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VARIATION OF WATER YIELD FROM CATCHMENTS UNDER INTRODUCED PASTURE GRASS AND EXOTIC FOREST, EAST OTAGO

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ABSTRACT

Eight years' data from four catchments in East Otago, New Zealand, two under introduced grass cover and two under exotic forest cover, were analysed for net differences in annual yields, quickflow volumes, delayed flow and recessions. Pasture catchments consistently yielded more water in all facets of the flow regime when compared to exotic forest catchments. Even for storms with high return periods (up to 100 years) causing simultaneous rainfall over all catchments, the forest catchments yielded less runoff. Recession curves of all catchments showed similar characteristics, but grass catchments consistently yielded more water during recession periods because they always commenced at higher discharges.

INTRODUCTION

In the East Otago region, South Island, New Zealand, there is a conflict of interest between pastoral grazing and forestry on the natural tussock country. The area is the catchment for both urban and rural water supply schemes for much of East Otago, and there has been concern that changes in land use may affect water supplied to these schemes.

This paper examines four catchments, two under introduced pasture grasses and two under exotic forest, to determine if they differ in hydrological behaviour.

THE STUDY CATCHMENTS

The four catchments analysed are in the headwaters of the Taieri River, and are located 40 kilometres southwest of Dunedin (Fig. 1). The catchments, ranging in area from 1.15 to 2.92 km^2, have each been instrumented with a Leupold and Stevens digital water level recorder behind a concrete weir with a sharp-crested 120^0 V notch. Theoretical ratings of all the weirs were confirmed by current meter gaugings. Each catchment has a network of storage rain gauges, and each land use pair has an automatic tipping-bucket rain gauge within it.

Haast Schist underlies the catchments, providing the parent material for Waitahuna Soils (yellow-brown earths) (New Zealand Soil Bureau, 1968). The catchments all have perennial flow, are within 5 km of each other and have a similar aspect. Each catchment was cleared of native grasses, tussock and scrub and developed into exotic forest or introduced pastoral grasses more than a decade before this study began. The two grass catchments (G1 and G2) still have some shady gully sides in manuka scrub, and gully bottoms

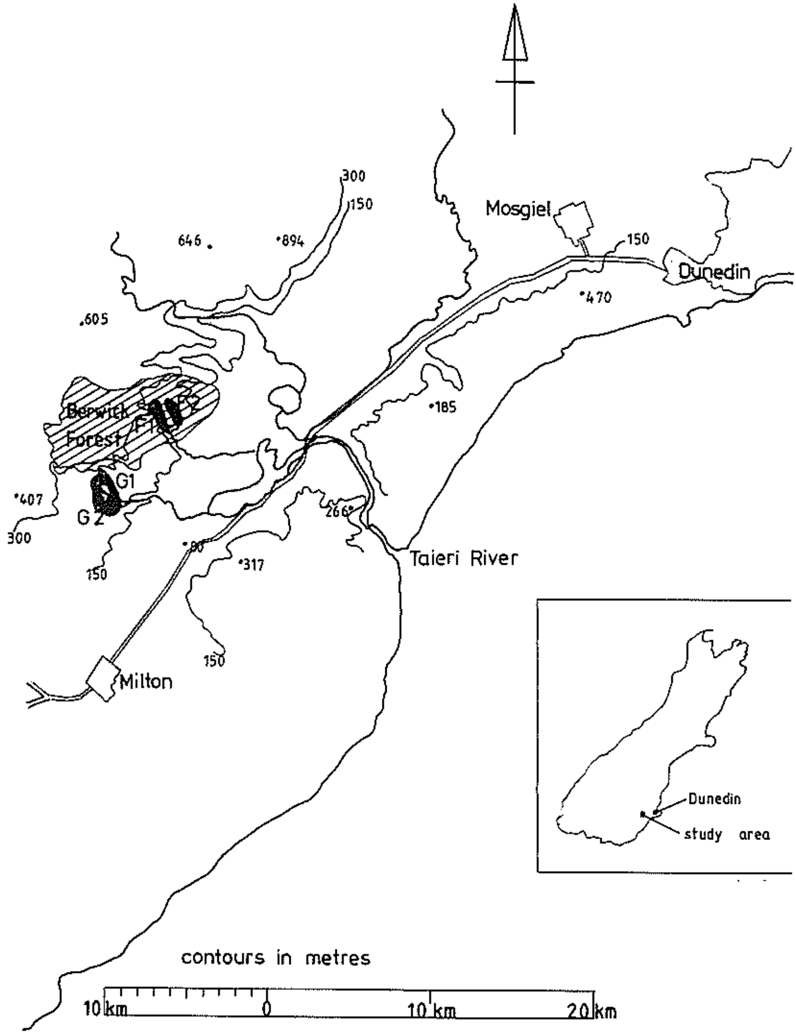

FIG. 1—Location of the study forest (F1 and F2) and grassland (G1 and G2) catchments in East Otago, South Island, New Zealand.

contain sedges, rushes and native grasses. These catchments are grazed by sheep. The forest catchments (F1 and F2) were planted in 1964 at a stocking rate of 2000 stems per hectare (sph). Catchment F2 is planted in *Pinus radiata,* while F1 has both *Pinus radiata* (65%) and *Pinus nigra* (31%). Catchment F2 has not changed during the study period, but 22% of F1 was thinned from 2000 to 370 sph in 1979 and one hectare was, in effect, removed from the catchment by being clear felled and flooded for the building of a rural–water

TABLE 1—Catchment Statistics

Catchment	Vegetation	Land Use	Area (km^2)	Mean Elev. (m)	Records Commenced
Kintore Creek (G1)	Introduced Grasses	Grazing	2.92	275	18.7.78
Vollweillerburn (G2)	Introduced Grasses	Grazing	1.63	275	27.5.80
Jura Creek (F1)	*Pinus radiata* *Pinus nigra*	Forest	1.92	290	21.6.78
Storm Creek (F2)	*Pinus radiata*	Forest	1.15	290	6.7.78

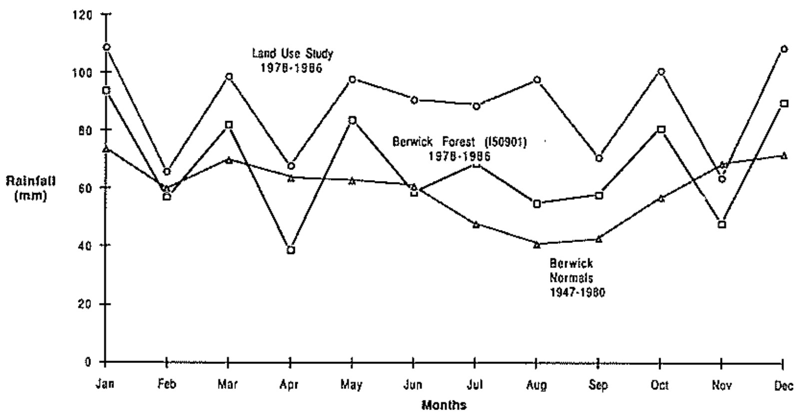

FIG. 2—A comparison of catchment mean monthly rainfalls for the study period (1978–1986) with long-term averages and the study period mean monthly rainfalls at the Berwick Forest site, three kilometres from the study catchments.

supply reservoir on the catchment boundary in December 1980. There has been no further management change of catchment F1 since 1980.

RAINFALL

A water year of 1 September to 31 August was used to make maximum use of early data, and to coincide with a water year adopted earlier by the Ministry of Works and Development for a national water resource publication (in press) of similar catchments elsewhere in New Zealand. The mean annual rainfall for the study area is around 1000 mm, with a range from 724 mm (1984/85) to 1250 mm (1982/83), during the study period 1978 to 1986.

The mean monthly rainfall values for the period (Fig. 2.) are compared with the monthly normals for the adjacent Berwick Forest Station (I50901) from

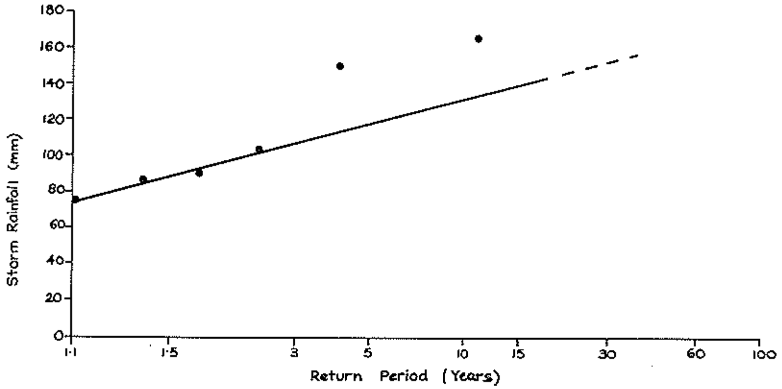

FIG. 3—Frequency recurrence of rainfall for major storms during 1978–1986. The outliers are consistent with Tomlinson (1980) calculations, suggesting that they are of a higher return than plotted.

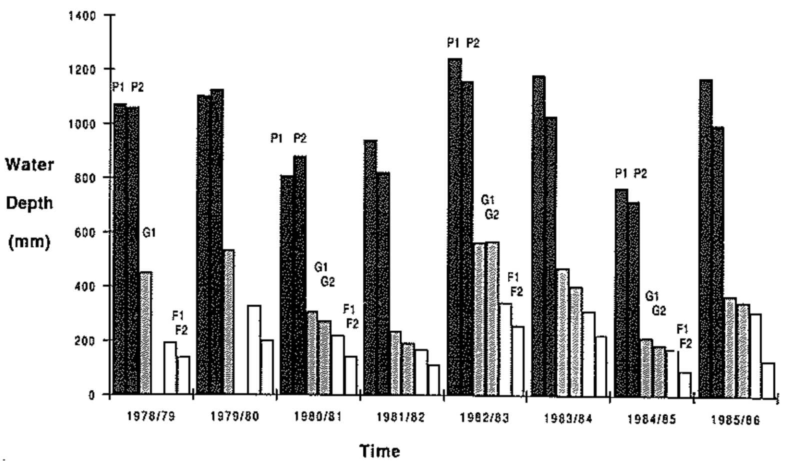

FIG. 4—Annual rainfall and runoff yields for forested (P1, F1 and F2) and grassland (P2, G1 and G2) catchments during the study period 1978–1986.

1947 to 1980 (New Zealand Meterological Service, 1983). Berwick is at a similar altitude, has a similar aspect to the automatic station in the forest catchments, and lies aproximately three kilometres from it. Rainfall has been above average for the area during the period of this study (Fig. 2). Mean rainfalls for February, April and November were close to the Berwick average, but the spring months of September and October were considerably wetter than average.

Rainfall in this area is characterised by storms of low intensity (2–3 mm per hour) and long duration (2–3 days). Light drizzle is common and up to twenty days a year of fog are recorded. During the study period, the average storm intensity was 2 mm per hour with a maximum one hour intensity of 9.3 mm.

TABLE 2—Comparison of Annual Yields Between Pasture Grass and Exotic Forest Catchments (mm)

		G1		G2			F1		F2	
	P2	R	E	R	E	P1	R	E	R	E
1978/79	1061	451	610			1076	196	880	143	933
1979/80	1129	538	591			1106	331	775	205	901
1980/81	885	312	573	273	612	812	221	591	146	666
1981/82	824	237	587	196	628	946	174	772	113	833
1982/83	1165	569	596	574	591	1250	347	902	261	989
1983/84	1033	474	559	410	623	1185	314	871	226	959
1984/85	724	216	508	192	532	771	177	594	96	675
1985/86	1003	374	629	351	652	1178	315	863	131	1047
MEAN	978	396	582	333	606	1040	259	781	165	875

P1 and P2 — total annual rainfalls determined from networks of storage rain gauges
P = precipitation
R = runoff
E = P–R

The largest storm occurred on 4–7 June 1980, when rainfall totalled 164 mm. This event had a return period of 95 years, using methods described by Tomlinson (1980). A frequency distribution curve of storm rainfalls (Fig. 3) gives this storm a return period of 11 years for this period of record. Using the Grigorten (1963) method, this plots as an outlier to the curve (along with the second highest storm total of 150 mm) (Fig. 3) but considering the short period of record, the storm totals measured are consistent with the Tomlinson (1980) method.

ANNUAL YIELDS

The annual yields (Table 2, and Fig. 4) differ with land use. The mean annual yields from G1 (396 mm) and G2 (333 mm) are higher than the means of F1 (259 mm) and F2 (165 mm). In a comparison between annual yields of G1 and F2 the yield from grass is always at least twice that of the forest. Mean annual rainfalls on each catchment are similar but a higher rainfall total in any one year can be recorded on any catchment.

Annual yields from F2, under *Pinus radiata,* are consistently less than those from the mixed *Pinus radiata/Pinus nigra* forest catchment, by up to 38%. Careful examination of the forest catchments showed no significant differences in soil type, geology, drainage patterns, rainfall catch, aspect or hydrology data collection. Perhaps the different tree species in each forest catchment vary in interception and hence yield, but no published data supports this suggestion.

For a simple water balance over a one year period, the change in storage

TABLE 3—Comparison of Mean Catchment Runoffs (mm): Grass and Exotic Forest Land Use

	$\overline{G}$	$\overline{F}$	$\overline{G}-\overline{F}$	$\overline{P}$
1978/79	451	170	281	1069
1979/80	538	268	270	1118
1980/81	293	184	109	849
1981/82	217	144	73	885
1982/83	572	304	268	1208
1983/84	442	270	172	1110
1984/85	204	137	67	748
1985/86	363	223	140	1091
Mean	385	213	173	1010

$\overline{G}$ = mean of two grass catchments

$\overline{F}$ = mean of two forest catchments

$\overline{P}$ = mean of two rainfall networks

TABLE 4—Hydrograph Separations for Four Study Catchments (1980–1986) (mm)

	G1	G2	F1	F2
Quickflow	601	640	164	139
Total Runoff	2182	1996	1548	973
Quickflow/Total Runoff (%)	28	32	12	14
Quickflow/ Total P (%)	11	11	3	2

Total Runoff and total P (1980–1986) are given on Table 2.

within the catchment is very small. For this study, using a water year commencing on 1 September, it is assumed that soil water is recharged each winter. If the catchments are assumed to be watertight, then the loss in yield from any catchment is represented by total evaporation and transpiration by the vegetation within the catchment. This total loss (E) is the difference between precipitation (P) and the water yield (R).

$$E = P - R \qquad (1)$$

In the forest catchments the wetter years produced the largest values of E, while in the grass catchments there was little variation in the annual value of E between wet and dry years (Table 3). The mean difference in yield between pasture grass and exotic forest is around 170 mm, but in wetter years (rainfall 1100–1200 mm) it is around 270 mm. In dry years (rainfall less than 1000 mm) the difference is around 100 mm. Differences in yield are greater in the years of higher rainfall; in wetter years less runoff is yielded from the forest catchments than from the grass catchments. This suggests that evaporation from wet or partially wet canopy vegetation is an important component of water loss from the forest catchments.

HYDROGRAPH SEPARATION

The runoff record of each catchment was separated into quickflow and delayed flow using the method of Hewlett and Hibbert (1967) (Table 4).

$$Rs = Q + D \qquad (2)$$

where
Rs = total storm runoff
Q = quickflow
D = delayed flow

A quickflow (Q) of 600 mm from the grass catchments is over three times that (180 mm) from the forest catchments, for the time period 1980–1986 (the record for 1978–1980 is not included due to lack of data for G2 for 1978–1979). Q averages 30% of the total runoff from grass catchments but only 13% of the total forest runoff. The grass catchment percentages are similar to those of the Glendhu forest where Q was found to average 30% of the total runoff (Pearce et al, 1984). The ratios of Q to Rs for the forest catchments of 13% and Q to precipitation (P) of 2–3% are very low. Results for the grass catchments are very similar to results from studies elsewhere in New Zealand: at Makaroa 11 quickflow was 41% of total runoff and 11% of gross rainfall, and, at Moutere 5, was 40% of total runoff and 10% of gross rainfall (Pearce and McKerchar, 1979). However, the ratio of Q to total runoff is moderate to low for grass catchments in this study compared to Big Bush (29%), Maimai (64%) and Hut Creek (50%). Similarly, the ratio of quickflow to total precipitation is very low compared to Big Bush (12%), Maimai (39%) and Hut Creek (25%). (Pearce and McKerchar, 1979).

The relationships between quickflow and the ratio of quickflow to gross storm rainfall (quickflow response ratio) for both land uses are shown in figure 5. The pairs with similar land use have each been averaged. The forest catchments yielded less than 1 mm of quickflow for the majority of individual events giving a ratio always under 5%. In contrast the grass catchments yielded between 1 and 20 mm of quickflow, for a ratio range of 3–50%. The larger events (> 10 mm quickflow) produced higher ratios for catchments under both land uses, but in each event the grass catchment ratio is always at least twice the forest catchment ratio. For the largest recorded event quickflow for the grass catchments was 80% of gross rainfall but for the forest catchments was only 31% of gross rainfall. Despite the high rainfall totals in large storms the forest prevented a large proportion of the rainfall from becoming runoff.

These findings are consistent with results from other studies in New Zealand

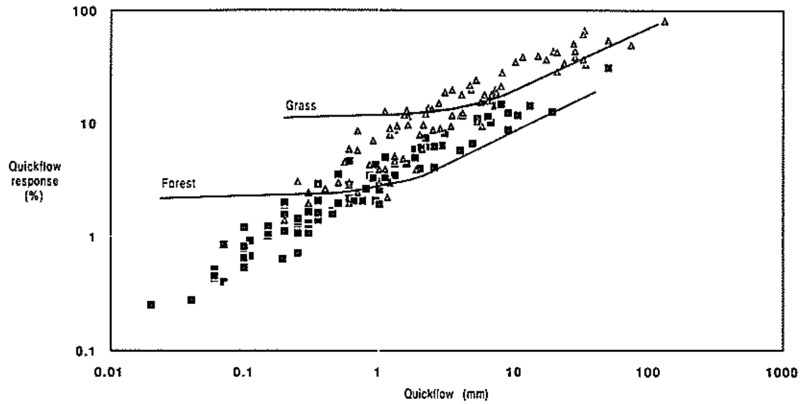

FIG. 5—Quickflow response of grass and forest catchments (both pairs averaged). Quickflow response = Quickflow/Storm rainfall.

and overseas, which have shown that the factor reducing runoff from catchments under forest cover is not transpiration, but interception and direct evaporation from the canopy. The difference in the rate of loss from forest and grass reflects the differing conditions: loss from grass is controlled by radiation, whereas loss from the taller and aerodynamically-different forest vegetation is governed by vapour pressure gradient. (Jackson, 1973; Stewart, 1977; Thom and Oliver 1977; Luckman and Duncan, 1978; Waugh, 1979; Pearce et al, 1980).

FLOW DURATION AND RECESSIONS

The flow duration curves (Fig. 6) reflect the physical similarity of the catchments in that the curves do not cross. The grass catchments yield more water at all percentages of time that the runoff is equalled or exceeded. For example a runoff of 5 l sec^{-1} km^{-2} is equalled or exceeded in G1 for 62% of the time, compared to the same runoff in F2 only being equalled or exceeded for 30% of the same time period. The lower end of the curves for the forest catchments is slightly flatter reflecting less summer transpiration from forest vegetation as compared to grass.

Master recession curves were constructed using the strip method as outlined by Toebes et al (1969) (Fig. 7). The recessions from catchments under different land uses decline at similar rates, and do not merge at the lower values of runoff. At any point in time on the recession curves the grass catchment recession commenced at a greater value of runoff when compared to the forest catchments. The similarity of these recession curves again reflects the physical similarity of the catchments. Waugh (1970) and Grant (1971) noted that in North Island catchments, similarly shaped recession curves occurred for catchments with similar lithologies.

CONCLUSION

In this study area in East Otago there is a considerable difference observed in water yield from land under introduced pasture grasses and land under exotic

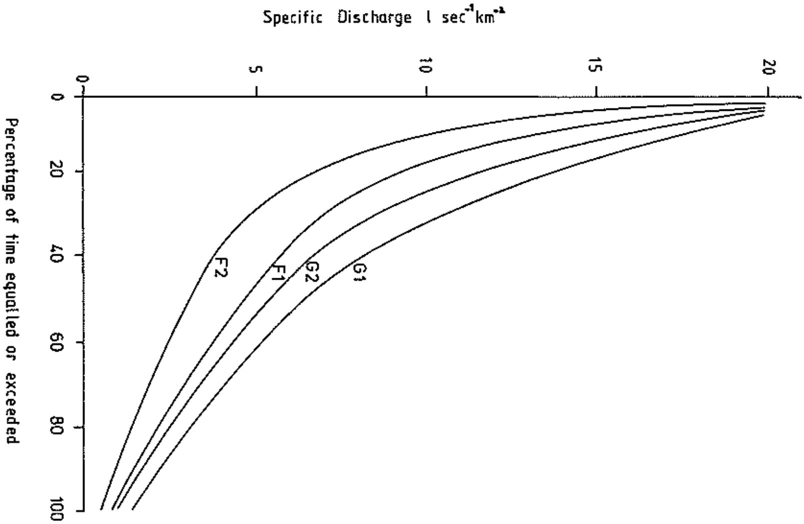

FIG. 6—Flow duration curves of each study catchment. Catchment G2 has shorter record (1980–1986) compared to the other three catchments (1978–1986).

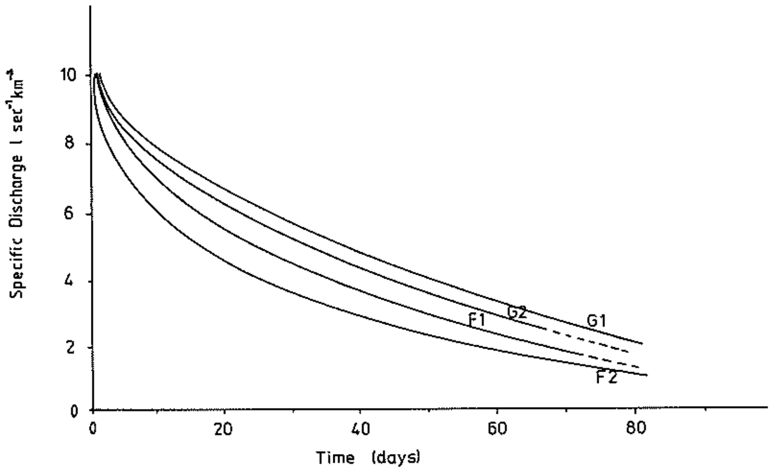

FIG. 7—Master low-flow recession curves of all four study catchments constructed by the strip method.

forest. Pasture grass catchments produce the greater water yield at all levels of the flow regime. Despite the occurrence of storms with up to a 100-year return period during the study period, the forest catchments yielded less storm runoff than the pasture grass catchments.

Thus, in this region, careful consideration should be given to water use requirements before large-scale changes in land use are allowed.

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Permission has been given by the Commissioner of Works to publish this paper.

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