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*A STUDY OF THE HYDROLOGICAL AND
SEDIMENTOLOGICAL CHARACTERISTICS OF
TWO CATCHMENTS OF CONTRASTING
LAND USE*

*A thesis presented in partial fulfillment of the
requirements for the degree of Master of
Agricultural Science in Soil Science
at Massey University*

Brian James Bargh

1976

ERRATA: Changes on page headed ABSTRACT
and pages 48 and 62 as follows:-

p. headed ABSTRACT , 4th paragraph, 3rd line to read

'and 1.22×10^2 kg / ha from the Tuapaka and
Ballance Catchments, respectively.'

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ABSTRACT

The hydrological and sedimentological characteristics of two catchments of contrasting land use were studied for a period of one year. Both catchments were situated in the Northern Taranaki Ranges, near the Manawatu Gorge, some 27 km from Palmerston North, New Zealand. The 10 ha Ballance Catchment has native forest vegetation, whereas the 180 ha Tuapaka Catchment is part of a mixed sheep and cattle farm.

The water balance estimated for the catchments indicated that a small amount of deep percolation occurred in both. Streamflow and rainfall were recorded at both catchments. During the study year approximately 26% and 14% of total rainfall was discharged as streamflow from the Tuapaka and Ballance Catchments, respectively. Throughfall and stemflow were also recorded at Ballance. The average monthly throughfall was 54% of total rainfall; the equivalent stemflow was 16% of total rainfall.

An attempt was made to identify and quantify the inputs of phosphorus (P) and nitrogen (N) forms to the two catchments. Phosphate fertilizer application, N-fixation by clovers, and rainfall, were considered as the inputs of P and N forms in the Tuapaka Catchment. In the Ballance Catchment, rainfall was assumed to be the only input of P and N forms.

The output of suspended sediment, dissolved material, and P and N forms, was measured during the study year. The output of sediment was 1.4×10^3 kg/ha and 1.6×10^2 kg/ha from the Tuapaka and Ballance Catchments, respectively. The output of dissolved material from the Tuapaka Catchment was only 13% of the sediment output. Significant quantities of P and N output were associated with suspended sediment. Of the annual loss of total P (1.6 kg/ha) from the Tuapaka Catchment, 76% was in the particulate form. At Ballance, 52% of the annual loss of total P (0.2 kg/ha) was in particulate form.

Within the bounds of error, the Ballance Catchment appeared to be slightly conservative of P and strongly conservative of N. At the Tuapaka Catchment, however, inputs of P and N balanced outputs, within the bounds of error. It is difficult, if not impossible, to determine whether a particular catchment is conservative for P and N unless adequate attention is paid to the errors involved.

The differences obtained for the output of sediment and P and N forms, from the two catchments, are interpreted in terms of the effects of agricultural activities, particularly vegetation differences, on the inputs of particulate and dissolved phases to the streams.

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SECTION 1

INTRODUCTION

Deterioration in the quality of natural waters is a problem of increasing concern in New Zealand and overseas. Interference with agricultural and recreational activities, and a reduction in the consumptive value of waters are just three of the undesirable side-effects of sediment and nutrient enrichment of waters.

Sediment is regarded by some workers as the major pollutant of surface waters (Wadleigh, 1968). Sediment originates from two sources: (i) the natural and man-accelerated processes of erosion of soils and geological materials, and (ii) the direct or indirect discharge of industrial, municipal, or agricultural wastes to watercourses. Both sources produce a variety of sediment materials. Sediments from natural and man-accelerated erosion include inert boulders, gravel, sands, silts, and colloidal materials such as clays, organics, and amorphous materials. Although sediment production is a natural process, it is suspected that most sediment results from the activities of man (Grissinger and McDowell, 1970).

Soil conservation practices can reduce the sediment loading of waters, the losses of valuable topsoil, and the flooding of downstream areas. Conservation practices by themselves, however, will not always reduce nutrient inputs, particularly dissolved components, to waters.

Nutrients, particularly phosphorus (P) and nitrogen (N), are frequently implicated as major factors in the undesirable side effects of eutrophication (Vollenweider, 1968; Ryden et al., 1973). Phosphorus and nitrogen, are frequently associated with sediment both directly and also indirectly through sorption-desorption reactions (Taylor and Kunishi, 1971; Schuman et al., 1973a, 1973b; Burwell et al., 1974).

The objectives of this study were to determine and compare the properties of two catchments of contrasting land use, and to examine the reasons for differences in their hydrological behaviour. Methods in current use or modified versions of them, were employed to measure or estimate inputs and outputs of P and N forms, and the output of sediment.

The small catchment technique (Borman and Likens, 1967) used in this study provides a means of estimating inputs and outputs, and certain interactions, at an ecosystem level. By choosing a catchment in native forest and one in pasture, comparative data can be obtained. It was hoped that such a study would provide new approaches and information, and point to directions for future research.

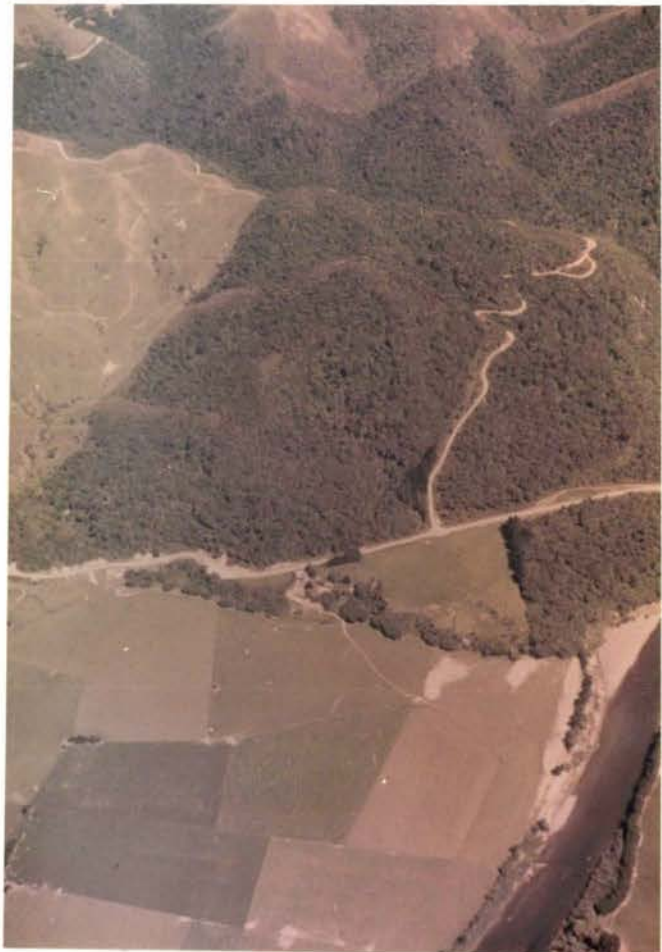
It is recognised that catchment studies involving water, sediment, and nutrient discharge should be conducted over reasonably long periods of time to minimise short-term effects, particularly climatic variation. Nevertheless, a short-term study, such as that reported in this thesis, gives an opportunity for the development of techniques and the collection and interpretation of comparative data. If treated with caution, useful information can be obtained for the behaviour of two catchments in the same study year.

PLATE 1. OBLIQUE VIEW OF TUAPAKA
CATCHMENT TAKEN ABOVE THE
MANAWATU RIVER LOOKING S.E.
TOWARD THE CATCHMENT HEAD.

(Photo: Mr P.R. Stephens, 1975)

PLATE 2. OBLIQUE VIEW OF BALLANCE
CATCHMENT TAKEN ABOVE THE
MANAWATU RIVER LOOKING
WEST TOWARD CATCHMENT
HEAD.

(Photo: Mr P.R. Stephens, 1975)



SECTION 2

LITERATURE REVIEW

Several aspects of the literature relating to the overall objectives of the present study are reviewed briefly below.

2:A Hydrological Characteristics of Catchments.

Boughton (1968) has reviewed the hydrological characteristics "which have, or may have, an effect on floods or catchment yield," and placed them into five basic classes (similar to Horton, 1932):

- (i) topographic characteristics,
- (ii) vegetative characteristics,
- (iii) soil characteristics,
- (iv) climatic characteristics, and
- (v) human effects.

It is surprising that geological characteristics of catchments are given little or no emphasis by several workers including Horton (1932) and Boughton (1968). These basic classes are further described in a variety of ways, some of which are used in this study and mentioned below.

Numerous workers have made detailed investigations of the geological and morphological features of drainage basins. A most significant contribution to this field of research was made by Horton (1932) who proposed a number of simple parameters for the morphological description of a catchment. These parameters included form factor, drainage density, and stream density. Subsequently, one of the most important quantitative studies of basin geometry was presented by Horton (1945). As part of this analysis, Horton was able to show simple geometric relationships between such parameters as stream order, number, length, and slope. A few of the more recent investigations, which were designed to study characteristics of drainage basins and the interrelations of geology and topography have been reported by Strahler (1952a, 1952b, 1954, 1957, 1964), Miller (1953), Schumm (1954, 1956), and Gray (1961). The primary aim of these papers was to present basic data and hypotheses relating the physical characteristics of the basin, longitudinal profiles, and valley slopes, to other features of the basin and to its geology.

With the establishment of basic parameters that quantitatively describe catchment form, several workers have attempted to relate these parameters to the processes occurring within the catchment, such as water and sediment yield.

Omitting the plant and soil environment, the geometric properties that affect streamflow from a catchment are its size, shape, and relief (Brush, 1961). The size of the catchment governs the average amount of discharge of a stream; catchment shape affects the timing involved in the concentration of runoff; and relief is an important factor in determining the erosion potential of the catchment. Taylor and Schwarz (1952) found that drainage area, length of the longest watercourse, main stream length to the centroid of catchment area, and "equivalent main - stream slope" were the most significant geometrical variables affecting hydrograph 'lag' and 'peak' flow. Carlston (1963) obtained a significant relationship between baseflow and drainage density, although this work was criticised by Cotton (1964) and Kirkby and Chorley (1967). In a later paper, Carlston (1966) re-examined the role of climate and concluded that it materially affects runoff intensity and drainage density. Kirkby and Chorley (1967) claimed that drainage density controlled the behaviour of the stream hydrograph and not the reverse, as postulated by Carlston (1963). A summary of topographic and meteorological catchment characteristics affecting streamflow has been given by Thomas and Benson (1970).

2:B Sediment Yield

Attempts to relate the sediment yields of rivers and streams to catchment characteristics such as physiography, geology, soil, vegetation, and climate have been made by Leopold and Maddock (1953), Schumm (1954), Anderson (1954, 1957), Strahler (1957), Maner (1958), Schumm and Hadley (1961), Roehl (1962), Copeland (1963), Guy (1964), Bobrovitskaya (1967), Branson and Owen (1970), and Imeson (1971). As Geiger (1958) has indicated, however, in most cases no quantitative analyses of the sedimentation processes and sediment sources have been made. Most of the quantitative analyses that have been made attempt to correlate sediment production with a single factor such as runoff or cover density. Because sedimentation is controlled by multiple factors (a comprehensive summary of these is given by Glymph, 1954), analyses based on a single causal factor are of limited accuracy and their usefulness is limited by the degree to which extrapolation of the results is justifiable. From the papers reviewed, the most significant factors affecting sediment yield from catchments are size of catchment, drainage density, relief ratio, stream discharge, cover density, and rainfall intensity. The effects on water and sediment yields of landuse and vegetation within a catchment have been discussed by Glymph (1957), Gottschalk (1962), Goodell (1967), Sopper and Lull (1967), Boughton (1970), and Patric and Reinhart (1971).

Detailed studies of the sedimentological characteristics of small catchments have been made by Dragoun and Miller (1966), Troake and Walling (1973), and Walling (1971, 1974). From these studies, suspended sediment rating curves and equations have been produced. Sediment predictive equations may have a fairly limited application, depending on the degree of accuracy required. Generally they apply only to very similar catchments in the immediate vicinity of the catchment from which they were produced. Troake and Walling (1973) and Walling (1971) have used short-term sediment yield data from their study catchments to calculate annual 'denudation rates'. As they intimate, without a quantitative evaluation of sediment source areas, the expression of a denudation rate is meaningless.

2:C The Nature of Sediment and its Relationship to Phosphorus and Nitrogen

The processes of sedimentation (erosion, transport, and deposition of organic and inorganic materials) may create a variety of environmental problems. These may be classified as physical, biological and chemical. The nature and extent of these problems have been discussed by a variety of workers such as Ellis (1936), Cordone and Kelly (1961), Wadleigh (1967), Walker and Wadleigh (1968), Grissinger and McDowell (1970), Guy and Ferguson (1970), Robinson (1971, 1973), Oschwald (1972), Stall (1972), Guy and Jones (1972).

Sediment is the worlds most widespread pollutant (Wadleigh, 1967). High sediment concentrations pollute water intended for most uses. Grissinger and McDowell (1970) reported ten major activities which are impaired by sediment:

1. Public Health
2. Public and Industrial Water Supply
3. Fisheries
4. Valley Agriculture
5. Drainage
6. Irrigation
7. Flood Control
8. River Commerce
9. Recreation
10. Electric Power Production

The magnitude of the sediment pollution problem tends to obscure the benefits of proper sediment concentrations. For example, sediment movement uses energy that would otherwise be available for other processes. For example, channel degradation, induced by sediment abatement, is discussed by Miller (1965) and Stall (1972). In the past, fertility of agricultural lands often depended on periodic flooding and sediment deposition. Reviewing available literature, Barrows and Kilmer (1963) concluded that significant losses of nutrients, particularly phosphorus (P) and nitrogen (N), occurred through water erosion. The amounts of various nutrients in runoff from rural catchments would be expected to result from the interaction of many factors, including type of cover, cultural and conservation practices, length and steepness of slope, amount and distribution of precipitation, soil infiltration and percolation characteristics, and size of the contributing catchment. The process of erosion tends to be selective in that finer soil particles are more susceptible to erosion than are the coarser fractions (Smith and Wischmeir, 1957). Massey and Jackson (1952) and others shown that these finer particles contain relatively higher amounts of nutrients, giving rise to the "enrichment ratio" effect. Surface runoff plot experiments conducted by Timmons et al. (1973), showed that variable amounts of "available P", ammonium - N, nitrate - N, and organic - N were associated with transported sediment, depending on antecedent rainfall, land-use management, and rainfall intensity factors. Several other runoff-plot studies have been carried out in an attempt to evaluate the potential sources of P and N to stream systems, but extrapolation of these findings to field situations is rather tenuous. Analyses of streamwaters draining a farmland and a woodland catchment (Taylor et al., 1971) showed that significantly larger amounts of P were lost from farmland than from woodland, and that a large proportion of the nutrient loss took place in a limited period of time. Minshall et al. (1969) concluded that storm runoff carried the major portion of P and N lost in streams in south Wisconsin. Hobbie and Likens (1973) found that the concentrations of dissolved P and fine particulate P changed little with variations in flow from a forested catchment and concluded that "a natural forest ecosystem is strongly conserving of P".

Hayes and Anthony (1958), Harter (1968), Latterell et al. (1971), and Li et al. (1972) have demonstrated that P and N may be removed from the aqueous phase by sediment or may be released from sediment to the aqueous phase, depending on environmental conditions. Kunishi et al. (1972) studied this aspect for P.

Although their study only involved sampling from two storm runoff events, they claimed that suspended sediment derived from subsoil and stream banks had a large sorption capacity for P and could thereby reduce the P concentration in the stream water, provided adequate mixing took place in the moving water. Taylor and Kunishi (1971) claimed that the sorption of P by sediment would be least efficient under low flow conditions, presumably because of the lower concentrations of sediment and the more limited mixing.

The hydrological and sedimentological characteristics of small catchments are generally closely interrelated. Where changes have occurred in the hydrological characteristics, these changes have usually affected sediment yield from the catchment. Most changes have tended to increase sediment yields. This is undesirable because sediment not only creates physical problems with the use of water, but potentially adds to the chemical problems of eutrophication.

FIGURE 1 LOCATION MAP

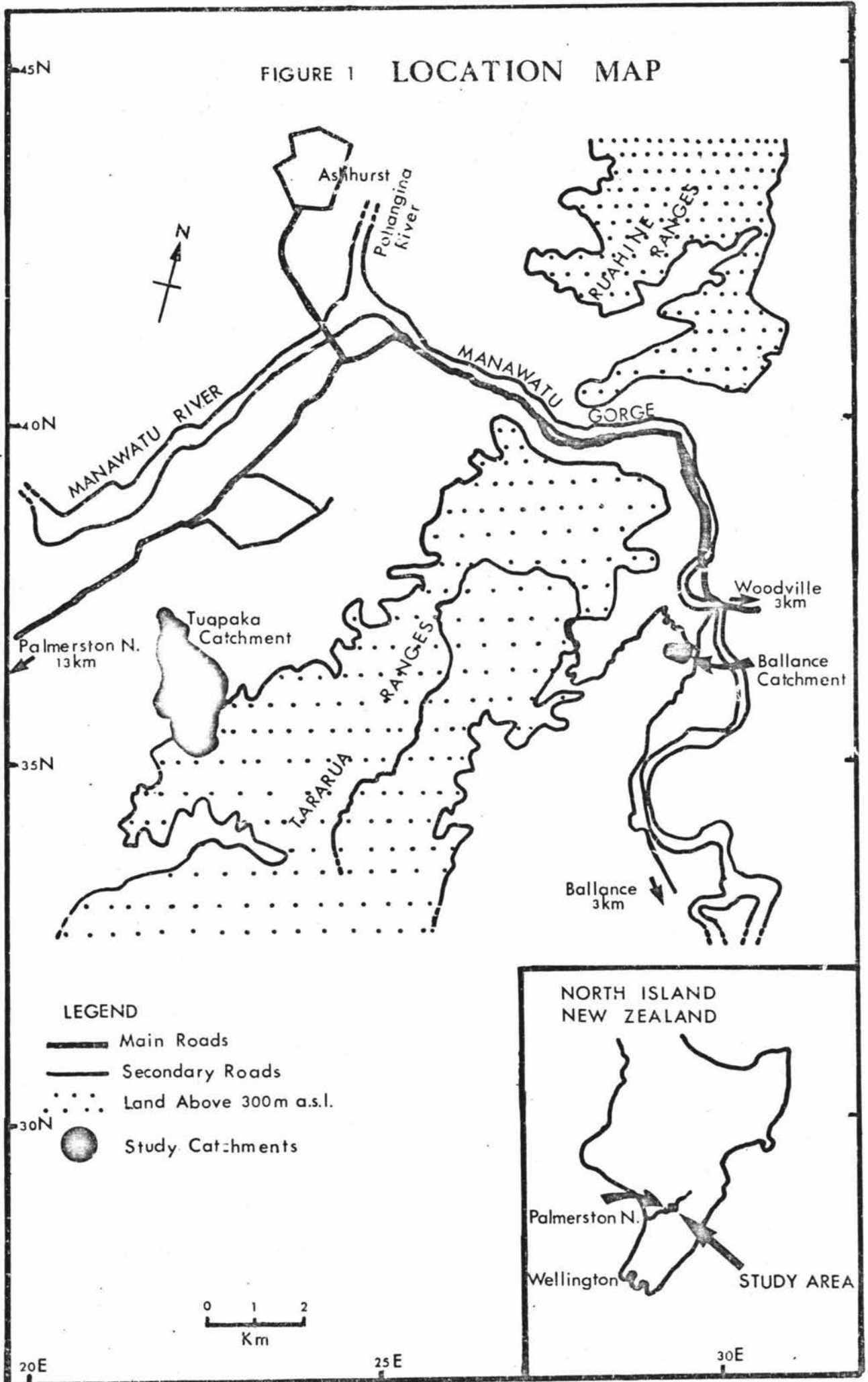


PLATE 3. VERTICAL VIEW OF TUAPAKA
CATCHMENT. SCALE APPROX 1:10,000
(Photo: Mr D.G. Bowler, 1974)

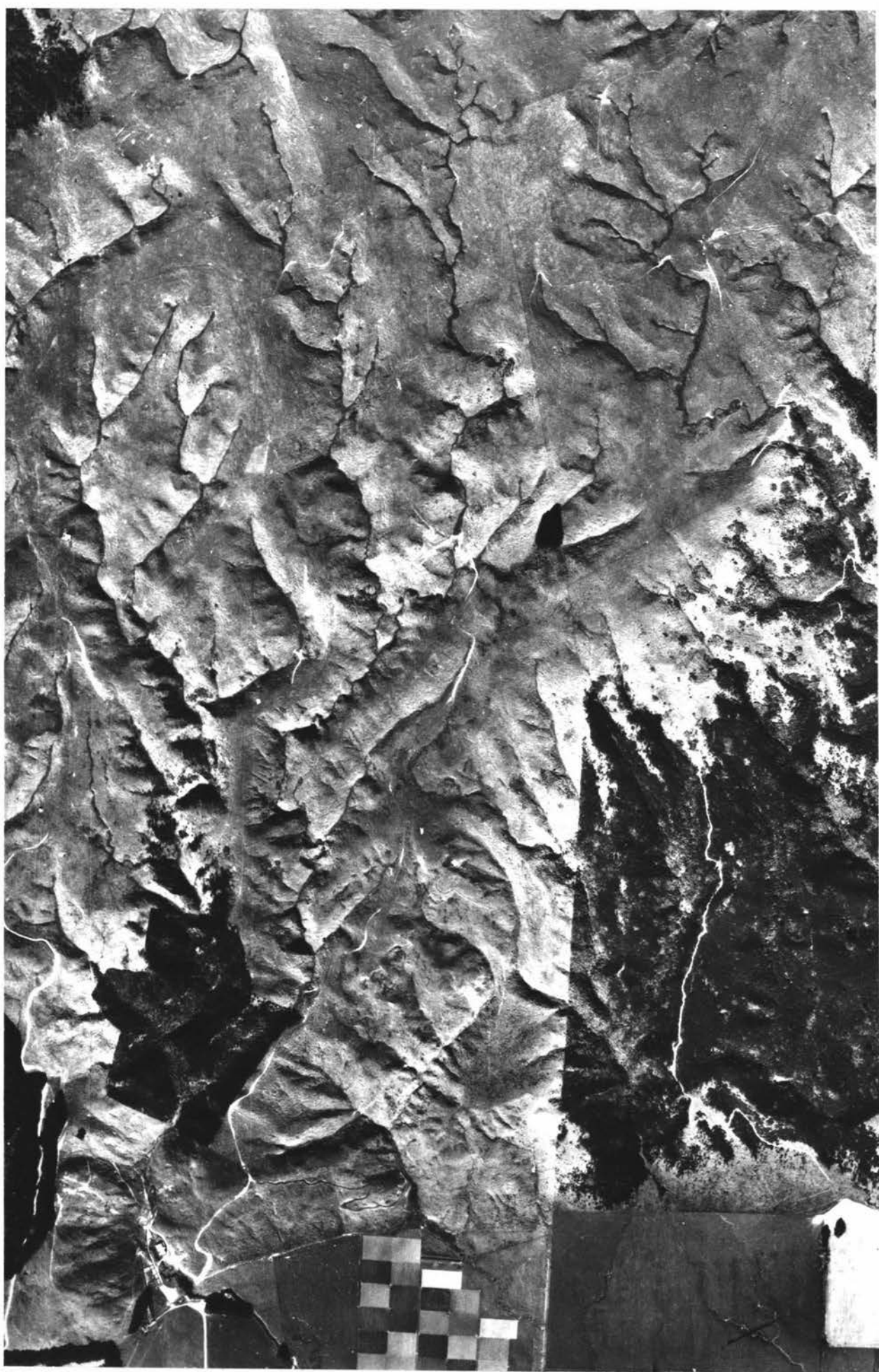
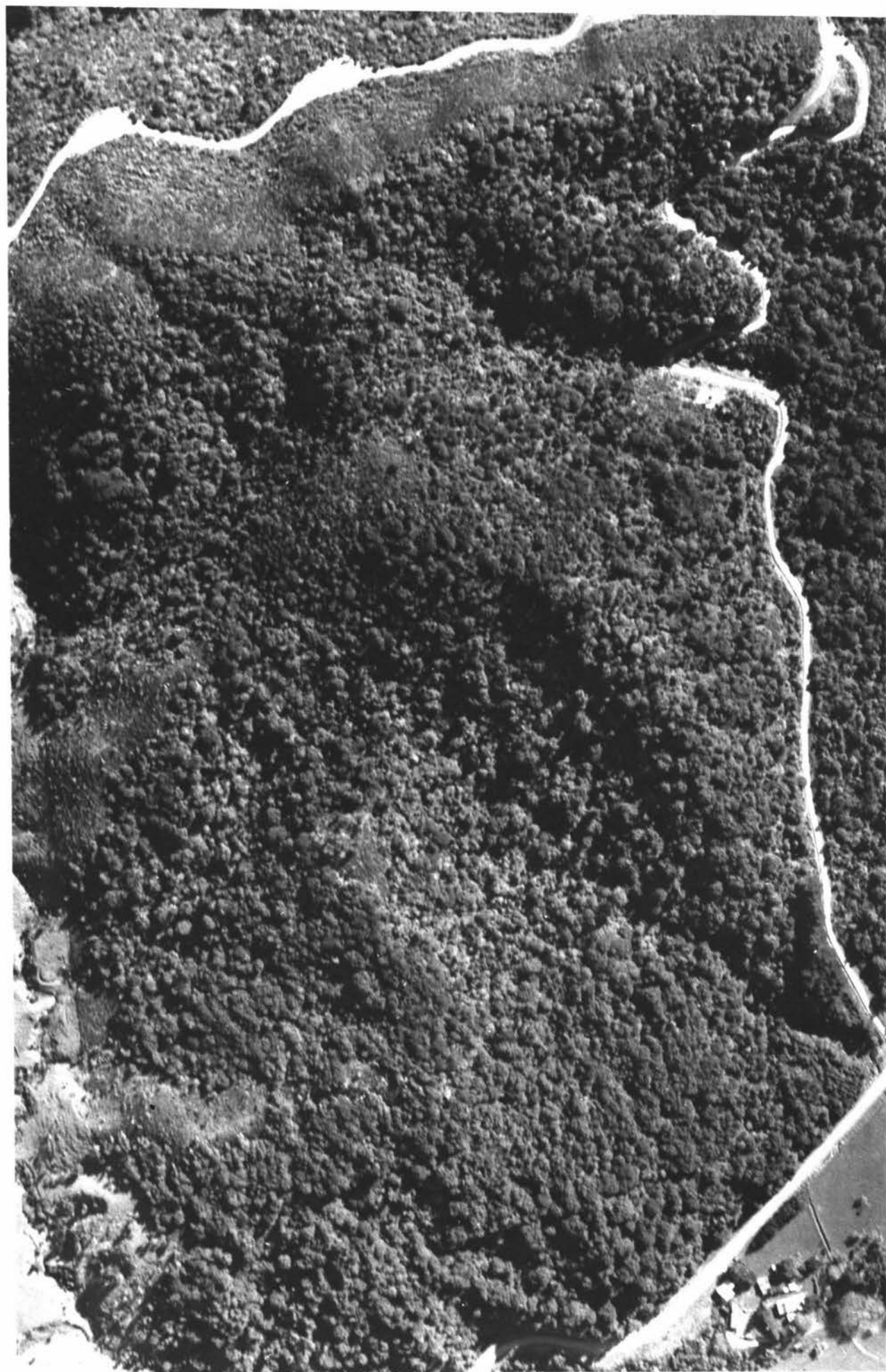


PLATE 4. VERTICAL VIEW OF BALLANCE
CATCHMENT.
APPROX. SCALE 1:3000
(Photo: Mr D.G. Bowler, 1974)



SECTION 3

CATCHMENT DESCRIPTION

3:A Catchment Location

The Tuapaka Catchment is located in the Northern Tararua Ranges 5 km south of the Manawatu Gorge (Fig.1). The Massey University Soil Science Department weir lies approximately 1.5 km east of the Manawatu River into which the Tuapaka Stream drains. The map reference for the weir, from the N.Z. Mapping Service Map 1 'Palmerston North', is N149/215371. The catchment is part of a Massey University sheep farm. On-farm access is provided by numerous tracks. The Palmerston N.-Woodville highway provides access to the weir.

The Ballance Catchment is also situated in the Northern Tararua Ranges at the eastern end of the Manawatu Gorge, 8 km due east from Tuapaka (Fig. 1). The Ballance Stream is ephemeral and drains into the Manawatu River. The map reference for the flume, from N.Z.M.S. Map 1 'Palmerston North', is N149/295366. The catchment forms part of a large area of publicly owned native bush (The Ballance Bridge Domain) which was designated a Scenic Reserve in 1971. Access is from an adjacent sealed road from Ballance which crosses the Manawatu River to join the Palmerston N.-Woodville Highway.

3:B Climate

3:B:1 General

New Zealand lies in a temperate climatic zone between a sub tropical high-pressure zone and a low-pressure trough in the southern polar regions. Westerly winds prevail and the country is subject to rapid fluctuations of weather produced by a series of anticyclones and depressions which move continuously from west to east. Because of latitude, oceanic surroundings, and relief, the climate is insular and marked by an absence of extreme variations of temperature. The effect of the mountain ranges is to cause large vertical movements in the atmosphere and much mixing of the various layers up to considerable heights. These processes in turn cause modifications in the distribution of rainfall which is irregular; the diurnal variation of temperature is relatively large; and there is a high percentage of sunshine.

The climate of the study catchments is determined by their topography and position in relation to the large scale weather system affecting N.Z.

3:B:2 Rainfall

The average annual rainfall for the climate station at Waipuna (Woodville) from 1924-1969 is 1301mm. Average monthly figures for the same period (Appendix 1a) were published by the N.Z. Meteorological Service (Misc. Publ. 141 'Rainfall Percentiles' 1973). Waipuna is 2 km and 9 km from the Ballance and Tuapaka Catchments respectively. Rainfall is relatively uniform throughout the year.

Rainfall intensity figures for Palmerston N. (Robertson, 1963) show that 24 hour rainfalls of 68.6 mm and 121.9 mm have return periods of 2 years and 20 years respectively. Records from the Climate Station at Ballantrae (Woodville) (N.Z. Met. Ser. Misc. Publ. NO 109) show that the maximum daily rainfalls for 1970, 1971, 1972 and 1973 were 58 mm, 71 mm, 85mm and 91 mm respectively. Further rainfall intensity values from Robertson (1963) are summarised in Appendix 1b. Rainfall intensity has been shown to be highly important in various forms of erosion by Dreibelbis (1953), Smith and Wischmeier (1957), and Guy (1964).

3:B:3 Wind

Average wind percentage frequency figures for Palmerston N. (Appendix 1c) from 1940-49 show that about 50% of wind is from the west and north-west. On average 30% of the year is calm. Short term figures for other Climate Stations in the region tend to show that Palmerston N. winds are not markedly different from those encountered in the study catchments.

3:B:4 Temperature

The mean annual temperature for the Manawatu Region is about 13°C. This figure is probably slightly high for the study catchments due to their elevation.

3:B:5 Water Balance

Using average monthly "Penman" values of potential evapotranspiration from Palmerston N. and daily rainfall data from Waipuna, a water balance was computed for the study catchments by Mr N.G. Robertson (1975; pers.comm.) of the N.Z. Meteorological Service (Appendix 1d). The average annual runoff for the period 1967-75 was 554mm and runoff occurred on an average of 64 days per year. The average annual water deficit for the same period was 153mm and a deficit, known as "agricultural drought" (as defined by Rickard, 1960) occurred on an average of 49 days per year.

FIGURE 2

TUAPAKA CATCHMENT

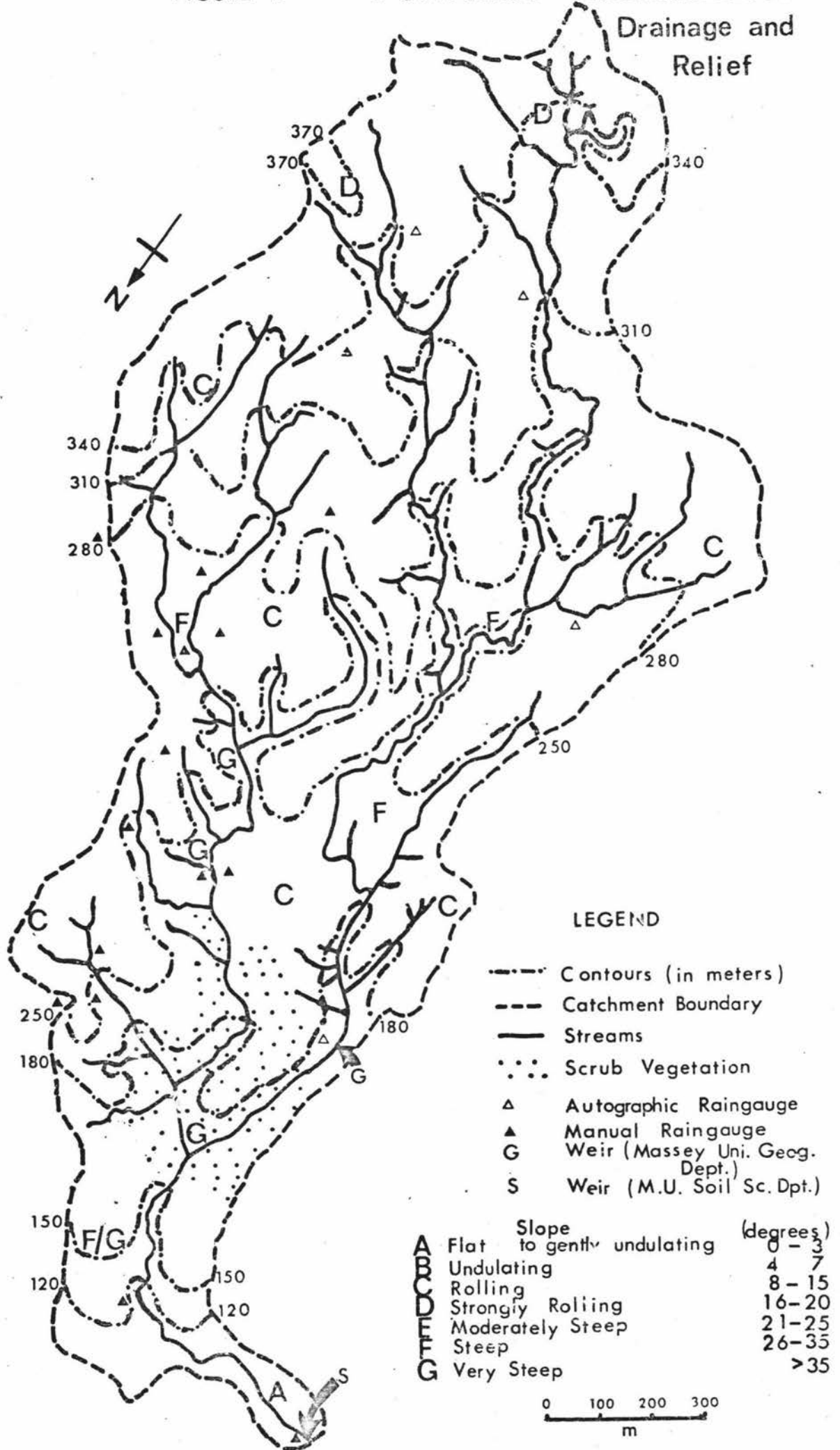
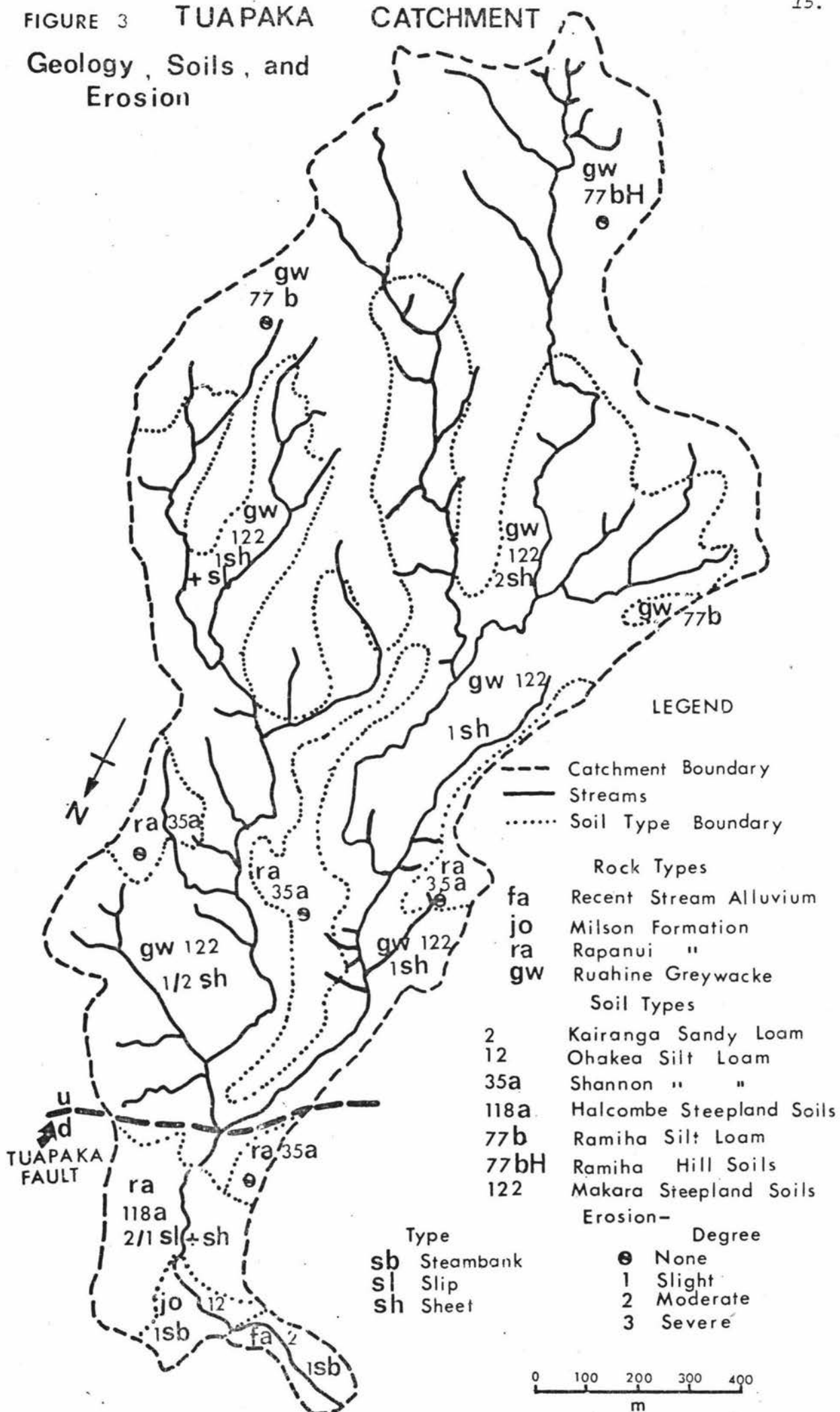


FIGURE 3 TUAPAKA CATCHMENT

Geology, Soils, and Erosion



3:C Geology and Soils

3:C:1 General

Both study catchments are located on the flanks of the northern Tararua Ranges about mid way along the axis of the North Island ranges. Studies on the Cenozoic geological history of the northern Tararua Range have concentrated on areas west of the Manawatu Gorge where well preserved marine benches, river terraces and their cover deposits highlight the youthful nature of the region's physiography (Cotton, 1942; Ongley, 1953; Rich, 1959; and Fair, 1968). Rich (1959) has identified four areas of Pliocene - Pleistocene sedimentation in the northern Tararua Ranges, immediately south of the Manawatu Gorge, which he assigns to the Lower Waitotoran, Upper Waitotoran/Lower Nukumaruan, Upper Nukumaruan, and Lower Castlecliffian stages. A Lower Castlecliffian formation termed the Tuapaka Formation extends 14km south from the Manawatu Gorge through the Tuapaka Catchment, being identified as a discontinuous series of flat topped spurs at about 150 m altitude.

The pattern of soils in the Ballance Catchment is relatively simple, reflecting its small, reflecting its small area. The Tuapaka Catchment in comparison is eighteen times as large and has a fairly diverse pattern of soils reflecting not only its size but also its geological history, (Figs. 3 and 4). Some physical characteristics (from Cowie, 1972) considered important hydrologically are listed in Appendix 2.

3:C:2 Geology of the Tuapaka Catchment

The Tuapaka Catchment rises from 80 m above sea level at the Massey University Weir, to 400 m at its highest point where a ridge separates the catchment from two un-named catchments that also drain north west to the Manawatu River. The Tuapaka Stream channel network descends from its highest points in a number of steep sided valleys which are cut in Ruahine Greywacke. Between 260 m - 108 m a.s.l. the greywackes are overlain by the Rapanui Formation, an uplifted marine bench deposit, now deeply dissected by the stream which continues to incise into the underlying greywacke. From about 100 m a.s.l. to the weir site the stream flows across the Milson Formation, a relatively flat, Recent, aggradational terrace of the Manawatu River. The stream has cut into the Milson Formation some 2 - 5 m.

The Rapanui and Milson Formations are composed of coarse gravel, derived from the greywackes of the axial range, and finer material derived from the erosion products of softer covering Tertiary and Quaternary strata which were deposited on the greywacke (Rich, 1959). Up to 2 m of loess mantles most of the aggradational terraces and older formations.

The catchment is situated in a tectonically unstable area, being crossed by at least two active transcurrent faults (Fig. 3). One of these (un-named) parallels the Fitzherbert East Road, the other, the Tuapaka Fault, runs parallel to this, crossing the catchment approximately 0.85 km east of the road (Rich, 1959).

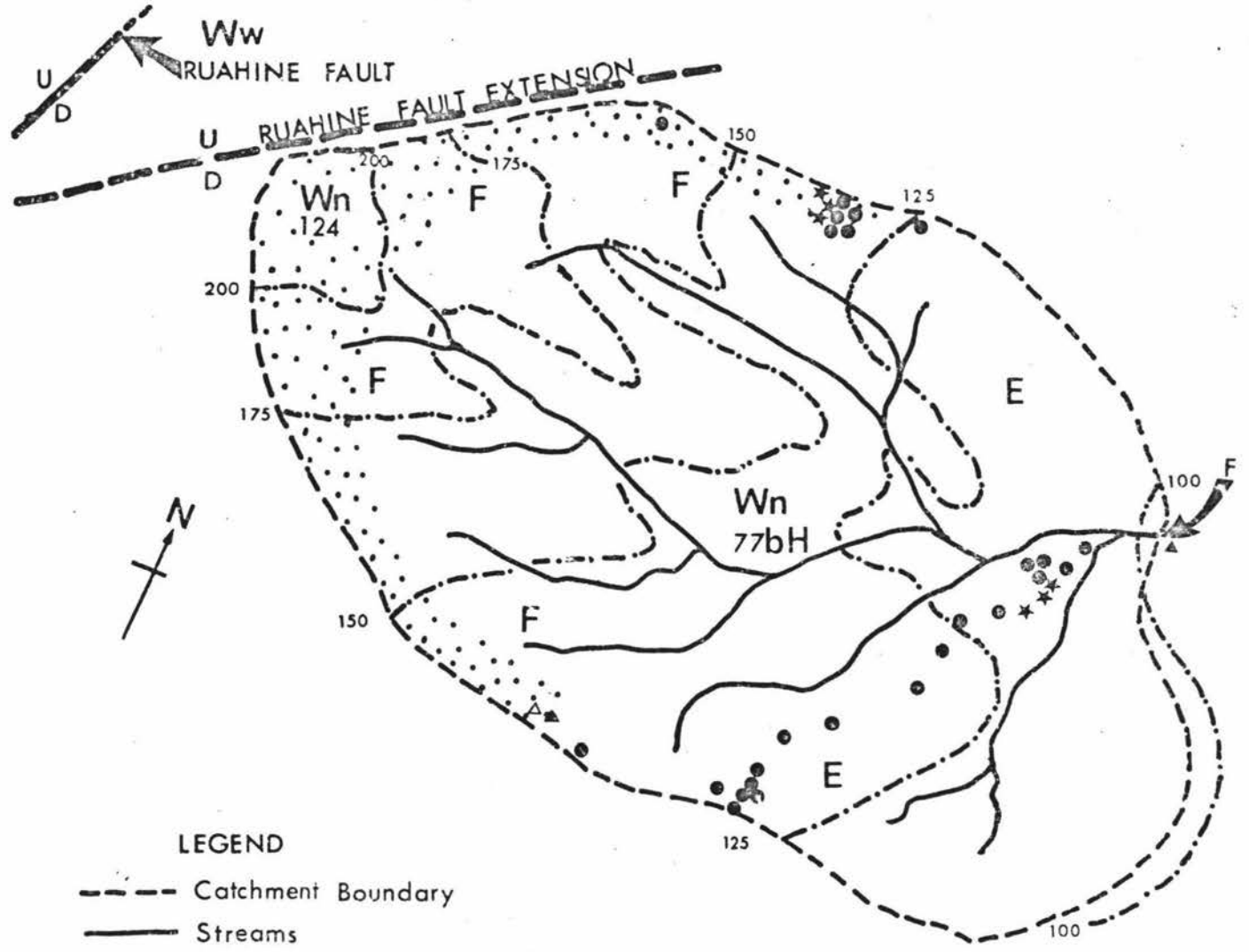
3:C:3 Soils of Tuapaka Catchment

There are five major soil types mapped over the Tuapaka Catchment, Fig. 3 (Gilchrist, 1969). Between 208 - 400 m a.s.l. Ramiha hill soils are mapped on ridges to the west of the catchment. At similar elevation, but to the east of the catchment, Ramiha silt loams occur. On ridges of the Rapanui Formation from 130 - 260 m a.s.l. Shannon silt loams are preserved but on a small section of these ridges between 108 - 130 m a.s.l. Halcombe steep-land soils occur. Makara steep-land soils are mapped along most of the Upper Tuapaka stream bed and immediate valleysides and these soils grade into a small area of Halcombe steep-land soils downstream. The Halcombe steep-land soils grade down into Ohakea silt loams and, near the weir, Kairanga fine sandy loams, which both overlie the Milson Formation.

A similar pattern of soils is likely to be replicated over other small catchments in the vicinity, which drain westwards to the Manawatu River. Therefore extrapolation of sedimentological and hydrological data obtained from the Tuapaka Stream study, to other areas of the eastern Manawatu should be possible.

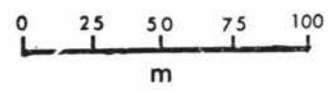
Because the land is covered in pasture a summary of the physical characteristics of the soil includes some information on its limitations for intensive use and its response to topdressing (Appendix 2). This information holds important hydrological implications for the catchment. For example, the majority of the soils have slow to medium internal drainage, indicating that surface water builds up quickly during rain and leads to the development of surface runoff. Significant areas of soils on the valleysides in the upper catchment exist on land classified as moderately steep (21° - 25°) to very steep ($>35^{\circ}$), (Fig.2). Without a considerable degree of careful grazing management on these soils, surface soil erosion, rill and gully erosion could become severe (see section 3:E on erosion).

FIGURE 4 BALLANCE CATCHMENT
Geology, Soils, and Drainage



LEGEND

- Catchment Boundary
- Streams
- - - - Contours (in meters a.s.l.)
- △ Autographic Raingauge
- ▲ Manual " "
- Thoughtfall " "
- ★ Stemflow Gauge
- F Flume



Geology

- Wn Nukumaruan Sedimentary Rock
- Ww Waitotoran " "
- Limestone
- Fault - Active
- - - " - Concealed

Slope - See Fig. 2 (Legend)

Soils

- 124 Ruahine Steepland Soils
- 77.5H Ramiha Hill Soils

3:C:4 Geology of the Ballance Catchment

The only detailed study of the geology of this small catchment was carried out by Neall (1974). He found that the, "Ballance Catchment stream is cut into the dip slope of Nukumaruan strata that dip 15° - 30° to the east, and overlie the eastern margin of the greywackes that form the main axial ranges. The strata consists of a coquina limestone with greywacke pebbles in the upper part and calcareous sandstones and siltstones in the lower part. The stream has eroded through the upper calcareous sandstones and siltstones into the lower sandstones and siltstones of Nukumaruan age (A. Beu 1975; pers. comm). To the immediate west of the catchment is a north - striking stream that appears to mark the contact between the Waitotoran strata and the underlying greywacke. It is therefore likely that greywacke underlies the Ballance Catchment stream at a depth of 50 - 100m."

About 0.45km before its junction with the Manawatu River the Ballance Stream emerges from the Nukumaruan strata and crosses a Recent aggradational terrace (Lillie, 1953).

The tectonic instability of this area has been shown by the presence of several minor faults to the south of the catchment (Rich, 1959). An extension of the Wellington Fault (named the Ruahine Fault by Kingma, 1957) lies to the west of the catchment.

3:C:5 Soils of Ballance Catchment

The soils of this small catchment have not been mapped in detail, only as part of an extensive soil survey of the Pahiatua County (Gibbs, 1959). Ramiha hill soils are formed on the lower portions of the catchment and these grade into Ruahine stepland soils towards the west. Characteristics of the two soils considered relevant to the hydrological properties of the Catchment are summarized in Appendix 2.

3:D Vegetation

3:D:1 General

Vegetation has an important effect on the hydrological properties of a catchment. Such factors as rainfall interception, infiltration, percolation, surface runoff, evapotranspiration, and various plant litter effects are markedly influenced by the nature of the vegetative cover. Kittredge (1948) has discussed these effects in detail.

3:D:1:1: Original Vegetation and Fires

The original vegetation of the study catchments was probably rimu (Dacrydium cupressinum)- tawa (Beilschmiedia tawa)- pukatea (Laurelia novae-zelandiae) dominant forest (Franklin, 1967). It is likely that pre-European fires some 200 years ago (Esler, 1963) marked the beginning of changes in the vegetation that, in conjunction with other factors to be discussed, have given rise to the present vegetation. Periodic fires have burnt along the Ballance Catchment ridges causing the replacement of some former vegetation with areas of bracken fern (Pteridium-aquilinum var. esculentum). A planting of pines (Pinus radiata) on the north and eastern ridges suggests that the Ballance Catchment was burnt over about 10 years ago. The Tuapaka farm was cleared by burning in the early twentieth century following logging of the larger marketable species (Franklin, 1967).

3:D:1:2 Introduced Animals and their Effects

The Tuapaka Catchment has been farmed since its early clearing therefore the following discussion does not apply to it.

Red deer (Cervus elaphus) had become established in the district by the early twentieth century. They have maintained their influence on the vegetation of the Ballance Catchment until recently when shooting pressure largely removed them from the catchment. Opossums became established in the region later than deer but their influence on the vegetation had probably begun by 1920 and continues today. It is evident also that domestic cattle and sheep stray into the Ballance Catchment and cause damage to the vegetation.

The effects of deer and opossums on the native forests of New Zealand have been discussed in detail by many workers including Esler (1963, 1969), Holloway et al. (1963), Elder (1965), and Franklin (1967).

It is thought that opossums are responsible for opening up the canopy by browsing the new growth of canopy species which causes their eventual death and allows light to penetrate to the forest floor. With the resulting increased growth of understorey vegetation the deer are encouraged into the area and they, in conjunction with the opossums, cause marked changes in the understorey vegetation. Most important of these changes is the virtual suppression of seedlings and the replacement of many palatable plant species by less palatable ones.

Within the Ballance Catchment evidence for the above processes can be found and it seems that a process has occurred which has been described by Esler (1969) in his account of the changing vegetation in the Tiritea Valley (Manawatu), as a 'degeneration sequence'.

3:D:2 Present Vegetation

In the Ballance Catchment except for a few small areas of bracken fern and native grasses along the burnt ridges, the whole catchment is effectively covered in native forest, most of which is composed of relatively few species. The more important species, and some measure of their abundance within the forest, are given in Appendix 3.

The present canopy is dominated by tawa although mahoe (Melicytus excelsum) occurs frequently and seedlings of hinau (Elseocarpus dentatus), rewarewa (Knightia excelsa), miro (Podocarpus ferrugineus), titoki (Alectryon excelsus), pukatea (Laurelia novae-zelandiae), and kahikatea (Podocarpus dacrydioides), are fairly numerous and should in time form part of the canopy. The forest is non-uniform in height or cover. Individuals of tawa, rewarewa and hinau emerge from the canopy up to 10m above it and breaks of 5 m² or more occur in it. There is a well developed understorey vegetation which is thickest where the tree canopy is broken and light can penetrate to the forest floor. The ground flora is well developed and is comprised predominantly of various species of ferns, interspersed with mosses and lichens. Most of the catchment has a thin to well developed litter on the floor which indicates reasonable surface stability and allows good rainfall infiltration and protection from raindrop erosion.

The Tuapaka Catchment forms part of a sheep and cattle farm. The majority of the catchment is covered in pasture with a predominance of browntop (Agrostis tenuis) and oversown white clover (Trifolium repens). Perennial ryegrass (Lolium perenne), through various seed transporting mechanisms, has managed to spread onto the catchment.

Other grass species present include danthonia (Danthonia spp.) and crested dogstail (Cynosurus cristatus). Grass swards on hill country farms vary considerably in botanical composition, according to soil fertility (natural or induced artificially), the class of stock, and the method of stocking according to Levy (1970). A 12 ha block of manuka (Leptospermum spp.) and gorse (Ulex europaeus) is situated on a steep, rocky section of the catchment. Small patches of similar scrub occur on some very steep sided, rocky, stream banks.

3:D:3 Pasture and Stock Management at Tuapaka

Sheep are grazed on the catchment at approximately 7/ha and cattle at 0.7/ha. Breeding cows are removed from the catchment to a 'holding pad' during calving. On average 320 kg/ha/year of superphosphate fertilizer have been applied to the catchment over the last ten years but during 1975 only half the farm was fertilized. Approximately 19 ha of the upper catchment was planted in a turnip and swede crop for winter stock feed in 1974/75. This measure has not been taken before but other farmers in the district have previously cultivated hill areas and planted various forage crops. The hazard of cultivating Land Capability Class iv and vi hill country and grazing the cover during winter months should be apparent. During spring 1975 the cropland was disced and resown with a ryegrass and white clover seed mixture.

The pasture and stock management procedures used on the Tuapaka Farm are similar to those used on similar hill country farms in the Manawatu. Specific soil conservation measures are rarely taken although this has not led to the appearance of severe soil erosion, as it has in various other hill country areas of New Zealand. This is due to the relatively greater degree of stability inherent in the soils of this area.

3:E Erosion

3:E:1 General

Erosion is the wearing away of the land surface by running water or other agents and is part of the sedimentation process occurring naturally in most streams and rivers. Through the activities of man, many catchments are undergoing a phase of accelerated erosion leading to greatly increased stream sediment loads. It was beyond the scope of this study to quantitatively assess the rates of erosion occurring at various sites within the study catchments. The net sediment yield from the catchments was considered the most important parameter of total erosion. The extent of various types of erosion occurring in the catchments was estimated from aerial photographs and by eye, with reference to a 'Land Use Capability Map' by Gilchrist (1969) and the Land Use Capability Handbook (MWD, 1974). An attempt was made to identify the major sources of stream sediment by observing erosion and transportation processes occurring in the catchments and this is referred to in a later discussion.

3:E:2 Tuapaka Catchment Erosion

The Tuapaka Catchment may be said to be in a 'disturbed state' because the original vegetation has been removed and replaced with pasture, farm tracks have been cut, cultivation has been carried out, and various animal grazing effects have been imposed on it.

Sheet erosion occurs on the steeper slopes of the catchment bordering the stream channel and varies in degree between slight and moderate (Fig. 3). Severe sheet erosion occurred on 19 ha of cropland during winter 1975. Rill erosion developed to a slight degree on portions of the cropland during the period it was grazed. Soil slip erosion is evident on Halcombe steepland soils particularly, and varies in degree between slight and moderate. Slight tunnel gully erosion occurs within the catchment. Slight streambank erosion occurs on Ohakea silt loams and Kairanga fine sandy loams.

3:E:3 Ballance Catchment Erosion

The Ballance Catchment has been relatively undisturbed by man although the vegetation is in an unstable state due to factors discussed. Due to this instability slight soil slipping occurs in the catchment and where there are larger breaks in the forest canopy some slight sheet erosion is evident.

SECTION 4

METHODS

4:A Rainfall

4:A:1 Tuapaka Catchment

A network of 15, 16-cm plastic funnel gauges (Plate 7) and 2 plastic 'Marquis 1000' type gauges, was distributed randomly over the north east portion of the catchment on 27th February 1975 (Fig 2). The Massey University Geography Department has operated four autographic Lambrecht - type raingauges in the south east of the catchment since 1970 and records from these were made available for this study. The autographic gauges were placed in position after a year of operation of a manual raingauge network. This allowed researchers to account for variations in the effective rainfall on the catchment. The amount of rainfall incident on the whole catchment was calculated by averaging values from the various gauges. This method was considered adequate, at the given gauge density, by Corbett (1967).

4:A:2 Ballance Catchment

Rainfall over the Ballance Catchment was measured by three types of gauge (distributed as indicated in Fig. 4);

- (i) One Lambrecht autographic gauge placed 23rd April 1975
- (ii) One Marquis 1000 plastic gauge placed 5th March 1975
- (iii) Two 16-cm plastic funnel gauges placed 27th February 1975

The amount of rainfall incident on the whole catchment was calculated by averaging the values from the various gauges. Rainfall figures for the period 1st November 1974 to 27th February 1975 were obtained from the N.Z. Meteorological Service for Waipuna (see Section 3:B Climate).

Throughfall was measured using a number of randomly placed 16-cm plastic funnel gauges. These were concentrated in two areas (Fig. 4) but linked by a transect of gauges, to ensure that rainfall variation from southerly and northwesterly storms was adequately recorded. The position of the gauges was altered at bi-monthly intervals in a random manner and throughfall was measured after each storm.

PLATE 5. TUAPAKA WEIR

PLATE 6. BALLANCE FLUME

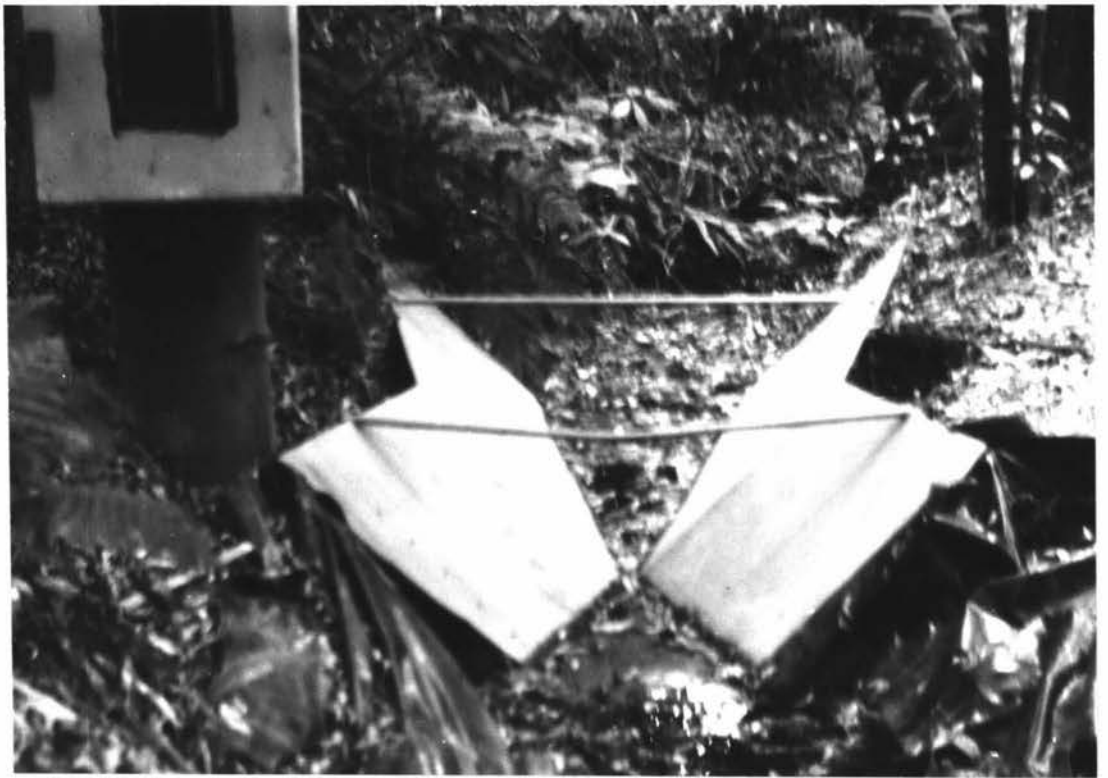
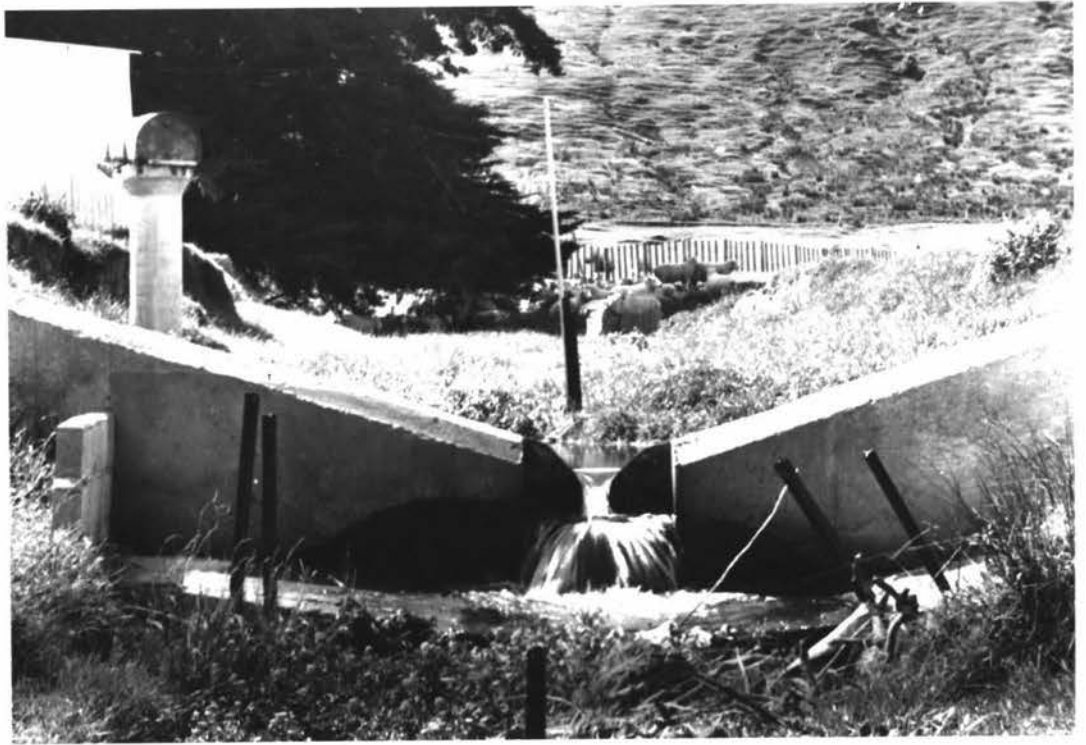
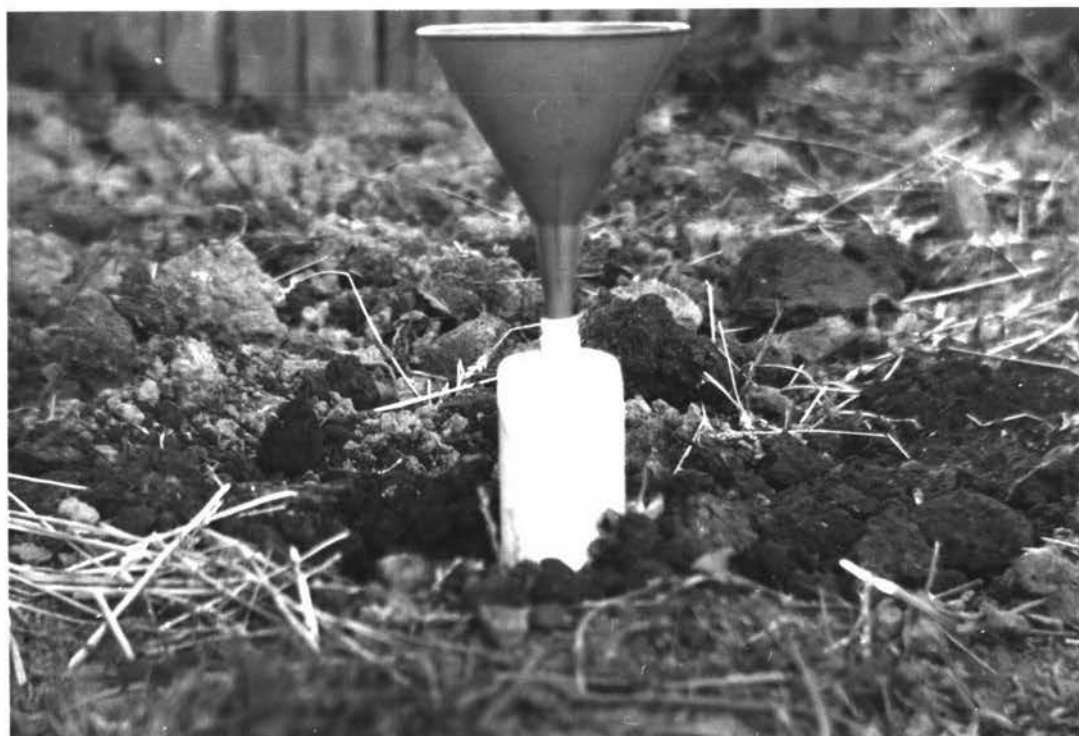


PLATE 7. STANDARD RAINGAUGE USED
 TO MEASURE THROUGHFALL
 AND RAINFALL

PLATE 8. PLASTIC TUBING CUT
 AND ATTACHED TO TREE
 TRUNK FOR COLLECTION
 OF STEMFLOW



Stemflow measurement on 6 Tawa (*Beilschmiedia tawa*) trees of varying diameter at breast heights, began on 1st June 1975 and was continued for five months. Collars to intercept stemflow were made from 3 cm plastic tube (Plate 8). The tube was slit and one edge secured to the tree with small tacks. The join between the tree trunk and plastic collar was sealed. Water was collected in 60 l plastic containers and the volume recorded after each storm.

4:B Stream Discharge Measurement

4:B:1 Tuapaka Catchment

The Massey University Soil Science Department installed a compound 3:1 triangular weir with an insert 90° V-notch and a Stevens F - type stage recorder on 1st May 1974 and this was used to measure the discharge for a year beginning 1st November 1974 (Plate 5).

4:B:2 Ballance Catchment

The Massey University Soil Science Department began recording discharges on 22nd November 1973 using a 90° V-notch weir and a 'Childs' recorder. A Lee stage height recorder replaced the Childs recorder on 26th March 1974 but due to the swampy nature of the stream bed and surrounding soil the V-notch structure tended to be scoured and was replaced by a trapezoidal cut-throat V-shaped flume on 10th February 1975. The flume was constructed from sheet steel from plans specified in Report W.E. 31-4 of the Utah Centre for Water Resources Research (1967) and Skogerboe and Hyatt (1967). On installation, a sheet steel plate was embedded 0.7m in the streambed at right angles to the stream flow to limit underground seepage, and the flume was sealed to this. Thin plastic sheeting was attached to the flume and extended for 2m up the streambed to prevent scouring around the flume (Plate 6). A Lee stage recorder was used in conjunction with the flume which operated at all times under "free flow conditions," (Skogerboe and Hyatt, 1967).

4:C Sediment Discharge Measurement

An intensive stream sampling program to determine suspended sediment concentrations was carried out during the year beginning 1st November 1974. Both streams were sampled at least once a week. During flood flows, samples were taken every 10 minutes by the writer with the help of staff from the Massey University Soil Science Department. In order to standardise the sampling method, over 60 simultaneous samples were taken at various stage heights using both a standard U.S.D.H 48 hand sampler (on loan from the Ministry of Works and Development), and 1.3 l. plastic containers.

The degree of correlation between the two sampling methods was determined. During low flows use of the U.S.D.H 48 sampler was impractical. Suspended sediment sampling involved recording the stage height and time then dipping the 1.3 l. plastic container to approximately 3/4 the stream depth at a point immediately upstream of the weir pool where the flow was unmodified.

Suspended sediment concentrations were determined by evaporating weighed samples to dryness. The results were corrected for dissolved matter concentrations. These were determined in a similar manner on samples filtered through 0.45 μ millipore filter circles. Results were expressed in milligrammes per litre (mg/l).

4:D Bedload Measurement

There seems to be no universally acceptable method of bedload estimation. The annual bedloads of both study catchments was relatively small and sophisticated measuring techniques were not required to obtain a reasonable estimate. During the installation of the Tuapaka Weir (on the 20th April 1974) surplus concrete was used to 'pave' the streambed for 5m upstream, affording an opportunity to weigh and carry out particle size analysis on any accumulated bedload. The trap efficiency of the weir was determined from periodic particle size analyses of the suspended sediment above and below the weir.

Plastic sheeting laid upstream from the 90 degree V-notch at Ballance provided a convenient base and trap for bedload. The material was removed and weighed after a year and particle size analysis carried out.

4:E Particle Size Analysis

Particle size analysis was carried out using the method involving screening and centrifugation developed by Jackson (1956). Particle sizes were expressed according to the Phi Scale. Analyses were carried out on bedload and suspended sediment samples collected over the year.

4:F Stream Water Nutrient Analysis

In order to study the distribution of phosphorus (P) and nitrogen (N) between dissolved and particulate forms in the stream waters, analytical data for stream samples from the Massey University Soil Science Department's Water Quality Project, (Chief Investigator, Prof. J.K. Syers) were kindly made available to the writer. Samples for analyses were collected as outlined previously in 1.3 l. plastic containers and treated prior to analysis according to methods outlined by Syers (1975).

Nutrient analyses were also carried out on samples of stemflow, throughfall and rain water from the Ballance Catchment.

4:F:1 Phosphorus

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 (PTP) was then determined by difference (O'Connor and Syers, 1975).

4:F:2 Nitrogen

Nitrate (NO_3) was determined as nitrite by the Griess-Ilosvay method following reduction by cadmium (Hendricksen and Selmer-Olsen, 1973). Total (TN) and total dissolved N (TDN) were determined on unfiltered and filtered samples, respectively, following a Kjeldahl-type digestion (Tenny, 1966). All of these nitrogen analyses were run on a Technicon auto-Analyser. Total N was then calculated as the sum of nitrate and total Kjeldahl-N. Total particulate N (TPN) was determined as the difference between total Kjeldahl and dissolved Kjeldahl N.

4:F:3 Organic Carbon

Organic carbon determinations were carried out on some sediment samples using a method outlined by Gaudette et al. (1974).

4:G Data Processing

Instantaneous flow rates, dissolved sediment fluxes, sediment fluxes and nutrient fluxes for P and N forms were calculated from stage height and component concentrations using card input to an object program. Total loads and total flow were calculated by numerical integration, over periods of interest, of the linearly interpolated nutrient flux and water flow curves respectively.

Regression analysis of various components was conducted using linear, multiple and polynomial regression source programs.

All programs were either wholly designed, or modified, by Dr. P.W. O'Connor and implemented on a Burroughs B 6700 computer.

SECTION 5

RESULTS AND DISCUSSION

5:A Characteristics

A number of parameters describing the morphology of the two study catchments (Table 2) were selected from those given by Boughton (1968). Some characteristics of the vegetation, soils, geology and climate, relevant to the hydrology of the catchments, have been discussed previously.

5:A:1 Drainage Pattern

The drainage pattern of both catchments was studied by aerial photography (photographs taken by Mr D.G. Bowler during 1974) and verified in the field. The analysis of drainage patterns is summarized in Table 1.

The drainage pattern of both catchments is dendritic with a drainage density of 13.9 km/km² and 8.8 km/km² for Ballance and Tuapaka, respectively. The greater drainage density of the Ballance Catchment may be explained by its more youthful geology. Streams at Ballance are cutting into soft, recent sedimentary rock whereas at Tuapaka the stream is cutting into harder Tertiary greywackes. A comparison of the drainage density values with those of earlier workers, such as Horton (1932) and Langbein (1947), is not possible because of the differences in scale used.

TABLE 1
DRAINAGE ANALYSIS OF
STUDY CATCHMENTS

Catchment	Stream Order	Stream Number	Length (km)
Tuapaka	1	52	7.5
	2	12	3.5
	3	3	2.4
	4	1	2.4
	Total	68	15.8
Ballance	1	11	0.93
	2	3	0.36
	3	1	0.10
	Total	15	1.39

TABLE 2

SUMMARY OF HYDROLOGICAL
CHARACTERISTICS

PARAMETER	TUAPAKA CATCHMENT	BALLANCE CATCHMENT	REFERENCE	METHOD
Area	180 ha	10 ha		Planimeter
Average width	485 m	232 m	Boughton(1968)	Map Wheel
Maximum length	2650 m	392 m	"	"
Hypsometric analysis	Fig 6 Hypsometric Curves		Strahler(1952)	Planimeter, altimeter
Form factor	0.13	0.59	Horton(1932)	Map Wheel
Shape	Fig 5 Area shape curve		Boughton(1968)	"
Maximum basin relief	300 m	120 m	Boughton(1968)	Altimeter
Relief ratio	0.11	0.29	Schumm(1956)	Altimeter, map wheel
Mean stream slope	0.08	0.23	Boughton(1968)	"
Stream frequency	0.38ha^{-1}	1.5^{-1}	Horton (1945)	Aerial photo
Drainage density	$8.8\text{km}/\text{km}^2$	$13.9\text{km}/\text{km}^2$	Horton(1932)	1 : 10,000
Bifurcation ratio	3.8	3.3	Horton(1932)	Map Wheel

FIGURE 5 AREA-SHAPE CURVES

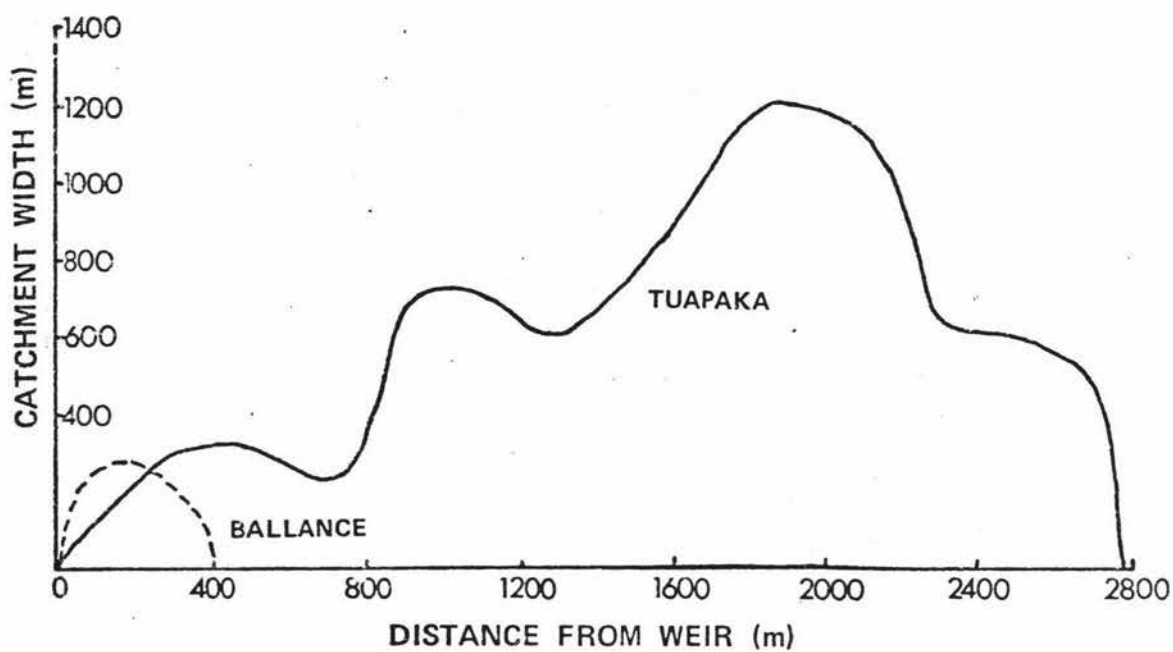
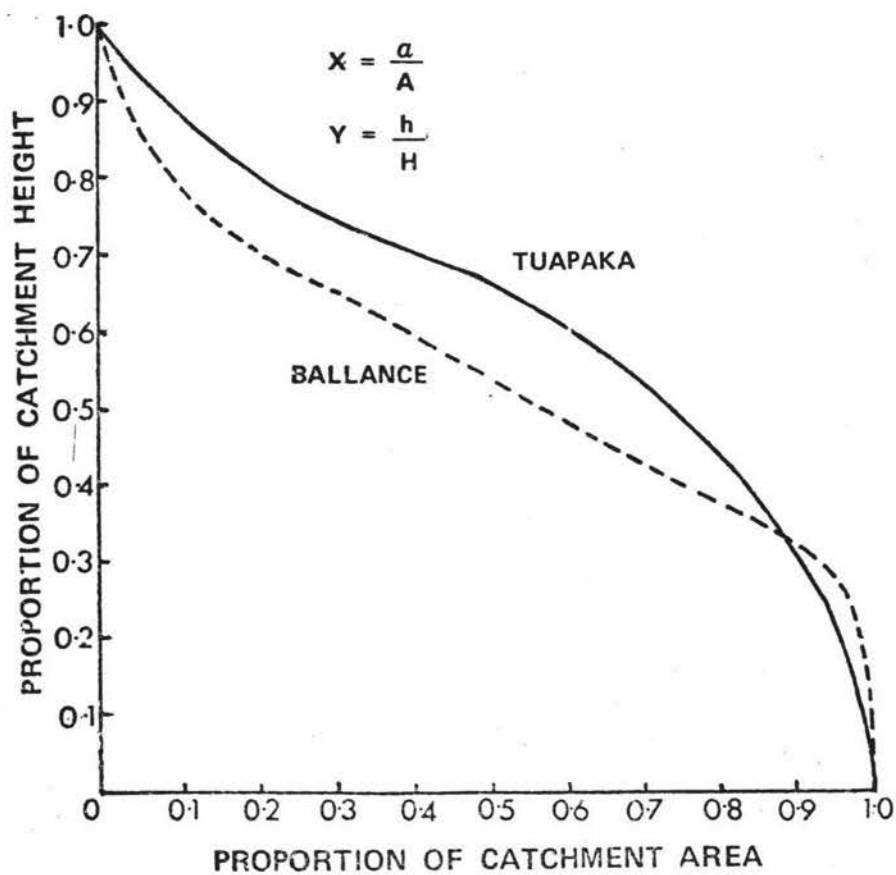


FIGURE 6 HYPSONETRIC CURVES



5:A:2 Hypsometric Analysis

When compared with the analysis given by Strahler (1964), the hypsometric curves for the study catchments (Fig. 6) show that both catchments are somewhere between 'mature (equilibrium)' and 'immature (inequilibrium)' stages. A comparison between the two curves indicates that the Tuapaka Catchment is at a less mature stage than the Ballance Catchment. A possible explanation for this difference is that contours could be more accurately placed at Tuapaka (larger scale maps were available) than at Ballance, making the Tuapaka hypsometric curve the more accurate of the two.

5:A:3 Bifurcation Ratio

Strahler (1957) noted that bifurcation ratios characteristically range from 3 to 5 for watersheds in which the geological structures do not disturb the drainage pattern. The Ballance Catchment has a bifurcation ratio of 3.3, which is relatively low according to Strahler (1957). This suggests that the catchment is distorted or 'rotund' and may produce a "sharply-peaked flood hydrograph". The area shape curve indicates that the Ballance Catchment is highly compact, almost circular, compared with the more elongate Tuapaka Catchment. The Tuapaka Catchment has a 'normal' bifurcation ratio.

5:A:4 Slope

Catchment slope was surveyed and categorized according to the Land Use Capability Survey Handbook (1974). The Ballance Catchment has a higher proportion of steeper slopes than Tuapaka (Figs. 2 and 4). At Tuapaka there are a number of areas of very steep slope ($>35^{\circ}$) where the soil cover is significantly reduced in depth or is non-existent.

The main stream slope of the Tuapaka Stream is 4.5° , whereas that of the Ballance Stream is 12° . If all other factors were equal this would imply that the smaller, steeper Ballance Catchment should be more responsive to rainfall inputs. The influence of vegetation, however, may modify this.

5:B Inputs of Water

5:B:1 Total Rainfall

Although snow is very occasionally recorded at both catchments, the term rainfall is used for convenience in this thesis. The annual rainfall totals for Tuapaka and Ballance were 1,048mm and 1,202mm, respectively.

TABLE 3
SUMMARY OF RAINFALL, THROUGHFALL,
STEMFLOW, AND STREAMFLOW FOR THE
STUDY CATCHMENTS

Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jly	Aug	Sep	Oct	Total
<u>Tuapaka</u>												
<u>Rainfall (mm)</u>												
36.9	101.5	70	48.3	61.4	90.8	130.8	118.9	110.4	149.1	69.9	59.6	1047.6
<u>Streamflow (mm)</u>												
12.3	22.8	3.7	3.1	2.1	4.4	34.2	40.5	47.9	69.6	23.0	9.5	273.1
<u>Ballance</u>												
<u>Rainfall (mm)</u>												
71	83	88	45	58	90	161	121.5	119.3	198.5	88.2	78	1202
<u>Throughfall (as percentage of rainfall)</u>												
49*	54*	53*	45	53	45	60	65	47	61	50	61	54
<u>Stemflow (as percentage of rainfall)</u>												
16*	16*	17*	15*	14*	14*	14*	15	13	28	17	13	16
<u>Effective rainfall (stemflow and throughfall, mm)</u>												
46.2	58.1	66	27	30.7	53.1	119.1	97.7	72.1	166.9	59	57.6	83.6
<u>Streamflow (mm)</u>												
8.4	20.1	6.8	0.03	0.2	0.3	7.1	17.1	17.5	51.3	20.4	8.4	157.6

* Estimated values.

The author was unable to collect rainfall data in the first three months of the study but these were available for the N.Z. Meteorological Service (Waipuna Station) and the Department of Geography, Massey University, for the Ballance and Tuapaka Catchments, respectively. Monthly rainfall totals are summarized in Table 3.

Rainfall intensity values recorded during the study had return periods of less than two years, except for a one-hour rainfall event on 3rd December, 1974. During this storm the maximum one-hour rainfall at Tuapaka was 30.2mm which had a return period of 35 years (Robertson, 1963). The resulting peak stream discharges in both study catchments were the highest recorded in the year of study. Maximum 6-hour and 24-hour rainfall intensities recorded at Ballance for a storm on 26th May, 1975 were 30.1mm and 51.9mm, respectively. These values had return periods approaching 2 years.

A comparison between monthly rainfall figures for Ballance and the long-term monthly averages reported from Waipuna shows that the values are lower, on average, for all months except May and August. For the year of study the annual rainfall was 99mm below the Waipuna 45-year average. A comparison of the monthly rainfall figures recorded at Tuapaka with those recorded by the Department of Geography, Massey University, over the last five years show them to be normal. In summary, rainfall during the study year was normal. It is possible that local topographic factors contribute to a difference in annual rainfall between Waipuna and the Ballance Catchment, which is situated 2km away.

Several small springs occur in the Tuapaka Catchment. It is not known exactly to what extent these contribute water to streamflow in the catchment, or whether their source of water is external to it. Two tile drains discharge into the Tuapaka Stream during storm events. They drain approximately 2ha of the catchment and contributed approximately 0.5% of water to the annual streamflow.

5:B:2 Throughfall

Monthly throughfall figures recorded for the Ballance Catchment are expressed as percentages of monthly rainfall and summarized in Table 3.

The percentage of total rainfall appearing as throughfall, expressed on a monthly basis, varied within the range of 45% to 66%.

During individual storms, the proportion of throughfall varied from zero (storms of less than 1mm) to 80% for storms accompanied by high winds and characterized by high rainfall intensity. The volume of throughfall collected in some gauges actually exceeded the equivalent rainfall; this may be ascribed to local concentrations of throughfall due to dripping from branch ends or bunches of leaves. Similar findings have been reported by Ovington (1954) and Veigt (1960). The average monthly throughfall was 54 % of the total rainfall. The standard error in the estimate of throughfall varied between 2% and 5% for individual storms. Estimates of throughfall, for the periods in which it was not recorded, were made by the author based on rainfall data from Waipuna with special regard to the nature of the storms involved. It was calculated that annual throughfall was 650.3mm, which corresponds to a volume of 6.5×10^7 litres for the catchment area.

The throughfall results obtained for the Ballance Catchment are similar to those obtained by Jackson and Aldridge (1973) for Weinmannia racemosa and for Nothofagus truncata by Aldridge and Jackson (1973), both native species.

Although Toebes and Ouryvaev (1970) claimed that up to 10% of throughfall may be absorbed by litter, litter interception was ignored in this study.

5:B:3 Stemflow

Stemflow studies were carried out on six tawa (B. tawa) trees, the dominant species in the Ballance Catchment. These trees were smooth barked and upright. Their diameters at breast height (indicative of size and age) varied between 0.27 and 0.64m (oldest and largest) and were thought to be representative of the sizes of that species present in the Ballance Catchment. Stemflow was expressed as a depth of rainfall over a given crown area and converted to a percentage of total rainfall (Table 3).

The average monthly stemflow was 16% of rainfall. This figure can only be a rough estimate of the average stemflow in the catchment because only a small number of trees of one species were sampled. Aldridge and Jackson (1973) and Jackson and Aldridge (1973) observed a similar average stemflow for the species Nothofagus truncata but the average monthly stemflow recorded for Weinmannia racemosa was 25.3% of gross rainfall, considerably higher than that reported by other observers.

Kittredge (1948) claimed that stemflow varied from 1% to 16% of total rainfall for a wide range of species, both evergreen and deciduous.

In general, the percentage of stemflow was higher during longer continuous rainfall and was less dependent on rainfall intensity than throughfall. The highest percentage of stemflow (30%) was recorded following a 42-hour period of almost continuous rain in which 70mm fell. The smallest percentage (0.2%) was recorded following a period of intermittent, light rain in which 8.3mm fell in 48 hours. The younger trees contributed by far the greater proportion of stemflow. This probably reflects their more upright growth form. There were several periods of light showers in which no stemflow was recorded.

Estimates of stemflow for the months in which it was not recorded were made by the author (Table 3). These were based on rainfall records from Waipuna and had regard for the antecedent moisture conditions in the catchment. It was calculated that annual stemflow was 187.5mm. This corresponds to a volume of 1.9×10^7 litres for the catchment area.

The standard error in the estimate of stemflow varied from 9 to 15% for the storms sampled.

5:C Outputs of Water

5:C:1 Streamflow-Tuapaka

Streamflow in the Tuapaka Catchment was continuous for the study period. Baseflow events during the drier months of January, February, March and April were commonly of the order of 1 l/sec but increased to flows of the order of 10 l/sec during the wetter, winter months of June, July and August. Peak storm discharges during drier months ranged from 30 l/sec to 60 l/sec. For wetter months, the peak storm discharges were of the order of 10^2 l/sec to 6×10^2 l/sec. A maximum discharge of 2.97×10^3 l/sec was recorded on 3rd December, 1974. A total of 273.1mm (4.9×10^8 l), or 26% of annual rainfall, appeared as streamflow during the study year (Table 3). The storm hydrograph had an average lag time and average time of rise of 3.5 and 3.0 hours, respectively. Examples of typical storm hydrographs are shown in Figs. 9 and 10.

5:C:2 Streamflow - Ballance

Streamflow in the Ballance Catchment occurred on 296 days of the study year. The stream ceased flowing for periods of up to 18 days during January, February, March, and April, 1975.

Baseflows during these drier months were of the order of 10^{-1} l/sec whereas those for the wetter, winter months were of the order of 3×10^{-1} l/sec. Peak storm discharges were characteristically about 6 l/sec.

A total of 157.6mm (1.6×10^7 l), or 13.9% of the gross annual rainfall was discharged as streamflow. The annual streamflow was 19% of the effective rainfall (Table 3).

5:C:3 A Comparison of Streamflow Between Study Catchments

Rainfall during summer storms was often more intense and characteristically more localized than that during winter. This explains, in part, the monthly rainfall and streamflow figures for the study catchment during January. During this month the rainfall at Ballance was 25% higher than that for Tuapaka but streamflow in the Ballance Catchment was more than twice that from the Tuapaka Catchment. Storms recorded near the Ballance Catchment were of greater intensity and, therefore, produced a greater streamflow.

Storm hydrographs had an average lag time of 4 hours and an average time of rise of 2.5 hours. This indicates that a given rainfall event took an hour longer, on average, to produce a hydrograph peak in the Ballance Catchment than in the Tuapaka Catchment but the time of rise of the peak was shorter. It appeared that the time of rise of the hydrographs was primarily affected by the intensity of rainfall and the antecedent rainfall. In both catchments, smaller lag and rise times were encountered during the more intense rainfall events.

The Ballance hydrograph was characterized by long periods of even flow, interspersed by a storm rise, which generally had a 'blunt' peak and a drawn-out recession curve (Fig.11). The shape of the large storm hydrographs (Fig.11) did not vary greatly from the shape of smaller storm hydrographs although they did not always have a 'blunt' peak (Fig.12).

The Tuapaka hydrograph showed greater variability during baseflow periods (data not presented). It tended to rise towards mid-day and fall, up to 4 cm, towards the end of the day. Storm peaks on the Tuapaka hydrograph were all very sharply pointed (Fig.9) and the recession curve was generally steeper than that of the Ballance hydrograph (compare Figs. 9 and 11).

Smaller storm hydrographs at Tuapaka were characterized by having an initial small peak then a larger peak discharge (Fig.10). This implied that an area of the catchment contributed streamflow later than most of the catchment. There was no apparent reason for this behaviour. The area which had been cultivated for a forage crop may have contributed to streamflow later because of its distance from the weir, thus possibly causing a later peak.

Surface runoff was not evident in the Ballance Catchment during any storm period. It is likely that surface runoff occurred on very small areas immediately bordering the stream channel, but this was not observed. In contrast, surface runoff occurred on areas bordering the stream channel during several storms at Tuapaka. Surface flow was also evident on the steeper hill slopes of the catchment and across a cultivated section of the upper catchment during storms in July of the study year.

Fluctuations in baseflow have been investigated by Hursh(1944). This worker claimed these were the result of evapotranspiration by vegetation immediately adjacent to the stream bed. At approximately mid-day, evapotranspiration was at a maximum. The resultant water loss provided a 'sink' into which stream water was drawn; this led to a depressed hydrograph which rose as darkness approached and evapotranspiration decreased. The pattern was repeated daily. This explanation can be accepted for the Tuapaka Catchment but does not seem to hold for the forested Ballance Catchment. It appears that fluctuations in the groundwater level do not occur in the Ballance Catchment. A possible explanation is that streamflow from the Ballance Catchment is derived almost entirely from interflow or 'quick subsurface flow' (as proposed by Hursh 1944). It is probable that streamflow in the Ballance Catchment is generated in accordance with the model described by Hewlett and Hibbert (1967). Evidence for this includes: 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 noted by Hursh (1944), and the stream was ephemeral.

Streamflow in the Tuapaka Catchment may also be explained using the model proposed by Hewlett and Hibbert (1967). In this case, however, overland flow is included and this would account for the smaller lag time in the Tuapaka Catchment.

It was suggested previously that the difference in size and compactness of the two catchments could be partly responsible for the differences in behaviour of streamflow. It seems that the effects of these morphological differences, described by Brush (1961), Taylor and Schwarz (1952), Carlston (1963), and others, are masked by effects due to differences in vegetation. The relative influence of morphological and vegetation differences require further investigation.

5:C:4 Evapotranspiration and Deep Percolation Losses

N.Z. Meteorological Service data (Robertson, 1975; pers. comm.) indicates that an average of 32% of annual rainfall appears as runoff at Palmerston North. In this context, runoff is defined as that part of precipitation that falls on land and ultimately appears in surface streams and lakes (Langbein and Iseri, 1960). Using Penman values for Palmerston North, the average computed runoff at Waipuna was 45% of rainfall. A comparison of the study year with long-term average water balance data shows it to be a normal year. Thus, on average, evapotranspiration accounts for 68 and 55% of rainfall at Palmerston North and Waipuna, respectively. If it is assumed that evapotranspiration losses at Waipuna and Ballance, and similarly at Palmerston North and Tuapaka, are the same, respectively, then a rough water balance for the study catchments can be computed.

The discrepancy between the computed average runoff for the Tuapaka Catchment (32% of rainfall) and the actual runoff (26% of rainfall) is not real in terms of the errors involved in its computation. There is geological evidence to indicate that deep percolation losses occur. Aerial photographs show a swampy area of upwelling, north of the catchment near the Manawatu River, which could indicate the upward movement of deeply percolated water from the Tuapaka Catchment. This is consistent with the structure described by Tolman (1937) as a discharge zone.

The discrepancy between the computed average runoff and actual runoff for the Ballance Catchment is 30% of annual rainfall. It seems unlikely that this loss can be explained by deep percolation alone. Because the computed water balance figures apply only to grass vegetation, some of the discrepancy may be explained by vegetation differences.

Penman and Schofield (1951) have indicated that where soil moisture is restricted, areas of soil supporting unlike species or vegetation types may differ markedly in water loss because of differences in rooting depth. Water balance data (Appendix 1) indicate that soil moisture is limiting for up to 50 days during the summer and autumn months of the year in the study catchments. Fedorov (1965) analysed evapotranspiration differences between a forested catchment and a pasture catchment. On average, during a 10-year period, evapotranspiration was 6% greater for the forest. Rutter (1968) analysed results from various countries and concluded that the ratio of field to forest evapotranspiration ranged from 0.8 to 1.0.

The differences between predicted runoff (Appendix 1) and actual streamflow are relatively large during the summer and autumn months but are quite small for the wet winter months. This indicates that the 'Penman Model', used to calculate runoff, is unreliable for the Ballance Catchment. Because of the greater rooting depth and depth of soil in this Catchment, the soil moisture capacity, assumed by the model to be 75mm, is too small (Scotter, 1976; pers. comm.). The monthly figures indicate that soils in the Ballance Catchment remain relatively drier (less runoff for a given rainfall, because of recharge to the soil) for a longer period during the autumn and winter. Because the model is unreliable, less emphasis can be placed on the deficit between computed runoff and actual streamflow.

The effective rainfall reaching the Ballance Catchment surface (excluding losses due to litter interception) was calculated as throughfall plus stemflow (Table 3). It may be argued that only the effective rainfall contributes to stream flow in forested catchments. On this basis the actual streamflow at Ballance would be 19% of total rainfall. McMillan and Burgy (1960), however, have stated that "evaporation from wetted leaf surfaces may replace all or part of normal transpiration and that the entire plant-soil system should be considered in evaluating interception loss". Whether these observations, which relate to grass, apply to forest vegetation is debatable (Leyton and Carlisle, 1959).

Actual interception losses from the Ballance Catchment varied from almost 100% of total rainfall, for very light showers, to about 7% of total rainfall for periods of intense rainfall with high winds. No attempt was made to measure the net interception losses from the grassed Tuapaka Catchment. The work of McMillan and Burgy (1960) suggests that these could be very small.

TABLE 4

PHOSPHORUS AND NITROGEN CONCENTRATIONS
AND INPUTS IN RAINFALL, THROUGHFALL,
AND STEMFLOW

Mean concentration (mg/l)	Confidence interval 1%	d.f.	Input (g/ha)		
			<u>Ballance</u>	<u>Tuapaka</u>	
<u>Rainfall</u>					
TP	0.034	(0.016, 0.052)	6	409	356
TDP	0.016	(0.006, 0.026)	2	192	168
PTP	0.018			216	189
TN	0.510	(0.350, 0.670)	6	6130	5340
TDN	0.300	(0.10, 0.50)	3	3610	3140
TNO ₃	0.060	(0.025, 0.095)	9	721	629
TPN	0.210			2520	2200
<u>Throughfall</u>					
TP	0.056	(0.006, 0.106)	5	364	
TDP	0.035	(0.150, 0.055)	8	228	
PTP	0.021				
TN	1.14	(0.640, 1.640)	6	7410	
TDN	0.780	(0.180, 0.138)	6	5070	
TNO ₃	0.120	(0.020, 0.220)	8	780	
TPN	0.120			780	
<u>Stemflow</u>					
TP	0.095	(0.350, 0.155)	7	178	
TDP	0.051	(0.041, 0.061)	8	96	
PTP	0.044			83	
TN	1.12	(0.220, 2.020)	5	2100	
TDN	0.810	(0.510, 1.110)	6	1520	
TNO ₃	0.20	(0.07, 0.33)	9	375	
TPN	0.110			206	

Therefore, it appears that deep percolation losses are occurring in both study catchments. This study also tends to support the concept that some intercepted rainfall, evaporated from a forested catchment, represents a net loss of water. The magnitude of both losses is unknown.

5:D Phosphorus and Nitrogen Inputs

5:D:1 Inputs in Rainfall

The major source of nutrient input to the two catchments, apart from fertilizer application to Tuapaka, is thought to be in rainfall. Other possible sources include windborne dust and seepage water. The former is probably important in both catchments because of their proximity to cultivated areas and the Manawatu River. The latter may be important in the Tuapaka Catchment. Springs discharged small amounts of water during much of the study year in the catchment, although the source of this water is uncertain.

Some of the P and N analyses done on rainfall samples during the study year had to be discarded due to contamination of the collecting vessel, possible by bird droppings and small insects. The average concentrations calculated were subject to relatively large errors (Table 4). Nutrient inputs (g/ha) depend upon annual rainfall and are therefore slightly lower for the Tuapaka Catchment.

Tamm (1951) found P concentrations in rain water at Bogesund (Sweden) of 3×10^{-2} to 1×10^{-1} mg P/l and Vollenweider (1968) reported up to 1.3×10^{-1} mg P/l near Rambouillet (France). Hobbie and Likens (1973) found the mean concentration of TP in rainwater at Hubbard Brook, New Hampshire, to be 8×10^{-3} mg/l. On the basis of these figures the annual loadings would amount to 1.5×10^2 and 5×10^2 g P/ha. year in Sweden, 4×10^2 g P/ha. year in France, and 10^2 g P/ha. year at Hubbard Brook.

According to Miller (1961), annual nitrogen - salt loadings carried by rain in New Zealand are between 2×10^3 and 2.3×10^4 g/ha. Matheson (1951) sets the TN contribution from rainwater and airborne particulate matter at 5.6×10^3 g/ha. year for a region in Ontario, Canada. Buckman and Brady (1961) estimate the average loading at 1.7×10^3 g N(NO₃)/ha. year in humid temperate climates.

The annual inputs of P and N to the study catchments are fairly typical when compared with those observed elsewhere. The N inputs found by Miller (1961) are, on the whole, smaller than those of the present study. The factors contributing most to the variability of nutrient loadings in rainfall, according to Hutton and Leslie (1958), are distance from the sea, proximity to industrial cities, and the direction of prevailing winds.

5:D:2 Nutrients in Throughfall and Stemflow

Throughfall and stemflow are rainfall-related but are part of the cycle of nutrients within the ecosystem. The concentration of all P and N forms, except particulate N, was greater in throughfall and stemflow than in rainfall, and greater in stemflow than in throughfall (Table 4). Contamination of rainfall samples by fallen litter caused a rather large variation in the measured concentrations. Extreme care should be taken in extrapolating the nutrient data for stemflow because it was sampled from one species of tree only. The data indicate the magnitude of inputs of various forms of P and N.

Nutrient cycling in forested ecosystems has been studied by Miller (1963), Borman and Likens (1967), Likens et al. (1967), and Eaton et al. (1973). The present study is concerned, in part, with the fate of the P and N which is cycling and their interaction with the stream system. The chemical composition of the sediment being lost from the catchment was considered to indicate a small part of this interaction. The increased nutrient content of stemflow and throughfall over that of rainfall is a minor part of the cycle. The increased nutrient content of stemflow over that of throughfall is probably due to the leaching of P and N from the mosses and lichens that cover the tree trunk. Eaton et al. (1973) also found that nutrient concentrations in stemflow were greater than those in throughfall. Species differences did not affect the concentrations of many nutrients studied. The work of Miller (1963) and Eaton et al. (1973) is not directly comparable with this study because different methods were used to collect and process the samples. For example, Eaton et al. (1973) filtered their samples prior to analysis. Miller (1963) did not analyse throughfall samples for several days after deposition. Recent work in this laboratory has shown that P and N concentrations can alter significantly over such time periods.

Losses due to the movement of nutrients from the plant to soil and back to the plant may occur at different stages. For example, where vegetation overhangs the stream, nutrients can enter the stream directly in throughfall. Where throughfall is absorbed by the catchment surface (litter or mineral soil) nutrients may be utilized by living organisms, or adsorbed on to soil particles and be recycled. Some of the nutrients in stemflow may be recycled as in throughfall but the concentration of relatively large volumes of water and nutrients at the base of the tree suggests that not all of the nutrients are recycled. There is a possibility of deep percolation losses or movement to the stream in interflow.

5:D:3 Fertilizer Inputs

A part of the Tuapaka Catchment was fertilized during the study year. Nineteen ha. were fertilized in November, 1974 and several paddocks (36 ha) within the catchment were aerial topdressed in April, 1975. A total of 1.4×10^4 kg of superphosphate was applied to the catchment. This was equivalent to 77kg/ha (7.2 kg TP/ha) applied over the whole catchment.

5:D:4 Inputs from N-Fixing Species

Field observations revealed no obvious N-fixing species in the Ballance Catchment although the possibility of free-living N fixers can not be discounted (Hoglund, 1976; pers. comm.).

Sears (1965) considered that 400-500 kg N/ha/year may be fixed by clover in New Zealand. Pastures in the Taupaka Catchment had a varying clover content but generally poor clover growth on the hills is a feature of N.Z. hill country (Levy, 1970). The amount of N fixed in the Tuapaka Catchment is unlikely to exceed 30 kg N/ha year (Hoglund, 1976; pers. comm.).

5:E Output of Sediment and Phosphorus and Nitrogen Forms

5:E:1 Sediment

5:E:1:1 Standardisation of Sampling Method for Sediment

The correlation between the concentration of suspended sediment in samples taken with a U.S.D.H. 48 depth integrating hand sampler and those taken at the same time with a 1.3 l. 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.

TABLE 5
 OUTPUT OF SUSPENDED SEDIMENT
 BEDLOAD, AND DISSOLVED LOAD
 FOR STUDY YEAR

Catchment	Suspended	Bedload	Dissolved
	Sediment	Tonnes	
Tuapaka	252	2.7	31.8
Ballance	1.2	0.07	2.3

TABLE 6
 OUTPUT OF SUSPENDED SEDIMENT,
 DISSOLVED LOAD, P, AND N FROM
 THE TUAPAKA CATCHMENT

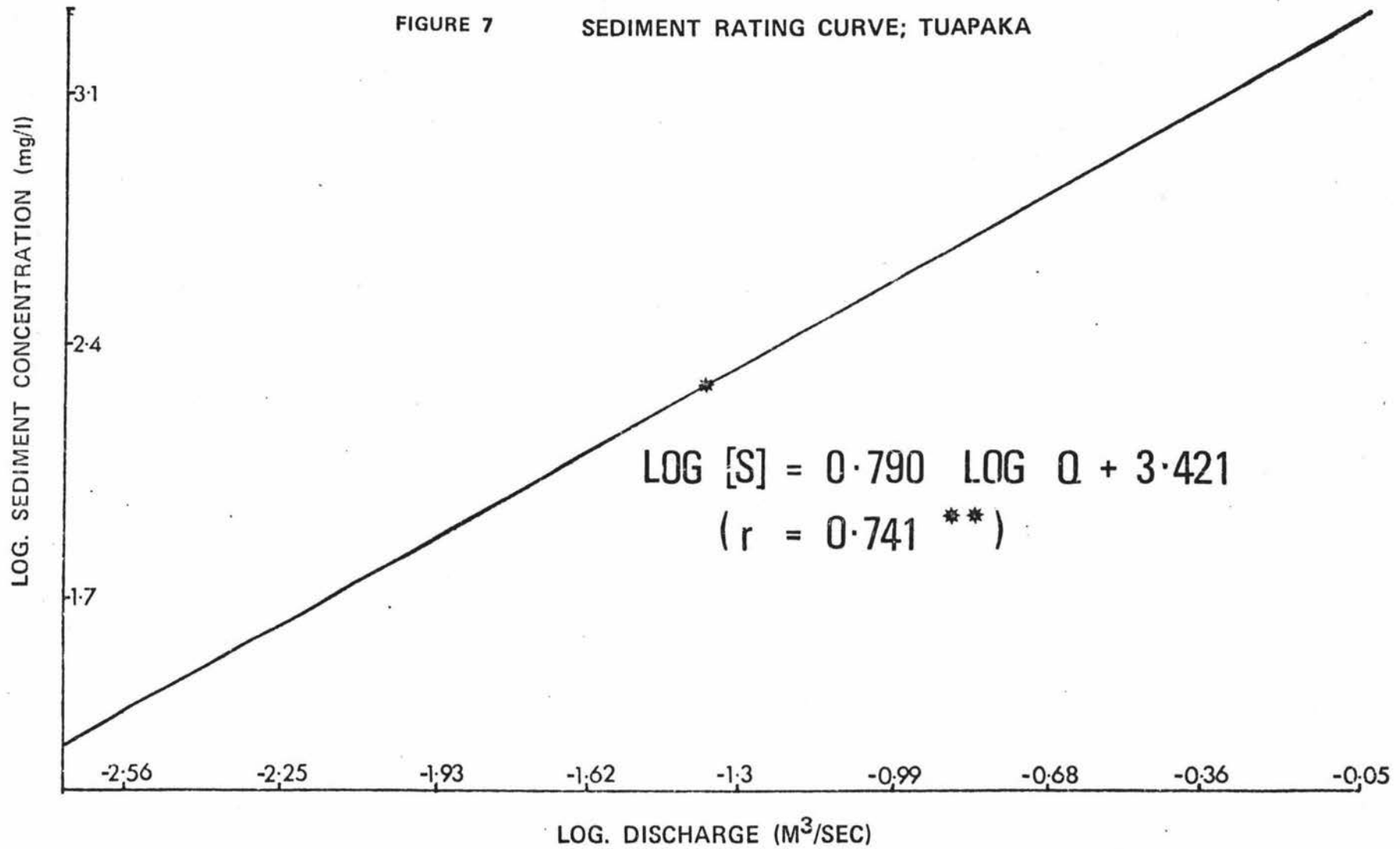
Month	Suspended Sediment	Dissolved load	TP	PTP	TN	TPN
	kg/ha		g/ha			
Nov	6.6	12.3	19.1	9.6	152.3	17.8
Dec	283.6	23.0	214.0	193.6	238.6	36.2
Jan	6.7	4.1	16.2	9.7	74.4	14.2
Feb	8.6	3.3	22.4	17.3	38.1	7.7
Mar	0.3	2.5	3.0	1.1	37.2	3.4
Apr	2.2	4.3	19.9	8.2	92.0	13.6
May	356.5	16.6	181.9	56.5	790.3	50.8
June	78.0	22.3	141.9	96.3	969.4	68.5
July	261.6	24.9	300.0	232.2	1143.6	217.5
Aug	372.4	39.2	666.7	597.9	1268.9	264.5
Sept	18.2	14.9	36.3	18.0	221.1	41.7
Oct	8.5	9.0	21.9	13.0	139.8	14.3
Total	1402.0	176.5	1643.3	1253.4	5165.7	750.2

p. 48 TABLE 7, column headed 'Suspended Sediment
Total' to read '122.0'.

TABLE 7

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			
Nov	16.8	1.5	8.0	2.1	59.0	19.0
Dec	39.2	40.1	73.3	50.2	207.3	48.2
Jan	2.5	13.7	10.1	3.6	76.4	19.1
Feb	0	0.1	0.02	0.01	0.4	0.1
Mar	0.1	0.4	0.3	0.1	1.6	0.3
Apr	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
Aug	34.8	64.7	59.5	28.9	912.8	296.3
Sept	0.9	36.5	7.7	1.5	153.1	11.4
Oct	2.1	16.0	12.1	7.4	51.6	8.9
Total	157.6	226.0	243.2	126.8	1960.0	491.0



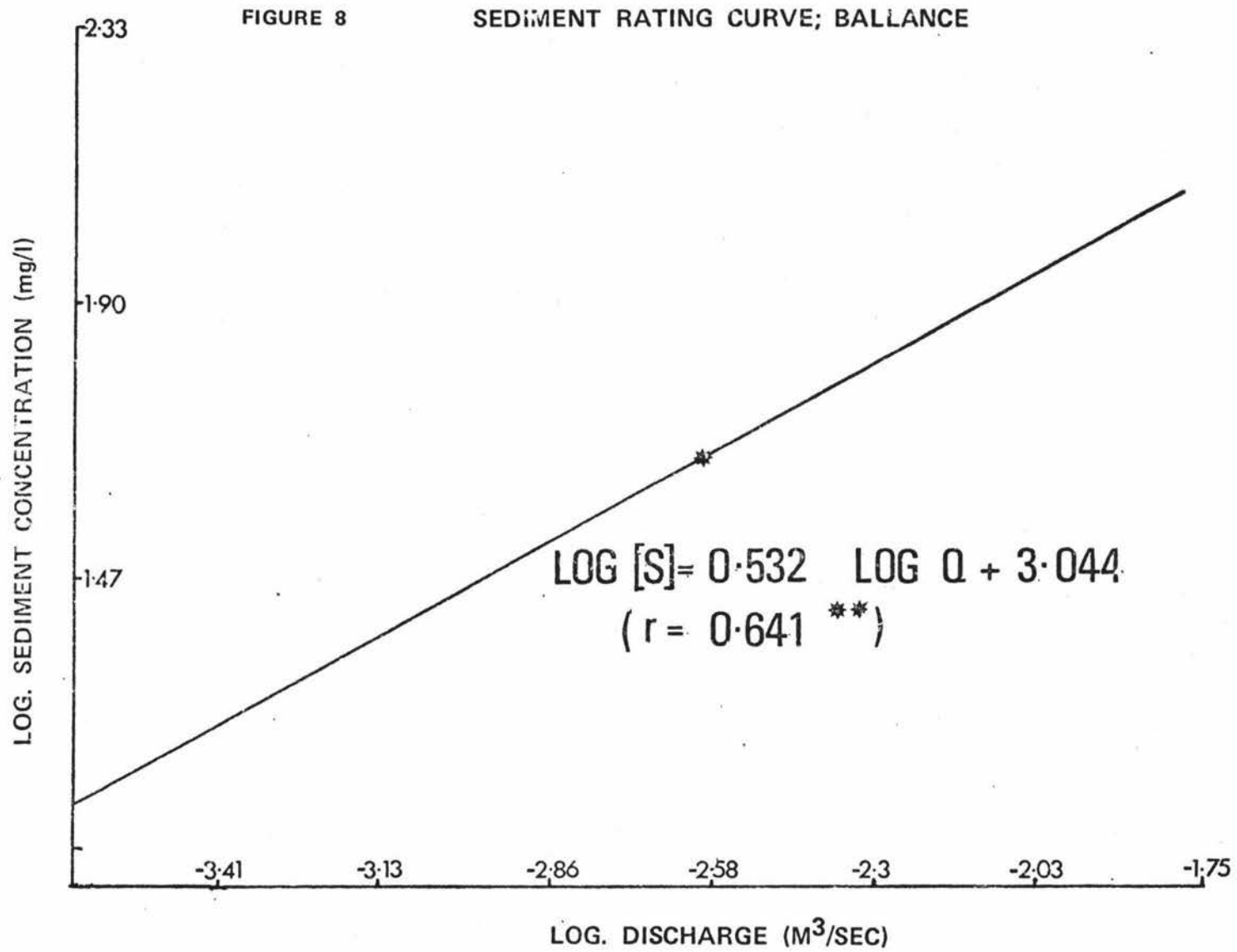


FIGURE 9

TUAPAKA: LARGE STORM HYDROGRAPH

SHOWING SUSPENDED SEDIMENT AND

NUTRIENT CONCENTRATIONS (26.5.75 to 27.5.75)

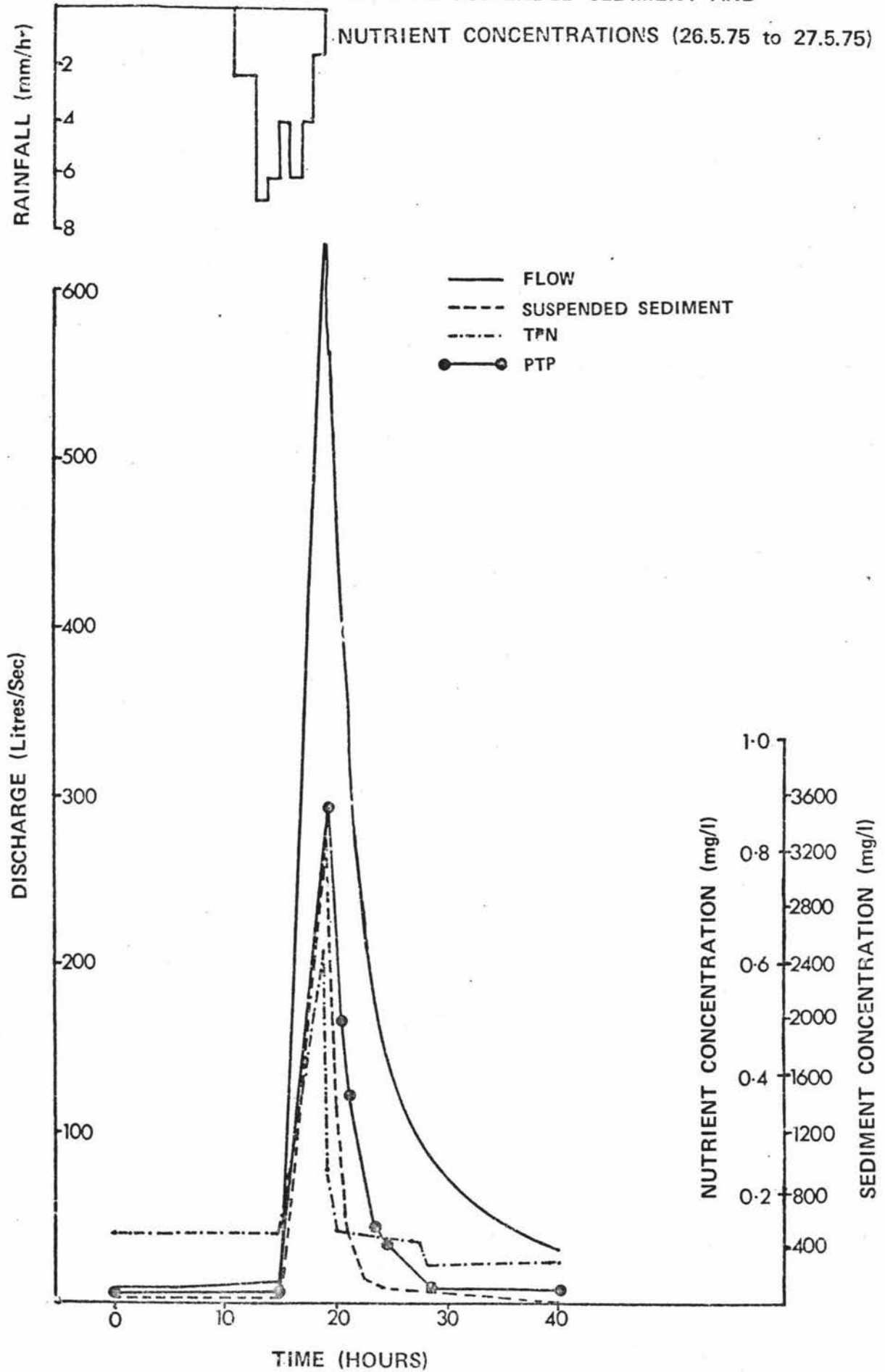


FIGURE 10 TUAPAKA: SMALL STORM HYDROGRAPH
 SHOWING SUSPENDED SEDIMENT AND
 NUTRIENT CONCENTRATIONS
 (25.4.75 to 27.4.75)

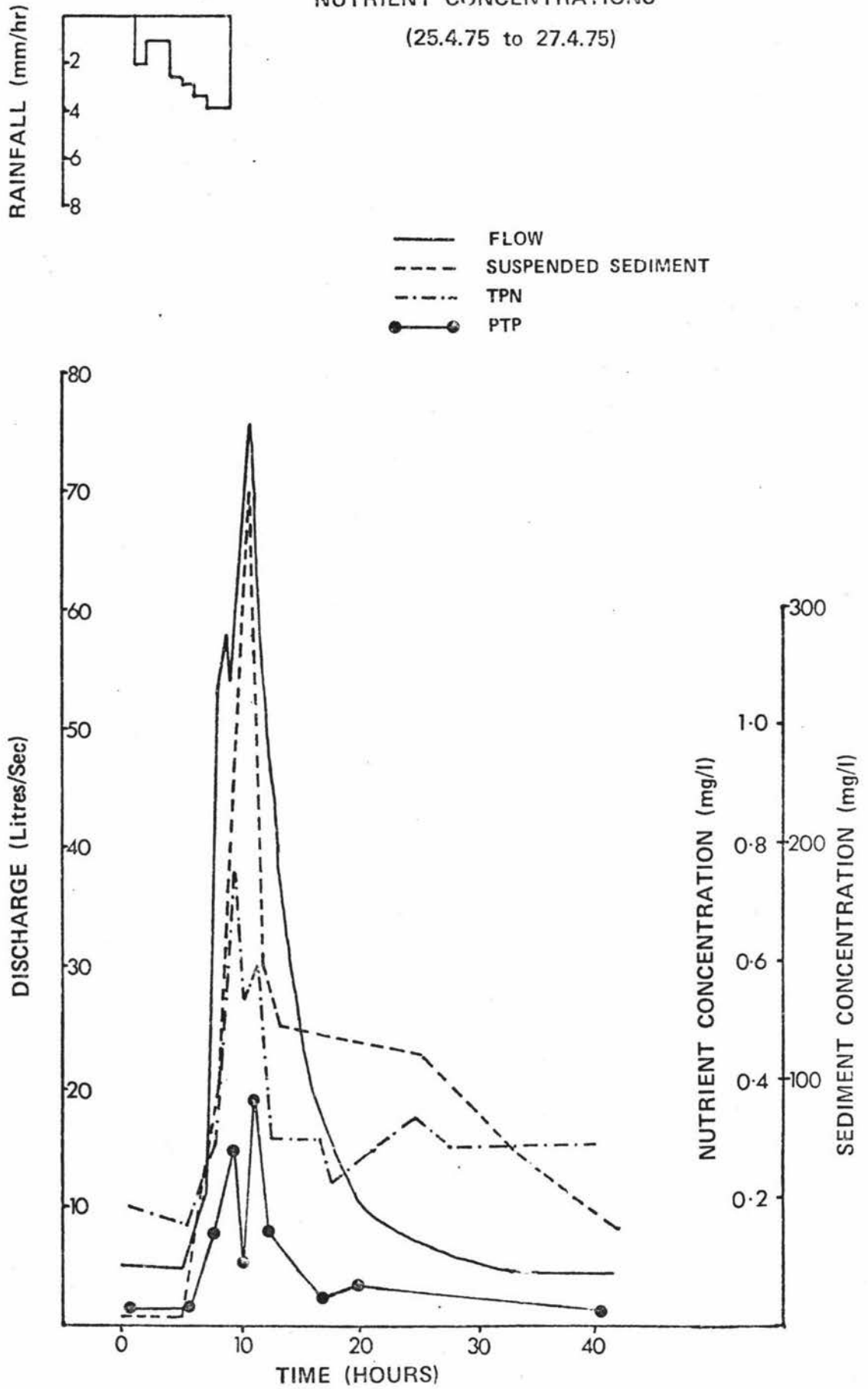


FIGURE 11 BALLANCE: MEDIUM STORM HYDROGRAPH
 SHOWING SUSPENDED SEDIMENT AND
 NUTRIENT CONCENTRATIONS
 (20.8.75 to 22.8.75)

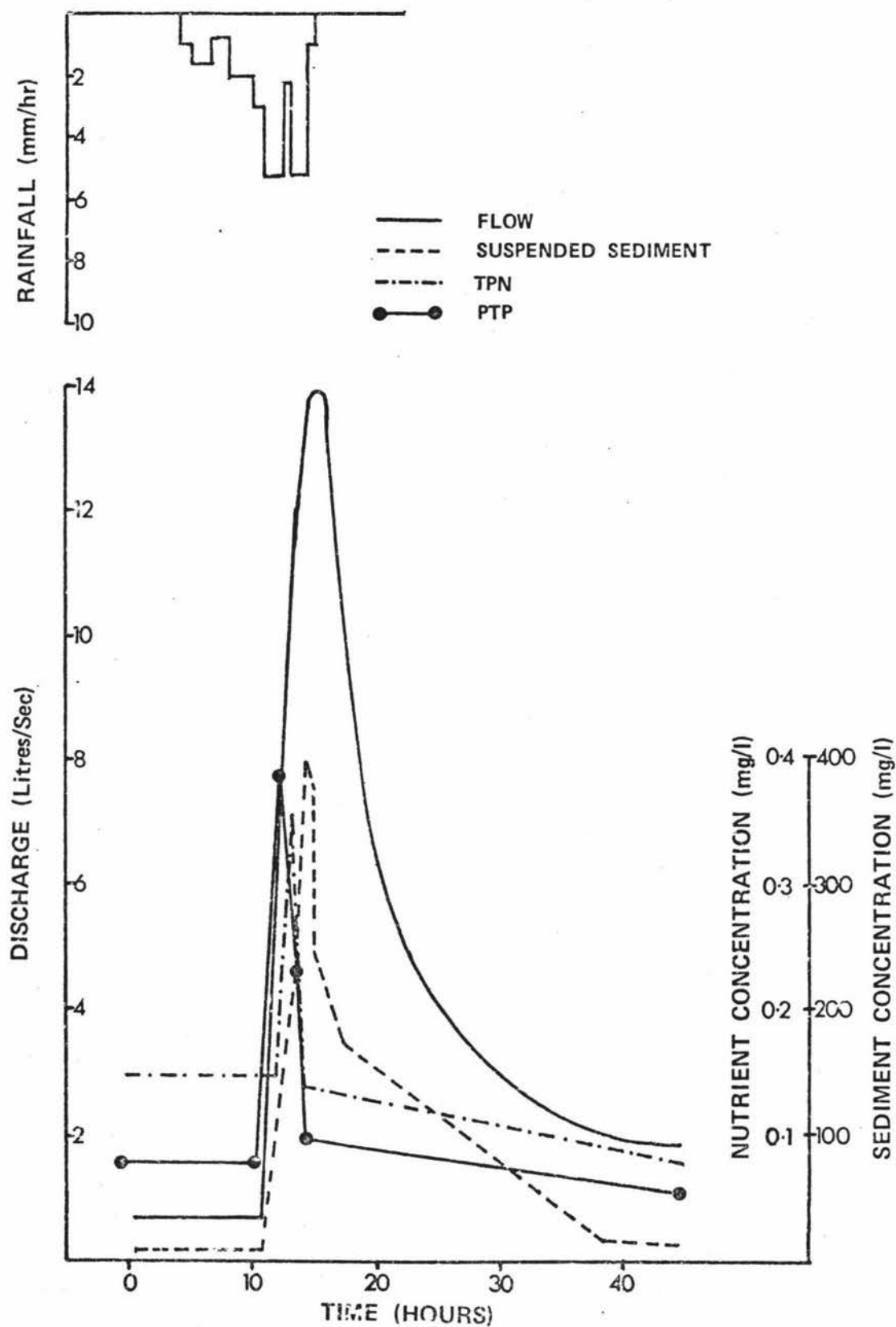
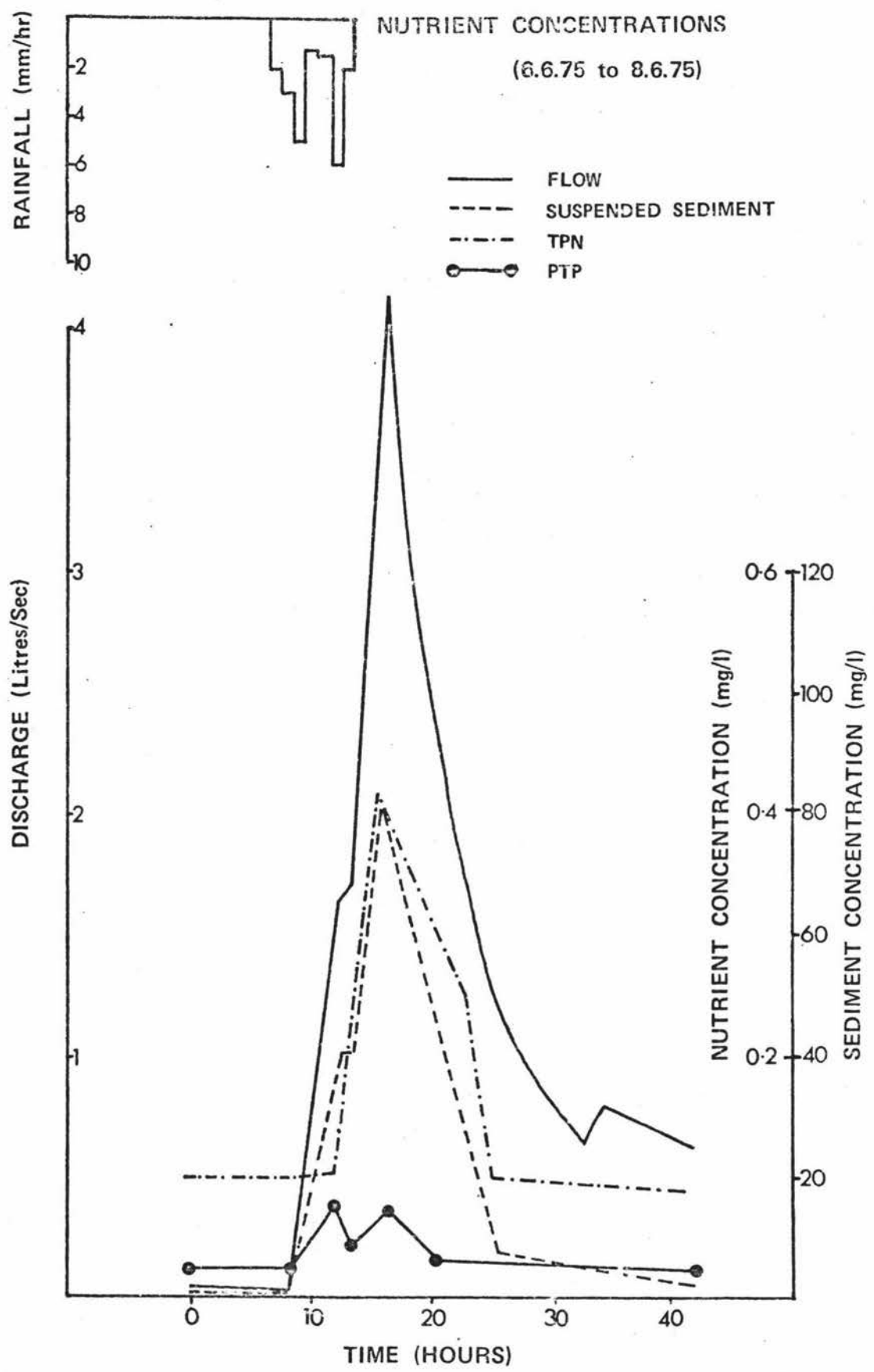


FIGURE 12 BALLANCE: SMALL STORM HYDROGRAPH
SHOWING CUSPENDED SEDIMENT AND



5:E:1:2 Sediment - Tuapaka Catchment

Using over 500 suspended sediment samples, sediment rating curves for rising and falling stages of the storm hydrograph were constructed. The analytical detection limit of sediment concentration was 5 mg/l. Samples containing less than this concentration were discarded for the purposes of the rating curves.

Sediment rating equations for the rising (i) and falling (ii) stage hydrographs were:

$$(i) \quad \text{LOG } [S] = 0.834 \text{ LOG } Q + 3.637 \\ (r = 0.798^{**})$$

$$(ii) \quad \text{LOG } [S] = 0.760 \text{ LOG } Q + 3.220 \\ (r = 0.740^{**})$$

where $[S]$ = Suspended sediment concentration (mg/l)

Q = Instantaneous discharge rate (m^3/sec)

The difference in slope between the two curves was tested and found to be non-significant (t observed = 1.33; d.f. = 165; c.f. t 0.05 = 1.96 and t 0.2 = 1.28). A single suspended sediment rating curve was constructed (Fig. 7). The suspended sediment rating equation was:

$$\text{LOG } [S] = 0.790 \text{ LOG } Q + 3.421 \\ (r = 0.744^{**})$$

The sediment rating equation was used to determine sediment concentrations during storm flows that were not sampled. The estimated total amount of suspended sediment discharged during the study year was 252 tonnes (Table 5). The error in this figure is discussed in Section 5:E:3. The weight of material which accumulated behind the Taupaka Weir, regarded as bedload, during the study year was 2.7 tonnes. This amounted to 1.1% of the total sediment and 0.9% of the total load (sediment plus dissolved load).

5:E:1:3 Sediment - Ballance Catchment

A similar suspended sediment rating curve was constructed for the Ballance Catchment using 70 samples from a total of 150 (Fig. 8). Sediment concentrations below 5mg/l were again discarded. The rating equation was:

$$\text{LOG } [S] = 0.532 \text{ LOG } Q + 3.044 \\ (r = 0.641^{**})$$

A split between the rising and falling stages of the stream hydrograph was not attempted for the Ballance Catchment due to the small number of samples.

The total weight of suspended sediment discharged during the study year (Table 5) was 1.2 tonnes (section 5:E:3 for errors). This amounted to 122 kg/ha in comparison with 1402 kg/ha from the Tuapaka Catchment.

The bedload of the Ballance Stream was 0.07 tonnes. This was 6% of the total sediment load and 2% of the total load carried by the stream during the study year. Chemical analysis indicated that the bedload contained a high proportion of organic matter.

5:E:1:4 Sediment Sources

Streambank erosion appeared to be the major source of sediment in the Ballance Catchment because overland flow was not observed. The effects of rain drops falling on small patches of bare earth and plant litter in, and adjacent to, the stream bed and turbulent streamflow are the mechanisms believed to be primarily responsible for sediment production in the catchment.

Several types of erosion occur in the Tuapaka Catchment (Section 3E). Overland flow and associated sheet erosion is an important source of sediment in this catchment. This was probably the major source of sediment during the winter months. At this time, severe sheet erosion and rill erosion occurred on cropland being grazed at the head of the catchment. Guy (1964) has shown that a large proportion of the total annual transport of sediment can occur in relatively short periods of stormflow. In fact 8 storm events in July and August carried about 40% of the annual sediment load of the stream at Tuapaka.

Farm tracks appear to be a further important primary source of sediment, based on field observations. Similarly, streambank erosion has been observed as a sediment source, particularly at the early rising stage of the storm hydrograph. A sediment concentration of tile drain discharge of up to 1000 mg/l was recorded on occasions. Overall, the sediment load from two tile drains was relatively small, although the fine silt and clay fractions discharged contributed significant amounts of N and P into the stream. This was particularly so following fertilization of the drained area in April, 1975.

FIGURE 13 PARTICLE SIZE DISTRIBUTION OF ALLUVIAL MATERIALS: TUAPAKA

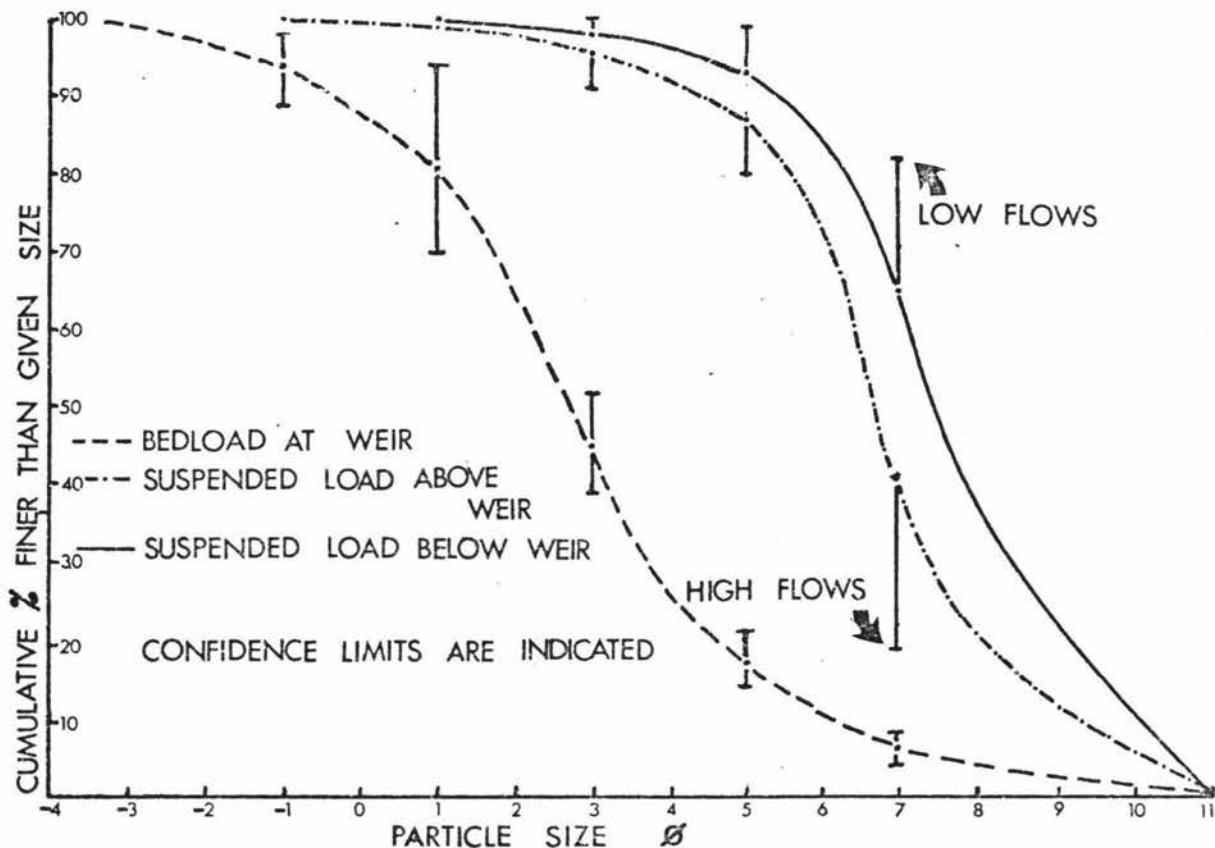
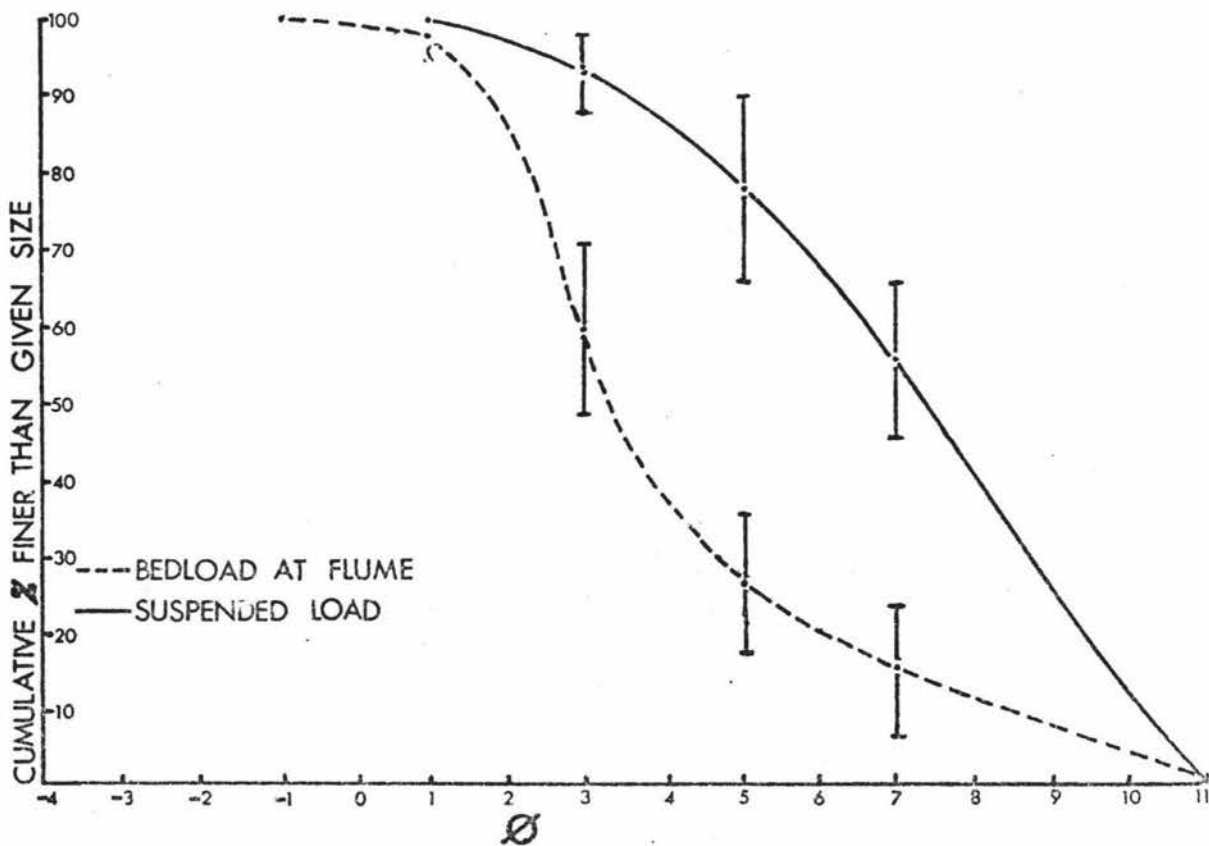


FIGURE 14 PARTICLE SIZE DISTRIBUTION OF ALLUVIAL MATERIALS: BALLANCE



5:E:1:5 Particle Size Distribution of Sediments

Particulate size analyses of suspended sediment carried by the Tuapaka Stream, at high and low flows (Fig. 13) showed that:

- (i) Suspended sediment in the stream above the weir consisted of very coarse sand and finer material (-1 to +7 Phi);
- (ii) Medium sand (+1 Phi) and finer materials were carried in the stream below the weir; and
- (iii) At lower flow rates (approximately 50 l/sec a larger proportion of finer materials (fine silts and clays) were carried, compared with flow rates of the order of 3×10^2 l/sec.

The upper size limit of material accumulated at the Tuapaka weir (bedload) was -4 Phi (medium gravel).

The number of suspended sediment samples taken for particle size analysis at Ballance was four. This gave a limited view of the way in which flow rate affected the proportions of various size fractions carried. The upper size limit of particles carried in suspension in the Ballance Stream was +1 Phi (medium sand). The relationship between the particle size fraction carried and its proportion of the total load was more linear for the Ballance Catchment (Figs. 13 and 14).

The trap efficiency of the Taupaka Weir was approximately 6%, as determined by the difference between sediment in waters above and below the weir. Approximately 5% of suspended sediment (depending on flow rate) and bedload, was trapped by the weir. Particles greater than 1 Phi were not observed passing over the weir.

At Ballance the bedload consisted of very coarse sand (-1 Phi) and finer materials (Fig. 14).

5:E:1:6 Pattern of Sediment Output

The pattern of suspended sediment output from both catchments appeared to depend primarily on antecedent moisture content, rainfall quantity, and rainfall intensity. Land management was also important in the Tuapaka Catchment. The data in Tables 6 and 7 indicate that the wetter months tended to give rise to the highest output of suspended sediment. During the months of May, June, July and August, 75 and 50% of the annual sediment load was discharged from the Tuapaka and Ballance Catchments, respectively.

During the dry months of January, February, March and April, only 1 and 10% of the annual sediment load was discharged from the Tuapaka and Ballance Catchments, respectively.

The raw data indicate that significantly higher sediment concentrations were, at times, recorded for a given flow rate in the wetter, than in the drier, months. A similar finding was also observed by Dragoun and Miller (1966) who produced seasonal rating curves to account for this phenomenon. Observations in the study catchments also showed that more intense rainfalls produced higher sediment concentrations for given flow rates. This was more evident in the Tuapaka Catchment, perhaps reflecting differences in rainfall modification by vegetation and the differences in sediment sources.

The effects of grazing management on sediment loads at Tuapaka were particularly obvious during July, 1975. By 9th July, 19 ha of land in the upper catchment had become bare due to heavy grazing of the forage crop (Section 3:D). It was not until 23rd July (a period of 14 days in which 45 mm of rain fell) that the tributary stream draining this area was noticeably more turbid. During a storm on 23rd July, the year's highest sediment concentration (6000 mg/l) was recorded and sediment concentrations were significantly higher for given flow rates at that time. This is consistent with the findings of Bogardi (1965) who concluded that the stream sediment load was governed by hydrological conditions of the catchment, as well as by the Laws of Hydrodynamics. Guy (1964) also claimed that the amount of fine sediment transported was the result of erosion in the catchment and the routing of the particles with the flow. If this was the case, he concluded, then the concentration of particles in transport during storm flow would be fairly unpredictable with respect to time.

During individual storms, peak sediment concentration and peak flow coincided (Figs. 9 and 11). The storm hydrograph indicated that there was no significant difference in the average rate of rise and fall of sediment concentration with respect to flow in the catchments. Large and small storms tended to act in a similar manner (Figs. 9 and 10).

A number of other studies have presented annual sediment losses without an error of the estimate obtained.

For this reason the results obtained in the present study are not strictly comparable with those in the studies of Dragoun and Miller (1966), Imeson (1971), Walling (1971) and Schuman et al. (1973a, 1973b). The annual loss of suspended sediment from small agricultural catchments has been reported by:

- (i) Walling (1971) to range from 94kg/ha to 8.4×10^2 kg/ha from pasture in S.E. Devon;
- (ii) Dragoun and Miller (1966) to be 1.4×10^4 kg/ha (where soil conservation practices were not used) and 9.0×10^3 kg/ha (where soil conservation practices were used) from arable land in Nebraska; and
- (iii) Schuman et al. (1973a) to be up to 4.4×10^4 kg/ha for a cultivated catchment in Missouri.

The loss of 1.4×10^3 kg/ha/year of sediment from the Tuapaka Catchment is about average, given that the amount of land cultivated is relatively small. For example, Cleaves et al. (1970) reported a sediment loss of 10.5 kg/ha/year from a catchment in Maryland. Borman et al. (1974) found that 25 kg/ha/year of particulate material was exported in streamflow from a mature forested ecosystem, little affected by erosion. Deforestation and repression of growth for 3 years increased sediment export to a maximum of 3.8×10^2 kg/ha/year. The relatively larger sediment output from the Ballance Catchment (over six times and fifteen times that reported by Borman et al. (1974) and Cleaves et al. (1970), respectively) may be explained by the comparative instability of the Ballance vegetation.

5:E:1:7 Organic Carbon Content of Sediment

From the few samples analysed, the organic carbon content of suspended sediment from the Tuapaka Stream varied from 1.0 - 1.5% during winter storms, to 2.9 - 3.5% during summer storms. The organic carbon content of suspended sediment from the Ballance Catchment was approximately double that from the Tuapaka Catchment. Use of a factor of 1.724 for the conversion of organic carbon to organic matter, indicates that suspended sediment in the Tuapaka Stream contained up to 6% organic matter depending on the season. The obvious differences in the amount of plant litter in the stream beds would be expected to indicate a difference of this nature.

The apparent seasonal variability of sediment organic matter content is thought to be influenced by the increased biological activity in summer. Both these processes could lead to an increased organic matter content of stream particulates.

5:E:1:8 Dissolved Load Output

The total dissolved loads for the study year were 31.8 tonnes (176.5 kg/ha) and 2.3 tonnes (226 kg/ha) for the Tuapaka and Ballance Catchments, respectively (Table 5). The annual dissolved loads were 11 and 64% of the total loads for the Tuapaka and Ballance Catchments, respectively. Without further chemical analysis it is difficult to explain the differences in dissolved load output between the two catchments. Two factors which may have contributed to the greater dissolved load of the Ballance Catchment are the deposits of limestone, giving rise to soluble calcium salts, and the thicker litter layer in the catchment, giving rise to dissolved organic materials. The pattern of dissolved load discharge varied through the year and during individual storms. During the winter months the concentrations of the dissolved load were of the order of 50 mg/l at Tuapaka and 120 mg/l at Ballance. During the summer months, the concentrations increased to about 100 mg/l at Tuapaka and 220 mg/l at Ballance. These concentrations persisted during both storm and baseflows and were therefore not closely related to dilution effects. Johnson et al. (1969) studied the seasonal changes in dissolved load and claimed that these changes were due to the interaction of the biological system with the geochemical and hydrological systems. Leaf fall, changes of chemical equilibrium, and the activity of aquatic organisms within a stream can cause changes in solute transport, according to Hem (1970). Perhaps the most acceptable explanation for the study catchments is provided by the work of Walling (1974). This worker claimed that at low flows during summer months, streamflow originated as baseflow from the soil and rock. Because of a long storage time, high solute concentrations would be obtained. During the winter months, baseflow was diluted by storm runoff and water from transitory storage which, because of its lower storage time and reduced contact with the soil and rock, gave rise to a lower solute content.

Dilution effects were evident during particular storms in both catchments. As flow increased during a storm, the dissolved load concentration decreased by up to 10 mg/l. The significance of this decrease in concentration was not tested.

p. 62 TABLE 8, column headed 'Output in stream
Ballance, Sediment (kg/ha) to read..... '122 ± 27'

TABLE 8
 ERRORS IN MEASURED INPUTS
 AND OUTPUTS OF P AND N FORMS
 AND SUSPENDED SEDIMENT

Parameter	Input in rainfall	g/ha	Output in stream
<i>Tuapaka</i>			
TP	356 ± 200		1643 ± 360
TDP	168 ± 55		390 ± 86
TN	5343 ± 580		5166 ± 1340
TDN	3143 ± 1030		4416 ± 1150
Sediment (kg/ha)	-		1402 ± 300
Fertilizer (kg TP/ha)	7.2		
<i>Ballance</i>			
TP	409 ± 120		243 ± 53
TDP	192 ± 48		116 ± 26
TN	6130 ± 670		1960 ± 510
TDN	3606 ± 1190		1469 ± 380
Sediment (kg/ha)	-		¹²² 157 ± ²⁷ 35

5:E:2 Phosphorus and Nitrogen Output

In this thesis major emphasis has been directed towards particulate P and N, because of their obvious potential relationships with sediment.

5:E:2:1 Phosphorus Output

The monthly discharges of TP, PTP, TN and TPN are summarized in Tables 6 and 7. Errors in the estimates of nutrient outputs are discussed in Section 5:E:3.

Of the annual discharge of TP from the Tuapaka Catchment (1.6×10^3 g/ha), approximately 76% (1.25×10^3 g/ha) was discharged as particulate P. The annual discharge of TP from the Ballance Catchment was 2.4×10^2 g/ha and 52% of this (1.27×10^2 g/ha) was in the particulate form.

The correlation between log PTP concentration and log flow was tested and found to be highly significant. The equations expressing this relationship for the catchments were as follows:-

(i) Tuapaka

$$\text{LOG [PTP]} = 0.545 \text{ LOG } Q + 0.056$$

$$(r = 0.520^{**})$$

(ii) Ballance

$$\text{LOG [PTP]} = 0.520 \text{ LOG } Q + 0.035$$

$$(r = 0.640^{**})$$

The correlation between log PTP concentration and log sediment concentration was also found to be highly significant for both catchments. The equations expressing this relationship were:

(i) Tuapaka

$$\text{LOG [PTP]} = 0.719 \text{ LOG [S]} - 2.309$$

$$(r = 0.764^{**})$$

(ii) Ballance

$$\text{LOG [PTP]} = 0.707 \text{ LOG [S]} - 2.561$$

$$(r = 0.754^{**})$$

The data obtained indicate that the loss of P is closely associated with the loss of sediment in both catchments. Burwell et al. (1974) and Schuman (1973 b) have also shown this to be true for agricultural catchments in Iowa. Only half the TP loss from the Ballance Catchment was in the particulate form. The annual loss of sediment from the Tuapaka Catchment (1.4×10^3 kg/ha) was approximately 9 times that lost from the Ballance Catchment (1.57×10^2 kg/ha) and the difference in PTP loss was of similar magnitude.

These differences were reflected in both the monthly losses and losses during individual storms (Figs. 9, 10, 11, and 12). Peak sediment and flow values corresponded with peak PTP concentrations and both decreased sharply following peak flow. A plot of PTP concentration against sediment concentration (data not presented) for both catchments revealed that the relationship was initially linear but that with increasing sediment concentration, the relative increase in PTP concentration was smaller. This may be explained by referring to the particle size distribution of suspended sediment during storm flows (Fig. 13). During larger storms, there was a disproportionate increase in the larger size fractions being carried. Because coarser fractions usually contain lower amounts of total P (Syers et al., 1969) and are less capable of removing P from solution by sorption reactions (Ryden et al., 1973), there was a disproportionately smaller increase in the amount of PTP transported.

By dividing the mean annual sediment output by the mean annual PTP output the mean P content of the sediment can be calculated. Values of $8.9 \times 10^2 \mu\text{g P/g}$ and $8.1 \times 10^2 \mu\text{g P/g}$ were obtained for sediment from the Tuapaka and Ballance Streams, respectively. However, this method of calculating the P content of sediment contains errors because not all stormflow and baseflow periods during the year were sampled with an adequate intensity. From the relationship between PTP and sediment concentration from the regression curve it was calculated that 1 tonne of sediment contained 1.13 kg and 0.89 kg of TP in the Tuapaka and Ballance Streams respectively. This indicates TP contents of the sediment of 1.1×10^3 and $8.9 \times 10^2 \mu\text{g P/g}$ for Tuapaka and Ballance, respectively.

The apparent differences in the P content of sediment using the two methods of calculation may be explained as follows. In the latter method, not all sediment samples (and their corresponding PTP concentrations) were used to construct the regression curve from which mean sediment and PTP concentrations were extracted. Therefore, the mean sediment and PTP concentrations were weighted toward stormflow periods. This factor, combined with the errors inherent in the former method, explain the different values obtained from the different methods.

The difference in P content of sediment between the two catchments is probably, in part, a reflection of the different sediment sources within each catchment. Ballance sediment is derived mainly from the erosion of subsoil material along the stream bed.

Such sediment could be expected to contain lower amounts of P. In contrast, Tuapaka sediment is derived largely from sheet erosion of surface soil. Such sediment could be expected to be somewhat enriched in P because of the higher TP content of surface soil, which is enhanced by fertilizer addition. Schuman et al. (1973 b) reported higher losses of particulate P from more heavily fertilized catchments. During baseflows, the concentrations of P forms investigated were essentially constant, although there appeared to be some seasonal fluctuations. This was also shown by Minshall et al. (1969) for streams in S.W. Wisconsin.

It has been suggested by Taylor et al. (1971) and Hobbie and Likens (1973) that stable forested catchments are conservative of P. These claims can only be substantiated, however, if errors in the estimates of rainfall inputs of P and of stream loadings of P, are obtained and adequately presented. This does not appear to be the case. The work of Miller (1963) can not be compared with this study as he determined different forms of P. It was not possible to determine whether the Ballance Catchment was conservative of TP or TDP within the bounds of error (Table 8). Deep percolation losses of TDP can not be discounted although if these did occur, they are expected to have been small. The processes of plant uptake and mineralization of P must also be considered in any P budget. They are assumed to be in balance in this catchment. It was thought that by comparing TDP input and output (thereby partly negating the effects of erosion in the catchment) that the catchment may have been conservative of TDP. Within the bounds of error, the data again showed no significant difference.

As indicated previously, few studies on the loss of P from agricultural watersheds are strictly comparable with the present study because they have not differentiated between the various forms of P in runoff. Campbell and Webber (1969) found 80 g TP/ha/year were lost from rangeland in Southern Ontario. Taylor et al. (1971) measured the annual loss of TDP in a stream draining farmland at Coshocton, Ohio, and found it to be 70 g/ha. Witzel et al. (1969) found annual losses of TP from a pasture - cultivation - hay rotation varied from 1.5×10^3 to 1.2×10^3 g/ha. Burwell et al. (1974) measured the amount of 'sediment P' (sodium bi-carbonate extractable P) and TP in stream water draining four small agricultural catchments in Iowa. They found that sediment was the prime transport medium of P. The average annual output of sediment P and TP were 42 kg/ha and 4.5×10^2 kg/ha, respectively, from a terraced watershed, and 7.9×10^2 g/ha and 9.7×10^2 g/ha, respectively, from a non-terraced watershed.

TABLE 9

TP LOSSES IN THE EXPORT OF
ANIMALS AND ANIMAL PRODUCTS
FROM THE TUAPAKA CATCHMENT

Animal	Product	Animals exported/ha	Av. Weight of animal (kg)	Animal weight/ha	Quantity P exported * (kg/ha/yr)
Sheep	Lamb	5	25	125	1.3
	Other	2	50	100	1.0
	Wool	7	2	14	0.1
Cattle	Weaner	0.5	300	150	1.5
	Cow	0.2	500	100	1.0
					4.9

* Obtained by multiplying animal weight by assumed P content of 1% of products.

It is clear from these studies that the quantities of P lost in streams draining farmland vary according to the nature of the soil and the type of farming. In comparison with the figures above the annual losses of 1.6×10^3 g TP/ha and 1.3×10^3 PTP/ha from the Tuapaka Catchment are high.

A number of studies have been carried out to evaluate the losses of P from forested catchments. Few have differentiated between the various forms of P lost. Hobbie and Likens (1973) divided TP into 'fine particulate P', 'large particulate P' and TDP. They found that the annual output of TP from an undisturbed catchment was 21 g/ha. The majority of this was as particulate P. Taylor et al. (1971) found that the annual TDP loss from a forested catchment at Coshocton, Ohio, was 50 g/ha. This figure is rather meaningless however, because by far the greater proportion of P lost in all other studies, is in particulate form. Annual TP losses of 60 g/ha and 68 g/ha were recorded by Brink and Gustafson (1970) near Uppsala, Sweden, and by Sylvester (1961) in Washington, U.S.A., respectively. The output of TP, in all cases above, is less than that reported in this study from the Ballance Catchment (2.4×10^2 g/ha), by a factor of at least four.

It is difficult to make any definitive comparisons concerning the amounts and forms of P lost from the two catchments. The Tuapaka Catchment is part of an agricultural ecosystem where outputs of P occur in the products and carcasses of animals removed from the farm. Losses may also occur where animals are grazed on the catchment but deposit urine and excreta elsewhere (fertility transfer).

Stock numbers are essentially constant at Tuapaka. If a 1% P content of animal products is assumed (Irving, 1973) and the weight and classes of animals removed from the catchment each year are known, then a rough estimate of TP lost may be made (Table 9). The error in this estimate of TP lost in animal products is probably less than 60%. The annual output of TP in streamflow and animal products was estimated at 6.3 ± 2.5 kg/ha for the study year. Within the error given, outputs of TP balance inputs of TP from fertilizer and rainfall (7.6 ± 0.2 kg/ha).

5:E:2:2 Nitrogen Output

The proportion of TN discharged (5.2×10^3 g/ha) in the particulate form in the Tuapaka Stream was 15%. The TN discharged from the Ballance Catchment was 1.96×10^3 g/ha and 25% (4.9×10^2 g/ha) of this was in particulate form.

In both cases TPN output is an appreciably lower proportion of TN output than PTP was of TP output. In contrast, Schuman et al. (1973 a) found that up to 92% of N losses were associated with sediment in runoff from four N - fertilized catchments.

Monthly discharge of TN ranged from 37 g/ha for February, 1975, to 1.27×10^3 g/ha for August, 1975, in the Tuapaka Catchment, and from 0.4 g/ha to 9.1×10^2 g/ha for the same months at Ballance (Table 6 and 7). Errors in these estimates are discussed in Section 5:E:3. Although in all months the TN output was greater from the Tuapaka Catchment, TPN output was greater from the Ballance Catchment during the summer months. The reasons for this are not clear. The amount of plant material (leaves and twigs) falling into the Ballance Stream during this period may have been partly responsible for this difference.

The significance of relationships between logged values of TPN concentration and flow, and TPN concentration and sediment concentration was tested for each catchment. The only significant correlation found was between log TPN concentration and log sediment concentration for the Tuapaka Catchment. This was expressed by the equation:

$$\text{LOG [TPN]} = 0.236 \text{ LOG [S]} - 1.163$$

$$(r = 0.310^*)$$

There is no real predictive power in this relationship.

During individual storms (Figs. 9, 10, 11 and 12) peak TPN concentrations coincided with peak flows in both catchments. Relationships between TPN concentration and sediment and flow were expected, as was the case for PTP. It was suspected that much of the TN was in the particulate organic form and this may have had some bearing on the poor relationships obtained. Because the dissolved fraction of TN was far higher than that of TDP or of TP, the 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, particularly in the Ballance Stream.

By the use of mean values of sediment and TPN concentrations, it was calculated that 1 tonne of sediment carried 0.54 kg ($5.4 \times 10^2 \mu\text{g/g}$) and 2.2 kg of N ($2.2 \times 10^3 \mu\text{g/g}$) in the Tuapaka and Ballance Streams, respectively. By using P values similarly obtained (previous section) the N/P ratios for the Tuapaka and Ballance Catchments were 0.599 and 2.7, respectively. The higher N/P ratio of the Tuapaka Catchment is probably due to the enrichment of surface soils with P fertilizer. Using the other method of calculating the TN content of sediment (mean annual TPN output divided by mean annual sediment output) the sediment appears to have an N content of $1.3 \times 10^3 \mu\text{g/g}$ and $4.6 \times 10^2 \mu\text{g/g}$ from the Tuapaka and Ballance Catchments, respectively. As mentioned previously, there are more errors inherent in this method. Using the similarly calculated values for the P content of sediment, the N/P ratios were 1.1 and 5.2 for the Tuapaka and Ballance Catchments, respectively.

The relatively higher N content of Ballance sediment probably reflects the greater proportion of organic material in the sediment. The organic matter content of sediment was up to 12% in the Ballance Stream and this was almost double that of the sediment in the Tuapaka Stream. The N and P content of organic matter is higher than that of mineral sediment, based on soil data.

The annual loadings of TN and TPN are summarized, with errors, in Table 8. Assuming that rainfall is the only N input at Ballance, this catchment is conservative of TN and marginally conservative of TDN.

It is likely that deep percolation losses of TDN occurred in both catchments because soluble N forms, particularly nitrate - N, are less readily immobilized by sorption reactions 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. Consequently, it would appear that the Ballance Catchment is conservative of TN and possibly conservative of TDN, within the bounds of error.

Vollenweider (1968) reported that the annual output of TN from a forested region in Central Sweden was 6.5×10^2 to 1.75×10^3 g/ha which was similar to the outputs from catchments near Lake Tahoe (U.S.A.).

He concluded that the probable average loss of TN from soils that have not been over-fertilized in Central Europe were in the range 5×10^3 to 15×10^3 g/ha/year. Weidner et al. (1969) reported that the average annual loss of TN from small cultivated catchments at Coshocton, Ohio, was 9×10^4 g/ha. In a comprehensive study of N losses from small, fertilized, agricultural catchments in S.W. Iowa, Schuman et al. (1973 a) differentiated between the various N forms lost. They found that the average annual loss of TN varied from 4.0×10^4 g/ha (for a cultivated catchment) to 2.4×10^3 g/ha (for a catchment in pasture). The TPN loss for the same catchments was 3.7×10^4 g/ha and 1.2×10^3 g/ha, respectively. The results obtained by Schuman et al. (1973a) for the catchment under pasture are approximately half those obtained for the Tuapaka Catchment (Table 6). Taylor et al. (1971) observed an average annual TN loss of 6×10^3 g/ha from a farmland, and 2.5×10^3 g/ha from a woodland watershed.

Likens et al. (1969) found the average annual output of N forms from a forested catchment at Hubbard Brook was 1.2×10^2 g TPN/ha and 2×10^3 g TN/ha. Miller (1963) also found that the average annual output of TN from a small forested catchment at Taita, N.Z. was 2×10^3 g/ha. These were in close agreement with the TN loss from the Ballance Catchment (Table 7).

The Tuapaka Catchment loses 40% more TN/ha in streamflow than the Ballance Catchment but the inputs and outputs of N from the Tuapaka Catchment are far more complicated than those of the Ballance Catchment.

The amount of N 'fixed' by clover in the Tuapaka Catchment has been estimated at 30 kg/ha/year (Hoglund, 1975; pers. comm.). A part of this may be lost by volatilization from dung and urine although this loss is unlikely to exceed 5kg TN/ha/year (Hoglund, 1975; pers. comm.). Whitehead (1970) estimated the output of N as animals and animal products to be 22 kg/ha/year. The output of TN in streamflow from the Tuapaka Catchment (5.2 kg/ha/year) is therefore only a small, but important, loss of this element compared with the overall flux of N in the catchment. The estimated total input of N to the Tuapaka Catchment from clover fixation and rainfall is 35 kg/ha/year. The estimated total output of N in streamflow, animal products, and volatilization is 30 kg/ha/year. Assuming that mineralization of N is low (Hoglund, 1976; pers. comm.) then, within the bounds of error, inputs of N to the Tuapaka Catchment balance the outputs of N.

5:E:3 Errors in Sediment and Nutrient Input and Output

The errors involved in sampling stream P and N loadings during storm events have recently been evaluated in this laboratory (Sharpley et al., 1976). Under conditions similar to those existing in the study catchments they 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). In associated studies, they found (O'Connor, 1975; pers. comm.) similar errors for suspended sediment. Annual stream hydrograph records for one pasture 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. Brown et al. (1972) showed that the standard error of a prediction from such regression curves is given by:

$$S_p = S_e \left[1 + \frac{1}{n} + \frac{(X - \bar{X})^2}{(\sum (X - \bar{X})^2)} \right]^{\frac{1}{2}}$$

where

- S_p = the standard error of a prediction,
- S_e = the standard error of the estimate,
- n = the number of observations in the sample,
- X = the independent variable,
- \bar{X} = the mean of the X values.

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 in the study catchments, 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 the frequency of sampling, and 14 were either not sampled sufficiently frequently or not sampled. At Tuapaka, of the 61 storms 33 were sampled adequately, in terms of frequency and 28 were not sampled. Some 80% of baseflows in both catchments were sampled adequately. Therefore the average error in the estimation of annual TP and sediment loadings in the study catchments was 22% and for TN, 26%.

SECTION 6

SUMMARY AND CONCLUSIONS

The hydrological and sedimentological characteristics of two catchments of contrasting landuse were studied from 1st November, 1974, to the 31st October, 1975. The catchments are situated 7 km apart and are believed to be reasonably similar in terms of climate and soils. The 10 ha Ballance Catchment has native forest vegetation whereas the 180 ha Tuapaka Catchment is part of a mixed sheep and cattle farm.

Differences in the hydrological characteristics of the two catchments appear to be reflected in their response to climatic factors and the effects of agricultural activities, particularly vegetation.

The climate for the study year was normal in terms of past records. A water balance was estimated for both catchments. This estimate was more successful for the Tuapaka Catchment because the water balance model used (Penman Model) required modification for a forested region. From the water balance data, it appeared that deep percolation losses occurred from both catchments. These losses were considered to be small.

Streamflow and rainfall were recorded at both catchments throughout the year. Approximately 26% of total rainfall was discharged as streamflow from the Tuapaka Catchment during the study year, whereas, only 14% of total rainfall (or 19% of effective rainfall) was discharged in the same period from the Ballance Catchment. Annual streamflow (mm) from Ballance was approximately 60% that from Tuapaka. The difference in response to rainfall of the two catchments, as evaluated from stream hydrographs, appeared to be due to differences in vegetation.

Throughfall and stemflow were recorded at Ballance for a part of the year. Average monthly throughfall and stemflow were 54% and 16% of total rainfall, respectively.

The output of suspended sediment from both catchments was higher on average, than that found by workers elsewhere for catchments of similar vegetation. The differences in sediment output and sources, between the two catchments, reflected differences in vegetation and land use.

The development of sheet and accelerated streambank erosion in the Tuapaka Catchment provided the majority of stream sediment there. The main source of sediment in the Ballance Catchment appeared to be minor streambank erosion and plant debris.

The output of dissolved material was approximately twice the output of sediment from the Ballance Catchment. In contrast, the output of dissolved material from the Tuapaka Catchment was only 13% of the sediment output.

An attempt was made to identify and quantify the inputs of P and N forms to the two catchments. The inputs in rainfall were subject to appreciable errors because of the rather limited number of samples taken and the possibility of contamination. Apart from fertilizer application to the Tuapaka Catchment, the major inputs of P to both catchments were considered to be in rainfall. Mineralization of organic P was considered to be a minor input to both catchments and was assumed to be balanced by plant uptake. Inputs of N were less easily defined. At Ballance, the major inputs of N were thought to be in rainfall. At Tuapaka, clovers contributed a substantial amount of N to the catchment in relation to the amount of N added in rainfall.

Outputs of P and N from the catchments approximately balanced inputs. Significant quantities of P and N output were associated with suspended sediment loss. Of the annual loss of TP (1.6 kg/ha) from the Tuapaka Catchment, 76% was in the particulate form. At Ballance, 52% of the annual loss of P (0.2 kg/ha), was in the particulate form. At Tuapaka, large amounts of P (up to 5 kg/ha) and N (up to 20 kg/ha) were lost annually as animals and animal products exported from the catchment. A P budget for both catchments was estimated. Outputs of N were more difficult to quantify and therefore errors in the N budgets, estimated for the catchments, were greater. Within the bounds of error the Ballance Catchment appeared to be slightly conservative of P and strongly conservative of N. At the Tuapaka Catchment, however, inputs of P and N balanced outputs, within the bounds of error. It is difficult, if not impossible, to determine whether a particular catchment is conservative for P and N unless adequate attention is paid to the errors involved.

Several possible areas for future research have been highlighted by the present study. There is a need for more detailed information on the water balance of forested catchments. In particular, the way in which streamflow is generated in forested catchments in New Zealand requires further study. There is an obvious paucity of data on sediment and nutrient outputs from catchments of contrasting land use in New Zealand. Naturally, before effective remedial measures can be taken to combat such problems as eutrophication, the nature and extent of the processes involved in nutrient runoff must clearly be identified and understood.

Although the dangers of extrapolating data from a one-year study are recognized, the comparative data obtained for two catchments of contrasting land use, point to the effects of agricultural activities on sediment yield and nutrient runoff. In addition, the study has provided the writer with an opportunity to develop and use a range of techniques, which is one of the basic objectives of post-graduate study.

APPENDIX 1

SUMMARY OF CLIMATOLOGICAL DATA

- (a) Rainfall (mm) for Waipuna (Woodville). Period 1924 - 1969.
from N.Z. Met Serv. Misc. Publ. 141 'Rainfall Percentiles' 1973.

	Jan	Feb	Mar	Apr	May	June	Jly	Aug	Sep	Oct	Nov	Dec	Year
Mean	104	96	84	105	113	124	114	111	91	123	113	126	1301

- (b) Rainfall Intensity (mm) for Palmerston N. (from Robertson, 1963).

Duration (Hours)	Return Period (Years)			
	2	5	10	50
1	17.3	22.4	25.4	32.8
6	36.3	45.2	51.3	64.3
24	61.0	81.3	94.5	124.5

- (c) Wind Summary for Palmerston N. 1940 - 1949
Percentage Frequency from Hourly Mean Winds at 3-hr Intervals.
(from N.Z. Met. Serv. Misc. Publ. 122, 1966)

Direction	N.	NE.	SE.	E.	S.	SW.	W.	NW.	Calm
Velocity (km/hr)									
6.4-24.1	7.3	0.9	8.3	9.2	2.0	1.8	11.8	13.1	
725.7	0.2	-	1.5	1.5	0.2	0.1	6.1	4.5	
Total	7.5	0.9	9.8	10.7	2.2	1.9	17.9	17.6	31.5

- (d) Water Balance for Waipuna* 1967 - 1975 (Estimated)
from N.G. Robertson 1975; pers. comm., N.Z. Met. Serv.

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Year
Av. Runoff	14	1	14	16	112	86	99	71	66	61	6	8	554
Av. Deficit	45	55	19	4	0	0	0	0	0	0	4	26	153

* All figures in (mm).

APPENDIX 2

A SUMMARY OF SOME PHYSICAL CHARACTERISTICS
OF SOILS IN THE STUDY CATCHMENTS (from
COWIE, 1972)

SOIL NAME	OVERALL DRAIN- AGE CLASS (i)	INTERNAL DRAINAGE CLASS (ii)	NATURAL NUTRIENT STATUS (iii)	LIMITATIONS FOR INTENSIVE USE
Ramiha hill soils	Well drained	Medium	Low: Medium P, low Ca & K	Hilly slope; Low nutrient status
Ramiha silt loam	Well drained	Medium	Low: Medium P low Ca & K	Low winter temps. Low nutrient status
Makara steep- land soils	Well excessively drained	Medium	Moderate: low P, Medium Ca & K	Steep slope; dries out in summer
Halcombe steep-land soils	Moderately drained	Slow	Moderate	Steep slope
Shannon silt loam	Imperfectly drained	Medium to slow	Moderate: Low Medium Ca, high K	Imperfect drainage
Ohakea silt loam	Imperfectly drained	Slow	Moderate: Low P, Medium Ca low K	Poor drainage, dries out in summer
Kairanga fine sandy loam	Imperfectly drained	Medium to slow	High: high P & Ca Medium K	Imperfect drainage

Extended Legend (Notes)

- (i) Overall Drainage class
(ii) Internal Drainage Class

Overall drainage and internal drainage classes are according to those given in Soil Survey Method (Taylor and Pohlen, 1962, 36-9).

(iii) Natural Nutrient Status

Natural nutrient status is described in relative terms of low, moderate, and high, according to Taylor and Pohlen (1962), based on the results of analyses of samples from un - topdressed sites.

APPENDIX 2 (Contd.)

Rating	Phosphorus Truog (mg%)	Exchangeable K. (me%)	Exchangeable Ca (me%)
Very low	1	0.3	2
Low	1-2	0.3 - 0.5	2 - 5
Medium	2-3	0.5 - 0.8	5 -10
High	3-5	0.8 - 1.2	10 -20
Very High	5	1.2	20

APPENDIX 3

LIST OF MAJOR PLANT SPECIES FOUND
IN THE BALLANCE CATCHMENT

An estimate of the abundance of major plant species in the Ballance Catchment. This estimate was made on the following basis;

- 5 - dominant or co-dominant
- 4 - abundant or plentiful
- 3 - common
- 2 - a minor but significant component
- 1 - rare

Names of plant species follow Allan (1961) and common names follow Poole and Adams (1964) and Richards (1947).

C = canopy or emergent species U = Understorey species G = Ground layer species.

Botanical Name	Common Name	C	U	G
<i>Alectryon excelsus</i>	titoki	2	3	3
<i>Beilschmiedia tawa</i>	tawa	5	2	3
<i>Brachyglottis repanda</i>	rangiora		3	
<i>Coprosma areolata</i>	karamu		2	
<i>C. polymorpha</i>	karamu		2	
<i>Cordyline australis</i>	ti kouka (cabbage tree)1			1
<i>Cyathea dealbata</i>	ponga (silver fern)		2	
<i>C. medullaris</i>	mamaku (black treefern)2		2	
<i>C. smithii</i>	ponga		2	
<i>Dicksonia squarrosa</i>	wheki	3		1
<i>Elaeocarpus dentatus</i>	hinau	3	3	3
<i>Hoheria sexstylosa</i>	houhere	2	1	
<i>Knightia excelsa</i>	rewarewa	3	1	2
<i>Laurelia novae-zelandiae</i>	pukatea	1		3
<i>Macropiper excelsum</i>	kawakawa		4	2
<i>Meliccytus landeolatus</i>			3	
<i>M. ramiflorus</i>	mahoe	4	2	1
<i>Myrsine australis</i>	mapou		2	
<i>Myrtus bullata</i>	ramarama		1	1
<i>Parsonsia heterophylla</i>	kaiku (liane)	3		
<i>Plagianthus betulinus</i>	manatu		1	

Botanical Name	Common Name	C	U	G
<i>Podocarpus dacrydioides</i>	kahikatea			3
<i>P. spicatus</i>	matai		1	1
<i>P. ferrugineus</i>	miro		2	2
<i>P. hallii</i>	totara	1		
<i>Pseudopanax</i> or boreum	pua-hou (five finger)		2	2
<i>P. crassifolium</i>	horoeaka (lancewood)		2	2
<i>Pteridium aquilinum</i> (Var. <i>esculentum</i>)	rahurahu (bracken fern)			2
<i>Rhabdothamnus solandri</i>	waiuatua		3	
<i>Rhopalostylis sapida</i>	nikau	1		1
<i>Ripogonum scandens</i>	kareao (supplejack)- (liane)	3		
<i>Rubus australis</i>	tataramoā (bush lawyer)			1
<i>Schefflera digitata</i>	pate		3	2
<i>Tetrapathaea tetranda</i> (liane)		2		
<i>Uncinia</i> spp.	(hook grass)			2
<i>Urtica ferox</i>	ongaonga (tree nettle)		2	2

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