BEFORE THE INDEPENDENT HEARING COMMISSIONERS

IN THE MATTER	of the Resource Management Act 1991 ('the Act')
AND	
IN THE MATTER	of the Proposed Canterbury Land and Water Regional Plan

BETWEEN	RAYONIER NEW ZEALAND LTD Submitter
A N D	CANTERBURY REGIONAL COUNCIL Local Authority

EVIDENCE OF DR CHRISTOPHER JOHN PHILLIPS ON BEHALF OF RAYONIER NEW ZEALAND LIMITED

Presented for filing by:
Adderley Head
Chris Fowler
15 Worcester Boulevard, Christchurch 8013
PO Box 16, Christchurch 8140
T 03 353 0231
F 03 353 1340
E chris.fowler@adderleyhead.co.nz

INTRODUCTION

1 My name is Christopher John Phillips and I am a Portfolio Leader and Senior Scientist with Landcare Research, a Crown Research Institute, at Lincoln. I hold the qualifications of BSc in Geology and Physical Geography from Otago University, an MSc (Hons) in Earth Science from Waikato University, a PhD in Agricultural Engineering from Canterbury University, and a Post-Graduate Diploma in Commerce from Lincoln University. I am a member of the New Zealand Geological Society, a member of the New Zealand Hydrological Society, an honorary (life) member of the New Zealand Association of Resource Management, and a past Director of the Australasian Chapter of the International Erosion Control Association (IECA).

2 I have 32 years' experience in research and consulting activities as part of the former New Zealand Forest Service, the Ministry of Forestry, and latterly Landcare Research. I have also carried out consultancies for most of New Zealand's forestry companies, advising them on aspects of erosion, slope stability, and environmental impacts relating to plantation forestry. Throughout my career I have focused on studying how and why erosion occurs, with an emphasis on how vegetation affects erosion and slope stability (including forestry and its various phases of management).

3 I have been involved in and led research and consultancy projects on the effects of forestry on erosion, sediment generation, sediment yield and vegetation recovery in many regions of New Zealand including Hawke's Bay, Coromandel, Marlborough and Marlborough Sounds, Central North Island, Nelson, West Coast, Gisborne-East Coast, Auckland and Canterbury.

4 Landcare Research was commissioned by Matariki Rayonier Forests in January 2013 to provide written evidence pursuant to submissions under the RMA relating to the Canterbury Regional Council Proposed Land and Water Regional Plan. We were asked to comment on erosion susceptibility including its mapping, sediment yield from forests generally and from within Canterbury, and on the effects of forest operations on erosion and sediment yield and how these are managed or mitigated.

5 I have read the Environment Court's Code of Conduct and agree to comply with it. My qualifications as an expert are set out above. I confirm that the issues addressed in this statement of evidence are within my area of expertise.

6 The data, information, facts and assumptions I have considered in forming my opinions are set out in the part of the evidence in which I express my opinions. I have not omitted to consider material facts known to me that might alter or detract from the opinions I have expressed.

SCOPE OF EVIDENCE

7 In my evidence I address the following issues:

(a) erosion processes in Canterbury,

(b) erosion susceptibility including its mapping in Canterbury,

(c) sediment yields in Canterbury (including sediment yield from plantation forests in relation to other land uses),

(d) the current state of knowledge of forestry influences on erosion (derived from studies largely elsewhere in New Zealand – including erosion processes and sediment yields), and

(e) how erosion is managed or mitigated by forest management practices.

METHODOLOGY USED IN PREPARING THIS EVIDENCE

8 A brief literature survey was carried out in addition to collating a number of unpublished findings and data that have relevance to the proposed land and water regional plan.

9 This evidence was prepared in consultation with my colleague Dr Les Basher, Senior Scientist with Landcare Research at Nelson. His qualifications include a BSc in geology from Canterbury University and a PhD in soil science from Lincoln University. He is a member of the New Zealand Geological Society, the New Zealand Hydrological Society, the New Zealand Society of Soil Science, and the Association of Resource Management. He has 35 years' experience in research with the former Ministry of Works, DSIR Land Resources and latterly Landcare Research and has been involved in consultancies involving erosion and sediment issues. His research focus includes erosion processes, soils and geomorphology, and sediment yield.

EROSION PROCESSES IN CANTERBURY

10 In general, erosion or sediment generation in the Canterbury region arises from three types of processes, irrespective of land use or activity:

(a) Fluvial processes include sheet, rill, gully, tunnel gully, streambank and stream bed erosion. Rill, gully and tunnel gully erosion are particularly important in loess-mantled landscapes in Canterbury (Hunter & Lynn 1990, Lynn & Eyles 1984).

(b) Landslides or mass movements – this is a key erosion process in New Zealand. In Canterbury, other than in extreme storms or prolonged periods of rainfall likely to cause widespread flooding (Harvey 1976, South Canterbury Catchment and Regional Water Board 1987), and in coastal areas and inland foothill areas on weak rock types, the frequency of mass movement is lower than in many other parts of New Zealand.

(c) Wind erosion from strong foehn winds may also generate sediment and be locally important.

11 One of the major drivers for fluvial and mass movement erosion is rainfall. Episodes

of major sediment generation and delivery may be correlated with the occurrence of large storm events in Canterbury (return period events greater than about 20–50 years). These large events are natural parts of the geomorphic cycle and will tend to overwhelm any land-use effects.

12 Glade (1998) carried out a comprehensive analysis of the frequency and magnitude of landsliding in New Zealand and its relationship with climatic characteristics. This analysis (Figure 1, Appendix 1) suggests that a landslide-triggering storm is expected once every 2–4 years somewhere in Mid and South Canterbury and every 4–6 years in North Canterbury; however, this frequency seems considerably higher than has actually been observed. However, Glade notes that these results in part reflect the limitations of the available data sources, which do not necessarily record all landslide events nor do they include all storm events that did not produce landsliding.

13 Unlike other parts of New Zealand that have experienced widespread regional landsliding in response to large magnitude regional rain events, Canterbury does not appear to experience these, typically exhibiting smaller local clusters or isolated landslides. This again reflects the lower erosion susceptibility of much of the region.

14 However, unusually heavy rainstorms or "wet" seasons can trigger mass movements (shallow slides of loess or colluvium) and there are documented historical cases in eastern Canterbury (Harvey 1976, South Canterbury Catchment and Regional Water Board 1987), the Kaikoura Ranges and the high country (Bell 1976), and Banks Peninsula (Ekanayake & Phillips 1997).

EROSION SUSCEPTIBILITY AND RISK MAPPING IN CANTERBURY

15 New Zealand is an erosion-prone country as a consequence of its geological setting and climate. Within New Zealand, erosion susceptibility varies widely in response to several driving factors – geology (including tectonics and rock type), rainfall, slope, vegetation cover, and anthropogenic activities. This variation occurs in Canterbury, with the least susceptible land on gentle slopes, stable rock types and lower rainfall, and the most susceptible land on steep slopes, erosion-prone rock types and high rainfall.

16 Most plantation forestry in Canterbury is concentrated on the plains and foothills. It covers 134,529 ha according to MfE's Land Use Map 2008 (Figure 2, Appendix 1). Most of this forest is on land classified in the New Zealand Land Resource Inventory (NZLRI) as downland (35% of the area of forest, with slopes typically 8–15º) and hill country (18% of the area of forest, with slopes typically 16–25º) (Figure 3, Appendix 1). A significant proportion is also on land classified as hilly steeplands (21% of the area of forest, with slopes typically 25–35º), with the remainder on gently sloping terraces and fans (19% of the area of forest). Most of the forests are underlain by alluvium or hard sedimentary and igneous rocks (c.78%) with a limited area underlain by more erodible loess (19%) and soft sedimentary rocks

(<1%) (**Figure 4, Appendix 1**). The combination of fairly easy slopes and generally strongly indurated and erosion-resistant rock types results in most of the area of plantation forest having relatively low susceptibility to erosion. This contrasts with many other parts of the country where plantation forestry is often located on much steeper and more erosion-prone land.

17 During development of the proposed National Environmental Standard for Plantation Forestry, MfE developed an erosion susceptibility classification to analyse the risks of erosion and sedimentation associated with plantation forestry activities (Bloomberg et al. 2011). Erosion susceptibility was derived from potential erosion severity recorded in the NZLRI and grouped into 4 classes – low, moderate, high and very high (Table 1; **Figure 5, Appendix 1**). This provides a consistent national approach to describe the inherent susceptibility of land to erosion.

Table 1 Distribution of erosion susceptibility classes for each region in New Zealand and for plantation forest land in Canterbury (from Bloomberg et al. 2011).

	% of area				
Region	**Low**	**Moderate**	**High**	**Very High**	***Undefined**
Northland	35	21	25	4	15
Auckland	41	28	13	2	17
Bay Of Plenty	25	19	18	6	33
Waikato	44	22	13	2	19
Gisborne	12	32	23	23	10
Manawatu-Wanganui	35	24	16	5	21
Hawke's Bay	35	24	11	10	21
Taranaki	43	13	16	7	21
Wellington	38	24	11	7	21
Marlborough	11	18	15	9	47
Nelson	7	23	42	7	19
Tasman	11	9	12	3	66
Canterbury	**38**	**17**	**8**	**10**	**27**
West Coast	11	1	2	1	85
Otago	41	18	15	6	21
Southland	33	8	2	1	56
Canterbury forestry	**6**	**47**	**38**	**7**	**2**

*DOC estate and unoccupied Crown land (river beds, etc.).

18 Excluding the undefined class (mainly DOC estate) Canterbury has a relatively high proportion of land rated as having low or moderate susceptibility to erosion with 75% falling in these classes (Table 1). Just over half the land on which plantation forests are currently located is in the low and moderate susceptibility classes (55% of the area of forests – Table 1; **Figure 6, Appendix 1**). However, much of the land that was classified as high or very high susceptibility is on hard sedimentary rocks and it is arguable whether its erosion susceptibility is correctly classified.

Defining and mapping erosion risk – NRRP and pLWRP

19 The Canterbury Regional Council (CRC) has adopted an "in-house" approach to

defining erosion risk. The Natural Resources Regional Plan identifies the areas most at risk of erosion as: coastal and inland dunes (wind erosion), loess-mantled hillslopes and soft rock hill country including the Kaikoura coastal zone (tunnel gully, gully, earthflow, slip and slump erosion – subsequently referred to as deep seated forms of erosion), arable soils of the plains and downs (wind erosion when cultivated), slopes >25º, all areas >900 m altitude, and stream banks. For the loess-mantled hillslopes and soft rock hill country the NRRP states that land >20º has an increased frequency of erosion (based on an unpublished study of the Akaroa catchment). Figures SCN2.1 and 2.2 in the NRRP maps the areas of non-arable land susceptible to erosion from earthworks and vegetation clearance using the following classes: coastal areas, land >20º subject to deep-seated forms of erosion, land >25º and <900 m a.s.l., and land >900 m a.s.l.

19.1 In the pLWRP, CRC uses this "in-house" classification of erosion risk to define three soil erosion risk zones: LH1 low and moderate soil erosion risk, LH2 high soil erosion risk, HH high country. Apart from zone HH (land >900 m a.s.l. or slope >25º) no definition of the land included in these zones is provided. Restrictions on earthworks and vegetation clearance are only proposed for zone LH2. This zone LH2 appears to be that land >20º subject to deep-seated forms of erosion, coastal areas, and high arable soil erosion risk due to cultivation. It is surprising that no formal definition of low, moderate and high soil erosion risk was provided in the pLWRP.

19.2 There are significant differences between the classification of erosion risk using the "in-house" classification and the NES classification, the primary one being that the loess-mantled hill country (e.g. on Banks Peninsula) is classified as high soil erosion risk by Ecan, but is only rated as moderate in the NES classification.

19.3 Based on submissions received, the CRC "recognised the somewhat onerous extent of the "LH2" zone, the unnecessary nature of the "LH1" map layer, and the uninformative nature of the "LH1" and "LH2" terms. On this basis, a revised summary map layer was produced ("High Soil Erosion Risk"), that shows only land that is over 20 degrees in slope and of soil types that are susceptible to deep-seated erosion". It is unclear if this summary map replaces the detailed maps or if the original maps will still be the basis of application of the risk mapping. I understand that about 10% of the current forestry estate is mapped to the "High Soil Erosion Risk" zone (see relevant Appendix attached to the evidence of Mr Kelvin Meredith).

19.4 While this summary map reduces the complexity of the original mapping schema, this simplification does not fully address the issue of erosion susceptibility and its regional variation. My concerns are:

(a) 20 degrees is a low slope threshold.

(b) There is unlikely to be any causal link between deep-seated forms of erosion and land use (geology is the key driver for these forms of erosion) so it is arguably inappropriate to be trying to manage these through land use controls. However, we acknowledge that Ecan appears to include shallow forms of mass movement erosion ("slips") within what they describe as deep-seated forms of erosion, and this type of erosion can be controlled with vegetation. We believe the lack of definition of erosion risk (including the types of erosion) may hinder clear application of the rules relating to erosion risk at an operational scale.

(c) The term "deep-seated erosion" seems to encompass a wide range of erosion forms and processes that is not in keeping with conventional definitions, though it is clear that the intent is to separate surface erosion processes from those where larger volumes of material may be generated.

(d) The section 42A report acknowledges that land use does not currently appear to be causing widespread erosion problems but clarity is needed on the definition of land considered to have high (or other classes) of erosion risk (which then allows translation from broad planning maps to operational scale) and better maps of their regional distribution.

19.5 In spite of the concerns listed above, the general identification of the rock and soil types that are most susceptible to erosion and their locations within the Canterbury region is acknowledged.

20 Conclusion:

20.1 Compared with the rest of New Zealand, the Canterbury region is not highly susceptible to erosion. However, there are some localities where erosion susceptibility is moderate to high, such as where weaker sedimentary rock types and deep loess occur in hill country areas. In the Canterbury high country, erosion susceptibility was classified as high or very high but it is arguable if this classification is correct because these areas are underlain by relatively stable rock types.

20.2 Much of the current forestry estate in Canterbury is on land that has low or moderate susceptibility to erosion and is generally less steep and erosion-prone than forest estates in other parts of New Zealand. About 10% of the forestry estate maps to the "High Soil Erosion Risk" zone.

SEDIMENT YIELDS IN CANTERBURY REGION

21 Suspended sediment yields (SSY) vary widely within the Canterbury region reflecting the strong west to east rainfall gradient and variety of rock types.

22 Suspended sediment yields (SSY) have been modelled by NIWA (Hicks et al. 2011) as a function of rainfall and terrain characteristics (erosion terrain). This model used measured yields from 27 catchments within Canterbury where measured sediment yields (expressed as tonnes per square kilometre per year) ranged from 2

t km^{-2} y^{-1} (refer to Glossary of terms in Section 10 for more detailed definitions) (Maryburn at Maryhill, a moderate-size catchment in the Mackenzie basin under moderate rainfall) to 2596 t km^{-2} y^{-1} (Hooker at Ball Hut Road Bridge, a moderate-size glacierised greywacke catchment under high rainfall).

23 These data are available as a GIS coverage (the Suspended Sediment Yield Estimator (SSYE) - ftp://ftp.niwa.co.nz/ResourceManagementTools/Sedmap/). The SSYE model suggests SSY ranges from <5 t km^{-2} y^{-1} to >10,000 t km^{-2} y^{-1} within the Canterbury region, with a mean value of 408 t km^{-2} y^{-1} (**Figure 7, Appendix 1**). There is a strong west to east gradient in SSY.

24 The SSYE model has been used to derive estimates of SSY associated with the plantation forestry estate in Canterbury. Since most of the plantation forestry estate is located on gentler terrain, moderate rainfall and stable rock types the range (<5 to 6,000 t km^{-2} y^{-1}) and mean SSY (132 t km^{-2} y^{-1}) are far lower than the Canterbury region as a whole. Most of the plantation forestry estate has SSY <100 t km^{-2} y^{-1} with higher values on soft sedimentary rocks in the foothills and in higher rainfall areas. These modelled yields are low compared with western Canterbury and many other parts of New Zealand and reflect the low erosion susceptibility for this part of the Canterbury region.

25 The SSYE model is a national model and at that scale the effect of vegetation cover on sediment yield is secondary compared with rainfall and geology (Hicks et al. 2011). However, at hillslope and small catchment scale vegetation cover has a significant effect on both erosion and sediment yield (e.g. Glade 2003, Fahey et al. 2003).

FORESTRY INFLUENCES ON EROSION AND SEDIMENT YIELD – CURRENT STATE OF KNOWLEDGE IN NEW ZEALAND

General effects of forests on erosion

26 Many studies show that erosion and sediment generation (see Glossary for definitions) from natural slopes is greatly reduced by the presence of a mature forest cover (exotic or indigenous). This is due to the soil-strengthening ability of roots and the influence of trees on slope hydrology through the process of evapotranspiration (Pearce et al. 1987; Phillips et al. 1990; Fransen & Brownlie 1995; Blaschke et al. 2008; Phillips et al. 2012).

27 The effectiveness of a planted forest cover in preventing a natural slope failure (i.e., landslide) is age dependent. There is limited protection from young trees but once canopy closure occurs (approximately 6–8 years+) protection appears to be constant until the trees are harvested (Hicks 1989; Marden et al. 1991; Marden & Rowan 1993).

28 In many erosion-prone areas of the world, including New Zealand, forests are planted to control erosion (Phillips et al. 1990; Marden et al. 1991; Phillips &

Marden 2005).

29 New Zealand studies of landsliding after large storms clearly show the protection value of a mature forest cover. In the Manawatu storms early in 2004, the probability of landsliding on forest land was 10% that on pasture land (Dymond et al. 2006). Similar results were recorded on the East Coast during Cyclone Bola (Marden et al. 1991).

30 Most erosion in New Zealand is caused by extreme rainfall events and in general terms landslides are the biggest generator of sediment. Forestry is not immune to the effects of these extreme events.

31 Erosion from forests (plantation and natural indigenous forests) caused by extreme rainfall has been documented from several areas in New Zealand, though is likely to be more widespread than just in those documented localities.

32 There are no documented reports of widespread storm damage in plantation forests in Canterbury.

33 In the absence of extreme rain events, sediment generation in a plantation forest is dependent on the degree to which soil and rock materials are exposed and the occurrence of rain events that cause erosion. This is mostly related to activities that disturb the soil such as site preparation, earthworks associated with roading, tracking, and landing construction, and physical soil disturbance during harvesting. This is expanded on in the following section.

34 Species, planting pattern, and planting density have an impact on root reinforcement and ultimately protection against shallow landslides. Erosion-susceptible slopes replanted 1 year after felling in radiata pine at 1250 stems ha^{-1} regained soil reinforcement in 4.7 years (Phillips & Watson 1994; Watson et al. 1999).

Harvesting effects on erosion

35 All commercial plantation forests will at some stage be harvested. For radiata pine this is usually between 25 and 30 years and for Douglas fir between 45 and 60 years.

36 Research has typically focused on steep hill country and in more erosion susceptible areas of New Zealand.

37 While sediment may be generated at any time in the forest cycle, it is usually greatest in the immediate period leading up to harvesting (earthworks associated with road and landing construction – Mosley 1980; Fahey & Coker 1989; Fahey & Marden 2000; Fransen et al. 2001; Fahey et al. 2003) and in the period post-harvesting when the tree crop has been removed and the slopes have limited ground and canopy cover (Marden et al. 2002; Phillips et al. 2005).

38 Within a harvested setting (clear-cut), sediment can be generated both as a

consequence of the harvesting practice (e.g. scalping or rutting during hauler-logging (Fransen 1998a) and by post-harvest erosion processes including raindrop impact, sheetwash erosion (Marden & Rowan 1997; Marden et al. 2006), rilling and by storm-initiated landslides on the cutover (Marden & Rowan 1995a), and from a mix of processes on, and from roads and landings.

39 Soil disturbance, soil compaction and channel disturbance during harvesting (ground-based and to a much lesser degree cable logging systems), together with reduced evapo-transpiration due to tree removal, generally result in increased slopewash/runoff and streamflow. In any rain event, this has the potential to increase channel erosion (bed and banks), initiate landslides, and generate sediment from bare soil surfaces thus ultimately increasing sediment yield.

40 Research indicates there is a period following harvesting when the net relative root reinforcement is low (O'Loughlin 1985; Marden et al. 1991; Phillips et al. 1999; Watson et al. 1999) as roots from the old crop decay and those from the new crop occupy the site. This period is the most vulnerable to landsliding and is often referred to as the "window of vulnerability". This risk is managed by planting as soon as practicable following harvesting and at a sufficient density to ensure root soil occupancy occurs quickly.

41 Forest roads were once considered to be a significant source of sediment, particularly for mass movement (Fransen et al. 2001). While roads will generate some sediment, modern engineering practice and erosion and sediment control measures have reduced these as a significant primary source. On roads, sediment may be generated from cut slopes, fill slopes, and from the road surface and water table drains (Coker & Fahey 1993; Coker et al. 1993).

42 Only a few studies have been carried out on the effects of roads on sediment generation, and these were in situations completely different from modern forestry. There are no recent data on forest road erosion for anywhere in New Zealand, including Canterbury.

43 Forest landing failures were also regarded as a significant cause of erosion, particularly in high-intensity-rainfall areas of New Zealand (Pearce & Hodgkiss 1987; Coker et al. 1990; Phillips & Marden 1999).

44 Soil scraping (sometimes called scalping) or rutting from haul paths caused by harvesting operations was the second largest sediment-generating process contributing sediment to the stream measured in Whangapoua Forest in the Coromandel (27%) (Table 3).

Table 2 Sediment generation data from different sources in Cpt 49 Whangapoua Forest following harvesting (Phillips et al. 2002). LD = Lightly disturbed, DD = Deeply disturbed, Scalped = areas where soil deeply disturbed due to log hauling.

Note: Not all of this eroded sediment enters the stream. Scalping or soil scraping accounted for 1.6 tonnes ha^{-1} of sediment entering the stream while landsliding accounted for 4.5 tonnes ha^{-1} of sediment entering the stream.

	Area (ha)	Total Sediment (t)	Sediment generation (t ha^{-1})
Undisturbed	14.5	0	0
LD plots	15.5	16	1
DD plots	3.6	57	16
Landslide	0.4	600	1500
Scalped (50–100 mm)	3.6	1200	333
Total	**36**	**1873**	
Mean value			**51**

45 Soil scraping may be mitigated or reduced by improving harvest operations such as the siting of landings and aiming for better log suspension at settings where scraping is likely, but these operations usually involve trade-offs with "other" types of soil disturbance, i.e. more construction of roads and landings.

46 Results from Whangapoua (Table 3) and elsewhere suggest slopewash is the least important of the sediment generation processes during and post harvesting. These findings are consistent with those of Fransen (1998b) and Fahey et al. (2003).

47 Most generated (eroded) sediment from bare areas, including landslide debris, does not travel far from its source, getting trapped by micro-topographic features on the slope or by harvesting residue such as branches (slash). However, where sources are close and connected to the stream network, sediment may enter the stream.

48 Most sediment that is generated off bare areas occurs in the first few rain events following disturbance (Marden et al. 2006) and reduces with time as the soil surface hardens. About 80% of the sediment is produced within 12 months of harvesting.

49 Vegetation recovers quickly on harvested areas (Marden & Rowan 1997; Fransen 1998b). Oversowing does not always reduce sediment generation because most sediment is often gone before vegetation is established.

Forest and land use effects on sediment yields

50 Various studies have shown that catchments with mature forest cover (both plantation and natural forests) produce 1.5 to 5 times less sediment that those under pasture and this holds for both base flows and storm events (Hicks 1990).

51 There are no studies of measured sediment yield from catchments with different land uses in the Canterbury region or any that document the sediment yield from fully forested catchments in Canterbury. This reflects a lack of concern historically about the effects of forestry on erosion in Canterbury.

52 Sediment loss from different land uses in New Zealand was summarized by McDowell and Wilcock (2008). Only a single Canterbury study, of dairy pasture,

was cited and it produced a sediment loss of 7.2 t km^{-2} y^{-1}. Many of these studies would have been from small areas where the sediment delivery ratio was high and may not be indicative of losses or yields at larger catchment scales (refer to Glossary in Section 10 for more detailed information on the relationship of erosion to sediment yield and sediment delivery ratio).

53 When forests are harvested the sediment yield rises relative to the pre-harvest phase of the rotation or when compared with a pasture or forested catchment (plantation or indigenous) (O'Loughlin 1979; O'Loughlin et al. 1980; Hicks & Harmsworth 1989; Hicks 1989, 1990; Fahey et al. 2003; Basher et al. 2011). This is due to two factors – more "effective" rainfall and more "bare" area from which to generate sediment.

54 When trees are harvested, the interception/evapotranspiration process is reduced and rainfall becomes more "effective" in a given rain event to generate runoff and move sediment within the fluvial system, i.e. there is more runoff after harvesting than before (Bosch & Hewlett 1982; Jackson et al. 1993).

55 In the harvesting phase there are more "bare" areas available to generate sediment as a result of additional earthworks associated with road and landing construction. Also the ground/soil may be disturbed during the harvest operation itself. The act of cutting the trees down does not in itself cause erosion.

56 Elevated sediment yields return to pre-harvest levels usually within 2 years of harvesting (Phillips et al. 2005; Fahey et al. 2003; Basher et al. 2011).

57 There are limited New Zealand forest harvesting-sediment yield studies. Annual sediment yields range from a few 10s to several 100s t km^{-2} y^{-1} (Table 2).

Table 3 Sediment yields from harvesting studies in New Zealand (From Phillips et al. 2005).

Location	Geology	Post-harvest sediment yield (t km^{-2} yr^{-1})	Reference
Maimai	Old Man Gravels	80–450*	O'Loughlin et al. 1980
Pakuratahi	Tertiary mudstone	18–112**	Fahey et al. 2003
Glenbervie	Deeply weathered greywacke	46	Hicks & Harmsworth 1989
Pokororo***	Weathered granite	21	Hewitt 2001a, 2002
Little Pokororo***	Weathered granite	45	Hewitt 2001a, 2002
Apahi***	Weathered granite	27–148	Hewitt 2001a, 2002
Greenhill***	Weathered granite	60	Hewitt 2000, 20001b
Herring***	Weathered granite	30–181	Basher et al. 2011

Whangapoua	Weathered volcanics	18–116	Phillips et al. 2005
Blue Mountains	Schist	10–20	Duncan 2012

* Annual data reported in $m^3\ km^{-2}$ – conversion at 1.7 t m^{-3}

** Data reported in t km^{-2} for various periods and phases of harvesting and converted here to annual yields by dividing by the measurement period in years

*** Only part of catchment logged

58 In a study of forested and pasture catchments in Hawke’s Bay, Fahey and Marden (2000) estimated that between a quarter and a third of the total suspended sediment yield over 29 months was contributed by one storm. This highlights the importance of storm events for generating sediment.

59 Despite a spike of increased sediment generation and yield associated with the harvesting phase (every 27–30 years), total suspended sediment production and yield over the length of one forest rotation will be less than that from pastoral farmland on equivalent land use capability classes. This was demonstrated in the Pakuratahi Land Use Study near Napier (Fahey et al. 2003).

60 There are no measured data from any harvested plantation forest catchments in Canterbury.

61 Conclusion

61.1 Research in the last few decades has improved our understanding of the mechanisms of sediment generation and delivery to streams in forests throughout New Zealand, and the relative contribution from different sources.

61.2 Mass movements, while small in areal extent, are the most significant sediment generation mechanism throughout the whole forest growing cycle. Slope wash processes from bare areas are the least significant, but in Canterbury may be proportionally more important though there are no studies to support this contention.

61.3 Connectivity between sediment source and stream is the most critical factor in determining the amount of eroded sediment reaching the stream and contributing to catchment sediment yield.

61.4 Sediment yield varies widely within the Canterbury region in response to rainfall, rock type and topography.

61.5 Sediment yields will rise in the harvest phase of the forest cycle but return to pre-harvest levels within 1–2 years.

61.6 There is no Canterbury-specific research related to forest management effects on erosion and sediment yield.

61.7 In the current Canterbury plantation forests, modelled sediment yields are relatively low. Sediment yield increases following harvesting are likely to be at the low end of similar studies from other parts of New Zealand because of the low erosion susceptibility of the current forest estate.

FOREST MANAGEMENT APPROACHES TO MITIGATE EROSION

62 A guiding principle adopted worldwide in erosion and sediment control is that it is better to prevent erosion or sediment being generated at source than to try and mitigate its effects once it has been generated. Where this is not possible, interception and dispersion of runoff or stormwater are the keys to reducing the sediment load entering a stream. Coarse particles drop out or are removed first. Once fine sediment is in suspension it is difficult to remove.

63 The key principle in relation to sediment-laden water getting into a stream is "connectivity". For example, if sediment is generated from a road, the runoff goes into the water table through a culvert and into the stream. Here the source and sink are connected. If the connection can be broken by a sediment trap, by a physical barrier such as harvesting slash on slope, or by dispersing the water rather than concentrating it, then the coarse sediment fraction is likely to be removed, and runoff has more chance of being able to infiltrate the soil and then be slowly released to the stream. Similarly, any bare areas on the cutover that are directly connected to the stream are likely to contribute more sediment than those not connected.

64 Erosion and sediment generation are mitigated throughout the forest cycle by employing a range of "good environmental practices". Both local experience and these practices found in voluntary codes such as the NZ Environmental Forest Code of Practice (2007) and the NZ Forest Road Engineering Manual (2012) have informed current forest management in New Zealand in relation to reducing sediment generation and sediment yield. These practices fall into several categories:

(a) "Whole of forest" planning approaches, including forest growth and age-class structure modelling, wood flow considerations, harvest planning, road and infrastructure planning, and erosion & sediment control planning, all of which are designed to integrate and manage all phases of the forest growing cycle.

(b) Specialised harvest planning and scheduling – road and landing construction, harvesting operations (both in time and space) and choice of harvest systems.

(c) Attention to good engineering design and implementation of infrastructure including construction of roads, landings, and stream crossings.

(d) Recognition of the risk of extreme events that might cause sediment-related problems and their inclusion into in-house environmental management systems (EMS) or similar systems that include maintenance scheduling, incident reporting, and follow-up procedures to ensure effects are limited and remediated quickly.

(e) Utilising a range of on-the-ground erosion, sediment and water control measures specifically to mitigate sediment generation or break connectivity between sources and streams.

(f) Training of staff and contractors in procedures to minimise sediment generation as well as training to show the range of values that the procedures are aimed at protecting, e.g. the presence of native fish, water supply catchments. etc.

65 Erosion and sediment control practices, engineering design standards, and harvest planning approaches in New Zealand tend to follow international best practice. New Zealand codes and guidelines, including erosion and sediment control, have been adapted for local conditions from countries such as Canada and the United States.

66 However, there is very little research (both in general and in New Zealand forests) on the performance of specific erosion and sediment mitigation measures associated with forestry operations. Anecdotal evidence and observation have largely informed the benefits of adopting these measures, i.e. we know they are better than nothing, but we do not know the actual performance limits of each measure either individually or collectively in reducing the amount of sediment entering a stream under a range of conditions.

67 As indicated in paragraph 41, what were once poor environmental practices are now less common, particularly in corporate forestry in New Zealand. Current engineering and management practices follow guidance in documents such as the NZ Forest Road Engineering Manual (2012) and have tended to mitigate much of the sediment generation from roads and associated earthworks and have reduced the amount of sediment entering streams. For example, modern engineering design and construction, coupled with good forest planning and management practices in landing construction (benching and compacting), and pulling slash back from the edge of landings and burning it, tend to mitigate the effects of these activities, sometimes even in infrequent or extreme rain events.

68 In following their codes of practice and engineering guidelines, the forestry sector in the rural environment has, in my view, provided the lead in terms of measures taken to manage and mitigate sediment. Many rural roads and farm tracks do not employ the same level of erosion and sediment control practices.

69 While some activities, such as culvert installation, inevitably involve disturbance of the streambed and temporary diversion of stream flow, these activities are necessary to ensure these infrastructure elements operate properly and do not fail in storm events that inevitably result in much greater overall environmental impact. Guidelines and methods are established in the NZ Forest Road Engineering Manual

(2012) and its predecessor documents.

70 Riparian buffers may act as a sediment source or a sediment control, i.e. in terms of reducing sediment generation within the zone (bank erosion or landsliding) or acting as a filter of runoff reducing sediment yield from harvested catchments (Fransen 2000).

71 The "window of vulnerability" that follows harvesting when net root reinforcement is low is managed by planting as soon as practicable and at sufficient density to ensure root soil occupancy occurs quickly.

72 Many forestry companies often exceed the "voluntary" performance standards in terms of codes of practice and engineering design and management because their own internal systems and/or shareholders demand higher levels of performance.

73 Conclusion

73.1 The standard of forest engineering design and construction has changed considerably over the last three decades. Significant improvements have occurred alongside the establishment of in-house environmental management systems (EMS).

73.2 While the road surface can still be a source of sediment, the occurrence of mass movement features related to roads and landings in particular, has reduced significantly. Further, current practices of avoiding excessive cuts and fills, end-hauling construction spoil, metalling road surfaces, surface runoff and sediment controls on roads and landings, pulling back logging debris on landings, and dispersal of road runoff back onto slopes in many areas, has, in my opinion, helped reduce both the amount of sediment entering streams as well as the overall risk of slope failure leading to sediment generation in many forest areas in New Zealand.

73.3 However, erosion can and will still occur as part of the natural geomorphic process, especially during large storm events and during the post-harvest phase of a forest rotation. However, the elevated risk of erosion during the post-harvest phase is more than offset by the beneficial effects of the forest in reducing erosion during the majority of a forest rotation

PROPOSED PLAN AND COMMENTS ON OFFICERS REPORT

74 Policy 4.19 originally sought to prevent sedimentation of water bodies as a result of land clearance, earthworks and cultivation. The recommendation to change the word "prevented" to "avoided or minimised by the adoption of control methods and technologies..." is supported as a practical solution to control the effects of erosion so far as it is possible to do so as a result of land-use activities.

75 I concur with Rayonier's original submission related to Rule 5.72 (now 5.72A) and the amendment and relief sought. Sediment "discharge" is highly variable, even under natural conditions of prolonged rainfall or extreme weather events, and the suggestion to base the allowable increase in suspended sediment concentration on

a percentage of the background concentration is a practical approach that acknowledges the natural variability in sediment concentration. It is also likely that there will be occasions, even when all best environmental practices are in place, that sediment discharges will exceed the concentrations outlined in the proposed rules. There is a lack of clarity about exactly where a measurement of suspended solids is to be taken in the "discharge" in relation to its mixing with surface waters.

76 I concur with Rayonier's original submission related to Rule 5.148. It is my opinion that corporate forestry leads the way in which it manages rural earthworks and land disturbance activities in New Zealand. It achieves this through the use of best environmental practices that are designed to mitigate or minimise the effects of those operations on sediment generation and discharge. Harvest plans, erosion and sediment control plans, and in-house environmental management systems are the key tools used to implement and meet high environmental performance. These will be far more effective, in my view, than having restrictive rules relating to distances from lakes and rivers that will require more resource consents by the forest industry. I support the suggested wording for a new condition 8 (Evidence of Mr Nick Boyes) as it appears to align with the Officer's stated intention to "not require resource consent for "normal" farming or forestry activities".

77 It is my opinion that the definition of soil erosion risk zones and their depiction on the planning maps could be improved. Deleting the low and moderate erosion hazard zone (layer LH1) only partly addresses this issue. There remains a lack of clarity about what constitutes "deep-seated erosion" and the definition of "high soil erosion risk" (previously LH2). I believe the slope threshold (20º) is too low and the land to which it is applied needs to be clarified to allow the identification of "high risk" land at an operational scale rather than having simple reliance on the published planning maps which are likely to be flawed at the detailed scale of forestry operations. Elsewhere in the country the slope threshold above which land is at risk from landsliding is well above 20º – Dymond et al. (2006) list values of 26º for loess, and 24–28º for Tertiary soft rocks.

CONCLUSIONS/SUMMARY

78 There is a lack of New Zealand data on forestry and erosion in general and no data relating to forestry and sediment/erosion in the Canterbury Region

79 The current forest estate in Canterbury is located on land less susceptible to erosion than most parts of New Zealand.

80 However, both extreme (infrequent high intensity/short duration) and more frequent rain storms can generate sediment through surface erosion processes and by landslides. Erosion can occur in native forest, plantation forests, and in pasture. This is part of the natural geomorphic process.

81 Erosion within, and sediment yield from, plantation forests is low for most of the forest growing cycle and equivalent to what one might expect from a natural

undisturbed forest.

82 Sediment yields will rise from a forest after trees are harvested. In part, the rise is a result of more water being present in the landscape as the intercepting capacity of the forest canopy has been removed, i.e. for a given-size rain event there will be more runoff where there are no trees compared with where there is an intact forest (all other things being equal).

83 The magnitude of the sediment yield rise may also be dependent on the occurrence of significant erosion-causing rain events in the few years following harvesting.

84 This additional water can infiltrate soils potentially leading to slope failure (landslides) when root reinforcement is low, it can generate sediment from bare areas via runoff processes, and it can mobilize stored sediment in the banks and beds of streams.

85 Sediment yields recover quickly to pre-harvested levels, usually within 2 years.

86 The elevated risk of erosion and increased sediment yields during the post-harvest phase is more than offset by the beneficial effects of a forest in reducing erosion during the majority of a forest rotation.

87 While we know that significant erosion occurs in big storms (>20 years ARI) and on steep slopes underlain by unstable geology, it is difficult to predict precisely when and where erosion will occur or where generated sediment will end up, particularly from mass movements. It is therefore difficult to totally avoid or mitigate both the occurrence of these and their products (sediment).

88 Erosion and its effects are largely mitigated by following industry good practice guidelines, giving attention to integrated planning across the forest growing cycle, implementing good engineering design and construction practices, and having suitable environmental management systems in place. The design standards and practices outlined in industry codes of practice and guidelines are aligned to international best practice, are in keeping with national current forestry practice, are appropriate for the Canterbury region, are designed to minimise effects, and will minimise the erosion risk and reduce sediment loss if followed.

Dr Christopher John Phillips
4 February 2013

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Erosion is the mechanical process of wearing or grinding down the earth's surface (as by particles washing over it) or the washing away of soil by the flow of water. This may be due to natural processes or induced by the actions of humans. There are many different types of erosion process. Erosion is usually measured or expressed as tonnes/unit area, e.g. t ha^{-1}, or sometimes as an equivalent surface lowering in millimetres.

Sediment generation or sediment production is analogous to erosion. Sediment is generated by a number of erosion processes such as mass movement (landslide), rain splash (detachment), surface erosion by water, road construction, wind, earthquake and so on. Water is generally, though not always, the cause of sediment generation (earthquake, wind, and construction are other examples), and is usually the vehicle for sediment transport. Rainfall and runoff in association with gravity are the driving forces of sediment delivery to streams.

Sediment yield is the quantity of sediment, measured in dry weight or by volume, transported through a stream cross-section in a given time; it includes suspended sediment and bedload. Sediment yield is the total sediment load that leaves a drainage basin and is often quoted over a time period of a year (usually measured in tonnes/unit area/year) – commonly t km^{-2} y^{-1}.

Measured sediment yield at a catchment outlet usually refers to suspended sediment (Suspended sediment yield – SSY) but can include bed load.

To calculate sediment yield (tonnes), measurements of water turbidity (usually as Nephelometric Turbidity Units NTUs (dimensionless)), obtained either continuously or from spot samples, are correlated with suspended sediment concentration from water samples (g cm^{-3}), and then related to flow volume.

Water clarity is affected by particles suspended in the water column including suspended sediment. The size and shape of sediment particles can affect water clarity (See Dr John Quinn's evidence for more explanation).

To allow for comparisons between different localities, sediment yield is usually normalized on an annual basis and by catchment area to provide specific sediment yield in tonnes per square kilometre per year (t km^{-2} y^{-1}).

Erosion is not directly correlated to sediment yield. Soil erosion (or sediment generation) is the first step in the sedimentation process that consists of erosion, transportation and deposition of sediment. A fraction of eroded soil passes through a channel system contributing to sediment yield. Some of it stays close to where it was eroded and some of it gets deposited in stream channels. The ratio of erosion to sediment yield is the sediment delivery ratio (SDR).

Sediment delivery ratio (SDR) is the percent of gross soil erosion by water that is delivered to a particular point in the drainage system. It is computed as the ratio of sediment yield at the watershed outlet (point of interest) to gross erosion in the entire watershed. Gross erosion includes mass movement, sheet, rill, gully and channel erosion.

SDR can be affected by a number of factors including sediment source, texture, nearness to the stream, channel density, basin area, slope, length, land use/land cover, and rainfall-runoff factors. The relationship established for sediment delivery ratio and drainage area is known as the SDR curve. Coarser textured sediment and sediment from sheet and rill erosion have more chances of being deposited or being trapped compared with fine sediment and sediment from channel erosion. Thus the delivery ratios of sediment with coarser texture or from sheet and rill erosion are relatively lower than the fine sediment or sediment from channel erosion. Less energy is needed to transport fine particles (i.e. silt and clay) than coarse materials (i.e. sands). Thus, sands are more likely to be deposited in the transport process, while eroded silt and clay particles are more easily transported downstream. As a result, sediment or source lithologies containing high clay content will have a high delivery ratio.

A small watershed with a higher channel density has a higher sediment delivery ratio compared with a large watershed with a low channel density. A watershed with steep slopes has a higher sediment delivery ratio than a watershed with flat and wide valleys.

In order to estimate sediment delivery ratios, the size of the area of interest should also be defined. In general, the larger the area, the lower the sediment delivery ratio. SDR is also associated with rainfall pattern. A longer duration rainfall event with less intensity has a lower SDR than a short rainfall event with higher intensity.

SUPPORTING FIGURES AND MAPS

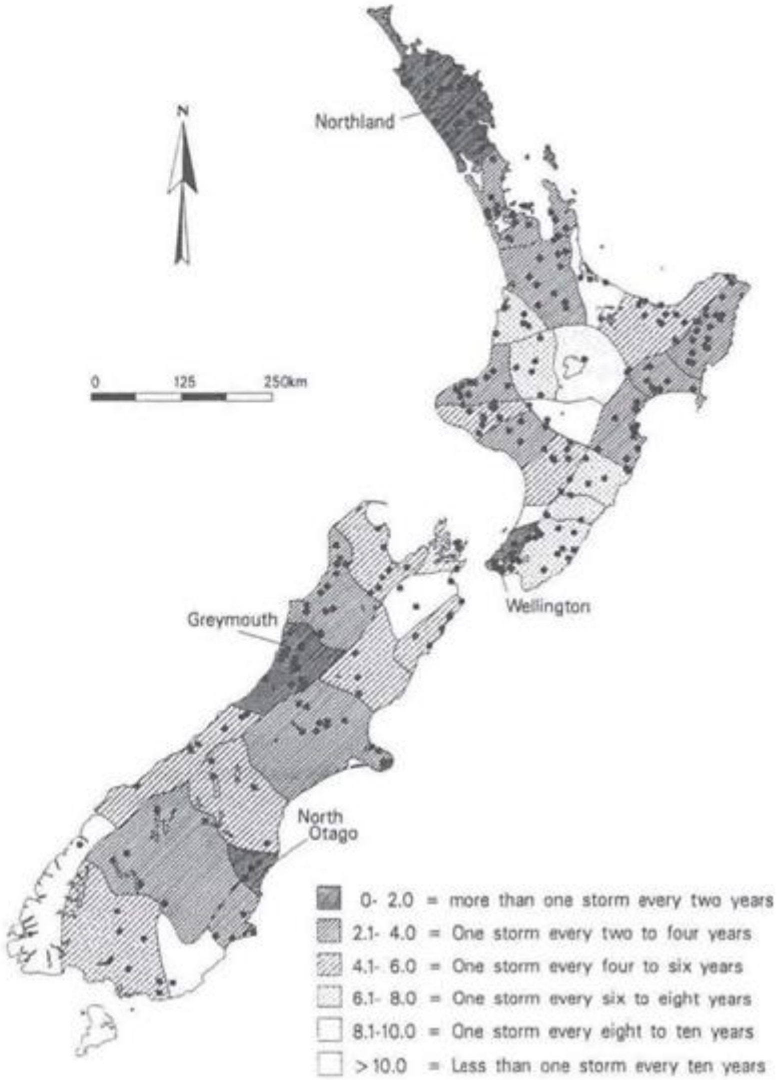

Figure 13: Regional frequency of recorded landslide-triggering rainstorms in New Zealand. Points are locations of recorded events (Sources: Glade 1997, 1998).

Figure 1 Regional frequency of recorded landslide-triggering rainstorms in New Zealand (Glade 1998)

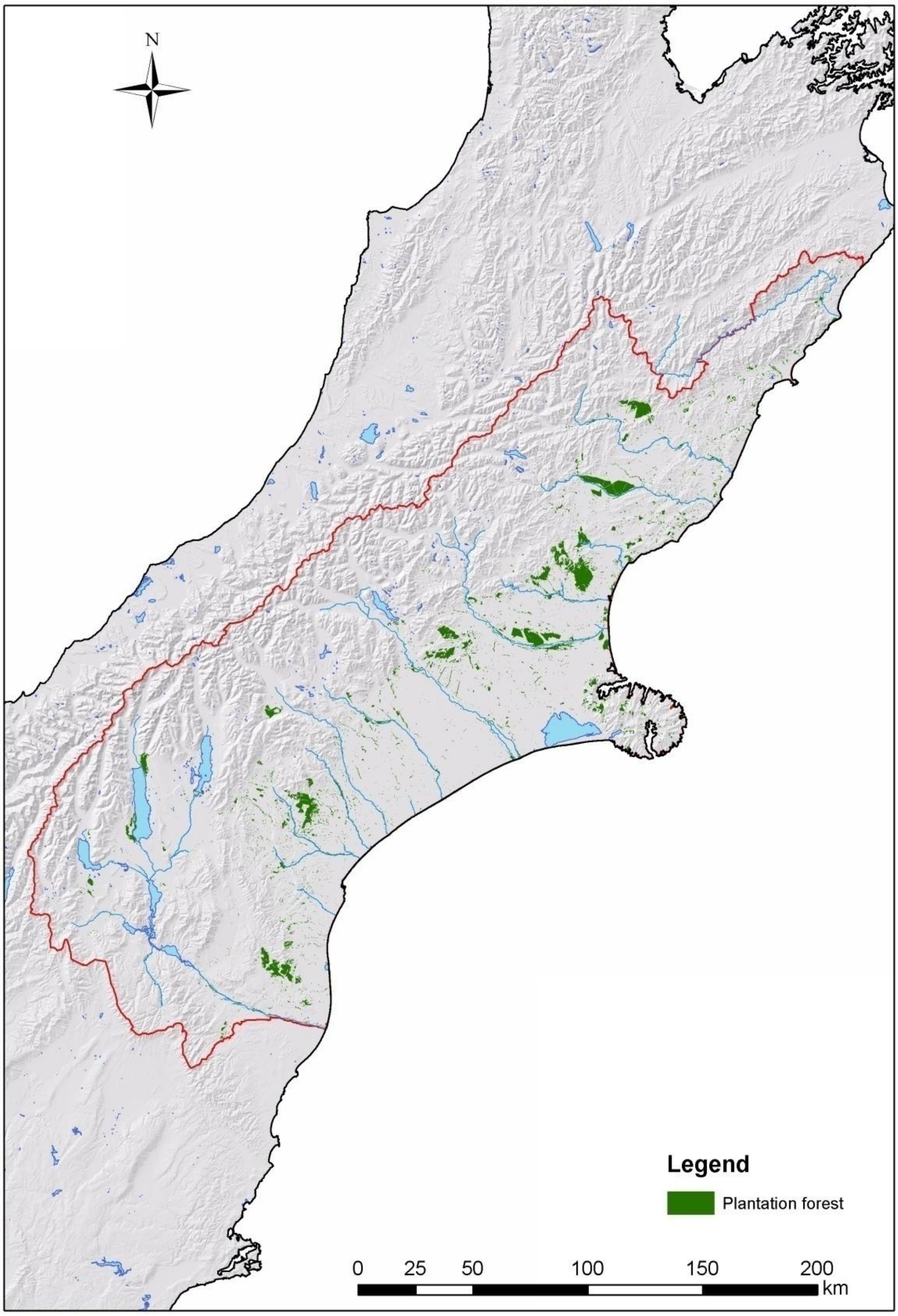

Figure 2 Distribution of plantation forest in Canterbury

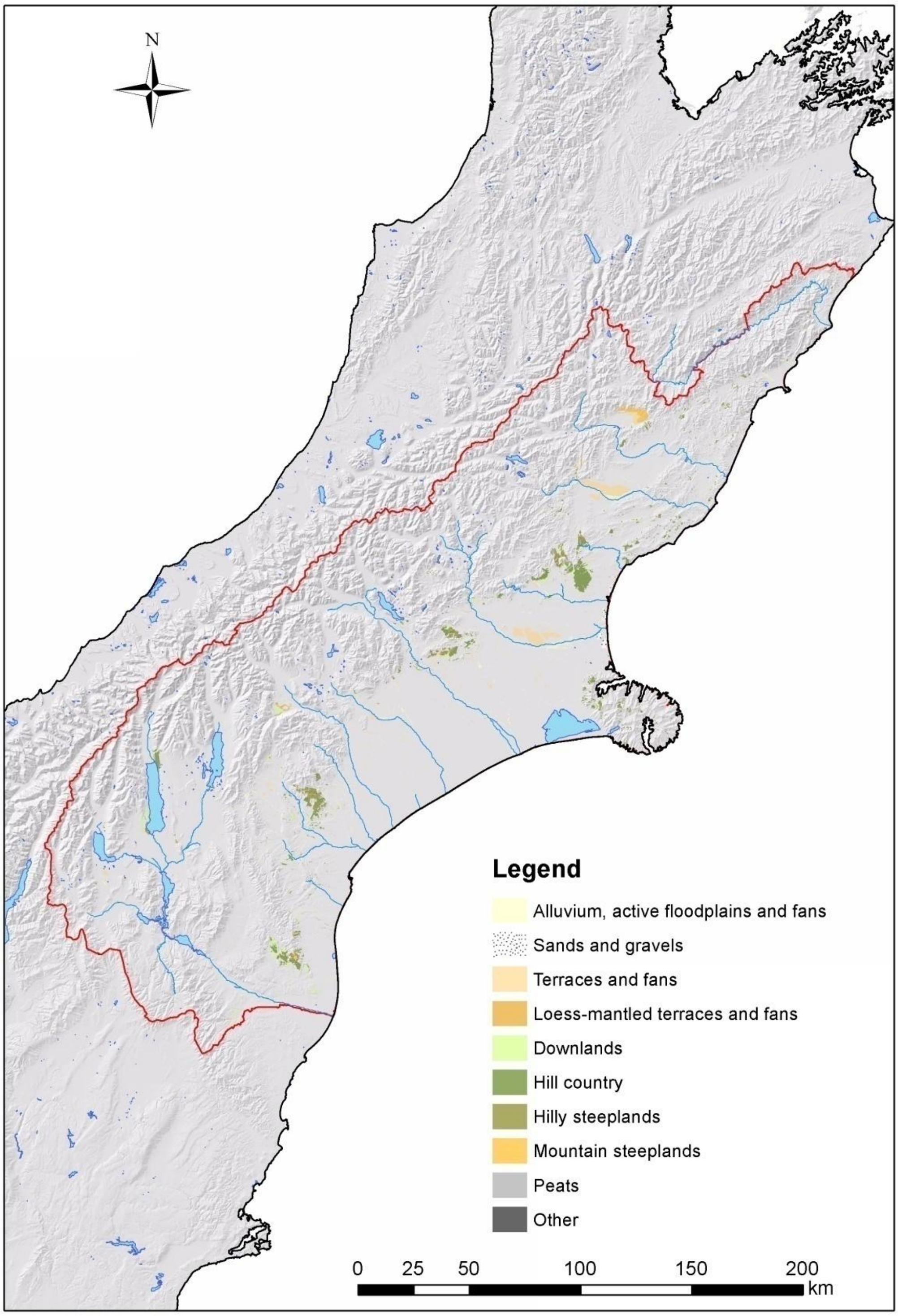

Figure 3 Classification of landforms in areas of plantation forest in Canterbury (derived from the NZLRI)

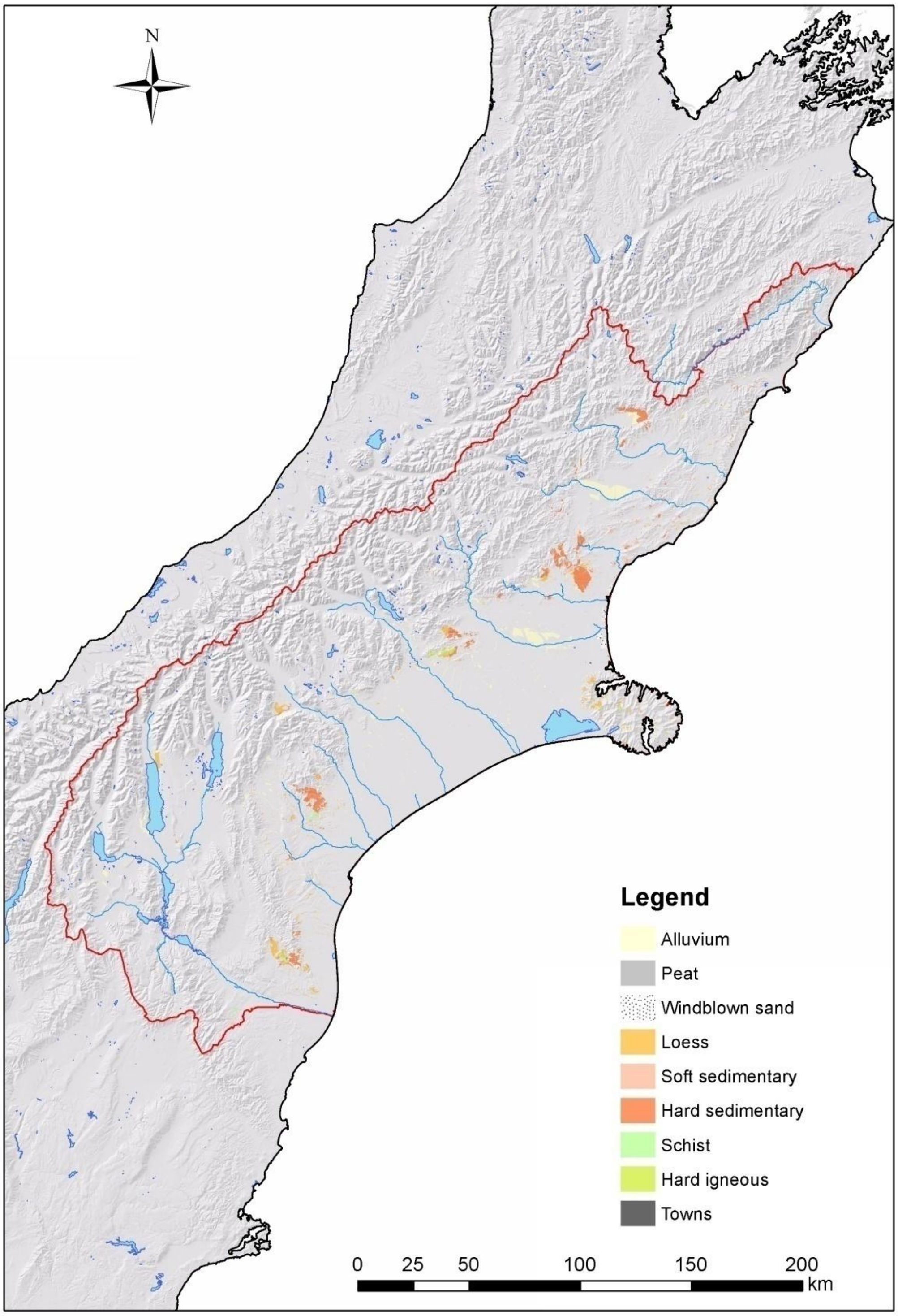

Figure 4 Classification of rock type in areas of plantation forest in Canterbury (derived from the NZLRI)

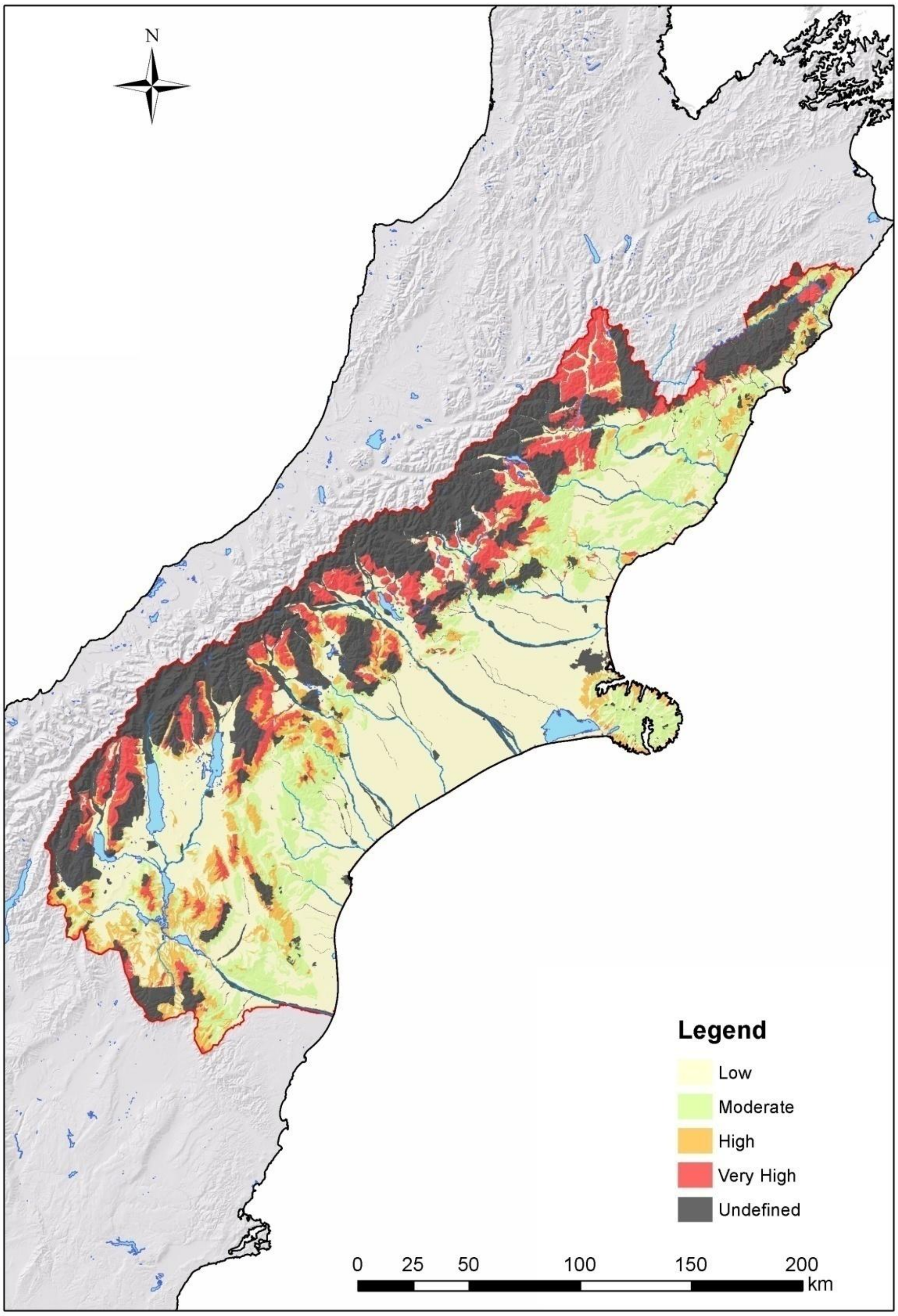

Figure 5 Mapped erosion susceptibility for Canterbury region (after Bloomberg et al. 2011)

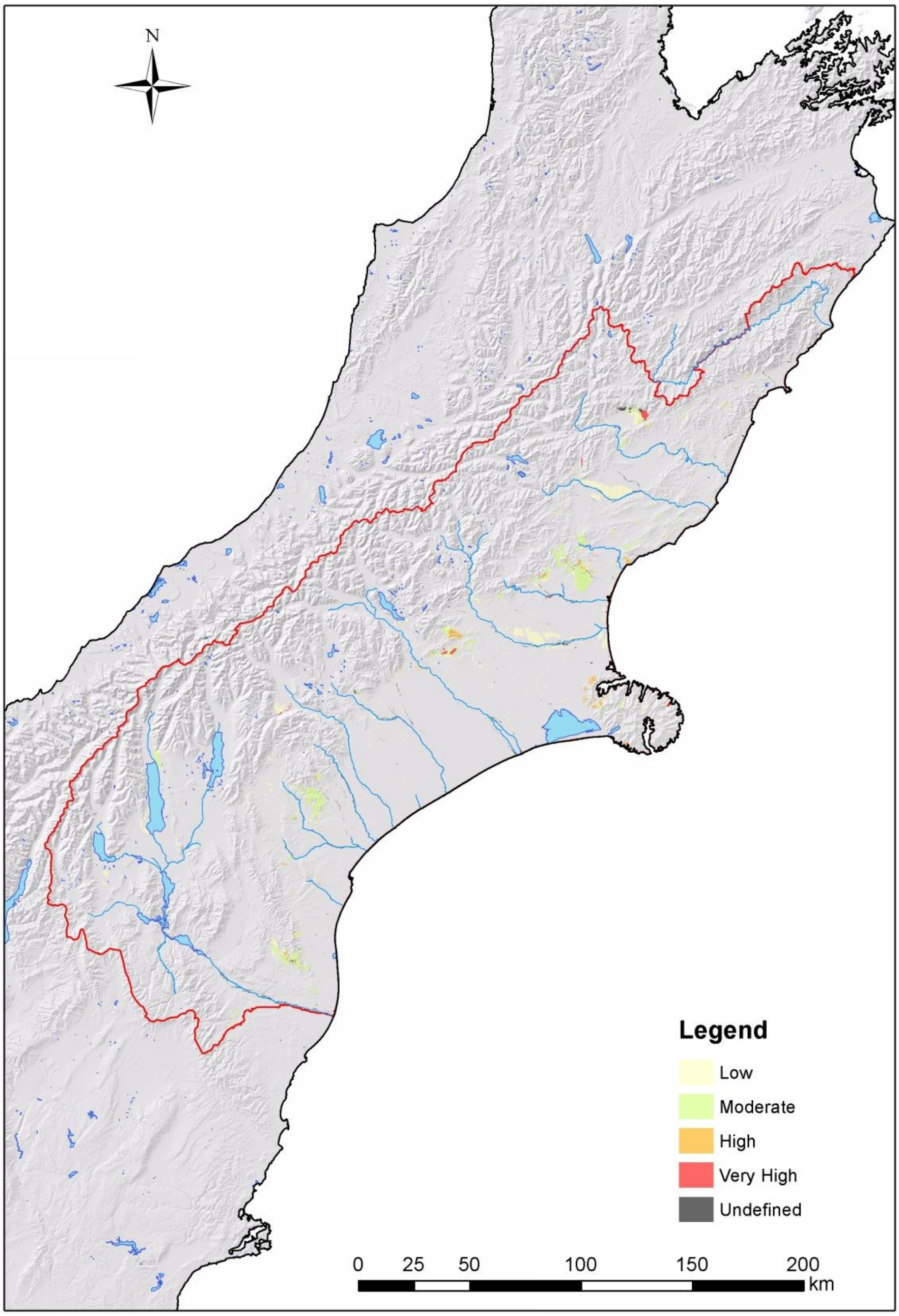

Figure 6 Mapped erosion susceptibility for plantation forests in Canterbury (after Bloomberg et al. 2011)

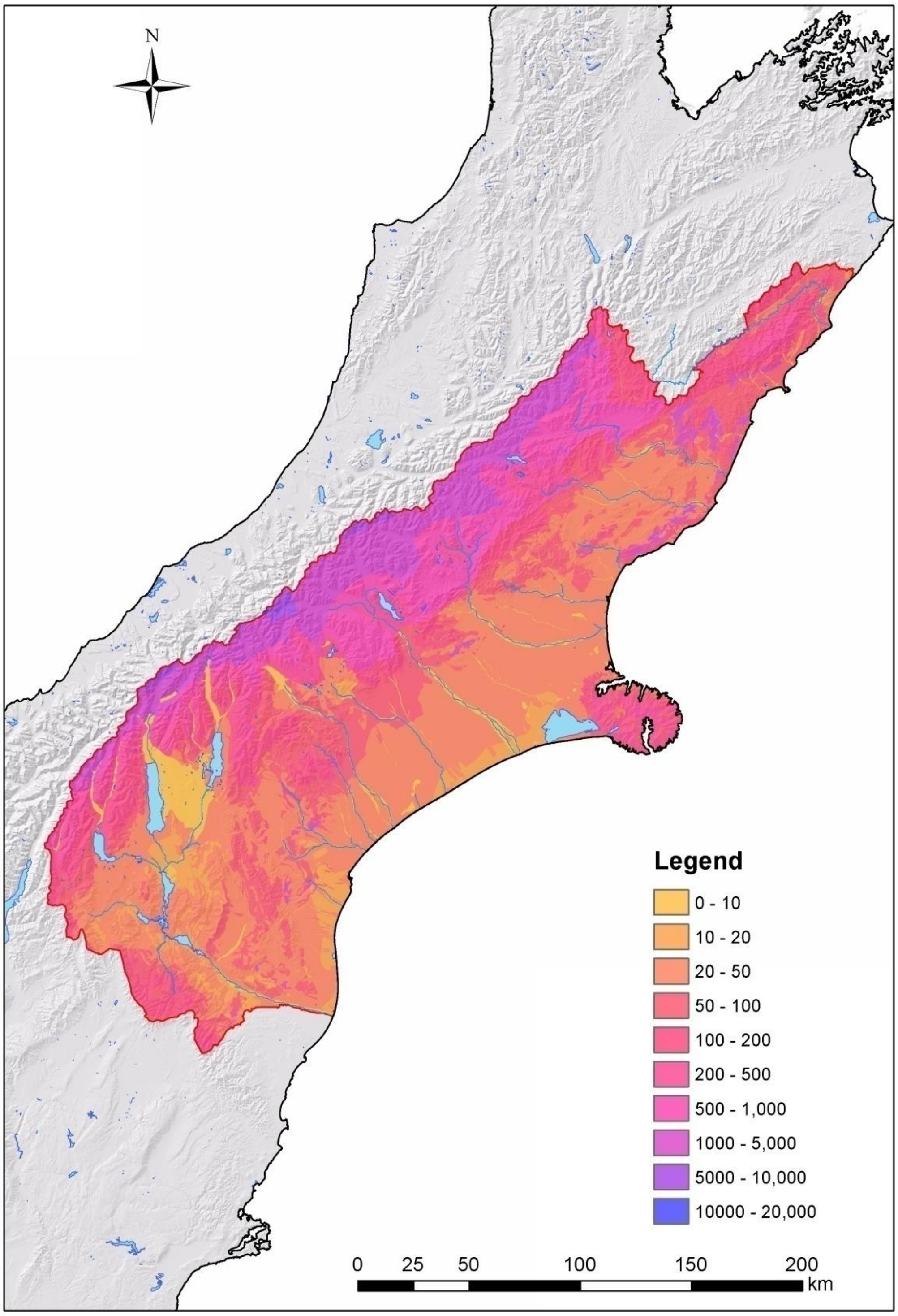

Figure 7 Mapped suspended sediment yield (t km^{-2} y^{-1}) for Canterbury region (source ftp://ftp.niwa.co.nz/ResourceManagementTools/Sedmap/)