Liro limited
PO BOX 2244, ROTORUA, NEW ZEALAND
TELEPHONE: 07 348 7168 FAX: 07 346 2886

PROJECT REPORT

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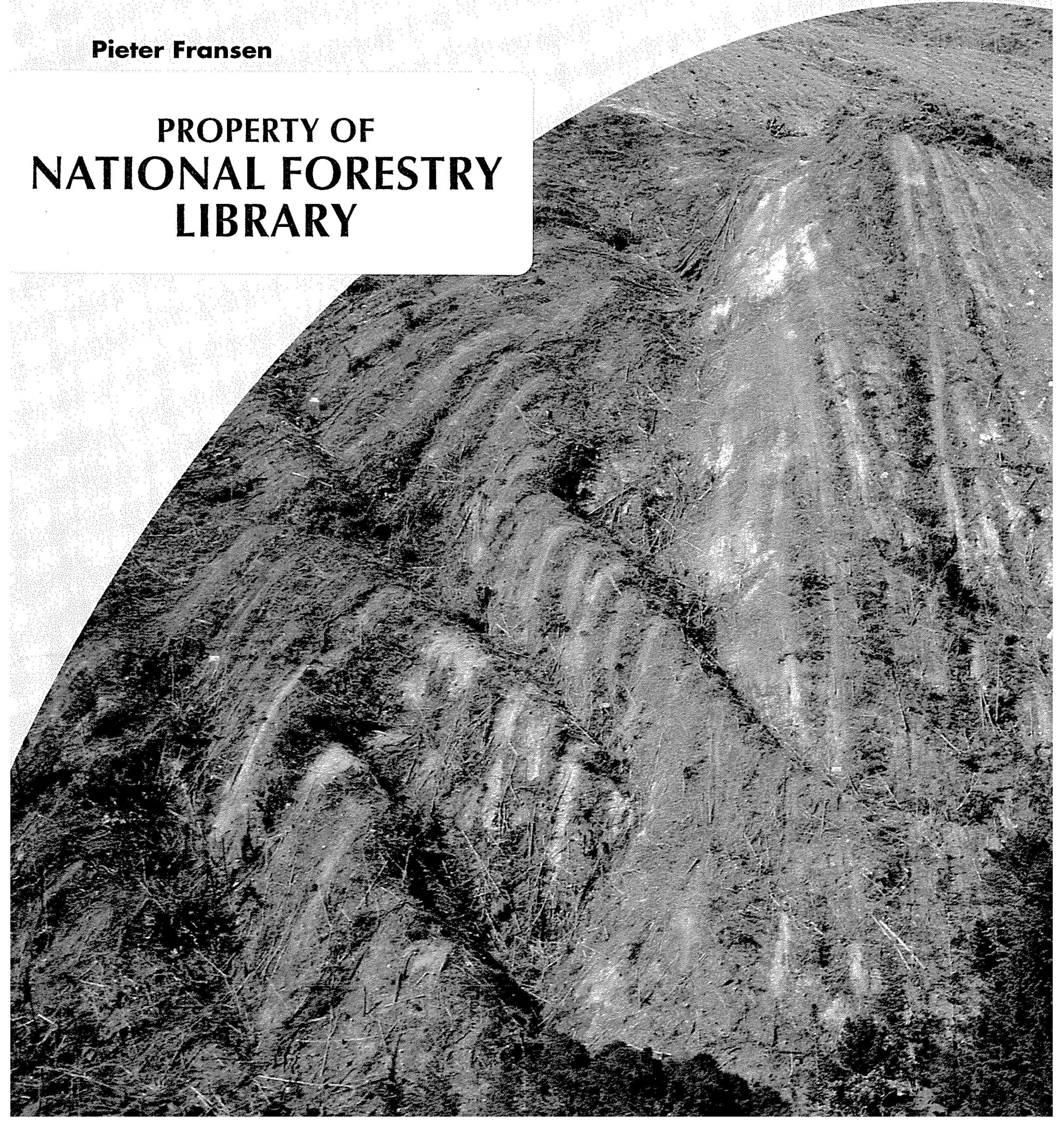
EROSION AND REVEGETATION OF HAUL PATHS IN CABLE LOGGED SETTINGS - NORTH ISLAND, NEW ZEALAND

Pieter Fransen



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P.R. 67 1998

Pieter Fransen
Forest Engineering Group
May, 1998

For information, please contact Liro Limited, P.O. Box 2244, Rotorua, New Zealand.

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SUMMARY

Haul paths in cable logged settings usually result in soil disturbance in the form of gutter-like depressions or ruts. These ruts channel surface runoff and soil material to the lower slopes. Erosion and revegetation rates of haul path ruts and less disturbed cutover (as controls) were evaluated at settings in Tairua Forest (Coromandel Peninsula), Taneatua Forest (Bay of Plenty) and Wharerata Forest (Gisborne). Change in ground profiles and percent and height of vegetation cover were measured at transect-plots from March 1996 to April 1997. Soil loss was determined using a fabric dam placed near the base of ruts.

After one year, average net soil depletion from all haul paths was 12 to 18 mm/m^2 , compared to 6 to 10 mm/m^2 from all the control plots. At Tairua and Taneatua sites, soil depletion from haul paths was about three times greater than adjacent less disturbed ground. No significant differences occurred at the Wharerata Forest site. Average yearly soil loss from all haul paths (fabric dams) ranged from 0.042 to 0.071 m^3 per rut. Significant storms (> 100 mm/day) resulted in average soil losses ranging from 0.004 to 0.008 m^3 per rut.

After one year, vegetation cover for ruts and control plots was 40 to 80%. There were no significant differences in cover between ruts and control plots at the Tairua or Wharerata sites. Increasing vegetation cover generally reduced the rate of soil depletion over the study period.

INTRODUCTION

Little information is available in New Zealand on both the quantity of soil lost from cable logged sites and the influence of oversowing or natural re-vegetation on slowing erosion rates. Marden and Rowan (1997), evaluated hauler logged settings at Mangatu Forest, East Coast North Island. They found rates of sediment generation from areas of deep soil disturbance averaged 11 kg/m^2 in the first year, and 4 kg/m^2 in the second year, after logging.

Other studies have focused on the area of soil disturbance within logged settings. Soil disturbance on cable logged settings is low, in comparison with ground-based logged sites. In New Zealand, 12 to 18% of a cable logged setting area may have deep soil disturbance (Murphy, 1984; McMahon, 1995), with similar levels reported in North America (Murphy, 1984). For ground-based clear-felling operations, the area of exposed mineral soil may range from 21 to 66 % (Bryan *et al.,* 1985). By contrast, ruts for a range of sites and cable logging systems cover less than 1 % of a setting area (McMahon, unpublished data).

Ruts are formed when a partially suspended tree is dragged on the ground along the haul path. One end only, or the entire stem may be in contact with the ground resulting in soil being ploughed and compacted. Cummins (1982) found evidence that the relationship between the drag angle relative to the working ground slope influences the depth of the rut and the process of rut formation (ploughing or rutting), soil physical conditions and the number of times contact is made with the ground.

This report evaluates soil erosion and revegetation of haul path ruts within cable logged settings at three North Island sites of contrasting soil type.

STUDY AREAS

Landscape characteristics of the North Island study sites (Figure 1), selected for a range of climatic and soil types, are summarised in Table 1

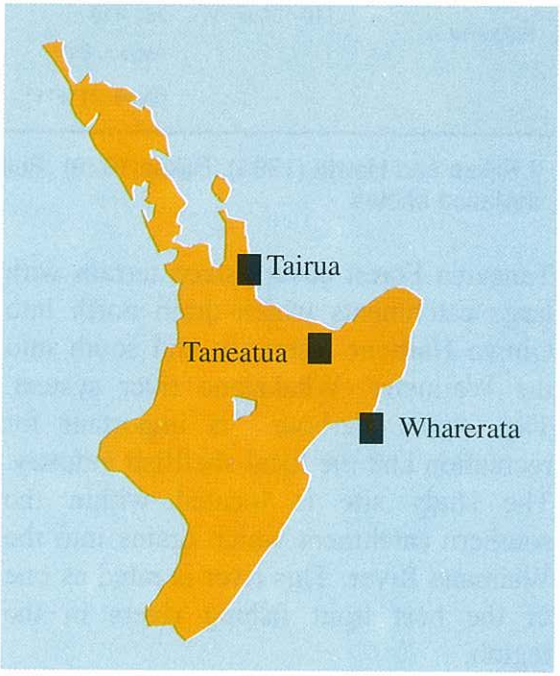

Figure 1. Location of study sites.

Slopes and gullies of the Tairua Forest site, near Whangamata, drain directly into the Wharekawa River, which flows into a harbour important for recreation and as a seafood resource. The gully streams exit through a wide riparian wetland and an indigenous and exotic pine tree buffer zone retained by the forest managers. Soils in the upper horizons are sandy, friable to loose, volcanic ash soils derived from Mayor (Tuhua) Island (coarse pumice beds of the Whangamata /Ash).The subsoils are clayey and overlie volcanic rock.

Table 1. Landscape characteristics of study sites.

Region	Climate	Topography	Geology	Soil Order §	Soil Description	Erosion types
Tairua Forest Coromandel Peninsula	Sub-humid to temperature humid 110-250 cm/yr	Elevation: 100-150 m Aspect: N Slope: 24°±11°	Volcanic rhyolite with ash cover	Allophanic Soils (yellow brown pumice, yellow -brown loams, red loams)	Sandy loam to clayey sand and gravel (pumice); sandy clay to clay (<2m)	Sheet, slip
Taneatua Forest Bay of Plenty	Sub-humid to temperature humid 110-250 cm/yr	Elevation: 235-280 m Aspect: SW Slope: 22°±11°	Greywacke with volcanic ash cover	Pumice Soils (yellow brown hill soils)	Sand loam to loamy sand and stony; very friable; greasy	Soil slips, rill, gully
Wharerata Forest Gisborne	Mild-humid 110-150 cm/yr	Elevation: 380-440 m Aspect: SW Slope: 21°±11°	Banded fine sandstone with volcanic ash cover in parts	Recent Soils (yellow brown earths and related steepland soils)	Fine sandy loam; friable; weak nut structure	Soil slip and sheet

§ Rijkse and Hewitt (1995), Rijkse(1979) Pullar *et al.*, 1972, Gibbs, 1980. Mean slope and standard deviation shown.

Taneatua Forest covers steep terrain with large catchments which drain north into Ohiwa Harbour (estuary); and south into the Waimana -Whakatane river system. The Ohiwa Harbour is important for recreation and the local shellfish industry. The study site is located within the southern catchment which drains into the Waimana River. This river is rated as one of the best trout fishing rivers in the region.

Soil thickness varies, depending on how much of the volcanic ash cover has been removed by erosion. The greywacke bedrock comprises weathered, fractured banded argillite, alternating siltstone and sandstone, and fine grained volcanic rock (Healy *et al.*, 1964)

Wharerata Forest is 30 km south of Gisborne. The forest lies within the Kopuawhara catchment whose stream is an important recreational trout fishery. The East Coast region is well known as an erosion prone area. Cyclonic storms trigger extensive slip erosion in the East Coast North Island about once in 10 years (Kelliher *et al.,* 1995). The fine sandy, volcanic ash derived soils are relatively thin (15 to 20 cm) and mantle unweathered sandstone. The study site is exposed to occasional strong south-westerly winds and rain.

SITE CHARACTERISTICS

Ground profiles & logging system

Four to five ground profiles were measured along selected ruts per site. Profiles varied considerably within and between settings (Figure 2). Cable hauler systems used to log the sites are summarised in Table 2. All systems achieved partial suspension, with the exception of the highlead system used in part of the Tairua setting.

The setting in Tairua Forest was broken by four to five spur and gully systems. Haul distances ranged from 200 to 435 m, and tailholds were 80 to 110 m lower than the landing level. On the western area of the setting a highlead system was used over short steep slopes. The area had no or poor deflection with nowhere to tie-off to lift tailhold. A 21 to 27 m tower would have improved deflection, however a machine of that size pulling small piece

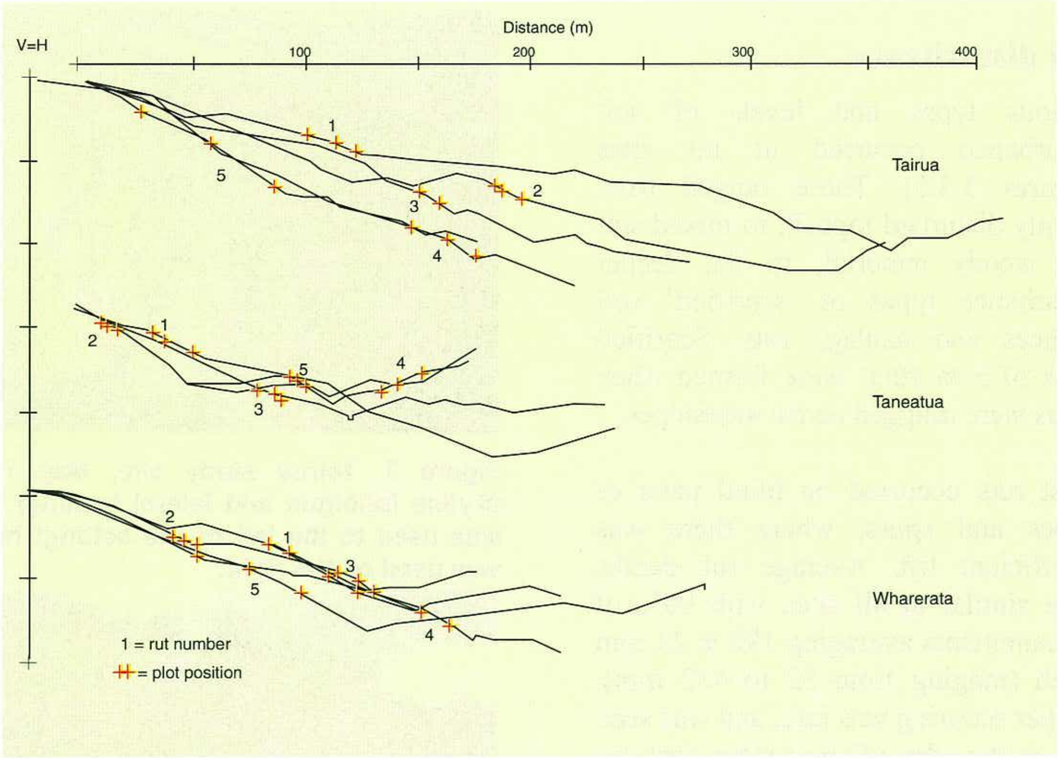

Figure 2. Ground profiles of cable yarding corridors and rut plot locations.

size was thought excessive in cost. The system was changed to a shotgun system with a Maki motorised carriage for long gentler slopes on the eastern side of the setting (Figure 3). With this system, lateral hauling of logs reduced the extent of deep soil disturbance.

At Taneatua Forest haul distances ranged between 160 and 240 m. Tailholds were 25 to 70 m lower than the landing level. Deep soil disturbance occurred on the blind side of a dividing spur ridge at 100 m distance, on the eastern side of the setting. Slopes were convex to constant. The landing site was less than 400 m^2, being on the upper part of a hill spur. This necessitated the use of a swing yarder to position stems for a skidder to haul to a larger processing site.

The setting at Wharerata Forest had slightly convex to constant slopes. Tailholds were 45 to 95 m lower than landing level and haul distances ranged from 200 to 300 m. For the long hauls, a mobile tailhold on a ridge was used over half the setting, and stumps on a steep spur over the other half.

Table 2. Logging system and stand characteristics.

Region	Hauler	System used	Species	Piece size	Production Target (m^3/day)	Completion of logging
Tairua Forest	Madill 071 (15m tower)	Highlead and Shotgun with Maki carriage	Pinus nigra 958 sph	0.1 - 0.4	65	20 April 1996
Taneatua Forest	PSY 200 (15 m tower)	Running skyline	Pinus radiata 524 sph (*c.* 50% windthrown)	1.9	200	6 March 1996
Wharerata Forest	Madill 009 (27m tower)	Scab skyline with mobile and stump tail holds	Pinus radiata 842 sph	1.3	170	6 December 1995

Soil disturbance

Various types and levels of soil disturbance occurred at all sites (Figures 3,4,5). These ranged from slightly disturbed topsoil, to mixed soil and woody material, to the deeper disturbance types of 'scarified' soil surfaces and haulage ruts. Scarified areas of 5 to 10m^2 were formed when stems were dragged across sideslopes.

Most ruts occurred on blind parts of slopes and spurs, where there was insufficient lift. Average rut depths were similar at all sites with 95% of measurements averaging 198 ± 23 mm depth (ranging from 32 to 432 mm). Deeper scouring was rare, and was seen only at the edge of short steep sections of slope formed by a slip or a small gully. Rut widths varied from 1.0 to 2.5 m. Soils were usually compacted in the deeper ruts, while the edges were sometimes mounded with loose mixed soil.

As a proportion of the total haul distance to the measured ground profiles, ruts occupied an estimated 30% of the distance for the running skyline and shotgun systems; and 43% and 53% of the total haul distance for the scab skyline and highlead systems respectively. Other statistics are shown in Table 3.

The distribution of slash was the other notable disturbance feature on the cutovers. In particular, all sites had heavy accumulations of slash in gully bottoms with nil to low (< 5l/s) water flow. Heavy slash trapped loose soil at the exits of some ruts. At the Tairua site, use of the Maki carriage resulted in good retention of understorey bush cover.

Figure 3. Tairua study site, May 1996. A skyline (shotgun and lateral hauling) system was used to the left of the setting; highlead was used on the right.

Figure 4. Taneatua study site, April 1996, logged using a running skyline.

Figure 5. Wharerata study site, April 1996, logged using a scab skyline.

Most ruts terminated more than 5m from a watercourse. Deep soil disturbance caused by hauling logs on stream banks was rare.

Table 3. Rut length statistics.

Rut length (m)	Tairua		Taneatua	Wharerata
	Shotgun	Highlead	Running Skyline	Scab Skyline
Average	32	36	16	33
Minimum	5	10	4	4
Maximum	80	100	55	135

METHODOLOGY

Soil erosion and revegetation

Quantification of soil depletion or accumulation was carried out by measurement of ground levels and by trapping soil. The term depletion is used here to define soil loss and *in situ* settlement of soil, both of which can result in a lowering of the surface.

Five typical ruts were selected per site. Plots were sited at the upper and middle regions, and near the termination of each rut. Overall, 43 rut and control plots were established over various elevations and slopes (Figure 2). Control plots were located on the less disturbed cutover, about 5m from each rut plot. Three transects were set in plots, 0.5 m apart. Rut transect stakes were set at their upper edge where possible and were no more than 1.8 m apart (the length of the reference rod used to measured the ground profile). Control plots were one metre square.

The transect stakes were used to form an erosion bridge (Ranger and Frank, 1978), where a graduated rod sat level on nails driven into the stakes. Ground levels were determined at 10 cm intervals using a vertical tape-measure sighted against the rod (Figure 6). This allowed changes in soil levels to be measured without further disturbing the soil.

Initial post-harvest ground cover within the plots varied from none to abundant, and comprised litter, small woody-slash and vegetation. Control plots generally had a greater level of ground cover, but one to two control plots (per site) represented broad areas of exposed subsoil. Ground cover was coded at measurement points to identify any material that might move as a result of wind or surface runoff, thus exposing the soil to erosion. This information was used in data analysis.

After initial set up, five surveys were conducted about every three months, or additionally about one week after a

Figure 6. Set up of fabric dam with trapped soil, and rut plot (blue painted stakes). Level rod at top-right was used as a reference from which to measure ground profiles. The board was used to avoid disturbing the soil beneath while accessing the upper transect for measurements.

significant storm event. The lengths of the study periods were 334 days (Tairua), 372 days (Taneatua), and 388 days (Wharerata). At the first survey, the level of the reference rod relative to transect stakes was checked for any disturbance due to ground settlement or animals. Any differences were measured and used to correct the level relative to the set up survey. Level checks were made at subsequent surveys.

Fabric dams (Dissmeyer, 1982) were installed at or near the end of each rut to trap soil for volume calculations. A 100 micrometre nylon mesh was used to ensure entrapment of very fine particles. The level of the accumulated soil behind the fabric dams was measured at 10 cm intervals using the reference rod. The width of soil accumulated behind the dam was also recorded (Figure 6).

Percentage vegetation cover, and the minimum, maximum and average height was recorded for each plot. Cover was visually estimated and verified by a second observer. Estimates were within 5% of each other.

Problems occurring with fabric dams included: (1) blowout due to trapped water 'seeking' a route out, (2) fabric torn due to high winds, goats, and moving debris. Dam failure caused unrepresentative soil losses, and data which could not be used in the analysis. Broken dams were repaired each time and re-measured. When full, dams were emptied of soil and re-measured.

Rainfall data at Tairua was obtained from an automatic raingauge within the forest. At Taneatua rainfall was initially read (fortnightly and after storms) from a 150 mm plastic raingauge and later from an automatic raingauge sited within the forest. Daily visual readings were obtained for Wharerata Forest.

Data analysis

The change in ground level for each survey period was determined relative to the first survey. Only exposed soil surfaces were considered in the analysis, as any covering of litter, woody matter or vegetation was assumed to prevent erosion. Disturbance due to planting and animal hoof prints was also omitted from the analysis.

A measurement precision of ± 3 mm (standard deviation) was determined from repeat measurements of 64 points. This error doubled with calculation of the change in soil level between surveys. Thus, when the change in level was more than 6 mm, the error was added for depleted soil, or subtracted for accumulated soil. When the change in level was less than or equal to 6 mm the error reduced the change to zero (not measurable).

The net change in soil level (mm/m^2) for each plot was calculated by summing all the point changes along the three transects, dividing by the total number of counts per plot, and dividing by the plot area. Finally, all plot means were averaged and 95% confidence intervals determined.

The average percent vegetation cover for measured plots was determined for each survey.

The volume of soil trapped by the fabric dams was calculated by a method of slices; that is, the product of the thickness and the average width of the deposit at each 10 cm interval, summed across the length of the dam.

RESULTS

Plots

Changes in soil levels from plots represented an average net soil depletion, and included any periods of soil accumulation during the year.

Soil depletion from controls was significantly less than ruts throughout the year at Tairua and Taneatua, with no significant differences (referred to throughout this report as the 95% confidence interval) between ruts and controls at Wharerata (Figure 7). At the end of the year, the average net soil depletion from controls ranged from 6 to 10 mm/m^2, whereas for ruts they ranged from 12 to 18 mm/m^2. No significant differences in rut soil depletion occurred between Tairua, Taneatua and Wharerata, except at the end of second period at Wharerata. The result was similar for the controls, except at the end of the fourth period, Tairua and Wharerata were significantly different.

Soil depletion from plots varied across the settings and did not necessarily increase downslope. For some ruts soil loss was greatest in the middle and upper sections. Also, increasing soil depletion was weakly correlated with increasing slope steepness.

Dams

Soil losses from the five ruts (as trapped by fabric dams) were averaged and then accumulated over the period of the study. Not all ruts are represented due to missing data from dams that were damaged and failed to trap soil. The average total soil loss from ruts at the end of the study was 0.042 to 0.044 m^3 per rut at Tairua and Taneatua. At Wharerata, a higher average total soil loss of 0.071 m^3 per rut (Figure 8) reflected a higher average rainfall in the last survey period and four storms $\geq$ 100 mm per day. Large variations in soil loss occurred at all sites: at Tairua the range was 0 to 0.022 m^3; at Taneatua 0 - 0.081 m^3; and at Wharerata 0.004 to 0.075 m^3.

Storms produced noticeable increases in

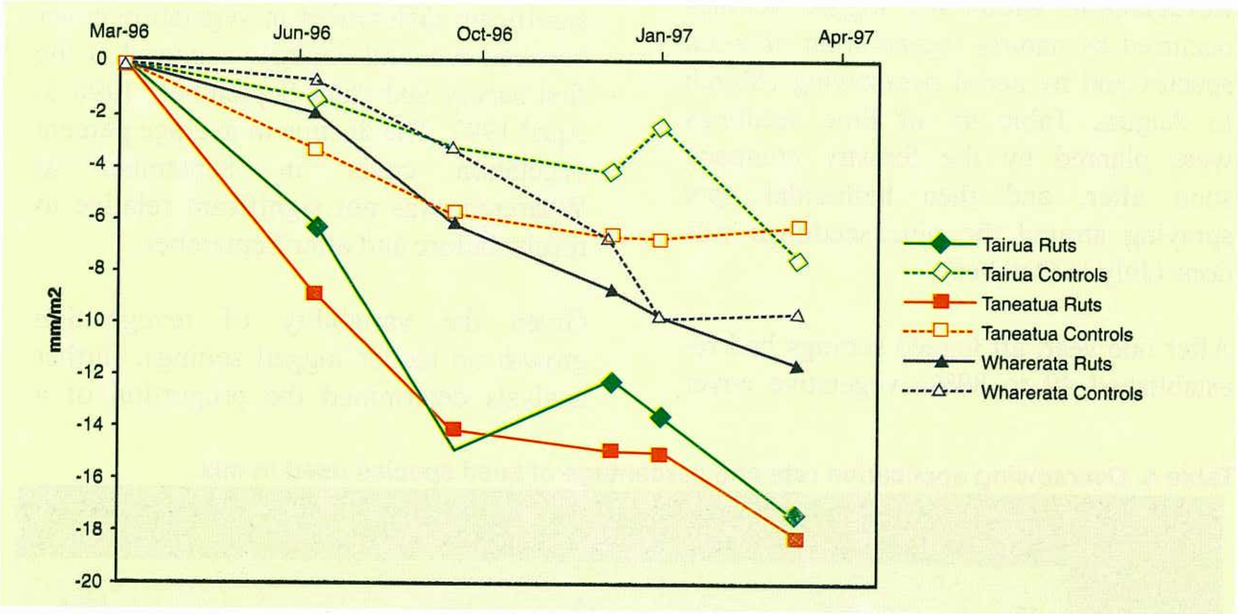

Figure 7. Average net change in soil levels from plots. Change was determined relative to the first survey in March 1996.

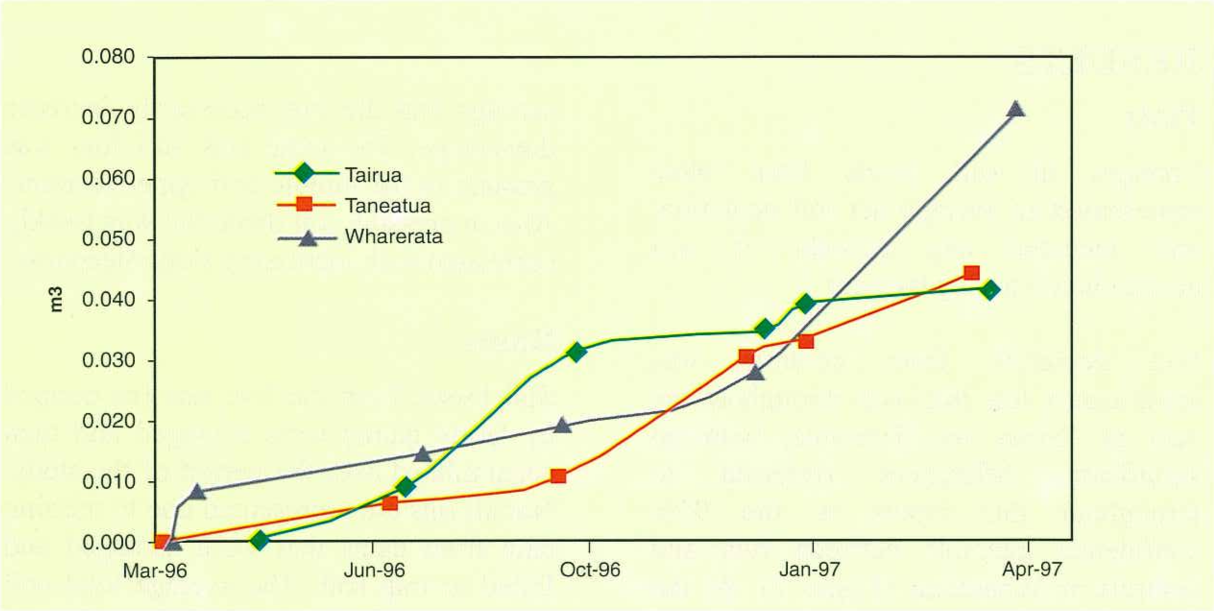

Figure 8. Time series of average cumulative soil loss from ruts.

soil loss from ruts of 0.003 to 0.004 m^3 (range 0 to 0.008 m^3) in Tairua and Taneatua, respectively, and 0.008 m^3 (range 0.004 to 0.021 m^3) in Wharerata.

Storm rainfalls were: 335 mm in 24 hours at Tairua, two storms of 92 mm and 112 mm in 12 hours at Taneatua, and a 237 mm in 72 hours at Wharerata.

Vegetation cover

Revegetation within the logged settings occurred by natural regeneration of weed species and by aerial oversowing (March to August, Table 4). of Pine seedlings were planted by the forestry company soon after, and then herbicidal spot spraying around the pine seedlings was done (July to October).

After one year, all logged settings had re-established 40 to 80% vegetative cover (Figures 9, 10, 11, 12). Vegetation cover at the beginning of the study varied from one to ten percent, and increased steadily through the study period.

At Tairua, intermediate spurs remained bare of vegetation where clayey subsoils had been exposed by log hauling. However, Tairua and Taneatua had no significant differences in vegetation cover between control and rut plots throughout the year (Figure 9). At Wharerata, significant differences in vegetation cover between ruts and controls occurred at the first survey and from September 1996 to April 1997. The decline in average percent vegetation cover in September at Wharerata was not significant relative to results before and after September.

Given the variability of revegetation growth on hauler logged settings, further analysis determined the proportion of a

Table 4. Oversowing application rate and percentage of seed species used in mix.

	Application rate (kg/ha)	Rye grass	Brown top	Fog grass	Maku Lotus	Cocks-foot	Trefoil	Month
Tairua	15	54	13	20	13			Mar
Taneatua	19	52	11	21	16			May
Wharerata	12					42	17	Aug

setting (represented by the plots) with 50% or more and 80% or more cover. Overall, fewer rut plots had the same proportion of vegetation cover than control sites at year end (Table 5). The effect of a low level of vegetation cover in ruts was limited due to the low (1%) proportion of ruts within a logged setting.

Spot spraying had negligible effect at Tairua, where pine seedlings were planted near two rut plots and one control plot.

At Taneatua, four control plots were affected by spot spraying, with two plots having 5% vegetation cover and the other two more than 60% cover. Five rut plots were also affected by spot spray with cover varying from 10 to 70 %. The level of effect depended on the distance of the spray spot from the plot. Vegetation cover was dominated by a range of vigorously regenerating weed species.

At Wharerata, the vegetation cover in six rut plots affected by spot spraying was not significantly different from those not affected. The control plots were not affected by spot spraying.

Slash and litter cover

Visual estimates of light slash and litter cover at the beginning of the study were carried out by two observers examining photographed plots. Estimates within a nominal 20% per plot were accepted for averaging. Results are shown in Table 6. Slash cover of the less disturbed cutover was significantly higher than for ruts at Taneatua and Tairua, but not at Wharerata. Control and rut cover was not significantly different between sites.

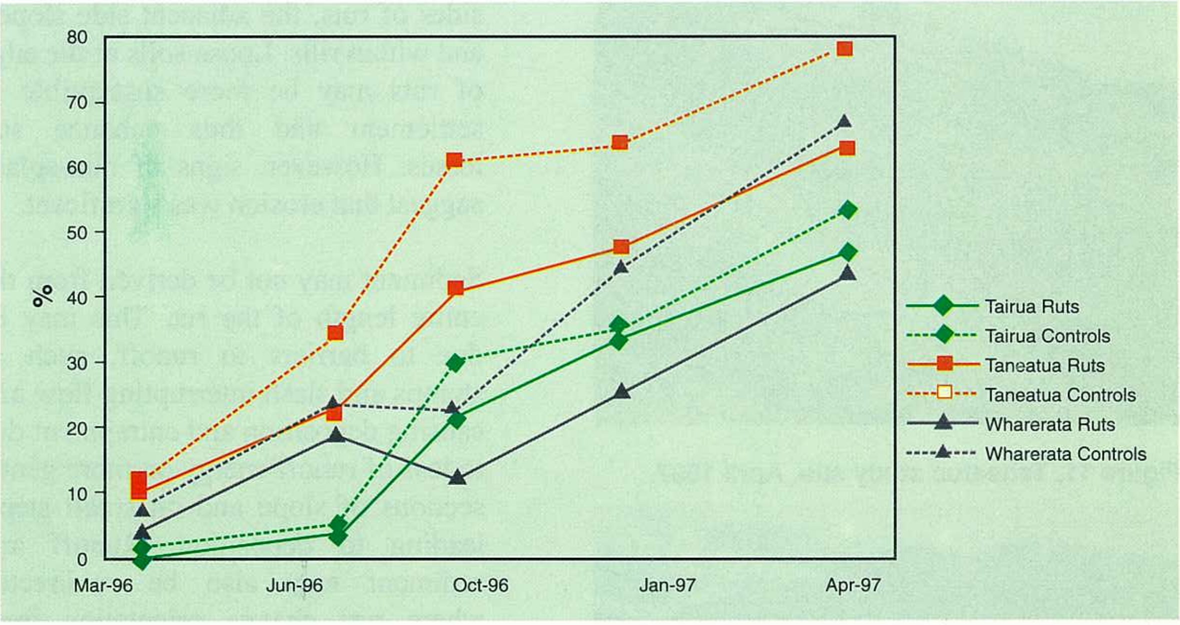

Figure 9. Average percent vegetation cover

Table 5. Percentage of plots with more than 50% and 80% ground cover.

Site	≥ 50% cover		≥ 80% cover		Cover height (cm)	
	Rut	Control	Rut	Control	Rut	Control
Tairua	43	64	7	14	22±2	17±3
Taneatua	53	86	33	73	50±24	51±21
Wharerata	33	67	27	40	9±3	14±4

Table 6. Percent average and 95% confidence interval for light slash and litter cover.

	Control plots	Rut plots
Tairua	66 ± 20	12 ± 3
Taneatua	66 ± 16	15 ± 10
Wharerata	47 ± 16	22 ± 9

Figure 10. Tairua study site, January 1997

Figure 11. Taneatua study site, April 1997.

Figure 12. Wharerata study site, April 1997.

DISCUSSION

Erosion processes

The plot and dam results are not comparable because plot results reflect average net soil depletion, a combination of soil erosion, settlement and accumulation. Soil trapped by dams represent a soil loss from up-slope.

Soil surface erosion processes are complex and include rain splash, sheet flow and rill flow. Sheet flow rapidly converges to rills which channels water and soil down-slope. Most ruts had rills which developed and enlarged during storm rainfall. As erosion is not a uniform process, soil eroded from one place will be deposited at varying distances down-slope. Soil may be derived from the upper 'ploughed' sides of ruts, the adjacent side slopes, and within rills. Loose soils at the edge of ruts may be more susceptible to settlement and thus enhance soil losses. However, signs of rain-splash suggest that erosion was significant.

Sediment may not be derived from the entire length of the rut. This may be due to barriers to runoff, such as stumps and slash interrupting flow and causing deposition and entrapment due to loss of runoff energy on more gentle sections of slope and on small steps, leading to deposition. Runoff and sediment may also be re-directed where ruts change orientation from down-slope to sideslope.

Estimating soil loss

The results presented so far only provide soil loss data for ruts rather than from the entire setting. To estimate or predict the total amount of soil loss from the logged setting it is necessary to count all ruts entering a watercourse. Ruts not directly entering a watercourse are less likely to contribute sediment. The number of ruts will vary depending on the terrain and the logging system. Aerial photographs and/or ground surveys can be used to determine the number of ruts. It may be necessary to sample a number of settings to obtain an average count of ruts per hectare.

The total soil loss can then be determined by multiplying the volume per rut to ruts per hectare to obtain volume per hectare.

Two methods can be used to determine soil loss:

1) The preferred method provides actual volumetric soil loss data obtained from soil/sediment entrapment in fabric dams.
2) The use of net soil depletion results from plots over-estimates soil losses as it does not take into account the down-slope delivery processes and deposition of sediment.

For example, assuming soil depletion under plots represent predominantly soil erosion, the volume of soil lost from ruts in a year can be calculated by multiplying the end of year plot results by the average rut length (Table 3) to give: Tairua, 0.6 m^3/rut, Taneatua, 0.3 m^3 /rut, and Wharerata, 0.4 m^3/rut. These volumes are 14, 7 and 6 times greater than the sediment volumes trapped by the dams respectively. This discrepancy highlights that plot results, while useful in determining net soil depletion, cannot be used in determining soil losses to watercourses. Nevertheless, it is apparent that very low volumes of sediment from ruts could potentially enter a watercourse. This is dependent on the extent and number of ruts connecting to channels, cover type, and slope gradient.

Vegetation and storm effects

Soil depletion gradually declines as vegetation cover increases for rut and control plots at all sites, despite some large variations and reversed trends (Figure 13 a, b). Reversed trends occurred at the end of year for rut plots and control plots at Tairua, and for rut plots at Taneatua and Wharerata. The increase in soil depletion in period five suggests that the corresponding level of vegetation cover was partly effective in mitigating erosion. Storm events during the latter part of the study period were in part responsible for the increased level of erosion.

Tairua was affected by two storms. The first storm was one week prior to the fourth period survey; a 335 mm rainfall in 24 hours (Figure 14) caused a small decrease in rut soil depletion. In control plots soil accumulation occurred. The second storm rainfall of 132 mm in 12 hours, prior to the last survey, corresponded to a relatively large soil depletion for both ruts and controls. During the fifth period at Taneatua, 153 mm rainfall in 72 hours probably accounted for the large increase in rut soil depletion. However, a 92 mm and a 112 mm in 12 hr storm during the fourth period at Taneatua did not have a noticeable effect on soil levels. At Wharerata, the first period of soil depletion reflected a storm of 218 mm in 48 hours. In the fifth period four significant storms between 105 mm and 196 mm appear to have increased soil depletion in ruts, despite the increasing vegetation cover.

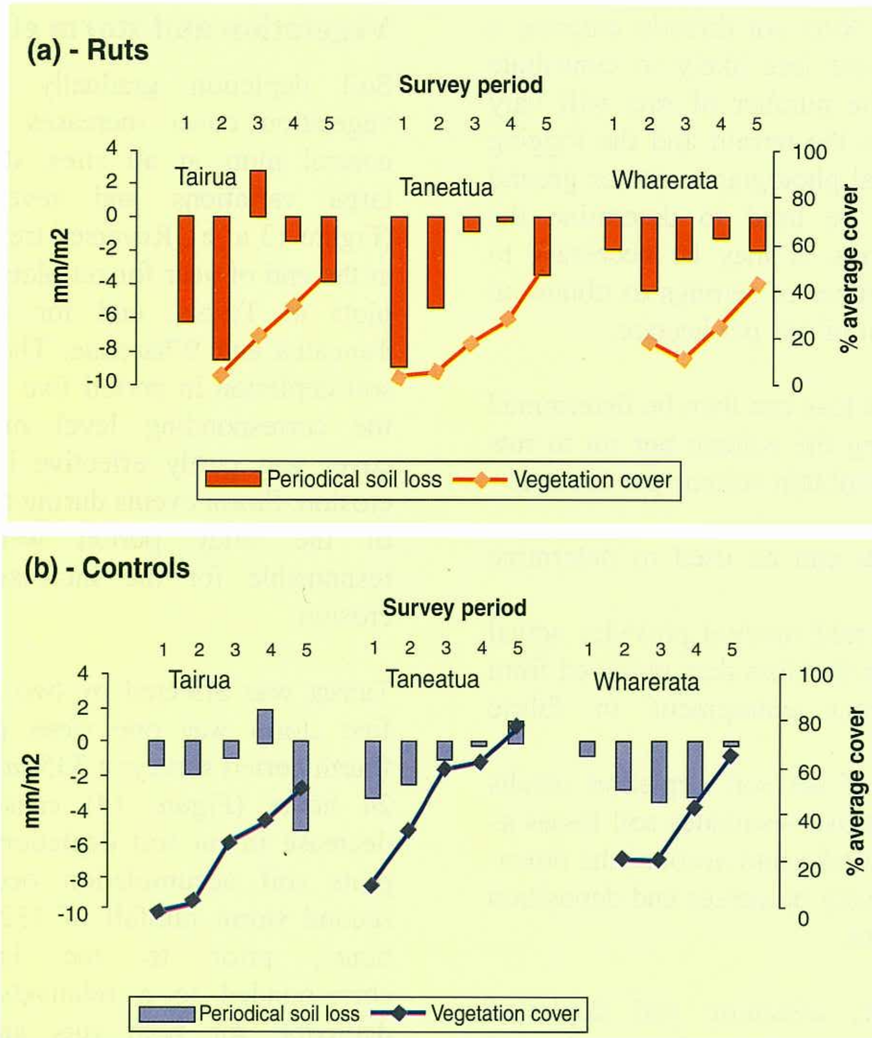

Figure 13. Vegetation cover and average net soil depletion /accumulation from plots.

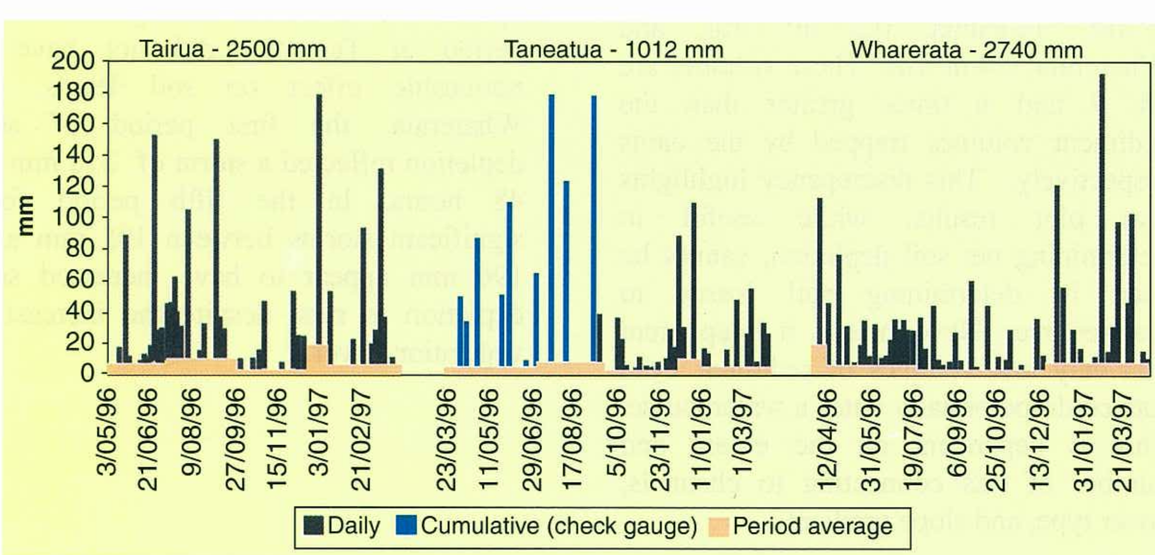

Figure 14. Rainfall chart for Tairua, Taneatua and Wharerata. Total rainfall is shown at the top of chart.

CONCLUSIONS

Erosion and ground vegetation cover were evaluated at three cable logged settings in North Island, New Zealand. Soil types were sandy loam and pumice 'gravel' to sandy clay (Tairua), sandy loam (Taneatua), and fine sandy loam (Wharerata). Average slopes ranged from 21° to 24°. Annual rainfalls during the study ranged from 2300 to 2600 mm. The cable logging haulers varied in tower height and skyline system used. General findings were:

- After one year, average net soil depletion from all ruts were 12 to 18 mm/m^2 compared to 6 to 10 mm/m^2 from the less disturbed cutover. The soil depletion from ruts was about three times greater than adjacent less disturbed ground at Tairua and Taneatua sites. No significant differences occurred at the Wharerata Forest site.

- Actual average soil loss volumes (as determined from entrapment in fabric dams) ranged 0.042 to 0.071 m^3/rut/year. Significant storms (> 100 mm/day) resulted in average soil losses ranging from 0.004 to 0.008 m^3/rut.

- Increasing vegetation cover was shown to reduce soil depletion from ruts and less disturbed parts of the logged setting. Aerial oversowing as well as strong regeneration of weeds was important in mitigating erosion. Spot spraying appeared to have little adverse effect on average net soil depletion rates. Significant storm events increased soil depletion when vegetation cover was 40 to 60% by area.

- Little can be said about the influence of specific logging systems on erosion, as there were no significant differences in the average soil depletion/losses from ruts between the study sites.

- These results may have application in the prediction of sediment yields from ruts, given that the number of ruts connecting to waterways within a setting(s) is known and that there are similarities in soil type, vegetation cover levels, annual rainfall, and storm frequency and magnitude as described in this study.

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