

Sediment yields from plantation forestry and pastoral farming, coastal Hawke's Bay, North Island, New Zealand

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Abstract

Suspended sediment yields have been monitored since 1995 in two catchments in the erodible hill country of coastal Hawke's Bay, one in pasture (the Tamingimangi, 7.95 km²), and the other initially in mature *Pinus radiata* plantation forest (the Pakuratahi, 3.45 km²). The latter was harvested by skyline hauler (85%) and skidder (15%) between December 1997 and October 1999. Post-harvesting preparation in early 2000 included over sowing with grass and legumes, and ripping of hauler pads before replanting. Suspended sediment yields were calculated for 50 events at the Pakuratahi and 30 at the Tamingimangi. The relationship between storm sediment yields and corresponding peak flows was used to estimate yields for all unsampled storms exceeding 20 L/s/km² in both catchments. Data for the sampled storms and those calculated for the unsampled ones were then summed to estimate annual suspended sediment yields and totals for given periods during the forest rotation. During the pre-harvesting period (January 1995 to June 1997) total suspended sediment yield for the pasture catchment was 3 times higher than for the catchment in mature pines. In the logging phase of the harvesting period (January 1998 to December 1999) the situation was reversed, with the total yield for the harvested catchment twice that of the one in pasture.

Despite the removal of the vegetation cover during harvesting, slope disturbance was minimal, with the increase in yields thought to have come predominantly from road sidecast, landslides, and channel bed scouring. Yields from the harvested catchment declined markedly after over sowing and replanting, and in 2001 were substantially less than those from the pasture catchment. This reduction is attributed as much to a decline in forest-related activities as it is to a steadily increasing grass cover across all disturbed sites. Over the 7 years of record (1995–2001) the catchment originally planted in pines and subsequently harvested has yielded only 20% more suspended sediment than the one in pasture. This suggests that, with average weather conditions during and immediately after harvesting, sediment yields from catchments in plantation forestry over a full forest rotation in this type of terrain should be less than from catchments left in pasture.

Key words

plantation forestry, sediment yield, harvesting impacts

Introduction

Plantation forestry is a common activity in the soft-rock hill country of the east coast of the North Island, New Zealand. Many of

these forests are approaching maturity, and concerns have been expressed that harvesting might trigger a phase of erosion similar in scale to that accompanying the removal of the original forest cover in the late 19th and early 20th centuries. In 1993, an experimental catchment project involving the Hawke's Bay Regional Council, local forestry companies, and government science providers, was established near Napier to assess short- and long-term changes in sediment yield and water quality in response to forestry operations in the area. A broader, and more fundamental question to be considered was whether land in pasture or forestry could be expected to yield more sediment in the longer term, i.e., over the length of a forest rotation (20–30 years).

As a first step in addressing these issues, the programme compared sediment yields from two catchments, one in pasture (the Tamingimingi) and the other in mature exotic plantation forest (the Pakuratahi) for the pre-harvesting period (January 1995 to May 1997) (Fahey and Marden, 2000). Between 1997 and 1999 the forested catchment was harvested. This paper assesses the sediment yield response to harvesting and subsequent over sowing and replanting, during the period June 1997 to December 2001. Furthermore, in order to assess the relative contribution of different sediment-generating processes to sediment yield, particularly during the post-harvesting recovery period, we have drawn on the findings of research in progress on slope wash, and those of Fransen (1998), who documented road-related, landslide and channel scour sources of sediment delivered to streams in the Pakuratahi during the winter of 1997.

Field area

The two catchments are located 18 km northwest of Napier (Fig.1). The Tamingimingi (7.95 km²) has been intensively grazed

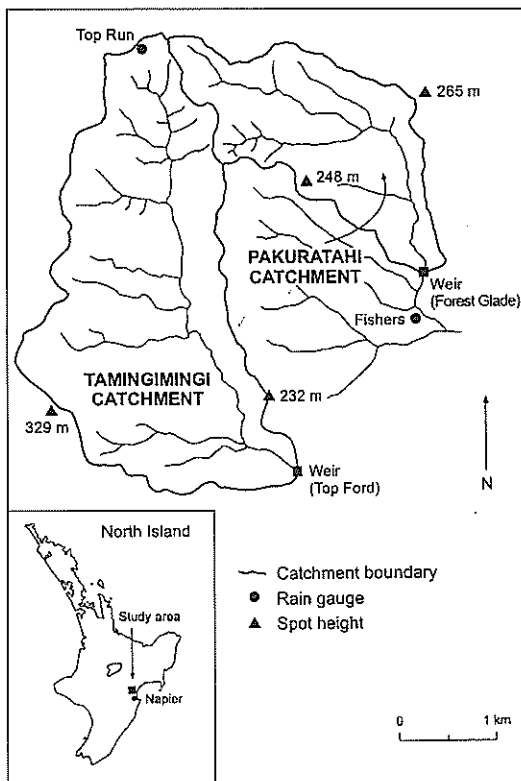


Figure 1 – Location map of study area showing the Pakuratahi and Tamingimingi catchments.

since the 1900s and is currently in improved pasture. The Pakuratahi (3.45 km²) was planted in *Pinus radiata* in 1971–1972. In the latter half of 1997 road clearance and landing construction began in preparation for harvesting, which took place through 1998 and 1999.

The catchments are underlain by gently dipping Tertiary sediments capped with gravels, volcanic ash and loess (Haywick *et al.*, 1991). The dominant soils are Pallic and Duric Pallic soils (Hewitt, 1998). Both may have hard pans that impede drainage, and are prone to surface erosion and mass movement. The climate is characterised by warm summers, and moderate winters. In 1980 the long-term mean annual rainfall at Tangoio 5 km to the north was 1501 mm (New

Zealand Meteorological Service, 1983), with high rainfall variability from month to month and year to year. Additional details on the geology, soils, and climate of the field area are given in Fahey and Marden (2000).

Methods

Rainfall was measured with two tipping-bucket rain gauges, one installed near the Pakuratahi weir (Fishers), and the other at the head of the Tamingimingi catchment (Top Run). Stream water levels were monitored with float-operated shaft encoders at Crump-type weirs, and recorded with Campbell CR10 data loggers. Details on weir ratings and accuracy of records can be found in Fahey and Marden (2000). Instrument malfunctions between January and May 2001 at the Tamingimingi weir required that the flow record for this period be estimated by comparison with the flow record from the Pakuratahi weir. This was achieved by comparing peak flows and low flows before and after the missing data period at the Tamingimingi, and visually adjusting the Pakuratahi flow on-screen with a time-series data management system (HYDSYS), to simulate the Tamingimingi record.

Two 24-bottle Sigma water samplers, controlled by a CR10 logger, were used to sample suspended sediment. They were set to sample above predetermined stage heights equivalent to 50 L/s (15 L/s/km²) for the Pakuratahi and 120 L/s (15 L/s/km²) for the Tamingimingi at intervals of either 30 or 90 minutes on the rising and falling limb of the storm hydrograph. Sampling ceased when the hydrograph fell below the predetermined stage heights. Instantaneous flows below 15 L/s/km² at both catchments were almost always in the base flow range, and thus not regarded as capable of generating significant amounts of suspended sediment. If, because of storm size or duration, all bottles were filled before the end of an event, the relation-

ship established between flow and sediment concentration on the falling limb for other storms was used to complete the record. Samples (0.5 L) were vacuum-filtered and oven-dried to determine suspended sediment concentrations. Storm sediment loads were measured in tonnes, and sediment yield in tonnes per square kilometre.

Suspended sediment yields for sampled storms were determined from the product of flow and the average suspended sediment concentrations calculated for the chosen interval. These were summed over the duration of the storm. Between January 1995 and December 2001, 50 storms were sampled for suspended sediment concentrations at the Pakuratahi weir, and 30 at the Tamingimingi weir. The numbers differ because of spatial variability in rainfall, and occasional equipment malfunctions. A total of 27 were monitored and sampled concurrently in both catchments.

Storm suspended sediment loads and associated peak flows for both catchments were log transformed and a least-squares regression model was used to establish the relationship between the two parameters (Hicks, 1990; Basher *et al.*, 1997). The procedure described by Basher *et al.* (1997) was used to calculate the 95% confidence intervals associated with the different stages of the forest rotation, and to calculate annual yields.

For the Pakuratahi catchment, all events between January 1995 and December 2001 with peak flows ≥ 20 L/s/km² were identified, and the list subdivided into the intervals assigned to the various forest rotation periods (pre-harvesting, road construction and crop removal phases, and post-harvesting). The use of the ≥ 20 L/s/km² threshold ensured that all medium- and larger-sized storms were included in the calculations. The regression equations (Table 1) derived from the relationship between suspended sediment

Table 1 – Rating-curve regression equations derived from the log-log relationship between peak storm discharge (PQ) and suspended sediment yields (SSY), where $\log SSY = a + b \log PQ$ is used to estimate suspended sediment yields for storms with no suspended sediment concentration data. The number of data pairs is given by n , and r^2 is the coefficient of determination.

Catchment	Period	a	b	n	r^2
Pakuratahi (forested)	Pre-harvesting	-6.00	2.33	18	0.779
	Road construction phase	-4.56	1.95	5	0.950
	Logging phase	-4.01	1.78	11	0.858
	Post-harvesting	-5.13	2.07	13	0.942
Tamingimingi (pasture)	Jan. 1995 to Dec. 2001	-4.71	1.84	28	0.914

yields and peak discharge for each of these periods were used to estimate the suspended sediment yields for those storms with no suspended sediment concentration data. In cases where storms displayed more than one peak, a single event was considered to have occurred if there was less than 6 hours between individual peaks. The biggest peak was used in the regression procedure. If there was more than 6 hours between peaks, they were regarded as separate events. These data were summed and added to those derived from sampled events to provide total yields for each interval. These totals were then compared with those for the Tamingimingi (based on events $\geq 20 \text{ L/s/km}^2$), calculated for the same intervals, using the regression equation for that catchment listed in Table 1.

We also identify here the methods used by others working on on-site, process-based studies on sediment sources in the two catchments. Their findings help explain relationships between sediment yield and land use, before and after harvesting in the Pakuratahi catchment. First, a site-disturbance survey method, based on McMahon (1995), was undertaken to identify the extent of potential sediment source

areas across the logged setting. Secondly, a plot-based assessment of the rate of revegetation by ground cover for a 24-month period following harvesting, was used as a measure of the persistence of those areas likely to generate most sediment. For the post-harvesting recovery period the effect of site-preparation practices, including desiccation and over sowing, on vegetation recovery and sediment generation was recorded. Thirdly, to measure the amount of sediment generated from disturbed sites and its potential to reach a stream channel, sediment fences were constructed

across four zero-order drainage basins each between 1 to 2 ha. The fences were positioned at the point where drainage from these basins entered a permanent stream channel, the assumption being that any sediment trapped behind these fences was destined to reach the main channel. So as not to influence the sediment yield figures measured at Pakuratahi weir the sediment fences were located in a sub-catchment downstream of the weir (Fig. 1).

Sediment accumulation behind each fence was measured using the "erosion bridge" method of Ranger and Frank (1978). Sediment volume was converted to t/km^2 using a bulk density of 1820 kg/m^3 . Data were collected at 6-weekly intervals for a 12-month period commencing immediately after the completion of harvesting and concurrent with harvesting activities on slopes upstream of the weir.

Harvesting procedures

The tree crop in the Pakuratahi catchment was harvested by Pan Pac Forest Products, Napier (Gilmore, 1999; unpublished report). Approximately 8 km of the existing road network required upgrading. This began in 1998 and was largely complete in early 1999.

New road construction began in July 1997 with the extension of a road on the true right bank just upstream from the weir. Approximately 2 km of new road were added in 1998, and 1.5 km in 1999. A total of 52 hauler pads were used. Of these, 25 were new, 20 were upgraded from thinning sites, and the remaining 7 did not require upgrading. Slash was kept to a minimum on all landings and away from the perimeters where possible.

Two main sites were established outside the catchments where the logs were processed and cut to customer specifications. The separation of yarding activities from log processing meant that hauler sites within the catchment could be smaller than the standard 50 × 50 m area. Approximately 15% of the catchment was harvested using an excavator and rubber-wheeled skidder, mostly on ridge tops and crests. The rest was skyline-logged using a BE70 and a BE85 yarder; their tower height meant more lift, less soil disturbance, and higher payloads.

Harvesting began in late December 1997 and by December 1998 141 ha, or approximately half of the area, had been clearfelled. The remaining 50% was logged by October 1999. The post-harvesting preparation comprised aerial desiccation to control the regeneration of pine and blackberry, over sowing with grass and legumes, replanting, and spot spraying. Many of the hauler pads were ripped with a bulldozer for replanting. At the end of the period reported here trees were 2 years old.

In summary, the first activity that might increase sediment production in the catchment was the extension of the road just upstream of the weir in July 1997. Extensive road upgrading began in 1998, together with the construction of new landings. In addition, half of the planted area in the catchment was harvested that year, mostly by skyline hauler. In 1999, 1.5 km of new road were constructed, and the rest of the tree crop was

removed. The harvesting operation was largely complete by October. Thus three main periods (one with two phases) can be identified to help explain any trends in sediment yield: a pre-harvesting period (January 1995–June 1997) described in detail by Fahey and Marden (2000); a harvesting period comprising an initial preparation phase of road and landing construction in the second half of 1997, and a 2-year logging phase extending through 1998 and 1999; and finally a post-harvesting period associated with over sowing and replanting commencing in 2000.

Results and discussion

Pre-harvesting period sediment yields

Nine events sampled concurrently in both basins yielded 3 times more sediment from the Tamingimangi catchment (in pasture) per unit area than from the Pakuratahi (in mature pines) (Table 2). Similarly, when the regression equation from Table 1 was used to calculate sediment yields for non-sampled storms over 20 L/s/km², and these were added to the sampled storms, the pasture catchment is estimated to have generated 3 times more sediment than the one in mature pines (Fig. 2). The confidence intervals are sufficiently small to suggest that the difference between the two totals is significant. Further details of the comparison between concurrent event-based suspended sediment yields from the two catchments for the pre-harvesting period are provided in Fahey and Marden (2000).

Harvesting period sediment yields

Table 2 shows that during the initial road and landing construction phase (July to December 1997) there is no evidence of additional sediment being mobilised during storms in the forested catchment. Indeed,

Table 2 – Suspended sediment yields for storms monitored concurrently at the Pakuratahi (forested) and Tamingimingi (pasture) catchments, and the ratio of the Pakuratahi to the Tamingimingi yields (July 1995 to July 2000)

Period	Date	Pakuratahi Yield (t/km ²)	Tamingimingi Yield (t/km ²)	Ratio Pak:Tam
Pre-harvesting (Jan. 1995 to June 1997)	5/7/95	0.28	1.6	1:2.80
	15/7/95	0.05	1.02	
	1/11/95	0.05	0.25	
	23/6/96	2.58	5.38	
	4/7/96	0.17	1.68	
	30/12/96	2.17	8.83	
	19/2/97	0.11	0.05	
	11/3/97	1.00	1.61	
	27/5/97	1.25	0.76	
	Total	7.6	21.2	
Road construction phase (July to Dec. 1997)	22/8/97	2.3	3.0	1:4.50
	24/9/97	1.3	9.3	
	15/10/97	1.3	9.7	
	Total	4.9	22.0	
Logging phase (Jan. 1998 to Dec. 1999)	15/7/98	14.7	12.0	1:0.52
	26/7/98	13.8	6.9	
	21/11/98	0.8	0.1	
	26/11/98	1.6	0.1	
	17/1/99	4.4	0.5	
	14/3/99	9.8	5.2	
	15/3/99	11.3	2.4	
	2/5/99	2.3	0.6	
	5/6/99	23.0	15.0	
	28/11/99	2.7	1.0	
	Total	84.4	43.8	
Post-harvesting (Jan. 2000 to Dec. 2001)	8/1/00	101.0	96.2	1:0.73
	9/4/00	60.2	17.7	
	27/6/00	0.14	0.1	
	3/7/00	15.4	15.0	
	27/7/01	0.10	0.05	
	Total	176.84	129.05	

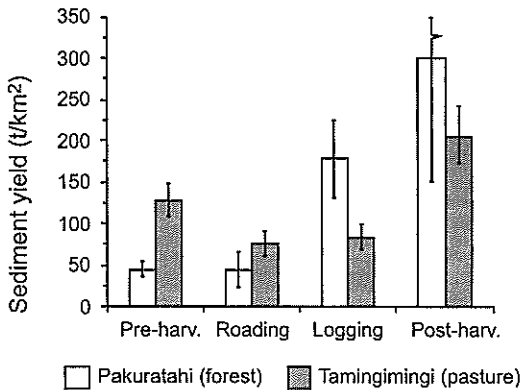


Figure 2 – Suspended sediment yields for the pre-harvesting, harvesting (road construction and logging phases), and post-harvesting periods. These were derived by combining the measured amounts with those calculated from the regression equations in Table 1. The 95% confidence intervals are shown on the bars.

specific yields from the pasture catchment were 4–5 times more than from the catchment in pines, which was a higher ratio than that observed during the pre-harvesting period. However, when all unsampled storms exceeding 20 L/s/km² were included using the regression equation in Table 1, specific yield from the pasture catchment was only about 1.5 times higher (Fig. 2), suggesting additional sediment may have entered the Pakuratahi catchment during this period.

During the logging phase (January 1998 to December 1999) the 10 concurrently monitored storms produced a total of 84 t/km² at the Pakuratahi catchment (in pines) but only 44 t/km² at the Tamingimingi (in pasture). Adding the non-sampled storms to this list using the regression equation in Table 1 produced estimated suspended sediment yields of 179 (±46) t/km² and 82 (±14) t/km² for the Pakuratahi and Tamingimingi respectively (Fig. 2).

Post-harvesting period sediment yields

Early in the post-harvesting recovery period, storm-based suspended sediment yields from the Pakuratahi remained substantially higher than those from the Tamingimingi (Table 2). During the storm of 9 April 2000, for example, the Pakuratahi yielded 3.5 times more sediment than the Tamingimingi. However, totals for the five storms over the whole post-harvesting period were similar (177 t/km² for the Pakuratahi, and 129 t/km² for the Tamingimingi), suggesting that the yields from the Pakuratahi are beginning to return to pre-harvesting levels. Adding yields from all unsampled storms ≥ 20 L/s/km², calculated using the regression equation from Table 1, shows the suspended sediment yield for the Pakuratahi (299 ±147 t/km²) to still exceed that for the Tamingimingi (205 ±35 t/km²) (Fig. 2). The large confidence interval for the Pakuratahi compared with the Tamingimingi suggests that the sediment response to storms is erratic early in the post-harvesting recovery period and will remain so until canopy closure.

Comparison of peak flows

To ensure that the higher sediment yields measured during the road construction and logging phases were not the result of a greater number of high-magnitude storms during that period, a comparison was made of the mean and maximum peak flows for each interval (Table 3). In the pre-harvesting period the mean peak discharge for large events (≥ 100 L/s/km²) at the Pakuratahi (211 L/s/km²) was substantially lower than that calculated for the same period for the Tamingimingi (295 L/s/km²). The maximum peak discharge for the Pakuratahi was 674 L/s/km², compared with 1030 L/s/km² for the Tamingimingi. By contrast, in the 2-year harvesting period the mean peak discharge for events over 100 L/s/km² at the Pakuratahi (385 L/s/km²) exceeded that for the Tamingimingi (339 L/s/km²). The

Table 3 – Mean and maximum peak flows ≥ 100 L/s/km² recorded at the Pakuratahi (forested) and Tamingimingi (pasture) catchments during the pre-harvesting, harvesting, and post-harvesting periods.

Period Catchment	Pre-harvesting		Harvesting		Post-harvesting	
	Mean	Max	Mean	Max	Mean	Max
Pakuratahi (forested)	211	674	385	943	407	2072
Tamingimingi (pasture)	295	1030	339	693	365	1224

maximum peak discharge for the Pakuratahi was 943 L/s/km², and that for the Tamingimingi was 693 L/s/km². Likewise, the mean peak discharge for the post-harvesting period at the Pakuratahi (407 L/s/km²) was higher than that at the Tamingimingi (365 L/s/km²) (Table 3). The same was true for the maximum peak discharge (2072 and 1224 L/s/km² respectively). These were recorded on the same day but very early in the post-harvesting period (8 January 2000). Overall however, the record of runoff events ≥ 100 L/s/km² in the pre-harvesting, harvesting, and post-harvesting periods at the Tamingimingi was similar, suggesting that the observed increases in storm sediment yields in the Pakuratahi catchment during the harvesting period are related to land use rather than to any increase in the magnitude and frequency of storm events.

Yearly comparisons

Rainfall: The mean annual catchment rainfall (based on data from Fishers and Top Run) for the period 1995–2001 was 1131 mm (Table 4). The harvesting period (1998–1999) was comparatively dry. The 850 mm recorded in 1998 was by far the driest between 1995 and 2001. However, the average annual number of runoff events ≥ 20 L/s/km² recorded at the Tamingimingi weir in the pre-harvesting period (1995–1997) was 27, whereas the average number recorded between 1998 and 1999 was 29.

Annual flow: Table 4 shows that between

1995 and 1997, the average annual flow for the Tamingimingi was about 8% higher than that for the Pakuratahi, but with the progressive removal of the forest canopy from the Pakuratahi catchment through the harvesting period (1998–1999), the average annual flow was 15% higher than from the Tamingimingi. In the post-harvesting period, the average annual flow for the Pakuratahi remained 14% higher than for the Tamingimingi.

Suspended sediment yields: In the 3 years from 1995 to 1997 that correspond approximately with the pre-harvesting period, the annual suspended sediment yields for the Tamingimingi were 2–5 times higher than those for the Pakuratahi. By the second year of the harvesting period (1999), the situation had reversed, with the yield for the Pakuratahi about 3 times that of the Tamingimingi. In the first year of the post-harvesting (recovery) period (2000), the suspended sediment yield for the Pakuratahi was still twice that from the Tamingimingi, but in 2001 that from the Pakuratahi had declined to the point where the Tamingimingi was generating almost 4 times as much, a situation not seen since 1995. The total suspended sediment yields for both catchments over the 7-year period were similar (568 t/km² for the Pakuratahi, and 489 t/km² for the Tamingimingi).

Site disturbance and vegetation recovery

Overall, 92% of the 22.6 ha of logged area surveyed in the Pakuratahi catchment sustained minimal ground-surface dis-

Table 4 – Catchment rainfall and annual flows for the Pakuratahi (forested) and Tamingimingi (pasture) catchments for the period 1995–2001. Annual suspended sediment yields were calculated by adding the measured storm totals to those calculated using the regression equations listed in Table 1. The figures in brackets are the 95% confidence limits.

Year	Rainfall 1	Pakuratahi (forested)			Tamingimingi (pasture)			Ratio Pak:Tam
		Flow (mm)	Events (≥ 20L/s/km ²)	Sed. Yield (t/km ²)	Flow (mm)	Events (≥ 20L/s/km ²)	Sed. Yield (t/km ²)	
1995	1130	271	15	5.1 (±1.3)	283	16	25.2 (±4.6)	1:4.9
1996	1299	387	25	21.8 (±5.0)	429	21	66.8 (±12.0)	1:3.1
1997	1463	484	22	62.3 (±14.4)	526	22	110.3 (±19.8)	1:1.8
1998	850	313	12	37.8 (±9.5)	271	12	34.0 (±6.1)	1:0.9
1999	1116	443	14	140.9 (±35.2)	373	16	47.4 (±8.5)	1:0.3
2000	949	416	18	282.4 (±121.5)	369	15	141.6 (±25.5)	1:0.5
2001	1167	391	17	17.1 (±8.4)	325	18	63.0 (±11.3)	1:3.7
Means	1131	386			368			1:0.8
Totals			123	568		120	489	

turbance or remained undisturbed. These are not considered to be important areas of sediment generation. Sites with deep disturbance, largely attributable to hauler-logging at the time of harvesting, occupied just 9% of the logged area. The extent of sites with deep disturbance attributable to hauler-logging at the Pakuratahi is at the low end of the range of values (9-15%) found for similarly logged areas in New Zealand (McMahon, 1995; Marden and Rowan, 1997) and North American forests (Dyrness, 1965; Garrison and Rummell, 1951; Wooldridge, 1960).

Harvesting effectively reduced groundcover vegetation to zero on sites with deep disturbance and to <10% on sites with shallow disturbance. Post-harvesting vegetation recovery was fastest on the less disturbed

sites, but vegetation covered about 80% of sites in both disturbance classes within 6 months of the completion of harvesting. Within 5 months of germination the over sown species had re-occupied 75% of sites with shallow disturbance, but were slower to re-colonise deep-disturbance sites, covering just 58%. Revegetation of sites in both disturbance classes steadily increased thereafter and within 2 years of the completion of logging the groundcover vegetation occupied 80% of deep-disturbance sites and 97% of shallow-disturbance sites.

Sediment mobility and vegetation relationships

Results from a previous study indicate that within 2 years of the completion of harvesting there can be up to an 83% reduction in on-

slope sediment generation and mobility, due to the combined effects of diminished slopewash generated per unit area of disturbed ground and a decrease in contributing area through time. The latter is a consequence of site re-colonisation by groundcover vegetation (Marden and Rowan, 1997). From sites of ground disturbance (9% of the logged area) slopewash processes in the first year after logging potentially delivered sediment to the stream at a rate of 2.4 t/km². In the first year of the logging period (January to December 1998, (Gilmore, 1999)), 1.41 km² were logged, during which a total of 3.4 t of sediment were delivered to streams. Logging over the planted area (3.13 km²) was completed in October 1999, and is estimated to have yielded 7.5 t of sediment, which is just over 1% of the 7-year total suspended sediment load (568 t/km²) that left the Pakuratahi catchment (Table 4).

Slopewash-transported sediment, derived from sites disturbed during harvesting, is therefore a minor contributor of sediment to streams and hence to stream sediment yield. We therefore agree with Fransen (1998), who identified the principal sources of sediment during this post-harvesting period as, in decreasing order of importance, sidecast from old roadlines, shallow landslides and channel bed scouring.

Comparisons with other studies

Few studies have been conducted in New Zealand to assess the effects of forest harvesting on stream sediment yields. O'Loughlin *et al.* (1980) compared the sediment yields from two of the Maimai experimental catchments near Reefton immediately after harvesting, one by skidder (M9) and one by hauler (M7), with an adjacent control (M6). Sediment yield rates were 264, 47, and 33 m³/km²/yr respectively. These figures are not considered typical of the longer term, as the measurement period was

drier than usual with fewer large storms. Hicks and Harmsworth (1989) monitored changes in suspended sediment yield during the harvesting phase of a section of Glenbervie Forest in Northland. They found that landing construction and road upgrading before harvesting caused storm yields to rise to 300 t/km², representing an increase of 40 times over yields from similar storms before harvesting.

Thus, the 2–3-fold increase in suspended sediment yields estimated for the Pakuratahi catchment following harvesting is low compared with that noted by Hicks and Harmsworth (1989) at Glenbervie Forest in Northland. This may be a reflection of the weather conditions during the critical harvesting period, differences in harvesting methods, or both.

Conclusions

Data from the Pakuratahi and Tamingimangi catchments have shown that pasture catchments in coastal Hawke's Bay can yield 3 times more suspended sediment than those in mature plantation forests. During the logging phase of the harvesting period, the situation can be reversed. Here for example, the catchment that had been clearfelled generated twice the amount of sediment compared with the one in pasture. Coincidental with the post-harvesting period a series of moderate-sized storms caused roadline scouring, landslide failure and channel bed scouring (Fransen 1998). These are the likely sources of increased stream sediment yield in the Pakuratahi. Ground disturbance during hauler-logging undoubtedly contributed to the increase in suspended sediment yield. However, site disturbance in the logged area was minor and the relative contribution of slopewash-derived sediment originating from disturbed sites on successively logged areas was therefore small.

Early in the post-harvesting period,

suspended sediment yields from the Pakuratahi were still above those of the Tamingimangi, but in 2001 they were marginally lower, showing that they are returning to pre-harvesting levels. The combined effects of decreased erosion rate per unit area of disturbed ground and a significant decrease in contributing area through time had effectively halted sediment generation and its mobility to streams, by slopewash processes, within a year of the completion of harvesting. The latter was a consequence of rapid site re-colonisation by over sown groundcover vegetation. However, since harvesting began, slopewash processes on disturbed sites contributed just 1% of the 7-year total suspended sediment load recorded at the Pakuratahi catchment weir.

We conclude therefore that slopewash was the least important of the sediment-generation processes during the harvesting and post-harvesting periods and concur with Fransen (1998) that the principal sources of sediment during these periods were, in order of importance, sidecast from old roadlines, shallow landslides and channel bed scouring. Most of the post-harvest reduction in sediment yield from Pakuratahi can be attributed to a lessening of forest-related activities such as reduced traffic flows, roading works and reduced runoff from revegetated landings and areas of roadside fill. In addition, the contribution to sediment yield by runoff from these sites will further diminish in response to improved on-slope sediment filtering by groundcover vegetation as it continues to spread, and as grass swards thicken.

The similarity in total suspended sediment yields for the two catchments over the 7 years of record suggests that, in the absence of any high-magnitude, low-frequency events during harvesting, total sediment yields over the length of a normal forest rotation (20–30 years) from erodible sediments in coastal

Hawke's Bay hill country will be higher from catchments in pasture compared with those in pines.

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