Technical Committee 20190612 Attachments

Minutes of a meeting of the Technical Committee held in the Council Chamber Council Chamber on 1 May 2019, commencing at 9:30 a.m.

Membership

Cr Andrew Noone	*(Chairperson)*
Cr Ella Lawton	*(Deputy Chairperson)*
Cr Graeme Bell	
Cr Doug Brown	
Cr Michael Deaker	
Cr Carmen Hope	
Cr Trevor Kempton	
Cr Michael Laws	
Cr Sam Neill	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Stephen Woodhead	

Welcome

Cr Lawton welcomed Councillors, members of the public and staff to the meeting.

1. APOLOGIES
No apologies were noted.

2. LEAVE OF ABSENCE
The leaves of absence for Councillor Kempton, Councillor Noone and Councillor Woodhead were noted.

3. ATTENDANCE

Sarah Gardner	*(Chief Executive)*
Nick Donnelly	*(General Manager Corporate Services and CFO)*
Gavin Palmer	*(General Manager Operations)*
Sally Giddens	*(General Manager People, Culture and Communications)*
Andrew Newman	*(Acting General Manager Policy, Science and Strategy)*
Liz Spector	*(Committee Secretary)*

4. CONFIRMATION OF AGENDA
The agenda was confirmed as tabled.

5. CONFLICT OF INTEREST
No conflicts of interest were advised.

6. PUBLIC FORUM
No public forum was held.

7. PRESENTATIONS
No presentations were held.

8. CONFIRMATION OF MINUTES
Resolution

That the minutes of the meeting held on 21 March 2019 be received and confirmed as a true and accurate record.

Moved: Cr Lawton
Seconded: Cr Hope
CARRIED

9. ACTIONS
Status report on the resolutions of the Technical Committee

Report	**Meeting Date**	**Resolution**	**Status**
Lake Hayes Restoration	1/8/18	*That the consultant report by Castalia be re-framed into a more public intelligible document and*	CLOSED

		follow up on receipt of the revised Castalia report	
Lake Snow technical workshop recommendations	18/10/18	*The CE engage on the with CEs at the regional CEOs meeting on 8 November 2018 on the primary objectives from the workshop.* *Invite Regional Councils and MPI to formally endorse and support the proposed research programme and to discuss funding arrangements.*	IN PROCESS

10. MATTERS FOR NOTING

10.1. General Manager Operations Report to Technical Committee
Dr Gavin Palmer, GM Operations, and Dr Jean-Luc Payan, Manager Natural Hazards, were present to review the GM Report with the Councillors. Cr Deaker noted the several meetings Dr Palmer had with DCC senior management and said he was pleased with the level of collaboration between the organisations. Cr Hope asked what the team had learned from the recent West Coast flooding. Dr Palmer said early mobilisation and having collegial cross-sector relationships was very important. Dr Payan said mapping software will be very useful to share with various organisations.

Councillor Bell asked if staff would provide regular updates on rabbit control measures on the committee report as that information was important to the Dunstan constituency. Dr Palmer agreed and said a review was underway to improve the quality of reporting through the Regulatory Committee on those types of issues. Councillor Lawton said she thought it would be good to include outcomes as a follow through to the Communications Committee.

Cr Scott asked if there were any key learnings from the large Leith Flood works project. Dr Palmer said the scale of the job lends itself to a comprehensive post-scheme wrap-up and he was working on the best way to provide this information to the Councillors. He suggested the wrap-up be reported alongside financials which would come out on a quarterly basis. A general discussion was held regarding the health and safety management of the construction site. Cr Hope said as the project was in the middle of campus, security needs might be different. Dr Palmer said there were good security measures in place, including having security personnel on site to manage access occasionally.

There was no further discussion and Cr Lawton asked for a motion.

Resolution

That the Council:

*1) **Receives** this report.*

*2) **Direct** staff to provide regular updates on rabbit control (biosecurity) on the GM reports.*

Moved: Cr Deaker
Seconded: Cr Hope
CARRIED

11. NOTICES OF MOTION

No notices of motion were submitted.

12. CLOSURE

The meeting was declared closed at 10:25 am.

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Chairperson Date

Glendhu Forestry Water Quality Monitoring Project: Summary Report

Prepared For: Otago Regional Council Technical Committee
Prepared By: Sarah Mager, Christina Bright and Sophie Horton
(Department of Geography, University of Otago)
Date: 30 Nov 2018

Suspended Sediment Yield during harvest of Pinus radiata at Glendhu Forest, South Island, New Zealand

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Abstract [350 words]

Keywords

1 Introduction

The Glendhu catchment study is a multi-year investigation into the effects of pine harvesting operations on suspended sediment yield, and the associated impacts on water clarity, and stream sedimentation. This report summarises the data and outcomes of the 18-month investigation into pine forest harvesting in the Glendhu Forest on water quality as pertaining to Plan Change 6A. Plan Change 6A enabled the discharge of sediment to water a permitted activity so long as the discharge does not result in a 'conspicuous change in water clarity or noticeable increase in local sedimentation'. In coordination with Rayonier Matariki Forests the ORC undertook a study of the effects of large-scale forest harvesting on sediment disturbance in the Glendhu Experimental Catchments. These catchments have significant long-term flow records and are part of a long-term research collaboration between Rayonier Matariki Forests, Manaaki Whenua Landcare Research, Otago Regional Council, and the University of Otago.

The Glendhu Experimental Catchments were developed in the late 1970s in collaboration with the New Zealand Forestry Service to establish the effects of converting indigenous tussock grasslands to plantation pine forestry in Otago. Specific concerns were related to the impacts of land use change, specifically what impact does pine plantation forestry have on the local water yield and water quality (Fahey, 2012). The original aims of the establishment of the Glendhu Experimental Catchments were to:

- Investigate the streamflow behaviour and water balance of lightly grazed tussock grassland; and
- Assess the impact of afforestation on annual water yields, storm peak flows, low flows, water chemistry, and sediment yield.

From the original study it was identified that:

- Little difference in stream flow during the first 6 years after planting;
- There was a 33% reduction in runoff from the planted catchment (relative to the control) for the 20 year period 1991–2011 following canopy closure;
- Reduced runoff from the plantation forestry was attributed to greater transpiration from the pine forest (relative to the tussock grassland);
- Reduced mean flood peaks (by 60–70%) were observed in the plantation forestry, due to reduced storm quick flow in the planted catchment;
- Reduction in Mean Annual Low Flow (MALF) in runoff from the plantation forestry, equivalent to approximately 25% over the period 1991–2011;
- No significant changes in water quality from runoff between plantation forestry and tussock grasslands; lower nitrate in the plantation forestry runoff (observed 1993–1994); and
- Greater abundance and diversity of invertebrates in the planted catchment compared to the pre-planting period.

Thus, from the original study it was identified that the conversion of indigenous tussock grasslands to plantation pine forestry had no affect on local water quality, and that measurements of bed load yield rates from both catchments showed low rates (< 0.5 m^3 km^{-2} a^{-1} for 1992–1994) suggesting that the schist steep-lands of Otago east of the main divide are very stable. There were, however, significant changes in the hydrology of the catchments, with pines intercepting and using more water relative to tussock grassland, and this resulted in a notable decline in mean annual low flows, and in particular, a reduction in summer low flows. Pine forestry, however, was effective at attenuating storm flows by reducing the magnitude and intensity of floods.

1.1 Study Objectives

The objectives of the current work was to:

Assess the effects of the clearance phase of plantation forestry on sediment discharge to waterways to ascertain the sediment yield; and relates to the ORC's Rural Water Quality implementation programme for the permitted activity rules related to diffuse suspended sediment.

Specifically, sediment discharge to waterways is a contaminant of concern because sediment loss from a catchment may cause:

1. Reduced aquatic habitat through the smothering and burial of river beds
2. Reduced water clarity that limits in-stream photosynthesis
3. Increased turbidity that reduces recreational and cultural stream values

4. Deterioration of water quality through increased nutrient yields that may contribute to downstream environments being vulnerable to eutrophication (e.g., lakes and estuaries).

The Glendhu Experimental Catchments represent the longest-running study of its kind in New Zealand and provides the only example of the potential sedimentation effects on the rolling hill country of Otago with its bespoke grassland headwaters and schist lithology. Management and mitigation measures in the Glendhu Forest are concordant with best industry practice so provides the potential to observe compliance with the permitted activity rules and to assess whether the activity resulted in a change in water clarity or result in local sedimentation.

2 Methods

Paired catchment studies are a widely-used tool to determine the effects of land use transformation on hydrology. The approach sets aside two similar catchments and allocates one as a 'control', and the other as a 'treatment' catchment, which has undergone transformation. In New Zealand, the paired catchment method has been used in Purukohukohu in the central North Island (see: Dons, 1987), Moutere in the Nelson region (see: Duncan, 1995), Maimai near Reefton (see: Rowe & Pearce, 1994) and Donald Creek in Nelson (see: Fahey and Jackson, 1997), all of which assess the effects of plantation forestry. At the Glendhu Experimental Catchments, two catchments were set aside, one retained in indigenous tall snow tussock (*Chionochloa rigida*), and a second ripped and planted in pine forestry (*Pinus radiata*) in 1982. The Glendhu Experimental Catchments are nationally recognised for their importance to contributing to New Zealand hydrology because the field site is the longest on-going catchment study in New Zealand (Fahey and Payne, 2017) and has contributed significantly to understanding the effects of afforestation on the hydrology of the indigenous tussock grasslands of the South Island (Rowe *et al*., 2002) as well as a venue for considerable scientific investigation into evaporation and runoff-generation processes in tussock grasslands (e.g., Campbell and Murray, 1990; Bowden *et al.,* 2001; Stewart and Fahey, 2010).

2.1 Study Location

The Glendhu Experimental Catchments are located in Eastern Otago, in the headwaters of the Waipori catchment in the Lammerlaw Range, approximately 60 km due west of Dunedin city. The tussock catchment (GH1) covers 2.16 km^2 and the pine plantation catchment (GH2) covers 3.10 km^2. Both catchments are north-facing and have an elevation range of 460–680 m a.s.l and are characterised by rolling hills with moderately to steep valley sides and fluvial dissection. Both catchments are low ordered streams, characterised by amphitheatre-shaped bowl subcatchments with riparian wetlands. These wetland areas and river network margins were retained in indigenous tussock grasslands in the planted forest catchment (GH2).

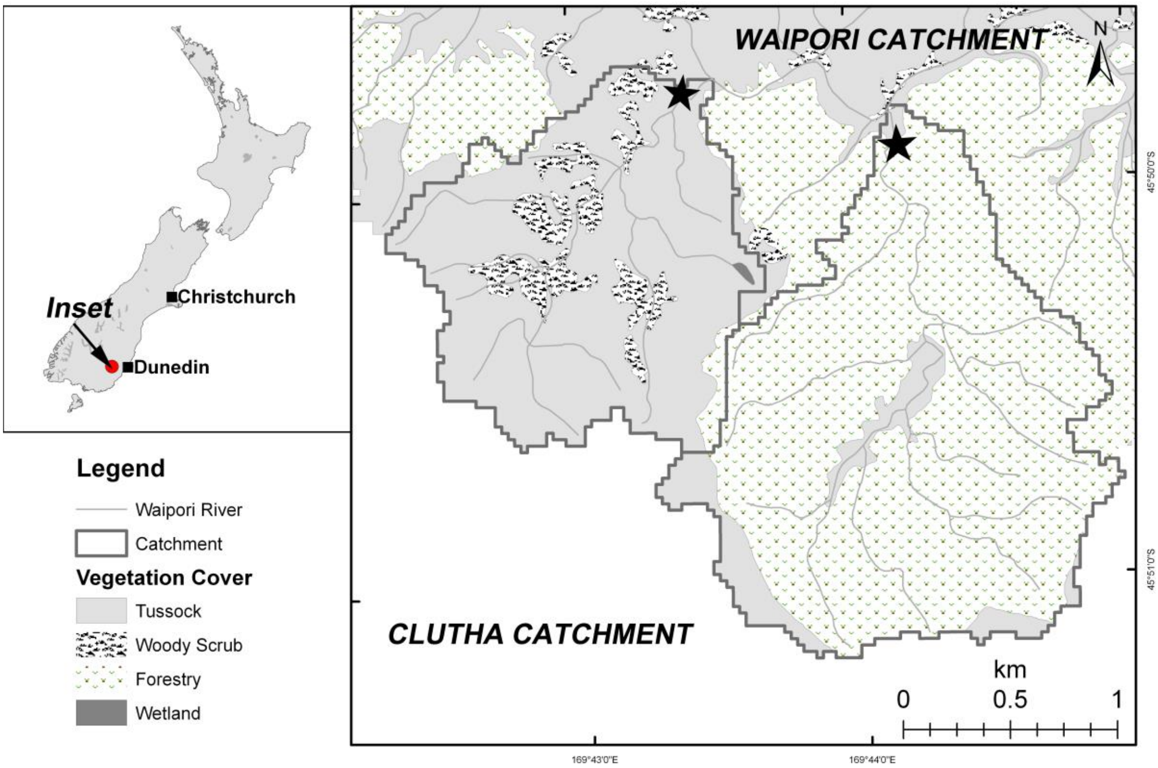

Figure 1 – Location Map of the Glendhu Experimental Catchments

3 Instrumentation and Data Analysis

Instrumentation in the Glendhu Experimental Field sites includes two large concrete v-notch weirs at the bottom of each catchment and stage recorded using a Dataflow Systems Odyssey capacitance water level loggers maintained by Manaaki Whenua Landcare Research with an accuracy of ±2 mm, and converted to discharge using a modified rating equation of Holton *et al.* (1962). Rainfall is measured through tipping bucket rain gauges near each weir, installed in 1988, and currently maintained by Manaaki Whenua Landcare Research. Rainfall between each catchment varies by ± 2% per annum (Pearce *et al*., 1984), although there is a small difference in incipient rainfall with elevation across the catchment (Fahey, pers. comm). To account for spatial differences in rainfall an area weighting procedure is applied to the rainfall data.

a) b) c) d)

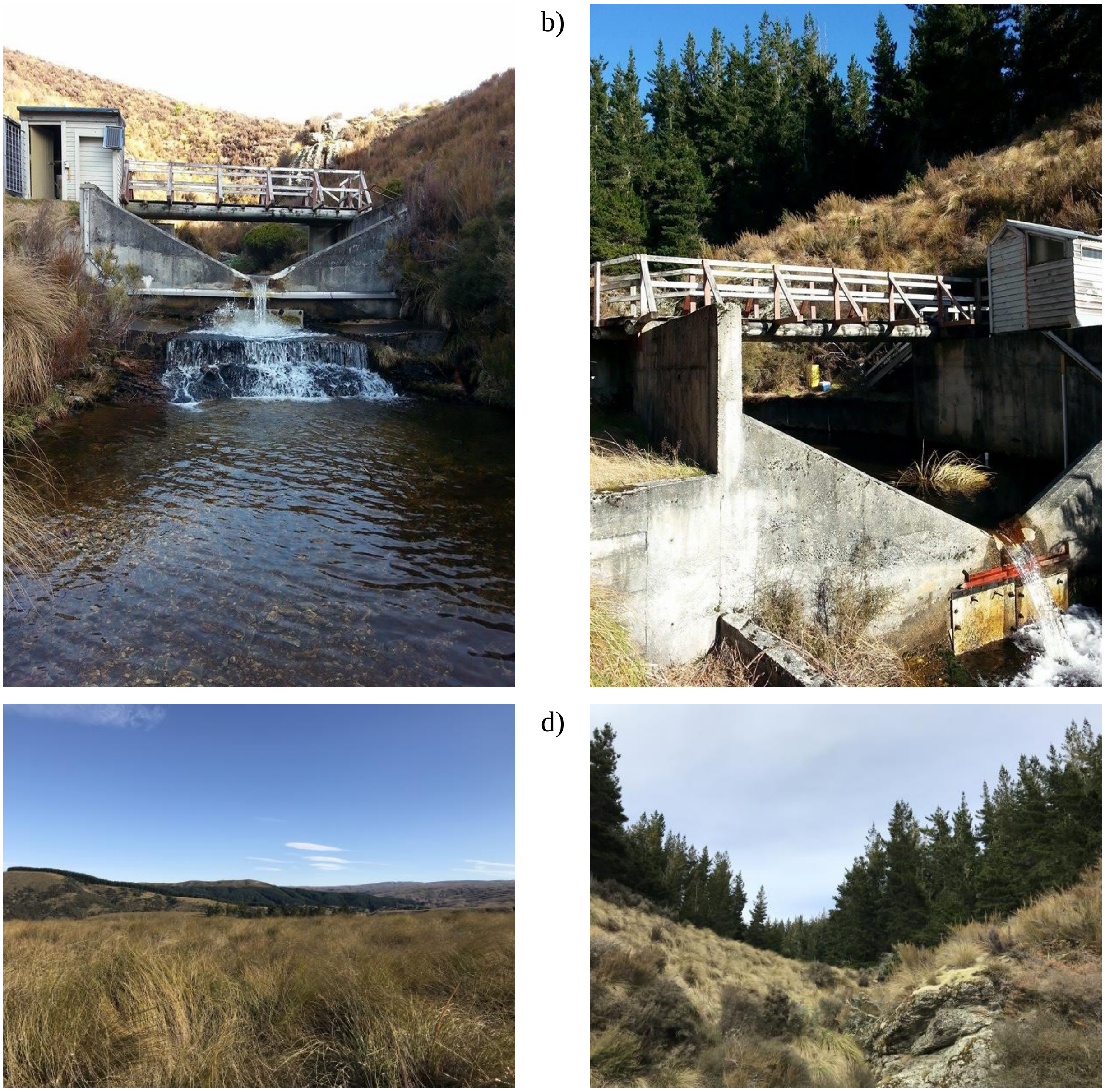

Figure 2 –Glendhu Experimental Catchments showing the weirs and monitoring recording locations for a) tussock catchment, b) pine plantation catchment as photographed in 2017. The tussock catchment is mostly covered in tall snow tussock (c) with incursion of scrub, whereas the pine plantation catchment (d) is planted in Pinus radiata but with riparian strips retained in tall snow tussock.

3.1 Turbidity Measurements

Runoff from the Glendhu Experimental catchments often exhibit a yellow hue from dissolved organic matter (Figure 3), so traditional turbidimeters that use a wide range light source (e.g., tungsten lamp 400–600 nm) tend to yield poor turbidity to suspended sediment relationships (e.g., Bright and Mager, 2016). Two YSI Exo Sonde Turbidimeters were installed upstream of the concrete weirs to continuously measure turbidity at 15-minute intervals and provided a continuous 18-month record from 7 Jul 2018 to 9 Jan 2018. These turbidimeters use a nearinfrared light source (860 nm) and optical 90 degree scattering of incident light, in units of formazin nephelometric units (FNU) with a range of 0–4000 NTU with an accuracy of ±2% below 999 FNU, and ±5% > 1000 FNU.

a)

b)

Figure 3 – Coloured runoff observed at the Glendhu Experimental Catchments with examples of coloured dissolved organic matter (CDOM) during a high stream flow event in the tussock catchment. The differences in colour between a) and b) reflect different stages of a 2016 storm event.

Turbidity was continuously field-measured in both of the experimental catchments at Glendhu. Analysis of the baseline conditions showed values < 0 indicating that a baseline shift for both the tussock and pine plantation records was required (Figure 4). A simple arithmetic baseline shift was applied to each record, so that turbidity ≥ 0 FNU units. The amount of baseline shift was calibrated relative to discrete grab samples turbidity (in NTU) in a laboratory. The baseline records show a small amplitude change over time, with higher turbidity during winter in the tussock catchment. The fluctuations in turbidity with seasonality was considered a reflection of actual conditions based on the observed grab sample turbidity, so no further corrections were made to the tussock turbidity record. The baseline record for the pine plantation record, however, shows evidence of baseline shift and drift during the observation record. To rectify this, the same approach was used, by shifting sections of the turbidity record so that turbidity ≥ 0 FNU units relative to turbidity derived from grab samples throughout the observation record.

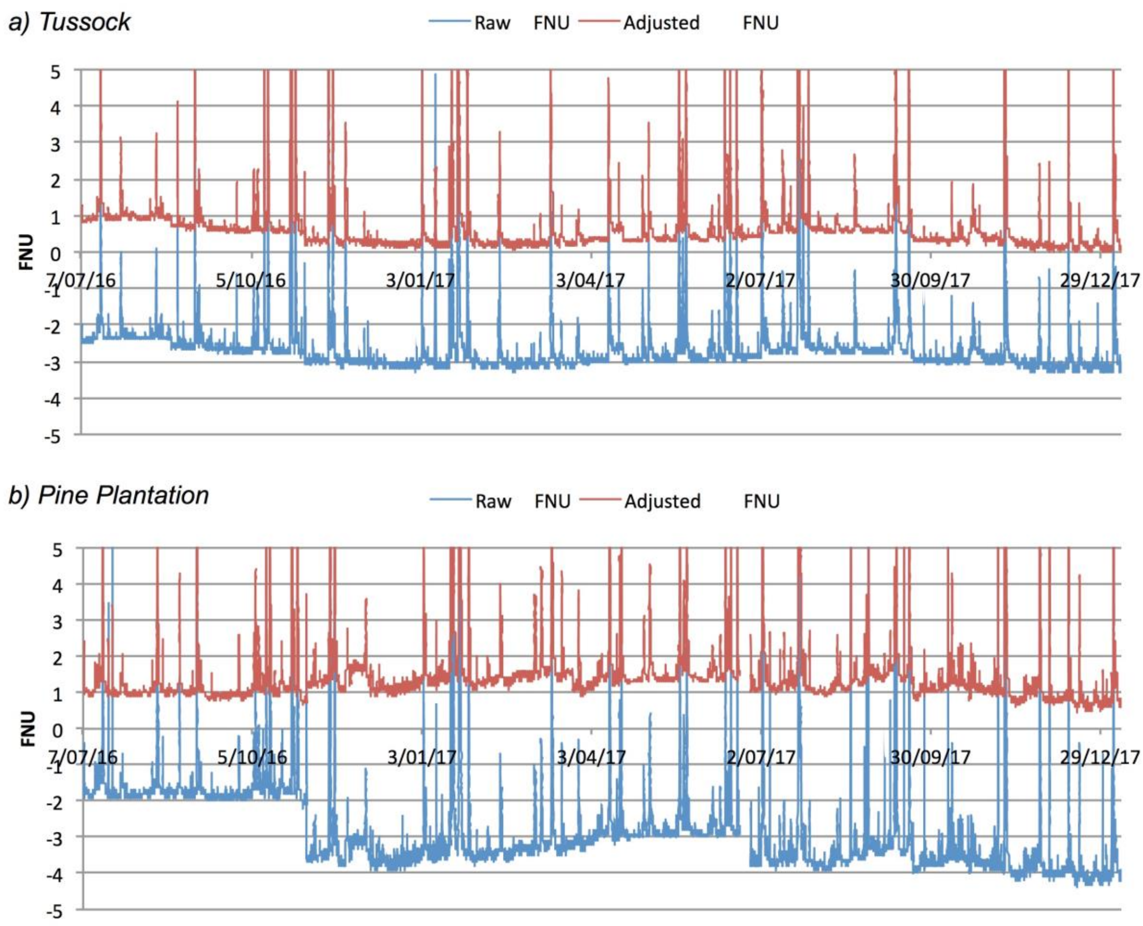

Figure 4 – 18-month record of turbidity recorded at Glendhu Experimental Catchments showing offset between raw output recorded on sondes (blue), and the corrected turbidity record (red). Instrumental drift is evident in (b), and adjusted using grab samples for base flow levels of 1 FNU. Base flow turbidity for (a) ranges from 0.5 to 1.0 FNU and seasonally varies according to grab samples so no further de-trending was applied.

3.2 Suspended Sediment Concentration

Automatic water samplers were installed upstream of the concrete weirs and attached to a water level trigger to collect water samples during event flow. These discrete samples were analysed for the suspended sediment concentration (SSC) using standard laboratory methods. Samples were collected using a water-level trigger, so that 24-samples (at 30-minute intervals) were mostly collected on the ascending limb of a hydrograph, and supplemented by discrete grab samples collected every one to two months, to develop a turbidity and suspended sediment relationship (Table 1).

Table 1 – Water samples collected for suspended sediment and turbidity measurements using automatic water samplers in the Glendhu Experimental Catchments.

Date	Tussock Catchment (GH1)			Pine Plantation Catchment (GH2)		
	No.	NTU Range	SSC Range	No.	NTU	SSC

17 Jul 16	13	2.1–19	4–30			
5 Sep 16	18	1.9–24	5.6–86	24	5.1–35	11–79
13–14 Oct 16	24	1.5–18	2.5–40	24	3.9–20	8–43
14–15 Nov 16	24	1.2–15	2–41			
22 Jan 17	24	3.2–30	4.7–100	24	14–140	22–260
Discrete Samples						
TOTAL	103			72		

4 Results

4.1 Flow Measurements

Stream flow records for the Glendhu Experimental Catchments started in 1980 and are maintained by Manaaki Whenua Landcare Research. The Glendhu catchments continue to show differences in water quantity between the tussock control land use and the pine plantation land use. Runoff during storms show a rapid flood peak in the tussock catchment, and a lower peak discharge with attenuated flow from the pine plantation catchment, even during partial clearance of the forest (Figure 5).

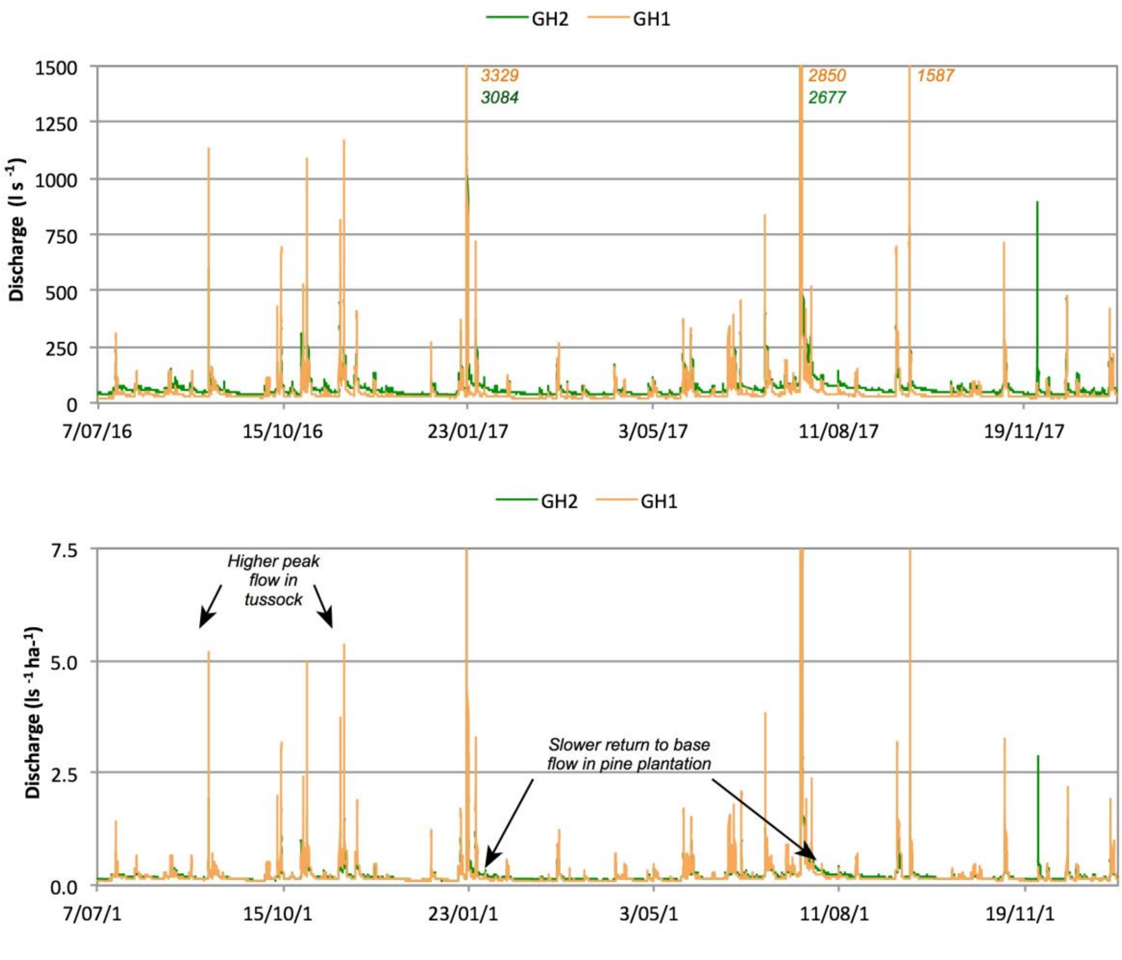

Figure 5 – Stream flow record for Glendhu Experimental Catchments showing differences in water quantity between the two catchments in units of a) discharge as litres per second and b) water yield as litres per second per hectare.

Storm peak flows are higher in the tussock catchment, whereas stream flow has greater attenuation in the pine plantation catchment with a slower return to base flow after rain.

Annual runoff for the period 2015–2017 shows that the tussock catchment (GH1) had a higher water yield than the pine plantation catchment (GH2). Higher water yields from tussock catchments are well documented (e.g., Campbell and Murray, 1990; Mark *et al*., 2013) and are a due to lower water demand and transpiration from tussock grasslands compared to pasture or immature forest. Differences in water yield between the tussock catchment and the pine plantation catchment appear to be diminishing (Table 2; Table 3). For example, in 2015, there was a 308 l s^{-1} ha^{-1} difference in annual water yield, but this reduced to 61 l s^{-1} ha^{-1} in 2017. The changes in water yield relative between the two catchments have been observed in other studies (e.g., Mills, 2018; Fahey and Payne, 2017) and can be attributed to:

1. Increased mānuka coverage in the tussock catchment, resulting in greater water loss via transpiration (see: Mills, 2018);
2. Reduction in forest coverage due to partial clearance initiated in 2015, with complete forest clearance completed by August 2018, resulting in a systematic decline in transpiration with tree loss and concomitant increase in runoff.

By the end of 2017, the difference in water yield between the two catchments for Oct–Dec was negligible (i.e., < 0.0 l s^{-1} ha^{-1}), and likely reflects the shift in water balance from reduced interception and transpiration losses in the pine plantation catchment.

Table 2 – Mean monthly water yield for the Glendhu Experimental Catchments for the three-year period of partial clearance in the pine plantation catchment (GH2) relative to the tussock 'control' catchment (GH1). Water yield reported in specific discharge units of litres per second per hectare (l s^{-1} ha^{-1}) to account for differences in catchment size.

GH1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2015	0.11	0.20	0.25	0.24	0.23	0.62	0.17	0.29	0.24	0.27	0.17	0.17	2155
2016	0.19	0.16	0.12	0.11	0.47	0.15	0.17	0.19	0.21	0.31	0.34	0.14	1863
2017	0.41	0.14	0.16	0.15	0.21	0.23	0.61	0.20	0.31	0.17	0.19	0.16	2156

GH2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2015	0.09	0.17	0.18	0.17	0.16	0.49	0.19	0.26	0.25	0.24	0.18	0.16	1847
2016	0.17	0.15	0.13	0.12	0.36	0.22	0.19	0.20	0.19	0.23	0.27	0.15	1754
2017	0.34	0.17	0.16	0.15	0.20	0.23	0.54	0.25	0.26	0.18	0.20	0.18	2095

Table 3 – Total annual runoff for the Glendhu Experimental Catchments for the period 2015–2017 in units of millimetres per year (mm a^{-1}).

Year	Tussock (mm)	Pine Plantation (mm)
2015	776	665
2016	671	632
2017	776	754

4.2 Turbidity Measurements

Turbidity varies with flow conditions, and is strongly correlated to rainfall events (Figure 6). The harvest phase of pine plantation forestry shows an increase in turbidity peaks from 2017 onwards, where spikes in turbidity occur out of synchronicity with the control catchment, and likely reflects episodic disturbance in the catchment related to forest clearance activities. Median turbidity was 0.5 FNU in the tussock catchment, and 1.3 in the pine plantation catchment indicating a general trend of higher turbidity in the pine plantation catchment. These differences were greatest during storm events, with the maximum recorded turbidity in the tussock catchment of 69 FNU compared to 453 FNU in the pine plantation catchment.

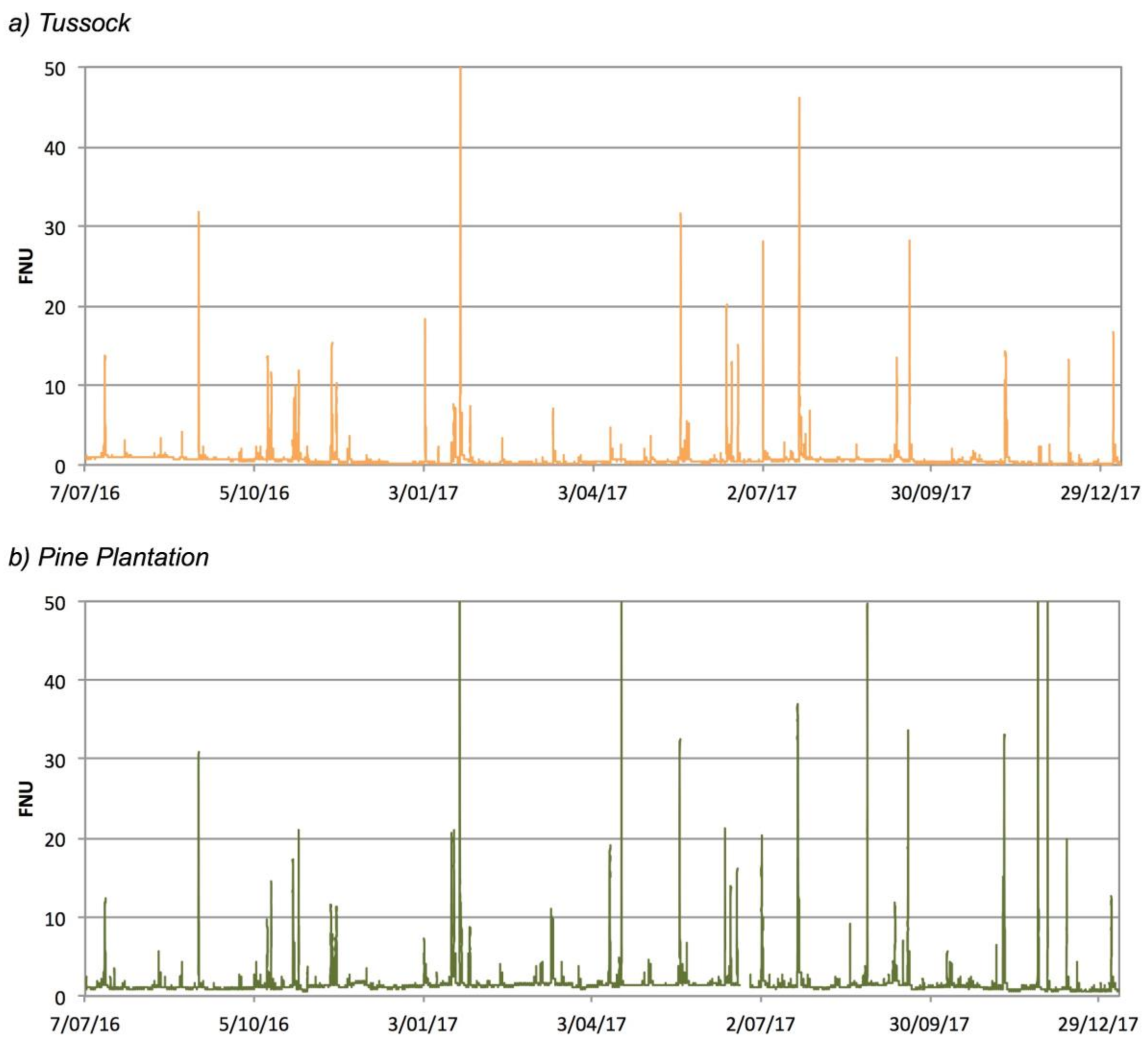

Figure 6 – Turbidity record for Glendhu Experimental catchments for a) tussock control catchment and b) mostly cleared pine plantation catchment.

There was a very strong linear relationship between field-measured turbidity and concurrent measurements of suspended sediment concentration in the tussock catchment (120 samples, r^2 = 0.92), which enables a conversion of in-situ turbidity to a continuous record of suspended sediment with a low level of uncertainty (± 10%) (Figure 7). Similarly, there was a strong relationship between in-situ turbidity and suspended sediment concentration in the pine plantation catchment (117 samples, r^2 = 75%), but the record has more scatter and several outliers were removed; therefore the uncertainty is greater, approximating ±25%.

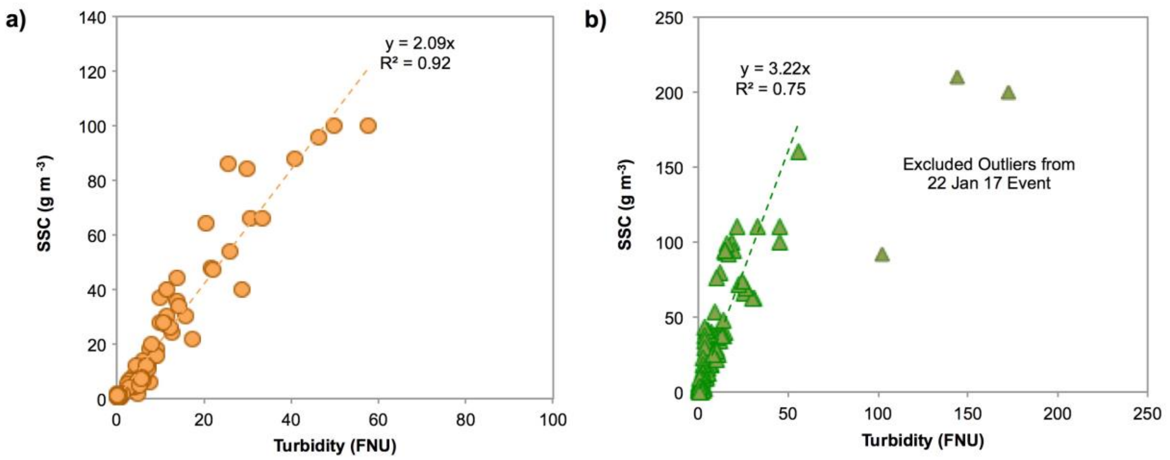

Figure 7 – Turbidity–Suspended Sediment Relationships for the Glendhu Experimental Catchments between field-measured turbidity (in units of FNU) and suspended sediment concentration (SSC) (in units of grams per cubic metre) as derived from samples collected using automatic water samplers in the a) tussock and b) pine plantation catchments.

4.3 Visual Clarity

Visual clarity was determined by concurrent measurement of turbidity (in NTU) and visual clarity (in m) and plotted to determine a decay curve using regression. Units of turbidity were converted from NTU to FNU, so that visual clarity could be determined for the 15-minute continuous turbidity record by establishing a regression relationship between laboratory-determined NTU from grab samples with concurrent in field observations of turbidity (in FNU). There was a very strong relationship between NTU and FNU that enabled a direct conversion between the two turbidity units.

Conversion models between turbidity units FNU and NTU

tussock catchment: FNU = 1.156 $NTU^{1.0058}$, n = 119, r^2 = 0.93;

pine plantation catchment FNU = 0.6789 NTU, n = 117, r^2 = 0.83

The relationship between turbidity and visual clarity in the Glendhu Experimental Catchments shows a different response between the two land uses, with a greater decline in visual clarity observed in the pine plantation forest (Figure 8). Such differences in visual clarity and turbidity measurements are likely attributable to the different turbidity characteristics between catchments, which are affected by different source material in the catchments, with likely greater amounts of soil particulates being disturbed in the pine plantation catchment, as well as differences in organic material being discharged from the different land covers.

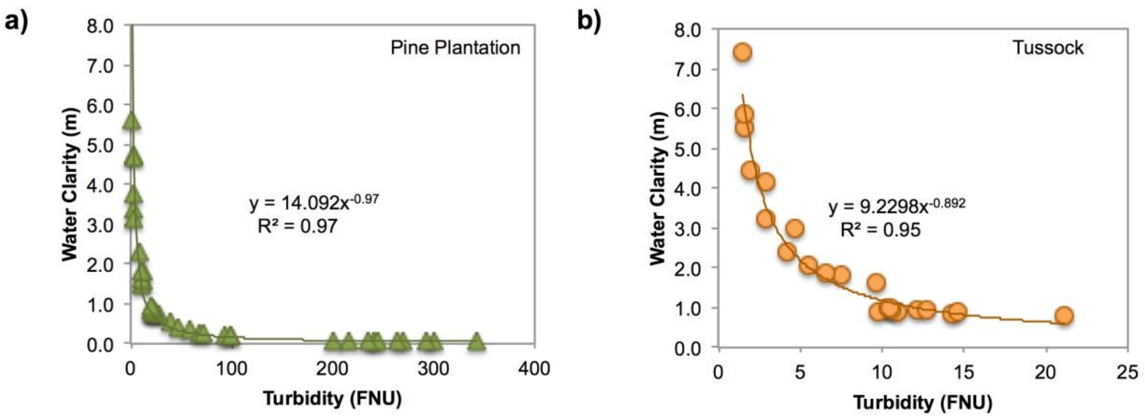

Figure 8 – Relationship between field turbidity (in FNU) and water clarity (in m) for the a) pine plantation and b) tussock catchments at Glendhu.

The pine plantation catchment has increased turbidity, higher suspended sediment, and reduced water clarity as a result of forest clearance (Figure 9). Average values of water clarity, as derived from a rating relationship with turbidity (FNU and NTU) were similar between the two catchments (12.7 and 11.1 m for the tussock and pine catchments respectively), but the pine plantation catchment occasionally dropped to < 0.05 m under storm events, whereas the minimum observed in the tussock catchment was 0.21 m. The high water clarity under base flow conditions (> 10 m with turbidity typically < 2 FNU) in both Glendhu catchments suggests that under normal flow conditions there is presently no concern for reduced light penetration in these small headwater catchments, even under active forest clearance. There is concern, however, that under event flow, there may be considerable decline in visual clarity and that during storms there is much higher turbidity and lower visual clarity in the pine plantation catchment. Under high flow events there are potential adverse effects on aquatic communities, as well as the potential for in-channel sedimentation to occur.

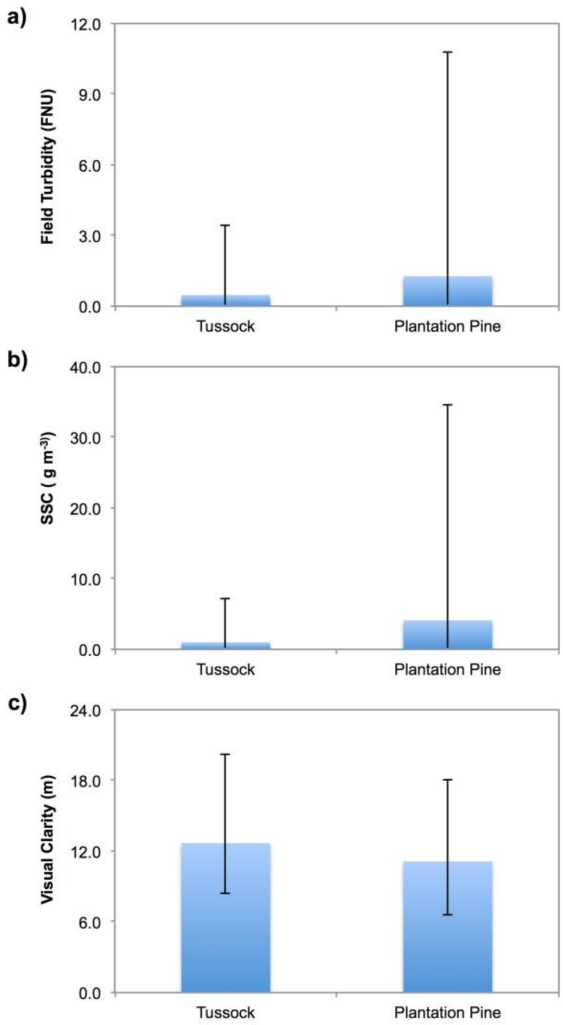

Figure 9 – Three different measures of water quality related to optical properties as observed in the Glendhu Experimental Catchments for the observation period of Jul-16 to Jan-18 during the clearance phase of the pine forest. a) Field measured turbidity (in units of FNU) measured at a 15-minute interval; b) Suspended sediment concentration (in units of g m-3) as derived from a turbidity-suspended sediment rating curve from > 100 grab samples and applied to the 15-minute field turbidity; and c) visual clarity (in units of m) as derived from a rating relationship with turbidity derived from grab samples, then applied to the 15-minute field turbidity.

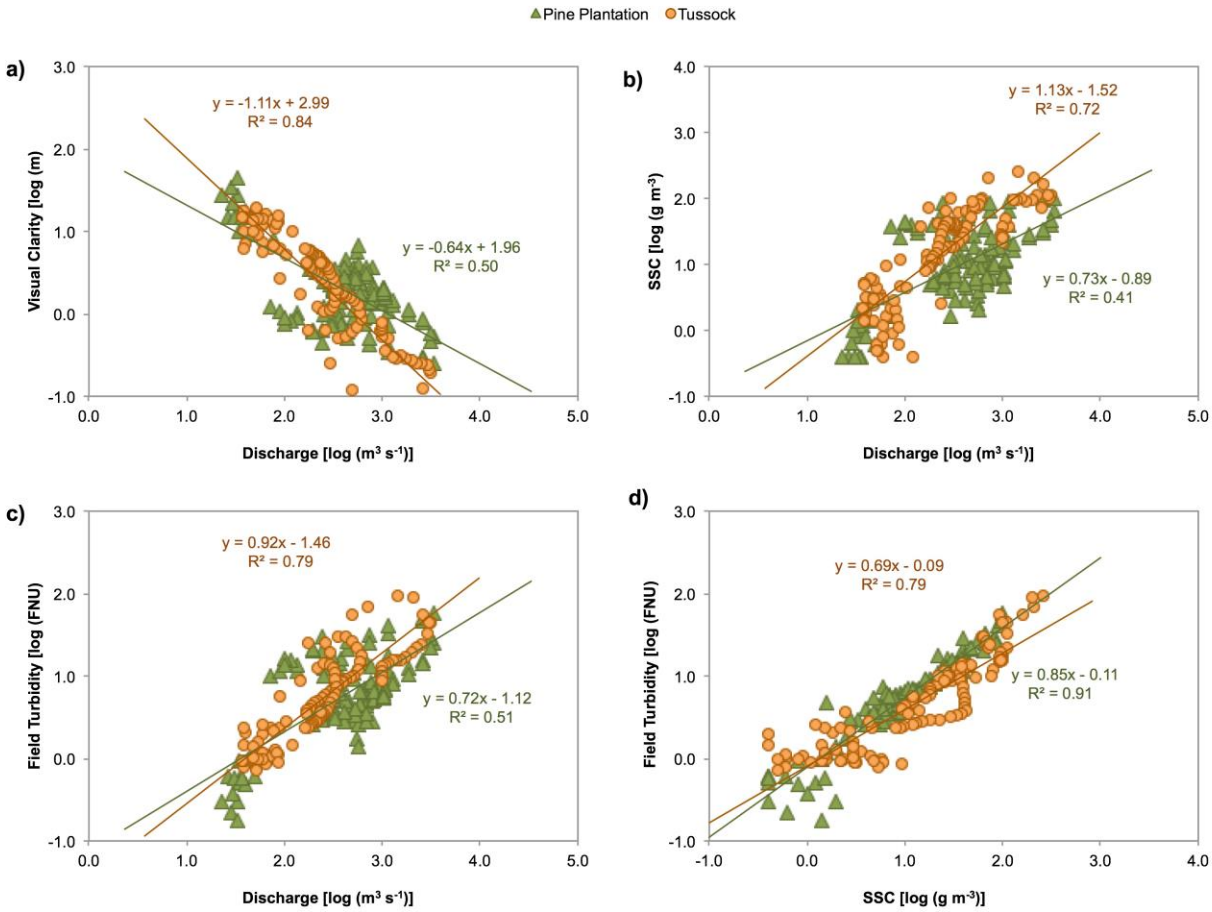

Figure 10 – Log-log plots of discharge, visual clarity, field turbidity, and suspended sediment concentration for the Glendhu Experimental Catchments.

4.4 Suspended Sediment Yields

The suspended sediment yield for the tussock catchment for the period 8 Jul 16 to 8 Jan 2018 (550 days) was 16.4 t, equivalent to 10.9 t a^{-1}, and a specific yield of 4.9 t km^{-2} a^{-1}, with an uncertainty of ±10% (0.5 t km^{-2} a^{-1}). The estimate of sediment yield of 4.9 ± 0.5 t km^{-2} a^{-1} is smaller than that previously reported for tall tussock at Glendhu (14 ± 3.5 t km^{-2} a^{-1} for the period 1983–1987) (Fahey, 2012), but is similar to measured yields from pasture in Berwick of 4–6 t km^{-2} a^{-1} (Hicks, 1990). Differences in these two estimates are due to:

1. Cessation of light grazing in the tussock catchment since 2003, which likely reduced ovine disturbance of the inter-tussock space;
2. Increased mānuka cover of north-facing steep slopes in the tussock catchment, increasing interception and reducing rain splash and potential erosion of steep sections of the catchment;
3. Variances in the suspended sediment and discharge effects between the observation periods, due to storm intensity effects that may vary considerably between years.

Table 4 – Sediment yield for the Glendhu Experimental Catchments for the 18-month period of observations (Jul-16 to Jan-18) derived using two methods, a sediment-turbidity rating curve for 15-minute field-derived turbidity data (continuous method), and a sediment-discharge rating curve method derived from discrete grab samples of suspended sediment and weighted relative to flow duration classes (flow duration method).

Land Use	Specific Sediment Yield (t km^{-2} a^{-1})	
	Continuous Method	Flow Duration Method
Tussock (GH1)	4.9 ± 0.5	4.6 ± 1.1
Pine Plantation (GH2)	17.3 ± 4.5	15.1 ± 3.8

Table 5 – Comparison of the flow duration method for weighted discharge frequency with mean suspended sediment samples for the period 1980–1986 (from Fahey, 2012), and the period 2016–2018 (this study).

GH2: 1980–1986 Stand age 1–4 years

Discharge Class	**Mean Q**	**Time (days)**	**Mean SSC (g m^{-3})**	**Total Q (m^3 x 10^6)**	**SSY (t)**
25–50	39	586	2.0	1.9	3.7
51–90	71	670	3.2	3.9	12.4
91–140	113	167	4.6	1.5	10.0
141–190	162	67	6.0	0.9	6.2
191–400	286	67	9.3	1.4	12.7
401–1200	805	17	20.2	1.1	23.0
1201–2500	1862	8	39.0	1.3	52.0
Total		**1582**			**120**

GH2: 2016–2018 During harvest

Discharge Class	**Mean Q**	**Time (days)**	**Mean SSC (g m^{-3})**	**Total Q (m^3 x 10^6)**	**SSY (t)**
25–50	39	170	2.76	0.57	1.58
51–90	71	255	5.71	1.56	8.92
91–140	113	66	7.99	0.64	5.15
141–190	162	17	9.76	0.24	2.32
191–400	286	25	12.56	0.62	7.76
401–1200	805	11	17.64	0.77	13.50
1201–2500	1862	3	21.76	0.48	10.50
Total		**550**			**49.7**

GH1: 1980–1986

Discharge Class	**Mean Q**	**Time (days)**	**Mean SSC (g m^{-3})**	**Total Q (m^3 x 10^6)**	**SSY (t)**
17–30	24	586	1.6	1.1	1.8
30–60	45	670	2.8	2.5	6.9
61–100	80	167	4.8	1.0	5.5
101–150	125	67	7.3	0.7	4.8
151–350	250	67	13.8	1.4	19.1
351–920	635	17	33.2	0.9	28.6
921–1800	1360	8	65.0	1.0	62.2
Total		**1582**			**129**

GH1: 2016–2018

Discharge Class	Mean Q	Time (days)	Mean SSC (g m^{-3})	Total Q (m^3 x 10^6)	SSY (t)
17–30	24	220	1.22	0.46	0.56
30–60	45	258	3.22	1.00	3.23
61–100	80	37	5.05	0.26	1.29
101–150	125	15	6.48	0.16	1.05
151–350	250	13	8.69	0.28	2.44
351–920	635	5	11.66	0.27	3.20
921–1800	1360	2	14.08	0.24	3.31
Total		**547**			**15.1**

The suspended sediment yield for the harvest pine catchment (GH2) for the period 8 Jul 16 to 8 Jan 18 (547 days) was 80.5 t, equivalent to 53.8 t a^{-1}, and a specific yield of 17.3 t km^{-2} a^{-1}. The reported yield of 17.3 t km^{-2} a^{-1} is derived from an FNU–SSC regression model, that has considerable scatter and an estimated uncertainty of ± 26% (± 4.5 t km^{-2} a^{-1}). The observation period used to derive the yield for the pine catchment covers a period of active clearance, where the pine stands were cleared from top part of the catchment, down towards the weir, where forest clearance had increased from 60% to 90% of the catchment area. Sediment yield doubled during the clearance phase at Glendhu rising from an estimated yield of 9 ± 2.4 t km^{-2} a^{-1} (Fahey, 2012) during the growth phase period (1983–1987) to 17.3 ± 4.5 t km^{-2} a^{-1} during active clearance.

The increased sediment yield associated with forest clearance observed at Glendhu (GH2) is consistent with the yield reported by Duncan (2012) in the Blue Mountains of Otago, where pine plantation forestry yields increased from 9–10 t km^{-2} a^{-1} under pine stands to 16 t km^{-2} a^{-1} in the two year period of post-harvest. The two year period post-harvest is the period of greatest instability and potential soil erosion (Baillie and Neary, 2015), and post-harvest yields are highly variable, with measurements across New Zealand ranging from 10–460 t km^{-2} a^{-1} (Table 6), although these yields are estimated from a range of different methods, underlying lithologies, and different rainfall regimes (Baillie and Neary, 2015). Overall, however, the sediment yields from eastern Otago schists are typically low (O'Loughlin *et al.*, 1984) and not prone to erosion (Fahey, 2012).

Table 6 –Specific Sediment Yields from various studies undertaken on eastern Otago Schist.

	Sediment Yields (t km^{-2} a^{-1})	Location	Source
Pasture	4–6	Berwick	Hicks (1990)

Tall Tussock	14	Glendhu	Fahey (2012)
Tall Tussock[1]	6	Glendhu	Hicks *et al.* (2011)
Indigenous Forest	6	Blue Mountains	Suren *et al.* (2001) Duncan (2012)
Pine Forest	9–10	Berwick	Hicks (1990)
Pine Forest	9–10	Glendhu	Fahey (2012)
Pine Forest[1]	6	Glendhu	Hicks *et al.* (2011)
Plantation Forest	9–10	Blue Mountains	Duncan (2012)
Harvested Pine	16	Blue Mountains	Duncan (2012)

[1] Derived from the Suspended Sediment Estimator Tool of NIWA (see: Hicks *et al*., 2011).

Table 7 – Post Harvest Sediment Yields of Pine Plantation as reported in New Zealand for different lithological terranes and regions.

Location	Lithology	Yield	Source
Maimai	Gravels	80–450	O'Loughlin *et al.* (1984)
Pakuratahi	Tertiary mudstone	18–112	Fahey *et al.* (2003)
Glenbervie	Indurated Greywacke	46	Hicks and Harmsworth 1980
Pokororo	Indurated Granite	21–148	Hewitt (2000, 2001, 2002)
Herring	Indurated Granite	30–181	Basher *et al.* (2011)
Whangapoua	Indurated Volcanics	18–116	Phillips *et al.* (2005)
Blue Mountains	Schist	10–20	Duncan (2012)
Glendhu Forest	Schist	18	This study

5 Discussion

5.1 Discharge of Sediment to Water (Plan Change 6A)

Plan Change 6A enabled the discharge of sediment to water as a permitted activity so long as the discharge does not result in a 'conspicuous change in water clarity or noticeable increase in local sedimentation'. Localised changes in visual water quality are naturally associated with high discharge events in the response to rainfall. Increased export of contaminants during high discharge events is a known response of landscapes. Managing these temporary and short-lived changes in water quality and water clarity are best mitigated by implementing effective mitigation measures. Matariki Rayonier Forests operate under best practice management already, and this reduces some of the discharge of contaminates at higher flows. A pilot study examining the preliminary effects of forest clearance in the Glendhu catchments during 2015 concluded that little to no effect of forest clearance was likely (at 40% catchment clearance) due to extensive riparian buffer networks, forest clearance techniques, keeping roads and landings to the periphery of the catchment, and carrying harvesting out in a staggered way over a longer period of time, which reduced the effects of landscape disturbance, and any further clearance related impacts would be best mitigated by these practices in place (Bright, 2015). Replanting has already begun in the upper reaches of the Glendhu catchment and this will have contributed to the stabilisation of the hillslopes and help prevent and reduce the risk of soil erosion, so that it is expected that by 2020 the sediment yield will return to normal forest-cover levels (e.g., 9–10 t km^{-2} a^{-1}).

The wider receiving environment, the Waipori River, is identified in Schedule 15 of the Regional Plan for Water and with regards to nutrient, bacteriological and turbidity contaminants, with turbidity limited to 5 NTU. The turbidity limits are met based on these levels being achieved when '80% of samples collected at a site, when flows are at or below median flow, over a rolling 5 year period, meet or are better than the limits in schedule 15'. For the plantation pine catchment at Glendhu (for the period 2016–2018) the turbidity 80th percentile was 1.5 FNU and 2.0 NTU, indicating that the harvest phase of the pine plantation catchment is within specified limits.

The assessment of water quality changes made in this report suggest that forest clearance has, and will likely continue to have, a small but measurable effect on the discharge of sediment as the landscape recovers in the immediate environment. However, the combination of a stable schist lithology, rolling hillslope and low risk of land erosion susceptibility in this region, combined with sediment attenuation mechanisms suggests that the impact of elevated sediment yields in the immediate post-harvest phase is small and unlikely to have lasting effects on the local and downstream receiving environments.

6 Conclusions

Declarations

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7 References

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