minimal log requirements)

However, there are commercial and environmental implications associated with higher stocking regimes. These include:

- Longer rotation ages to meet marketing constraints on minimal permissible log diameter
- Thinner logs at the same rotation age, therefore lower value per cubic metre and higher extraction costs per metre
- More costly to plant and prune
- Where planted in steep and /or broken terrain, or where there are environmental constraints on ground-based extraction, the retrieval of thinnings will not be feasible
- Greater volumes of slash to be removed from slopes and stream channels
- Absence of understorey and groundcover vegetation
- Possibly a higher incidence of windthrow (as opposed to wind-snap) (Maclaren 1993).

For the most at risk areas, such as gully heads, we suggest that instead of increasing the planting density of radiata pine, that consideration be given to replacing the pines with alternative species that have a longer rotation (either exotic or indigenous), planting of coppicing species, or retiring such areas from production forestry (tactical withdrawal) and allowing them to revert (see below).

3.1 Alternative species

Alternative species (exotic and indigenous) especially coppicing species such as eucalyptus or redwood, and/or species with a longer rotation could be considered for slopes with the highest sensitivity to forest harvest practices and/or for areas identified as having the highest risk of slope failure, such as the steepest parts of gully heads, within a larger catchment/watershed area.

Advantages of using alternative species include:

- The retention of a live root system and its root-soil reinforcement, though the interception function of the tree canopy is still lost upon harvesting.
- Re-establishment costs may be less although management of the new growth to a single leader would be required.
- Forest management options such as having a longer rotation and or coppicing species reduces the frequency of forest clearance.
- A smaller proportion of a catchment/watershed would likely be clearfelled at any one time, though this is not guaranteed, thereby reducing the risk of slope failure during periods when steep slopes are at their most vulnerable to the influence of storm events.

Disadvantages include:

- Implementation of different management regimes within a single forest would likely increase costs.
- The longer rotation has a greater possibility of management risk (e.g. availability of funding), physical risk (e.g. wind, fire, disease, volcanic eruption) and market risk (e.g. sale price, product demand).

3.2 Retirement and reversion

It has previously been suggested that slopes >35° be excluded from forest development or if already planted they be retired following harvesting (Pearce & O'Loughlin 1976). Page et al. (2012) identified 30–45º slopes in the Nelson region as having the highest susceptibility to landsliding following harvesting, and Harmsworth et al. (1987) recorded the highest frequency of shallow landsliding on slopes 38–40º, that is, predominantly Class VII land. Notwithstanding, the initiation of slope failures on steep slopes in places is limited because much of the soil and colluvium has already been stripped during previous storm events (Marden & Rowan 1995). Although the general consensus for the steepest of slopes favours their retirement to reversion, it has to be acknowledged that well-vegetated slopes established as mature indigenous forest are no less vulnerable to the initiation of slope failure than are mature stands of exotic pine.

These options have been put forward as an alternative management solution primarily, but not exclusively, for gully heads that have traditionally contributed the greatest sediment load to streams and to the Sounds. Gully heads are part of the drainage network, and although ephemeral, they were formed by channel incision, are characteristically steep-sided, and are the main conduit for water. Slope failures occurring within these gully heads inevitable contribute sediment directly into the

stream network, and other than to prevent their occurrence, there is little intervention practise available to reduce this sediment reaching the Sounds. Prevention, or at least a reduction in their incidence, is more likely if alternative land management options including those suggested in this review were to be considered for these gully heads. In considering alternative management options, it is also important to determine the position of the gully head within the drainage system, and the size of the watershed catchment upslope of a gully head. It is the size of the watershed area, and the nature of the vegetation cover (e.g. maturity, extent of coverage, evergreen or deciduous) that determines how wet the soils within steep-sided gully heads become during storm events-the very time when slope failures are most likely

4 Harvest controls

The main concern appears to be centred around the prevention or removal of slash from permanent streams and ephemeral gullies to minimise the risk of such material being incorporated into debris flows and transported to the sea (page 12 of MDC report).The proposed prevention or removal of slash from permanently flowing and/or ephemeral gullies is considered an effective means of minimising the risk of this material being incorporated into a debris flow. However, most, but by no means all, of the woody material that ends up in stream channels is a consequence of slope failures that incorporate woody debris as the dislodged slope material travels downslope. While the prevention of slope failures is not always possible, the amount of woody debris that could potentially become incorporated into the failed slope material can be limited by requiring the removal of slash from harvested slopes. However, the rules regarding the removal of woody debris from harvested slopes vary considerably. For example, some forest operations have slash management plans that require the removal of as much woody debris as is practical from harvested slopes, and in some cases from landings, and its relocation to a 'safe' storage site. Elsewhere, the retention of on-slope woody debris is permitted as a means of slowing sediment mobility or intercepting it especially during small storm events.

While the current forestry rules in the Marlborough Sounds require the removal of woody material >100 mm diameter and 3 m in length from stream channels, stricter rules have been applied elsewhere, such as if a watercourse is deemed to have significant ecological or water quality values or, for example, in the Gisborne region where the downstream effects or risk of material moving downstream is high, the standard condition for slash, in line with the general regional rule 6.6.2 of the district plan is:

> *'At the conclusion of logging at each relevant setting, all logging slash, log ends, tree heads and other waste logging material, other than tree needles, twigs, detached branches less than 50mm in diameter, pine cones and pre-harvest windfalls shall be removed from the watercourse as marked in crosshatched blue on the accompanying resource consent map' (Courtesy of Nicki Davies, Gisborne District Council).*

In areas like the Marlborough Sounds, where stream channels are short, steep, and drain directly into the Sounds, and where adjacent slopes are predominantly >30°, and have a history of debris avalanche failure, the benefits of removing slash from harvested slopes and streams at the time of completion of harvesting outweigh the probability that significant damage could result from debris avalanche

failures, and that associated large volumes of woody debris would enter stream channels and subsequently be conveyed to the Sounds. Additionally, Coker (1994) noted that slash accumulation on landings in the Marlborough Sounds became a problem and had to be relocated for fear of 'birds nests' collapsing. Elsewhere in New Zealand, where landings are confined to ridgelines considered too narrow and unstable to leave 'birds nests' of slash in place, woody debris is transported to a safe storage space.

Should the removal of woody debris require additional tracking and associated ground disturbance, for example from gully heads, then perhaps the construction of slash traps further down a valley, and where machine access can be gained via established tracks, is the better option. However, this tracking then becomes a source of fine sediment itself, that can then deliver sediment via runoff directly into the streams, particularly if there is no flood plain or flat areas in which to construct sediment traps.

We concur with consideration being given to limiting the size of harvest coupes and spatially separating cutover so that areas clearfelled in successive years are not contiguous (Coker 1994). Economics aside, this often means that roads and tracks are often trafficked over longer periods becoming longer duration sediment sources that can't be decommissioned or treated.

Furthermore we recommend that consideration also be given to alternative management options for 'high risk' slopes such as:

(i) scheduling the harvesting of the most at risk sites to periods of the year when storm events are least likely though in many areas this may be difficult to define, and

(ii) removal of woody debris from ridge top landings for storage elsewhere

5 Earthworks requirements

Our experience of forest roading design and construction over the last 3–4 decades indicates that within the corporate forestry sector at least, significant improvements in both engineering design and construction, and erosion and sediment control have taken place, though we acknowledge issues still can arise. While we agree that engineering standards need to be improved, at least to the standards outlined in the New Zealand Forest Road Engineering Manual Operations Guide (New Zealand Forest Owners Association 2012), we are unsure that this would necessarily require certification by professional engineers.

Historically, a large proportion of all geo-hydrological problems associated with exotic forests are related to poor road location and minimal construction standards (O'Loughlin 1977). Figures 2 and A1i (Appendix 1) in the MDC report indicate that there remain problems with slope stability related to earthworks. The area of spoil shown in Figure 2 will be extremely difficult to stabilise (e.g. by over sowing or by hydro-seeding) and natural colonisation by local vegetation species will be slow such that this and similarly-located sites will remain a source of suspended sediment for several years.

In Figure A1i (Appendix 1), the side casting of spoil has resulted in trails of spoil extending the full length of the slope with material being deposited directly into the Sounds. Historically, the side casting

of spoil during road construction was considered to be the norm. A recent survey of storm-related damage in a North Island steepland forest identified that many of the sites that had failed during this event were linked to roads, and more specifically to sites where material had been side cast during the forest establishment period some 40 years earlier.

It is inevitable that material side cast during road construction in steepland terrain will contribute to the sediment load of streams or other waterbodies either at the time of road construction or at some later stage in the forest cycle. In forest settings such as the Sounds where fine sediment entering sensitive waterbodies is an issue, the end-hauling of spoil to a storage area would help reduce the amount of fine sediment generated as a result of road construction practices from entering the Sounds. Coker (1994) noted that better and more co-ordinated planning of a shared road network between neighbouring forestry blocks would advantage the environment.

6 Summary

In this review we have endeavoured to provide additional evidence in support of the sediment mitigation measures already proposed, and as verbally requested suggest alternative on-slope sediment mitigation options and areas where current land management practices could be improved.

- While there is little scientific evidence available to evaluate whether the sediment trapping efficiency of the different setback options proposed for coastal setbacks (30 m, 100 m or 200 m) and for permanent streams (10 m, 20 m) improves with increased setback width, there is however general consensus that setbacks are ineffective in trapping sediment generated by mass failures but are likely to be effective in reducing sediment derived from diffuse sources by surface processes.
- There is also consensus that the effectiveness of any proposed buffer or setback will largely depend on the type of vegetation, its stature and density, the local slope conditions, the mechanisms in which sediment is generated, and the potential for delivery pathways to cut through or bypass such buffers.
- Landslides and debris flows are inevitable in the Marlborough Sounds and we support the requirement for a Plan to Minimise Erosion. While our ability to determine exactly where landslides and debris flows will occur is currently poor, it is possible to broadly zone land in terms of its risk of erosion by terrain stability zoning, and we suggest that this should be an integral part of the PME.
- We suggest that increasing the planting density above 1250spha would not necessarily result in significant additional contribution to slope stability.
- Alternative species (exotic and indigenous) especially coppicing species such as eucalyptus or redwood, and/or species with a longer rotation could be considered for slopes with the highest sensitivity to forest harvest practices and/or for areas identified as having the highest risk of slope failure, such as the steepest parts of gully heads.
- Retirement and reversion should be considered as an option for the most at risk sites such as gully heads.

- The requirement for the removal of woody material >100 mm diameter and 3 m in length from stream channels is a practical approach to manage the risk of slash mobilisation in gullies and streams.
- We concur with consideration being given to limiting the size of harvest coupes and spatially separating cutover so that areas clearfelled in successive years are not contiguous.
- Engineering standards for roads and earthworks need to be improved, at least to the standards outlined in the New Zealand Forest Road Engineering Manual Operations Guide, but this may not necessarily require certification by professional engineers.

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