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SEDIMENT YIELDS FROM LOGGING TRACKS IN KAINGAROA FOREST

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ABSTRACT

This report summarises the results from two separate studies aimed at investigating sediment yields from logging tracks in Kaingaroa Forest. Data were collected for the two studies during 1991 and 1992.

The first study examined the sediment production from tracks using unbounded plots of 10m and 25m length on slopes of 18° - 23°. Results show that high intensity rainfall is necessary to cause runoff from the porous soils of the area. Annual sediment yields in this study ranged from 0.171 - 1.235 kgm^{-2}. There was no notable low frequency, high intensity rainfall event during the study.

The second study measured sediment production from 10m long bounded plots on slopes of 4°, 14°, and 23°. The effectiveness of oversown grass and legumes for controlling erosion was evaluated. Annual sediment yields on the unvegetated tracks ranged from 0.001 kgm^{-2} on 4° slopes to 0.219 kgm^{-2} on 14° slopes. Annual sediment yields on the oversown tracks ranged from 0.009 kgm^{-2} on 4° slopes to 0.011 kgm^{-2} on 14° slopes.

A field survey of the area showed that ridge top roads and landings with poor water control were the largest sources of runoff and sediment. However, very steep logging tracks, which had experienced repeated machine passes, were also prone to rilling. Where cutoffs were constructed on the tracks, they provided adequate protection from runoff generated on the track itself.

Figure 1 - A bounded trial plot indicating the response to oversowing

INTRODUCTION

Tracking is an integral part of many ground-based logging operations. Difficult areas with short steep slopes or areas too small to be economical for a hauler are often intensively tracked.

Exposing soil to erosion and the resulting loss of site productivity are the major impacts of tracking operations. However, careful construction and maintenance of water control and drainage features can minimise erosion, sedimentation and further loss of downslope productive area.

Little research has been done on logging track erosion and sedimentation in New Zealand (Wallis, 1993 in prep.). Tracks tend to have much steeper gradients than roads, and an unprotected surface which is often prone to erosion. Research has been conducted on erosion from unsurfaced forest roads in southwest Nelson, but unlike logging tracks these typically have drainage ditches and culverts for water control (Fahey and Coker, 1989).

Two studies are outlined in the report: Sediment Production Trial on bare unmanaged tracks, and Oversowing Trial using a range of oversowing treatments.The objectives of the two studies were to:

- estimate sediment yield from a typical logging track in the volcanic ash soils of Kaingaroa Forest's Northern Boundary
- identify the causes of runoff and erosion on the tracks
- determine the type of rainfall event necessary to invoke erosion
- determine the effectiveness of oversown grasses and legumes at controlling erosion
- discuss possible management options for preventing and controlling the erosion.

The Northern Boundary of Kaingaroa Forest was chosen because it will be an area of major logging activity over the next decade. A number of major streams draining this area flow into Lake Aniwhenua, a hydro lake on the eastern side of the forest. Sedimentation in this hydro lake has been, and still is a concern of Bay of Plenty Electricity and the Regional Council.

It would be physically and economically feasible for much of the area to be logged by ground-based systems. Many of the gullies are dry due to the free draining soil. The risk of sediment reaching a stream is minimal in some areas because of the large distances over flat ground that it would have to travel.

FIELD AREA DESCRIPTION

Location

The trials were located in compartments 1288 and 1289 in the northwestern part of Kaingaroa Forest.

Geology and Soils

The Kaingaroa Plateau is formed from various ignimbrite layers with several late Quaternary cover deposits (N.Z. Soil Bureau, 1960). In particular, air-fall tephra deposits from Taupo, Kaharoa and Tarawera eruptions cover the study area on the Northern Boundary of the forest. The Tarawera and Kaharoa deposits are both typically between 50mm and 400mm thick in the study area. The total thickness of pyroclastic cover deposits is about 6m (Pullar and Birrell, 1973).

The study area is characterised by steep terrain with short slope lengths of about 100 to 200m separated by a fairly wide valley bottom. Due to high infiltration rates of the volcanic soils, most of the gullies have no flowing surface water which minimises the risk of sediment transport.

The mean annual rainfall at Kaingaroa Forest is 1562mm. It follows a slightly seasonal pattern with more rainfall during winter (N.Z. Meteorological Service data 1951 to 1980). The rainfall often occurs in short duration, high intensity storms in summer. Pumice soils with a low moisture content have a lower infiltration rate than moist pumice. Consequently the potential for erosion is greatest when dry summer conditions are combined with high intensity rainfall (Selby, 1972).

Logging Track Characteristics

Ground-based tracking in the area typically consists of contour tracks and climbing tracks which give machinery access to felled trees. Once the trees or logs are attached to the machine, the shortest path back to the landing is often taken resulting in steep downslope tracks. Tractor and skidder operators often drop the machine's blade on very steep tracks to control sliding. This results in greater soil disturbance.

Track construction involves the removal of the top soil and any vegetation or litter exposing the various ash layers. After repeated machine passes, turning of machines and dragging logs, the soil layers are mixed up to a metre in depth. Slash and logging debris are also churned into this mixture of soil.

The study compartment areas surrounding the trials were not oversown at any stage.

SEDIMENT PRODUCTION TRIAL

Description of Plots

In July, 1991 four plots were established on a climbing, logging extraction track. The track had been used by a tractor and skidder logging crew to extract clearfelled 36 year old radiata pine.

The track was constructed by sidecasting with the D65 tractor used for the logging operation. A cut batter height of between 1 to 2.5m was initially formed but this increased as the bank gradually eroded and collapsed toward the soils natural angle of repose. A final height of approximately 4m occurred in places.

The track surface was left in an "as used" condition with tractor grouser marks still indenting the soil. The track was not used by any machinery after the plots were installed.

A 70m stretch of track was divided into four plots - two of 25m length and two of 10m length. A footed board was buried to form a cutoff at 45° to the axis of the track. These divisions directed runoff from the base of each plot to the collection points. The plot characteristics are described in Table 1.

Initially the plots were completely clear of vegetation. They were planted through with radiata pine seedlings two weeks after monitoring began and there was some weed growth during the year. No special treatment was given to the plots and they were allowed to remain under normal forest management practices.

Methods

Data were collected on rainfall and sediment production for the one year period July 1991 to July 1992. Sediment production was measured at all four plots on a fortnightly basis, with some visits after major storms. Rainfall was measured using a Belfort recording rain-gauge.

Runoff and sediment were collected in 200 litre drums placed at the outfall of the cutoff boards.

Table 1 - Sediment monitoring trial plots

Plot Number	Slope Angle (degrees)	Slope Length (m)	Treatment	Annual Sediment Total (kgm^{-2})
1	22	10	None	1.235
2	22	25	None	0.171
3	18	10	None	0.357
4	18	25	None	0.893

Sediment collected in the drums was weighed on site using a bucket and spring balance. Representative subsamples were taken periodically and returned to the laboratory for drying, weighing and particle-size analysis. The average moisture content of the samples was used to estimate the dry weight of the sediment in the drums.

The surface and subsurface of the track were sampled at the conclusion of the trial to assess which particle sizes had been eroded.

The kinetic energy of individual storms was calculated using the method described by Morgan (1979). An erosivity index (EI_{30}) was estimated for storm events, and is the sum of the total storm energy and the maximum 30 minute rainfall intensity of that storm (Wischmeier and Smith, 1958).

It has been suggested that the erosional resistance of a road surface increases with time from disturbance by grading (Fahey and Coker, 1989). Results were analysed to assess if the same phenomenon was occurring on the track surface in this trial.

Results

Rainfall and Storm Characteristics

Annual rainfall totals for Kaingaroa Forest during the study period were below the average of 1562mm. Annual rainfall totals measured at the site for 1991 and 1992 were 1424mm and 1400mm respectively.

Monthly totals from rainfall records for January, 1990 to November, 1992 show that the period July to October was the wettest. However, January also had high rainfall.

For the purposes of this study, a storm was defined as a discrete rainfall event of 5mm or more which is separated from preceding events by at least six hours (Wischmeier and Smith, 1958).

The maximum 24 hour rainfall intensity recorded on site was 58mm on February 15, 1992 which was lower than the estimated five year return period intensity of 200mm (Tomlinson, 1980). The maximum one hour rainfall intensity recorded at the site was 25mm on February 15, 1992. This is well below the estimated five year return period one hour intensity of 40mm for this area (Tomlinson, 1980). The Belfort rain-gauge used for the study did not have sufficient resolution to allow 10 minute intensities to be obtained.

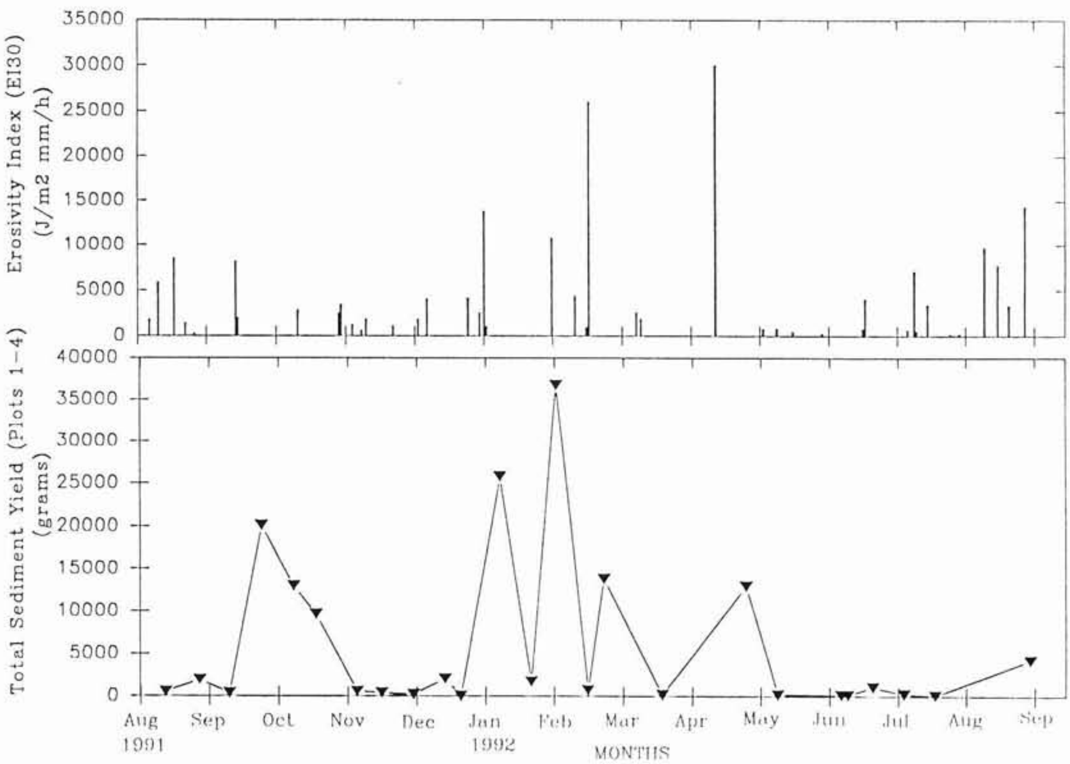

Figure 2 - Maximum storms and their associated sediment yield totals (Plot 1-4), sediment monitoring trial

At the rain-gauge site 68 storms were recorded during the period July, 1991 to July, 1992. Of those 68 storms, at least 23 produced a measurable amount of sediment on the sediment production trial. The average available storm kinetic energy at the site was 397 Jm^{-2} and the maximum 1397 Jm^{-2} (October 1, 1992).

Sediment Results

It was evident from the rainfall records that more than one storm contributed to the fortnightly sediment totals. Only four sediment totals could be attributed to individual storms. The smallest storm capable of mobilising a measurable amount of sediment (> 0.1kg) was on 15 May, 1992 (maximum intensity 4mmh^{-1}, EI_{30} = 432 $Jm^{-2}mmh^{-1}$). Figure 2 shows the maximum storm (EI_{30}) between monitoring sediment yields and the respective sediment totals. The erosion index showed a trend of decreasing erodibility over time for all plots.

An unweighted least squares regression analysis of EI_{30} against sediment yield for the maximum storm between successive sediment measurements showed no significant relationship, except for Plot 4, which was significant at the 1% level. However, the relationship between EI_{30} and sediment yield did show the same visual trend of increasing sediment yield with increasing EI_{30}.

For all plots, the sediment yields for EI_{30} less than 8000 $Jm^{-2}mmh^{-1}$, were less than 1500g, except for Plot 4, when on one occasion three months into the study, a storm of EI_{30} = 2831 $Jm^{-2}mmh^{-1}$ yielded 7510g of sediment. This storm triggered the formation of a rill on the plot which would account for the high sediment yield. The rill was the only major one to develop on Plot 4.

The annual sediment yields from the plots ranged from 0.171 to 1.235kgm^{-2} (mean 0.664 kgm^{-2}) (Table 1). These figures are of the same order as those found by Fahey and Coker (1989) which ranged from 0.3 to 1.7 kgm^{-2} for a metalled road surface.

Sieve analysis of sediment samples showed that 62% of the sediment was in the sand sized range (2mm-0.063mm) with 32% in the gravel range (>2mm) and about 6% silt size (<0.063mm). Samples taken from the surface of the trial plots at the conclusion of the study showed that the surface layer of soil had significantly less sand and silt size particles than the subsurface soil. This indicates that the fine particles were either washed down into the subsurface layer or removed from the site by runoff. The most erodible soil particles are generally silt and sand (Morgan, 1979) which accounts for their presence in the drum sediment samples. The high gravel size content could be due to the presence of low density Taupo lapilli particles which are also easily transported.

OVERSOWING TRIAL

Description of Plots

Nine plots were established for this trial. Each plot measured 3x10m and was completely bounded by a board buried in the ground (Figure 1). This effectively isolated it from outside sources of sediment and runoff. The surface of each plot was left as undisturbed as possible allowing slash and debris to remain as existing ground cover. The plots were on three different slopes (4°, 14°, and 23°) and were given three different treatments: control (no treatment), oversown with seed mix, and oversown with seed mix and fertiliser (Table 2). The seed mix used for all plots was:

- Concord Ryegrass 5 kg/ha
- Massey Baysn
- Yorkshire Fog 20 kg/ha
- Maku Lotus 5 kg/ha

Fertiliser: - Nitrophoska (12:10:10) 500 kg/ha

The high rate of fertiliser was used to ensure the grasses and legume were established successfully for a good comparison with the other treatments.

The oversown plots were protected from an aerial desiccant spraying by covering them with polythene sheet during the spraying operation.

Methods

Sediment and rainfall data were collected for the one year period November, 1991 to November, 1992.

On three plots sediment was collected in drums as described above. However, a method was trialled on the other six plots using empty PVC fertiliser sacks to catch sediment. Sediment was collected and weighed on site using a bucket and spring balance.

Storm kinetic energy and erosivity index were estimated using the same method and rainfall data as for the sediment monitoring trial.

Ground cover was estimated periodically by considering the amount of ground surface covered by vegetation and expressing this area as a percentage of the total area.

Results

The raingauge recorded 48 storms for the period November, 1991 to November, 1992, of which only 13 produced any sediment from the oversowing trial.

Table 2 - Oversowing trial plots

Plot Number	Slope Angle (degrees)	Slope Length (m)	Treatment*	Annual Sediment Total (kgm^{-2})
1	4	10	N	0.001
2	4	10	O	0.003
3	4	10	O+F	0.009
4	14	10	N	0.219
5	14	10	O	0.009
6	14	10	O+F	0.011
7	23	10	N	0.142
8	23	10	O	0.013
9	23	10	O+F	0.007

* N=None, O=Oversown, O+F=Oversown and Fertilised

A graph of the average ground cover versus time is shown for the various treatments (Figure 3). Plots with fertiliser applied demonstrated considerably more success in grass growth, especially in the first few months after sowing. Early establishment of roots enabled them to better survive the dry summer conditions. By the second summer, the vegetation growth on the fertilised tracks was providing excellent ground cover and binding of the soil with its dense root mass. A noticeable decline in cover occurred when the Lotus and Ryegrass died back over winter.

On Plot 9 ground cover reached 75% within two months of oversowing. The control plots, which were not treated, had no ground cover even after 18 months, except for one or two weeds.

The surface condition of the tracks was particularly unfertile where the deep layer comprised of Taupo ash was exposed. Establishment of grasses without fertiliser on this soil was limited.

The annual sediment totals ranged from 0.001 kgm^{-2} to 0.219 kgm^{-2}. The plots without oversowing on slopes of 14° and 23° yielded significantly more sediment than all the other plots.

The erodibility of the site was estimated by the erosion index (K) and showed a non-significant trend of decreasing over time. This result agrees with the results from the sediment production trial and of Fahey and Coker (1989).

FIELD SURVEY

Methods

A field survey of the surrounding compartments was conducted to determine the rate of establishment and success of oversown grass and legumes on tracks. These areas were oversown, without fertiliser, as part of the normal management practice for weed control.

Tracks in the compartments were also examined to determine their characteristics

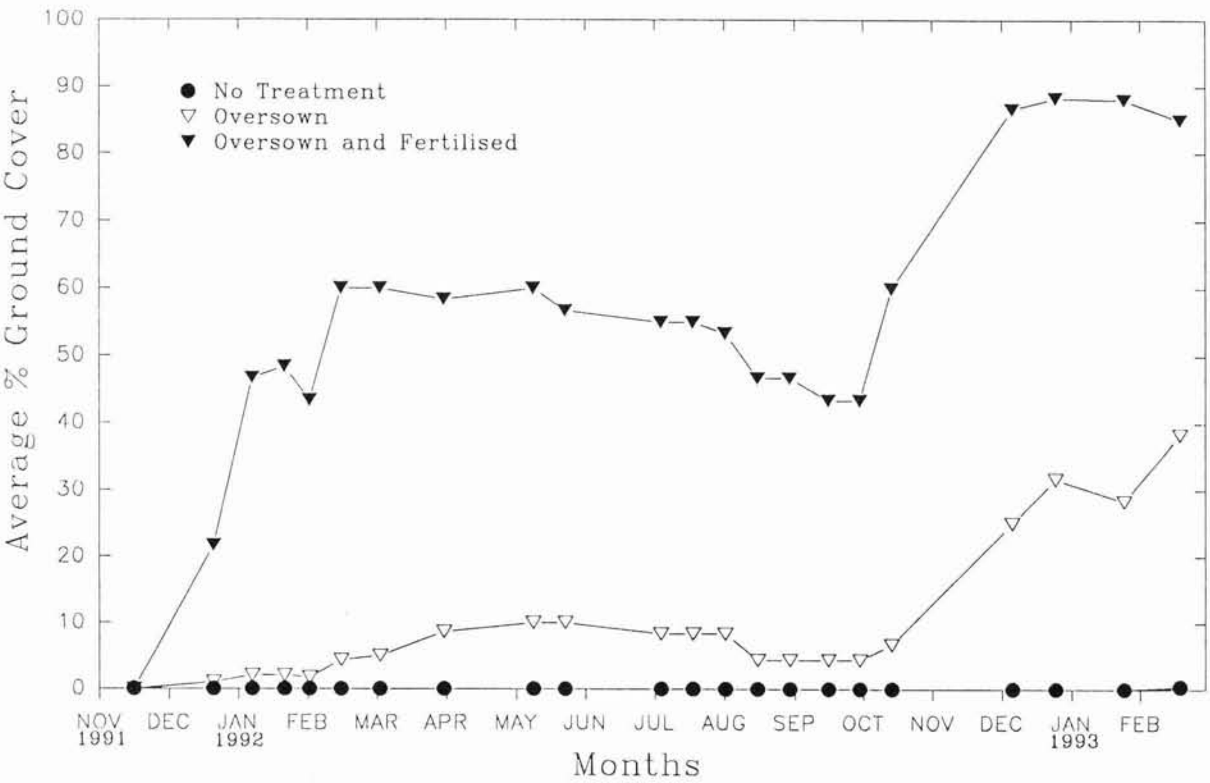

Figure 3 - Average ground cover for various treatments over time

gradients, post-logging treatment, whether erosion was taking place, the cause of any erosion and the potential impact of the sediment down slope.

Results

The field survey of the area surrounding the study site highlighted some important aspects of sedimentation and erosion control. Most logging tracks in the area did not have any significant rill or gully erosion. In several areas, uncontrolled road or landing runoff had entered the tracks causing severe erosion. Cutoffs installed on the tracks were inadequate for controlling the volume of runoff generated from roads and landings.

Sediment volumes from these sources were estimated to be in the order of tens of tonnes. The main impacts from the large volumes of sediment were the burying of newly planted radiata pine trees and loss of productivity on site - both from top-soil removal and top-soil buried by sediment. Potential impacts also exist where this sediment is stored as it may move further with large storm events or even during future harvesting periods.

Surface runoff generated on tracks and any small scale rilling was easily controlled by the installed cutoffs. The main source of surface runoff on tracks was where finer textured soil was present and had been compacted resulting in decreased soil permeability.

On a number of tracks where cutoffs had not been installed, rilling occurred. The field survey showed that tracks over 50m in length without cutoffs and having a gradient greater than 15° were likely to have significant rilling present. It is worth noting that in almost all cases gully erosion encountered on logging tracks was derived from runoff generated upslope of the track on a road or landing, and not from the track itself.

DISCUSSION

Compaction by machines and animals has been identified as having an important effect on infiltration by reducing soil porosity (Selby, 1972). The overlying Tarawera lapilli is not as prone to compaction as are the other ash layers because its particle size distribution is 80% to 90% gravel with only a small amount of fines. The track surface is generally a mixture of soil/ash layers all combined with slash, especially lower down on the track where soil has been moved by repeated passes. Once runoff was generated in these areas it could easily erode any less compacted, loose material. Many variables affect infiltration rates and the range of infiltration rates in pumice soils is large (Selby and Hosking, 1971). It is difficult to know where runoff will be generated on a track by visual inspection. It is, therefore, difficult to optimise the placement of cutoffs.

In pumice soils intense precipitation is required to generate overland flow because the rainfall only exceeds the infiltration rate during high intensity storms. However, surface runoff is generated from compacted landing and road surfaces at relatively low rainfall intensities.

Slope appears to have a limited effect on the formation of major rills or gullies in these soil types until it exceeds about 24°. On steep downhill extraction paths where track slopes reach 36° and compaction is high, due to repeated machine passes, erosion potential is high. It is usually too difficult to successfully install cutoffs on these tracks because a bulldozer will be unable to reverse uphill. In most instances, it would be possible for an operator to construct a cutoff at the top of the steep section of track, thereby removing the possibility of runoff from the catchment area above entering on to the track. The were no large rainstorm events (high intensity, low frequency) during the period of this study. Such events are known to cause major sediment movement and changes in site morphology. The results of these studies are, therefore, unable to predict the impact of such large events.

Oversown grasses and legumes have the benefits of preventing erosion, providing weed control, reducing visual impact and improving soil structure and nutrition. The major role of vegetation is the interception of raindrops so that their kinetic energy is dissipated by the plants rather than imparted to the soil (Morgan, 1979). However, a substantial cover is required to provide for minimal erosion control (Weaver and Seltenrich, 1981; Morgan, 1979). Grass does not trap significant quantities of sediment derived from upslope erosion (Weaver and Seltenrich, 1981).

From observations in the area, it takes about 18 months for the weeds to start establishing themselves on the tracks. However, the weeds provided little ground cover on tracks (< 5%) and would be ineffective for controlling erosion and runoff.

CONCLUSIONS

From these two trials a number of conclusions can be made:

- erosion from trial plots ranged from 0.001-1.235 $kgm^{-2}yr^{-1}$ and are strongly correlated to slope

- erosion and sedimentation from tracks with cutoffs appears to be insignificant in comparison with that generated by runoff from roads and landings in the area

- any ridge top roading or landings must have sufficient drainage and water control to prevent significant runoff entering on to tracks or fill slopes where the erosion potential is high

- successful control of erosion in pumice soils requires runoff to be controlled where it is generated, before it gains volume and velocity

- roads and landings pose the biggest threat to soil conservation in the Northern Boundary area; maintenance of cutoffs and sediment traps and post-logging drainage control is critical to avoid initiating gully erosion

- oversowing is effective at controlling erosion on pumice soils by providing a strong dense root system; to be effective at controlling erosion and sediment, grasses and legumes need to be well established and have good ground cover

- fertiliser should be applied to enhance growth on infertile and bare tracks; oversowing also has the benefits of weed control, nitrogen fixing and production of organic material for soil structure and stability

- careful selection of track location, rehabilitation with oversowing, and consistent operational management of drainage controls will significantly reduce erosion and sedimentation from ground-based operations.

REFERENCES

Fahey B.D., Coker R.J. (1989) : "Forest Road Erosion in the Granite Terrain of Southwest Nelson, New Zealand". Journal of Hydrology (N.Z.), Vol 28, No. 2.

Morgan R.P.C. (1979) : Soil Erosion. Topics in Applied Geography. Longmans.

New Zealand Soil Bureau (1960): Soils, Forestry and Agriculture of the Northern Part, Kaingaroa State Forest and the Galatea Basin. N.Z. D.S.I.R Soil Bureau, Bulletin 18.

Pullar W.A., Birrell K.S. (1973) : "Age and Distribution of late Quaternary Pyroclastic and Associated Cover Deposits of the Rotorua and Taupo Area, North Island, New Zealand". N.Z. Soil Survey Report 1.

Selby M.J. (1972) : "The Relationship Between Land Use and Erosion in the Central North Island, New Zealand". Journal of Hydrology (N.Z.), Vol 11, No. 2.

Selby M.J., Hosking P.J. (1971) : "Causes of Infiltration into Yellow-brown Pumice Soils". Journal of Hydrology (N.Z.), Vol 10, No. 2.

Tomlinson A.I. (1980) : "The Frequency of High Intensity Rainfalls in New Zealand: Part 1". Water and Soil Technical Publication No. 19. Water and Soil Division, M.W.D.

Wallis G. (1993) : "Sedimentation and Erosion in New Zealand Plantation Forestry". LIRO Project Report (in prep.).

Weaver W., Seltenrich M. (1981) : "Summary of Results Concerning the Effectiveness and Cost Effectiveness of Labour Intensive Erosion Control Practices used in Redwood National Park 1978-1979". Technical Services Div., Redwood National Park. Memorandum report.

Wischmeier W.H., Smith D.D. (1958) : "Rainfall Energy and Relationship to Soil Loss". American Geophysical Union Transactions. Vol. 39, No. 2.

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