OUTPUT OF WATER, SUSPENDED SEDIMENT AND PHOSPHORUS AND NITROGEN FORMS FROM A SMALL FORESTED CATCHMENT

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ABSTRACT

The outputs of water, suspended and dissolved material, and phosphorus (P) and nitrogen (N) forms from a small (10 ha) catchment under indigenous forest were studied for a period of one year. Streamflow and rainfall records indicated that approximately 14% of total rainfall was discharged as streamflow. The output of suspended sediment was 120 kg/ha, and the dissolved load 226 kg/ha. Much of the P and N output was associated with sediment. Of the annual loss of total P (0.2 kg/ha), 52% was in particulate form. The catchment appeared to be slightly conservative of P and strongly conservative of N.

INTRODUCTION

This study was to determine the quality and quantity of water discharged from a catchment in native forest. Although water, sediment and nutrient discharge should be measured over a reasonably long period to minimise short-term effects (particularly climatic variation), results from a single year can, within limitations, provide useful information on catchment behaviour and act as a basis for evaluating catchments in a more disturbed state.

Catchment Description

The Ballance catchment is situated in the northern Tararua Ranges at the eastern end of the Manawatu Gorge (Fig. 1). The Ballance Stream is ephemeral and drains into the Manawatu River. Average annual rainfall is 1200 mm, distributed throughout the year and characterised by infrequent intense falls. Approximately 50% of wind is from the west and north-west. On average 30% of the year is calm. The mean annual temperature is 13°C (N.Z. Met. Serv., 1966).

Concerning the geology, Neall (1974) found that: "(the) Ballance catchment stream is cut into the dip slope of Nukumaruan strata which overlie the eastern margin of the greywackes that form the main axial ranges. The stream has eroded through the upper calcareous limestones and siltstones into lower sandstone and siltstone of Nukumaruan age". Tectonic instability is shown by the presence of several minor faults to the south of the catchment (Rich, 1959). The Ruahine Fault (Kingma, 1957) lies to the west of the catchment.

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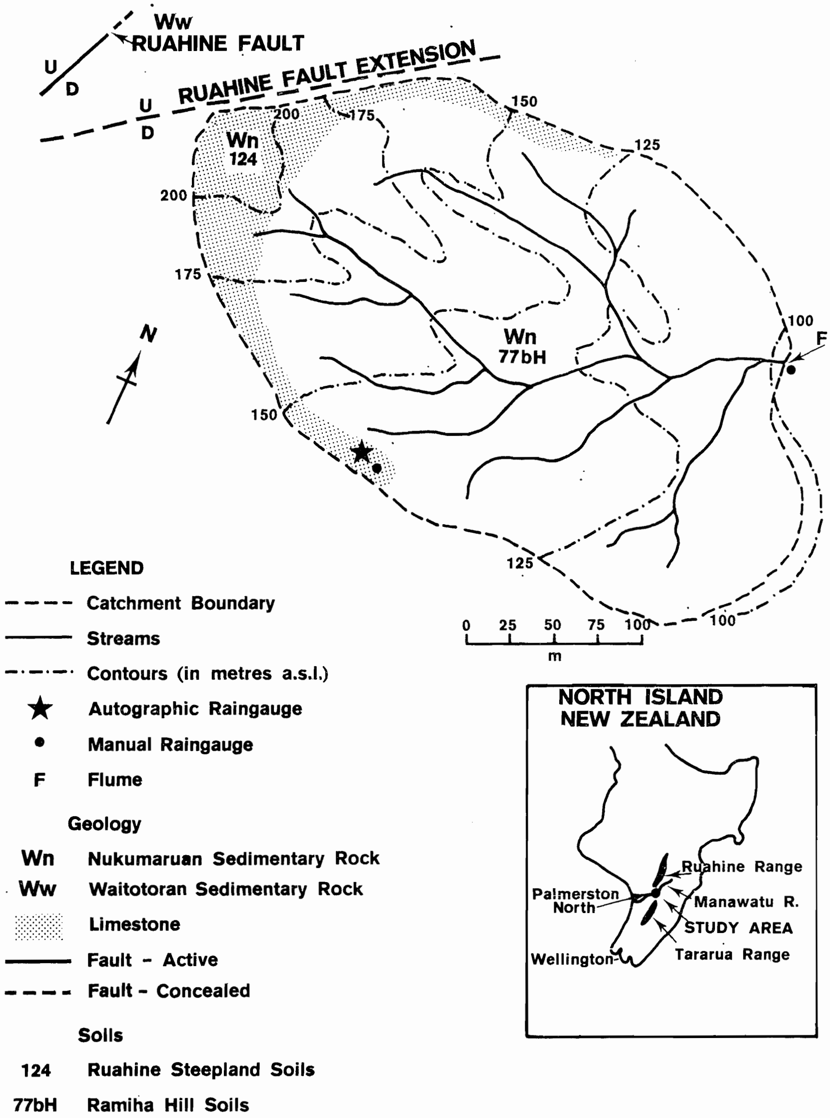

FIG. 1—Map of the Ballance catchment.

Ramiha hill soils, which are well drained and of low fertility, have been formed on the lower portions of the catchment. These grade into Ruahine steepland soils toward the west. The drainage pattern of the catchment is dendritic. A number of other hydrological characteristics are summarised in Table 1 and by Bargh (1976).

The original vegetation was probably rimu (*Dacrydium cupressinum* Lamb.)-tawa (*Beilschmiedia tawa* A.Cunn.)-pukatea (*Laurelia novae-zelandiae* A.Cunn.) dominant forest (Franklin, 1967). It is likely that pre-European fires some 200 years ago, and then

TABLE 1—Summary of hydrological characteristics of Ballance catchment

Parameter	Value	Reference	Method
Average width	232 m	Boughton (1968)	Map wheel
Maximum length	392 m	Boughton (1968)	Map wheel
Form factor	0.59	Horton (1932)	Map wheel
Maximum basin relief	120 m	Boughton (1968)	Altimeter
Relief ratio	0.29	Schumm (1956)	Altimeter
Mean stream slope	0.23	Boughton (1968)	Map wheel
Stream frequency	1.5/ha	Horton (1945)	Aerial photo
Drainage density	13.9 km/km^2	Horton (1932)	1 : 10,000
Bifurcation ratio	3.3	Horton (1932)	

later introduced deer (*Cervus elaphus* L.) and opossum (*Trichosurus vulpecula* Kerr), caused changes in the vegetation. The present canopy is dominated by the broadleaf evergreen species tawa and mahoe (*Melicytus ramiflorus* J.R. et G.Forst.). There is a well-developed understorey vegetation, thickest where light can penetrate the canopy. Common species include titoki (*Alectryon excelsus* Gaertn.), rangiora (*Brachyglottis repanda* J.R. et G.Forst), hinau (*Elaeocarpus dentatus* (J.R. et G.Forst) Vahl), kawakawa (*Macropiper excelsum* (Forst. f.)Miq.) and pate (*Schefflera digitata* J.R. et G. Forst.). There is a ground flora of numerous tree seedlings, ferns and mosses. Usually there is a thin to well developed litter layer.

Thus although the Ballance catchment has been relatively undisturbed by man, the vegetation is in an unstable (successional) state. Some slight soil slipping may be related to this, and also slight sheet erosion evident under larger breaks in the forest canopy.

METHODS AND PROCEDURES

Rainfall was measured by a Lambrecht automatic gauge and two manual gauges. Stream discharge was measured using a trapezoidal cut-throat, V-shaped flume, sealed to a steel sheet embedded transversely to 0.7 m to limit underground seepage. A Lea stage recorder was used in conjunction with the flume which operated at all times under "free flow conditions".

Intensive sampling to determine suspended sediment was carried out during the year. During sampled flood flows, samples were taken every 10 minutes about the flood peak, and every 20 minutes during flow recession. For suspended sediment determination, samples were taken at approximately 3/4 depth in unmodified flow immediately upstream of the flume. The sampling method, using 1.3-litre plastic containers, was standardised by duplicate sampling at various stage heights with a United States standard depth integrating hand sampler.

Suspended sediment and dissolved matter were separated by a 0.45 μm millipore filter, and were determined by evaporating samples to dryness.

Plastic sheeting laid upstream from an old V-notch weir, upstream from the flume, provided a convenient base and trap for bedload. The material was removed and weighed after a year.

Nutrient analyses were carried out on stream and rainwater samples, the latter collected in the open in acid-washed plastic containers. Samples were treated prior to analysis according to methods outlined by Syers (1975). Total (TP) and total dissolved P (TDP) were determined following perchloric acid digestion of an unfiltered sample and acid persulphate digestion of a filtered sample, respectively. Total particulate P (TPP) was then determined by difference (O'Connor and Syers, 1975). Nitrate (NO_3-N) was determined as nitrite by the Griess-Illosvay method following reduction by cadmium (Henricksen and Selmer-Olsen, 1973). Total (TN) and total dissolved N (TDN) were determined on unfiltered and filtered samples, respectively, following a Kjeldahl-type digestion, using a Technicon auto-Analyser. Total N was then calculated as the sum of NO_3N and total Kjeldahl-N. Total particulate N (TPN) was determined as the difference between total Kjeldahl and dissolved Kjeldahl N.

Instantaneous flow rates, dissolved material fluxes, sediment fluxes and nutrient fluxes for P and N forms were calculated from stage heights and component concentrations using card input to an object program. Total loads and total flow were calculated by integration, over periods of interest, of the nutrient flux and water flow curves, respectively. Regression analysis of various components was conducted using linear, multiple, and polynomial regression source programs.

RESULTS AND DISCUSSION

Input of Water

The annual precipitation was 1202 mm. Monthly rainfall totals (given below) show good agreement with long term averages from a nearby New Zealand Meteorological Service station at Waipuna.

Output of Water

Streamflow in the catchment occurred on 296 days of the study year. The stream ceased flowing for periods up to 18 days during January, February, March and April, 1975. Baseflows during these drier months were of the order of 0.1 litre/s whereas those for the wetter, winter months were of the order of 0.3 litre/s. Peak storm discharges were characteristically about 6 litre/s.

A total of 157.6 mm (1.6×10^7 litres) or 13.9% of the gross annual rainfall, was discharged as streamflow. Rainfall (mm) and streamflow equivalent (mm) for months November to October are summarised as follows:—

Month	N	D	J	F	M	A	M	J	J	A	S	O
Rainfall	71	83	88	45	58	90	161	121.5	119.3	198.5	88.2	78
Streamflow	8.4	20.1	6.8	0.03	0.2	0.3	7.1	17.1	17.5	51.3	20.4	8.4

During December a relatively large proportion of the rainfall appeared as streamflow, due to an intense rainstorm which generated the year's peak flow. Intense rainstorms and wet antecedent conditions during August and September also, resulted in a high proportion of stream flow during those months. Storm hydrographs had an average lag time of 4 hours and an average time of rise of 2.5 hours. It apeared that the time of rise of the hydrographs was primarily affected by the intensity of rainfall and the antecedent rainfall; lag and rise times were shorter during the more intense events. The hydrograph was characterised by long periods of even flow, interspersed by storm rises, which generally had "blunt" peaks and drawn out recession curves (Fig. 2).

Surface runoff was not evident during any storm period although it may have occurred on small areas immediately bordering the stream channel. This indicates that streamflow is derived almost entirely from interflow or "quick subsurface flow" (Hursh, 1944). It is probable that streamflow is generated in accordance with the model described by Hewlett and Hibbert (1967). Evidence for this included: overland flow was not observed, the time of rise of the hydrograph was relatively small, the baseflows (so called) did not conform to a pattern of daily fluctuations noted by Hursh (1944) and, the stream was ephemeral.

The computed average runoff at Waipuna (2 km from the catchment, and with a grass vegetation) was 45% of average annual rainfall (N. G. Robertson, pers comm.). The difference between this value and that for the Ballance catchment, almost certainly due to the forest cover introducing interception loss of about 30%, will be discussed in a subsequent paper (Bargh, 1977).

Phosphorus and Nitrogen Input

The major source of input to the catchment is considered to be rainfall. Another possible source is windborne dust.

Some P and N analyses had to be discarded due to contamination of the collecting vessel, possibly by small insects. There were still relatively large variations (Table 2). According to Miller (1961), annual N salt loadings carried by rain in New Zealand vary between 2 and 23 kg/ha.

TABLE 2—Mean P and N concentrations and input in rainfall, Ballance catchment

Mean concentration (mg/litre)		Confidence interval 1%	d.f.	Input (g/ha)
TP	0.034	(0.016,0.052)	6	409
TDP	0.016	(0.006,0.026)	2	192
TPP	0.018			216
TN	0.510	(0.350,0.670)	6	6130
TDN	0.300	(0.10,0.50)	3	3610
NO_3-N	0.060	(0.025,0.095)	9	721
TPN	0.210			2520

Output of Sediment, Dissolved Load and Nutrients

Sediment. The correlation between the concentration of suspended sediment in samples taken with the standard depth integrating hand sampler and those taken at the same time with a 1.3-litre plastic bottle was highly significant ($r = 0.95^{***}$, d.f. = 65). Therefore, suspended sediment data from this study are directly comparable with those from similar studies.

The total weight of suspended sediment discharged during the study year was 1.22

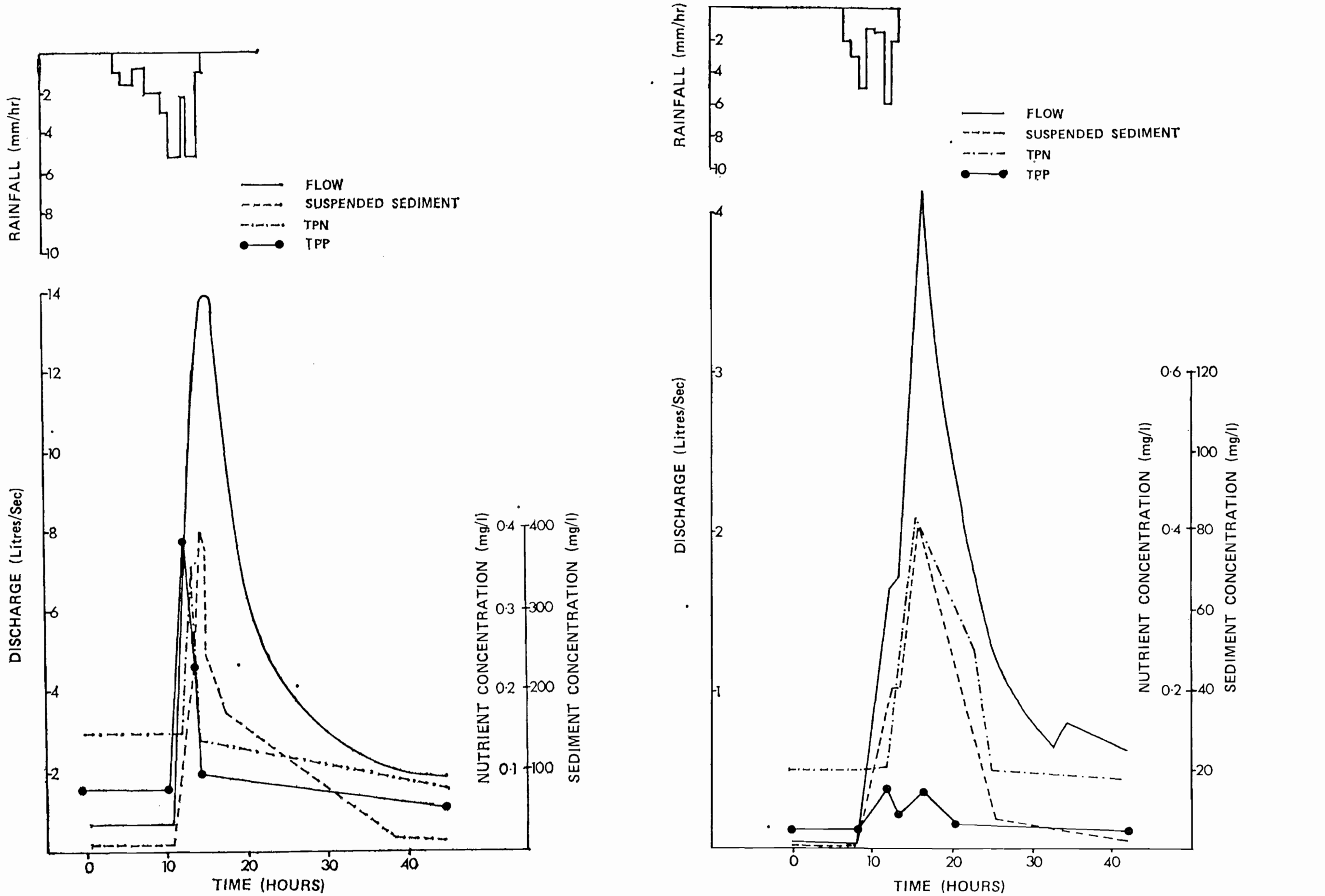

FIG. 2—Storm hydrographs for: (left) medium storm, 20-22 August 1975; and (right) small storm, 6-8 June 1975.

tonnes and the bedload was 0.07 tonnes. The bedload contained a high proportion of organic matter, up to 12% in summer.

Streambank erosion and rain impact along the stream course appeared to be the major source of sediment because overland flow was not observed.

During the wetter months of May, June, July and August, 50% of the annual sediment load was discharged, whereas only 10% was discharged during the summer months (Table 3). Relatively greater sediment loads were discharged during months in which more intense rainstorms occurred (December and June).

The raw data (not presented) indicate that significantly different sediment concentrations were, at times, recorded for a given flow rate. A similar finding was also observed by Dragoun and Miller (1966) who produced seasonal rating curves to account for this phenomenon. More intense rainfalls produced higher sediment concentrations for given flow rates in the catchment.

Peak sediment concentration and peak flow coincided (Fig. 2) for both large and small storms.

Dissolved Load. The total dissolved load output from the catchment was 2.3 tonnes (Table 3). Concentrations were of the order of 120 mg/litre and 220 mg/litre during the winter and summer months, respectively. These concentrations persisted during both storm and base flows and were therefore not closely related to dilution effects. Perhaps (cf. Walling, 1974) at low flows during summer months, streamflow originated as base flow from the soil and rock. Because of a long storage time, high solute concentrations would be obtained. During winter months, baseflow was diluted by storm runoff and water from transitory storage.

Dilution effects were evident during particular storms, the dissolved load concentration decreasing by up to 10 mg/litre.

TABLE 3—Output of suspended sediment, dissolved load, and P and N forms from the Ballance catchment

Month	Suspended Sediment	Dissolved Load	TP	PTP	TN	TPN
	—— kg/ha ——		—— g/ha ——			
November	16.8	1.5	8.0	2.1	59.0	19.0
December	39.2	40.1	73.3	50.2	207.3	48.2
January	2.5	13.7	10.1	3.6	76.4	19.1
February	0	0.1	0.02	0.01	0.4	0.1
March	0.1	0.4	0.3	0.1	1.6	0.3
April	0.1	0.6	0.5	0.2	3.8	0.6
May	9.7	12.0	13.7	7.7	54.0	9.8
June	11.3	18.6	24.9	8.4	246.5	30.5
July	4.5	21.8	33.1	16.7	193.4	46.3
August	34.8	64.7	59.5	28.9	912.8	296.3
September	0.9	36.5	7.7	1.5	153.1	11.4
October	2.1	16.0	12.1	7.4	51.6	8.9
Total	122.0	226.0	243.2	126.8	1960.0	491.0

Phosphorus. The annual discharge of TP from the Ballance catchment was 243 g/ha and 52% of this was in particulate form. The correlations between log TPP concentration and log flow, and between log TPP concentration and log sediment concentration were found to be highly significant. The equations expressing these relationships were as follows:—

$$\text{Log (TPP)} = 0.520 \text{ Log } Q + 0.035$$
$$(r = 0.640^{**})$$
$$\text{Log (TPP)} = 0.707 \text{ Log (S)} - 2.561$$
$$(r = 0.754^{**})$$

where (S) = Suspended sediment concentration (mg/litre)
Q = Instantaneous discharge rate (m^3/sec).

The data indicate that the loss of P is closely associated with the loss of sediment (Fig. 2). From the relationship between TPP and sediment concentration, using the regression curve, it was calculated that 1 tonne of sediment contained 0.89 kg TP.

It was not possible to determine whether the Ballance catchment was conservative of TP or TDP within the bounds of error although the figures suggest that it is (Table 4).

Nitrogen. TN discharged from the catchment was 1.96 kg/ha and 25% of this was in particulate form, an appreciably lower proportion than TPP was of TP. Monthly discharge of TN ranged from 0.4 g/ha for February 1975, to 910 g/ha for August 1975 (Table 3). Although during individual storms (Fig. 2) peak TPN concentration coincided with peak flow, relationships of TPN concentration with sediment and with flow were found to be nonsignificant, perhaps because much of TPN was in the particulate organic form. Because the dissolved fraction of TN was far higher, TN concentrations were more responsive to the behaviour of the dissolved fraction than were TP concentrations. During the recession stages of the hydrograph, TN concentrations did not fall as rapidly as TP concentrations. This is attributed to TDN concentrations remaining higher, for a longer period.

Annual loadings of TN and TPN are summarised, with errors, in Table 4. Assuming that rainfall is the only N input, this catchment appears to be conservative of TN and marginally conservative of TDN. It is likely that deep percolation losses of TDN occurred because soluble N forms, particularly NO_3-N, are less readily immobilised by sorption in the soil profile than are soluble P forms. The magnitude of such losses could not be estimated but it is unlikely that they were greater than 10% of inputs. This is the proportion of water estimated to have been lost as deep percolation.

TABLE 4—Standard errors in measured input and output of P and N forms and suspended sediment (g/ha)

Parameter	Input in Rainfall	Output in Stream
TP	409 ± 120	243 ± 53
TDP	192 ± 48	116 ± 26
TN	6130 ± 670	1960 ± 510
TDN	3606 ± 1190	1469 ± 380
Sediment (kg/ha)		122 ± 27

Miller (1963) found that the average annual output of TN from a small forested catchment at Taita, New Zealand, was 2 kg/ha. This is in close agreement with TN loss from the Ballance catchment (Table 3).

Errors in Sediment and Nutrient Output

Under conditions similar to those existing in the Ballance catchment Sharpley *et al.* (1976) found that errors in storm loadings of TP were less than 15% (5% confidence level) with hourly sampling during stream hydrograph rise, and two-hourly sampling for stream flow recession. During periods of stream baseflow, errors in TP loadings were less than 5% (5% confidence level). Similar errors were found for suspended sediment (O'Connor and Syers, 1975). Annual stream hydrograph records for a catchment were separated into periods of baseflow and stormflow, both sampled and unsampled. Unsampled periods of stream flow were predicted from sediment and P and N regression curves. The standard error of a prediction may be calculated from such regression curves (Brown *et al.,* 1972).

The maximal error of prediction is given by the observation of greatest magnitude, for this observation is furthest from the mean. Thus, the percentage error in estimation of streamflow loadings was less than 16% and 26% for periods of baseflow and stormflow, respectively. The percentage error for N loadings was estimated at 25% and 30% for baseflow and stormflow periods, respectively, because a strong correlation between TPN and flow, and TPN and sediment concentration was not obtained.

Of the 28 storm events which occurred at Ballance, 14 were sampled adequately, in terms of frequency of sampling, and 14 were either not sampled sufficiently or not sampled. Some 80% of baseflows were sampled adequately. Therefore the average error in the estimation of annual TP and sediment loadings was 22% and for TN 26%.

Within these limits, the results indicate that the catchment is slightly conservative of P and strongly conservative of N.

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