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MANAGEMENT IMPACTS ON NUTRIENT FLUXES IN BEECH-PODOCARP-HARDWOOD FORESTS

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SUMMARY: Clearfelling and downhill, skyline-hauler extraction of pulpwood and sawlogs in beech-podocarp-hardwood (PB5) forest, followed by slash-burning, produced increased streamflow yields of N, P and dissolved cations. Nutrient outputs in the first four months after treatment were from 1 to 1.5 times the normal annual output. Yields of Na, Mg, Ca, and K were from 1 to 6 times the normal output; K output showed the largest increase. Nutrient and cation concentrations in streamflow remained within drinking water quality limits except for 12 hours following burning, when ammonium-N was greater than 0.5 mg/l.

Losses of K from this treatment appear greater than any reported in the literature and constitute 5% of the readily-available K, but less than 0.1% of the total K capital in the forest and soil. N and P losses are in the low to middle range of results reported from elsewhere.

The high K losses are related to: (1) the combination of steep terrain, complete pre-extraction felling, and the logging method, which concentrated crown material near the stream; (2) the greater fire intensity near the stream which, because of the fuel concentrations and an up-valley wind, converted much of the slash to K-rich ash; and (3) two small storms which occurred shortly after burning and removed most of the ash from the catchment.

INTRODUCTION

Nutrient fluxes and the nature of nutrient cycles in most indigenous forest ecosystems in New Zealand are poorly understood. Miller (1963a, 1963b, 1968), Claridge (1970), Aldridge and Jackson (1973) and others have documented the nutrient fluxes in hard beech (*Nothofagus truncata*)-dominated forest at Taita. Information for other indigenous forest types is sparse. Much less is known about the magnitude of alterations to nutrient cycles caused by logging and burning of indigenous forests.

This paper outlines the nutrient inputs and outputs in a beech-podocarp-hardwood forest in North Westland and describes the initial impacts of clear-felling and controlled burning on nutrient outputs in streamflow. It does not attempt to do a complete accounting of total nutrient flows or all flux pathways. Its objective did not give any consideration to nutrients attached to sediment, removed in merchantable logs, or volatilised during the burning operation.

The data used in this study derive mainly from the calibration phase of the Maimai catchment study, 3 km west of Reefton (Pearce *et al.*, 1976), and from a preliminary logging trial carried out in catchment 7 (M-7) of the Maimai study. Some additional data from the Big Bush catchment study, 5 km north of the Hope Saddle on State Highway 6 between Nelson and Murchison, are used.

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SITE DESCRIPTION

The Maimai catchment study is located within the northern portion of Tawhai State Forest, which lies on the divide separating the Inangahua and Mawheraiti rivers. The forest is underlain by moderately weathered, firmly compacted, and poorly to moderately permeable, early Pleistocene gravels of the Old Man Group. Local relief is in the range of 100-150 m, and slopes are short (less than 300 m) and steep (average of 36°). The soils are typically stony, podsolised, yellow-brown earths of the Blackball Hill Soils (Mew *et al.*, 1975). These soils are strongly weathered and are very low in natural fertility. Much of the total nutrient content is in the organic horizons (Mew *et al.*, 1977). The forest floor litter, fermenting and humus horizons, averages 17 cm in thickness (Webster, 1976).

The forest cover is beech-podocarp-hardwood forest (N.F.S. Type PB5) dominated by hard beech, rimu (*Dacrydium cupressinum*), and kamahi (*Weinmannia racemosa*), with red beech (*N. fusca*), miro (*Podocarpus ferrugineus*), quintinia (*Quintinia acutifolia*), southern rata (*Metrosideros umbellata*), and silver beech (*N. menziesii*) as sub-dominant species. Mean annual rainfall (for the period 1963-1975) is

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2610 mm. Rain falls, on average, 186 days per year in Reefton, and snow falls on 2 days.

Nine small (1.6-8.3 ha) catchments on the south-facing slope of Powerline Stream (informal name) have been instrumented with V-notch weirs and sediment traps (Fig. 1). Catchments 7 and 9 have 2:1 broad-crested weirs and the remainder have 90° sharp-crested weirs. Rainfall is recorded at four locations and throughfall is measured at one site in catchment 8 (M-8). The nutrient content of rainfall is measured from samples collected at the meteorological station.

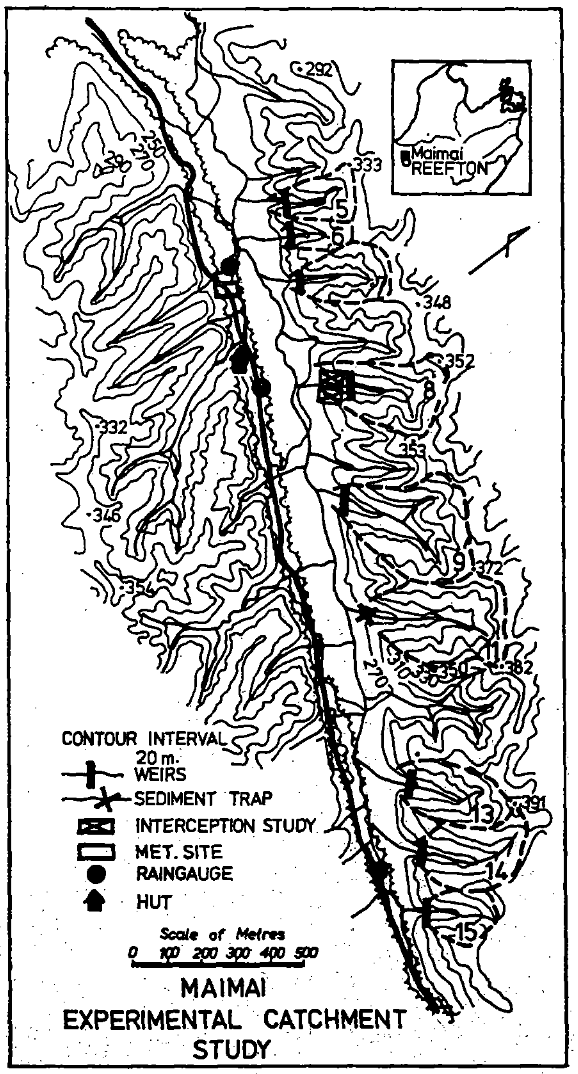

FIGURE 1. *Topographic and location maps, Maimai catchment study.*

Catchment 6 (M-6), with an area of 1.63 ha, is used as a control comparison catchment for the purpose of this study. It lies immediately west of M-7 and is one of two control catchments selected for the main, six-catchment experiment which is being undertaken in the Maimai study (Pearce *et al.*, 1976). Data from a two-year calibration (undisturbed) period indicate that M-6 is representative of the group of catchments in terms of annual and storm-period runoff, flow duration, and dissolved chemicals. Catchment M-6 thus serves as a fairly accurate representation of M-7 in the undisturbed state. The discharge of this catchment has equalled or exceeded 1.0 $\mathrm{l.sec^{-1}.ha^{-1}}$ only 10.9% of the time and 10.0 $\mathrm{l.sec^{-1}.ha^{-1}}$ 0.4% of the period of record.

M-7 is a steeply incised, narrow catchment of 4.14 ha. Over the period of record, discharge has exceeded 1.0 $\mathrm{l.sec^{-1}.ha^{-1}}$ only 14.4% of the time and 10.0 $\mathrm{l.sec^{-1}.ha^{-1}}$ 0.3% of the time. No pre-logging monitoring was carried out as M-7 was not originally included in the Maimai study.

METHODS

Sample collection

Water samples have been collected periodically in six of the Maimai catchments since December 1974. Baseflow samples have been obtained mainly by hand, together with precipitation and throughfall samples. Automatic discrete and bulk samplers were used to collect some stormflow and most of the logging and burning period samples. Natural polythene containers have been used to gather rainfall samples at the hut meteorological station, and throughfall/leaf drip samples have been taken out of the M-8 throughfall collection system.

All water samples were placed in 1000 ml or 500 ml natural polythene bottles, labelled with the appropriate information, and then preserved with 40 mg/l mercuric chloride and frozen. The frozen samples were air freighted to Rotorua in insulated containers for analysis.

Analytical procedures

Phosphorus (P) and nitrogen (N) contents of the water samples were analysed on an autoanalyser system after filtration with GF/C filters. Indophenol colorimetry (ascorbic acid method) was used to determine soluble ortho-phosphate P, hydrazine copper sulphate reduction for nitrate N, and indophenol colorimetry (cyanuric acid method) for ammonium N. Total N and total P were measured by ultraviolet photo-oxidation of unfiltered samples and subsequent analysis for the nitrate N and ortho-phosphate P forms. Sodium (Na), potassium

(K), magnesium (Mg) and calcium (Ca) were determined by atomic absorption spectrophotometry.

Catchment 7 treatment

Because of the terrain and difficulties in constructing either skidder-access tracks or ridge-top roads, the N.Z. Forest Service Experimental Utilisation and Management Unit in Reefton decided to attempt a downhill, skyline-hauler log extraction technique (Bryan *et al.*, 1977). Both the terrain and the forest type of the Maimai area are typical of the areas that may be converted to *Pinus radiata* if any major West Coast forestry project goes ahead. Such a project would require that conversion areas be logged to pulpwood specifications. Thus, this logging trial extracted all wood down to a 7 cm small-end diameter, and minimum log length of 2 m. The entire 5 ha catchment was felled prior to extraction to allow selection of the most favourable position for the overhead cable (skyline) on which logs were hauled out to the logging area. The bulk of the wood was extracted with the skyline in a position immediately adjacent to the stream. Because the skyline was next to the stream, no riparian protection strip was left and large quantities of slash (up to 3 m deep) accumulated in and above the streambed. The combination of prefelling, steep slopes, and hauling down the line of the stream resulted in much of the tree crown material accumulating in the valley bottom.

This logging technique may seem unduly harsh and insensitive to environmental protection requirements. In fact, it is a serious attempt to achieve a satisfactory trade-off between several undesirable effects of logging in this terrain. In particular, logging roads are reduced to the minimum distance and are located in valley bottoms or on easy slopes where erosion problems associated with road construction are far less serious than those commonly found in ridge-top roading.

After completion of the logging and a short period to allow for drying of slash material, M-7 was burned in late February 1977. The burn was successful in yielding a clean site. The heavy accumulations of slash in both gully bottoms and the main stream channel were almost entirely consumed, leaving substantial volumes of ash.

RESULTS

Rainfall/throughfall/inputs

The concentrations of nutrients in rainfall, shown in Table 1, part A, were very variable. This was a result of meteorological factors such as differing storm track directions and air mass histories and contamination from ground sources such as dust, insects and litter. The Maimai input values are of the same order of magnitude as those reported by Miller (1963b) and Claridge (1970) at Taita. With the exception of P and K, the inputs of nutrients in rainfall at Taita are two to three times those in the Maimai study. This is expected, since the Maimai site is further from the sea and in the rain shadow of the Paparoa Range.

The throughfall data (Table 1B) should be viewed with some caution as they represent a very limited number of samples. However, they do reveal some interesting trends which were also noted by Miller (1963b). Potassium and P appear to be leached out of the canopy in throughfall (actual throughfall plus leaf drip) and Na tends to be filtered out of the incoming precipitation.

Undisturbed streamflow outputs

The mean streamflow nutrient concentrations for M-6 are shown in Table 2. These values include weekly baseflow samples and some detailed sets of storm samples taken during 1975. Total annual output was calculated by using (1) the flow duration curve method, and (2) the grand mean method. The first method involved determining group means for samples in nine flow classes and then using those

TABLE 1. *Estimated nutrient inputs in total annual precipitation and throughfall, Maimai Catchment Study.*

	Total P	PO_4-P	Total N	NO_3-N	NH_4-N	Na	K	Mg	Ca
A. *Total rainfall: 2600 mm*									
Mean concentration (mg/l)	.010	.006	.108	.025	.028	1.11	.22	.15	.08
Input (kg/ha)	.26	.16	2.81	.65	.73	28.86	5.72	3.90	2.08
B. *Throughfall: 1900 mm*									
Mean concentration (mg/l)	.039	.020	.122	.048	.015	.85	1.16	.18	.22
Input (kg/ha)	.74	.38	2.32	.91	.29	16.15	22.04	3.42	4.18

means in conjunction with the flow frequency distribution (flow duration curve) to produce total output. The second method used the grand mean for all samples across the full range of flows and the total annual water yield to determine nutrient output. Despite the different approaches of these two methods they produced similar results.

Outputs of total P and ortho-phosphate P were about 1.5 times the rainfall input. For N, total N and nitrate N outputs were two-thirds the input and ammonium N output was one-third the input. Cation outputs in streamflow, except for Ca, exceeded inputs by a factor of about 1.3. The Ca output was greater than input by a factor of seven. The excess cation output over input is normally supplied by mineral weathering. The large excess of Ca in this instance is surprising, since the parent materials of the Old Man Gravels are not particularly Ca rich.

10 times those observed in M-6, and P concentrations were up by a factor of 2 to 5. The maximum concentrations during the pre-burn period were 0.103, 0.056, 0.508, 0.172, and 0.090 mg/l for total P, ortho-phosphate P, total N, nitrate N, and ammonium N, respectively. The N and P levels were approaching those of the control catchment (see Fig. 2, total N) prior to burning. During the 92 days after logging, outputs of total P, ortho-phosphate P, total N, nitrate N, and ammonium N were 94, 67, 98, 77 and 83% of the normal annual output.

Catchment M-7 was burned on 25 February 1977. Two small storms which occurred during the next two weeks produced outputs of both N and P which were substantial but short-lived. Three weeks after the burn, concentrations and yields were approaching pre-treatment levels again. Maximum concentrations after the burn were 0.413, 0.326, 1.242, 0.425,

TABLE 2. *Estimated yearly nutrient outputs (1975); Maimai Catchment 6 and Big Bush Catchment 1.*

	Total P	PO_4-P	Total N	NO_3-N	NH_4-N	Na	K	Mg	Ca
A. *Maimai Catchment 6: 1550 mm runoff*									
Mean concentration (mg/l)	.025	.015	.107	.031	.015	2.29	.48	.27	.93
Output estimated from flow duration curve (kg/ha)	.35	.21	1.58	.44	.23	35.12	7.29	4.18	13.88
Output estimated using annual mean (kg/ha)	.39	.23	1.66	.48	.23	35.49	7.44	4.18	14.42
B. *Big Bush Catchment 1: 700 mm runoff*									
Mean concentration (mg/l)	.030	.022	.084	.028	.014	3.00	0.61	0.40	1.16
Output estimated using annual mean (kg/ha)	.21	.15	.59	.20	.10	21.00	4.27	2.80	8.12

As a comparison to catchment M-6, mean nutrient concentration and estimated output data for catchment 1 (BB-1) of the Big Bush catchment study in southern Nelson are also shown in Table 2. This area is considerably drier than the Maimai region with one-half the runoff. The area is underlain by the similar, but less weathered, Moutere Gravels. The forest type is also PB5 but is a more open-structured hard and red beech forest with a less dense understorey. Nutrient outputs in BB-1 appear to be in about the same proportions as those at Maimai.

Logging and burning effects

Nitrogen and P outputs in M-7 were distinctively above normal after logging (Fig. 2). During this period slash was lying on the ground and decomposing. Nitrogen concentrations were typically 2 to

and 0.798 mg/l for total P, ortho-phosphate P, total N, nitrate N, and ammonium N, respectively, and, except for ammonium N, remained well within water quality standards. During a 12 hour period over the night of the burn, ammonium N exceeded the 0.5 mg/l upper limit for drinking water. Nutrient outputs during the first 21 days after the burn were 54, 52, 44, 20, and 57% of the normal annual outputs of total P, ortho-phosphate P, total N, nitrate N, and ammonium N, respectively.

By far the most spectacular responses to the logging and burning of catchment M-7 were the increases in cation outputs. Potassium, Mg, Ca, and Na losses during the post-logging and pre-burning phase were 245, 103, 58, and 45% of the annual outputs in the undisturbed catchment. Maximum concentrations after logging reached 7.74, 1.43, 2.69 and 3.95 mg/l for these four elements. As is clearly

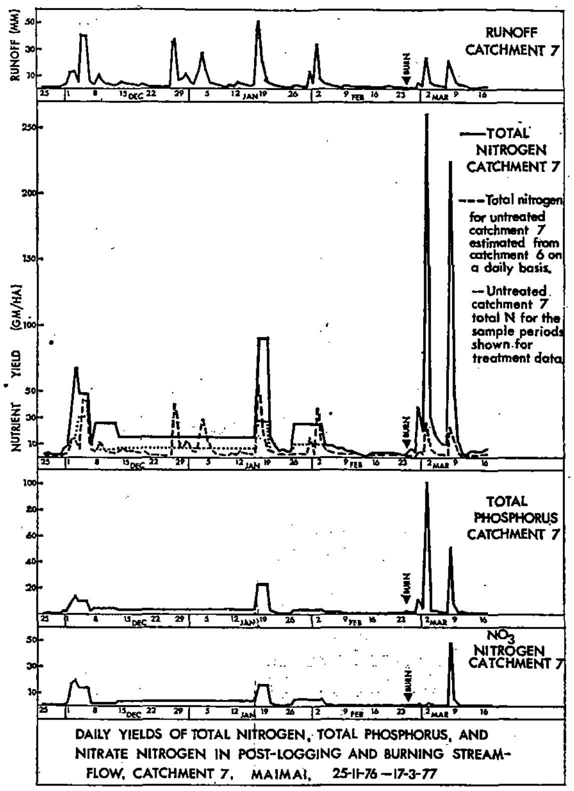

FIGURE 2. *Catchment 7 post-logging and burning nutrient outputs.*

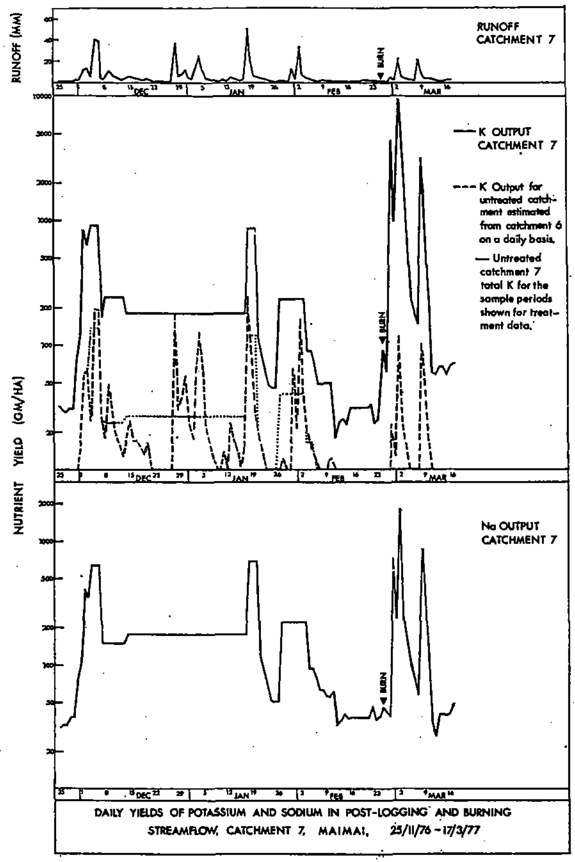

FIGURE 3. *Catchment 7 post-logging and burning cation outputs.*

indicated in Figure 3, the burning greatly increased nutrient losses, especially that of K. Outputs for the 21 days subsequent to the burn were 295, 89, 76 and 14% of the annual figures for K, Mg, Ca, and Na, respectively. Peak levels reached 135.60, 12.54, 25.79, and 12.34 mg/l but were well within drinking water quality limits. The K output from M-7 during the small storm on 2 March was 100 times that from the undisturbed catchment.

The total increases in nutrient output during the

TABLE 3. *Nutrient outputs in stream flow after logging and burning, Catchment 7, Maimai Catchment Study.*

Catchment Condition	Time (days)	Total P	PO_4-P	Total N	NO_3-N	NH_4-N	Na	K	Mg	Ca
					(All in kg/ha)					
Pre-logging (estimated from Catchment 6)	365	.35	.21	1.58	.44	.23	35.12	7.29	4.18	13.88
Post-logging and pre-burning	92	.33	.14	1.55	.34	.19	15.67	17.89	4.29	8.05
Post-burning	21	.19	.11	.69	.09	.13	4.98	21.47	3.72	10.48
Post-logging and burning	113	.52	.25	2.24	.43	.32	20.65	39.36	8.01	18.79

113 days after the treatments to catchment M-7 were carried out are listed in Table 3. The yields of N and P were 1.0-1.5 times the annual output of the undisturbed indigenous forest catchment. Since concentrations of the various forms of N and P were returning towards pre-treatment levels, the total annual outputs of N and P for the first post-logging year would probably be about two or three times normal. The loss of Na was least, at 60% of the annual figure, with an estimated output during the first year of about double the normal. The yields of Ca and Mg during the first 113 days were 1.4 and 1.9 times the normal annual yield. Losses of these two elements would probably be two to three, and three to five times normal, respectively, over the first year. The K output was 5.4 times the annual figure for the undisturbed M-6 and would probably be 8-10 times normal during the first year after treatment.

DISCUSSION

Nutrient outputs

Most of the nutrient outputs resulting from the logging and burning of Maimai M-7 lie towards the low end or middle of the range reported for North American studies. Losses of nitrate N in streamflow in $kg.ha^{-1}.yr^{-1}$ were reported to be 103.9 the first year at the clearfelled and herbicide-sprayed Hubbard Brook W2 (Pierce *et al.*, 1970); 11.0 in the stripcut Hubbard Brook W4 (Hornbeck *et al.*, 1975); 3.0 from a clearfelled catchment at Fernow Forest (Aubertin and Patric, 1974); and 0.7 during the first twelve months in a clearfelled and burned catchment at the Andrews Forest (Fredriksen, 1971). Calcium outputs were 77.5, 23.0, 6.5, and 81.4 $kg.ha^{-1}.yr^{-1}$ in the previously mentioned Hubbard Brook W2, Hubbard Brook W4, Fernow, and Andrews studies.

The large increase in the yield of K in streamflow from M-7 appears to be larger than anything previously reported in the literature from other catchment studies. The loss of K from Hubbard Brook W2 amounted to 23 kg/ha the first year and 36.5 the second. Most other studies report K losses in streamflow of 1-10 $kg.ha^{-1}.yr^{-1}$. The high yield of K from M-7 appears to be related to four factors. Firstly, the combination of prefelling, the steep terrain, and the logging method concentrated slash, especially crown material, into the stream bed area. Twigs, leaves, and bark form the largest pool of readily mobile K. Miller (1963b) estimated that in hard beech stands 24.8 $kg.ha^{-1}.yr^{-1}$ of K is cycled from foliage to the forest floor in leaf-drip. While branches, twigs, and leaves constitute only 15% of the biomass of beech, they contain 35% of the tree K content. The second factor aggravating K losses was the intensity of the burn. The fire was very intense, especially in the streambed area and gully bottoms, because of the heavy concentrations of slash and a fire-induced wind blowing up the valley. Large quantities of ash were left in the vicinity of the stream. Thirdly, the combination of terrain and the logging technique used prevented the use of a buffer strip which might have prevented slash from accumulating in the streambed, or limited any downslope movement of the ash. The fourth factor was the occurrence of rainfall 5 and 11 days after the burn. These storms, with maximum daily runoff of 23 mm and 22 mm respectively, certainly contributed to the movement of K in streamflow. Johnson and Needham (1966) noted only minor effects of a wildfire on the cation content of a stream in California because of the occurrence of a very light rainfall which allowed the ash to dissolve and leach into the soil.

The impact of the high losses on the K cycling in the beech-podocarp-hardwood forest can be estimated using data from Miller (1963a, 1963b), Mew *et al.* (1975), Adams (1976) and Mew *et al.* (1977). Miller (1963a) estimated that the K content (immobilised pool) of beech forest is about 446 kg/ha of which leaves, twigs, and branches (15% of a total tree) contain 67 kg/ha. He also determined that the mobile, fast-cycling pool of K found in leaf drip amounted to 31 kg/ha (Miller, 1963b). This compares with 22 kg/ha measured in the Maimai study. Rainfall inputs of K were 5.7 kg/ha for both the Taita and Maimai sites. Mew *et al.* (1975) and Adams (1976) estimated that average figures for K in the humus layers and upper 75 cm of soils of the Inangahua depression are 108 and 270 kg/ha, respectively. Thus, considering these source pools of K, the amount lost from catchment M-7 in 113 days' streamflow amounted to 5% of the readily- available K. In relation to the total K capital of 51 000 kg/ha present in the beech forest ecosystem (Mew *et al.*, 1975), the increased yield represents a loss of only 0.08%. The streamflow losses were 59% of the branch-leaf immobilised pool, and were greater than the fast-cycling pool of K.

Management implications

No real water quality problems for downstream areas were created by the logging and burning of M-7. Ammonium N levels did exceed the maximum limit for a few hours during the burn, but these would have been quickly reduced by flow from unburned areas. Nitrate N, often claimed to be a major source of water quality problems, stayed well within the limits for drinking water. A rough estimate of the initial impact on water quality of the logging/burning methods described above over a large basin is as follows. The annual area of conversion required to sustain an exotic timber logging industry from 1990 onwards is about 400 ha. Much of this conversion would occur in the Grey catchment because of the combinations of forest type, terrain, and the location of the present logging industry. If the 400 ha were logged and burnt in the manner of catchment M-7, using the figures for the first 113 days as a minimum estimate of the first year output, and three times the 113-day yields as a likely upper limit for the first year yield, the additional input into the Grey River per year would be 210-630 kg P, 900-2700 kg N, 8260-24 780 kg Na, 15 750-47 250 kg K, 3200-9600 kg Mg, and 7510-22 530 kg Ca. The additional input of K averaged over the entire year would add 0.002-0.006 mg/l of K at the mean annual flow of the Grey at Dobson. The actual effect on K levels would depend on the timing of logging and burning in relation to low flows; nevertheless, the downstream impact seems likely to be small, even with the most adverse timing.

If the outputs of N and P found in this study are typical of the effects of logging and burning of beech-podocarp-hardwood forest, then the likelihood of dramatic eutrophication of downstream waters appears to be small. More research is needed on this aspect to determine what the long-term impacts will be.

The most adverse impact of this particular logging trial was the K output in streamflow. This would probably be considerably reduced by limiting the accumulation of slash in the streambed area. In particular, reducing the volume of leaves, twigs, and small branches reaching the stream would help. Retention of even a limited stream protection strip would be of great value in preventing the build-up of fine slash in the stream. Whether this is feasible with the downhill hauler logging method is as yet not known. Further trials are now underway where improved protection of the stream zone is being attempted using the same logging system.

The accelerated nutrient output from M-7 may necessitate replacement of selected elements with commercial fertilisers before establishment of a crop of exotic trees can be considered. Since the nutrient losses in streamflow during the first year are likely to average two to three times the 113 day figure, the fertiliser required to replace these losses would amount to 5.2-15.6 kg/ha superphosphate (P), 4.9-14.7 kg/ha urea (N), 79-237 kg/ha KCL (K), 16-48 kg/ha calcined magnesite (Mg), and 47-141 kg/ha lime (Ca). Sodium is not normally applied as a fertiliser. The fertiliser requirement to replace losses in streamflow would amount to 152-456 kg/ha at a cost of \$20-\$30/ha, excluding application cost. Under a suggested silvicultural regime for *Pinus radiata* on West Coast hill country, the first large application of fertiliser would occur after the first thinning at age eight. This would involve 1000 kg/ha superphosphate and 435 kg/ha urea. Sidedressings of K, Ca and Mg fertilisers could be required at the time of establishment where localised reductions in nutrient availability occur as a result of the particular combination of logging method and burning described in this paper.

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