Some Observations of Erosion as a Result of the 28 December 2010 Storm Event

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Executive Summary

On December 28 a severe storm occurred in parts of the Wairau Northbank hill country, Kaituna Valley, Wakamarina Valley, eastern Grove Arm and the Rai/Pelorus region. A key feature of this storm event was not so much the total amount of rainfall that fell over this area, but rather the intensity of the rainfall. For example peak rainfall intensities reached 44 mm per hour at Tunakino, with over 180 mm recorded in 6 hours, and a total of 254 mm for the event. The approximate return interval (ARI) for this rainfall event is greater than 50 years for durations from 2 through to 6 hours. The storm occurred after a prolonged period of rain in the area, hence antecedent soil moisture conditions were high. One of the more noticeable effects of the storm event was in places the significant localised soil erosion.

To assess the types of erosion that occurred as a result of the storm event, major land failures were photographed across the affected area – inclusive of all landcover/uses. The aim of this report is to provide a visual and descriptive record of the erosion and specifically to make comment on the types of erosion that were observed e.g. soil slip, debris avalanches, debris flow etc, the landforms and characteristics associated with erosion i.e. soils, geology, slope; Land Use Capability (LUC) class and the landcover/use.

It is important to recognise that this assessment was undertaken as a rapid aerial photographic reconnaissance of damaged sites in the wake of the storm. Comments received from a participant in the data analysis (DLH) and from a peer reviewer (LJB) indicate that more information about the reasons why the storm damage was more severe in some land uses but not in others, might be obtained by taking a continuous photographic transect through intervening sites that have little or no damage. Doing so would have enabled quantitative measurements and statistical comparisons amongst sites. Nonetheless there a number of important observations and comparisons that can still be made with respect to the erosion that occurred. This report stands as a descriptive record of the storm damage to various land uses and therefore has value as a document for future reference.

In total 33 sites across the storm-affected area were identified which were considered areas of ‘major erosion’. At each site the forms of erosion were described from representative photos of the site taken from the air and the ground along with supporting information in some instances collected from site visits.

The area where the storm event impacted is underlain by schist to semi-schist that is moderately to weakly weathered. Slopes are typically steep (26 – 35º) to very steep (>35º). The dominant soils are the Onamalutu and Kenepuru Steepland soils which are both considered to be well to moderately well drained soils. Soil depth varies depending on slope, which along with altitude affect the degree of weathering of the soil parent material. Both of these soils are known to be prone to moderate to severe sheet and soil slip erosion when there is inadequate vegetative cover. Because of these factors the LUC classification for the land across this area is largely class 7e land with lesser amounts of 8e and 6e. In summary, along with climate, the land has physical limitations to land use through severe erosion risk, steep to very steep slopes and in places shallow soils.

The most common types of erosion present, irrespective of landcover/use, are soil slips, debris avalanches and debris flows. These types of erosion have been found at other sites where similar scale storm events have occurred e.g. Tapawera. Localised areas of sedimentation were also present on small fans and on floodplains where stream gradients decreased in the lower parts of some channels. Rilling and sheetwash erosion also occurred on exposed soil (mostly from forestry harvest disturbance), however it was not thought to be a major source of off-site sediment.

Soil slips were often small with long debris tails and commonly mid-slope failures. Although there were numerous small slips associated with forestry tracks and cut road banks. While there was a range in erosion severity for soil slips, at the majority of sites slips were ranked as moderate (using the LUC classification). However, under exotic pasture sites, the severity of soil slips appeared to be lower (although not statistically tested) compared to sites that had recently harvested pines or <10 year old pines.

Debris avalanches and debris flows (although not statistically tested) appeared to be at a higher density and their erosion severity generally higher at plantation forests sites compared to other

landcover/uses. In a number of instances it appears that debris avalanches on these landcover/uses have coalesced at the head of ephemeral stream channels on steep slopes and developed into debris flows. In some cases these flows have collected woody debris that has accumulated in these ephemeral channels and it has contributed to stream channels being scoured farther downslope. This woody debris along with soil and rock was often deposited onto small fans and flood plains on valley floors, sometimes damaging roads and other infrastructure, blocking culverts and resulting in washouts.

It would appear that the severity of the erosion observed from the storm event was driven by a combination of factors. Firstly a period of high and unusually intense rainfall falling onto soils that were already saturated. Secondly a land environment that had steep slopes recognised as at severe risk of some types of erosion. Thirdly rainfall occurring on a proportion of plantation forestry land that had been recently harvested and/or replanted.

It is important however to appreciate that while the implementation of 'best practice land management' to minimise erosion and offsite effects is desirable, many of the industry standards are only designed to withstand the effects of 1 in 10 storm event. Given the magnitude of the storm event experienced in December (i.e. up to 1 in 50 in places), many of the best practices were unlikely to have been effective at preventing or minimising erosion and in fact could be expected to fail. Nonetheless, management practices which minimise soil loss and debris accumulation in channels may help reduce some of the effects of erosion during large storm events and at the very least be beneficial when lesser magnitude storm events occur in the future. These should be advocated to all primary industries in Marlborough.

Furthermore, if predicted climate variability for Marlborough results in an increase in the number and frequency of intense storm events in the future, this has the potential to result in an increase in the amount of soil erosion occurring in parts of the region. Therefore, thought should be given as to whether as a community we will accept the potential for an increase in soil erosion and if not, what, can be done to prevent or mitigate erosion occurring.

Contents

1. Introduction

On 28 December 2010 a severe storm occurred in parts of the Wairau Northbank hill country, Kaituna Valley, Wakamarina Valley, eastern Grove Arm and Rai/Pelorus region. A key feature of this storm event was not so much the total amount of rainfall that fell, which was not considered excessive for this area, but rather the intensity of rainfall. For example peak rainfall intensities reached 44 mm per hour at Tunakino, with over 180 mm recorded in 6 hours, and a total of 254 mm for the event (Figure 1). The approximate return interval (ARI) for this rainfall event is greater than 50 years for durations from 2 through to 6 hours. About 6 km to the east of the Tunakino site, a farmer in the head of the Opouri Valley recorded 376 mm for this event (about 50% more than Tunakino) and a total of 1070 mm for the month, most of which fell within 12 days. This illustrates the spatial variation in rainfall even within relatively short distances.

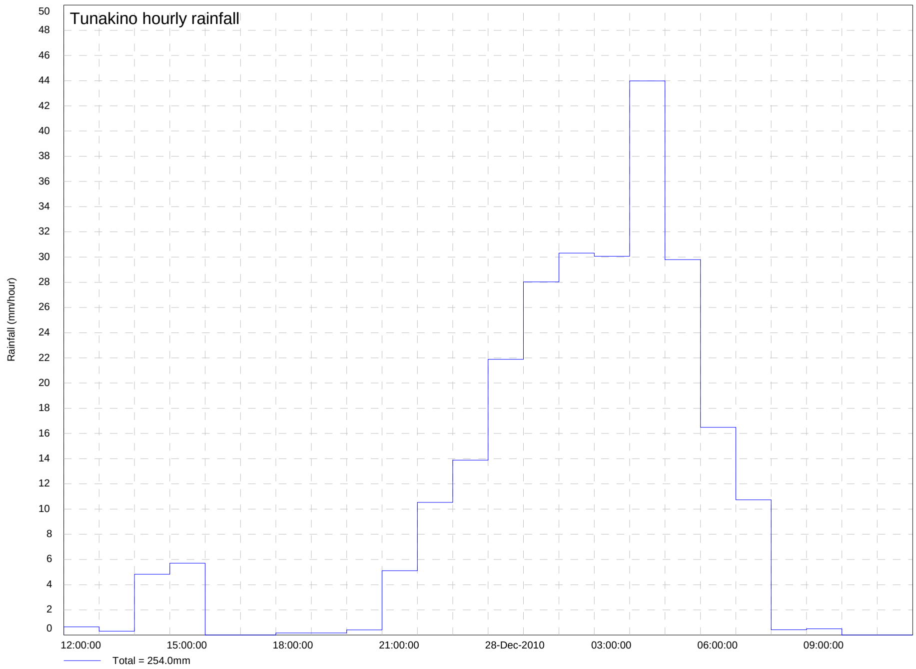

Figure 1 Rainfall intensity at the Tunakino rainfall site

Other rainfall sites in the Richmond Range and Marlborough Sounds also received significant rainfall amounts, although they were lower than Tunakino (Figure 2). Unfortunately the Council's Onamalutu gauge failed early in the event, and data is not available for analysis. Because the locations of Council's rainfall sites do not cover the Wakamarina or upper Pelorus valleys, it is not known the amount of rain that fell in those catchments. A Tasman District Council site behind Nelson, about 5 km north-west of Dun Mountain on the northern Pelorus ridge recorded 120 mm, but is likely that rainfall further inland over the Bryant Range was significantly higher.

What is also important to recognise is that while there was intense rainfall on 28 December, this occurred after a period of prolonged rainfall so antecedent soil moisture conditions were high. For example, rainfall for the period from the 17th to 22nd December, together with the December monthly average (where known) showed Tunakino had 488 mm (196 mm); Rai Falls 364 mm and Top Valley 171 mm (133 mm).

As a result of the rainfall, there was evidence of flooding and erosion that resulted in significant damage to roads and other infrastructure. For example, by mid-morning on the 28 December every major road in northern Marlborough was closed due to either flooding or slips. State Highway 6 was closed in at least three places i.e. south of Havelock and in two locations between Havelock and Canvastown. Queen Charlotte Drive was closed by a number of slips leaving Havelock isolated. Port Underwood and Kenepuru Roads were closed by slips, Ronga Road was closed by flooding and Opouri Valley Road was closed due to a bridge approach being washed out. Most of the side roads running off SH 6 were also closed either by surface flooding or washed out culverts.

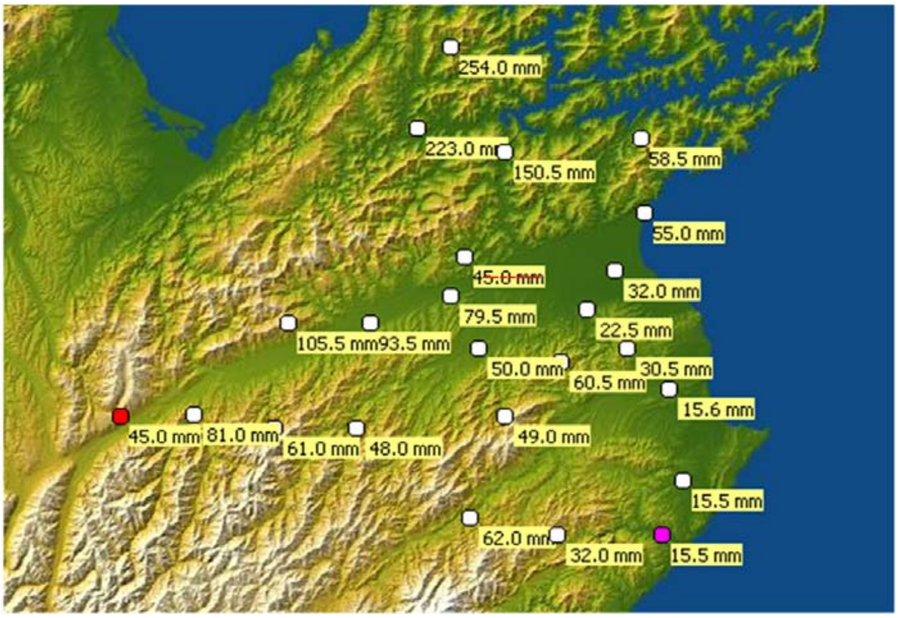

Figure 2 Total rainfall (mm) for the 24 hours of the storm event across different parts of Marlborough

In addition to the road damage, there were also reports of dwellings being flooded in the Northbank, Onamalutu, Kenepuru Road area and Linkwater. In one instance damage to a property as a result of sedimentation from land slips, pines logs and other woody forestry debris occurred south of Havelock.

As a result of the rainfall there were also floods in many rivers and streams. The return periods for the floods varied between locations from a five year ARI flood to approximately 100 year ARI flood. For example the Onamalutu stream and Bartletts Creek in the Northbank had flood flows in the order of a 50 year ARI, while the Wakamarina river draining the northern side of the Richmond range had an estimated flood of a 100 year ARI. For the Wairau and many other rivers it has been the largest flood since July 1998.

As well as flooding and damage to roads and other infrastructure, as alluded to already, the storm event also triggered severe erosion in some areas. While in some cases this potentially exacerbated flooding and damage to infrastructure i.e. washouts, blocked culverts and bridges, it also resulted in localised loss of our soil resource and in some cases resulted in offsite effects through deposition of sediment/woody debris into streams.

2. Aim

To assess the types of erosion that occurred as a result of the storm event, Council staff took aerial photographs across the area in the days after the storm. Major land failures were photographed regardless of landuse. The aim of this report is to provide a visual and descriptive record of the erosion that occurred as a result of the storm event on 28 December 2010 from the photographs and site visits to the storm affected area. Specifically, to make comment on the types of erosion that were observed (soil slip, debris avalanches, debris flow etc), and the site characteristics associated with erosion (soils, geology, slope; Land Use Capability class and the landcover/use).

3. Methods

There are numerous approaches that can be used to assess erosion. The approach used depends very much on the goal of the assessment and the level of detail that is required. A compilation of the various approaches that have historically been used in New Zealand to measure soil erosion and their relative practical and scientific merits has been summarised by Harmsworth and Page (1991). Techniques include various types of field measurements using Global Positioning System (GPS) and survey equipment, assessment using aerial photographs and also interpretation of satellite imagery. These techniques can collect information on things such as the percentage of area affected by erosion, the landslide density etc.

Several of these approaches were considered by Council to assess the effects of erosion from the storm event in this study. These included assessment of the types and amounts of erosion from ortho-rectified aerial photographs using photo point interpretation (Burton et al., 2009) flown over the affected area shortly after the storm event. And similarly, interpretation of erosion from Spot-5 satellite imagery. While both approaches allow a systematic way of quantifying the amount of erosion, its extent, the landforms it occurred on and the landuse, it obviously relies on obtaining recently flown photographs/imagery which is very expensive.

3.1. Erosion

As an alternative to using photographs/satellite imagery, Council decided to adopt a qualitative approach to assessing the effects of erosion by interpreting photographs taken from the air and ground by Council staff in the days after the storm event. Several hundred aerial photographs were taken during two helicopter flights in the days following the storm event on the 29 December and again on 5 January. The aerial photos attempted to capture the major land failures across the storm affected area regardless of the landuse. In total 33 different sites across the storm affected area were identified which were considered areas of 'major erosion'. A 'site' was considered to be a single failure or group of failures occurring within a restricted area in the landscape. For each of these sites a Google Earth image was obtained to help put into context where in the landscape the erosion was present. At each site the dominant forms of erosion were described from representative photos of the site taken from the air. The area that was assessed is marked in red on the Google Earth image. In addition, all the major failures in forestry blocks were inspected and photographs taken after the event and photographed from the ground where access permitted. This was undertaken to determine whether forestry activities were compliant with resource consent conditions. These photographs were also used to help determine the types of erosion found at each site.

3.1.1. Erosion Interpretation

There are many criteria available for distinguishing the types of slope failure e.g. the velocity and mechanism of movement, shape of moving mass, water content of material etc and thus many classifications in use (Selby, 1985). In this study erosion was described using the definitions given in the Land Use Capability Survey Handbook (Lynn et al., 2009) which is a New Zealand developed classification. The erosion classification is descriptive and incorporates form and process rather than a geotechnical classification. It describes erosion in terms of surface erosion, mass movement, fluvial erosion and deposition (Table 1).

Table 1 Erosion types (from Land Use Capability survey handbook (Lynn et al., 2009)

Category	Erosion types	Symbol
Surface erosion	Sheet	Sh
	Wind	W
	Scree	Sc
Mass movement	Soil slip	Ss
	Earthflow	Ef
	Slump	Su
	Rock fall	Rf
	Debris avalanche	Da
	Debris flow	Df
Fluvial erosion	Rill	R
	Gully	G
	Tunnel gully	T
	Streambank	Sb
Deposition	Deposition	D

In addition, erosion severity rankings were made for each type of erosion identified at each of the sites. Ordinal rankings on a scale of 1 to 5 partly reflect the area of each site occupied by each erosion type and also how much soil appears to have been scoured, based on the scars (i.e. soil slip, debris avalanche) or deposited along watercourses (i.e. soil flows, debris flows) (Table 2).

Table 2 Guidelines for relating area eroded to erosion severity for each erosion type (Lynn et al., 2009)

		Soil slip	Debris avalanche	Debris flow	Earthflow & Slump
		Area	Area	Area	Area
Symbol	**Severity**	(%)	(%)	(%)	(%)
θ	**Negligible**	<0.5	<0.5	<0.5	0
1	**Slight**	0.5 - 2	0.5 - 2	0.5 - 2	<0.5
2	**Moderate**	2 - 5	2 - 5	2 - 5	0.5 - 1
3	**Severe**	5 - 10	5 - 10	5 - 10	1 - 5
4	**Very severe**	10 - 20	10 - 20	10 - 20	5 - 10
5	**extreme**	>20	>20	>20	>10

3.2. Landcover/Landuse

The dominant landcover/use at each site was also recorded as 5 classes including;

1. pine forest >10 years
2. pine forest <10 years
3. recently harvested pine forest
4. exotic pasture
5. scrub and bush (both native and exotic)

The rationale behind separating forestry classes is based on the recognition that the age of the forest cover can affect land stability. Young trees and recently replanted trees are known to be less effective in mitigating erosion than older trees. This is discussed in more detail in section 4.7.2.

3.3. Site Physical Parameters

Because the photographs were all geo-referenced, the underlying physical properties at each site i.e. soil type, slope, geology that may affect land stability could be assessed. This information was derived from the New Zealand Land Resource Inventory (NZLRI). The NZLRI is a national database of physical and land resource information and includes an inventory of five physical factors which have been compiled from field assessments i.e. rock type, soil type, landform and slopes, erosion types and severities and vegetation cover.

3.4. Land Use Capability (LUC) Classification

In addition at each site the Land Use Capability (LUC) classification was noted. This was primarily taken from the NZLRI, although at some sites where there was clearly more than one LUC class present the site was divided into more than one LUC class. The LUC system is an evaluation of the capability of land for permanent sustained production. It takes into account the physical limitations of the land. The assessment of land for permanent sustained production is based on an interpretation of the physical information in the NZLRI, along with other supplementary information on climate, flood risk, erosion history and the effect of past landuse practices.

The LUC classification has three components i.e. LUC class, subclass and unit – each represented by a number or symbol. There are 8 LUC classes with limitations to use increasing and versatility decreasing from class 1 to class 8. The 8 classes are further subdivided according to the main kind of physical limitation or hazard to land use at a site i.e. erodibility (e), soil limitation within the rooting zone (s), wetness (w) and climate (c). LUC units are a subdivision of the subclass, and group together parcels of land with similar characteristics that require similar management.

4. Results and Discussion

4.1. Location

Figure 3 shows the location of the 33 sites used to assess erosion. It provides a good indication of the spatial extent of the storm event which predominantly affected areas in the Wairau Northbank hill country, Kaituna Valley, Wakamarina Valley and extending out to eastern part of the Grove Arm in the Marlborough Sounds. Interestingly while significant rainfall fell in the Tunakino/Opouri Valleys no significant land failures were noted in these valleys. This may be related to several factors including the soils and underlying geology of the area which compared to other locations is dominated by the Opouri soil and greywacke geology and the dominant land use which is estimated to be 60 percent native cover in the Rai catchment which covers the Tunakino/Opouri Valleys.

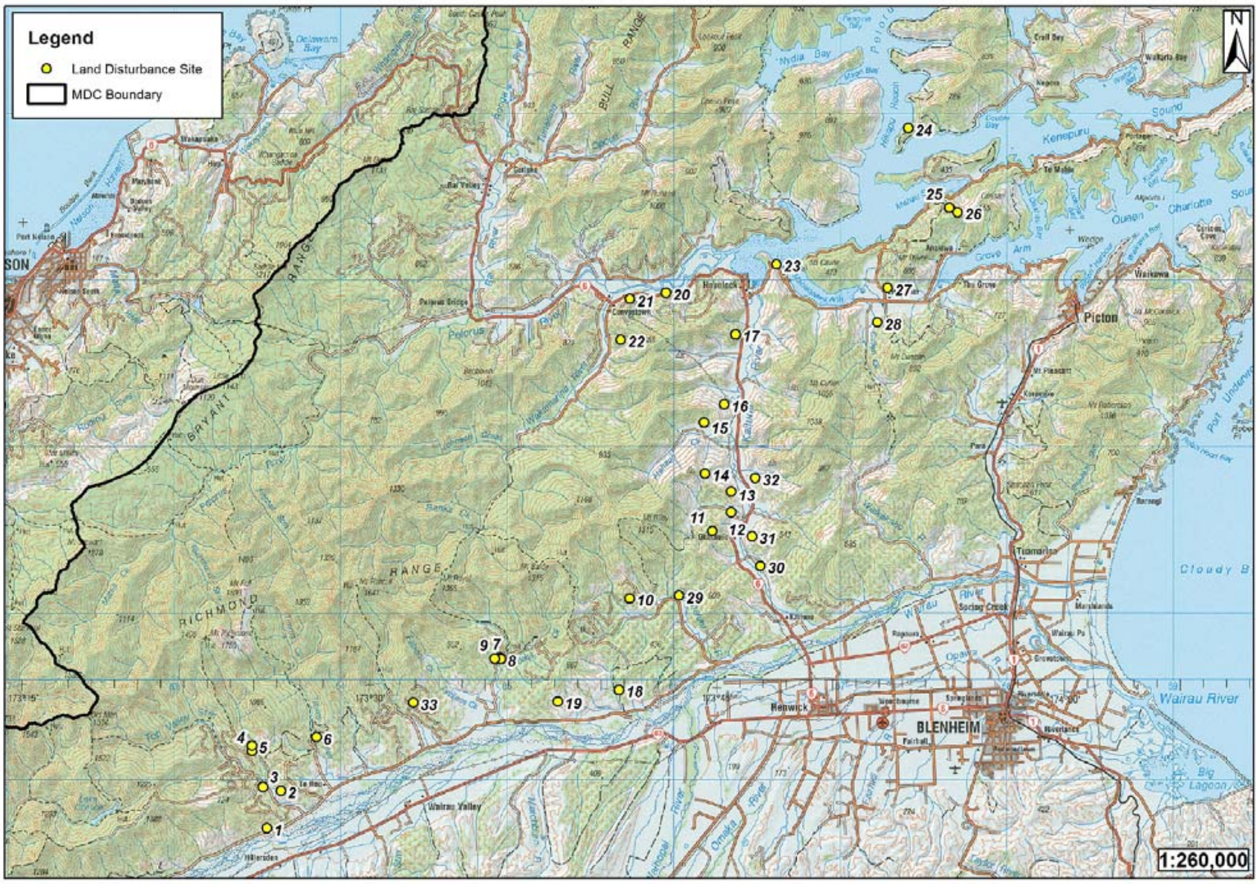

Figure 3 Map showing the locations of the 33 sites used to assess erosion

4.2. Physical Site Details

The type, amount and location of erosion is controlled to a large degree by the physical characteristics of the environment. Table 3 summarises the geology, slope and soil types found at each of the 33 sites.

Table 3 The underlying geology, slope, soil type and landcover/use at each assessment site

Site	Geology	Slope (°)	Soil	Landcover/use
1	Schist	26 - 35	Onamalutu soil	Pines < 10
2	Schist	21 - 25	Tuamarina soil	Pines < 10
3	Schist	26 - 35 + 21- 35	Onamalutu soil	Pines < 10
4	Semi-schist	26 - 35 + >35	Onamalutu soil	Pines < 10
5	Semi-schist	26 - 35 + >35	Onamalutu soil	Recently harvested
6	Schist	26 - 35	Onamalutu soil	Pines < 10
7	Schist + Semi-schist	26 - 35	Onamalutu soil	Recently harvested
8	Schist + Semi-schist	26 - 35	Onamalutu soil	Recently harvested
9	Schist + Semi-schist	26 - 35	Onamalutu soil	Recently harvested
10	Schist	>35 + 26 - 35	Onamalutu soil	Recently harvested
11	Schist	26 - 35	Onamalutu soil + BR	Pines < 10
12	Schist	21 - 25 + 26 - 35	Onamalutu soil	Exotic pasture
13	Schist	26 - 35	Onamalutu soil + BR	Scrub; Exotic pasture
14	Semi-schist	26 - 35 + >35	Kenepuru soil + BR	Pines > 10
15	Semi-schist	>35 + 26 - 35	Kenepuru soil	Recently harvested
16	Semi-schist	26 - 35 + 21 - 25	Kenepuru soil + BR	Scrub
17	Semi-schist	>35	Kenepuru soil + BR	Recently harvested
18	Schist	26 - 35 + 21 - 25	Onamalutu soil	Recently harvested
19	Schist	16 - 20 +21 - 25	Tuamarina soil	Scrub
20	Semi-schist	26 - 35 + 21 - 25	Kenepuru soil + BR	Recently harvested
21	Greywacke	>35	Kenepuru soil + BR	Pines > 10
22	Schist + Semi-schist	26 - 35 + >35	Kenepuru soil + BR	Pines < 10
23	Semi-schist	21 - 25 + 26 - 35	Patutu soil	Scrub
24	Greywacke	26 - 35 + >35	Opouri soil	Recently harvested; pines > 10
25	Semi-schist	26 - 35 + >35	Kenepuru soil	Pines < 10
26	Semi-schist	26 - 35 + 21 - 25	Kenepuru soil	Scrub
27	Semi-schist	26 - 35	Kenepuru + BR	Recently harvested
28	Semi-schist	21 - 25	Kenepuru + BR	Recently harvested
29	Schist	26 - 35 + >35	Onamalutu soil + BR	Pines > 10
30	Schist	26 - 35	Onamalutu soil	Exotic pasture
31	Schist	26 - 35	Onamalutu soil	Exotic pasture; scrub
32	Schist	26 - 35	Onamalutu soil	Exotic pasture; scrub
33	Schist	26 - 35	Onamalutu soil	Pines > 10

4.3. Geology

The underlying geology of the storm affected area is largely made up of high grade metamorphic rocks i.e. schist or weakly metamorphosed rocks i.e. schistose greywacke (semi-schist), although there are lesser amounts of greywacke which were found at two sites (Table 3). An understanding of the underlying geology is important because in North Marlborough it influences the soil parent material, in combination with the degree of weathering. Typically in the Northbank hill country, at lower altitudes i.e. below 400m the degree of weathering decreases with increasing slope. Parent material on slopes less than 25º is generally highly-weathered. On steep (26 – 35º) to very steep slopes (>35º) parent materials are moderately to weakly weathered. At altitudes above 400 m regardless of slope, parent materials are weakly to moderately weathered.

4.4. Slope

Slope varies widely throughout North Marlborough with values typically ranging from strongly rolling (12 - 15º) in parts of the Northbank hill country to very steep (>35º) in the Richmond ranges. Across the storm affected area slopes were in nearly all instances on steep (26 – 35º) to very steep (>35º) land with only minor amounts of moderate (16 – 25º) slopes (Table 3).

4.5. Soils

The pattern of soils in North Marlborough is governed largely by parent material, slope, altitude, and climate (Rae and Tozer, 1990). Nearly all of the erosion occurred on the Onamalutu and Kenepuru Steepland soils which reflected the dominance of these two soils across the storm affected area, with a couple of sites having the Tuamarina Hill, Opouri hill and Patutu steepland soils (Table 3). The Onamalutu and Kenepuru Steepland soils include well and moderately well drained soils formed from variably weathered schist or schistose greywacke and their derived slope deposits. Soil profiles commonly contain stones and rock fragments and soil depths vary depending on slope and the degree of weathering, ranging from shallow to moderately deep. Typical soil profiles have greyish brown topsoils overlying yellowish brown stony silty clay loam subsoils. Both soils have moderately developed nutty/blocky soil structure and moderate profile available water holding capacities.

In terms of the erosion susceptibility, the Onamalutu and Kenepuru Steepland soils are reasonably structured, have a high aggregate stability, and therefore they would not normally be inherently susceptible to sheet erosion, as long as there isn't any significant depletion of vegetation cover. The exception being when the topsoil is removed and less well structured deeper subsoils may be exposed which have a lower aggregate stability e.g. at forestry landing sites where there can be significant earthworks.

In comparison, the risk of mass movement such as soil slips in these steepland soils is a bit more complex. The main cause for soil slips is usually soil saturation, because of some impedance or slowly permeable layer in the soil profile. As soil moisture content increases, soil strength decreases. So when soils reach saturation, the probability of failure increases, especially on steeper slopes. However, also important to consider in these steepland soils is the weathering characteristics of the subsurface materials that transition into bedrock. For example if soils overlie unweathered impermeable bedrock the likelihood of slipping can increase. In addition, soil strength can be affected by the presence or absence of vegetation, in particular tree roots which can reinforce soils (see section 4.7.2). Because soil characteristics (i.e. permeability and drainage) in steepland landscapes can vary widely, that is why the distribution of slips in these environments can be very random. So all things being equal, if soils are saturated, in places where soils are reasonably well structured, have no slowly permeable layers and pass into fragmented bedrock then the erosion potential is likely lower than at sites where vegetation and topsoil is removed and soils overlie unweathered impermeable bedrock.

Interestingly, according to the Soil Bureau (1968) 'these soils should remain in protection forests or be used for exotic forestry for which they are well suited', and it also indicates that 'care is necessary in harvesting forest crops because of the erosion risk'.

4.6. Land Use Capability Classification

The LUC is an integration of the physical site details described above along with an assessment of the land's capability for sustained use. It was found that more than 80% of the sites assessed were on land rated as LUC 7e9 or 7e12 (Figure 4). The dominant limitations to land use on class 7e land are a severe erosion risk and steep slopes. The potential erosion risk for class 7e9 land is moderate to severe sheet, soil slip and scree while for 7e12 it is severe sheet and soil slip (Lynn, 1996). LUC class 8e land was found at three sites. Class 8e land has very severe to extreme erosion potential which, along with very steep slopes, (greater than 35º in this study) make it, according to Lynn et al. (2009), unsuitable for pastoral grazing or production forestry. It is considered best managed for catchment control/nature conservation (Lynn et al. 2009). The potential erosion risk for class 8e2 land is extreme sheet, soil slip and gully erosion (Lynn, 1996). The remaining three sites were LUC class 6e land, which has a moderate erosion risk and all had lower slopes than the other sites.

It is worth noting that erosion potential as outlined in the LUC is essentially assessed assuming a pastoral landcover/use. For example NWSCO (1979) state 'an assessment is given of potential erosion of each unit under actual or assumed grassland cover with assumed average management and no soil conservation measures applied'. Therefore strictly speaking it isn't an assessment that can be directly applied to different landcovers/uses such as plantation forestry, which would likely have a lower potential (Basher pers comm.).

Interestingly, the Ministry for the Environment currently has a National Environmental Standard (NES) for Plantation Forestry out for comment. A central requirement of the NES is the development of a national erosion susceptibility classification. What is being proposed is the categorisation of land parcels into four classes from low to very high based on the land parcel's maximum erosion potential. The maximum erosion potential is based on the LUC classification and takes into account all forms of mass movement erosion, plus gully and tunnel gully erosion. As described above, there are some limitations in using this assessment of erosion potential. Based on the current draft of this classification (which based on review by Regional Council is unlikely to change significantly) all the sites assessed in this study would be in either the high to very high zone and therefore there would be restrictions on some forestry activities such as afforestation, harvesting and earthworks.

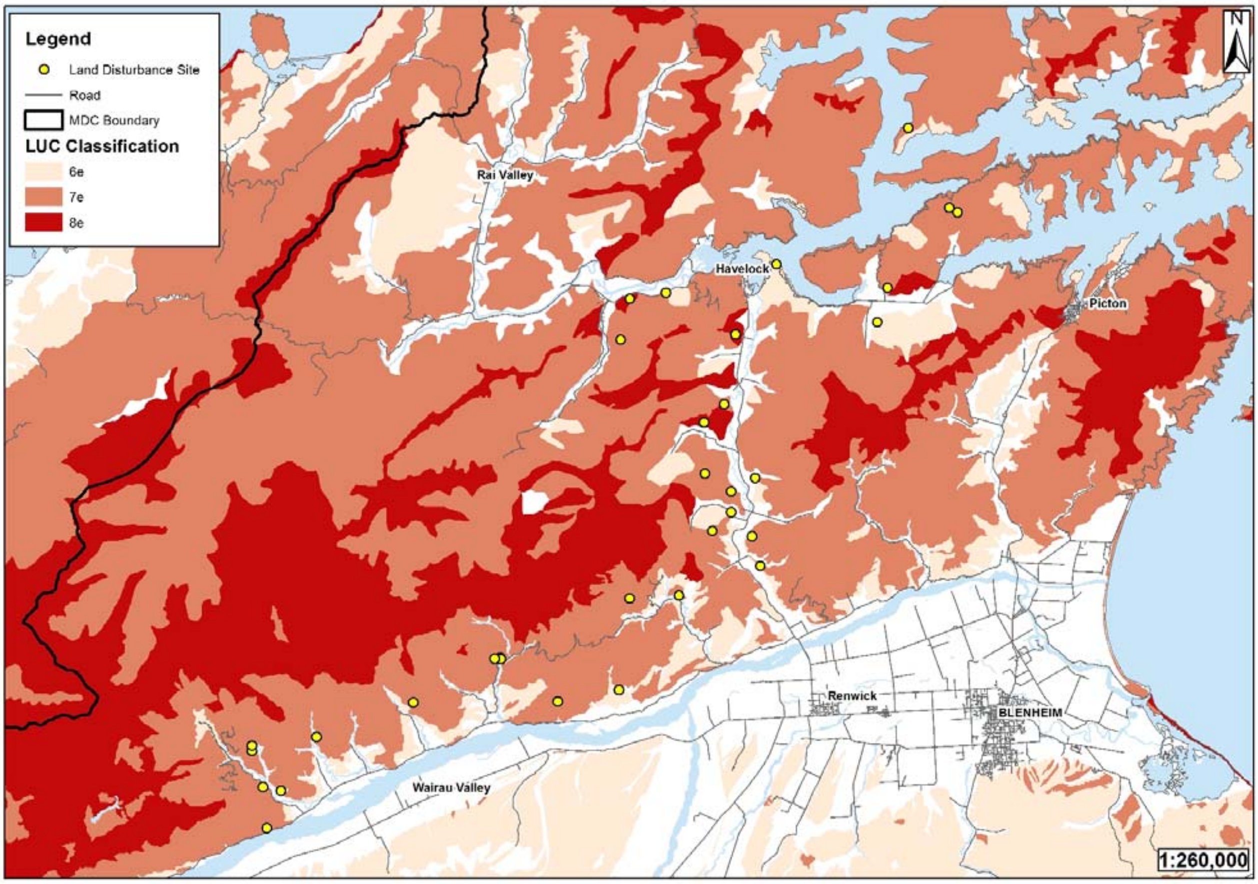

Figure 4 Distribution of Landuse Capability class 6e, 7e and 7e in North Marlborough in relation to the 33 sites of erosion

4.7. Assessment of Erosion

Figures A1 – A33 (Appendix A) provide an overview of sites where major erosion was observed after the storm event. Each figure shows the landscape in which the erosion occurred along with photographs of examples of erosion. These photographs along with additional photographs (contained in Appendix B) were assessed to identify the types of erosion present and their severity. As well as observations from photos, in some cases supporting information was collected from site visits. Because at some sites there were different slopes or landcover/use (and therefore different types of erosion), the site was broken down to into sub-sites for analysis and reporting (e.g. 22a, b, c, d).

It is important to recognise that this assessment was undertaken as a rapid aerial photographic reconnaissance of damaged sites in the wake of the storm. Comments received from a participant in the data analysis (DLH) and from a peer reviewer (LJB) indicate that more information about the reasons why the storm damage was more severe in some land uses but not in others, might be obtained by taking a continuous photographic transect through intervening sites that have little or no damage. Doing so would have enabled quantitative measurements and statistical comparisons amongst sites. Nonetheless there a number of important observations and comparisons that can still be made with respect to the erosion that occurred, specifically the types of erosion, the nature of the land it occurred on, and the landcover/use using the approach adopted in this study.

For ease of reporting, the LUC system of erosion type and severity for recording erosion was used as outlined in Table 1 and 2. As an example, a site with a erosion description of 2Ss 3Da 4Df is defined as a site containing moderate soil slip (2Ss); severe debris avalanche (3Da) and very severe debris flow (4Df).

4.7.1. Landcover/Use

Of the 33 sites used to assess erosion, there were five types of landcover/use. These included three categories related to commercial forestry (pines older than 10 years – 5 sites, pines younger than 10 years – 8 sites, and recently harvested pines - 11 sites). In addition some sites occurred on exotic pasture and scrub (9 sites).

4.7.1.1. Pines Older Than 10 years

The five sites that had pines considered greater than 10 years of age were subject to a range of different erosion classifications. Soil slips were present at three of the five sites (Table 4) with erosion severity moderate. Debris avalanches were present at all but one site, ranging in severity from moderate to very severe. In contrast debris flows were present at only three of the five sites and where present they were either moderate or in one instance classed as very severe where there were significant scour and deposition of both sediment and woody debris.

Table 4 Erosion type and severity derived from LUC for land with plantation forestry >10 years age

Site	Erosion type and severity
14a	2Ss 2Da 2Df
21	2Ss 4Da
24b	0Ss 0Da
29	0Ss 2Da 2Df
33a	2Ss 2Da 4Df

4.7.1.2. Pines Younger Than 10 years

For sites that had pines younger than 10 years of age, soil slips were present at eight of the eleven sites (Table 5). Their erosion severity was variable ranging from slight to severe. Debris avalanches were present at all of the sites and erosion was ranked as severe at more than half of the sites. Debris flows are present at over half the sites and were ranked as severe or very severe.

Table 5 Erosion type and severity derived from LUC for land with plantation forestry <10 years age

Site	Erosion type and severity
3	3Ss 3Da 3Df
4	2Ss 3Da 4Df
6	1Ss 3Da
11	0Ss 3Da 3Df
22a	2Ss 2Da

Site	Erosion type and severity
22b	3Ss 3Da 3Df
1	0Ss 2Da 3Df
2	0Ss 2Da 3Df
22c	3Ss 3Da
22d	1Ss 1Da
25a	2Ss 3Da 3Df

4.7.1.3. Recently Harvested Pines

Where pines have been recently harvested soil slips were present at all sites except one (Table 6). Their erosion severity ranged between slight to severe although on balance soil slip erosion was mainly moderate. Debris avalanches were present at all but two sites with erosion severity ranging from slight at one site to very severe at two sites. Debris flows were present at more than half the sites i.e. 13 sites of the 21 sites and the erosion severity was fairly evenly spread between moderate through to very severe.

Recently harvested pine sites also display numerous small patches of soil bared by cable hauling through ground cover or by downslope movement of slash. Sheetwash and rills are visible on these bare patches. However they have not been recorded as erosion types because their severity would be recorded as slight (1). This is because the bare patches are surrounded by logging slash or residual ground cover which will have trapped most of the removed soil a short distance down-slope. Furthermore rills' and sheetwash's contributions to on-site soil loss (and off-site sediment accumulation) appear minimal, relative to the substantial soil shifted by other erosion processes identified.

Table 6 Erosion type and severity derived from LUC for land in plantation forestry recently harvested

Site	Erosion type and severity
5	2Ss 2Da 2Df
7	2Ss 2Da 2Df
8	3Ss 3Da 2Df
9	2Ss 4Da
10a	2Ss 3Da 3Df
10b	2Ss 2Da 3Df
10c	3Ss 2Da 3Df
10d	3Ss 4Da 4Df
15a	2Ss
17a	2Ss 3Da 4Df
17b	2Ss 1Da
18	2Ss 3Da 3Df
20a	3Ss 2Da 2Df
20b	2Ss 3Da
24a	2Ss 3Da
24c	2Ss 3Da
27a	2Ss 2Da
27b	2Ss 3Da 3Df

Site	Erosion type and severity
27c	1Ss
28a	2Ss 2Da 2Df
28b	2Ss 2Da 4Df

4.7.1.4. Exotic Pasture

All sites under exotic pasture showed the presence of soil slips (Table 7), erosion severity was slight to moderate. Debris avalanches were observed at three out of ten sites and where present their severity was slight.

Table 7 Erosion type and severity derived from LUC for land with under exotic pasture

Site	Erosion type and severity
12	1Ss
13b	2Ss
30	2Ss 1Da
31a	2Ss
31b	2Ss 1Da
31d	2Ss
31e	1Ss
32a	1Ss 1Da
32b	1Ss 2Su
32c	1Ss

4.7.1.5. Scrub and Bush

Five out of the eight sites under scrub/bush were assessed as having soil slips (Table 8), although like the exotic pasture landcover/use their erosion severity was slight to moderate. Similarly four sites had debris avalanche and these also were slight to moderate. Two sites were found to have debris flows and like the other forms of erosion were only slight to moderate.

Table 8 Erosion type and severity derived from LUC for land under scrub and bush

Site	Erosion type and severity
13a	2Ss 2Da
14b	2Ss 2Da
16	2Ss 2Da 2Df
19	1Da 1Df
23	1Ss
26	1Ss 2Da
31c	0Ss 0Da
32d	0Ss

4.7.2. Type of Erosion

What is clear from the photographs and site visits is that the most common types of erosion present at most sites irrespective of landcover/use are soil slips, debris avalanches and debris flows. This is similar to what has been found at other sites where there have been similar types of storm events e.g. Tapawera. Localised areas of sedimentation were also present on small fans and on floodplains where stream gradients decreased in the lower parts of some channels. Rilling and sheetwash erosion also occurred on exposed soil (mostly from forestry harvest disturbance), however it was not considered to be a major source of off-site sediment.

Soil slips were observed across all landcovers/uses. Commonly they were mid-slope failures (i.e. site 30, 31a, 25) although there were numerous small slips associated with forestry tracks and cut road banks (i.e. site 20 a, b). Typically soil slips were small with long debris tails (e.g. site 13) suggesting failure was fairly fluid. While there was a wide range in erosion severity for soil slips, at the majority of sites they were ranked as moderate. Although what is worth noting is that the erosion severity for soil slips under exotic pasture appeared to be lower (although not statistically tested) compared to forestry sites that had recently harvested pines or <10 year old pines. One possible reason for the lower severity of soil slips and also other types of mass movement under exotic pasture is that the slopes at these sites were generally (although not always) lower than the slopes where debris avalanches or flows typically develop (i.e. site 12, 31e).

Conversely the reason why there have been more severe soil slips on recently harvested sites and sites with <10 year old pines could be because it is well recognised that while growing, vegetation contributes to slope stability through root reinforcement (Marden et al., 1991; Watson et al., 1997). However once vegetation is cleared, the strength roots impart to slopes decreases. For example a model of the relative root reinforcement changes after clearfelling of *pinus radiata* showed that after 3.7 years the nett root reinforcement percentage was zero. However if sites were replanted at 800 stems ha^{-1} (commercial forestry regime) one year after felling, within 5.6 years root site-occupancy for a site could be regained (Watson et al. 1999). So for sites that have been harvested and replanted under about 6 years of age, the contribution to slope stability through root reinforcement potentially can be quite low.

The effect of forest age on erosion susceptibility has been noted several times in the field at sites that have been subject to intense storm events. For example Marden et al., (1991) calculated the percentage area of land eroded in 0 - 1, 2 - 8 and >8 year old pines trees after Cyclone Bola in the East Coast as 21%, 4 - 12% and 2% respectively. Although less dramatic, a similar pattern was observed by Hicks, (1990) where the percentage area of soil erosion in 1 - 5, 6 - 10, 11 - 20 year old pines was 1%, 0.5% and 0.6% respectively at a site in the Taranaki during a heavy winter rainfall.

Debris avalanches and debris flows were also present at all landcover/uses. However, it would appear (although not statistically tested) that as for soil slips they were at a higher density and their erosion severity generally higher at plantation forests sites. In a number of instances it appears that debris avalanches on these landcovers/uses have coalesced at the head of ephemeral stream channels on steep slopes (e.g. sites 1, 5, 17a). Here they have developed into debris flows as a result of surface runoff from the intense rainfall collecting and being channelled along with debris from upslope such as soil, rock and vegetation. In some cases this dense mixture has collected woody debris (i.e. tree branches and pieces of woody material from forestry harvesting and occasionally windthrow material) that has accumulated in these ephemeral channels. It appears that at some sites this has resulted in stream channels being scoured (e.g. site 5, 10) exacerbating the volume of sediment being lost from sites. This woody debris along with soil and rock was often being deposited onto small fans and flood plains on valley floors (e.g. site 1, 4, 17), sometimes damaging roads, blocking culverts and resulting in washouts.

4.8. Ecological Effects

While it is clear that one of the more noticeable results of the December storm event was partial loss of soil from hillslopes, as alluded to already, in some cases there were offsite effects through scouring of channels and deposition of soil and other debris from slopes into streams. For example an ecological assessment of a stream near the Onamalutu Reserve found that it has been heavily impacted as result of erosion that occurred in the catchment. A large quantity of pine debris from a skid site failure and sediment has been deposited in the valley floor smothering the existing stream (Fig 5).

Figure 5 Pine debris and sediment deposited in the stream bed

In places the sediment and logs that had been deposited in the stream bed were in excess of 1.5 metres deep. When the slipping occurred, the sediment and debris that entered the stream would have killed all fish and macroinvertebrate life present at that point in time. Since the deposition event a new stream channel has formed in the surface of the deposited material. The substrate of the stream is now a mixture of fine gravels and silt with very few larger cobbles and boulders (Figure 6).

Figure 6 New stream channel has formed in the surface of the deposited material

Iron bacteria smother the bed of the stream below the confluence of the valley where the skid site failure occurred. This has further reduced the habitat availability. The source of the iron that allows the iron bacteria to flourish is unknown. However, it is assumed to be from naturally occurring iron deposits that have been exposed by large boulders from bedrock outcrops which have been dislodged by the movement of logs and debris down the stream.

There is no sign of instream life in the stream below the confluence of the valley where the skid site was sited. However, above the confluence mayfly and caddis fly larvae are present. As the large mass of logs that are in the water and sediments decay they will consume oxygen from the water and it is envisaged that there will be large fluctuations in oxygen concentrations in the stream until the breakdown of the logs is complete.

4.9 Current Best Practice Management

Primary land use activities such as farming and forestry typically involve varying degrees of land disturbance i.e. earthworks, roading/tracking and vegetation clearance. These activities are, if not satisfactorily managed, potentially capable of causing erosion and sedimentation problems which may be exacerbated during intense storm events. For example, practices which remove topsoil or result in debris accumulation in channels have the potential to exacerbate runoff and erosion. This is because soil loss effectively reduces the capacity of soil to absorb water, may expose poorly structured and finer textured subsoils with lower infiltration rates, increasing the potential for surface runoff. Debris such as woody material left in channels creates a potential for temporary blockages to form when there is excessive water, and when released this high energy water has the potential to exacerbate stream scour and in extreme cases mobilise trees (e.g. site 17).

In recognition of these problems, there are a number of excellent publications available which highlight the design and specifications required to minimise the effects of erosion from primary land use activities. These include industry codes of practice i.e. NZ Environmental Code of Practice for Plantation Forestry, central government handbooks i.e. Soil Conservation Technical Handbook and Regional Council technical publications i.e. Taranaki Regional Council Guidelines for Earthworks. Some of the recommendations in these publications relate specifically to activities like earthworks, roading/tracking and vegetation clearance.

4.9.1 Tracks and Roads

There are a number of practical measures that can be employed around tracks and roads which essentially centre around minimising the generation of sediment and also stormwater which can move off-site and exacerbate erosion. These include:

- Minimise the number of tracks and roads on a site
- Sow fill batters to stabilise exposed soil
- On well used roads consider applying metal aggregate
- Avoid constructing tracks with high gradients
- Form tracks with a crown to help shed water
- Ensure there are an adequate number of appropriately sized and spaced culverts
- Ensure that stormwater from culverts is discharged onto stable ground

4.9.2 Vegetation Clearance

Removing vegetation, especially harvesting trees, creates the potential for erosion through the exposure of bare soil, removal of topsoil and creating preferential storm-water runoff patterns. There are however practices which are recognised as being better than others when harvesting trees and include:

- Uphill hauling is preferable over downhill hauling
- Minimise ground based harvesting
- Fell away from water bodies
- Pull logs away from water bodies
- Avoid pulling logs across slope

4.9.3 Riparian Buffers

Riparian buffer zones generally encompass the vegetated strip of land that extends along streams and rivers and is the interface between terrestrial and aquatic ecosystems. Buffers of native or introduced vegetation are often advocated as suitable protection or environmental management tools for reducing the impacts of land use activities.

While not necessarily directly preventing mass movement erosion, the use of riparian buffers in forestry landuse have been shown to be effective in reducing the input of logging slash to stream channels (Fahey et al. 2004). As discussed already, logging slash in channels may in some instances exacerbate erosion and practices which minimise inputs should be advocated.

Furthermore, riparian buffer also have many other benefits. For example, research on the influence of logging operations on Coromandel Peninsula streams has shown riparian buffers can be effective in protecting streams. Where streams had no riparian buffers (i.e. catchments were clearcut) it was found stream channels were wider, there was more bank erosion, they had higher light inputs and maximum water temperatures and invertebrate communities had a lower diversity (Quinn et al. 2004; Boothrody et al., 2004). In contrast, streams that retained intact buffers of riparian forest (on average 18 m wide either side) throughout the logging operation maintained low light intensities, cooler air temperatures in the near stream area and reduced bank erosion (Boothroyd et al. 2004; Meleason and Quinn, 2004; Quinn 2004).

In pastoral landuse, riparian buffers may also provide many of the same benefits as those listed above. However, they are also effective in some situations at removing soluble nutrients (N and P), microbes and sediment from entering streams.

4.10 Limitations of Best Practice Management

It is important to appreciate that while the implementation of best practice to minimise erosion and offsite effects is desirable, many of the industry standards for things like culvert numbers, sizing, spacing to control runoff at a site or earthwork activities are only designed to withstand the effects of a 1 in 10 storm event. For example, resource consent conditions in Marlborough for forestry related land disturbance typically stipulate that 'the earthworks must be stable when subject to a storm event of return frequency 1:10 or less'. Given the magnitude of the storm event experienced in December (i.e. up to 1 in 50 in some places), many of the best practices listed above were unlikely to have been effective at preventing or minimising erosion and in fact could be expected to fail.

In addition, the current permitted activity standards in Council's resource management plans relating to activities such as directional felling, excavation setbacks and deposition of woody material in proximity to a waterway all relate to permanently flowing waterways. There are currently no controls with respect to activities undertaken along ephemeral waterways which appeared to be sites where some significant erosion occurred during the storm event.

4.11 Future Planning

While the storm was estimated to be equivalent up to a 1 in 50 year rainfall event, something that now needs to be recognised when planning for activities in the future are the potential effects of climate variation, and how this may impact on our economy, environment, infrastructure and way of life. For example, one of the predicted impacts of a moderate rate of climate change for Marlborough include more varied rainfall patterns and flooding which could become up to four times more frequent by 2070 (MfE, 2008). So there is the potential for an increase in the frequency of large magnitude storm events.

Furthermore, most of the forestry was established in Marlborough between the 1970's to 1990's. Using the current age-class of trees as a guide and assuming trees are harvested at around 30 years, there will be a significant increase in harvesting from 2010 to 2015 and then again from 2020 and 2025. As many of these forests will be in their first rotation, a significant amount of new earthworks will be required to harvest trees i.e. roads, skid sites etc.

Something that was evident from the observations in this study, and others in New Zealand was the significant erosion on recently harvested forestry sites. If extreme weather events become more frequent and severe due to climate variability as predicted, combined with an increase in the amount of forest harvesting over the next few years, there is the potential for an increase in the amount erosion. Although it has to be recognised that soil erosion from slope failure due to a high intensity rainfall events vary very much in time and space, and therefore it will be difficult if not impossible to plan for the effects of these events.

4.11.1 Management Options

The potential for an increase in climate variability over the remainder of the century obviously raises the questions as to what we should or could do to prevent or mitigate the erosion effects of these storm events if their frequency and magnitude increases.

Management options we may need to review could include:

- Changing the design standards which must be met for some types of activities such as earthworks? For example increase design standards to met 1 in 15 or 1 in 20 year events?
- Have maximum coupe sizes for forest harvesting operations in some catchments.
- Requiring riparian buffer areas to reduce the impacts of adjacent land use activities. The issue of ephemeral waterways also needs to be considered.
- Given that mature vegetation is often the most effective landuse at preventing/minimising soil erosion, should we be advocating for areas that have been identified as being erosion prone to be allowed to revert back to permanent native scrub/forest?

5. Summary

- A key feature of this storm event was not so much the total amount of rainfall that fell over this area, but rather the intensity of the rainfall.
- The rainfall occurred after a prolonged period of rain in the area hence antecedent soil moisture conditions were high.
- One of the more noticeable effects of the storm event was erosion and in places significant localised soil erosion.
- The most common types of erosion present at most sites irrespective of landcover/use are soil slips, debris avalanches and debris flows.
- Localised areas of sedimentation were also present on small fans and on floodplains where stream gradients decreased in the lower parts of some channels.
- Soil slips were commonly mid-slope failures although there were numerous small slips associated with forestry tracks and cut road banks.
- Typically soil slips were small with long debris tails.
- Of the 33 sites used to assess erosion, there were five types of landcovers/uses. These included three categories related to commercial forestry (pines older than 10 years – 5 sites, pines younger than 10 years – 8 sites, and recently harvested pines - 11 sites). In addition some sites occurred on exotic pasture and scrub (9 sites).
- At the majority of sites soil slips were ranked as moderate, although under exotic pasture severity appeared to be lower (although not statistically tested) compared to sites that had recently harvested pines or <10 year old pines. However this may be because all pasture sites were class 6e, where most of the pine sites were class 7e.
- Debris avalanches and debris flows (although not statistically tested) appeared to be at a higher density and their erosion severity generally higher at plantation forests sites compared to the other landcovers/uses. However, this may have been because there was only a small number of other landcovers/uses.
- In a number of instances debris avalanches on plantation forestry sites coalesced at the head of ephemeral stream channels on steep slopes and developed into debris flows. In some cases these flows have collected woody debris that have accumulated in these ephemeral channels and it has contributed to stream channels being scoured.
- This woody debris along with soil and rock was often deposited onto small fans and flood plains on valley floors, sometimes damaging roads, blocking culverts and resulting in washouts.
- While Council should advocate that best practice management is undertaken by all sectors of our primary industries to prevent or minimise erosion, many practices are unlikely to prevent erosion in circumstances where there are large storm events. Nonetheless, practices which minimise soil loss and debris accumulation in channels may help reduce some of the effects of erosion during large events and at the very least be beneficial when lesser magnitude storm events occur in the future.
- It would appear that the severity of the erosion observed from the storm event was driven by a combination of factors including:
    - a) A period of high and unusually intense rainfall falling onto soils that were already saturated.
    - b) A land environment that had steep slopes recognised as at severe risk of some types of erosion – especially when the vegetation cover is removed.
    - c) Rainfall occurring on a proportion of forestry land that had been recently harvested and replanted.

6. Glossary/References

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