BEFORE THE ENVIRONMENT COURT
I MUA I TE KOOTI TAIAO O AOTEAROA

ENV-2018-CHC-49
ENV-2018-CHC-40
ENV-2018-CHC-46
ENV-2018-CHC-50

IN THE MATTER OF	of the Resource Management Act 1991
AND	
IN THE MATTER OF	of an appeal under Clause 14(1) of First Schedule to the Act
BETWEEN	**RAYONIER NEW ZEALAND LIMITED** a duly incorporated company having its registered office at Level 5, 32-34 Mahuhu Crescent Auckland
	Appellant and section 274 party
AND	**SOUTHLAND REGIONAL COUNCIL** a local authority constituted under the Local Government Act 2002
	Respondent

AFFIDAVIT OF CHRISTOPHER JOHN PHILLIPS

Date: 25 February 2022

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I, Christopher John Phillips, of Christchurch, Senior Researcher – Erosion Processes, affirm as follows:

INTRODUCTION

1 In my capacity as Senior Researcher – Erosion Processes at Manaaki Whenua Landcare Research, I was commissioned by Rayonier New Zealand Ltd (**Rayonier**) in 2021 to provide written evidence pursuant to submissions/appeals under the RMA relating to the Proposed Southland Regional Council Water and Land Plan (**PSWLP**).

2 My involvement with Rayonier's appeal and s274 proceeding is in relation to Decisions Version (4 April 2018) of the PSWLP: Cultivation Definition and Rule 25 - Cultivation on sloping ground. I refer to these two provisions collectively as the **cultivation provisions**.

3 I participated in the expert conferencing that took place on 29 November 2021 between several scientists and forestry experts, termed "Expert Conferencing – Forestry". As a result of that Conference, I contributed to, and signed, the Joint Witness Statement for the Forestry Conference, also dated 29 November 2021.

4 I am aware that a Planning conference occurred on 9-10 December 2021 and which resulted in planning experts signing a joint witness statement regarding the Forestry topic (the **Planning (Forestry) JWS**).

5 The Planning (Forestry) JWS records that the cultivation definition in the PSWLP should be amended, and another definition added to the PSWLP on stick raking and slash raking (**the agreed amendments**). My understanding is that the purpose of the agreed amendments is to specifically exclude herbicide spraying and low-risk stick raking or slash raking activities associated with a plantation forest from the cultivation definition.

6 I have been asked to prepare this affidavit to provide technical evidence that is focussed on the agreed amendments to the PSWLP cultivation definition. I have reviewed the agreed amendments and can support them for the reasons discussed below.

7 The contents of this affidavit broadly reproduce the material in my Will Say Statement dated 29 October 2021 and my Statement of Evidence in Chief dated 20 December 2021 but excludes material that is not relevant to the agreed amendments and includes additional technical material that supports the agreed amendments.

8 For completeness and to avoid confusion I record that this affidavit supersedes and replaces my Statement of Evidence in Chief.

QUALIFICATIONS AND EXPERIENCE

9 I am a Senior Researcher – Erosion Processes at Manaaki Whenua – Landcare Research.

10 My qualifications include a Bachelor of Science in Geology and Physical Geography from Otago University, a Master of Science with Honours in Earth Sciences from the University of Waikato and a PhD in Agricultural Engineering from the University of Canterbury.

11 My specialist areas are the assessment of erosion processes and slope stability, forest harvesting effects on erosion and sediment delivery to streams, the role of vegetation in mitigating erosion and integrated catchment management.

12 I am a past 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, a past Director of the Australasian Chapter of the International Erosion Control Association (IECA), and Secretary and board member of ecorisQ (an international association of global professionals working on sustainable solutions for natural hazard risk management).

13 I have over 40 years' experience in research and consulting activities as part of the former New Zealand Forest Service, the Ministry of Forestry, and currently Manaaki Whenua - Landcare Research. I have provided consultancy services for most of New Zealand's forestry companies advising them on aspects of erosion, slope stability, and environmental impacts

relating to plantation forestry. Similarly, I have provided advice to district and regional councils on matters relating to erosion and its management.

14 I developed and currently co-lead a 5-year MBIE research programme "Smarter targeting of erosion control" and have led previous research programmes involving erosion and catchment science.

15 I have authored and co-authored many peer-reviewed publications in relation to geomorphology, erosion and forest management in New Zealand's erodible steeplands, mitigation of hillslope instability and post-harvest erosion risk in steepland plantations in New Zealand, soil reinforcement by tree roots, and in integrated catchment management.

16 I have appeared as an expert witness for forestry companies on district and regional council plan change hearings and in the Environment Court, providing evidence on erosion processes and sediment implications of forestry operations.

17 I have read the Code of Conduct for Expert Witnesses in the Environment Court Practice Note (November 2011). This affidavit has been prepared in accordance with the Code and I agree to comply with it.

18 I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

19 My qualifications and experience as an expert are set out above. I confirm that the issues addressed in this affidavit are within the scope of my expertise, except where I state that I rely upon the evidence of another expert witness

SCOPE OF AFFIDAVIT

20 My affidavit will cover the following:

(a) the issues that the cultivation provisions give rise to, being:

(i) the susceptibility of Southland landscapes to erosion generally and regional sediment yields.

(ii) how forestry activities/operations affect erosion processes and sediment yield.

(iii) the specific forestry activity of windrowing /stick raking and its influence on erosion and sediment yield.

(iv) the specific forestry activity of herbicide spraying and its influence on erosion and sediment yield.

(v) the suitability of Rule 25 (Cultivation on sloping ground) to act as a "control" to reduce the impacts of erosion within plantation forests and deliver the water quality outcomes it seeks.

(vi) The suitability of the agreed amendments with respect to the impacts of erosion within plantation forests from windrowing / stick raking activities and herbicide spraying.

21 Windrowing, stick raking and slash raking are similar terms used throughout the New Zealand plantation forest industry to describe the re-positioning of organic residue in to "wind rows" by mechanical diggers to prepare the land for planting. For ease of reference and to be consistent with the Planning Forestry JWS and the agreed amendments (Planning (Forestry) JWS), I use "stick raking" throughout the remainder of my affidavit.

CONTEXT AND BACKGROUND

22 To assist the Court in its consideration of the agreed amendments I have prepared technical commentary that provides context and background to the more specific issues relating to the cultivation provisions in the PSWLP that are discussed below. For ease of reference the technical commentary is attached and marked **Annexure A**.

23 Compared to other parts of New Zealand, Southland is not regarded as being highly erosion prone. It ranks at the bottom of regions in terms of inherent susceptibility of land to erosion (erosion risk) as mapped under the National Environmental Standard for Plantation Forestry (**NES-PF**) erosion susceptibility classification system.

24 Excluding Fiordland National Park, only 11% of land in Southland is zoned either high or very high erosion risk under the NES-PF. Most land (75.9%) is zoned low erosion risk.

25 Modelled suspended sediment for Southland indicates 8% is derived from bank erosion, with 92% from surficial erosion. Surficial erosion is thus the key erosion process in much of Southland.

26 In the context of plantation forestry, harvesting is often associated with a period where erosion and sediment yields will increase. In part this is due to land disturbance by earthworks associated with the construction of roads and landings and in part because the physical removal of the tree canopy exposes the soil's surface to the direct impacts of rainfall.

27 Following harvesting, the land is prepared for the next rotation (planting of trees). This is often accompanied by stick raking of harvest residues and using herbicides to suppress weed growth and allow the seedlings to grow.

28 Research indicates that if areas of deep soil disturbance can be minimised on the cutover (the area where the trees were removed from; sometimes called the general harvest area) this will have a positive effect on post-harvest sediment generation from rain splash and surface erosion (slope wash). Deep disturbance occurs in areas where mineral soil is exposed by soil scraping (i.e., logs being dragged to landings, or by earthworks associated with the construction of roads and landings).

29 To put this into perspective, research indicates that slope wash or surface erosion is the least important sediment generating process and slope wash from deep disturbance sites contribute only a very small proportion (2%) of total sediment to waterways in the areas where this has been assessed. By comparison, soil scraping and land sliding contribute 26% and 72% respectively. This type of research has however, not been conducted in Southland to my knowledge.

30 Research also indicates that most generated (eroded) sediment from bare or disturbed areas, including landslide debris (not a common process in Southland), does not travel far from its source, getting trapped by micro-topographic features on the slope or by harvesting residue. Where sources

are close and connected to the stream network, sediment may enter the stream.

31 Sediment generation and any potential increases in sediment yield that might occur during and following site preparation activities such as stick raking will be affected by geology, soil type, slope steepness, initial vegetation cover, litter and residue cover, climate (rainfall), amount of bare area immediately following harvesting and the amount and degree of soil disturbance following such mechanical site preparation.

STICK RAKING

32 Stick raking is the movement and stacking of leftover vegetation, slash and other organic matter into long narrow rows (wind rows), usually following harvesting, but can also occur as part of vegetation clearance to establish forests. Its purpose is to clear enough space for the planting or replanting of new trees and to ensure that nutrients are not completely lost from the site. Stick raking is a common site preparation practice in New Zealand forests and can occur on both flat and sloping land.

33 Topsoil has the potential to be disturbed, displaced and removed during raking and it is often the skill of the machine operator that determines how much, if any, soil disturbance occurs.

34 In flat areas this rarely matters but if the site is sloped and can connect with a water way there is a risk sediment can be lost from the site and water quality affected. It's difficult to exactly quantify this risk. I am not aware of any research on this.

35 Good management practices and sediment control measures can reduce the risk of sediment loss from the site and potential effects on water quality.

36 For example, contoured wind rows are preferred as they tend to act as barriers to any downslope movement of soil particles under gravity or as "brush filters" filtering any runoff.

37 I don't consider stick raking to be deep disturbance in the sense I have commented on above, i.e., soil scraping by logs and earthworks.

NES-PF regulation of erosion and sediment yield from forestry activities

38 The Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017 (**NES-PF**) has regulations that control a range of activities within a plantation forest including afforestation, mechanical land preparation, earthworks and harvesting.

39 Of relevance to the agreed amendment are NES-PF regulations relating to the management of sediment - largely earthworks, river crossings, quarrying, harvesting, and mechanical land preparation. The latter activity is the focus of this evidence.

40 Earthworks and harvesting tend to be the phases/activities in the forest cycle where risk of erosion and sediment generation are the greatest. Mechanical land preparation can have an impact, but this will be orders of magnitude lower than for earthworks.

41 NES-PF regulation 74 relates to mechanical land preparation. Stick raking is not explicitly mentioned as a mechanical land preparation method. Roller crushing and downhill ripping are mentioned. These land preparation practices can be regarded as being on a continuum in terms of their potential to disturb the soil. For example, ripping physically breaks up the soil while stick raking moves vegetation across it.

42 The key part in this regulation is that these methods should be carried out parallel to the contour (unless it is unsafe to do so). Further if it can't be carried out parallel to the contour sediment control measures must be employed (see regulation 74(1) and (2)).

43 Such measures can include locating a parallel wind row at the base of a section of non-parallel windrows and/or installing sediment traps/water bars/cross ditches to pick up any sediment washing down the slope between non-parallel windrows.

44 The second pertinent factor is regulation 74(5) which requires exposed areas to be stabilised as soon as practicable after the completion of the activity. This (if required) would usually be done by oversowing. The timing of this relative to when planting occurs is the key factor here. If planting occurs

quickly after stick raking then there is probably little point in oversowing if it is going to be desiccated (herbicide sprayed) and then planted. However, depending on the "weediness" of the site this may need to happen irrespective of whether oversowing is or is not carried out.

45 The setback regulation 74(8)) states that mechanical land preparation must not occur within 5 m of a perennial river or wetland. This is consistent with, though in part, more explicit than the proposed Rule 25.

46 In terms of slope controls, the NES-PF provides for ESC categories and (as mentioned) most of Southland is likely to be green, yellow and orange. If orange and greater than 25° (and the subsoil is affected and the area is more than 2 ha in a calendar year) then mechanical land preparation including stick raking is a restricted discretionary activity (regulation 75(1)(b)).

47 The setback regulation and methods as set out in regulation 74 if appropriately implemented, are sufficient in my opinion to manage the effects of mechanical land preparation including stick raking. Again, the key is to reduce the amount of soil disturbance where possible, to reduce the severity of that disturbance (light v deep), and if soil is disturbed implement methods to avoid loss of soil to waterways by having barriers or filters (erosion and sediment control).

48 In summary to this point, stick raking is not considered deep soil disturbance and is regulated through the NES-PF by way of employing contour windrows. Where this cannot occur due to safety reasons, then sediment control measures must be used to minimise sediment discharges to water bodies.

49 Sediment mitigation measures are likely to be effective in reducing sediment discharges to water bodies, though their performance (% effectiveness) has not been quantitatively assessed in a plantation forest setting as far as I know. Currently, there is one study nationally that I am aware of that has recently got underway in the Nelson region aimed at addressing this need.

50 The Forestry JWS considered that the NES-PF controls for mechanical land preparation (including stick raking) (Q5) were effective in reducing risks from sediment runoff and that there were no circumstances in the Southland

region (Q6) that would justify a more stringent approach than the NES-PF in relation to stick raking.

51 As a signatory to the JWS, I confirm that in my opinion there are no special circumstances of the Southland region which would justify greater regulation for stick raking activities than those contained in Regulation 74.

HERBICIDE SPRAYING

52 In the context of plantation forestry, it seemed odd that spraying was included in a rule that was focused (titled Cultivation) on practices that physically disturb the soil. Spraying doesn't have a physical impact on the soil – it is what comes next that does.

53 Herbicides in a forestry context are used to kill plants such as weeds, grass and unwanted vegetation and reduce competition to allow tree seedlings to be easily planted and become established. It takes time for sprayed plants to die. The dead plant material will form a natural 'mulch' on the soil surface depending on its initial density and 'canopy thickness'. With time, this may be moved by the wind, or it may bind with the soil surface.

54 Also, with time, new weeds and plants will emerge from seed within the soil or dispersed by wind or birds. Thus, the amount of bare ground that is exposed to rainfall following successful herbicide spraying may vary considerably. It is the exposure of bare ground that has the potential to contribute to sediment generation, but not all bare ground will do so.

55 Spraying of herbicide has a low to negligible impact on erosion and sediment yield compared to other practices that disturb the soil. For this reason, I cannot think of any useful or cost-effective mitigation other than not spraying that could be used to minimise its effect.

56 The Forestry JWS considered that the risks from sediment runoff associated with herbicide spraying within a plantation forest are very low because the activity is not physically disturbing the soil (Q11) and that no mitigation measures can be used to manage these risks (Q12).

PLANNING (FORESTRY) JWS - AGREED AMENDMENTS

57 I have read the Expert Conference – Planning (Forestry) JWS dated 09-10 December 2021 which details the agreed amendments to the definition of cultivation in the PSWLP.

58 In my view the amendments respond appropriately to the points agreed in the Forestry topic JWS as they relate to the activity of stick racking and herbicide spraying associated with a plantation forest.

59 From my perspective there are no outstanding issues arising.

OTHER MATTERS – CRITICAL SOURCE AREAS, SETBACKS, AND EPHEMERAL WATERWAYS / FLOW PATHS

60 I am aware that the agreed amendments mean that Rule 25 Cultivation will not apply to plantation forestry herbicide spraying and stick raking activities. For completeness I make some comments regarding Rule 25 to explain why I do not support application of Rule 25 to these plantation forestry activities.

61 Amending Rule 25 to include ephemeral waterways or flow paths would entail practical difficulties relating to definition of these features on the ground in a plantation forest. For example, how would these waterways be defined when the cutover is covered with slash and harvesting residue following harvest of the forest?

62 There is no equivalent of a Farm Environment Plan in forestry. Activities such as harvesting and associated earthworks are required to have a plan under the NES-PF for all erosion susceptibility classification zones (Regulation 66).

63 The concept of critical source area tends to be associated with farming activities and where contaminants at points in the landscape have the potential to be connected to waterways. In forestry, the "critical" or most important areas for sediment generation are not those landscape features as indicated by the PSWLP definition of critical source areas, they relate to earthworks and construction of roads and landings. This subject was discussed as part of the Forestry JWS (Q8-Q10 and Q13-Q14) and the risks

of sediment generation are managed through the harvest and earthworks plans and the sediment control plan required under the NES-PF (see regulations 27 and 66, and Schedule 3 NES-PF for details).

64 Activities around waterways are controlled by regulation 68 of the NES-PF, including graduated setbacks. The Forestry JWS considered the issue of graduated setbacks for all water bodies based on slope (Q8 and Q9). It agreed there was little need for such setbacks for stick raking due to the low risk it posed with respect to sediment generation and because the NES-PF already regulates this, though these are not slope-based.

65 In my opinion, amending Rule 25 to include ephemeral waterways/ephemeral flow paths will make little difference from an erosion perspective with respect to stick raking and herbicide spraying.

66 However, amending Rule 25 to include ephemeral streams/ephemeral flow paths and setbacks around these could result in a perverse outcome. It would likely require more tracking of machinery across the landscape to undertake stick raking that could result in potentially more soil disturbance.

CONCLUSIONS

67 I am comfortable with the amendments to the definition of cultivation and the new definition of stick racking agreed at the Planning (Forestry) JWS.

68 In my view the amendments respond appropriately to the points agreed in the Forestry topic JWS.

69 I am willing to answer any questions that the Court or other parties may have arising from the above matters.

Affirmed at Christchurch

this 25th day of February 2022

before me:

Christopher John Phillips

Olivia Kate Macfarlane
Solicitor
Christchurch

A Solicitor of the High Court of New Zealand

ANNEXURE A

Technical Commentary

1 New Zealand is an erosion-prone country because 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 Basher 2013). This variation occurs in Southland, 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.

2 Compared to other parts of New Zealand, Southland is regarded as not being highly erosion prone (e.g., Donovan 2021).

3 In general, erosion or sediment generation in the Southland 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.

(b) Landslides or mass movements – this is a key erosion process in New Zealand. In Southland, other than in extreme storms or prolonged periods of rainfall likely to cause widespread flooding, and/or in the Western Mountains, the frequency of mass movement is lower here than in many other parts of New Zealand.

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

4 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 Southland, i.e., big floods (return period events greater than about 20–50 years). These large events are natural parts of the geomorphic cycle and will overwhelm any land-use effects or may overwhelm any attempts to control or mitigate erosion and sediment generation.

Exhibit Note:
This is the document marked " A " referred to in the annexed affidavit of CHRISTOPHER JOHN PHILLIPS
Affirmed / sworn at CHRISTCHURCH
This 25th day of February 2022 before me OLIVIA KATE MACFARLANE
Solicitor

Olivia Kate Macfarlane
Solicitor
Christchurch

Erosion Susceptibility Classification Zoning in Southland

5 The National Environmental Standard for Plantation Forestry (NES-PF) has at its core an erosion susceptibility classification that highlights 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. This national approach spatially describes the inherent susceptibility of land to erosion.

6 Southland ranks at the bottom of regions (Table 1), has very little "red" zone or very high risk land (3% excluding Fiordland National Park). Excluding Fiordland National Park land, only 11% of land in Southland is zoned either high or very high erosion risk. The vast majority (75.9%) is zoned low erosion risk suggesting the Southland Region is not highly susceptible to erosion.

Table 1 Distribution of erosion susceptibility classes for each region in New Zealand (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

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

7 Figure 1 shows the distribution of Erosion Susceptibility classes for the Southland area and Fiordland National Park highlighted within purple line.

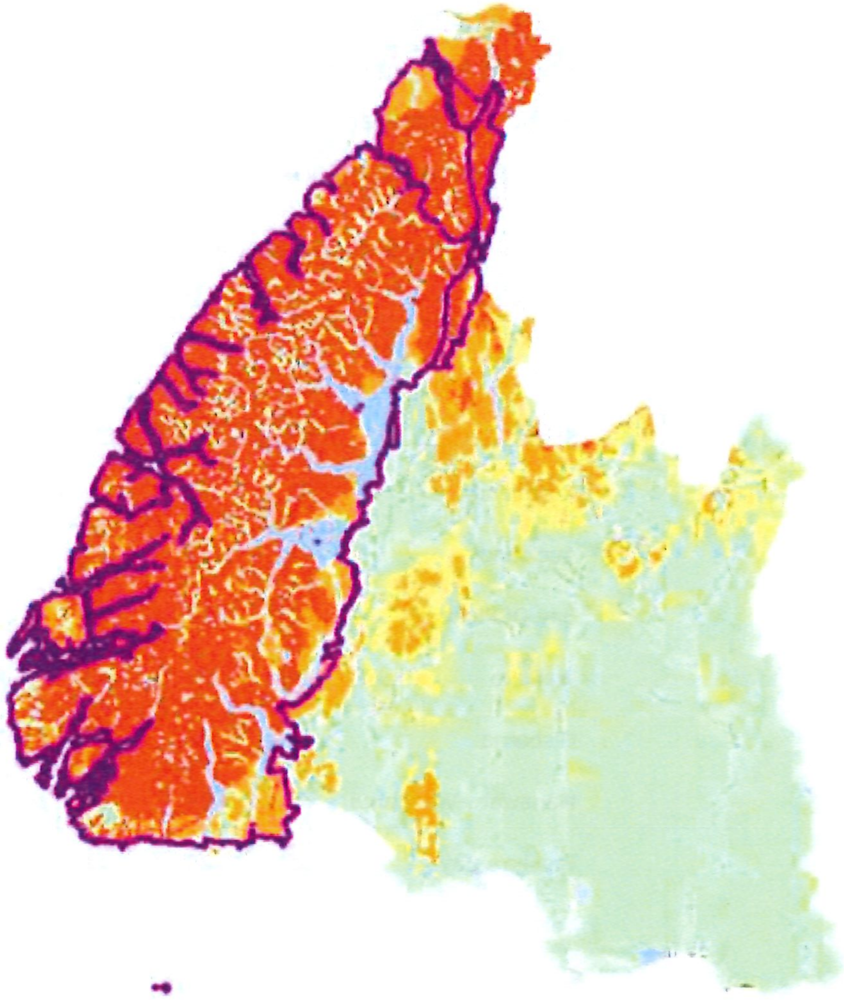

Figure 1 Erosion susceptibility classification zoning in Southland from the NES-PF (MPI) with area in Fiordland identified (purple line). Note the limited areas of very high (red) and high (orange) susceptibility and large areas of low (green) to moderate (yellow) erosion susceptibility (source: Rayonier Matariki Forest GIS team).

8 Suspended sediment yields (SSY) vary widely within the Southland region reflecting the strong west to east rainfall gradient and variety of rock types,

Specific sediment yields in the Southland Region are relatively low compared to other parts of the country (Hicks et al. 2011).

9 The highest rates of erosion occur in the headwaters and along the main channel in the middle to lower reaches of the main catchments. Modelled suspended load (e.g. Hicks et al. 2011; Neverman et al. 2021) suggests 8% is derived from bank erosion, with 92% from surficial erosion. Surficial erosion is thus the key erosion process in much of the 'productive' parts of Southland, i.e., outside of Fiordland.

10 Erosion is a natural process. It can be exacerbated by land use activities. Various practices are used to minimise erosion and reduce sediment loss to waterways. These are termed erosion and sediment controls (ESC). The aim of erosion and sediment control (many of which are included in regulatory controls/rules) is to reduce erosion from occurring in the first place or to intercept any sediment before it reaches a waterway.

11 Each ESC technique has a range of 'performance' associated with it and they are only effective for a range of event sizes, i.e., rainfalls, and in the conditions in which they are used. Extreme or rare rainfall events will largely negate or override the usefulness of such practices.

Forestry influences on erosion and sediment yield in New Zealand

12 Many studies show that erosion and sediment generation 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.

13 The primary benefit of a forest cover is in the prevention of mass movement erosion. In many regions of New Zealand, but particularly on steep land prone to rainfall-triggered shallow landslides trees and forests have been used to reduce erosion, e.g. the East Coast of North Island.

14 There are no documented reports of widespread storm damage in plantation forests in Southland that I am aware of nor significant areas of rainfall-triggered mass movements. And while the latter are the primary processes of

concern in other parts of the country their low frequency in Southland suggests that they can largely be ignored. However, it is important to understand that like many natural processes, they cannot be discounted completely. The following information provides further context.

15 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.

16 Harvesting is often associated with a period where erosion and sediment yields will increase. In part this is because the physical removal of the tree canopy exposes the soil's surface to the direct impacts of rainfall.

17 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 – 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)

18 Within a harvested setting (clear-cut or cutover), sediment can be generated both as a consequence of the harvesting practice (e.g. scalping (soil scraping) or rutting during hauler-logging (Fransen 1998) and by post-harvest erosion processes including raindrop impact, sheetwash erosion (Marden & Rowan 1997; Marden et al. 2006), rilling and by storm-initiated landslides (Marden & Rowan 1995), and from a mix of processes on, and from roads and landings.

19 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.

20 Research indicates there is a period following harvesting when the net relative root reinforcement is low (O'Loughlin 1985; Marden et al. 1991; 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.

21 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).

22 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 Southland.

23 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). Better engineering standards and practices have reduced these failures but they still occur, particularly in extreme events.

24 Soil scraping (sometimes called scalping) or rutting from haul paths caused by harvesting operations was the second largest sediment-generating process measured in Whangapoua Forest in the Coromandel (27%) (Table 2).

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 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

25 Slopewash erosion following harvesting in pumice terrain was investigated by Marden et al. (2007). They found deep disturbance sites produced about 5 times more sediment than from shallow-disturbance plots. Twenty-one months after harvesting when groundcover had occupied 80% of plot area, sediment generation had declined to almost zero. This highlights the importance of ground cover in reducing sediment generation. Similar findings were found in another study in the Coromandel (Marden et al. 2006).

26 Marden et al. (2006) found that desiccant had its greatest effect on sites of shallow disturbance where ground cover declined to 46% of plot area 5 months after application of desiccant (or 12 months after harvesting). On deep disturbance plots, groundcover vegetation was low to start with (19% cover) and recovered to 27% after the following 4-month spring period while the shallow-disturbance sites recovered to 59% – close to pre-desiccation coverage levels. Within 24 months of the completion of harvesting,

groundcover vegetation had increased to 80% on sites of shallow-disturbance, but only occupied about 40% of deep disturbance sites.

27 To put this into perspective, from Marden et al's (2006) study, slope wash was the least important sediment generating process (Table 2) and slope wash from deep disturbance sites contributed only a very small proportion of total sediment delivered to waterways (Table 3).

Table 3 Process-based sediment generation and percent of total sediment delivered to streams from coupled sites over a 2-year post-harvest period, Compartment 49, Whangapoua Forest.

Process	Sediment generating site	Sediment (t)	Sediment delivered to stream (t)	% of total
Slopewash	Shallow-disturbance	n/a	n/a	n/a
	Deep disturbance	2.9	2.9	2
Soil scraping	Deep disturbance	60	60	26
Landsliding	Landslides (n=9)	330	165*	72
Total	**All sources**	**392.9**	**227.9**	**100**

n/a, Not assessed; * 50% of sediment generated estimated to have remained on slope

28 Further findings from these studies suggests that 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. However, where sources are close and connected to the stream network, sediment may enter the stream.

29 Most sediment found to have been 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.

30 These studies reinforce the view that if areas of deep disturbance can be minimised this will have a positive effect on post-harvest sediment generation from rain splash and surface erosion (slope wash).

31 When forests are harvested the sediment yield rises relative to the pre-harvest phase of the rotation or when compared to a pasture or forested

catchment (plantation or indigenous). This is due to two factors – more "effective" rainfall and more "bare" area from which to generate sediment.

32 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.

33 In the harvesting phase there are more "bare" areas available to generate sediment because of additional earthworks associated with road and landing construction. Also, the ground/soil may be disturbed during the harvest operation itself or in mechanical treatment of land prior to re-planting. The act of cutting the trees down does not in itself cause erosion.

34 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}. 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).

35 There are limited studies that have assessed the effectiveness of riparian buffers on reducing sediment generation and delivery to streams in New Zealand plantation forests (Boothroyd et al. 2004; Phillips et al. 2017). Their effectiveness depends on many factors and they may not produce the expected outcome in terms of water quality improvements.

36 There are no studies that I am aware of that have measured sediment yield from catchments with different land uses (including forestry) in the Southland region or any that document the sediment yield from fully forested catchments.

37 The management and control of erosion and sediment from plantation forestry activities is covered by the National Environmental Standard – Plantation Forestry (NES-PF). These regulations cover all aspects of plantation forestry activity from afforestation through to harvesting.

Summary of key points

- 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.
- 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 Southland may be proportionally more important though there are no studies to support this contention.
- 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.
- Sediment generation and any potential increases in sediment yield that might occur during and following site preparation will be affected by geology, soil type, slope steepness, initial vegetation cover, litter and residue cover, climate (rainfall), amount of bare area immediately following harvesting and the amount and degree of soil disturbance following any mechanical site preparation.

References

Basher LR, Hicks DM, Clapp B, Hewitt T 2011. Sediment yield response to large storm events and forest harvesting, Motueka River, New Zealand. New Zealand Journal of Marine and Freshwater Research 45(3): 333-356.

Basher LR 2013. Erosion processes and their control in New Zealand. In: JR D ed. Ecosystem services in New Zealand - conditions and trends. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 363-374.

Bloomberg M, Davies T, Visser R, Morgenroth J 2011. Erosion susceptibility classification and analysis of erosion risks for plantation forestry. Report prepared for Ministry for the Environment. Christchurch, New Zealand: University of Canterbury.

Boothroyd IKG, Quinn JM, Langer ER, Costley KJ, Steward G 2004. Riparian buffers mitigate effects of pine plantation logging on New Zealand streams: 1. Riparian vegetation structure, stream geomorphology and periphyton. Forest Ecology and Management 194(1–3): 199-213.

Coker RJ, Pearce AJ, Fahey BD 1990. Prediction and prevention of forest landing failures in high intensity rainfall areas of northern New Zealand. IAHS-AISH publication No. 192: 311-317.

Coker RJ, Fahey BD 1993. Road-related mass movement in weathered granite, Golden Downs and Motueka Forests, New Zealand: a note. Journal of Hydrology (NZ) 31: 56-64.

Coker RJ, Fahey, BD, Payne JJ 1993. Fine sediment production from truck traffic, Queen Charlotte Forest, Marlborough Sounds, New Zealand. Journal of Hydrology (N Z) 31: 65-69.

Donovan M 2021. Modelling soil loss from surface erosion at high-resolution to better understand sources and drivers across land uses and catchments; a national-scale assessment of Aotearoa, New Zealand. Environmental Modelling & Software: 105228.

Fahey BD, Coker RJ 1989. Forest road erosion in the granite terrain of southwest Nelson, New Zealand. Journal of Hydrology (NZ) 28: 123-141.

Fahey BD, Marden M, Phillips CJ 2003. Sediment yields from plantation forestry and pastoral farming, coastal Hawke's Bay, North Island, New Zealand. Journal of Hydrology (NZ) 42: 27-38.

Fahey BD, Marden M 2000. Sediment yields from a forested and a pasture catchment, coastal Hawke's Bay, North Island, New Zealand. Journal of Hydrology (NZ) 39: 49-63.

Fransen PJB 1998. Erosion and revegetation of haul paths in cable logged settings – North Island, New Zealand. Logging Industry Research Organisation, Project Report PR-67, 15p.

Fransen PJB, Phillips CJ, Fahey BD 2001. Forest road erosion in New Zealand: overview. Earth Surface Processes and Landforms 26: 165-174.

Hicks DM, Shankar U, McKerchar AI, Basher L, Jessen M, Lynn I, Page M 2011. Suspended sediment yields from New Zealand rivers. Journal of Hydrology (NZ) 50: 81–142.

Marden M, Phillips CJ, Rowan D 1991. Declining soil loss with increasing age of plantation forests and farmland in Uawa catchment, East Coast region, North Island, New Zealand. In: Proceedings of International Conference on Sustainable Land Management, Napier, New Zealand, November. Pp. 358-361.

Marden M, Phillips C, Rowan D 2002. Soil loss, vegetation recovery, and sediment yield following plantation harvesting. In: Stephens P, Callaghan J, Austin A ed. Proceedings : Soil quality and sustainable land management workshop : 3-5 April 2002, Massey University, Palmerston North. Palmerson North, Landcare Research. Pp. 111-116.

Marden M, Rowan D 1995. Assessment of storm damage to Whangapoua Forest and its immediate environs following the storm of March 1995. Unpublished Landcare Research Contract Report LC9495/172 prepared for Ernslaw One

Marden M, Rowan D 1997. Vegetation recovery and indicative sediment generation rates by sheetwash erosion from hauler-logged settings at Mangatu Forest. New Zealand Forestry 42(2): 29-43.

Marden M, Rowan D, Phillips C 2006. Sediment sources and delivery following plantation harvesting in a weathered volcanic terrain, Coromandel Peninsula, North Island, New Zealand. Australian Journal of Soil Research 44: 219-232.

Marden M, Rowe L, Rowan D 2007. Slopewash erosion following plantation harvesting in pumice terrain and its contribution to stream sedimentation, Pokairoa catchment, North Island, New Zealand. Journal of Hydrology (N.Z.) 46(2): 73-90.

Neverman A, Smith H, Herzig A, Basher L 2021. Modelling baseline suspended sediment loads and load reductions required to achieve Draft Freshwater

Objectives for Southland. Manaaki Whenua Landcare Research Contract Report LC3749 for Environment Southland. 66p.

O'Loughlin CL 1985. Influences of exotic plantation forest on slope stability – implications for forest management in the Marlborough Sounds. In: Campbell, I.B. (Ed.) Proceedings of the soil dynamics and land use seminar, Blenheim, May 1985. New Zealand Society of Soil Science, Lower Hutt, and New Zealand Soil Conservators Association. Pp. 313-328.

Watson AJ, Marden M, Phillips CJ 1999. Root strength, growth and rates of decay: root reinforcement changes of two tree species and their contribution to slope stability. Plant and Soil 217: 39-47.

Pearce AJ, Hodgkiss PD 1987. Erosion and sediment yield from a landing failure after a moderate rainstorm, Tairua Forest. New Zealand Forestry 32(2): 19-22.

Phillips CJ, Marden M, Rowan D, Garrett L 2002. Soil loss, vegetation recovery, and sediment delivery to streams following plantation harvesting, Coromandel. In: Programme abstracts from All the Easy Water Has Gone. New Zealand Hydrological Society annual conference, Blenheim, 3-6 December 2002.

Phillips CJ, Marden M, Rowan D 2005. Sediment yield following plantation harvesting, Coromandel Peninsula, North Island, New Zealand. Journal of Hydrology (NZ) 44(1):29-44.

Phillips CJ, Marden M, Betts H, Basher LR 2017. Effectiveness of riparian buffers for trapping sediment in steepland plantation forests. Landcare Research Contract Report LC3039. 74 p.