THE PRACTICE OF FORESTRY WITHIN AUCKLAND'S OPERATING WATER CATCHMENTS

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SUMMARY: Part of Auckland's water supply is obtained from 16,190ha in the Hunua ranges. Some 7600ha of this area is suitable for production forestry. The desirability of forestry practice within an operating water catchment is discussed, experimental work being done is outlined and tentative conclusions drawn.

Providing adequate safeguards are maintained there appears to be no reason why forestry should not be practised within catchments operated for domestic water supply.

INTRODUCTION

The water for the half million people living in the Auckland metropolitan area comes mainly from two upland catchment areas, the Waitakere Ranges in the north-west and the Hunua Ranges in the south-east. A total of some 21,000ha of land within 50km of Auckland is used for water collection and storage purposes.

It was originally proposed that these two catchment areas should be used solely for water production. This is wasteful policy for land use as certain other activities should be possible on this land without detriment to the water supply. One such activity is forestry.

In the early 1960s a small forestry section was formed within the Water Department, the aim being to plant exotic forest species on about 1200ha of reverting farmland around the edges of the Hunua catchments. Further consideration has recently been given to the whole idea of forestry within water catchments, and it has been decided to go ahead with the planting of exotic species, mainly radiata pine (*Pinus radiata*), over the 5600ha of the area which was originally cleared for farming (Fig. 1). At the same time management of parts of the indigenous forest is being attempted.

PHYSIOGRAPHY OF THE HUNUA AREA

This has been described in detail by Barton (in press). The Hunua Ranges are a group of fault defined hills lying 40-50km south-east of Auckland (Firth 1967). The basement rocks of

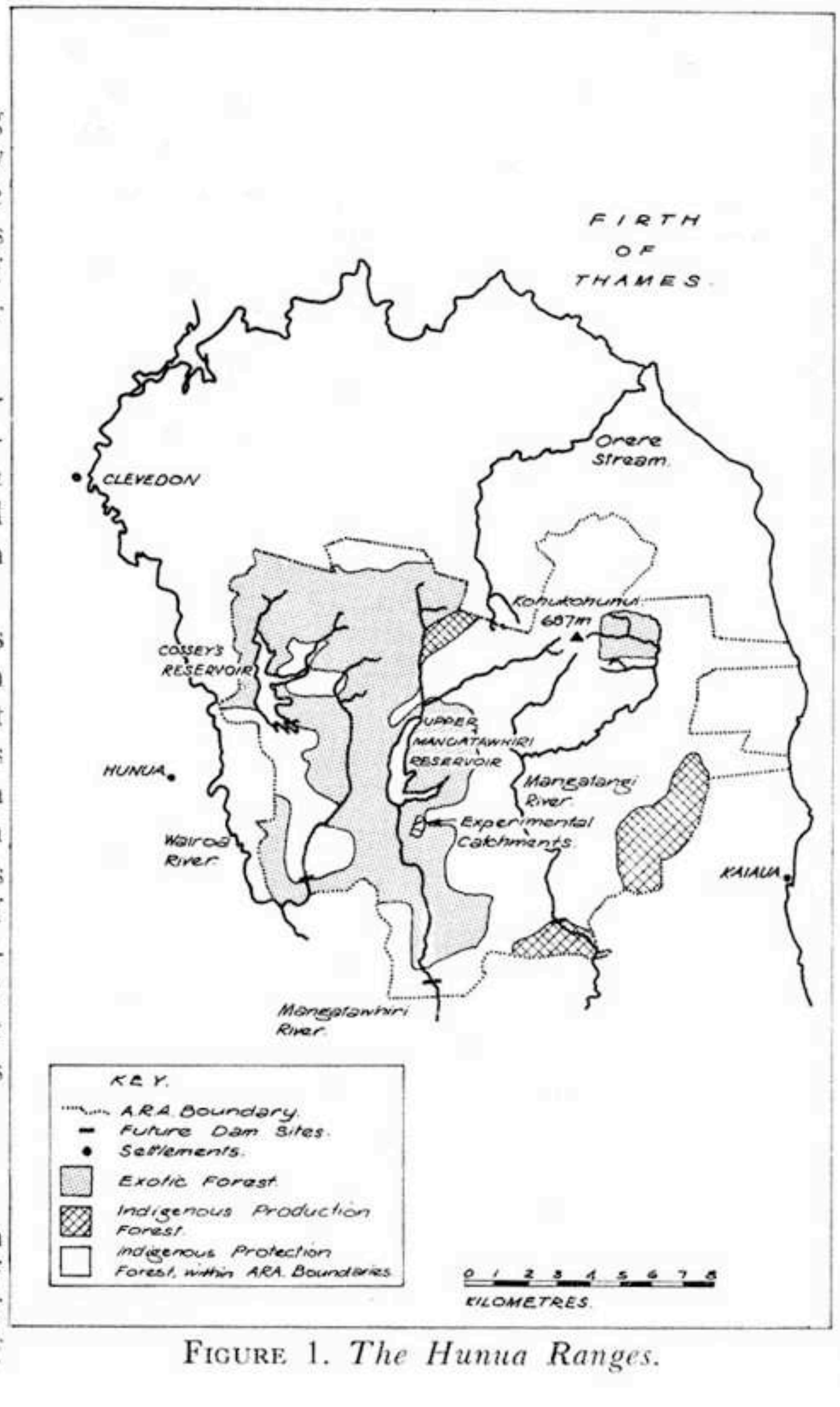

FIGURE 1. *The Hunua Ranges.*

the area are mesozoic greywackes and argillites with a remnant of tertiary sandstone in the north. Soils are predominantly Te Ranga clay loams which in many places are mixed with Hamilton ash to form Hunua clay loam.

The area is drained by three main river systems, the Mangatangi and Mangatawhiri, flowing south to the Waikato, and the Wairoa which flows south and then swings north into the northern part of the Firth of Thames (Fig. 1).

Rainfall over the area varies between 1500mm and 2390mm per year and the mean annual temperature varies from 10.5°C to 13.8°C, depending on location. Screen frosts occur on up to 39 days each year—usually between May and September. Light and infrequent snow falls occur above 450m altitude. Winds of up to 115 km/hour are sometimes experienced, especially from the north-east.

Indigenous forest covers about 65 percent of the total catchment area, the remainder carries scrub, grass or exotic forest. Three quarters of the total forest is a tawa-podocarp association, for the most part poorly stocked with merchantable trees and, except for some small areas, it has not been logged. The remaining indigenous forest includes kauri-hard beech-tanekaha forest, tarairi forest, montane scrub forest and coastal forest. Kauri forest, which is mainly confined to the sourth and east, and tarairi forest, to the north, are the most important of these other types.

HISTORICAL BACKGROUND

Europeans began to settle the perimeter of the Hunua Ranges about 1860, although prior to this there had been a considerable Maori population. Land within the ranges was cleared between 1885 and 1920, but during the depression in the 1930s the cleared land began to revert to forest.

Some parts of the area were reserved for water supply purposes as early as 1919, but most of it was acquired between 1936 and 1960. In 1956 the first earth dam, on Cosseys Creek, was completed, and the Upper Mangatawhiri dam was finished in 1965. The Wairoa and the Mangatangi dams are scheduled for completion in 1976 and the Lower Mangatawhiri about 1983. At present the Wairoa and Mangatangi catchments are operating on a "run of the stream" basis.

Thus four of the five potential catchments are being used, supplying up to 53 million gallons of water per day at present.

CURRENT CONCEPTS IN FOREST AND WATER RELATIONS

After analysing 39 studies of forest treatment on water yield Hibbert (1967) concluded that:—

1. reduction of forest cover increases water yield;
2. establishment of forest cover on sparsely vegetated land decreases water yield;
3. response to treatment is highly variable and, for the most part, unpredictable.

In addition to the studies discussed by Hibbert there have been many papers written on the effects of the vegetation cover and its manipulation on water yield and quality. Unfortunately, most of these relate either to the northern hemisphere, where forest types are vastly different to those in New Zealand, or to relatively dry areas such as South Africa or Australia.

Water Yields

Misconceptions about the relationship between forests and water yields are widespread. One such misconception is that forests increase rainfall, but the evidence for this is inconclusive (Rutter 1967). Another long held belief is that transpiration and evaporation of water is greater from forests than low vegetation. This appears to have some basis (Rutter 1967), but the evidence is largely qualitative (Pereira 1967). The reasons are not clear but they are probably related to the varying reflection coefficient of different vegetation types, the aerodynamic roughness of different vegetations, the stomatal variation of different species, the ability of the leaf of a species to hold water and the depth of the rooting system (Rutter 1967, Morris 1969, Zinke 1967).

On the other hand Pereira *et al.* (1962) reported no difference in water usage between radiata pine, Mexican pine (*Pinus patula*), Monterey cypress (*Cupressus macrocarpa*) and bamboo thicket in East Africa when the roots of all four species descended less than ten feet (*ca.* 3m).

However, data from Australia (Bell and Gatenby 1969) indicates that an immature pine forest has a higher water yield than mature pine or eucalypt forests, from which yields are approximately equal. Morris (1970) felt that water use may be largely independent of vegetation type but dependent upon rooting depth.

Although Zinke (1967) was able to assign interception storage values to different species, Pereira (1967) considered that attempts to assign characteristic water usage values to different species cannot succeed. The amount of water used by different species also depends upon such variables as soil types, vegetation density and rainfall quantities and intensities.

Removal of vegetation increases water yield in most instances (Hibbert 1967, Lull and Reinhart 1967, Witter 1965, Rich 1968) and the converse also applies (Watt 1969, Lull and Reinhart 1967, Hibbert 1967). However, there may be exceptions to the rule. McArthur and Cheney (1964) found that pine needle litter retards infiltration and increases surface runoff and Ayer (1968) showed that decreases in water yield were insignificant 18 years after planting, although tree growth was slow and canopy closure not complete.

Partial cuttings and thinnings do not have a great effect on yields; at least 20 percent of the vegetation must be removed before any significant increase in water yield occurs (Hibbert 1967, Lull and Reinhart 1967). What then is the best method of managing a forest for timber and water production? Lull and Reinhart (1967) report only minimal response to thinning, partial cutting and all-aged management, but even-aged management, which involves the clearing of areas of forest and then re-planting, can increase water yields considerably. For equal volumes of timber cut, selection felling is estimated to be only 38 percent as effective as clear-cutting.

Water Quality

Sartz (1969) stated "It is not the disturbance itself that matters but rather how much it changes the physical characteristics of the watershed that affect its hydrologic behaviour". This statement is borne out by findings at Coweeta, North Carolina, where all vegetation in a forested catchment was cut and left lying (Dills 1957). The result was no increase in sedimentation but considerable increase in water yield. Factors contributing most to increased soil erosion following logging are exposure of mineral soil and compaction of the soil surface (Dyrness 1967, Sartz 1969, Bullard 1966).

Considerable work has been done in the field on the effects of logging and roading operations within water catchments. Tractor logging exposes about 23 percent, cable logging about 10 percent and horse logging about 12 percent of the soil (Garrison and Rummell 1951, Woolridge 1960 and Dyrness 1965). No figures appear to be available on the effects of rubber-tyred skidders, but the amount of disturbance caused by these is expected to fall somewhere between tractor and cable logging. Balloon logging, not yet tried in New Zealand, would cause very little erosion (Jeffrey and Goodall 1970).

Logging activities, particularly the formation of roads and skid trails, disturb the soil and cause erosion (Jeffrey and Goodall 1970, Packer 1967, Gilmour 1965 and 1971, Bullard 1966). At least 80 percent of the sedimentation caused by the development of mountain forests has been attributed to access road construction (Dunford 1960). However, it is possible to minimise the problem and this was proved at the experimental watershed in Fernow, Virginia using five calibrated catchments (Packer 1967). Turbidities of up to 56,000 ppm were recorded in one catchment subjected to uncontrolled roading and logging, whereas turbidities of 25-210ppm followed controlled activity and water from the untreated catchment showed a maximum turbidity of 15ppm. Fire breaks are also an important source of sediment. Gilmour (1965) found that soil loss from a bare firebreak was about 37 times greater than from a 30 year old pine plantation and 22 times that from low eucalypt forest. Basic safeguards which should be applied to road construction in water shed areas have been set out (Trimble 1959, Gilmour 1971, Lull 1962, Reigner and Ningard 1967). These involve minimising grades, keeping roads certain distances from streams, crossing streams on bridges or culverts and leaving strips of uncut vegetation beside streams and reservoirs.

The effects of fertiliser on water quality are little studied but this is an important consideration since, in the future, application of fertiliser to forest stands will probably increase. Evidence from Lake Rotorua (Mathews 1967) suggests that the amount of phosphate entering the lake from farmlands if fairly low and only about 1/40th of that entering in sewage. The use of limited quantities of fertiliser in watersheds may have little effect on water quality, but more study is needed.

Little is known about the use of herbicides and pesticides in water catchments. Tests in Pennsylvania and New Jersey indicated that with normal precautions 2,4,5-T could be used in municipal watersheds (Lull and Reinhart 1967). Pierce 1969) reported similar results with 2,4,5-T and Bromacil. Most herbicides, with the exception of metallic toxins such as arsenical salts, can probably be used safely in watersheds providing reasonable care is taken. However, the use of most persistant pesticides is a different question (Bullard 1966).

Research into the effects of grazing and fire on watersheds is limited. Fire, however, appears to have little effect unless it is so fierce that it burns the organic matter in the soil and exposes the subsoil to erosion (Sartz 1969).Excessive grazing destroys the litter layer and many plants in the lower storeys and compacts soil. These influences increase rates of erosion (Sartz 1969).

Conclusions

1. While it is likely that increased vegetation height does have an effect on water yield there is insufficient evidence, especially in New Zealand, to say what this effect is.
2. Water yield is probably affected by the relative mass of vegetation rather than the species although, once again, the evidence is inconclusive.
3. The removal of at least 20 percent of the vegetation from an area will increase water yields. Conversely, increasing the vegetation cover by planting trees on land previously covered with scrub or grass will eventually decrease water yields.
4. The chief cause of water pollution from logging operations is increased sedimentation from erosion, and this is caused, not by the felling of the vegetation, but by the mechanical methods employed to remove the timber.
5. Erosion caused by roading, firebreak construction and logging can be minimised.
6. The effects of using fertilisers, herbicides and pesticides on municipal watersheds are largely unknown.
7. Similarly, there is little evidence on the effects of fire and grazing animals within watersheds but the suggestion is that used in moderation they are not harmful.

The decision to proceed with foresty operations in the Hunua catchments was based to some extent on the conclusions outlined above. However, as many of these conclusions are by no means definite certain investigation and research projects are proposed to ensure the protection of the water supply.

CURRENT INVESTIGATIONS

Experimental Catchments

Three contiguous experimental catchments on the eastern side of the Moumoukai Valley were set up in 1967 (Fig. 2). All are steep sided with permanent streams and range in size from 8.83ha in the north to 11.42ha in the centre and 14.90ha in the south. The valley bottoms all contain some swamp areas. These are probably not important in the north and centre catchments but the swamp in the south catchment is approximately one hectare in extent and appears to have considerable effect on water flow and purity.

Five manual weekly rain gauges are maintained in the catchments, one in the centre of each valley, one on a saddle between the south and centre catchments and one on a spur in the south catchment. An automatic gauge is located 400m west of the catchments.

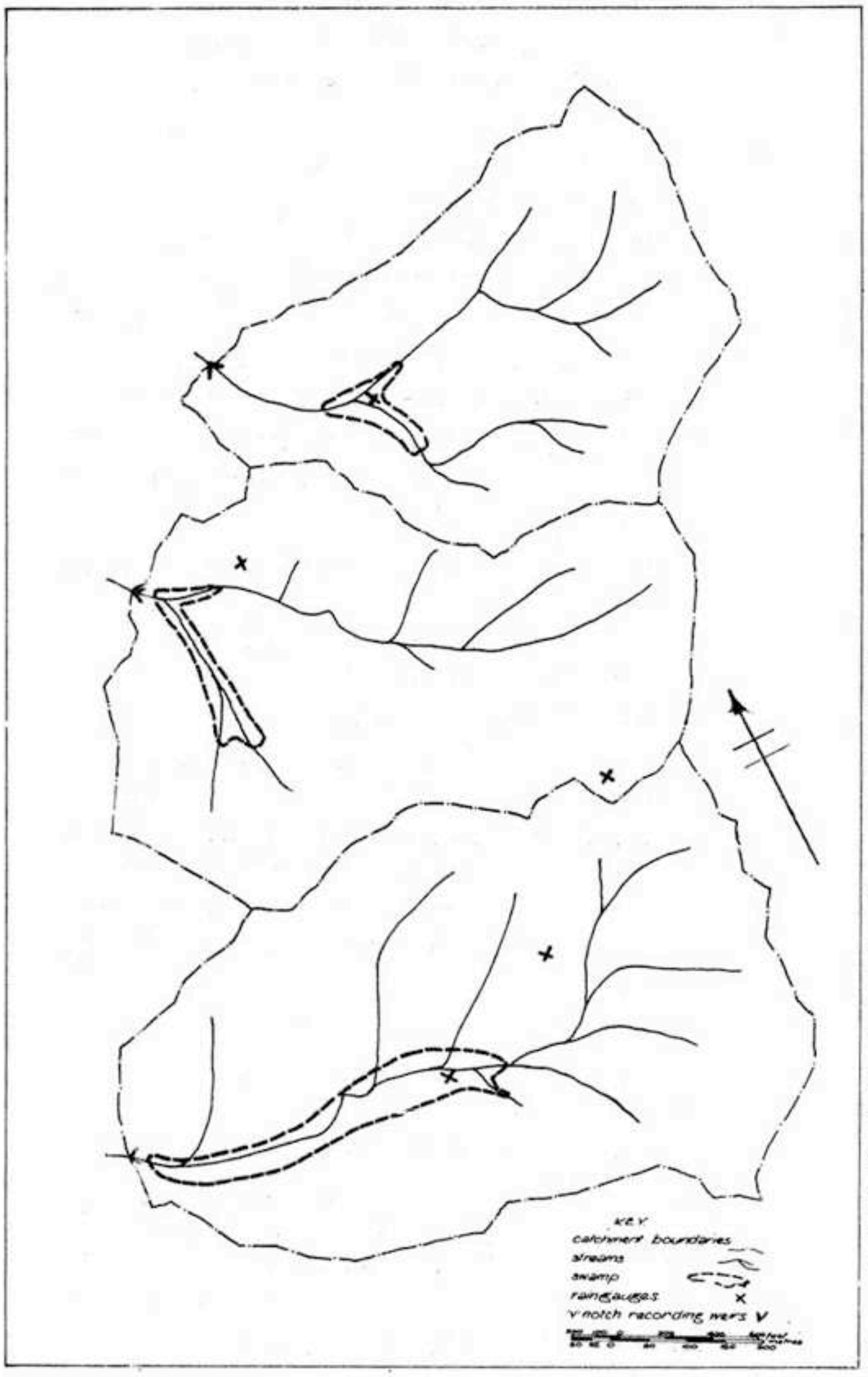

FIGURE 2. *Experimental catchments in the Hunua Ranges.*

Flow gauging using 'Lea' recorders began on these catchments at the beginning of 1968 and, at the same time, the larger vegetation, chiefly kanuka (*Leptospermum ericoides*), was felled to reduce the vegetation on each catchment to a mixture of low scrub, treeferns (*Cyathea* and *Dicksonia* species) and bracken (*Pteridium aquilinum* var *esculentum*). In March 1970 the vegetation on the south and central catchments was burnt and in the following August the south catchment was planted with radiata pine and the centre catchment with Japanese cedar (*Cryptomeria japonica*).

A comparison of total water flows from the three catchments has been made and this is illustrated in Figure 3. Following the removal of kanuka from the sourth and central catchments, the water yield increased and remained high until the following summer when new growth, especially that of bracken, reached its maximum. It was not until 18 months later, when the south and centre catchments were burnt off, that the yield from these two again exceeded that from the north catchment. This advantage was again lost by the following summer. Water yield from the south catchment is always relatively low during summer, but it rises to approximately equal the other two during winter. This is thought to be due to evapotranspiration from the swamp in this catchment during summer.

The increase in water yield following burning was calculated using the flow data for the nine months before and after the burn and, as a check, the difference between rainfall input and flow output for 12 months before and after the burn. The increased yield was between 25 million litres and 30 million litres per catchment over 12 months. This is equivalent to between 200mm and 220mm of rainfall. Because of the rapid regrowth of vegetation, especially of bracken, this increase is not expected to persist beyond the first year.

Stream turbidity has been analysed periodically since December 1969 and the various activities undertaken to date have had only a small effect on turbidity. The untouched north catchment often has turbidities as high or even higher than the other two, although the centre catchment records the greatest range and highest mean (Table 1). The south catchment is usually lowest due to the filtering effect of the swamp. The turbidity during a typical storm is compared with runoff in Figure 4.

Although there is little variation in pH between the three catchments (Table 1), it is inversely

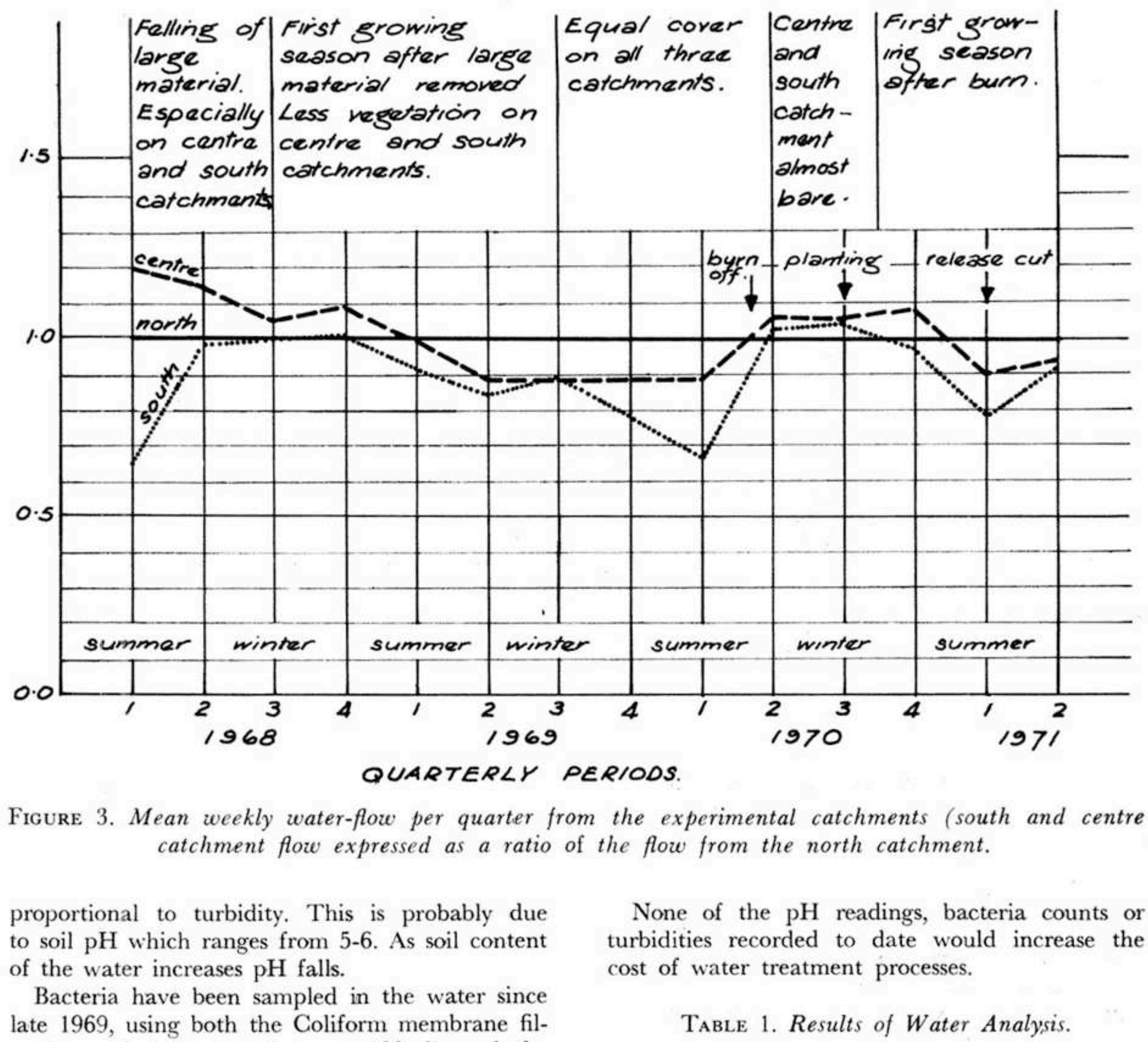

FIGURE 3. *Mean weekly water-flow per quarter from the experimental catchments (south and centre catchment flow expressed as a ratio of the flow from the north catchment.*

proportional to turbidity. This is probably due to soil pH which ranges from 5-6. As soil content of the water increases pH falls.

Bacteria have been sampled in the water since late 1969, using both the Coliform membrane filtration technique (number per 100ml) and the count on nutrient agar at 37°C after two days incubation (number per ml). Despite the fact that human activities have been quite heavy on the treated catchments at various times the bacteria count does not appear to have been significantly increased. The range of these counts are shown in Table 1. The readings are fairly consistent between the catchments with the undisturbed north catchment reading lowest. Seventy percent of all coliform counts are below 100.

None of the pH readings, bacteria counts or turbidities recorded to date would increase the cost of water treatment processes.

TABLE 1. *Results of Water Analysis.*

		Experimental Catchments			Hunua Raw Water
		North	Centre	South	Average
pH (37 samples)	Arithmetic mean	6.82	6.84	6.79	6.95
	Range	6.3-7.7	6.3-7.4	6.4-7.3	6.5-7.4
Turbidity (p.p.m.) (44 samples)	Arithmetic mean	19.8	24.6	13.9	6.7
	Range	3-150	1-175	1-25	0.7-9.6
Coliform/ 100 mls (23 samples)	Geometric mean	24.4	26.4	25.0	13.8
	Range	0.9-600	0.9-500	0.9-250	0.9-350
Agar/ml (22 samples)	Geometric mean	27.8	50.8	36.4	52.5
	Range	0.9-400	3-500	0.9-500	0.9-700

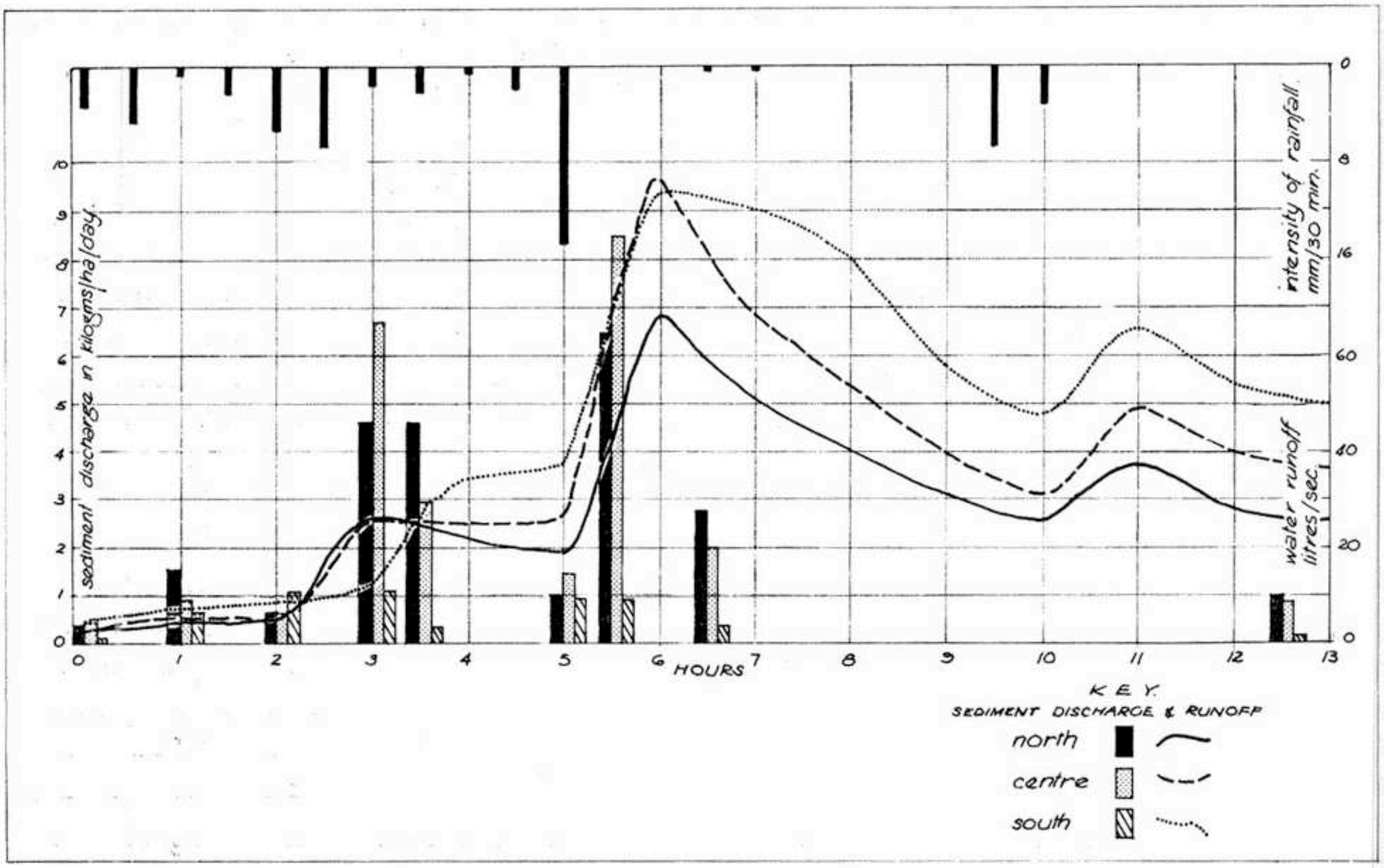

FIGURE 4. *Sediment discharged compared with rainfall intensity and water runoff from the three experimental catchments on 2 July 1971.*

Species Trials

The first of these was begun in 1961 when five acres of Douglas Fir (*Pseudotsuga menziesii*) were planted. Further trial planting has been carried out each year although it has not been very extensive since 1967. In all some 60 different species have been planted including 14 indigenous species, 10 *Pinus* species, 10 deciduous and four *Eucalyptus* species. Of all these only four have shown definite possibility with another ten worthy of further study (Table 2).

Present annual planting comprises 80-90 per cent radiata pine with the balance made up by blackwood, Japanese cedar and Mexican cypress. Further small plantings of some of the other species may be carried out. The three indigenous species will continue to be planted in selectively logged native forest.

TABLE 2. *Potential Forest Trees.*

Species with definite management potential	*Pinus radiata*	(radiata pine)
	Cryptomeria japonica	(Japanese cedar)
	Acacia melonoxylon	(blackwood)
	Cupressus lusitanica	(Mexican cypress)
Species worthy of further study	*Dacrycarpus dacrydioides*	(kahikatea)
	Dacrydium cupressinum	(rimu)
	Agathis australis	(kauri)
	Thuja plicata	(western red cedar)
	Chamaecyparis lawsoniana	(Lawson's cypress)
	Pinus patula	(Mexican pine)
	Picea sitchensis	(sitka spruce)
	Cupressus macrocarpa	(Monterey cypress)
	Populus Spp.	
	Eucalyptus delegatensis	(mountain ash)
	Pseudotsuga menziesii	(Douglas fir)

Growth rates of radiata pine vary considerably over the area, due probably to varying levels of available phosphate. On better sites height growth exceeding 1.5m per year can be obtained.

Indigenous Forestry

There are 10,000ha of indigenous forest in the Hunua Ranges—mostly on steep terrain and properly designated protection forest. However, possibly 2000ha could be economically and safely logged (Fig. 1).

The protection forest has been badly damaged in the past by noxious animals, especially goats and cattle. Because of this, and the possible effects of climatic changes, the forest is now in an unstable state (Barton in press). Animal numbers are being reduced and limitations placed on human use. To date this has been reasonably successful and the considerable reduction in animal numbers (over 33,000 animals including 6500 goats have been killed since 1962) has resulted in a visible improvement to the lower forest strata.

Production forest work to date has consisted of selection logging experiments aimed at managing pole stands of kauri in the lower Mangatangi valley. Results look promising but have not yet been fully analysed. As almost all the trees larger than 30.5cm d.b.h. were bled for gum between 30 and 40 years ago the timber is of relatively poor quality. The aim has been to remove the large trees leaving up to 750 stems per hectare of vigorous, unbled poles between 2.5 and 30.5cm d.b.h. Several plots were established in 1967 to study the response of kauri to thinning intensity and fertiliser application, and responses to fertiliser, particularly to a urea-superphosphate mixture, have been encouraging. Native trees—mainly rimu, kauri and kahikatea—are being planted in areas where stocking of naturally established trees is low, i.e. less than 250 stems/ha. This work was begun in 1970.

Application of Fungicide to Forest Stands

The effect of chemicals on the purity of the water supply is an extremely important question. As it seems likely that the needle blight, *Dothistroma pini*, which is present in all our *P. radiata* stands, will need to be sprayed with cuprous oxide for many years, the effect of copper on the water needs to be known. To date one pilot trial has been carried out. Samples of water were taken from a stream within the area sprayed in December 1970 (Table 3).

TABLE 3. *Copper Concentration in Streams.*

Sampling Time	Copper Concentration (parts per million)
Before spraying	less than 0.02 p.p.m.
During spraying	less than 0.02 p.p.m.
During first heavy rain following spraying	less than 0.02 p.p.m.

Application of Fertilisers to Forest Stands

At least some stands of radiata pine in the area are known to be phosphate deficient and aerial topdressing is expected to start shortly. As a check on the effect of phosphate application and in collaboration with the Forest Research Institute one of the experimental catchments described above was topdressed by hand in November 1971. Unfortunately the south catchment was chosen and although 4588kg of superphosphate was applied at the rate of 113g per tree, the phosphate discharged in the water did not rise significantly. This, it is suspected, was due to the swamp, which has effectively stopped any phosphate washed off the surface from leaving the catchment. Recent visual observations show the colour of the swamp to be markedly greener than a swampy area outside the catchment. Figure 5 indicates the total phosphorus yield compared with runoff and rainfall for a typical storm. Although this sampling was done eight months after the fertiliser was applied the yield of phosphate from the first storm after application showed a similar pattern.

CONCLUSIONS

Experimental Catchments

Few of the results show definite trends although they generally indicate that the various activities within the catchments have so far had no significant effects on water quality and quantity.

Species Trials

At present there is no doubt that radiata pine is the best economic proposition and present intentions are to manage it on a 35 year rotation

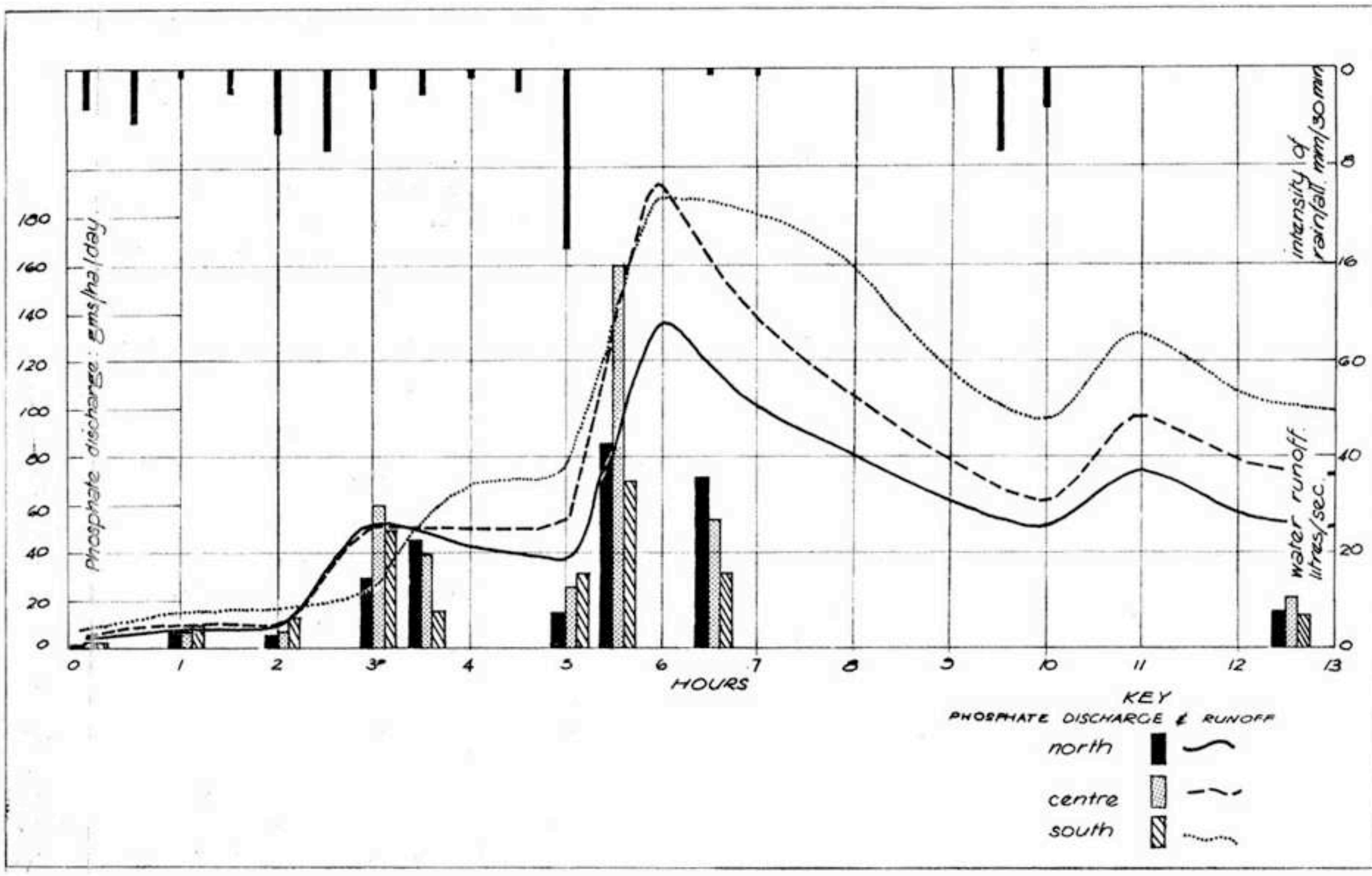

FIGURE 5. *Discharge of total phosphate compared with rainfall intensity and water runoff from the three experimental catchments on 2 July 1971.*

producing peeler logs and saw timber; however other possible species should be persevered with for two reasons.

1. Some species such as blackwood, Mexican cypress and kauri should have a higher unit value than radiata pine and could give almost as high a return per unit area.

2. If radiata pine is proven to use more water than other species it may become necessary in the future to replace it with one or more of these other species. In order to build up knowledge of the capabilities and potential of suitable alternatives it is necessary to continue planting them on a limited scale.

Indigenous Forestry

The work done in the field of noxious animal control is beginning to pay dividends but it will be necessary to persevere with intensive control for the foreseeable future since goat and possum populations increase quickly when hunting pressure is removed.

Management of pole stands of kauri appears to be a relatively successful operation. The selection logging programme will be continued at least for a few more years, removing some 700m^3 of timber annually. It is hoped to begin growth studies of rimu poles shortly.

Herbicide, Fungicide and Fertiliser Application

The careful application of herbicides, copper and superphosphate, appears to give no cause for concern, but knowledge is scanty and more detailed investigation is needed.

Erosion Control

The rate of sedimentation in the reservoirs might be higher than desirable. If this is proved then consideration will need to be given to re-revegetating slips and road cuttings. At present firebreaks are grassed and regularly mown.

Future Work

There are some aspects of forestry in watersheds which have been little explored to date and, whilst data obtained from the experimental catchments gives useful pointers, no attempt has yet been made to observe the effects of forestry operations on a wider scale.

A study will soon be done which will enable the effects of large scale land preparation on water turbidity to be more accurately assessed, and, in the future, studies of thinning and felling operations in the watershed will be made.

The stage has now been reached where water catchments can be used for timber production, providing adequate precautions are taken to ensure that water yield and quality are maintained.

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