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A HYDROLOGICAL COMPARISON BETWEEN TWO WATERSHEDS
IN POHANGINA COUNTY

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of
MASTER OF AGRICULTURAL SCIENCE
IN SOIL SCIENCE
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FRONTISPIECE - PLATE 1

Oblique Aerial View of Study Catchments from Ridge Road Looking
towards the Pohangina River



SUMMARY

Sequential aerial photographs taken in 1946, 1958, 1966 and 1972 were used to study the changes in erosion and vegetation over two adjacent catchments in the Pohangina County, 35 km north east of Palmerston North. Infra red colour and Kodachrome prints were used as well as black and white film for added interpretive value.

The major problem in these watersheds is the severe canyon gullyng that occurs in the unconsolidated Castlecliffian Sand underlying this area.

Number 1 catchment (240 ha) is in a more critical state with regard to erosion, than Number 2 catchment (200 ha). It yielded extremely low dry weather flows, with much of the streambed completely dry except in flood events, or fed only by seepage from small springs. Reasons for the significant differences in the behaviour of the two catchments are suggested.

Attempts were also made with limited resources to look at the flood levels and sediment loads contributed to the Pohangina River by these catchments. It was calculated from a flood 10/3/72 that sediment loads in the order of 3 tonnes/min could be reached at the flood peak. Mechanical analyses showed that 80 per cent of this load falls in the size range of fine sand.

Using a mirror stereoscope and simple morphometric and photointerpretive methods, the physical factors contributing to the erosion and headward gully movement in the two catchments were compared and a series of deductions made in conjunction with the history and management of the properties involved. Headward gully movement and increased erosion was proposed to result from climatic events and changes as well as the removal of large areas of scrub and regenerating native bush on the gully sides. Fencing off

the gullies, complete withdrawal of stock from them and allowing unrestricted regeneration of native species coupled with the planting of exotic trees and the erection of conservation structures should have been instigated as soon as the problem became apparent. These measures have also been advocated by other workers and organizations for similar problems in the same area.

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CHAPTER ONE

INTRODUCTION

The study area consists of two adjacent catchments situated on the unconsolidated Castlecliffian Sand country in the Pohangina County. This parent material was first recognized as an erosion problem with respect to canyon gullying in the middle 1930s, and since the late 1940s has been an area of major concern for the Manawatu Catchment Board. Various conservation structures and extensive planting of different exotic tree species, coupled with improved pasture and stock management, have resulted in the near stabilization of some of the watersheds in the district. Other watersheds are still contributing unknown quantities of sediment to the Oroua and Pohangina Rivers in each runoff event.

This study, although mainly qualitative in approach, endeavours to compare the sediment loads produced at peak runoff times in 1972 by the two study catchments. Flood level recorders were installed to provide an indication of the peak levels reached by flood waters. With the simple equipment available, flood water samples were taken as near to the flood peak as could be judged. Mechanical analyses carried out on these samples determined the proportions of coarse sand, fine sand, silt and clay in the sediment load.

Dry weather flows were recorded monthly and daily rainfall records were kept for 1972. The lack of automatic recording equipment and rainfall and runoff data for preceding years, however, limited the study largely to photointerpretive work with sequential airphotos combined with consequent field checks and observations.

The comparison between the two catchments and

the reasons behind the significant differences in behaviour despite the same climatic and geologic regime, was a major aspect of the study. Catchment Number 1 exhibited a far more severe degree of canyon gullying than Catchment Number 2. In conjunction with this, was the fact that although Number 2 was the smaller catchment, (200 ha compared with 240 ha) the streamflow throughout the year was always several times as great as that in the larger catchment. Even during flood events the flow was greater but the sediment yield much smaller. Another anomaly arises from the fact that Number 2 catchment has a much greater proportion of its area covered with scrub and bush. Hence one would expect the runoff to be correspondingly less instead of greater.

The flow regime of Number 1 catchment is such that for much of the year a large proportion of the streambed is completely dry. Those areas that are permanently wet appear to be fed from small contact springs originating in seepage zones up the gully sides in several different places.

Whereas the streambed in Number 2 catchment is generally grassed right down to water level, with the flow contained in a narrow channel at no place more than 1 m across, the streambed in Number 1 catchment is a relatively wide aggraded channel with the gully walls rising almost vertically on each side. Judging from the speed at which the sand built up behind the two concrete drop structures installed in this gully by the Manawatu Catchment Board in 1971 and 1973, there is a considerable depth of sand over much of the length of the gully, suggesting a high level of interflow and baseflow in place of surface runoff.

Aerial surveys flown in 1946, 1958 and 1966 were obtained from Aerial Mapping Ltd., Hastings and a 1972 survey was flown by Mr. D.G. Bowler, Department of Soil Science, Massey University. These photographs were supplemented by 35 mm Kodachrome and infra red colour transparencies for further information, and enabled a sequential study of the erosion and regeneration of scrub and native bush in each

catchment to be made. Headward gully movement and a change from slip erosion to a predominance of canyon gullying were observed over the 26-year period.

The Kodachrome and infra red colour transparencies were particularly valuable in that they could be projected side by side and the features of interest examined, identified and compared on a large scale. In conjunction with the black and white prints, they permitted a more accurate inventory of vegetative species to be made.

These observations were all tied in with the management practices and history of the holdings making up the two catchment areas. This was a difficult task as the upper part of each watershed is managed as part of one property, while the lower part is owned and managed by another farmer. Also small areas on the western side of the Number 1 gully fall into two different properties again.

With the aid of simple morphometric and photogrammetric techniques, a number of exercises and measurements were made in order to determine physical differences that could help explain the dissimilar behaviour of the two catchments. These included natural drainage analyses, stream profile construction, crestline profiles and the patterns exhibited by the subwatersheds of each watershed. All such exercises are simple to carry out and once the results have been interpreted for a minimum number of cases, could have wider application to other catchments in the same geologic and climatic region.

Thus, as well as being an attempt to explain the difference in behaviour between two eroding catchments in the same district, this study is also aimed at encouraging the greater use of a variety of photographic films for analysing soil conservation problems. It is also hoped that other workers in this and allied fields will make fuller use of the numerous simple techniques available in

morphometry and photogrammetry. Qualitative rather than quantitative field observations, and measurements requiring no expensive equipment or recording materials can also be made to produce valuable information at very small cost.

* * * * *

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

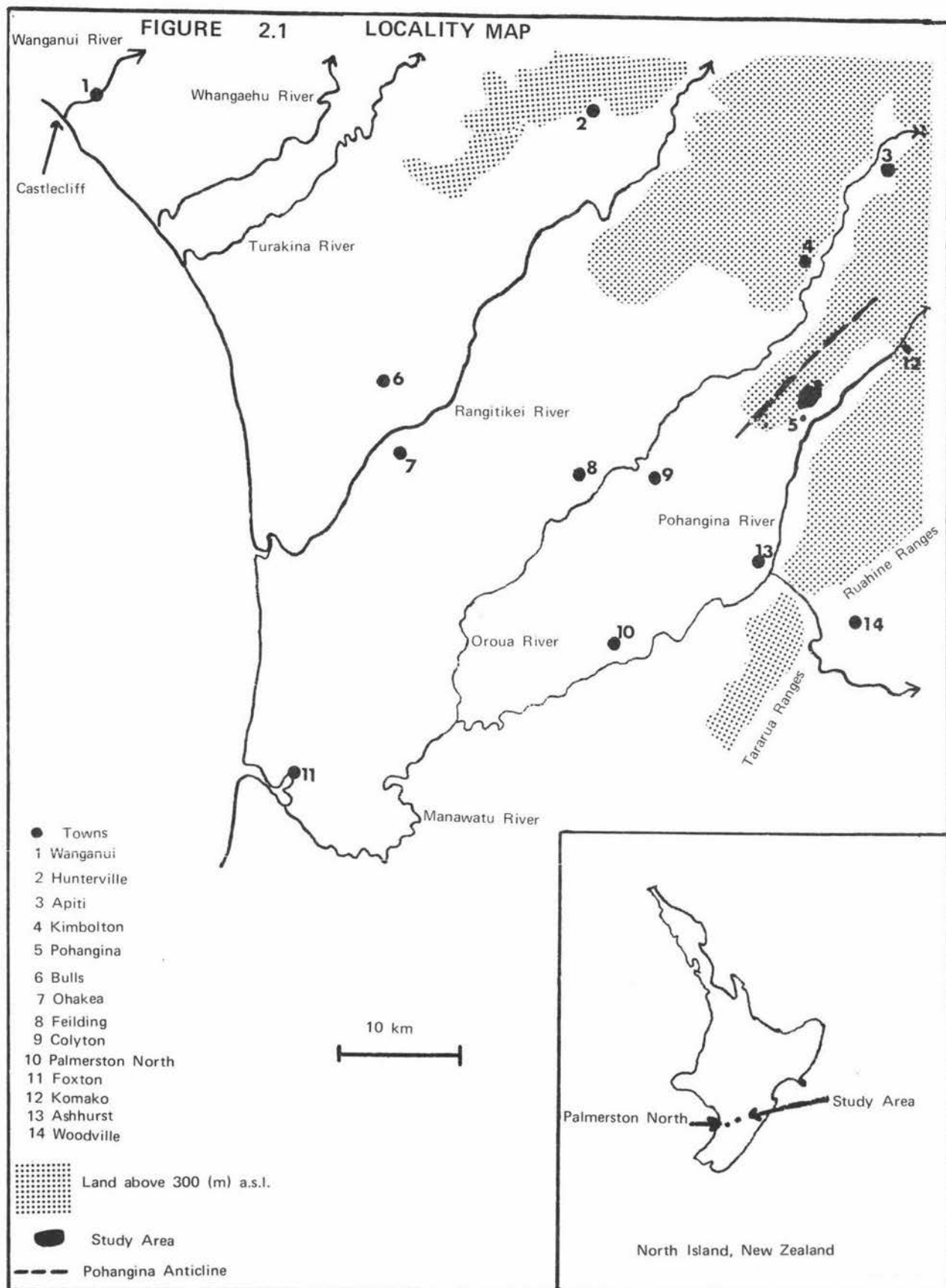
2.1 LOCATION

The area of study is located in the Pohangina County of the Manawatu district about 35 km north east of Palmerston North (Figure 2.1). It consists of two adjacent catchments, approximately 240 ha and 200 ha, in area. Known as Culling's gullies, these catchments extend from headwaters bordering on Ridge Road, to their confluence near the Pohangina township end of Branch Road, and join the Pohangina River below the northern end of the township. The study area thus forms part of the eastern flank of the Pohangina anticline which lies between the Pohangina and Oroua Rivers (Plate 2.1). The map reference from the New Zealand Geological Survey Map, 1:250,000 Sheet 11, is N32/2761.

The headwaters and upper parts of the two watersheds are owned by Mr. W.M. Stewart of Te Awa, R.D. 3 Feilding. The lower parts are farmed by Mr. J. Culling, Pohangina, Utuwai R.D., Ashhurst in conjunction with another block of land in Finnis Road. Smaller periphery areas of the catchments fall into the properties of a further two farmers. Thus the overall management of the watersheds as a whole is complicated by multiple ownership.

The western gully system will henceforth be referred to as Number 1 gully, and the eastern system as Number 2 gully, (Figure 2.2).

Access to the gullies is made either from Ridge Road and dropping into the headwaters, or through the gate onto Branch Road just to the right of Mr. J.M. Passey's dairy



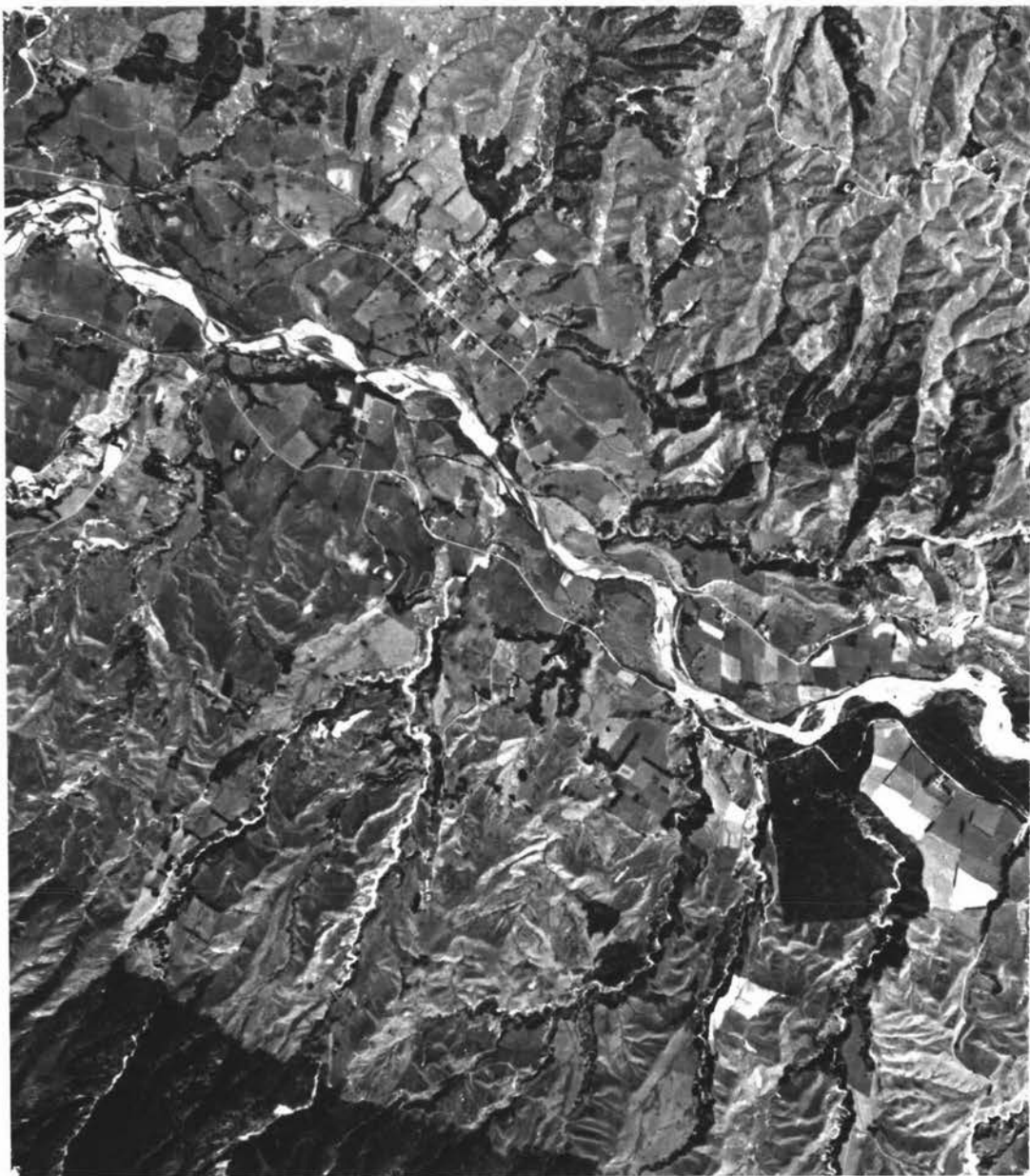
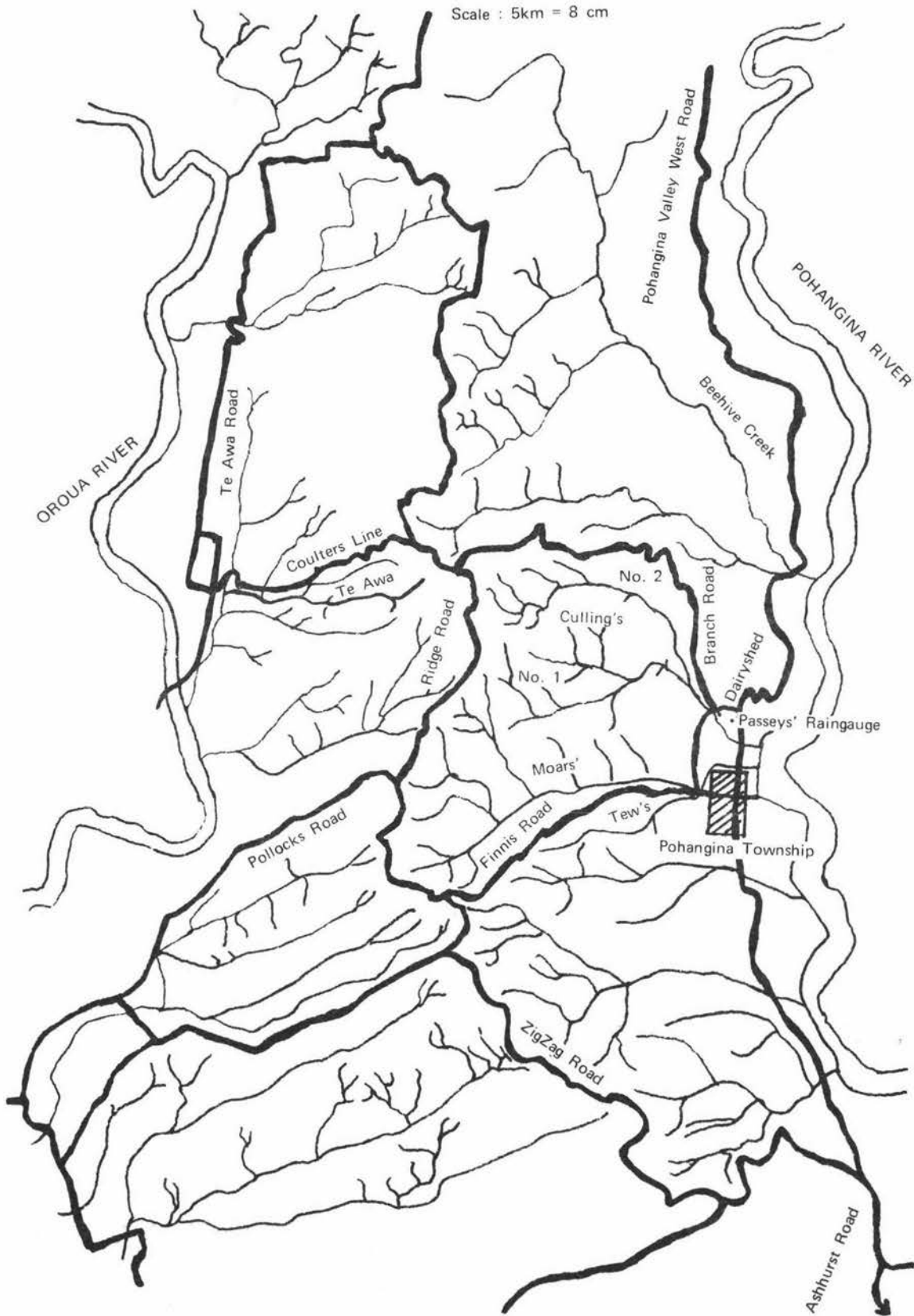


PLATE 2.1

Aerial view of the Study Area, showing Location on the Eastern Flank of the Pohangina Anticline between the Pohangina and Oroua Rivers.

FIGURE 2.2 SPECIFIC LOCALITY MAP

Scale : 5km = 8 cm



shed and up the stream to the confluence of the two gullies. Branch Road has been closed to traffic for the last decade, but provides walking access up the eastern perimeter of the watersheds. A farm track up the eroding hillslope from the confluence of the two streams provides access to the ridge between the two catchments. In times of flood, access to the bottom of both gullies is rather difficult as the stream has to be forded several times before the confluence is reached.

Plate 2.2 shows the confluence of the two streams in dry weather, during which flow never exceeded a total of 170 l/min, in 1972 when monthly recordings were made, (see Chapter Five). During flood events however, the two streams meet in a raging muddy torrent, the contribution from Number 1 catchment being noticeably more turbid and carrying a greater sediment load than Number 2. The frontispiece, shows the general view of the two catchments looking down towards the confluence from Ridge Road.

The study area falls within the Manawatu Catchment Board's Pohangina/Oroua Catchment Control scheme, one of the five major river schemes undertaken in the Board's area. The unconsolidated Castlecliffian sandstone underlying relatively erodible soils in the region is particularly susceptible to canyon gully erosion and is probably the Board's major soil conservation priority on farmed hill country in its district.

The Te Awa Experimental Area is situated on Coulter's Line about 4 km from the top of Culling's gullies on the western flank of the Pohangina anticline. Tew's (MacDonald's) demonstration farm is situated at the Pohangina township end of Finnis Road on the same side of the anticline as Culling's gullies.

Thus the work done on these and other demonstration farms in the County has provided useful information for the present investigation.



PLATE 2.2

Confluence of Number 1 and Number 2 Gullies



PLATE 2.3

Erosion Debris at Foot of Waterfall, Number 1 Gully "Knickpoint"

2.2 TOPOGRAPHY

Although topography refers to the size, shape and distribution of features of the earth's surface and comprises of relief, drainage and cultural features, (Lahee 1931), only the first of these categories will be dealt with in this section. A detailed discussion of the drainage pattern of the study catchments and the adjacent watersheds is described in later chapters. The cultural features will be dealt with in Section 2.8, Agriculture and Management History.

Topography, according to Boughton (1968) is the only catchment characteristic that has been adequately described in a systematic manner by hydrology texts. Since the work done by Horton (1932) and (1945) however, even topographic characteristics have tended to be overlooked. Boughton lists the various characteristics which have an effect on floods or catchment water yield and the measurements that can be made. Most of his categories will be dealt with under the discussion of morphometric and photogrammetric techniques in a later chapter, and only qualitative descriptions will be given at this point.

Curtis et al (1965) also point out the importance of accurate descriptions of topography in field studies of soils. Since the soils of the area are classified according to slope criteria, quantitative comments on the range of slopes present in the catchments are made in Section 2.5. Soils. The nature of the slopes in relation to canyon gullying and other forms of erosion is also further dealt with under Section 2.7. Erosion.

However, a large proportion of the area under investigation has steep slopes with areas of easier tops separated by the canyon gullies. Many of the slopes would fall into the " Moderately steep to steep " (most slopes under 30° : many slopes between 18° and 30°)

class of Taylor and Pohlen (1970). There are also pockets of more gentle topography, and vertical and near vertical gully walls and faces particularly in Number 1 catchment.

The headwaters of the two study catchments rise to an altitude of about 360 m above sea level at Ridge Road, from an elevation of about 150 m at their confluence. In the headwater regions, the hill slopes fall into Classes 5/ and 6/, "Moderately steep to steep" and "steep", (Taylor and Pohlen, 1970). Headward gully erosion proper has not invaded this far and the occurrence of slips has decreased with improved stock and pasture management since 1946.

Distinct "knick points" in the form of major waterfalls are present in each gully. Downstream from this, extremely severe and spectacular canyon gullying is the main feature of the western Number 1 gully system. The difference between the two gully systems is quite marked. Number 2 gully is generally well-grassed right down to the actual streambed with the flow contained in a narrow channel no wider than 1 m across. There are only occasional areas of gullying and steep cliffs.

Number 2 gully is one continual canyon from the "knick point" down to the confluence with Number 2. The gully bottom is devoid of vegetation in most places; a wide flat sandy aggraded channel with the gully sides rising almost vertically on either side. At some points the valley floor is narrow, dark and overhung with trees; at other points extremely broad with soaring cliffs reaching up for more than 50 m.

Most of the tributaries flowing into Number 2 gully drop over waterfalls of the order of 1.5 - 5 m high. Headward gully erosion has not extended into the tributaries, as it has done in Number 1 gully and is in fact only severe just below the "knick point", a waterfall of about 4 m high.

In Number 1 gully, many of the tributaries, like

the main channel have also been gauged out to form flat bottomed dry sandy corridors that culminate in a jumble of blocks of crumbling unconsolidated sandstone and mobile loose sand of incredible steepness, or in a waterfall, (Plate 2.3).

The streamflow in Number 2 gully is permanent flow from the waterfall downstream, in most years, whereas the only permanent flow in Number 1 gully is for the last few hundred metres above the confluence. With the larger area of watershed contributing to flow in Number 1 (240 ha cf. 200 ha in Number 2), a correspondingly higher permanent flow over a longer distance of the channel is to be expected. This anomaly is explained by the much higher interflow and baseflow through the deep layers of sand on the channel floor. The channel floor in Number 2 gully, in comparison still has a stony bottom in many places or flows through siltstone and less permeable sandstone.

The short distance of actual streamflow in Number 1 gully issues from several small seepage zones on the sides of the gully where small contact springs originate, (Plate 2.4). The flow at these points runs into a completely dry channel, (Plate 2.5) and in the drier months has joined the underground flow before reaching the permanent flow further downstream. In the wetter months the overland flow extends further up the gully, but still is not necessarily continuous.

Throughout 1972 the surface runoff measured monthly in Number 2 gully was always 5 - 9 times greater than that measured in Number 1 for the above reason, (see Chapter Five).

Due to the large number of tributaries flowing into each catchment and thus the highly dissected nature of the study area, any one aspect cannot be said to predominate. However, as recorded in the Manawatu Catchment Board's Conservation Farm Plan for Mr. J. Culling's property, the block is reasonably sheltered from the north



PLATE 2.4

Seepage Zone Contributing to Streamflow Number 1 Gully



PLATE 2.5

Seepage Flow Meeting Dry Channel Number 1 Gully

and west but becomes more exposed at the higher altitudes.

However, the aspect of the individual slopes does have considerable importance with respect to erosion potential, as has been observed by workers in other parts of New Zealand (Archer, 1969) and Australia, (Newman, 1957). For example, northerly aspects bear more impact of N.W. winds and thus undergo more moisture loss from evaporation than do south facing slopes. Also contributing to this effect is the greater insolation received. Sunny faces also attract a higher grazing pressure from stock and thus more likelihood of depletion of ground cover. Thus north facing slopes tend to suffer pasture deterioration and a higher degree of erosion potential before the south facing slopes.

The actual axis of the Pohangina anticline runs in a N.N.E. direction, and can be traced for about 32 km from about 30 m a.s.l. at Palmerston North to about 340 m a.s.l. at Beehive Creek, which also extends from the top of the anticline and drains eastwards into the Pohangina River. On the eastern flank of the anticline, most of these catchments, described by Te Punga (1954) as secondary consequent streams, flow straight into the Pohangina River, but the more northerly ones are all tributaries of Beehive Creek. The western flank of the anticline is similarly drained, the streams flowing directly into the Oroua River at the northern end, but joining the Mangane Stream at the southern end of the anticline.

In the district around Culling's gullies and Beehive Creek, all the streams have very steep longitudinal profiles. Some of the streams have eroded headwards with such vigour that their heads now lie west of the anticlinal crest. Thus as erosion proceeds the divide is shifting progressively westward of the crest of the fold. From the geological cross sections observed in Culling's gullies, the crest of the anticline now lies a considerable distance down the catchments.

Thus the study area exhibits remnants of mature topography in the form of the ridges and crests above the steeper rejuvenated slopes. This rejuvenation and down-cutting of the valleys is still active, leading to the rapid and severe degrade of the valley floors. Terrace remnants are found on the easy tops between the two gully systems and to the west of Number 1 gully. After the confluence of the two streams at an elevation of about 170 m, the stream flows over a low terrace into the Pohangina River.

* * * * *

2.3 CLIMATE

2.3.1 General Introduction

In his list of climatic characteristics that should be recorded in catchment studies, Boughton (1968) lists the four main categories of :

Rainfall and Snow

Radiation and Temperature

Humidity and Evaporation

Wind

Unfortunately most of the measurements that can be made under these headings require access to an extensive period of records.

The only records actually kept from the study area were the dry weather monthly streamflows, flood flows (when feasible), and daily rainfall for 1972. The figures closest to those expected from Culling's gullies will be those kept at the Te Awa Experimental farm. However, because Te Awa lies on the western flank of the anticline, considerable differences due to aspect, elevation and slope could exist. Otherwise, any available records of relevance to the area under investigation are considerable distances away, but will be discussed where applicable.

The dissected nature of the catchments and the multitude of different aspects and elevations within them obviously leads to large variations in microclimate over the study area. These large variations in microclimate in turn greatly affect erosion potential and stability.

Some of the main elements of the district climate are summarized in Appendix I.

2.3.2. Precipitation

From Te Awa towards the Ruahine Ranges in both easterly and north easterly directions the annual rainfall increases, reflecting the orographical influence of both the ranges and the anticline, (Greenall et al. 1951; Wright, 1968). This influence tends to be more marked for rainfall totals of wetter years.

An average annual rainfall of 1145 mm is recorded for Mr. J. Culling's property in his Conservation Farm Plan (M.C.B. Files). Te Awa has an average rainfall of 1020 mm per year. Awahou, 15 km to the east has an annual average of 1190 mm; Apiti, 32 km to the north averages about 1300 mm per annum, (Wright, 1968). This same source quotes the annual variability of rainfall as being 70 mm for the district. Komako, 25 km to the north east of Te Awa has an annual rainfall mean of 1319 mm, (N.Z. Met. Service, 1973, Rainfall Percentiles). Another relatively close centre is Colyton, with an annual average of 1027 mm.

The variation from year to year of the annual rainfall over the Pohangina district as a whole, can be interpolated from Komako and Colyton figures and is as follows. (Feilding and Palmerston North figures are also included for the comparison.)

TABLE I : VARIABILITY OF RAINFALL AT KOMAKO AND COLYTON

	Length of record :	minimum rainfall :	maximum rainfall :	mean :	SE m
Komako	1913 - 1969	879 mm	1830 mm	1319	30.1
Colyton	1912 - 1969	716 mm	1398 mm	1027	22.6
Feilding	1890 - 1969	651 mm	1226 mm	931	15.2
P.N. DSIR	1928 - 1969	713 mm	1299 mm	994	19.5

Thus, remembering that the Pohangina district is closer to the ranges than Feilding and Palmerston North, the year to year variability in the average rainfall figures is not excessive compared with other districts. Greenall et al (1951) note that years of high rainfall have generally been followed by years of low rainfall.

Wright (1968) describes the drought risk in the Pohangina County as low, but Glass (1957) mentions a tendency for summer droughtiness in the general area. Greenall et al (1951) state that "although subject to summer drought, the area has good drought resisting characteristics and seldom becomes completely browned off."

Most of the rainfall falls from late autumn to spring, with the maximum rainfall in winter. March and September are usually the driest months with a slight increase in rainfall in the summer months. The rainfall variability during January and February is much greater than for any other months, e.g. extremes of February rainfall range from 7 mm in 1939 to 190 mm in 1936, as quoted by Greenall et al. Much of this summer rainfall is from instability showers. Thunderstorms occasionally occur causing high intensity precipitation of short duration.

At the Ballantrae research area on Saddle Road 14 km S.S.E. of the study area, thunder has been recorded on three days per year over the last three years.

Severe local damage has sometimes resulted from these heavy but short duration summer storms. For example, the great storm of February 1936 caused widespread damage over much of the Manawatu, Tararuas, and Southern Ruahines. Following this storm accelerated erosion became widespread in the Pohangina district. Other high intensity falls pre 1950 could have had similar effects, especially on areas of poor vegetative cover and stability.

The following intensities were recorded from Te Awa in 1949.

63 mm in 1 hour (7/1/49)

89 mm in 1.5 hours (3/1/49)

88 mm in 4 hours (7/1/49) on this date 120 mm in

2 hours were recorded at Awahou North.

One would expect high runoff from intensities like these, especially in summer if the soils have dried out, hardened and cracked resulting in surfaces of low permeability. With the steep slopes and highly erodible substrata, concentration of runoff is rapid and velocities high, leading to fast and severe degrade in the gullies and high sand and sediment loads in the streams.

In the winter months of high rainfall, the soil and substrata become saturated. This leads to slope instability and the steeper slopes especially are predisposed towards erosion. Both Wright (1968) and Greenall *et al* (1951) however, describe the climate of the Pohangina district as a whole as "not particularly erosion producing".

2.3.3. Temperature

Aspect and slope influence the temperatures experienced over different parts of the catchments. Radiation reaching the earth at an angle is scattered over a wider area than the same radiation striking the ground surface perpendicularly. Thus the steeper the slope, the smaller amount of heat received per unit area. North facing slopes undergo greater diurnal temperature variation than south facing slopes. Thus there will be considerable temperature variations that will affect the microclimate throughout the study area, due to its dissected nature.

At Ballantrae the three hottest months are January, February and March, with daily means of 16.2°C , 15.8°C and 15.1°C respectively. The three coldest months are June, July and August, with daily means of 7.6°C , 7.5°C and 7.4°C respectively. (These figures are derived from the N.Z. Met. Service Observations for 1970 - 1972.)

From temperature records kept at Awahou, (Wright, 1968) the warmest month is February, the coolest month,

July, with an average annual range in temperatures of about 10°C . The diurnal ranges are "probably about 10°C in summer and 7°C in winter". Higher westerly facing slopes would be expected to undergo less of a diurnal temperature range. Deeper valleys, especially the canyon gullies would be expected to exhibit greater ranges.

2.3.4. Wind

Over the whole of the Manawatu area, the prevailing winds are from the west and north west, but in the Pohangina district, channeling by the topography produces a local dominance from the N.W. and S.W. directions (Wright, 1968).

As recorded at Ballantrae between 1970 and 1972, the average annual percentage frequency of surface wind directions were greatest from the N.W. 38.4%; E 16.0%; and W 15.9%. See Appendix I.

Typical of the rest of the Manawatu, wind velocities are greatest during the spring equinoxal period. During September and October daily wind runs up to and in excess of 1000 km per day have been recorded from Ballantrae. However, for the period 1970 - 1972, the Ballantrae figures show no one month with abnormally low wind runs (See Appendix I). Wright (1968) quotes the windiest month as being November and the least windy month, July, with winds above the annual average from September through to February, for the Pohangina County.

The wind effect with respect to erosion potential is mainly related to its influence on the angle of impact and velocity of the raindrops. Microclimatic observations indicate marked differences between sunny and shady faces with respect to moisture retention, soil temperatures and evaporation. Wind contributes to

evaporation especially on exposed gully faces. Where dry unconsolidated strata is exposed, erosion by wind has been observed, over the summer months. On windy days, the whirling sand particles give the gullies the appearance of smoking.

* * * * *

2.4 GEOLOGY

2.4.1. General

The study area and indeed much of the Pohangina district is geologically very young and has a highly erodible substrata of unconsolidated Castlecliffian sediments. The loose unconsolidated nature of this substrata, combined with the long steep slopes, the loose textured soils and the elevation of the hills and streams above base level, all contribute to the severe erosion problem in the area (Plate 2.6).

Castlecliffian rocks outcrop over a wide area in the Hawkes Bay and Wanganui basins and in the Wairarapa Syncline. In places they are recorded by Saunders and Anderson (1964) as being at least 435 m thick.

The "Castlecliffian Stage" was originally proposed by Thomson (1916), for the upper part of the continuous succession of beds exposed on the coast between Wanganui and Patea. The term "Castlecliffian" now embraces beds of a similar age from an area far and beyond the type locality on the coast at Castlecliff.

In the Pohangina and Oroua Valleys the Castlecliffian rocks are predominantly slightly compacted coarse sands frequently current and cross bedded and closely laminated by wave action (Plate 2.7). Interbedded in these coarse sands are laminated siltstones, sandy siltstones and occasional conglomerate bands. Pumice bands, iron sands and concretions occur throughout. These sands, silts, pumice bands, conglomerates and gravels are either in marine sequences or in much dissected high terraces.

2.4.2. Geological History

Throughout geological time, New Zealand's rocks have been formed by a continuous interplay of the pro-

PLATE 2.6

Steep Gully Wall Showing Highly Erodible Laminated Castlecliffian Sand Substrata and Poplar Poles Planted at the Bottom.

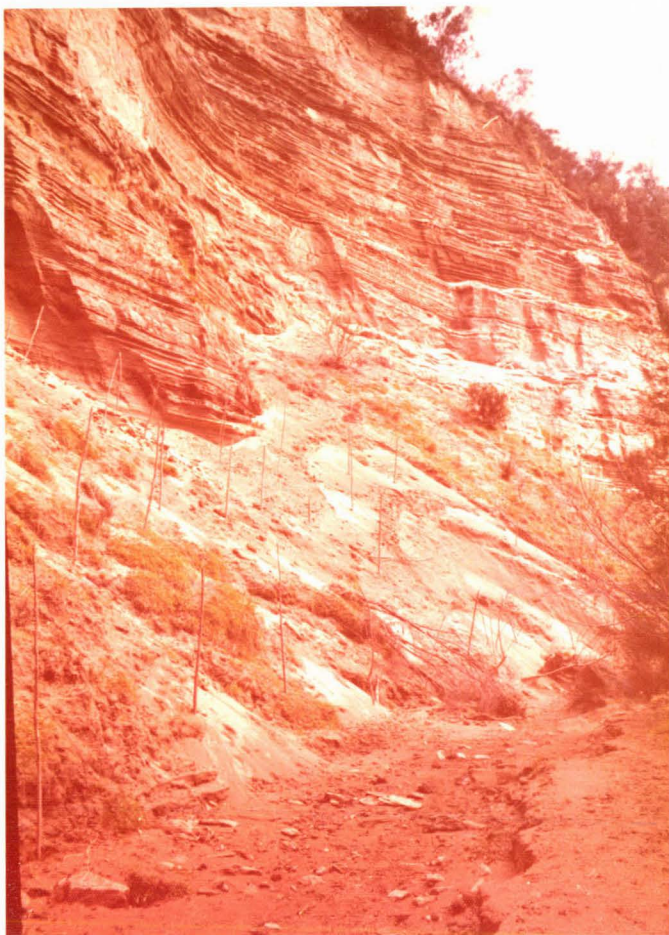
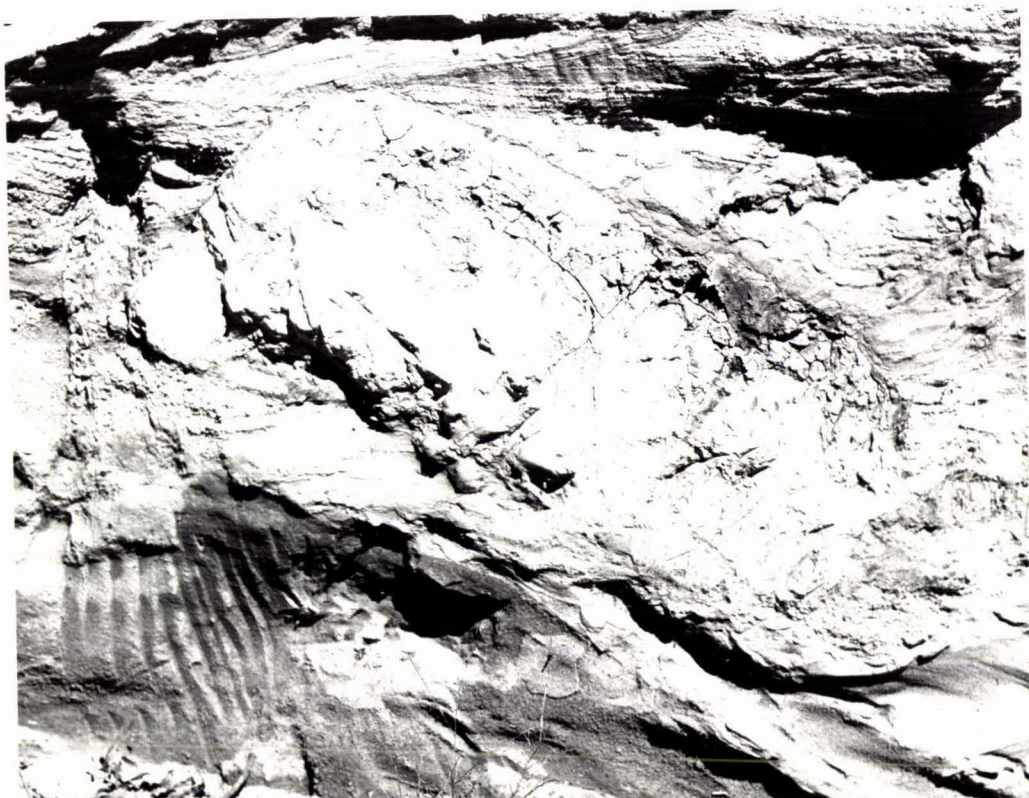


PLATE 2.7

Buried Ash Clast with Soil developed on one Surface, in Matrix of Coarse Pumiceous Sand.



cesses of erosion, sedimentation, metamorphism, igneous activity and tectonic movements. The most important periods in the development of the New Zealand landscape are the Late Tertiary and the Quaternary. See Table II Geological Time Scale. However, it is extremely difficult to define the actual boundary between the Tertiary and Quaternary, i.e. between the Pliocene and Pleistocene Periods, in the New Zealand situation.

The Castlecliffian Stage of the Wanganui Series was originally placed in the Upper Pliocene (Finlay and Marwick, 1940). Later workers, (Fleming, 1953; Te Punga, 1952 and 1957; Couper and McQueen, 1954; and Kingma, 1960b after Hornibrook, 1958) all place the rocks of Castlecliffian age in the Pleistocene on paleobotanical and fossil evidence.

Underlying the Manawatu area and outcropping in the ranges are rocks of the undermass laid down in the Jurassic and then uplifted in the Rangitata Orogeny between the Upper Jurassic and Lower Cretaceous.

By the end of the Upper Cretaceous a long period of erosion had worn down the mountains to low relief and part of the Manawatu-Wanganui area was submerged again. There followed a stable phase of peneplanation and quartzose sedimentation.

Throughout much of New Zealand, submergence continued until the Oligocene, with the seas spreading over the land from the east. There was no complete withdrawal of the sea from the New Zealand region compared with that observed elsewhere in the world, between Cretaceous and Eocene sedimentation.

In the Lower Oligocene any small limestone areas in the Manawatu area were laid down. This only occurred where the sea floor was shallow, yet far enough from land to be clear of pebbles, sand and other erosional debris. Clastic sediments were still laid down nearer the diminished land areas. The Oligocene then saw the maximum submergence of New Zealand by the Tertiary sea. The country was a changing archipelago. For over 30 million years the Manawatu

TABLE II : GEOLOGICAL TIME SCALE

(From Holmes (1959)
 NZGS Map 10, (Lensen, 1959
 and NZGS Map II, Kingma,
 1962)

ERAS :	PERIODS :	SERIES :	FORMATION OR STAGE :
CENOZOIC	QUATERNARY		
	Holocene (Recent)	Recent	Undifferentiated alluvium Sand Dunes River Terraces Woodville Alluvium
		10,000 years ago	
	Upper	Upper Hawera Lower	Undifferentiated Rapanui Formation Brunswick Formation Kaiatea Formation
	Lower		Castlecliffian Stage
	(indefinite boundary)	Wanganui	Nukumaruan Stage
	TERTIARY	(1 million years ago)	Waitotaran Stage
	Pliocene		Opoitian Stage
	Miocene Oligocene Eocene		
	(50-70 million years ago)		
MESOZOIC	CRETACEOUS	Taitai-Oteke	Korangan-Puaruan Stages
	Lower		
	(Distinct break in sedimentation)		
	JURASSIC		
	Upper	Kawhia-Oteke Kawhia-Herangi	Wakarara Greywacke Group Ruahine Greywacke Group
PALAEOZOIC	TRIASSIC		
	(160-220 million years ago)		
	PERMIAN		
	(Distinct break in sedimentation)		
	Upper	CARBONIFEROUS	
PALAEOZOIC	DEVONIAN		
	SILURIAN		
	Lower	ORDOVICIAN	
	CAMBRIAN		
PRE CAMBRIAN	(500-600 million years ago)		

area was probably a shallow basin lying on the back slope of a slowly rising central mountain axis of the North Island.

Short gaps in the fossil records point to local withdrawals and readvances of land in the Lower Miocene. At this stage the Manawatu-Wanganui district was above the sea again and remained so, until it was submerged again in the Pliocene in the latest marine transgression in New Zealand's history. In fact there is no distinct break in sedimentation between the Pliocene and Pleistocene, where the boundary between the Tertiary and Quaternary is usually placed. Climatic conditions at this time were subtropical.

During this time intermittent earth movements increased, culminating in the Kaikoura Orogeny with its vigorous mountain uplifting (Fleming, 1962). This Kaikoura Orogeny started well back in the Miocene, (Fleming, 1949). Thus when the sediments of the Wanganui Series were being laid down tectonic upheaval was considerable, resulting in the appearance of the Ruahine-Rimutaka Horst in the form of an elongated greywacke ridge between the eastern and western basins.

Soon after the Pliocene, the sea regressed and New Zealand assumed approximately its present coastal outline. Any transgressions of the sea since then have only been along narrow coastal strips. Thus the Wanganui Series of rocks were deposited from the Pliocene throughout the Lower to Mid Pleistocene. Te Punga (1954), describes the Wanganui Basin as receiving sediments from the older Tertiary rocks of the Taranaki district to the north, from the rising axial ranges to the east and from a granitic and metamorphic terrain to the south. As the development of the basin continued, periodic centripetal tilting at the margins resulted in the emergence of progressively younger sediments of the Wanganui Series which in their turn supplied sedimentary material to the trough.

Thus rewashed Waitotaran sediments contributed to the Nukumaruan, and both Waitotaran and Nukumaruan sediments are represented in the Castlecliffian. Even within the Castlecliffian, sediments deposited early on were uplifted and served as a source of material laid down in later beds.

Saunders and Anderson (1964) describe the climate as gradually deteriorating throughout the Waitotaran, and apart from a temporary onset of warm conditions in the early Nukumaruan, cool climates continued to prevail until the Upper Castlecliffian. It must be recalled at this point that the temperatures in the Miocene had reached tropical conditions, so that a "deterioration" from these temperatures might not have made the climate any cooler than in the present day. Thus it can be suggested that the climate in the Castlecliffian was similar to what it is at present. This is also backed up by work done by Finlay and Marwick, (1940), Fleming (1949), Couper and McQueen (1954), Te Punga (1957) and (1962). Kingma (1960a) mentions indications of the sea withdrawing from time to time causing land conditions to alternate with those of shallow seas.

Also, during the late Pliocene and early Pleistocene there was a succession of glacial and interglacial periods. During the glacial periods there was a fall in sealevel and much of the seafloor around the Manawatu-Wellington coastline was exposed to wind erosion. Fine sediment was blown inland at this time as loess and the land was subjected to a frost climate. In the interglacials the sealevels rose again, and where the rocks were soft, the sea was able to cut broad terraces and marine deposits were left at higher positions than during the glacial periods. Four main glaciations in the Pleistocene are indicated by the alternation of warm and cool fossil faunas found in these younger marine sedimentary rocks.

Marine sedimentation continued from the Castlecliffian into the Hawera times without a break in some areas, though not over the study area. Thus the idea that a long period of time elapsed between the deposition of the youngest Castlecliffian beds and the oldest Hawera strata, is no longer tenable. Also the supposed climax of the Kaikoura Orogenic movements in this and other districts can no longer be regarded as having taken place in the interval between the Castlecliffian and Hawera times. The alternative suggestion is that these movements commenced at the time of deposition of the coarse conglomerates of Upper Castlecliffian age and have continued intermittently until the present day (Te Punga 1954).

During Hawera times during the alternations of cold glacial and warm interglacial climates with their accompanying low and high sea levels, there was local folding and general uplift. The folding of the beds of the Hawera Series into youthful anticlines following a slight pause in tectonic activity, marks a very late phase of earth movement in this district. Terrace country was cut during the marine transgressions and then dissected during the following marine withdrawals.

As well as the tectonic activity and glacial action in the Castlecliffian, volcanic action was also important. Fleming (1949) records the great ignimbrite eruptions of the Taupo and Bay of Plenty area as dating from the Castlecliffian. Te Punga (1954) reports " three stupendous explosive eruptions of rhyolite from the volcanic districts " in the Castlecliffian marine sediments in the Rangitikei district. These were the Pakihikura Pumice, the Potaka Pumice and the Rangitawa Pumice. He suggests that each of these major eruptions was closely associated with the production of an ignimbrite sheet in the central volcanic district. These materials of volcanic origin are of especial importance as stratigraphical and chronological markers.

In the Superior Oil Company's report (1943) the Castlecliffian Stage at Wanganui is separated from the Nukumaruan at the prominent ash bed which they designated the basal Castlecliffian ash. Saunders and Anderson (1964) call this ash horizon at the base of the Castlecliffian, the Pakihikura Pumice in the Manawatu area. Fleming (1953) calls the basal Castlecliffian pumice bed the Makirikiri Tuff. The Pakihikura Pumice, is thus the lowest ash in the Makirikiri Tuff formation.

The tuffaceous fossiliferous sands in the Pohangina district referred to as Pohangina Pumice Sand in the *Lexique Stratigraphique International*, (Fleming, 1959) were correlated by Park (1887) with the similar pumice beds at Kaimatira (on the Wanganui River) and Okehu (on the coast) in the Wanganui district. Reworked pumice sands and pumice blocks occur throughout the sequence in Cullings gullies and in Finis Road. The conspicuous ash bed at the top is referred to as the Kimbolton Ash Bed by Greenall et al (1951) where it outcrops along Finnis Road. Saunders and Anderson (1964) refer to this pumice as the Potaka Pumice.

Seward, (1973 pers. comm.) dates the Potaka pumice at 0.61 ± 0.07 million years and suggests that the Finnis Road ash is possibly the equivalent of this. The Makirikiri Tuff she states as being made up of detritus from at least three major volcanic eruptions and gives ages from the Rangitikei section where these ashes are distinct and obvious, as; 1.09 ± 0.14 million years, and approximately 0.96 and 0.88 million years for the upper two. There are also other ash horizons both above and below the Potaka Pumice which date at approximately 0.57 and 0.74 million years.

Towards the end of the Castlecliffian time, andesitic volcanoes also contributed material to the Wanganui Basin.

By the end of the Castlecliffian the seabed had withdrawn over the greater part of the Wanganui Basin as earth movements continued. Locally, as in the Rangitikei

River Valley, river gravels were deposited without a break on the soft Castlecliffian sediments, but over much of the area there was, as previously mentioned, a break in the sedimentation and a period of erosion.

In some of the sections, studies of the faunal communities have proved useful, e.g. the section at Castlecliff, (Finlay and Marwick, 1940) and in the Rangitikei Valley, (Te Punga, 1952).

However, the only intact fossil shells found in the sections in Culling's gullies, were those of the bivalve Paphies (Mesodesma) pliocenica (Oliver) as identified by Fleming, (pers. comm. 1973).

2.4.3. Stratigraphy

The type formation of the Castlecliffian Stage is taken to be the Tainui Shellbed at Castlecliff, near Wanganui. (See Appendix II Stratigraphic Table of the Castlecliffian Stage.)

This Table of the different formations in the Castlecliffian Stage refers to the outcrops of Castlecliffian rocks in the Wanganui district and was used as a guide to the formations likely to be found in the Pohangina district in the Culling's gullies sections.

Fleming (1947) and (1953) gives detailed accounts of the sections and subdivisions of the Castlecliffian Stage and its stratigraphy as it occurs in the Wanganui district. He divides the formations of the Pukitean and Okehuan substages into three groups; the Okehu, Kaiwi, and Shakespeare, with the boundary of the Putikian and Okehuan Substages occurring below the Kupe formation of the Kaiwi Group.

It is the basal formation of the Kaiwi Group that we are most interested in with regards to the section in Culling's gullies. This is the Kaimatira Pumice Sand,

which was correlated by Park (1887) with the Pohangina Pumice Sand of the study area.

On the Wanganui Coast this formation is 15 m thick and consists of barren alternating tuff sands and silts, then coarse crossbedded sands and pumice gravels with scattered mollusca, then shell grit with abundant mollusca. In the Whangaehu Valley the formation consists of 42 m of fine irregularly interbedded tuff sand and silt. Rusty pumice gravel and sands, locally fossiliferous, are interbedded with silts or lie at their base. Pebbles of rhyolitic pumice, vesicular rhyolite, ignimbrite, quartzite greywacke and andesite occur in the conglomeratic members of the Kaimatira Pumice. The upper limit of the formation is established by the occurrence of the Lower Kaiwi Blue Siltstone, (Fleming, 1953).

The crossbedded pebbly sands and molluscan faunas indicate deposition in shallow water. This occurred after an erosion interval. Abundant rhyolitic pumice and tuff brought down from the Taupo area by the rivers then built out a marine and estuarine delta of tuffaceous sediment on the subsiding Wanganui Basin. Subsidence then rapidly carried the Kaimatira Pumice Sand below wavebase and allowed deposition of the Lower Kaiwi Siltstone in the mud zone without much interference from bottom currents. Thus the formation directly on top of the Kaimatira Pumice is light blue-grey fine-grained micaceous massive siltstone and fine muddy sandstone containing scattered fossil mollusca.

General observations were made of the section exposed in Culling's gully, Number 1. Much of the sequence was highly pumiceous. Rounded pumice pebbles up to 10 cm diameter were found in very coarse pumiceous sand. Large convolute laminations were common in the pumiceous and tuffaceous sand. Cross bedding was also common. In other places alternating sands and silts were enriched with iron, and breccia set in coarse pumiceous sand and gravel appeared. Examples were also seen of very

glassy rhyolitic sand and buried soils (Plate 2.7). West of the anticline axis the section is estimated to be about 70 m thick; east of the axis, over 100 m thick.

The section was measured westward from the axis of the anticline up to the waterfall knickpoint, and eastwards from the anticline axis, by Seward (pers. comm. 1973), see Appendix III, and Figure 2.3, Stratigraphic Column.

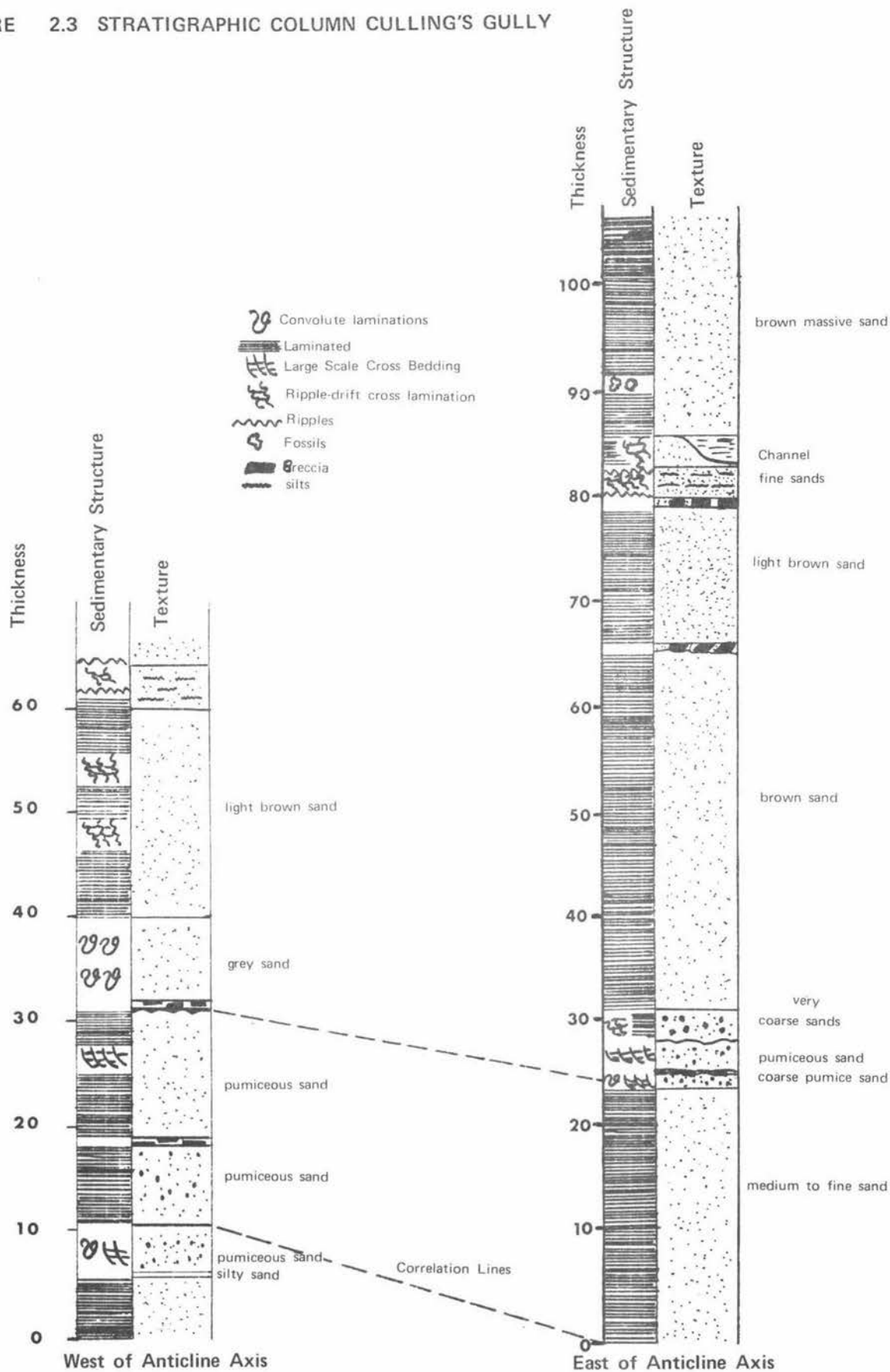
It can be noted at this point, that where bands of siltstone occur, these lend greater stability to the strata against erosion. As observed at the waterfalls at the knick points and at the smaller waterfalls over which the tributaries flow into the main gullies, it is always the more resistant siltstone that is holding these up and preventing further headward gully movement. The unconsolidated pumiceous sand however, is extremely mobile and once exposed is highly erodible.

2.4.4. Development of Topography and Structure

A look at the evolution of the physiography of the study area helps explain its extremely youthful topography. As seen in the previous section, the area is a small part of the South East margin of the Wanganui basin that extended northwards from the Manawatu Gorge along the western side of the Ruahine Range up to the volcanic Plateau and out to the coast. The "sag" in the Ruahine horst at the Manawatu Gorge was originally a strait connecting the Pliocene and Pleistocene sea of the West and East Coast basins.

The main elements of the structure as outlined by Greenall et al (1951), are the Pohangina Fault which strikes parallel to and just east of the Pohangina River downstream from its junction with Coal Creek; the Pohangina syncline which lies immediately to the west of the Pohangina Fault; and the Pohangina anticline which is parallel to the syncline and the axis of which lies just east of Ridge Road. The western side of the syncline merges into the

FIGURE 2.3 STRATIGRAPHIC COLUMN CULLING'S GULLY



eastern wing of the anticline. The axis of the anticline lies between Ridge Road and Beehive Creek and passes to the west of the Pohangina township through the study catchments and then plunges at a low angle to the south.

On the western side of the anticline, the tributaries draining into the Oroua River are less deeply incised than the streams on the shorter eastern flank due to its strongly assymetrical nature. The tributaries on the western side have a considerably longer distance over which to lose the height produced by the uplift, down to the base level of the Oroua River. Beds of this western flank dip gently to the W.N.W. at $2 - 4^{\circ}$, while beds of the steeper eastern flank dip east at 6° near the northern end of the fold in the vicinity of Culling's gullies. (Te Punga, 1954.)

The Pohangina anticline and syncline were formed in the Upper Tertiary when the Kaikoura Orogeny resulted in the slight emergence of the area flanking the Ruahine Range. Fluctuating fluvial and terrestrial conditions followed in the Lower Pleistocene, with the deposition of basal gravels and clays over the Tertiary strata. This was followed by regional tilting to the south west and the establishment of a consequent drainage system on the tilted surface. Remnants of the mature topography that developed on this surface only slightly above base level of the drainage are left as the crests and ridges above the rejuvenated slopes. (Greenall et al, 1951.)

Regional uplift with the rejuvenation of streams and the formation of terraces with differing degrees of adjustment to the new base level by the tributaries followed in the Upper Pleistocene. As observed by Miller (1966), the attainment of maturity is reached earlier in a larger valley or main stream, than in a small valley or tributaries. Thus in recent times there has been adjustment of the streams to a new base level, with the rapid downcutting of tributaries through terraces and mature topography. Where the rejuvenation extends some distance up the tributaries, it ends in a distinct knick. For example, the

side branches in Number 2 Catchment that terminate in waterfalls when joining the main gully have not undergone the rejuvenation that the tributaries in Number 1 gully have experienced.

Thus the extremely youthful topography is a result of rejuvenation of the otherwise maturely dissected anticline of rounded topography and once mature drainage pattern. All the tributaries joining the Pohangina River and Coal Creek further north along the anticline have become deeply incised and tend to end in steep valley heads or in a series of waterfalls.

The development of this two cycle topography has also been aided by the tectonic movement which is still active over the anticline. According to Te Punga (1954), it can be assumed that the folding of the Pohangina anticline began over 20,000 years ago and that there has been an average uplift of about 1 m per 120 years.

However, this downcutting of the valleys and rejuvenation which is still in progress, proceeded in late geologic time with the land covered in dense bush under the current climatic regime. The gradients and slopes that established did so in relation to these prevailing physical conditions and tended towards a high degree of stability. Where these conditions have persisted, so has the valley floor stability, i.e. most of the area until the original bush cover was removed. The readily erodible substrata soon undergoes rapid development of waterfalls and gullying as soon as any of the original physical factors are disturbed, resulting in a secondary readjustment of gradients. This downcutting to the new base level is still active.

In cases where there has been less degrade in geologic time, but later removal of the vegetative cover accompanied with increased runoff, very rapid and severe degrade of the valley floors has resulted.

The terrace remnants on the tops between the two gully systems represent the former height of the rivers and were produced by elevation of the area above base level

to its present height. The presence of a broad high level terrace may help account for the lack of adjustment to base level of some of the tributaries in the area. This is because the gravel and alluvium tread of the terrace is relatively resistant to erosion compared with the unconsolidated sandstone of the underlying strata. Once the streams cut through this veneer, downcutting proceeds exceedingly rapidly. Thus the surfaces of the terraces have been well dissected and the terrace gravels well weathered.

The valley plain terrace that the stream flows over into the Pohangina River has been correlated with Pleistocene fluctuations of climate and sealevel.

* * * * *

2.5 SOILS

2.5.1 General

Continuous automatically recorded soil moisture data was not obtained because of lack of personnel for daily observations and lack of the necessary equipment. Thus there was no way of relating soil moisture variations with rainfall and streamflow variations. Several soil profile pits were dug and described, but apart from this, the only information on the soils of the study area is qualitative, not quantitative.

The soils that cover the study catchments are mainly Pohangina Steepland Soils over much of the area. On the easier country on the tops between the two gullies the soil is Raumai Sandy Loam with Raumai Hill Soils in the south-west corner. The small remnants of terraces are covered with Ohakea Silt Loam (Figure 2.4).

All the soils are formed from the same parent material. Thus the differences between them are basically due to differences in slope, vegetation and microclimate.

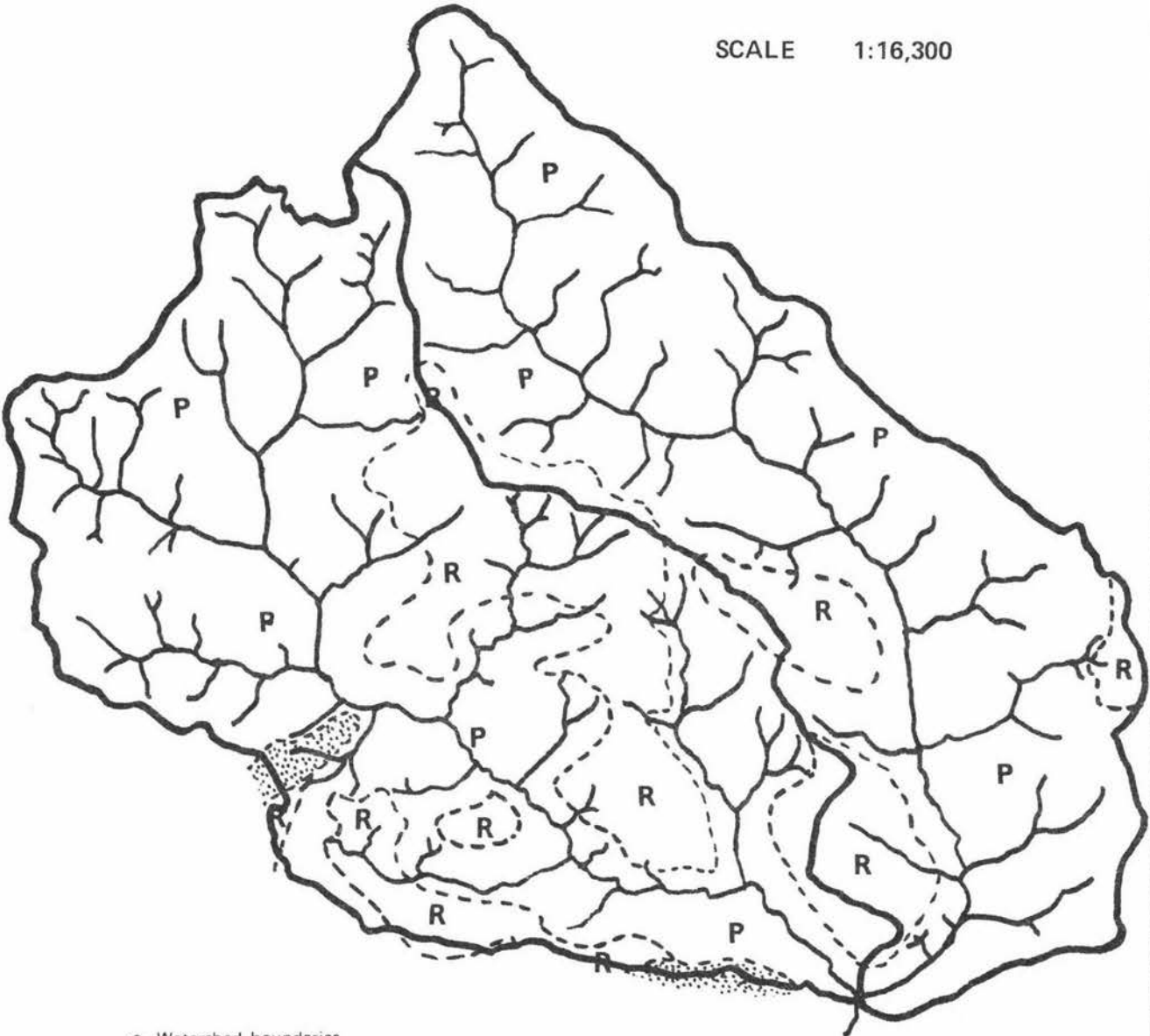
These soils are all included in the Yellow-Grey Earths, (Saunders and Anderson, 1964) and are of medium natural fertility except the Pohangina Steepland soils which are of medium to low fertility (Manawatu Catchment Board Files).




The Pohangina soils are classified under "Yellow-Grey Earths - Intergrades to Central Yellow-Brown Earths, Related Steepland Soils," in the New Zealand Soil Bureau Bulletin Number 26 (1968). Soil Bureau Bulletin Number 5 (1954) includes the Pohangina Sandy Loam under the heading of "Skeletal Soils of the Steep Hillsides".

Thus, because the majority of the soils over the two catchments are officially classified as Steepland Soils, they should be recognized as such. Ross (1971) quotes a number of studies dealing with Steepland Soils, that have demonstrated the erosive nature and inherent

FIGURE 2.4 DISTRIBUTION OF SOILS OVER THE STUDY AREA

SCALE 1:16,300



-  Watershed boundaries
-  Stream Channel
-  Soil Boundary
-  Ohakea Silt Loam
- R** Raumai Soil
- P** Pohangina Soil

instability of this group. The need for halting such practices as removal of protective vegetation by burning and grazing has frequently been stressed, and retirement from farming has often been advocated. The New Zealand Soil Bureau Bulletin Number 26 (1968) describes the soils of hilly and steep lands as having a severe to very severe soil limitation to pastoral use and suggests that the rapidly erodible soils in this category such as the Pohangina soils, are unsuitable for pastoral use.

2.5.2. Description of the Soils of the Study Area

(1) Ohakea Silt Loam

This soil is formed on the terraces and has a slightly compact subsoil with terrace gravels within a short distance of the surface, often less than 1.0 m. According to Saunders and Anderson (1964) these soils originally carried a light cover of scrub as they were too dry for forest growth. This soil occurs on the only part of the study area that would be cultivateable, (were access feasible), and is more fertile and friable than the other soils described.

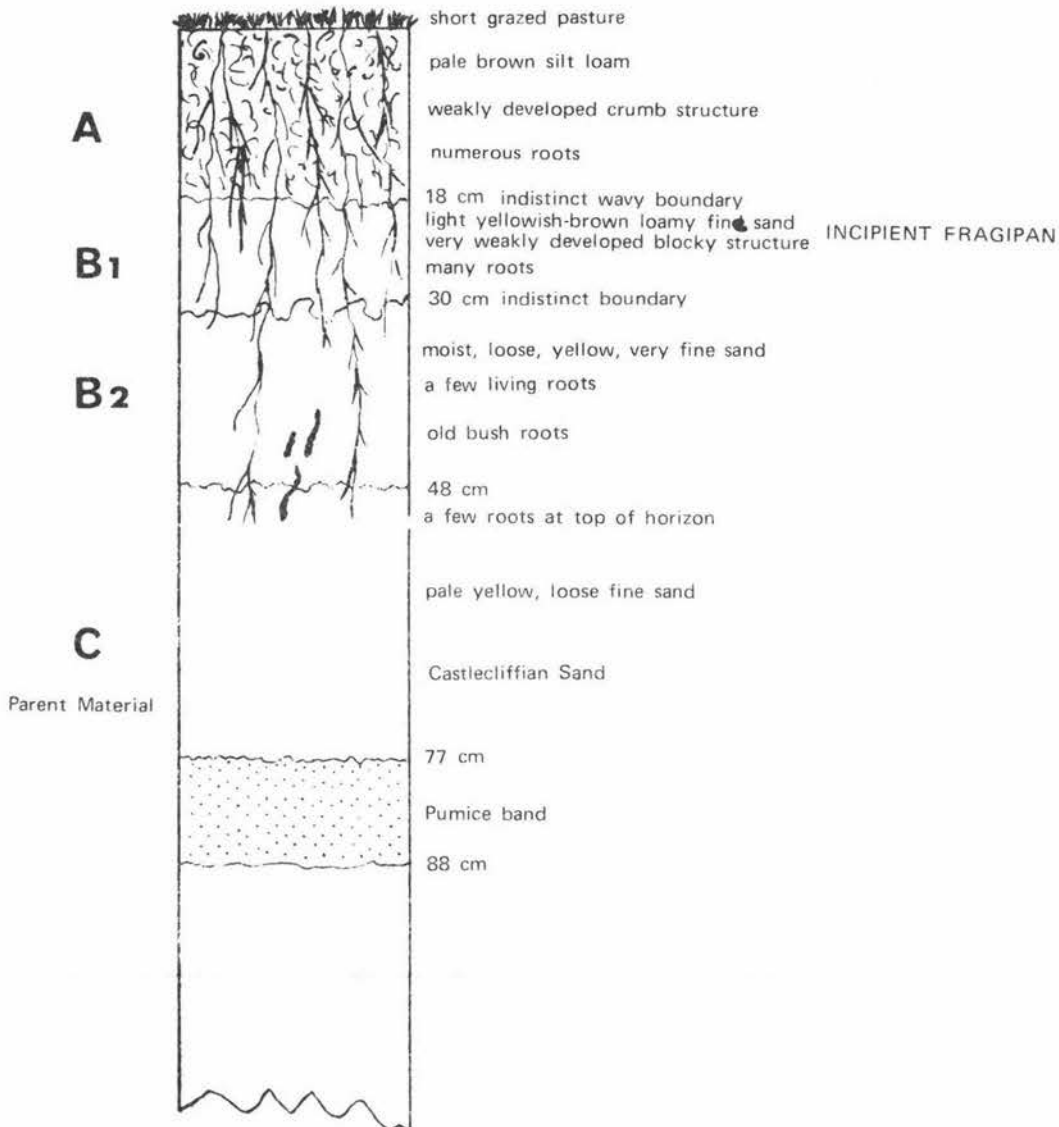
The area of Ohakea Silt Loam is negligible in the study area, (in the order of 4 ha) but important in the surrounding parts of the County.

(2) Raumai Sandy Loam

This is the rolling member of the Raumai Soils with a typical slope range of 6 - 12°. Two profile pits were dug in this soil and are shown in Figures 2.5 and 2.6. For the detailed descriptions of the profiles, see Appendix IV (1) and (2). Plates 2.8 and 2.9 picture the two profile pits; Plate 2.10 shows the rolling nature of the surrounding country.

FIGURE 2.5 RAUMAI SANDY LOAM

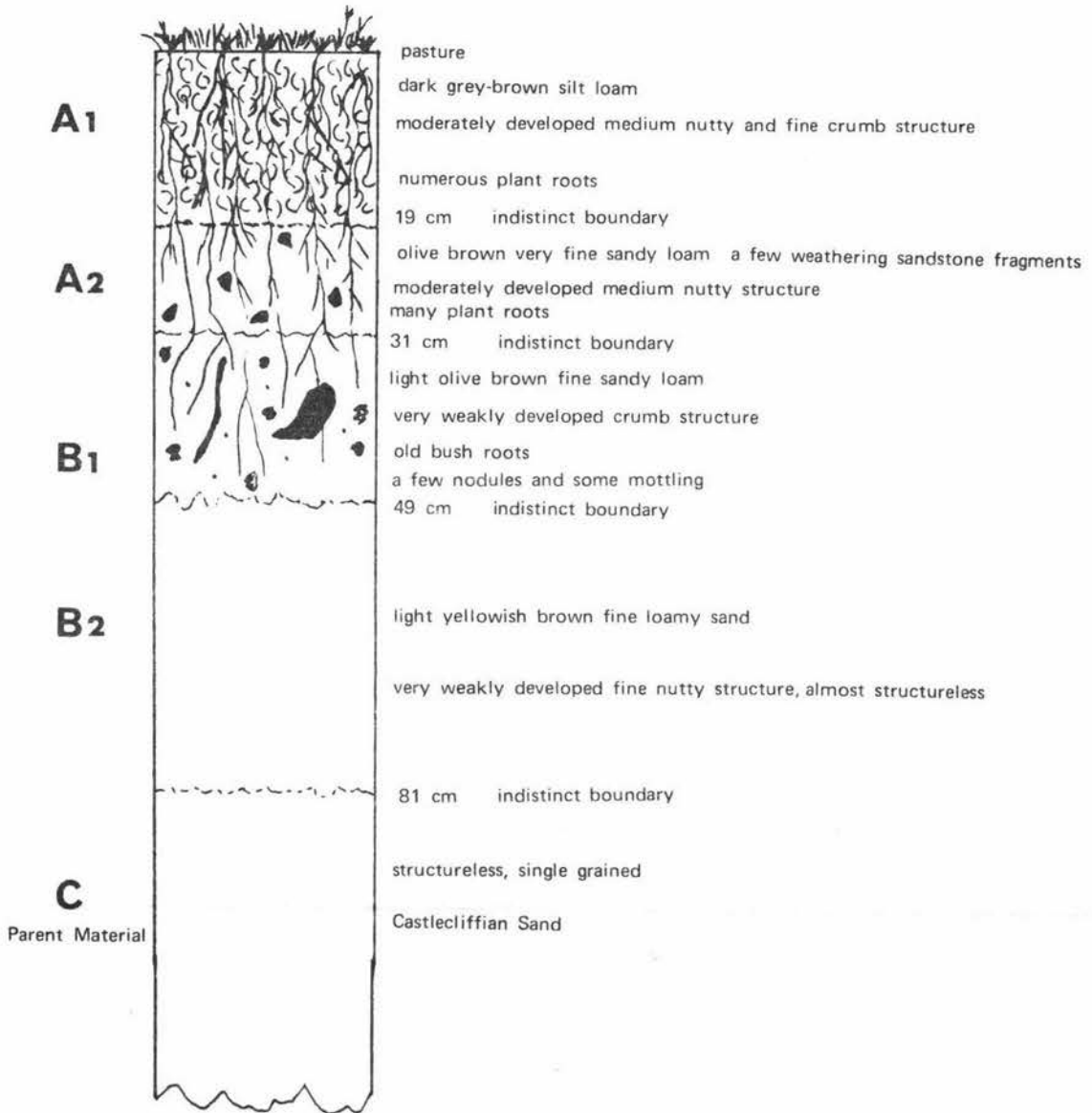
Profile No. 1



- MAIN FEATURES:
- (1) Unconsolidated loose parent material.
 - (2) Influence of original bush cover.
 - (3) Yellow-Brown Earth/Yellow-Grey Earth Intergrade with incipient Y.G.E. fragipan forming in B1 horizon.

FIGURE 2.6 RAUMI SANDY LOAM

Profile No. 2



This profile has developed to a greater extent than the No. 1 profile.



PLATE 2.8

Raumai Sandy Loam Profile Number 1

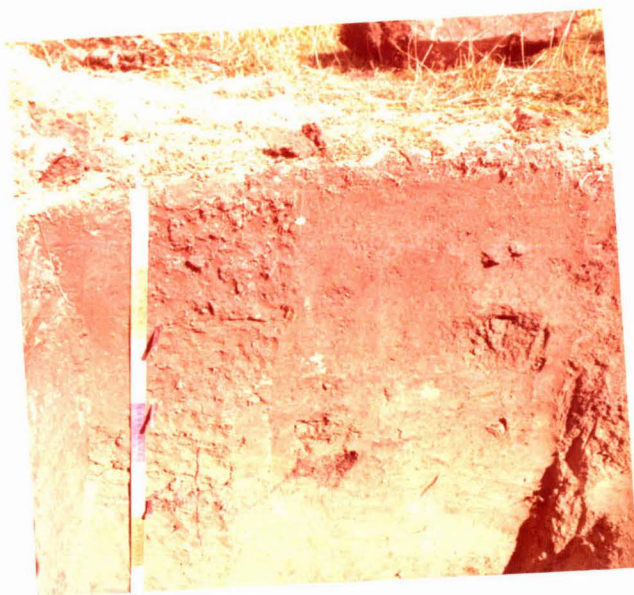


PLATE 2.9

Raumai Sandy Loam Profile Number 2



PLATE 2.10

Rolling Area of Raumai Sandy Loam Soils with Terraces of Ohakea Silt Loam in the Background and Infestation of Thistles in Drier Areas

PLATE 2.11

Colonization of Steep Gully Face by Lupins



Thus the soil is moderately well drained with relatively little erosion because of its rolling nature. The profiles dug in this soil varied, but had a weakly to moderately developed structure with 18 cm of dark grey brown light silt loam over 30 cm of olive brown fine sandy loam grading down to light yellowish brown loamy sand overlying the structureless single grained parent material.

Unpublished information on the Raumai Soils (Rijkse, in press) described the Raumai Sandy Loam as weakly leached and weakly acid; low to very low in citric soluble phosphorus; medium carbon to a depth of 30 cm; medium exchangeable calcium in the topsoil dropping to low values in the subsoil; medium exchangeable magnesium in the topsoil; and high potassium in the topsoil due to topdressing. The soil was described as having a weakly developed soil structure with 15 cm of brown friable sandy loam merging in 13 cm of greyish brown firm fine sandy loam. This overlies olive brown compact loamy sand with orange brown mottlings. It is added that the weakly developed topsoil structure breaks down easily and wind erosion may become a hazard.

However, in the study area under good grazing management keeping an intact vegetative cover, this soil type is not particularly prone to erosion due to its rolling rather than steep nature.

(3) Raumai Sandy Loam (hilly)

This is the Hill Soils member of the Raumai Soils, with a typical slope range of 13 - 23°, i.e. Moderately steep, according to the classification of Taylor and Pohlen (1970).

Like all the Raumai soils, it was developed beneath podocarp-broadleaf forest under 890 - 1140 mm of rain per annum. Greenall et al (1951) report orange mottling and compaction.

As this was not one of the two main soils in the study

area, detailed profile descriptions will not be given. However, the following information was available, (Rijkes, in press).

Raumai hill soils are weakly leached, but base saturation rises to medium values in the lower subsoil. A high Truog figure of the topsoil sampling site is the result of recent topdressing. Generally these soils are low in phosphorus and low phosphate retention values indicate good response to phosphate topdressing.

Exchangeable calcium and magnesium are medium in the upper horizons but fall to low and very low values in the lower subsoil. Exchangeable potassium is low and low reserve potassium values indicate that the soil is likely to respond to potash applications.

The soil profiles are described as variable, depending on whether the site is stable or whether slips have occurred. In the places where slips have occurred, the soil profiles consist of 5 cm of olive brown friable sandy loam with some slight mottling, overlying 13 cm of olive brown firm loamy sand with many mottles over pale brownish grey hard sand with abundant mottling.

In a stable site 18 cm of dark greyish brown friable sandy loam overlies 38 cm of olive brown friable sandy loam. At approximately 60 cm depth this changes to pale olive firm loamy sand with many orange brown mottles. Soil structures are weakly developed in topsoils and upper subsoils, and lower subsoils are structureless.

The soils are moderately well drained except on lower parts of slopes where clay movement from higher situated areas gives heavier subsoil textures. Such areas are infested with rushes and other water tolerant plants.

The Raumai Hill soils are classed as "weakly leached intergrade Yellow-Brown Earths-Yellow-Grey Earths from loose sandstone".

Thus by virtue of their greater slope, these hill soils of the Raumai soils tend to be more prone to erosion

and in need of more intensive conservation measures.

(4) Pohangina Steepland Soils (Pohangina Loamy Sand)

These are the soils that occur most extensively over the study area. They are the steepland soils associated with the Raumai Soils. Parent material is of course similar, and the typical slope range steeper; i.e. classified as "Steep and very steep", over 31° .

Table III shows the comparative range of slopes in each slope group of the three different soils.

TABLE III. SLOPE GROUP TABLE (From Greenall et al 1951)

Soil Type :	Typical Slope Range :	A :	B :	C :	D :	E :
Raumai Sandy Loam	Rolling 6 - 12°	0 - 10°	11- 15°	16- 20°	21- 27°	
Raumai Sandy Loam (hilly)	Moderate- ly Steep 13 - 23°		12- 16°	17- 23°	24- 30°	$31^{\circ}+$
Pohangina Sandy Loam	Steep and very steep over 31°			15- 21°	22- 28°	$29^{\circ}+$

The Pohangina soils originally carried Black Beech forest, but are now extremely susceptible to slipping and gullyng where they have not been retired from farming, or successfully planted in Pinus radiata. Because of

the erosion, the soil profiles would be expected to be very variable. Differences in aspect and slope will also create differences in the resulting soil profile. The drier sites are generally more mottled with more of the Yellow-Grey Earth features - i.e. incipient fragipan in the subsoil and greyer colours.

The two profile pits dug in this soil are shown in Figures 2.7 and 2.8 and on Plates 2.12 and 2.13. A detailed description of the profiles is given in Appendix IV, (3) and (4).

There is a considerable difference between the two profiles, as could be expected, considering the first is under pasture and the second under a reverting pasture cover of manuka, bracken fern and weeds. The profile under pasture exhibited 11 cm of friable fine sandy loam, over 30 cm of firm compacted light olive brown light sandy clay loam - i.e. an incipient fragipan, over 20 cm of yellow friable sandy loam, overlying the loose structureless very fine sand parent material.

The topsoil of the profile under the reverting pasture was a dark brown silt loam with very weakly developed structure, over fine sandy loam, overlying the structureless very fine sand.

Glass (1957) described the Pohangina loamy sand as consisting of 2 - 13 cm of a light brown loamy sand on greyish yellow sand. He mentioned its tendency to revert to manuka in the absence of phosphate dressings.

Further information was available from Rijkes, (in press) which described the Pohangina steepeland soils as moderately leached, moderately acid in the topsoils and weakly acid in the subsoils. They are generally low in organic matter, with low phosphorus levels. C.E.C. is medium in the top 5 cm (organic matter) but low in the subsoil. Calcium is low and magnesium is medium in the A horizon but drops to low and very low values in the subsoil. Soil fertility is reported as especially low

FIGURE 2.7

POHANGINA STEEPLAND SOIL

Profile No. 1

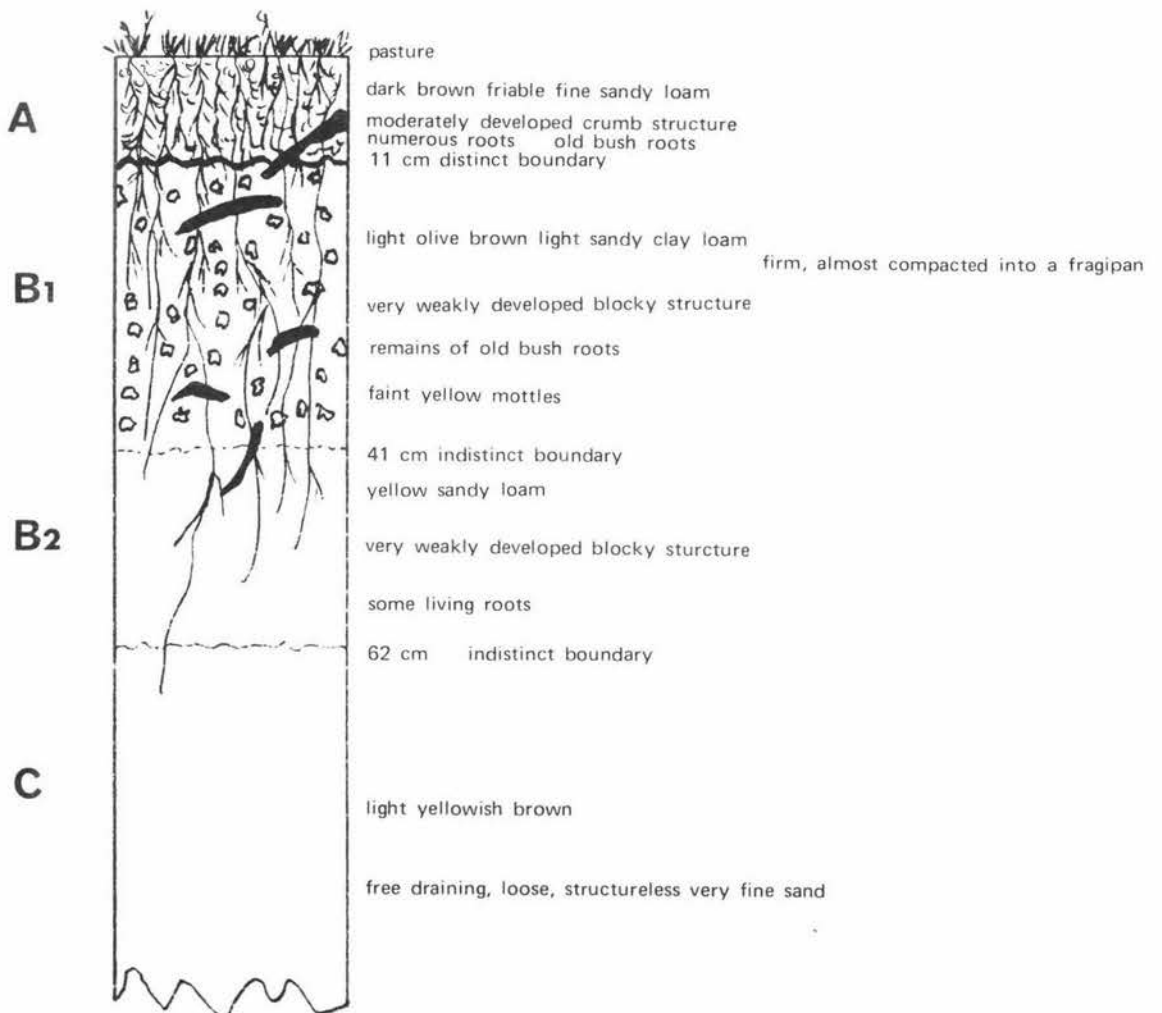


FIGURE 2.8 POHANGINA STEEPLAND SOIL

Profile No. 2

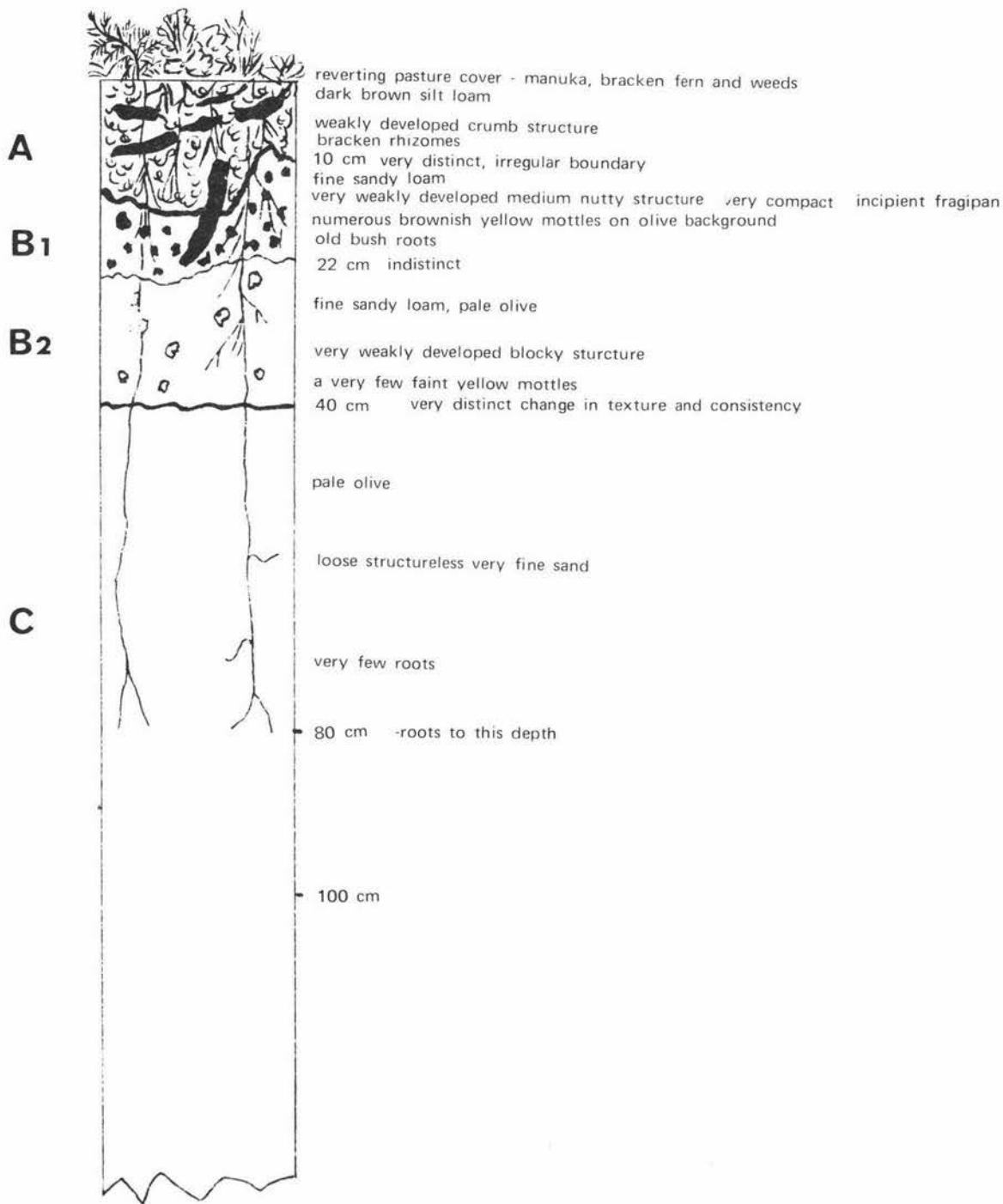




PLATE 2.12

Pohangina Steepland Soil
Profile Number

1

PLATE 2.13

Pohangina Steepland Soil
Profile Number

2



on the spurs and ridges where the former vegetation was Black Beech. Potassium values indicate that these soils are potentially not potassium deficient.

Saunders and Anderson (1964) report high carrying capacities being achieved on these soils with heavy phosphate topdressing and close subdivision, and realise that intensive soil conservation measures will be necessary to prevent increased erosion if these soils continue to be farmed.

Thus, the Pohangina Steepland soils are extremely steep, extremely prone to erosion, and require careful pastoral management if not retirement from farming, allowing regeneration of the original vegetation and scrub, if the occurrence of slips and gullyng is to be decreased.

* * * * *

2.6 VEGETATION

The study catchments were originally covered in Black Beech forest on the crests of ridges and spurs and other generally less fertile areas, and in Podocarp-Broad-leaf forest on the more fertile less steep exposed portions. In between, the Beech forest tended to be invaded by the Podocarps and other mixed forest species.

Black Beech, was thus the major canopy tree over much of the area and small remnants still exist. This canopy was one that allowed a considerable amount of light penetration; therefore the associated species were usually light demanding and drought resistant. Associated species included : mingi-mingis, kohuhu, mapou, lancewood, kowhai, Coprosma spp., and Helichrysum sp., plus epiphytes.

In the Podocarp mixed forest, northern rata, podocarps, especially rimu - and trees such as rewarewa and pukatea, made up the canopy. The subcanopy included species such as tawa, hinau, the maires and titoki. Many epiphytes including climbing ratas, were carried on the larger trees. Smaller shade tolerant trees and shrubs were present beneath the canopy, along with plentiful lianes, especially supplejack, (Wright 1968).

This bush cover was cleared at the turn of the century, except for the less accessible gully sides and very steep slopes, and pasture species sown after burning. The story from here is similar to that on much of New Zealand's poorer hill country following forest removal and burning, see Levy (1949).

The seed mixtures varied, but generally contained ryegrass, crested dogstail, browntop, cocksfoot, danthonia and white clover of uncertain purity and quality. This bush-burn mixture thrived well initially, due to the high fertility of the forest litter and ash. However, the pastures rapidly deteriorated and opened up under a system

of lax grazing accompanied by leaching and lack of replenishment of the soil nutrients. This effect has been re-enacted by Miller and FitzPatrick (1959) at Taita, where immediately after burning, pH and plant nutrient levels were extremely high, but fell off rapidly, leading to rapid deterioration of the pasture.

As soon as the pastures began to open up, the land began to revert to scrub and bracken. Thus when the property was taken over the late Mr. R.J. Culling, (Mr. J. Culling's father) fifty years ago, it was covered mostly in bracken fern.

Improved management, topdressing and oversowing with white clover has now led to a relatively high producing improved pasture on the areas of Raumai Sandy Loam. Poorer hill country pasture reverting to manuka and bracken fern is present on the Pohangina Steepland soils and native bush as well as scrub is regenerating in the gullies and steeper valley sides.

Regenerating native bush species and original remnants include rangiora - hinau, Coprosma spp., wineberry, kawakawa, mahoe, five finger, rewarewa, hangehange and other Neopanax spp. Treeferns are also common.

Small clumps of macrocarpas and pines were established on the gully sides by the late Mr. R.J. Culling. A small number of willows and poplars were also planted.

More recently, (from 1969), a large number of poplars and some willows have been planted in the gully systems as soil conservation measures.

Other exotic species that are also contributing to gully stability, are Acacia sp., tree lucerne, and the ordinary yellow lupin. Plates 2.11 and 2.14 illustrate the colonization of a vertical gully wall by lupins, and young poplar poles planted at the receding head of a side gully, off the main Number 1 gully. The aerial photos (black and whites and infra reds) further serve to illustrate the differences



PLATE 2.14

Young Poplar Poles Planted at the Receding Head of a Tributary
of Number 1 Gully, note the Felled Manuka



PLATE 2.15

Stock Water Dam with Rush Growth and Improved Pasture in the Foreground

in vegetation over the two catchments, (See Chapter 5 where a detailed comparison of the two gully systems is made).

On the damper, often concave slopes and southerly aspects, the pasture is often infested with rushes, while on the drier areas, usually ridges and spurs, convex slopes and northerly aspects, thistle infestation is common. Examples of these are shown in Plates 2.15 and 2.10.

The task of keeping this country clothed with an adequate vegetative cover is of course complicated by the highly erosive nature of the substrata once exposed. As quoted by Greenall and Hamilton (1954), generally the taller, more dense and deeper rooted the vegetation, the greater the protection against erosion.

It is obvious that the original condition that was previously stable under bush is now unstable under pasture. Greenall et al (1951) in the Pohangina Survey indicate that close grazed pasture is less stable than lax grazed pasture which is not as stable as rough grass. In order of increasing stability we can list : bare ground, poor pasture, good pasture, pasture and trees, scrub, bush. Runoff is also affected in this order.

The effects of changing the original bush cover to the present pasture and reverting pasture can be summarized as follows.

Replacement of the forest by pasture has resulted in a loss of rainfall interception by the foliage, meaning that a greater percentage of the rainfall comes into direct contact with the soil, leading to increased erosive losses. It is well documented that even when the soil is covered in scrub, the interception rate is considerably greater than that of pasture- e.g. work carried out at Taita by Aldridge and Jackson (1968) showed that over a 10 month period interception loss under a stand of manuka amounted to 39 percent of the gross rainfall. Here then is good reason for permitting the steeper slopes to revert completely to a manuka cover to decrease the erosive power of the rainfall.

Greenall et al (1951) describe the value of manuka as a soil binding plant as a subject of considerable controversy and make the following conclusions.

- (1) Where a gully is actively degrading by waterfall action or where lateral slipping due to undercutting occurs, it is of little value.
- (2) In gullies as yet not actively eroding its value is probably considerable in as much as it tends to decrease the velocity of water flowing in the gully.
- (3) Steep faces covered with manuka exhibited few recent slipping surfaces. This may point to it being a valuable binding agent on such areas or a method of maintaining a static microclimate on the soil surface.
- (4) On scrub covered areas it acts as a valuable nursery plant for both native and exotic species.

Against these advantages are the disadvantages :

- (1) Loss of grazing area.
- (2) Increased fire hazard.
- (3) Haven for pests, especially opossums.
- (4) Seed source resulting in invasion of open pastures.

The original forest litter provided a "sponge" effect for infiltrating rainfall. With the inferior grass humus layer at the soil surface and the compaction by the soil surface by stock and rainfall, the infiltration capacity of the soil is greatly reduced, leading to increased runoff and leaching out of plant nutrients.

The pasture roots are generally finer and more shallow than the original roots of the forest cover which played a large part in physically holding the soils on the

steep slopes in place, and maintaining a favourable soil structure and biological activity.

For many years after the bush had been removed, the old roots and root channels remained in the soil so that the above effects did not become evident for a long time. With the breakdown of the old bush roots, infilling of the channels and compaction, infiltration capacity was further lessened and the erosive capacity of every rainfall event increased.

Thus, unless a highly productive improved pasture can be maintained, it is probably more beneficial to permit much of the steeper country to revert to a more protective scrub and bush covering.

* * * * *

2.7 EROSION

2.7.1. Erosion Control in the study area

From 1936 on, erosion began to make its presence felt within the Pohangina district in general. In February 1945 the Pohangina County Council drew the attention of the Manawatu Catchment Board to the soil erosion occurring in the county. As this erosion was affecting vital road access, the Council asked for an inspection and advice to assist it in its efforts to alleviate the problem.

In August 1949 there is mention in the Manawatu Catchment Board files of a survey of the whole area in Pohangina County affected by erosion, being carried out by Mr. Greenall of the M.O.W. This resulted in the Pohangina Survey of Greenall et al (1951).

By this time 3:1 and 1:1 subsidies were available for any farmer whose property was threatened by active or incipient erosion. The Manawatu Catchment Board files, however, have no record of any conservation work being done in the study catchments until in Moar's Conservation Plan of 1958 it was planned to install a light steel or galvanized iron flume at the eroding gully head above the top branch of Number 1 gully. After detailed investigations of the site, access for machinery previously thought impossible was found and it was decided to construct a dam there instead. Regulation of runoff by a dam would then eliminate the need for installing a flume at the head of this deep and actively eroding gully.

The headward movement of Culling's gully was a real threat to this paddock on Moar's property and in January 1961 it was proposed that a small clearing in the bush at the head of the gully be thickly planted in poplar poles. Pair planting of poplar poles in the paddock itself was also recommended. By 1962 the flood detention dam had been constructed about 100 m from Culling's boundary.

In July, 1969, there is the first record of Mr. J. Culling applying to the Catchment Board for advice and subsidy for soil conservation work, though elsewhere there is reference to poplar poles being planted in Culling's gully in 1968.

Thus it is only in the last few years that any soil conservation work has been carried out in most of the study area. In winter 1969 under the Pohangina Oroua Catchment Control Scheme, a helicopter drop of plant materials was made into the Number 1 gully and tributaries. This consisted of 180 cattle poles, 4,848 sheep poles, 3,850 stakes, 8 posts, 25 kg barbed wire, and netlon sleeves. The resulting strike from these plantings was excellent despite the following dry season.

The 5 year Conservation Farm Plan for Culling's property from 1970-1974 involved about \$2,540, subsidized at 2 for 1. In the first year of the farm plan, 200 poplar cattle poles were planted with netlon protection up as far as the gully confluence and 420 m of fencing were erected in the flat paddock above this.

Where cattle poles are planted, it is considered essential to keep cattle out of the planted area for at least 12 months after planting and "desirable that they be kept out for much longer", (Holland, 1968). No special precautions are needed for sheep. Cattle were however, observed in the gully in 1971 and 1972.

A number of methods for protecting the newly planted poles have been devised, including stock repellents (Pearse, 1964) and various plastic tree protectors, e.g. Edwards 1967, 1968 and 1969. The netlon sleeve has proved successful, though it still fails to prevent cattle using the poles to rub on, thus damaging the young roots as they form, by causing the pole to move round in the soil.

Fencing to keep cattle out of the gullies has been proposed in the Farm Plan, with sheep only to be grazed in the main tributary of Number 1 gully after heavy planting and fencing off.

In order to lessen the flow of sand from the gullies into the river system in runoff events, a series of debris dams have been proposed for the Number 1 gully. The first of these was constructed in April, 1971, in the bottom reaches of Number 1 gully not very far above the junction of the two catchments, Plate 2.16. This concrete drop structure filled up with sand extremely rapidly, the streambed behind it achieving its new level before the winter was over. This alleviated incipient channel degradation caused by irregularities in the stream, that had been observed prior to the build up of the streambed to the new level.

The second concrete structure was installed in January, 1973, several hundred metres upstream from the first one. By June, aggradation raised the channel to the level of the dam and consisted of supersaturated material of the consistency of quicksand. After the winter this dried out to a solid aggraded sandy surface, Plates 2.18 and 2.19. This represents the deposition of at least 1 m of sand over the area immediately behind the structure, with progressively less depth upstream, illustrating the vast quantities of sediment that are moved down the gully in a relatively short time.

At the Te Awa Research area and on Tews Demonstration Farm, both with similar gully problems to Culling's gullies, pole and netting type debris dams were initially used in gully control work. These however were prone to scouring out in the stream bed below the dam accompanied by rapid downcutting to form a fall below the structure. This tended to undermine the whole dam and cause a washout. Thus constant attention was needed to maintain this type of structure. The concrete drop structures are initially more expensive but require considerably less maintenance.

A considerable amount of work has been carried out by various workers on the use of different sorts of dams and structures in gully and runoff control, (Borlase 1967; Simons and Spence 1968; Falconer 1969).

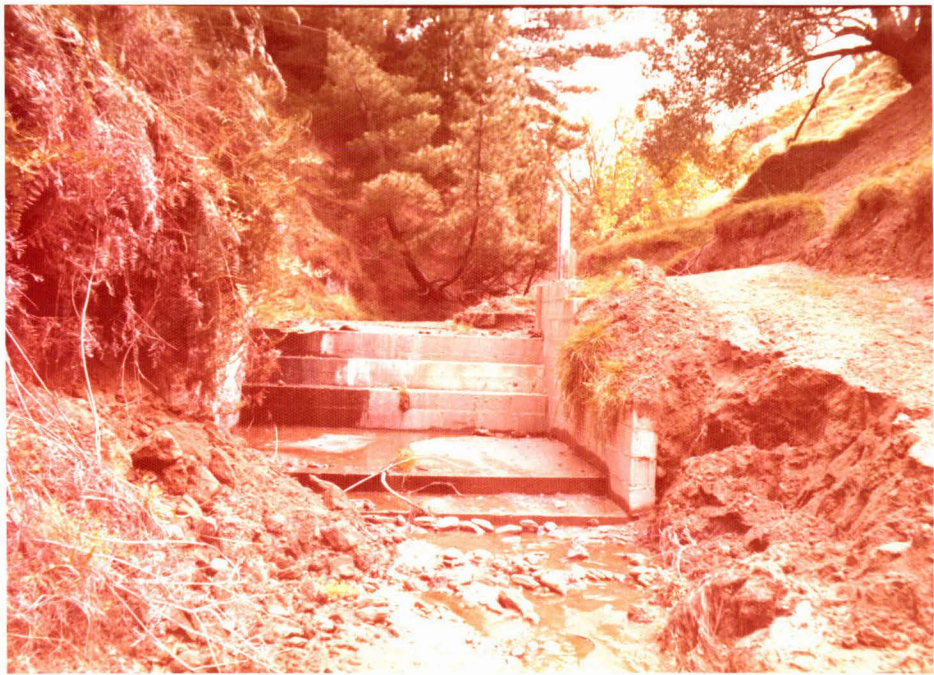


PLATE 2.16

Concrete Dam Installed in Number 1 Gully April, 1971 Showing New Slip in Foreground



PLATE 2.17

Undercutting and Slipping on Farm Track April, 1972.



PLATE 2.18

Concrete Dam Installed in Number 1 Gully January, 1973.



PLATE 2.19

Wide Flat Aggraded Channel Behind this Dam Showing the Huge Build-up of Sand Within 10 Months

Similarly, much has been done relating to the use of poplars and other vegetation in erosion control, both in New Zealand and overseas, (Van Kraayenoord, 1966; U.S.D.A., 1964; Edminster and May, 1951).

At the gully head on Moar's property there is a record of 1090 m of gorge fencing having been completed by April 1971 and a proposal to plant 200 poplar and willow sheep poles between the gully head and the retirement fence. The number of poles was in fact doubled as by August 1971 the erosion was increasingly more active.

The conservation farm plans for the study catchments also include proposals for scrubcutting, and this has been carried out in a number of places, both on the Raumai soils and on the Pohangina Steepland soils. Plate 2.14 shows the anomaly of poplar pole planting to arrest headward gully movement in a tributary of the Number 1 gully, accompanied by felled manuka. The standing manuka caused less shading effect and less loss of pasture than the felled manuka. Also, the root systems contributed to the mechanical binding of the soil and substrata.

Tractor access to the easy block between the two gullies was put in during winter 1971 at a grade of about 1 in 5. Protection planting along the track was carried out at the same time with 200 poplar cattle poles with netlon sleeves. The following summer, slipping and slumping and undercutting of the track (Plate 2.17 was severe, but by the end of 1972, this situation had improved slightly. However, as the poplars increase in size and if a grass cover on the steep slopes can be established, this erosion hazard should be alleviated to a large extent.

Sheep and cattle tracking down the steep slope to the top of the first concrete dam from the track was the cause of some of the damage and minor slips associated with the new track before it became consolidated. One slip from this area was the cause of a remarkably high sediment yield in the measured flood flow from Number 2

catchment during the winter of 1972.

Cattle damage was also observed at other points in the gully systems during the winter of 1972. However, until more of the fencing programme is completed, it is difficult to keep cattle out of the gullies if they are to have access to the easier country between the two gully systems.

The dissected nature of the two catchments makes separation of sunny faces from shady faces an impossible task, requiring a much greater degree of subdivision than is feasible. This practice of separating sunny and shady faces greatly facilitated management at Te Awa where the sunny faces then outproduced the shady faces in the winter and vice versa in the summer.

It can thus be concluded that retiring the gullies from stock altogether, and additional planting along the streams will ultimately be the only answer. Further concrete structures may be necessary if the vegetation by itself cannot sufficiently reduce the sediment yields of the gullies in flood events. Farm forestry would be an alternative solution. The former method of debris dams and extensive planting up of the gully bottoms has been successful in the Te Awa gullies and in Tew's (McDonald's) gullies at the Pohangina township end of Finnis Road. The latter is showing success in Moars' gullies on the right hand side of Finnis Road driving up towards Ridge Road.

2.7.2. Types of Erosion

The dominant erosion over the Pohangina County as recorded by Greenall et al (1951) in the Pohangina Survey, was slumping, sheetwash and gullyng. The New Zealand Soil Bureau Bulletin No. 5 (1954) mentions the danger of gully erosion on the Pohangina Sandy Loam soil, and the fact that parts were already deeply gullied and that pastures tended to revert to manuka. Soil Bureau Bulletin 26 (1968) also describes the chief farming problem on the

Pohangina soils as "instability" due in part to the effects of replacing forest with grass.

About 70 percent of the study area is steep to very steep with a high potential for erosion, falling into Class VII of the Land Capability Classification Scheme. 20 percent i.e. the gorges, would fall into Class VIII. The canyon gullying is described as being so severe that much of the Class VIII land would be best used for forestry, (M.C.B. files).

Note: Greenall et al (1951) in the Pohangina Survey and Greenall and Hamilton (1954), use slightly different Land Capability Classes, (Appendix VI). Class V in their classification, corresponds to the conventional Class VIII of the Land Use Capability Survey Handbook (1969)

The basic types of erosion present in the study area can be broken up into mass movements varying from shallow to deep and gullying.

Surface slipping is the most common form of mass movement. This is most common on the long steep slopes especially where the vegetative cover is inadequate and under conditions of moisture saturation in spring and winter. High intensity summer storms may also create conditions for soil slip and flow movements.

It was observed from the sequential aerial photographs, that slips are not nearly as common as they were in the 1940s, (see Chapter 5). Many of the old slipped faces in both catchments are now healed over. This is due in part to the improved pasture and management over the last 25 years. Aerial topdressing and oversowing does much to alleviate slipping. Also the planting of cattle poles at intervals in the zones where the slipping occurs and is likely to occur provides good protection.

The sunny northerly faces generally suffer more from slips than the colder southerly faces, probably due

to higher stock concentrations in the months when the soil is saturated.

Some slips have also occurred where gullying has caused undercutting, and off the steep gully sides. Plate 2.20 shows a badly slipped gully side with newly planted poplar poles finding difficulty in establishing due to the continual movement of the face.

Once slips of any description have occurred exposing the substrata, this leaves the unconsolidated sand susceptible to sheetwash and rilling with the development of incipient gullying if revegetation does not take place. Thus gullied slips result.

Small slips were observed falling from the sides and tops of the Number 1 gully during the winter of 1972 when the ground was saturated with moisture after heavy rain. Examples of these occurred above the first concrete dam in Number 1 Gully. Plate 2.16 shows the debris from a small slip directly in front of the dam.

Similar phenomena were also observed on a smaller scale in the dry summer months, when the dry sand, lacking any sort of cohesion or structure is prone to drop into the gully if sufficiently undermined and then disturbed, e.g. by stock.

Localized miniature mudflows were observed at the peak of the flood in March, 1972. One of such originated above the concrete dam in Number 1 gully, from the unconsolidated material on the new farm track. In this case there was enough clay from the topsoil to aid lubrication, a steep slope and abundant water supply. Such flows, however, would only occur during flood events and would not be very common.

Gully erosion is of course the most spectacular form of erosion in the study area. As previously mentioned, the entire Number 1 stream is severely gullied up as far as the "knick point", with headward gully movement extending up most of the tributaries and above the waterfall. Number 2 catchment only suffers severe



PLATE 2.20

New Poplar Poles Planted
on Active Slip

PLATE 2.21

Degraded Streambed in Number
1 Gully Showing Original Fence-
line Suspended in the Air



gullying for a short distance below the "knick point." By volume of material displaced and contributed to the drainage system, gullying dwarfs slip and flow erosion. Gully erosion is a hazard with regard to stock losses and greatly increases fence maintenance costs. Plate 2.21 shows the original fence across Number 1 gully suspended 3 m above the ground with the degrade of the gully over the years. Internal farm access is complicated by the deep canyon gullies between the areas of easier country. Gullies also induce slipping and slope regrade.

Associated with the slope regrade in the gully bottoms is the alternating aggradation and degradation of the streambed. Banks of sand may be built up to 1.5 m high in one flood event as flood levels drop, and subsequently cut down and removed in the next flood flow. This action caused silting up of the flood level recorder installed in the Number 1 Gully in each flood, thus preventing its proper functioning. It also caused changes in the channel which meant that the dry weather flow in Number 1 gully and the smaller flows from rainfall events no longer flowed in the vicinity of the recorder, reducing its usefulness to zero. This displaced material gradually finds its way down into the Pohangina River and contributes to the sediment load of the Manawatu River.

Greenall et al (1951) divide the gully erosion into two distinct phases. Firstly, the primary adjustment at a very accelerated rate, of the former drainage pattern to the new base level, causing severe canyoning; secondly, the smaller readjustments of the partially adjusted valley floors to the present existing conditions of runoff, gradient and supply of waste.

Waterfall erosion, or the retreat of waterfalls at the gully heads and in the tributaries is another facet of gully erosion. Plate 2.3 shows the erosion debris at the foot of the large waterfall in Number 1 gully. At the bottom of the waterfalls there is usually a plunge pool which is continuously scoured out. If the lip of

the waterfall is relatively resistant (e.g. a siltstone band between the more highly erodible sandstone and pumice) undermining from the bottom, causes the resultant retreat of the lip of the waterfall. Fluming the water away from the bottom of the waterfall has been used in such circumstances in other parts of the district to prevent this undercutting. When the resistant strata holding up the waterfall finally gives way headward gully movement also advances rapidly.

Serious undercutting is taking place along the length of the Number 1 gully. When the material collapsing from the sides of the gully collects in the gully bottom, the loose material is readily removed in runoff events exposing the toe of such slips to further undercutting and collapse.

In the summer when the exposed unconsolidated sandy substrata has dried out, it is easily dislodged by the wind (Bisal and Hsien, 1966) and thin layers are continuously removed. This in turn exposes the next layer to the action of the wind. Although not a major form of erosion or source of sediment, wind erosion nevertheless contributes to the problem of gullying in the two catchments.

Glass (1957) observes that it was established by the Pohangina Survey of Greenall et al (1951) that there were three basic causes of the severe erosion prevalent in the Pohangina district. These were, the geological nature of the area - i.e. the unconsolidated sand; the rapid change from a dense forest vegetation to one of generally poor pasture; and the failure through lack of knowledge to adjust the landuse to this combination of conditions.

A fourth basic cause that can be added to this list, lies in the nature of sudden intense climatic events that occur at random over the area.

2.8 AGRICULTURE AND MANAGEMENT HISTORY

2.8.1. History

The study area is part of the Te Ahuaturanga land block which was bought from the Maoris in 1864, (Buick, 1903). It falls into the Settlement block of the Pohangina Farm Homestead Association taken over in 1892, (Wright, 1968). Thus it was only after all the available lowland of the Manawatu had been taken up that the settlers were forced out into the surrounding hilly districts. Unaware of the highly erodible nature of the substrata on the Pohangina anticline, they gradually cleared the dense bush previously unsettled by the Maoris. As far as can be ascertained, the whole area was relatively stable prior to settlement. Colenso mentioned the Pohangina district in his early writings, (McCaw, 1971) describing the river as difficult to navigate and the surrounding hills steep and the valley full of gorges. There was very little life along the river, only one or two very small Maori villages.

By 1900 most of the readily accessible forest had been cleared and burnt and by the early 1900s the pastures were already beginning to deteriorate as the induced fertility of the burn declined. There are records of heavy flooding over the district in 1897 and 1902, (Wright, 1968). These floods would have been a result of the greatly increased runoff from the new pasture vegetation coupled with storms of unusual severity. However, they occurred at a time when the land was ill prepared to deal with the excessive runoff.

By the time the lower part of the study area was taken over by the late R.J. Culling in the early 1920s, it was almost completely covered in fern and secondary growth. Cutting, burning and heavy stocking in an endeavour to restore the country to pasture was carried out at a time when the stumps and roots of the original forest

were decaying. By the mid 1930s (as in most of the surrounding district), the current economic depression, the reversion to scrub following further deterioration of the pastures and the increasing incidence of slips and gully erosion were the major problems. Prior to the storm of February, 1936, the gully erosion and slips had been more intermittent in nature, but from this date onwards the mistakes made in earlier years were only too apparent in the severe accelerated gullying occurring over the whole county. As stated by Greenall et al (1951), "It is apparent that a physical setup previously stable under bush is now unstable under grass."

2.8.2. Present Agriculture and Management

As previously pointed out, the study catchments are not farmed as a unit, but are divided up into two properties with the margins of the two watersheds included in two further properties. This complicates management of each catchment as a unit. Also the lower part of the study area farmed by Mr. J. Culling is farmed in conjunction with a 80 ha block at the top of Finnis Road. The upper part of the study area, owned by Mr. W.M. Stewart is run in conjunction with other properties near Te Awa and Kimbolton. About 900 - 1000 ewes and some 25 cattle are wintered on the lower part of the study area. In the spring of 1972, 400 ewes were lambed on the block and then 650 hoggets run over the summer. Cheviot rams are being used at present with the aim of running all Perendales in three years time. Lambing percentage is estimated at about 95 percent. Sheep losses in the gullies are relatively low at 1 percent, but cattle losses for 1972 were placed at 4 - 8 percent.

Fencing and soil conservation planting are subsidized by the Catchment Board. See Conservation Farm Plan No. 59, (M.C.B. Files) for record of future proposals for management of the gullies.

About 10 tonnes of fertilizer are applied each year and some oversowing of clover is carried out. Plate 2.15 illustrates the improved pasture that is present over much of the Raumai Soils area between the two gullies and the stock water dam which was installed in 1962.

Management is thus complicated by the adverse effects of the erosion in the following ways.

Where slipping has occurred and on the badly slipped steeper gully faces, increased scrub invasion has decreased the amount of pasture available for stock, and necessitates periodic cutting at considerable effort and expense where practical. Plate 2.22 shows cutover scrub above Number 1 gully.

Similarly, increased time and expense are required to maintain the fences in the gullies and on slopes subject to slipping, as shown in Plate 2.21.

The vertical gully faces and steep access to the gully floors, have led to increased stock losses, especially with cattle.

Access to the easier blocks of country is complicated by the dividing gullies, and the farm tracks are difficult to maintain due to frequent slipping and incipient gully-ing.

Thus it can be suggested that, were the properties making up the major part of the study area not farmed in conjunction with other blocks, the magnitude of the gully erosion problem would make them depressingly uneconomic ventures.

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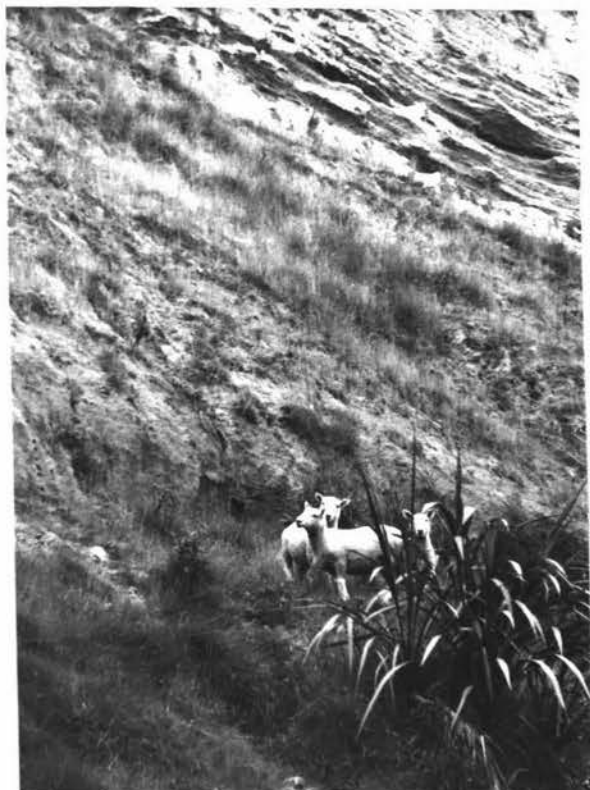
PLATE 2.22

Cut-over Scrub above
No. 1 Gully, showing
incipient Rilling and
Gullying.



PLATE 2.23

Sheep Grazing on the
Steep Exposed Gully
Faces.



CHAPTER THREE

LITERATURE REVIEW3.1 FLOW AND SEDIMENT MEASUREMENTS AND OTHER FACTORS
AFFECTING EROSION3.1.1. Analysis of Stream Flows

There is a considerable amount of literature dealing with streamflow measurement and analysis. Most of it, however, deals with river catchments and large flows as opposed to farm-sized catchments and flows less than 500 l/min. There is evidence in the literature that small streams behave differently from large streams. Lewis (1966) presents data illustrating that the width, depth and velocity of some small streams adjust to small discharges in a different manner than do larger streams. He shows that different equations must be derived to illustrate the relationships among width, depth, and velocities for small flows.

Also, most of the methods incorporate the results of recorded data over a relatively long term. It is stressed throughout the literature that data must be observed over a reasonably long period to be of any use in hydrological studies- e.g. Toebes and Neef (1962). Boughton and McKerchar (1968) demonstrate possible errors that can arise when short records are used to estimate monthly means of flows. Where records are of insufficient length to obtain extreme values and critical sequences required for the design of water-resource system components, methods for generating synthetic records have been proposed by various workers including Pearson (1968).

A number of different methods have been used for measuring time of flow. Radioactive tracers have been utilized with a high degree of success (Pilgrim 1966a;

Straub et al 1958), as have chemicals such as salts, (Calkins and Dunne 1970; Straub et al 1958) and various dyes (Buchanan 1964; Straub et al 1958). Tribble, Straub et al 1958). Tribble, (1951) observes that coloured dyes are simple and rapid, but depend upon ones ability to observe the beginning and end of the colouring material. He considered the salt velocity method the most accurate and practical for measuring the rate of flow in small channels. Floats, according to Tribble (1951) are believed to be very inaccurate. Current meters are an effective method of measuring flow in large channels, but impossible to use in small channels. The pitot tube, although accurate for laboratory work is limited by turbulent flow.

Some of the alternatives available with respect to gauging structures suitable for small experimental basins are outlined by Smith and Lavis (1969). They describe site restrictions of slope and access in conjunction with the structures considered. Taylor (1959) describes the design, construction and operation of a flow meter for measuring low flows. A velocity head rod for measuring stream flow is described by Wilm and Storey (1944), and Drost (1963). Drost (1966) found the flume weir combination a solution to measuring low flows with a high degree of accuracy. Smoot and Buchanan (1968) used an instrument that recorded both cumulative rainfall and flood stages in small drainage basins. This water stage and rainfall dual recorder gave continuous automatic records between visits that could be 6 - 8 weeks apart in the event of no floods occurring.

A number of minimum and maximum water recording devices are available, (Kelly 1968; Dyer 1970; Grant 1962). These include the float and ratchet type, the cup type and soluble paint types. Grant describes the float and ratchet type as overall unsatisfactory, and the cup type as very satisfactory as long as the neoprene cups have water tight seals with the cable.

Gonzalez (1969) discusses the special problems associated with determining the total amount of water passing a gauging station in streams with sand channels.

These are subject to changes in roughness and to scour and fill. Thus weirs are often necessary to stabilize the stage discharge relation if automatic recorders are to be installed.

Blake (1971) quotes work that has shown that low flows are influenced by the geological characteristics of the catchment rather than the surface characteristics. Flow is, after all, an integrated expression of a catchment's condition. Taylor (1967) stresses the importance of geomorphology as a factor influencing stream flow. He found catchment dimensions rather than climatic factors to be critical for predicting flow regimes.

Regression equations utilizing a number of morphometric variables have been used for correlating discharge parameters. As described by Eiselstein (1965) there are an infinite number of interacting variables which influence the hydrologic characteristics of a catchment. He advocates the use of multivariate techniques such as factor analysis to consider these variables in the method known as area stream factor correlation. Such methods are, however, only possible where long term records of a large number of variables are available. Thomas and Benson (1970) also estimated streamflow characteristics using multiple regression analysis to develop the relations between streamflow and drainage basin characteristics. Hedman (1970) correlated mean annual runoff with channel geometry. Skurlow (1960) made use of nomograms derived from standard formulae such as Mannings formula for estimating measures of rainfall intensity, maximum discharge, time of concentration and velocity of flow.

In all these methods appropriate values of the different parameters have to be determined for the particular locality. Skurlow (1960) advocates the use of the method of rainfall and runoff estimation as recommended by the Australian Stormwater Standards Committee especially where accurate data for other methods of calculating design rainfall intensity are not available.

Hydrograph analysis methods and base-flow analysis methods are all commonly used in New Zealand (Toebe 1962a; 1962b; 1962c; M.O.W. 1969). However, any water balance studies where runoff, interflow, baseflow and changes in storage are needed to be measured, require a considerable amount of data to have been collected. As observed by Blake (1971), the varied physiography and financial restrictions within New Zealand, limit ideal data at best to short term records in the order of five years. For long term records, modeling techniques will continue to have to be relied on. Burton (1966) points out that a period of up to five years is generally necessary to iron out any problems in hydrologic experiments.

3.1.2 Flood Flow Characteristics and Measurement

Considerable data and experience have been collected in the field of flood data, (Benham, 1950; 1951; Schnackenberg, 1951; Dick and Darwin, 1954; de Leon 1963; Raudkivi, 1963; and Henderson and Wooding, 1964).

Flood estimation methods are reviewed by Pilgrim (1966b). Most involve the selection of a design rainfall, or else are empirical formulae. The unit hydrograph method is generally recognized as the best available method for larger catchments. For small catchments the design hydrograph type of procedure is possibly the best method. Runoff routing methods of flood estimation, he considers of limited application to small catchments.

The standard procedure for estimating flood discharges in New Zealand is given in the M.O.W. Technical Memorandum No. 61.

Probable maximum floods in an area can be estimated from probable maximum precipitation data. Wiesner (1968) outlines the method used to determine the probable maximum precipitation in any catchment in any country using the United States maximum depth, duration, area data for

short duration, small area convergent type storms. This estimate is useful in the design of flood and sediment control structures.

Benson (1962a) reviews the methods for evaluating the occurrence of floods and outlines the various characteristics influencing their occurrence, (1962b). These include topography and such characteristics as drainage, slope and areal factors as well as meteorological characteristics such as rainfall and temperature. Because morphological characteristics influence flood regimes, various morphometric and photogrammetric techniques (further discussed in Section 3.3) can be used in planning and predicting flood events.

Ross (1921) used simple morphometric techniques to draw time contour lines on a plan of catchment area. From this plan he could calculate the rate of flow at the discharge point in the catchment. Firmin (1968) used photogrammetric procedures in planning flood control projects. Burgess (1970) discusses the use of airphotos as an aid to flood studies. Photos taken at flood peaks are rare and much detail is submerged under water. Special post-flood photography is usually uneconomic. Much information, however, can be produced by photos taken under non-flood conditions and various indications of past floods can be identified.

Thus floods can be evaluated to a certain degree from aerial photographs.

3.1.3. Stream Sediment Loads.

(1) Sediment Collection and Analysis.

Methods for collection and analysis of water samples are outlined by a number of authorities including Rainwater and Thatcher (1960), and the standard procedures carried out by the M.O.W., (Hopkins, 1962a). These deal mainly with rivers where sampling is done at a number of depths along a cross-section. Hopkins, (1962a) in The

Handbook of Hydrological Procedures, Suspended Sediment Sampling, outlines the standard method used in New Zealand for sampling suspended sediment and analyzing the samples. Further information is given by Hopkins (1962b). Instantaneous equivalent erosion rate at the time of sampling can be obtained by the method used by the Manawatu Catchment Board (M.C.B. Files). Tables for converting the suspended sediment concentrations into weight of material eroded from a catchment are available.

Witzigman (1962) discusses several devices that obtain automatic records of suspended sediment discharge in streams. Methods for rapid determination of concentration and particle size of the samples are also discussed. These include the turbidimetric method for suspended sediment analysis and electronic sensing of sediment.

Kunkle and Comer (1901) used the turbidity method to measure sediment concentrations in the 16 - 6, 366 mg per L range. Graphs of turbidity versus concentration could be constructed and the sediment concentration read off for future turbidity measurements.

Tracer methods have also been utilized for measuring sediment and sand transport in rivers, (Crickmore, 1967). Methods such as sediment traps have also been used for measuring total sediment yield from watersheds, (Brown et al 1970). Pumping samplers have been devised to facilitate the construction of more detailed sediment rating curves for storm events, (Walling and Teed, 1971). Various filters for sampling sediment have been developed (Blocker and Bower 1963) for automatic measuring methods. Correlations between the composition and quantity of suspended solids can be made and were found by Engelen (1968) to be directly related to the velocity of flow.

Thus suspended sediment may be determined by its optical properties through light absorption and scattering methods, by its physical properties of particle range, filtrability and settling, and by chemical properties through inorganic and organic methods of analysis, as

described by Baalsrud and Henriksen (1964). Recent papers on erosion and sedimentation processes are listed by Anderson (1967).

Provided daily mean discharges are available, a flow duration-sediment rating curve can be constructed. Suspended sediment discharge can be obtained from the sediment rating curve. Direct calculation of sediment yields can be made programming a computer with information incorporating the sediment rating equations, as described by Fraser (1965).

Practical problems involved in analysing the samples include the amount of manpower and laboratory space required for a large number of samples. Hamilton (1970) describes a rapid method for determining the dry weight of silt in runoff suspensions based on the specific gravity of the particles in a constant volume of suspension. His method is as accurate as the gravimetric method of determination and requires far less time, manpower and laboratory space.

Although sediment discharges are used to determine the extent of catchment erosion, they are limited by the difficulty of measuring the total sediment discharge for a particular point in time. Suspended sediment data is available for a number of catchments, (Fraser, 1965; M.O.W. 1966) but there is no satisfactory ready way of measuring bed-load transport, (Jones and Howie, 1970). Lane and Borland (1951) also stated that it was difficult to measure total sediment load because most sampling methods can only measure the suspended sediment, and not the bed-load as well. Numerous factors are involved in the estimation of bed-load and so it is difficult to draw up rules or formulae which will give quantitative answers to all cases.

McPherson (1971) using a bed-load sampler, still found that accurate determination of bed-load discharge was difficult. Bed-load movement was restricted to a

relatively short time span with most of it associated with the maximum flood of the season.

Campbell (1962b) describes six separate ways in which the collection and study of data is being developed with the object of evolving suspended sediment measurements as an indicator of catchment condition. A number of workers quoted by Blake (1971) have used runoff plots to determine overland sediment movement and for measuring soil loss and erosion, e.g. Hayward (1968, 1969, 1971). In this last paper, it is concluded that the runoff plot method is not suited to erosion research in hill and high country and will have limited usefulness elsewhere, for the New Zealand situation. Burton (1966) also points out that the results from runoff plots can not be directly extrapolated to a large catchment where the routing effects of channel storage completely mask the overland flow effects measured on the plots.

A number of studies, including that of Brush et al (1962) have been made using mathematical models.

(2) Characteristics of Sediment Production

Various studies dealing with the properties of flowing sediment have been made, e.g. Bruk (1962), who concluded that no rational theory of sediment transport can be developed without a solid knowledge of the properties of granular materials in sheer flow.

Accurate determinations of bed-load also require measurements of channel characteristics such as width, and mean depth. Leopold and Maddock (1953) and Leopold (1953) looked at the influence of channel slope on velocity of flow. The commonly observed decrease in slope downstream is widely held to be associated with a decrease in velocity in the same direction, but according to Dury (1955), the opposite is true. Observations show that mean velocity tends to increase downstream despite the lessening of slope. It may well be suggested that mean velocity is

not the most significant value in the shaping of the profile.

Leopold and Maddock (1953) also studied the quantitative relationships between depth, width, velocity and suspended sediment load, finding that for a given river cross-section, they vary as simple power functions of discharge. For a given width of channel at a given discharge, an increase in suspended sediment requires an increase in velocity and a reduction in depth. Thus a rising flood is marked by deposition in the bed.

The different modes of transport and the changes to be expected in bed profile with varying transport rates are described by Sutherland (1969). He concludes that the available techniques for predicting sediment discharge in alluvial channels can only give rough estimates of true discharge.

A number of workers including Wilcock (1970) have investigated the relations between bed-load transport and channel shape. Mapes (1969) observes that accurate determinations of bed-load require measurements of channel width, mean depth, mean velocity, temperature, suspended sediment discharge and particle size both of the bed material and the suspended sediment. Such data is however generally not available for most streams.

McGuinness et al (1971) found that sediment yield measured from small one and two acre agricultural watersheds was largely a function of rainfall energy, rainfall intensity and cover characteristics. From a larger catchment (6,000 square miles) the suspended sediment yield was primarily a function of the transport capacity of the streamflow. Thus the size factor certainly has a major effect on the pattern of sediment yield.

Roehl (1962) attempted to correlate sediment delivery ratios (the percentage relationship between annual sediment yields at a specified location in a watershed and the annual gross erosion above that point)

with a number of morphological factors. Significant relationships existed between the delivery ratio and drainage area and average total stream length. Little or no relationship was found between the delivery ratio and relief, stream order, number of streams within an order, and drainage density, when considered singly.

Lueder (1959) notes that studies of airphotos have shown that some young primary erosive streams deposit only slight amounts of coarse sediments at restricted locations, while other graded streams may produce large quantities of variable sediments throughout their length. Some streams deposit throughout the year, others seasonally. Obviously, the general sedimentation pattern of a stream is a function of its geomorphic history and stage of development and a function of the type of terrain through which the stream passes. These factors can be studied by airphoto methods.

Colby (1964) describes the general principles that govern scour and fill in sand-bed streams. Conclusions made included the following. In a straight sand-bed channel of uniform cross-section slope roughness and bed material, the streambed does not either scour or fill appreciably during the passage of a flood. But in a straight channel of uniform cross-section but varying slope or roughness along the channel, fill during a rising stage is usually followed by scour on the falling stage.

3.1.4. Rainfall and Climatic Effects on Erosion

(1) Rainfall Records

It is generally considered that 35 years is the minimum period required to give a reasonably steady value for the average annual rainfall at any station, (Miller, 1966; Bowler, 1970). In New Zealand such figures are not commonly available. However, the problem of relating annual or monthly runoff to the corresponding rainfall,

is relatively easier than dealing with storm rainfall. Over a period of a year, the averaging of a number of different storms tends to make the questions of rainfall intensity and antecedent conditions less important. Consequently, according to Linsley (1967), simple plots of annual rainfall against annual runoff are often quite accurate. With monthly figures, however, there is the problem of rain near the end of the month and runoff occurring the following month.

A number of equations have been developed to forecast runoff volumes from rainfall figures, e.g. Lee and Bray (1969).

Rainfall characteristics are so varied that the erosion caused by one rain can seldom be compared with that produced by another, (Neal, 1938). The antecedent moisture condition of the soil, the soil structure, the surface condition and vegetative cover are continually changing, thus altering the erodibility of the ground. An intense rain falling on wet soil will have an entirely different runoff and erosion pattern from the same type of rain falling on dry soil. Crozier, (1968) found that the seasonal variation of soil moisture, temperature, evaporation and rainfall were particularly important for discreet earthflow types of erosion in Otago. Variations in earthflow movements were most closely associated with variations in rainfall during winter and early spring when evaporation and temperature were lowest and soil moisture, high.

Dreibelbis (1952) working in Ohio found that there was little correlation between annual or monthly precipitation and soil erosion. However, a direct correlation was revealed when amounts of rain falling at the higher intensities were compared with amounts of soil erosion. Greer (1971) also found that low frequency high intensity rainstorms contributed greatly to soil erosion. Dakshinamurti and Biswas (1962) found no definite relation between actual sizes of particles eroded and the intensity

of the rainfall, when investigating the relations between runoff and rainfall.

Similarly, work done in Georgia by Carreker (1954) showed that erosion was influenced more by a few thunderstorms of high intensity and short duration, than by rains of larger volume, long duration and low intensity.

Short period rainfall intensities and the size of the individual drops of rain have an important effect on the extent of erosion. Total annual rainfall has more of an effect on erosion if it is mainly concentrated into one season or falls on less than 100 days, than if it is evenly distributed throughout the year. Pain (1968) presents evidence of the importance of low frequency, high density rainstorms in causing slope failure and increases in debris supply to the channel system. Other workers who have also noted the importance of high intensity rainstorms include Scott (1963) in the South Island hill country, and Cunningham and Arnott (1964) in the Rimutakas. Grant (1966) found that massive earth movements in Hawkes Bay were related to periodical exceptionally heavy rainfalls, whereas surface-soil movements occurred with every runoff producing rainfall.

Related to these observations of rainfall events, are the results of work done by Swenson (1964) who noted that infrequent flows from occasional heavy rain, tend to transport much of the sediment moved by a stream. He quotes work done in North Carolina where 90 percent of the total sediment is transported by flows that occur on the average, about three days each year. Further examples of this nature are quoted in the same reference.

Ayoade (1970) stresses the fact that we need to know not only the mean rainfall conditions, but also the variability around these means. Monthly histograms can be improved by using values derived by expressing the mean monthly rainfall as percentages of the mean annual rainfall. He quotes various methods of looking at the seasonal incidence of rainfall and suggests a simple index that

does not appear to suffer from any of the defects present in the other methods. This index is derived by adding the absolute deviations of the mean rainfall for each month of the year from the expected monthly value if the annual rainfall were uniformly distributed throughout the year. The result is then expressed as a percentage of the maximum possible deviations.

Seelye (1946) gives a representative figure for the fluctuations of monthly rainfall in New Zealand as being an average variation of 44 percent about the average of the month.

In the North Island the percentage variations are greatest in February and least in July. Monthly rainfall has an asymmetrical distribution, occasional very wet months compensating for numerous months with moderately light falls.

(2) Extrapolation of Rainfall Records

There are several methods that have been developed to enable areal extension of rainfall records to assess the rainfall in an area not gauged. Unwin (1969) reviews a number of methods ranging from subjective isoplething, various graphical methods, to simple multiple linear regression analysis. Miller (1966) describes a method for extending short term rainfall records to 35 year averages.

If a sufficient number of raingauges are present over a watershed, then rainfall records can be used to construct maps showing the distribution of precipitation over the catchment, (Rodda, 1962). A number of principles are outlined by de Laine (1969) for planning a network of raingauges to give the maximum information for given effort and equipment. Complications of measuring rainfall in forested areas are discussed; measures of throughfall below trees and stemflow are often valuable figures. Chidley and Keys, (1970) use mathematical models for computing the total volume of rainfall over an area from the available records from a number of gauges.

(3) Long-term Changes in Climate and Rainfall
Patterns

There is sound evidence for significant climatic changes over New Zealand in the post glacial period, (Molloy, 1969; Fleming, 1963). These may be summarized as follows :

Present	-	A.D. 1940	Warmth Decrease
A.D. 1940	-	A.D. 1850	Warmth Increase
A.D. 1850	-	A.D. 1500	"Little Ice Age"
A.D. 1500	-	A.D. 1300	Climatic Deterioration set in
A.D. 1300	-	A.D. 1000	Lesser Climatic Optimum
A.D. 1000	-	500 B.C.	Climatic Deterioration of the Sub-Boreal
3000	-	5000 B.C.	Climatic Optimum. Annual Mean Temperatures about 2°C above the present.

Molloy (1969) concludes that there is no convincing proof of a major change in our post glacial climate other than a general rise in temperature about 10,000 years ago. For the most part, the climate since has been essentially the same as that today. The mounting evidence for local and relatively short term fluctuation of weather and climate is not disputed, but regarded as a characteristic feature of the environment. But there is no conclusive evidence that these minor variations were of sufficient amplitude and geographic extent to be ecologically significant.

However, as pointed out by Grant, (1971a) it is extremely easy to identify changes in a catchment, such as increased erosion, as the effect of biotic or man-made changes when it is in reality the result of some climatic parameter. Many major man-made changes coincide closely

in time with variations of one or more climatic parameters. Thus it is extremely important to determine the effects of climatic variation so that they are not mistaken for effects of cultural or biotic change.

Seelye, (1950) summarized the annual rainfall at a selection of stations throughout New Zealand into annual indices which were percentages of the 1911 - 1940 means. He found a decreasing trend for the period 1863 - 1947 but the standard errors of the determination were large and the description of the slow movements of rainfall, as a linear trend, he considered an oversimplification.

Grant (1971) states that over the North Island, atmospheric temperatures started to rise soon after the turn of the century. They increased markedly in the 1940s and 1950s and have remained at a generally higher level to the present. This temperature change has extended the length of the growing season especially for trees. Thus without any changes in the rainfall regime, this temperature change alone would hasten the depletion of water in the root zone. However, there have also been changes in rainfall, as reflected in the increase in drought and storm frequencies. Since the 1930s he quotes, the climate has become more variable.

Annual runoffs for Eastern Hawkes Bay were at their highest level during the period 1890 - 1910, (Grant, 1969) and annual rainfalls have been lower since about 1910 than they were in the preceding 20 years. This accounts for the drying up of a number of streams since the early part of the century, despite the removal of forest.

Grant, (1969) also found that since 1890, the 1890s were the stormiest decade. This period coincided with the clearing of much of the forest over many parts of the country. Also, the period, 1930 - 1960 had a higher average level of storminess than 1901 - 1930 . In fact, compared with 1900 - 1930, the period from 1930 - 1960 has tended to be more variable. With this increase in the range between drought and storm in regard to land

instability, the intensity of drought has resulted in storms being effective beyond a lower threshold than formerly, he suggests.

Earlier overseas work carried out in the United States by Leopold, (1951) demonstrated that although in this instance there was no perceptible trend in the totals of annual rainfall, there had been a change in the frequency of individual falls of various orders. From 1850 to about 1930 the frequency of rains smaller than 0.5 inches per day progressively increased. Thus a century ago the country was experiencing a low frequency of small falls with a high frequency of large rains. These conditions in this case favoured a weak vegetative cover and a high incidence of erosion. Thus the climatic factor helped start the epicycle of erosion which began about 1885. Thus changes in rivers from alluviation to degradation is less a function of total rainfall than of frequency of individual falls of varying size.

In the New Zealand situation there could also have been long term changes in the frequency of different sized rainfall events, influencing the potential erodibility of the country.

3.1.5. Miscellaneous Effects on Erosion

(1) Changes in Landuse.

Numerous studies have been carried out observing the effects of landuse on catchment behaviour. The effects of removal of forest on catchment stability and streamflow have been examined by workers including Hornbeck et al, 1970; Hibbert, 1969; Storey, 1959; and Gray, 1970. Other modifications of vegetation and their effects on catchment characteristics have been documented by Swank and Miner, (1968); Harrold et al, 1962; Miller et al, 1962; Toebe et al, 1968; Yates and Scarf, 1969, Bailey, 1948; Bond et al, 1964; Dragoun and Kuhlman, 1968; and Minshall, 1961.

Generally, depletion of vegetative cover tended to increase streamflow, water yields, erosion, flood flows and sediment loads. Additional ground cover was found necessary for protection against excessive runoff and erosive losses, as slope increased, (Carreker, 1954). Stannard, (1957) under Australian conditions found that the influence of climate as a causal factor in erosion is bound up with its ability to maintain a good protective ground cover. Under normal climatic conditions, including periods of drought, this is so and thus where management practices are sound, short frequent drought periods have little effect on erosion.

The value of oversowing and topdressing has been demonstrated in terms of improved cover, increased pasture production and higher carrying capacity, (Yates, 1966 and 1971). These changes were accompanied by reductions in the peak runoff flows and total flows. Lax grazing of the improved pasture further reduced runoff and provided greater protection against flood damage.

Generally a cover of forest or scrub makes less severe demands on the soil than the pasture that has so widely replaced it throughout New Zealand, (Gradwell and Jackson, 1969). Studies of interception of rainfall by vegetation, (Aldridge and Jackson, 1968; Blake and Taylor, 1967 and N.Z.F.S., 1967;) are providing data on the significance of interception.

Fleming, (1963) notes that man's arrival in New Zealand and his subsequent deforestation of the country has confused and prevented us from seeking climatic causes for the changes wrought at this time. Molloy, (1969) suggests a close link between fire (man-made or natural) or volcanicity and subsequent erosion. Thus, changes in landuse are not necessarily the primary causes for the increased incidence of erosion over the country, but nevertheless do have major effects.

(2) The effects of Soils and Topography
on Erosion

Middleton, (1930) looked at the various properties of soils which influence soil erosion. As stated by Gradwell and Jackson, (1969) where soils are able to accept large amounts of water and release it slowly to the stream, large flood peaks do not eventuate. Thus a high rate of infiltration is important. Birrell, (1962) observes that macroporosity is regarded as the value most likely to be related to the ultimate infiltration rate shown by a soil. Macroporosity is greatly affected by the heavy trampling of the surface soil under high stocking rates, (Gradwell, 1966). This may have a disproportionately serious effect on the infiltration of rain-water and cause intense rainfall to be lost as runoff.

The surface cover determines the rate at which water enters the soil. This influences the structure which in turn effects the amount of moisture storage. Thus man's influence on a catchment in land development is almost entirely directed to, or results in the elimination of natural storage. This inevitably alters the runoff hydrograph and increases the peak rate of runoff, (Spence, 1971).

A number of workers have looked at the influence of topography on runoff and erosion, e.g. Potter, (1953) and Hoover and Hursh, (1943). Baver, (1956) quotes degree and length of slope as the two most important factors with respect to erosion. Losses from steeper slopes do not increase in the same proportion as the losses from more gentle slopes. On slopes below about 10 percent, the amount of erosion approximately doubles as the degree of slope increases twofold, depending in part on the intensity of the rain. Work done by Zingg, (1940) showed that increasing slope length increases total runoff; increasing degree of slope increases total runoff and soil loss.

Newman (1957) in Australia and Archer. (1969) in the Ben Ohau Range looked at the influence of aspect and found marked differences in erosion potential between north and south facing slopes. Altitude as a topographic factor increases the erosion potential from lower to higher altitudes.

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3.2 AERIAL PHOTOGRAPHY IN SOIL CONSERVATION AND HYDROLOGICAL STUDIES

3.2.1. The Applications of Aerial Photography

(1) Introduction

The use of aerial photographs and photointerpretation in soil conservation and allied fields has been recognized for several decades. But, as pointed out by Colwell, (1964), although aerial photography is commonly relied on as an irrefutable source of information, there are still many workers who refuse to acknowledge the facts which photos offer them. Certainly in New Zealand airphotos could be more fully utilized than they currently are, especially for simple measurements in work related to soil erosion and hydrology.

Numerous workers have listed the various uses to which airphotos can be put in Soil Conservation. Smith, (1945) mentions land classification, soil erosion surveys, mapping of soil types, land slope, gradients and landuse, areal measurements (such as field acreages) and planning of erosion control measures. Bomberger and Dill, (1960) list a number of analytical elements that can be described from airphotos. These include drainage pattern, gullies, watershed pattern, water and drainage conditions, landuse and vegetative species. Norcross, (1963) has prepared a comprehensive list of all the values and uses of photogrammetry in all fields of science.

It is widely accepted that airphotos are obviously more comprehensive than maps of the same scale, and that mapping with airphotos is more accurate and rapid than conventional field surveying.

Information from airphotos is thus of much use for general watershed plans and land treatment on the large scale, as well as for individual farm plans and small watershed surveys. The following sections deal

with the evidence presented by a number of workers on the applications of aerial photography under a number of headings related to Soil Conservation. Further evidence of the value of aerial photographs is presented in the results of this study, in Chapter Five.

* * * * *

(2) Land Use Studies

Various workers have used sequential aerial photographs for evaluating and mapping changes in land use, (Avery, 1965; Steiner, 1965; and Board, 1965).

Gimbarzevsky (1966), was able to interpret soils data from aerial photos in order to determine land productivity. Various studies of land use using small scale photos giving broad aerial coverage have been performed, e.g. Draeger and Pettinger (1972).

Anderson (1971) records that the land classification scheme employed by the Tennessee Valley Authority in the 1930s, made extensive use of aerial photography to deal with land use problems.

In New Zealand aerial photographs are used in land inventory surveys in Land Use Capability Classification, (N.Z. Water and Soil Division, 1971).

(3) Evaluation of Soil Erosion

A relatively early reference to the use of air photos for describing soil erosion, especially gullyng, is that of Gouffon (1953). Areas of woods, severe and moderate gully erosion, and total number of gullies, were recorded stereoscopically, and then field checked. This air-photo survey enabled a calculation of the probable control costs, to be made.

This type of erosion survey was accurate, simple, quick and inexpensive.

The use of sequential air photography for detecting incipient soil erosion, planning protection measures and observing changes in erosion is demonstrated by von Richter (1962). In a report on air photo use in Malaya, erosion features and gullyng in lateritic soils are identified, (Kee 1962). Unturfed, undrained vertical cuttings in such soils, run the risk of surface runoff carving out

gullies that can be clearly identified on the air photos. Mike (1968) describes the surveying of eroded areas. Aerial photography was also used in the preparation of soil conservation schemes, for revealing erosion areas, soil deficiencies and gullies.

Where persistent soil creep causes a belt of broken ground, it is readily recorded on an air photo, but not so easily appreciated from the ground (St. Joseph, 1966). The fact that conditions not readily recognized at ground level are easily recognized in air photos, is of extreme importance.

Board (1965) detected soil erosion and related it to land utilization. Fezer (1971) was even able to identify the beginning of erosion caused by the hooves of cattle on photos of sufficiently large scale. The scale of the photos used in the study of the Pohangina catchments, however, was not sufficiently large to identify this feature although it was evident from field surveys. Spurr (1960) recognized gully erosion frequently showing up through the covering vegetation. Where subsoil was considerably lighter in colour than the top soil, sheet erosion was clearly visible. On the ground, sheet erosion can quite easily be overlooked because there is no striking change in relief as there is with gully erosion, (Lueder, 1959).

Planning of erosion control is obviously greatly facilitated by the use of airphotos. The use of photo interpretation and photogrammetric methods can provide basic information such as vegetative cover, slope and erodibility, watershed boundaries, and runoff, rapidly and inexpensively. The processes of erosion can be observed, the source of deposited material found, the movement of sediment traced and alluvial deposits identified according to Zinke (1960). Erosion processes that might otherwise pass unnoticed, and land use changes due to soil conservation activities can also be evaluated from a series of sequential photos. This exercise was attempted

in the present study.

Thus the historical development of problems and control, as well as present conditions are readily observed from air photos.

(4) River and Flood Problems

In a comprehensive review article, the use of sequential air photos for recording flood levels and sedimentation is reported (Fezer, 1971). Steiner (1965) mentions information on the distribution of land use types on flood plains being obtained from aerial photographs. This information was then used to obtain flood damage data in order to calculate the extent to which a flood control scheme or dam would benefit the land and intensify its use. Lueder (1959) observed that sedimentation tends to occur at predictable points which are readily identifiable on air photos. Also, a broad index of the relative amount of suspended load may be obtained through the tone analysis of a stream at various points at different times during the year. Streams with wide beds offer the best opportunities for measurements of the amount of sediment in transport (Zinke, 1960). Bomberger and Dill, (1960) found that photos taken periodically during times of flooding greatly facilitated control measures, both at the time, and for the future. Sequential photos of the receding floodwaters, facilitated estimates of the length of time crops had been inundated, the direct physical damage done, the degree of erosion or silting, and consequently the probable crop mortality and yield reductions to anticipate.

Such photos are of obvious value for floods that affect a large area and do considerable damage. In small water sheds, such as the study catchments where floods are often flash floods, such methods are more difficult, although they would still however, yield interesting data.

(5) Drainage Analysis

In air photo interpretation work, the form and density of the drainage network is one of the most common and important subjects.

With large enough scale, even the first order drainage streams can be identified. Markovic et al (1962) observed that quantitative statistical analysis of drainage networks could be made from aerial photographs.

Parvis (1950) reported on the use of air photos for analysing drainage patterns for their use in identifying soils and bedrock.

Drainage density in a watershed, is an expression of rainfall and infiltration capacity. This means it can be regarded as a quantitative physical description of the watershed, (Zinke, 1960).

Smith (1943) observed that streams which are dry for part of the year, show the characteristic colour and texture of sand, thus enabling identification. This was particularly evident in the study area. Drainage patterns not clear in the field, are much more readily identified from aerial photographs (Rijkse, 1966).

(6) Soil Studies

Soil mapping and analysis is essential in the appraisal of soil conservation problems and control work, and much work relating to soils has been done using air photos.

Aerial photography is especially important in surveying mountainous areas where access is difficult, and where dense vegetation reduces visibility. Retzer (1962) describes aerial photographic soil surveys in such country. Soil types were plotted stereoscopically on the photographs and then checked at intervals in the field. Good air photos, quality stereoscopic equipment,

skilled personnel, and familiarity with the general area are requirements he stresses.

Mike (1968) demonstrated that different soil types can be delimited more accurately and easily, and in greater detail, by means of air photos than by means of complete field surveys. In the study area where soils are classified according to slope, they were readily identified. Certain features not clear in the field are easily observed, and much time is saved. Webster and Wong (1969) however, noted that on flat land, although there were marked changes in the soil, corresponding changes in the air photo image were not noticed until after the field check. Also, more experience was required for interpreting soil boundaries on flat terrain, than in terrain of greater relief, where boundaries were more obvious. Jarvis (1962) also looked at the use of air photo interpretation for detailed soil mapping. Vinogradov (1968) goes as far as to say that the use of aero methods in soil mapping increases its speed by a factor of 2-3, and reduces the amount of necessary soil sampling by 60 - 70 percent, especially at medium scales.

In most soil surveys, the maps used in the field are 1:20,000 photos enlarged to a scale at 1:15840

(7) Hydrological Information

Zinke (1960) lists discovery and measurement of ground water as being aided by aerial photographs. Porous and water bearing forms can be identified and location, elevation and other ground conditions affecting the storage and movement of ground water can then be considered. Any area being studied, can always be compared with other areas that have already been investigated. The study of the natural vegetation will often allow water quality, especially its salt content to be ascertained. Air photos also serve as base maps or records of different land use classes, allowing estimates of water consumption to be made. Thus it is possible to plan storage and

distribution facilities adequate to meet present and future needs.

The use of air photos for choosing sites for the placement of raingauges is also reported. Sites with local peculiarities likely to introduce error into the measurements can thus be avoided, and accessibility determined.

Zinke also mentions the use of air photos for studying the various surface conditions influencing or controlling the phases of the hydrologic cycle. Precipitation deposition as runoff, storage or seepage can be estimated in part from interpretation of the physical conditions of an area, and a rough estimate of water yield be made. Factors affecting moisture supply to plants and evapotranspiration, (e.g. depth and stoniness of soil) seepage and riparian areas, can often be detected from photos. Seepage areas were readily picked out from the study area photographs. Areas where the soil has little moisture storage capacity will dry out and turn brown sooner, and the same sequence of light and dark toned areas will appear in photos taken in successive years.

Runoff rate varies with the infiltration capacity of the soil, vegetative cover, and the geology of the area. Classes of slope, soil, vegetation and rock can all be interpreted. Then when these factors have been considered and their effect on runoff determined, a preliminary estimate of the hydrograph can be prepared for the various streams in a watershed.

Areas with a marked dry season generally offer the best opportunities for determining seepage and springflow areas from photos. Fault lines which intercept the flow of ground water are often the sites of seepage and springflow, and are usually visible in stereoc pairs. Air photo interpretation has thus been adopted for a wide variety of hydrological information.

(8) Geomorphology

Various workers have observed that vertical air photos are a more abundant source of many simple measurements applicable to quantitative geomorphology, than are topographic maps. Such measurements include those of stream length, basin area, and slope measures, and are extremely time consuming and difficult to obtain in the field. This was certainly the case in the study area, even though access for field work is reasonable. Nakano (1962) discusses land form analysis using air photos that give information about the land surface; e.g. microrelief, drainage groundwater condition, cultural features, and the interrelationships of all these factors. Bowden and Jeffers (1967) were able to map slope changes from air photos, but could only deduce their significance after ground investigation. Measurement of slope angles is definitely more readily and accurately achieved on air photos than from maps, and Fezer (1971) quotes instances where workers have been able to correct existing maps, adding new and important contour lines.

Many geological surveys are now made with the help of aerial photography, but according to Vinogradov (1968), the development of adequate methods is still very slow. Features of relief and drainage too small to appear on topographical maps have long been exploited for the identification of rock units. Large scale characteristics which cannot be appreciated by ground observation, can also be captured on air photos.

(9) Vegetation Studies

Various aspects of vegetative cover are important in relation to soil conservation problems. Lueder (1959) was able to relate the effects of sheet erosion to the productivity of the land, by looking at the resulting patchiness and uneven crop and grass growth. These features were looked out for in the study photographs.

Numerous vegetation features observed from aerial photos provide useful indicators of ground conditions.

Wickens (1966) discusses the practical applications of aerial photography for ecological surveys, and stresses the strong correlation between vegetation, topography and soil. Robins (1934) found a very definite correlation of the vegetation types with moisture, soil and rock. Vertical photos, he found gave more detail than obliques, but obliques showed clearly the main boundaries which were sometimes obscured on the verticals, by excessive detail. Air photos are of extreme use in forestry surveys. Photo interpretation keys for forest cover types have been developed for the American situation, e.g. Avery (1970).

Vinogradov (1968) quotes numerous Russian publications on forest photo interpretation, and the use of plants as indicators of a variety of surface conditions. In the study photographs, rushes and thistles were identified as indicators of wet and dry conditions.

Northrop and Johnson (1970) concluded that many forest types appear so similar, regardless of the type of film used, that it is difficult if not impossible to distinguish between them, but the broader cover types are distinguishable.

Large scale photos were used by Sayn-Wittgenstein (1962) for identifying Canadian forest species. Von Zdenko Tomasegovic (1962) advocates the use of stereoscopic surveys for vegetation analysis in hilly and mountainous country where access is difficult.

3.2.2. Factors affecting Photointerpretation

It has been recognized that air photos are of considerable value in soil conservation work, but there are numerous factors that must be taken into consideration.

(1) Tone

Objects which reflect considerable sunlight back to the camera, photograph light in tone, while objects absorbing light, photograph dark. Although different tones may permit the identification of different soil and vegetation types, it must be remembered that tone is highly variable, e.g., trees growing on a hillside sloping away from the sun, will photograph darker in tone than similar trees growing on a hillside sloping towards the sun (Spurr, 1960). Also many aerial cameras admit more light through the centre of the lens than around the margins. Thus tones around the outside of the photograph are likely to be slightly darker than in the centre. Thus a uniform forest stand could register a wide variety of tones depending on the location of the sun with respect to camera and topography.

(2) Texture

Texture may also differ from one part of a homogenous stand to another, because of the relative locations of the sun and the camera. Trees viewed directly from above may appear finer textured than the same trees viewed obliquely (Spurr, 1960).

(3) Resolution

When the precise size or number of small objects on a photo is required, resolution is an all important characteristic, (Allum 1970). But when we are concerned with interpreting what, (rather than how many things), is represented on the photographs, then colour and the interpreter's past experience with the type of photo, are more important than resolution. Other limiting factors related to texture include contrast, and shadows.

(4) Ground Control Data

Any meaningful interpretation of aerial photographs depends on adequate ground control data which is best obtained in the field at the same time as the photography is taken, by workers who are familiar with the area, and who are to interpret the photos. This is stressed by numerous workers including Schneider (1968), Benson et al (1971) and Fezer (1971)

(5) Time of Day of Photography

Time of day, because it influences the angle of the sun, is another limiting factor in air photo interpretation. An angle of approximately 30° has been found to be the most satisfactory, (Hackman 1967). Decreasing the angle of illumination, tonal differences became less apparent, but shadow effect, and enhancement of texture become more apparent.

(6) Seasonal Effects

The season in which the photography is taken has a bearing on its usefulness, (Kreig 1970). In summer most agricultural activity is occurring, and heights of trees are easier to determine stereoscopically while they have their leaves on. This is of course not as important in the New Zealand situation where most trees are not deciduous. The effects of seasonality on air photo interpretation were also assessed by Steiner (1966) and Sayn-Wittgenstein (1967). Choice of optimum times improves the quality of the photos and measurably reduces the number of man-hours necessary for photointerpretation, (Vinogradov, 1968).

(7) Photo Scale

Any interpretation of vertical air photographs whether in colour or black and white, is limited by scale. Numerous tests have been made correlating the sizes of objects with suitable scales for viewing them, including those of

Helbling (1949), Simakova (1964), and Pena (1970). When selecting for scale, the smallest scale possible for the practical solution of a given problem, is chosen. Generally however, work is done with scales that are too small for the objectives required in photointerpretation. This is probably due to the higher costs involved if the photos are taken at a different scale, or enlarged.

Keeping costs in mind, Thurrell (1943) concluded that, a photo scale of about 1:20,000 is probably most desirable. This scale has been considered the most useful in the majority of interpretations. Schneider (1968) considered scales of 1:8,000 - 1:12,000 sufficiently large to permit detailed interpretation of water related factors. Sayn-Wittgenstein (1962) mentions 1:2,400 scale photos being used to identify forest species in Canada. Mike (1968) describes the surveying of eroded areas on air photos at scales of 1:25,000, 1:10,000 and 1:5,000.

Pena (1970) lists the most convenient scales for the different specialities of photointerpretation. General and regional studies obviously require a smaller scale, anything from 1:20,000 - 1:60,000 whereas more detailed studies are better carried out at scales below 1:25,000. Pena concludes that optical instruments for magnifying objects should be used with any scale. He notes that enlargement of aerial photos to obtain a convenient scale, is not as desirable as interpreting the original contact prints with the aid of optical instruments which will magnify the image to the technically tolerable limit.

(8) Other Considerations

Other factors such as focal length of the camera lens, type of camera, types of emulsion, types of processing, and the overall resulting photo quality will also effect the value of the photograph with respect to photo interpretation. The recording of an interpretation on the photos or on photographic overlays, varies with different photos (Allum 1970). The most common methods are drawing

directly on the photos with grease pencil, or on transparent or translucent overlays with ink or felt tipped pen.

Whether the photographs are used as transparencies, or printed on paper is important. It is general knowledge that, other things being equal, transparencies show finer details than the paper photographs, but they are less convenient to use, Allum (1970). Cost, and suitability for field use must also be considered. Perhaps the greatest influence on the interpretative value of the photograph, is the type of film used, and this is discussed in the next section.

3.2.3. The Relative Merits of Different Film Types.

(1) Introduction

The different film types that will be discussed in this section are as follows :

- (a) The conventional black and white pancromatic.
- (b) Natural or true colour film, generally Kodak Ektachrome Aero film Type 8442, unless stated otherwise. This film is designed for medium to high altitude aerial colour photography. A haze filter (Kodak Wratten Gelatin Filter HF-3) is usually recommended to reduce the excess bluishness caused by atmospheric haze, (Eastman Kodak Co., 1968).
- (c) Black and white infra red.
- (d) Colour infra red, or "false colour". This is Kodak Ektachrome Infra Red Aero film, Type 8443, unless stated otherwise. A yellow filter (e.g. Kodak Wratten Filter No. 12) is always used on the camera lens to absorb the blue radiation to which all three layers of this film are sensitive.

The three layers of the film are sensitive to green, red and infra red light instead of the usual blue, green and red sensitivities of true colour film. Green, red and infra red light record as blue, green and red respectively, (Allum 1970). Eastman Kodak Co. (1968) state that when the film is processed, the green sensitive layer is developed to a yellow positive image, the red sensitive layer to a magenta image, and the infra red sensitive layer to a cyan image. This combination of sensitivities and dyes produces colour photographs in which the colours are false for most natural objects. Thus a knowledge of the infra red reflectivity of the various objects photographed is helpful in interpreting results.

Water which reflects some green, but very little red and no infra red, and thus records blue. Under some conditions so little green is reflected that water appears black. Chlorophyll reflects infra red light. Thus green foliage reflects much green and infra red, but very little red light and thus records as a mixture of blue and red, (Allum 1970).

Materials such as rocks record as blue-green and red mixed in the same proportions as they reflect green, red and infra red light respectively.

Each of the four film types has specific advantages and disadvantages, depending on the use they are put. Specifications as to the type of film to be used are generally dependent on the nature of the problem to be interpreted.

(2) Panchromatic versus Colour Photography

Today in New Zealand the greater proportion of aerial photography is carried out using the conventional black and white panchromatic aerial film. However, from the following discussion it may seem that due to limitations of this film, other film types should be more widely used than they currently are.

Parry et al (1969a) report that the human eye can distinguish approximately 200 gradations on a neutral or grey scale, whereas it can differentiate more than 20,000 hues and chromas. Thus the visual contrast available in colour photography is considerably greater than that available in panchromatic photography. Because colour is fundamental to our perception, it is a distinct advantage to have a coloured image as opposed to an achromatic one. Photointerpreters, have, however, become so accustomed to working with black and white photos that their optical reflexes have been conditioned to automatically translate the various shades of grey into approximations of terrain detail, (Anson, 1970).

Parry et al (1969a) found soil boundaries easier to identify and plot from colour photos. Further work, found colour to be superior for identifying different tree species, (Doverspike and Heller 1962; Sayn-Wittgenstein, 1962; Parry et al 1969b); in water resource investigations, (Schneider 1968; Bay 1968); for geomorphological measurements (Ray and Fischer 1960); for identification of geologic features (Fischer 1958); and for agricultural inventories of crops and livestock (Colwell 1968).

A number of investigations of the relative merits of black and white versus colour photography have been carried out. Reeves (1970) expected to find that colour film would cut down production costs and offer superior accuracy to black and white photography. He was unable to prove conclusively the superiority or economy of using either film in preference to the other. Colour photography did cut down production time by ten percent. In the New Zealand situation, however, it would be the costs of such an operation that would be prohibitive.

Parker et al (1970) found that small details of landscape could be more quickly and easily recognized, and that flood boundaries could be drawn in with greater ease, rapidity and confidence on colour photos than on black and whites. Carnegie and Reppert (1969) were even able to

detect soil surface disturbance by cattle trampling on large scale 70 mm aerial colour photography.

Sorem (1967) collated a lot of general information and observations on colour aerial photography. He seriously considers using colour negative film for all photography. Indeed, black and whites from colour negatives are of excellent quality and considered by many to be superior to conventional black and white photography despite the greater cost involved. This is partly due to the fact that shadow penetration is lost in panchromatic photos because of the minus blue filtration required to eliminate haze. It is this short wavelength light at the blue end of the spectrum which by virtue of its scattering, provides much of the illumination of shadowed areas. Using colour photos in conditions of shadow, good evaluation is still possible, whereas in panchromatic, considerable detail is lost. (This was encountered with the 35 mm colour photos used in the study, when comparing them with the black and whites).

Colwell (1965) concluded from a number of independent investigations, that panchromatic film (with a minus blue filter) was the best of all film/filter combinations for general purpose use. For information more readily discernable on other film/filter combinations, it was felt justifiable to fly special purpose photography as well. Generally, aerial photographers seem to consider that the advantages of colour photography do not outweigh the disadvantages of increased cost, despite the convincing demonstrations that colour does offer worthwhile advantages over black and white.

(3) Panchromatic versus Black and White Infra Red Imagery.

Infra red photography records relative absorption of infra red solar energy. Thus the warmer an object is, the lighter it appears on the image; the cooler it is, the

darker the shade. Thermal reflection is greater from vegetation than from bare rock or damp soil which absorbs more and reflects less solar energy, (von Bandat 1968).

A number of comparisons between black and white infra red imagery and panchromatic photographs have been made. Steiner (1965) found that the infra red photos were superior for separating vegetation species, identifying bodies of fresh water and locating fallow ground. The panchromatic photos were, however, superior for locating moist depressions in agricultural land, for recognizing cultivation marks and distinguishing differences in crop maturity. Colwell (1965) found panchromatic photos more effective for bringing out differences in shadow density. Infra red photos made all shadows appear black. A partial remedy for this problem is to take the photographs with an overcast of clouds at a higher altitude to diffuse the light sufficiently to soften the shadows. This permits greater detail to be obtained even from the shaded parts. Infra red photography is of course, superior to black and white panchromatic photography in that it can be taken under cloudy conditions.

To its disadvantage, is the fact that poorer resolution and thus less total detail is available, (Cochrane, 1970).

Drainage networks are more readily delineated on infra red photos, (Parry and Turner, 1971). The jet black appearance of water, even if only intermittently visible, as when overhung with vegetation or contained in a narrow gully, is generally of such high contrast to the lighter tone of the vegetation, that water studies are greatly facilitated, (Colwell, 1965 ; Carneggie and Lauer, 1966; Parry and Turner, 1971).

According to von Bandat (1968) infra red photography is of definite advantage in vegetative studies as a far greater range of grey tones are available than with panchromatic. Northrop and Johnson (1970) in work concerned with identifying forest types, suggested that black and white infra red photography was probably most suitable due

to its relatively low cost as compared with colour films. Sharpness of features is better on infra red than panchromatic; objects are better defined and tonality richer.

Thus, black and white infra red photographs have their specific uses, though like false colour and panchromatic, they also involve an interpretation step which is eliminated with colour photography as the eye is able to recognize colours as they really are. Spurr (1960) notes that infra red photography is primarily useful in penetrating light haze and for specialized photointerpretation uses.

(4) Colour Infra red Photography

The currently used colour infra red film, also referred to as "false colour" film, was originally developed to detect the presence or absence of chlorophyll for military purposes, (i.e. camouflage detection) and then applied to the recognition of diseased or damaged foliage as evidenced by chlorophyll deficiency.

Normal colour and infra red colour photography was used to detect crop diseases, (Colwell, 1960; Philpotts and Wallen, 1969; Wallen and Philpotts, 1971) and other aspects of crop health, (Colwell, 1960). It is in the field of disease identification that infra red colour photography has been the subject of much controversy, (Benson and Sims, 1967; and Cochrane, 1968). On the false colour film diseased or damaged tissues show up as yellowish, straw coloured, golden-brown or silver-grey as compared with the pink or red colour of healthy tissues. The contrast is thus quite marked, whatever the actual difference in colour. Tarkington and Sorem (1963) report chlorophyll deficiencies appearing as blue-green rather than straw-coloured. Other studies referred to by Cochrane (1968) have also shown a variety of results. In a later note, Benson and Sims (1970) again examine the confusion with regards to the behaviour of false colour film. This prompted a statement based on European experience, (Hildebrandt and Kenneweg, 1970) who

reported that the use of false colour film has advantages for separating species in vegetation stands. Also its use extends the number of days when weather conditions are suitable for photography.

Cochrane (1968) found that another advantage of false colour is that it reduces haze, giving better resolution than the true colour film. Other workers, (e.g. Fricke and Volger, 1965) claim that the utilization of the infra red zone of the spectrum gives an essential improvement in the differentiation of the entire green zone as compared to normal colour films. This observation was very noticeable in the present study, and makes false colour film of particular value for vegetative studies.

Cochrane (1970) used false colour film successfully for vegetation studies in a wide range of environments, including New Zealand mixed podocarp-broadleaf forests. Anson (1966) observed that discrimination between tree and understorey layers is facilitated with infra red colour as compared with normal colour photography, and that there was a greater contrast between vegetation and soil. Actual soil types are, however, more readily distinguished with colour film.

Thus, false colour is probably of most value when photographs are required under conditions of poor visibility, for plant health studies and in separating and identifying vegetative species.

However, there are a number of limitations involved with the use of false colour. Firstly, there is the complication of the unfamiliar colours requiring an interpretation step. Cochrane (1968) points out that panchromatic film also requires an interpretation step, yet panchromatic is the most widely used film for aerial photointerpretation. Thus, in his opinion, this disadvantage cannot be seriously considered.

Secondly, on ageing, the film undergoes changes in colour balance if stored at room temperature. This effect

is partially reduced by refrigeration and practically eliminated by storage in a freezer, (Fritz, 1967).

Eastman Kodak Co. (1968) also point out that high temperature and relative humidity are damaging to all photographic films, but that colour films are more seriously effected than black and white films because of the heat and moisture affecting the three emulsion layers to different degrees, thus creating a change in colour balance as well as a change in overall film speed and contrast. Also, for optimum colour balance and to provide maximum detectability for particular applications, it has been found desirable to take a series of photographs in which both the exposure and the colour balance are varied systematically. Thus an exposure series is made to obtain an array of infra red colour photos, which can then be studied to find optimum discrimination. This depends partly on the subject matter. An exposure of three photographs spaced at half stop intervals usually suffices. (Fritz 1967). This was found to be so in the study. It was still, however, difficult to obtain transparencies of the optimum contrasts required. Thus with infra red photography we have the added complication of having to store the film in a freezer, and wasting film on trial and error exposure settings; these two factors seriously limiting its ease of use.

(5) Comparative Studies Using Several Film Types

Various comparative studies have been carried out using three or four different film types. In one such study, Anson (1966) established the superiority of colour and colour infra red for analysis of drainage, vegetation soils and culture. Normal colour was better than both panchromatic and infra red colour for mapping soils and land use. Colour infra red was superior to both colour and panchromatic for mapping drainage and vegetation. Vegetation species differences are best observed on colour photographs, (Sims and Benson 1966) as they can be directly recognized. On infra red colour the same trees

necessitated an interpretation, as opposed to direct recognition. This was a problem in the present study due to lack of experience with the false colours, but readily remedied by field checks. Shadow penetration and thus information on the composition of the understorey and ground conditions was much better on the colour photos, as compared with the black and white and infra red. Thus especially, if the interpreter is aware from past experience or field inspection of the photo appearance of the range of species in an area, a natural colour film is of greater value than the false colour, or black and white.

Cochrane (1970) believes that the increase in costs using colour or false colour film, is more than offset by the greater ease of interpretation and the greater information thus obtained. Not only does colour photography enable one to interpret more categories or classes than on comparable panchromatic photography, but much more detail can be determined and more positive identification of features made. Tone and textural differences are enhanced by colour variations. Thus, colour photography clearly differentiates between tree and scrub cover. However, by using suitable filters to emphasize the spectral regions with greatest difference, and to eliminate areas of no difference, panchromatic photographs can be made just as useful or more so. But Cochrane wonders if this is necessary when the results can be more readily achieved from colour and false colour photography. Fritz (1967) also refers to the technique of optimizing required results by using panchromatic film with various filters, and concludes that better results are attainable using colour infra red film, with much less bother. For geological photo interpretation it is also possible to design film-filter systems to permit easy differentiation of rock types (Ray and Fischer, 1960).

Work has been carried out by Duddek (1967) in order to become acquainted with the various problems of exposure and processing colour films. The greater information con-

tent as compared with black and white photos, offers obvious advantages, but there are also disadvantages. Exposure and processing of colour films are more difficult, cost of colour materials is greater, and requirements in terms of time and instruments are greater. But with colour negative film, there is the advantage that any required filtering to achieve the correct colour balance, takes place in the laboratory during processing, not during exposure. Also, exposure latitude ($\pm 1\frac{1}{2}$ stops) is greater than with colour infra red or black and white. Either colour transparencies on glass or film, black and white diapositives, or black and white prints can be produced from colour negatives, as well as colour prints. The choice of film still depends on the project in hand, and recommendations are made (Duddek, 1970).

The expense of infra red systems is often mentioned as being inhibitive. Estes (1966) however, notes the value of infra red in determining certain hydrologic and geologic features, and in more readily differentiating certain types of vegetation.

Trees with similar density foliage, or scrub with similar texture, are more readily identified with colour film (Anson, 1966). Forest species composition (discriminating between conifers and hardwoods) is more accurately identified by infra red colour than any other film/filter combination (Lauer, 1969). Soils characteristics, slope categories and drainage patterns are all enhanced by false colour, (Vinogradov 1968; Kuhl 1970; and Fezer 1971).

More specific tests using colour infra red and normal colour for use in identifying soil types was carried out by Gerbermann et al (1971), on air dried soils. From optical density measurements, they found that soils of low chroma (grey or neutral in colour) were distinguished best with the false colour film, but soils of high chroma, were easiest distinguished with normal colour film.

A definite advantage of the colour infra red film is in locating very small seeps and springs along the banks of rivers (Wood, 1972) and under conditions of haze, such as are encountered when flying photography at higher altitudes, (Pressman, 1968; Eyre, 1971).

Conclusions that can be made in respect to the relative merits of the different film types, are as follows :

Colour infra red photography is unexcelled for the discrimination of vegetative species, and for the identification and delineation of water bodies and drainage patterns, and wet ground, and for differentiating bare rock from vegetation covered ground, (Anson, 1968; Anson, 1970; and Allum, 1970). This was verified in the present study.

Natural colour photos are superior to colour infra red and panchromatic photography for mapping culture, discriminating soils and identifying crops. Also, colour aerial photography gives the interpreter more confidence in his decisions, permitting quicker and clearer more positive identification.

Anson (1968) also concludes that black and white prints from colour negatives are superior to those obtained from panchromatic film, even though they are of less contrast, because the differentiation of the images as on the colour prints is still evident.

Naturally, the current field knowledge of the area being interpreted greatly increases the accuracy of any landuse interpretations, and the importance of frequent field checks by the interpreter, conditions permitting, can not be over emphasized (Olsen, 1967).

(6) Conclusions

Firstly, it can be seen that the use of colour aerial photography is increasing. Colour adds innumerable tonal differences not detectable in the standard black and white photography, thus greatly increasing the amount of information that can be gained from aerial photographs.

In the past, for reasons both of cost and state of technology, most aerial photography has been taken on panchromatic film, and most prints have been made on a paper base.

There is reason to believe that more information can be obtained from infra red colour than from true colour or panchromatic photos. But, as seen, there are also reasons why they cannot be recommended for general purpose photography. When infra red colour photos are first observed, the unfamiliarity of the colours is a great disadvantage, but with more experience with the film, the strange colourings may be found at no disadvantage. Although infra red colour may (and does) actually record more information, it does not necessarily result in a better interpretation because of the interpreter's lack of familiarity.

True colour photos, however, provide more realistic colours. So, if true colour is to have any advantage over other types of colour photos, the colours must be in accordance with the interpreter's past experience at the objects themselves. If the photos reproduced the same colours that an observer in the plane taking the photographs would see, then the results would be regarded as unsatisfactorily hazy, subdued and overblue. To avoid this, a selection of filters must be used during printing. The so called "true colours" are thus the arbitrary creation of the photographic process to a certain extent. What is most important, however, is that the colours are consistent, and as reminiscent as possible of the colours that would be seen from close quarters on the ground (Allum, 1970).

Another important point with regards to true and false colour photography is that colour changes and thus the related fine differentiations that can be made, are only of value to the interpreter, if they are closely related to what he is looking at. If the colour variation is virtually unrelated to his subject, then it will be a distraction rather than an aid to interpretation. For soil conservation purposes, however, the interpreter is interested in practically everything that he can interpret

from the photos, so this is not really a disadvantage. However, if he was merely interested in the geology of an area, vegetation effects on colour photography can somewhat hinder the interpretation of geological subjects (Allum, 1970).

The costs of film and processing true and false colour film are considerably higher than those of panchromatic. Final choice of the type of photography to use for a particular project can only be made after much thought has been given as to all the uses to which the photos are to be put. If general purpose photography is required, serious consideration should be given to colour negative photography seeing this provides a wide choice of photographic prints available, and produces a black and white print thought by many to be superior to panchromatic.

Some workers advocate the use of simultaneous photography using panchromatic, colour, and infra red films, in order to obtain the advantages of each, e.g. Lamboit (1970). Carneggie and Lauer (1966) found that both infra red and panchromatic are often necessary to detect and identify as many pasture and range conditions as possible. With both types of film available, overgrazed, and trampled areas, moisture conditions, and any stream bank erosion, are more easily identified. In the present investigation, having three film types available certainly increased the interpretive value.

Thus, perhaps two or more different types of photos would be of greatest value for interpretation purposes, depending on the type of information required, but until colour photography becomes less costly to print, the conventional panchromatic black and white photography will remain the most popular for general purposes.

3.3 PHOTOGRAMMETRIC AND MORPHOMETRIC TECHNIQUES

3.3.1. Areal Analysis

Most textbooks dealing with photo-interpretation describe the methods of measuring area from airphotos, e.g. Avery (1970) and Spurr 1960. These methods include the use of planimeters, transects and dot grids. Naylor, (1956) used clear celluloid sheets on which he traced the boundaries of the areas he required to measure, cut them out and weighed them, with less operator strain than the other methods. A very early reference to using the weight method to determine areas, is that of Anon. (1937).

Other papers of interest on the subject of measuring areas, include those of Abell (1939); Newman (1940); Bryan (1943); Aldrich (1955); Wood (1954); and Wilson (1968).

Slope is generally the main source of error in area measurements on hilly country, according to Spurr (1960). But in areas of low relief, the sum of errors due to scale, tilt, and slope should not affect area estimates on aerial photographs by more than five percent, providing the total variation in elevation does not exceed three percent of the flying height. Under such circumstances, areas may generally be measured directly on the photos.

Moessner, (1957) found that it was not worth while correcting for elevation differences when carrying out dot grid surveys, even though this has been advocated by other workers including Hartman (1947); Rogers (1948); Wilson (1949); and Aldrich (1955). However, as stated by Avery (1970) the reliability of areal estimates made directly from contact prints is also dependent on the precision with which photo scales and area conversion factors are determined. He gives examples of the magnitude of the errors incurred, if new conversions are not computed for each significant variation in land elevation. Thus, if large areas are to be measured, it is advisable to adjust for scale differences if elevation differences are significant. In areas of low relief differences, this is not necessary.

3.3.2. Slope Analysis

(1) Contours and Formlines

Avery (1970) defines formlines as relative contours that are drawn from visual observations to show the general configuration of terrain; thus they do not necessarily represent true elevations nor have a uniform contour interval. He describes an exercise on the method of constructing these. Spurr (1960) and Smith (1943) also describe the method of constructing these with the aid of a few key elevation points and a stereometer.

As well as conventional contours, generalized contours can be drawn tangent to the existing contours on the interfluves. This often permits the initial form of ancient plateaus or terraces preserved only in remnants on ridge crests, to be reconstructed, (Miller, 1966). Contour lines can be used for determining the aspects of the different slopes over an area. England (1971) outlines a simple and useful method for quantifying slope aspect by projecting the normals to contours, downslope to define the aspect.

(2) Slope

Quantitative slope analysis was dealt with comprehensively by Strahler (1956). He describes average slope maps such as those prepared by Raisz and Henry (1937) and Calef and Newcomb, (1953). The method for constructing these is also given by Miller (1966) after Wentworth (1930). Thoman (1952) also describes a method for constructing average slope maps. Calef (1950) uses Wentworth's method. Rich (1916) used a graphical method for determining the average inclination of a land surface from a contour map. More recent attempts at measuring slope from contour maps include those of Ollier and Thomasson (1957) and Park et al (1971).

Strahler (1956) also discusses slope frequency distribution, as it differs with differences of stage in the

geomorphic cycle of erosion of a region, and the ways of measuring it.

The above methods are perhaps more morphometric than photogrammetric. There are however, also numerous references in the literature to the measurement of terrain slopes directly from aerial photographs, including Apostolov and Gel'man (1965); Komarov and Pavlov (1964); Mekel et al., (1964); Hackman, (1956); and Howard (1968).

A slightly different approach to the analysis of surface configuration is that of Wolfanger (1941). He uses quantitative graphical methods to look at the proportions of each gradient class within a landform type, and constructs a number of indices that enable useful quantitative comparisons of different regions to be made. These include such calculations as Relief Index, (the average difference in relief over a given area), Steepness Index and indices he calls Landform Indices, Basal Indices and Mean Landform Units. He also clarifies and suggests suitable terminology and classification of landforms.

According to the American Society of Photogrammetry (1960), the abruptness of the change of slope between gully sides and the surrounding ground is one of the surest indicators of soil texture in the American situation. Gullies in gravels have "V" slopes, in silts, "U" slopes and those in clays, softly rounded forms. The eroding gullies in the study area, although relatively coarse textured, are extremely steep in many places.

Clarke and Orrell (1958) assess the reliability of a number of morphometric methods of analysis with special reference to slope and area-altitude analysis, reviewing the work done on measuring average slope, since methods were first developed in the 1890s. Given reliable contours and intimate knowledge of the terrain, they consider the Raisz and Henry method the most satisfactory for the analysis of slope. A further review and summary of the literature concerned with morphometric studies including average slope angles, is that of Neuenschwander (1944).

(3) Profiles

The significance of valley shape in transverse and longitudinal profile, can be observed from the construction of a number of profiles including stream profiles, valley cross profiles, crest-line profiles, projected profiles and spur profiles. In the evolution of relief in the normal erosional cycle, the headward and sideways erosion of streams extends its influence so far that adjacent valley systems meet at the divide and begin to destroy it when maturity is reached. Prior to maturity, the interfluvium retains its previous form, altered only by weathering. Its relief may be regarded as the survival from the previous cycle.

As observed by the American Society of Photogrammetry (1960), streams in flat clay or silty clay plains assume meandering courses while streams on gravelly soils are nearly straight. The thalweg of a river as defined by Miller (1966) is the curve of the river from its source to its mouth, a profile along the valley floor. Miller describes the standard method for construction of stream profiles, which show at a glance the form of the curve of the river. This may be the concave graded curve of maturity, or it may show breaks of slope which may be caused by a number of factors. Resistant rocks may interrupt the gradient; there may be differences in the rate of valley lowering due to change of rock type; glaciation may have created flattened reaches and even reversed slopes above a break in slope; rejuvenation may have caused the grading of curves above and below the "knick point".

This method usually yields best results in streams of intermediate size and in the tributaries of larger rivers. Miller stresses the fact that the reality of "knick points" must be checked in the field before being accepted and used in geomorphological analysis. Early conclusions drawn from the use of this method are given by Wooldridge and Kirkaldy (1936).

The transverse section of a valley is also readily

able to be drawn as a profile. These can be drawn at intervals up a stream to ascertain how far a certain form extends. Miller describes how the original valley cross-section can be constructed, and the old valley floor approximately deduced. This exercise could be useful for determining the amounts of material removed from the valley over this time period.

Similarly the crest-line profiles can be constructed. These can provide evidence of the former erosion cycles. Projected profiles give a clearer view of the crests, more like that in a photograph. The method of projected profiles is outlined by Miller (1966) and was used as early as 1920, by Barrell, (1920). By this method, Barrell was able to project the scattered remnants of ancient peneplains into one section, showing all visible summits. A further example of the value of this method is given in Miller (1937).

The amplitude of relief is the vertical distance between the valley bottom and the hill crests, and can be demonstrated by combining stream profiles and crest-line profiles on the same graph, as described by Miller, (1966). The available relief, i.e., the elevation of the initial surface above the base level, can also be mapped, (Smith 1935; Dury 1951; Johnson 1933; and Glock 1932). Available relief offers a useful basis for judging the progress of landmass removal.

(4) Hypsometric, (Area-Altitude) Analysis

Aspects of hypsometric analysis of topography are dealt with in detail by Strahler (1952), who found practical applications of this technique in hydrology, soil erosion and sedimentation studies. Hypsometric analysis is the study of the distribution of ground surface with respect to elevation. The simplest form of hypsometric curve is one on which the elevation is plotted against the area lying above a contour of given elevation. This produces a cumulative curve, any point on which expresses the total

area lying above that plane. This has been used to show the presence of extensive summit flatness or terracing where the surfaces lie approximately horizontal. Dimensionless parameters independent of absolute scale of topographic features make this sort of analysis more meaningful and able to be compared with similar curves from other areas. Thus the proportion of total basin height is plotted against proportion of total basin area. This is the Clinographic Curve of Hanson-Lowe (1935).

The characteristics of the hypsometric curve are closely related to ground slope characteristics. Where the land is not deeply dissected and where a large proportion of the ground surface has not been transformed into valley slopes the hypsometric curve will show most of the area at a relatively high altitude. Where erosion has proceeded somewhat more, a larger portion of the curve will encompass lower altitudes. Strahler (1952) discusses the meanings of the different shapes of curves that may be obtained from different catchments. He also relates hypsometric forms to drainage forms, such as stream orders and lengths.

Miller (1966) outlines the method of construction of the area-height and hypsometric curves. Various other workers have used hypsometric methods for drainage basin analysis, including Hollingworth (1938); Chorley and Morley (1959); Christofolletti (1970); and Pike and Wilson (1971).

Height Range diagrams are also useful in the identification of past surfaces. The diagram is a method of reading the height affinities of mapped fragments of erosion surface and hence of determining denudation stages in a given area, (Coleman, 1954). Further information on the use of the Height-Range diagram is given by Miller (1955), who considers the device as one that has its limitations and which is not without its dangers of misrepresentation and risks of misuse.

Altitude Frequency curves are also based on similar principles to the Height Range and Hypsometric curves,

namely that hill-tops offer the last refuge of vanishing relief. A statistical count of the number of hill-tops in each altitude range may reveal a preponderant frequency of certain levels. This in turn may give a clue to the presence of old terraces. Miller (1966) describes the method of construction of these curves.

3.3.3. Drainage Analysis

(1) Drainage Patterns

A number of workers including Smith (1943); Parvis (1950); Lueder (1959); and Howe (1960), have used aerial photos for evaluating drainage patterns in hydrological studies. There have been numerous studies carried out on the analysis of drainage and the significance of drainage patterns, e.g. Zernitz (1932); Horton (1932, 1945). Drainage density has been the subject of a number of further studies including those of Trainer (1969); Wilson (1971); McCoy (1971); and El-Ashry (1971).

Although drainage patterns have been classified into a number of specific patterns, from which much can be inferred with regard to soil type, geologic structure, and rainfall characteristics, the various types grade into one another and are almost infinitely variable (Avery, 1970). Thus, no single pattern appears to predominate, though Parvis (1950) quotes the dendritic pattern as being the most common form of drainage type.

Drainage pattern is largely a function of the infiltration-runoff ratios of the soil in question. Relatively impervious materials such as clays and shales resist infiltration and promote runoff which erodes surface drainageways creating a relatively dense drainage network. Relatively pervious materials such as gravels and sandstones have a comparatively high infiltration capacity and will resist formation of surface drainageways. Thus generally a well developed drainage pattern implies relatively low infiltration and relatively impervious materials.

Lack of surface drainage indicates high infiltration and general perviousness. Lueder (1959) further discusses other implications that can be made from studies of drainage patterns, in detail. Similar comments are made by Smith (1943); Zinke (1960); Spurr (1960) and Feyer (1971).

(2) Drainage Composition

Horton (1932) developed the idea of drainage density, (or texture) i.e. the average length of streams within the basin per unit area. Differences in drainage density are attributed to differences in relief, rainfall, infiltration capacity of the soil and resistance of the soil surface to erosion.

The system of stream ordering generally accepted is that of Horton, (1945). In fact, Horton's laws of stream lengths and method of ordering are referred to by numerous subsequent workers including, Smart (1967); Scheidegger (1968 a, b, and c;) Liao and Scheidegger (1969); Werner (1970) and Lewin (1970).

The smallest unbranched tributaries are designated as first order; streams which receive first order tributaries and these only, are designated as second order; third order streams receive second and first order streams and so on, until finally the main stream is of the highest order. The significance of different proportions of different order streams in different watersheds is outlined by Horton (1945). Miller (1966) describes a number of measurements that may be obtained from the analysis of drainage and their practical applications.

A number of studies have been carried out observing the morphological characteristics of drainage basins and the differences in drainage networks, e.g. Gage (1950); Gregory (1966); Selby (1967); and Schumm and Khan (1972).

Thus the significance of drainage pattern and composition in hydrological studies is readily determined by photogrammetric and morphometric studies.

(3) Headward Gullying

Headward gullying is not really a factor of drainage analysis but is most readily studied when measurements on the drainage network are being made from aerial photos. Gully boundaries are easily delineated on airphotos, and the relative lengths as a proportion of the total drainage length can be measured. Seginer (1966) observed that rainfall characteristics, watershed area, and soil characteristics are the main factors affecting gully head movement. From quantitative data on the advancement of gully heads he was able to propose statistical models to describe the advancement of the gullies.

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CHAPTER FOUR

FIELD AND LABORATORY TECHNIQUES AND EQUIPMENT

4.1 SEDIMENT AND FLOW MEASUREMENTS

4.1.1. Monthly Flow Records

The dry weather stream flow from each catchment was measured at the end of each month from December, 1971 to December, 1972.

Number 1 Catchment

Dry weather flows over the period did not exceed 20 litres per minute. This permitted the flow to be directed over the top step of the concrete dam about 100 m upstream from the confluence of the two streams, (Plate 4.1) into a 9 litre bucket and timed with a stop watch. Flows in litres per minute were then calculated from the average of three repeats. The flow was allowed to stabilize so that three flows of the same volume in the same time were obtained.

Number 2 Catchment

Dry weather flows ranged from 20 litres per minute to 150 litres per minute. The stream bed was sealed with a 5 m length of black polythene and the entire flow passed through a 90° vee notch cut in a plank set in place across the channel. The water was directed into a large plastic container and timed with a stop watch. This volume was then poured into the 9 litre bucket and measured. When the system had equilibrated three consecutive identical amounts were obtained and the flow in litres per minute calculated.

Errors and limitations of this method were as follows :

PLATE 4.1

Number 1 Gully Flood Level
Recorder Showing Build-up
of Silt at the Base after
10/3/72.



PLATE 4.2

Number 2 Gully Flood Level Recorder Looking Downstream.

- (1) Incomplete capture of total stream flow.
This was manifest as a small trickle of water under the vee notch and was remedied by more thoroughly sealing off the polythene until the stream floor under the vee notch was completely dry.
- (2) The procedure could be time consuming in that up to 15 to 60 minutes might elapse before the flow had stabilized to constant volume.

The main advantage of both systems of measurement was their simplicity. No sophisticated equipment was needed. One person could usually carry out the measurements by himself except for the higher flows.

Each measuring site was selected by virtue of the relatively long straight stretch of channel, (at least 20 m) extending immediately upstream. In the Number 1 catchment, however, the stream changed its course in the channel during the study period, such that the immediate upstream reach was not a straight stretch of flow. The flow was at all times (except in flood events) so small that no other method of measuring the flow other than over the dam would have been feasible.

Interflow and baseflow were not measured, though in the case of the Number 1 catchment, these would have been most valuable as most of the flow probably occurred through the deep layer of sand covering the aggraded channel.

4.1.2. Flood Flow Records

An attempt was made to visit the study area each time sufficient rain fell to cause discolouration of the water in the two streams. As a result several futile trips were made as the streams rise and fall extremely rapidly. Conversely, several flood events were missed

due to a variety of reasons. Ideally, measurements should have been taken at given time intervals during the rise of each flood event, at the peak and as it fell. However, without automatic recording equipment this was extremely inconvenient and usually impossible as the streams invariably rose at night and were falling by the following morning.

Where possible, the flood flows were measured at their peaks and sediment samples collected.

At the onset of the study, an inverted cup flood level recorder was installed at the measurement site in each catchment (Plates 4.1 and 4.2). This enabled the maximum level to which flood waters rose to be recorded. Even if the water had evaporated from the rubber cups before the recorder was checked, the sediment left behind indicated the maximum flood level. Care had to be taken to thoroughly wash out any traces of the sediment load after examining the recorder, so that none was left behind to give a false reading for the next flood event.

The sediment loads were, however, so large that in both catchments the bottom of the recorders became silted up preventing further entry of water. In the case of Number 2 Catchment, this buildup was easily dug away and removed after each flood flow and did not really inhibit the functioning of the recorder to any degree, as the sediment was deposited as the flood waters were declining. In the case of the Number 1 Catchment, the first major flow caused a buildup of 35 cm of sediment in the vicinity of the recorder and caused the dry weather flow to change its course to the other side of the wide aggraded channel so that it no longer flowed anywhere near the recorder except in the highest flood flows.

The obvious solution might initially appear to have been to shift this recorder to the opposite side of the channel so that it could continue to function. However, this was impractical as the bank immediately above the

dam on this side tended to drop a succession of small slips into the channel at this point (Plate 2.16). Also the wall of the dam was hard up against the gully side which would have presented difficulties in attaching and stabilizing the recorder. Thus it was dug out and emptied of sediment, but remained non-functioning for the rest of the course of study as there were insufficiently large flows for it to record. This illustrates the limitations of this type of recorder under such conditions.

The method of measuring the actual flood flows was as follows :

The cross sections at the point of measurement were measured at the commencement of the study. This was the dam in Number 1 Catchment. This was uniform throughout the study period. The actual channel was measured in Number 2 Catchment and the cross section area calculated several times throughout 1972 in case the dimensions should change.

An average depth of flow was measured with a metre rule. The height which the flood reached at its maximum flow was measured from the flood level recorder on the next occasion a visit was made to the study area.

The velocity of flow was measured using floats (ping pong balls as these were easy to see) and a stop watch over a 10 or 20 m length of straight channel.

This measurement although subject to error, required virtually no equipment, was simple and more accurate than merely estimating the flow by eye. Automatic recording gauges would not have functioned anyway, as the flow was so highly charged with sediment and usually not sufficiently deep, even during flood flows, in which to install a gauge.

4.1.3. Flood Sediment Collection and Analysis

Sediment sampling was unable to be carried out in the conventional manner by suspending the standard bottle in the flow and sampling at different depths and different positions across the stream. The flood flows, especially in Number 1 catchment were of a shallow nature but spread out over a wide area of streambed. Several containers were tested for uniformity of sediment sample and a 500 ml graduated measuring cylinder used thereafter for the Number 2 stream and a 100 ml graduated measuring cylinder used for the No. 1 stream.

These were held in the stream to fill. Four samples were taken across the width of flow.

The samples were evaporated down over a bunsen burner, oven dried at 104°C for 24 hours and weighed to obtain total sediment load. Mechanical analyses were carried out on each of the four samples according to the procedure outlined by Piper (1942), and the percentages of coarse sand ($2.0 - 0.2\text{ mm}$), fine sand ($0.2 - 0.02\text{ mm}$), silt ($0.02 - 0.002\text{ mm}$), and clay (0.002 mm) calculated.

4.1.4. Rainfall Records

Rainfall measurements were recorded each morning at 0900 hours by Mr. J.M. Passey on his property at the bottom of the study area. The altitude here was slightly lower than that at the confluence of the two streams, but the only feasible site for obtaining daily records. Ideally, automatic raingauges could have been installed at a number of sites over the study area but these were not available. However, a considerable variation of rainfall could be expected over the study area anyway, due to its diversity of altitudes and aspects.

Rainfall figures were also available from Te Awa, the Pohangina Domain and Komako for comparison with these figures for the period of the study. Longer term records were available from Te Awa, but as previously stated, this area lies on the opposite flank of the anticline and does not necessarily give values very representative of the study area.

4.1.5. Other Measurements and Observations

General observations were made each month of damage caused by stock in the gullies, changes wrought by flood events and the state of each stream channel.

* * * * *

4.2 COMPARISON OF DIFFERENT FILM TYPES

The following film types were used in the comparison.

- (1) Kodachrome 35 mm slides taken from the air.
- (2) Infra red slides taken from the air.
- (3) Black and white photographs taken with a Linhof Aero Technika camera with UV filter and 135 mm lens on HP4 Ilford film with 10.2 x 12.7 cm negatives. The contact prints were enlarged to whatever size required and the observations and measurements taken from these.

These photographs were all taken by Mr. D.G. Bowler, Department of Soil Science, Massey University during a number of flights over the study catchments.

The Kodachrome and infra red slides were able to be projected side by side onto a screen for visual comparison. A number of general observations were made and the merits of each type of film are outlined in the results with their applications to certain problems and references to the factors affecting interpretability.

* * * * *

The following equipment was used to analyse and interpret the above air photos :

- (1) Pocket Casella lens stereoscope for rapid observations of general purposes.
- (2) Casella mirror stereoscope with attached light, for all measurements done under stereo.
- (3) Stereometer for measuring differential parallax for substitution in the parallax formula for determining the relative heights of objects as required when constructing formlines (contours) for the study area. (See Avery (1970) for method of using stereometer). A parallax wedge could have been just as easily used with a comparable degree of accuracy. This device is far less expensive than the stereometer, but the latter was used (a) because it was available, (b) due to personal preference and (c) because the mirror stereoscope was used for all measurements and a parallax wedge can only be used under a lens stereoscope.
- (4) A number of transparent celluloid aids such as the Dot Grid with 256 dots per square inch, photo alignment guides and tables showing circles of given diameter were used in the study.
- (5) Map wheel for measuring distances on the photos.

It is suggested that for further simplicity, the lens stereoscope could have substituted for the mirror stereoscope thus dispensing with the stereometer. However, where the more expensive equipment is available, it permits more rapid measurements and is less tedious and easier on the eyes.

4.3.1. Areal Analysis

There are numerous methods of measuring areas from aerial photographs and maps. It is often pointed out that aerial photos are not maps and that point locations are subject to displacement in areas of high relief. High points, being nearer the camera, photograph larger. Thus the scale varies within the photograph. In the study area there was a range in altitude of about 240 m (i.e. 800 ft.) from altitudes of 120 m to 370 m (i.e. 400 ft to 1200 ft). Thus the question of correcting for scale when calculating for area arose. If these measurements and techniques are to be used more generally by people in the field of Soil Conservation and allied work, then they must be as simple and as rapid as possible. Correcting for altitudinal differences makes the measurements considerably more time consuming and adds appreciably to the cost of the exercise.

Work done by Moessner (1957) on area estimates on aerial photos using the dot sampling method, concluded that it was not worthwhile to correct the dot sampling data for changes due to elevation differences. Thus in the following estimates of area the average elevation over the catchments has been taken as 240 m (800 ft.). The scale of the photos has been calculated from this height. ($R.F. = \frac{f}{H-h}$; where H is the height of the aircraft above datum, i.e. flying height; h is the local relief; f is the focal length of the camera; and R.F. the Representative fraction, or scale).

However h could be corrected for by taking the proportion of total area falling between the different contour lines and working out the scale for each section, if this was so desired.

(1) Total Area

A comparison of the following methods of calculating area was made, with regard for accuracy, time and simplicity.

- (a) Use of Automatic Area Meter, (made by the Hayashi Denko Co. Ltd., Tokyo).
The 1:16,300 scale photos of the study area (1958 to 1966 enlargements) were set up in stereo under the mirror stereoscope and the watershed boundaries traced out onto a celluloid overlay with a fine tipped felt pen. These were then transferred onto graph paper and the study areas cut out with a pair of fine tipped dissecting scissors. These catchment shapes were then put through the Area Meter which read out the area in square cm. This machine (owned by the Agronomy Department, Massey University,) is commonly used for measuring plant leaf areas and tends to overestimate areas if the belt is dirty.
- (b) Weight Proportion Method.
The celluloid overlay from the above method was cut out and weighed. The weight of a known area of celluloid enabled the area of the catchments to be worked out. This method has been used for many years for determining areas from aerial photographs e.g. Anon, (1937).
- (c) The graph paper templates from method were taken and the areas of the study catchments calculated from the number of squares of graph paper they covered.
- (d) Planimeter Method.
The areas were measured directly from the photo using the planimeter.
- (e) Dot grid Method.
A celluloid dot grid overlay with 250 dots per square inch (metric grids not being

available) was placed over the photo and the dots tallied for each area. Positioning bias was avoided by aligning the grid with the fiducial marks on the photo. This exercise was carried out in stereo or else the boundaries of the study area were first marked on the photo under stereo.

(2) Areas of Erosion and Regeneration in Sequential Airphotos.

It was felt that a quantitative measure of the actual area of the study catchments effected by erosion in the different years would show just how serious and extensive this problem was becoming. Erosion was first widely recognized as a serious threat in the mid 1930s, but the earliest available photos are those taken in October 1946. The 1958, 1966 and 1972 photos follow the pattern of erosion through to the present. Similarly, quantitative measures of the amount of bush and scrub regeneration and thus the loss of pasture could be made on the sequence of photos, with the aim of correlating changes in erosion with changes in vegetative cover.

There are several simple methods of measuring small irregular areas. The Dot Grid method as described in (1) (e) was used as was the Line Transect method. This latter technique involved the use of a celluloid overlay ruled up in lines 0.1 inches apart. Knowing the total area of the catchments, the proportion of the area occupied by scrub and bush and by erosion could be calculated from the formula

$$a/A = t/T \quad \left(\begin{array}{l} \text{where } a \text{ is the area of} \\ \text{regeneration or erosion;} \\ A \text{ is the total area;} \\ t \text{ is the sum of the lengths of} \\ \text{transects over } a; \text{ and} \\ T \text{ is the total sum of the} \\ \text{transects i.e. the total lengths} \\ \text{of the lines over the total area.} \end{array} \right)$$

For the 1972 photos with the larger scale, the width apart of the line transects was increased to 0.2 inches.

There are numerous references in the literature to both these methods including Avery (1970) and Spurr (1960).

(3) Analysis of Subwatersheds.

The boundaries of the subwatersheds making up each watershed and the inter-watershed areas are more accurately delineated under stereo than by merely looking at the photograph. To compare the patterns of sub and inter-watershed areas over the two catchments, these were traced onto the transparent acetate paper under stereo and the areas of each calculated using the Dot Grid method.

4.3.2. Slope Analysis.

(1) Construction of Formlines.

The greater the number of contour lines on a map and the closer they are together, the steeper the slope. A measurement of the number of contours per unit distance provides a measure of the general slope. Because the study area was so dissected, and the N.Z.M.S. 1:63,360 (1 inch to 1 mile) map of too small a scale for accurate measurements from the contours, it was decided to construct contours over the two catchments by the method of formlining. "Formlines" are defined as relative contours that are drawn from visual observation to show the general configuration of the terrain, (Avery, 1970).

These were constructed before the enlargements to 1:16,300 of the 1958 and 1966 photos were available and were thus drawn from the total of six stereo pairs making up the study area on the 1946 photos. This meant contouring each piece of photo and then shifting it and joining it up with the contours drawn on the next piece of photo. Irregularities in flight line and scale,

and continually lifting the stereometer onto the next stereo pair produced a degree of error in the final product.

Several excursions were made up to the study area with an altimeter to measure a number of heights along the ridges and in the gully floors for reference heights and as a check on the calculations of differential parallax. The average photo base and flying height of the stereo pairs were determined for obtaining parallax conversions. This enabled 50 foot contour intervals to be established.

As the stereometer bar traced round a given contour line this was drawn in with a fine felt tipped pen on a transparent overlay. This was easier than drawing in a series of dots and joining them up later. On the completion of one contour line, the stereometer bar was set on the reading calculated for the next contour interval.

(2) Determination of Average Slope

Several methods exist for measuring the general slope of an area. The method used in this study is that described by Miller (1966) after Wentworth (1930). This simply involves placing a grid over the contoured area and counting the number of times the grid lines cross each contour line.

Each slope can also be measured individually if so desired. This involves measuring the parallax difference between the top and bottom of the slope to determine the difference in elevation and then measuring the horizontal distance between the top and bottom of the slope. Slope percent can then be computed from the trigonometrical ratio :

$$\text{Sin Angle (\%)} = \frac{\text{Opposite side}}{\text{Hypoteneuse}} = \frac{\text{Elevation}}{\text{Slope length}}$$

(See Moessner and Choate, 1966)

On such a dissected area as the study catchments, there was such a large diversity of slope and such a large number of short slopes that this method was not practical.

(3) Construction of Generalized Contours

The initial form of a plateau or terrace can often be reconstructed by drawing generalized contours tangent to the existing contours on the interfluvies. Miller (1966) describes the method used for constructing these generalized contours. This involved the use of the contour map in conjunction with a tracing of the ridges and spurs over the study area.

(4) Stream Profiles

These were constructed according to the method of Miller (1966). Points plotted were based on altitude readings taken along the bottom of each gully, rather than levels interpreted from the photographs.

(5) Valley Cross Profiles

The limitations in constructing these as described by Miller (1966) were experienced. The valley sides were too steep for the separation of the 50 foot contour lines and 25 foot contours were impossible to draw. This prevented accurate reconstruction of the former stream profile from the transverse profiles. Had this been possible over sufficient length of channel, then the gross amount of material removed from the gully since the time of the original stream profile could have been calculated. The valley sides were also too steep to permit differences in valley cross profiles in the sequential photos to be determined. Had this been possible it would have been feasible to have calculated the volume of substrata removed from the gullies since 1946. Stream profiles for 1946, 1958, 1966 and 1972 could then have been constructed and the differences observed.

(6) Crest-line Profiles

These were constructed according to the method of Miller (1966) and plotted with the stream profiles to give an indication of the amplitude of relief.

(7) Projected Profiles

The crest-line profiles were foreshortened onto a straight line running parallel to the main direction of the divide to reproduce a view of the crest-line much as a camera might show, (Miller, 1966). The three crest-lines from the study area- i.e. the western and eastern boundaries of the watersheds and the boundary between the two study catchments, were projected in turn from the foreground on the eastern side towards the background to reproduce a panorama of crests, i.e. multiple projected profiles. This method of constructing projected profiles is also outlined by various workers as far back as Barrell (1920).

(8) Construction of Area-Height and Hypsometric Curves

A number of workers have looked at the altitudinal distribution of area over watersheds including Wright and Koutsos (1969). The area height curve shows the proportion of land in a given area at each altitude, i.e. between each pair of adjacent contours. According to Miller (1966) the area-height curve will often provide the evidence for important conclusions on physiographic history. He suggests a Line Transect method of sampling for the different areas between the contours. In practice the Dot Grid method of estimating areas was found to be more satisfactory and the actual areas were plotted against altitude.

The hypsometric curve expresses the total area above each altitude. Thus the summed areas were plotted against altitude to give a curve that reflects the mean

slope over the whole area at each height.

(9) Quantitative Slope Aspect Determination

Normals to contours projected downslope define the aspect of a slope. Values for aspect can be determined by point sampling on regular or random coordinates of a fixed grid placed over the contoured area. If the map is aligned east-west the aspects can be identified as follows. Horizontal tangents to contours which are concave upward identify north aspects; concave downwards are south aspects. Vertical tangents to contours concave to the right identify east aspects; those concave left are west aspects. This method is further elaborated by England (1971). These aspect classes can then be plotted on the outline of the area. The dissected nature of the study area and difficulty of constructing contour lines closer than 50 feet make this method of doubtful value for the two catchments. However, it could be most valuable in other situations and is simple to carry out where the countryside is not too dissected.

* * * * *

4.3.3. Drainage Analysis

(1) Pattern of Drainage.

The drainage pattern of the two study catchments was traced onto a transparent overlay from the 1:16,300 photos under stereo. The surrounding drainage network between the Pohangina and Croua Rivers was also traced off in like manner from the 1:64,400 photos. This enabled a classification of the natural drainage pattern to be made.

(2) Hydrographic Network and Texture of Dissection.

As outlined by Miller (1966) a number of various measures can be made on the drainage system once the pattern has been traced out. These include the length of watercourses per unit area, the number of streams per unit area, and the number of confluences per unit area. The ratio water length/area (drainage density) may be used as an index of the texture of drainage. If the total length of the valleys and water channels wet or dry, are measured, then the ratio total valley length/area can be used as an index of the texture of dissection. Thus assuming that the valleys were all cut by water at some time, the index total valley length/water length gives a measure of the decline of the water table- i.e. an index of the degree of drying up. The ratio of the total length of tributaries to the length of trunk may reflect the geological texture of the rocks or substrata over which the water flows.

(3) Channel Orders.

Using the stream ordering system of Horton (1945) and Strahler (1957) the streams were labelled from first to fourth order and the following measures carried out for each order : number of streams were recorded; average stream length; length of channel per hectare; and number of channels per hectare.

(4) Headward Gully Movement.

The difference in headward gully movement could be determined from the 1958 and 1966 photos, by tracing off the drainage pattern onto a transparent overlay and marking in the extent of the active gullying. Due to the different flight lines of these two sets of photos, and the different casting of shadows in the gullies some inaccuracies were involved in this measure. The gullying as a percentage of the total length of drainage could be calculated and compared for the two different years.

* * * * *

CHAPTER FIVE

RESULTS

5.1 SEDIMENT AND FLOW MEASUREMENTS

5.1.1. Monthly Flow Records

Figure 5.1 shows the means of the monthly dry weather flows determined for each catchment. A Table of the actual measurements is given Appendix VII.

The flows for the badly eroding Number 1 Catchment were extremely low and relatively uniform throughout the year, with flows under 10 l/min for the months December to February and from October to December, 1972. The maximum flow recorded was 18.2 l/min at the end of May; the minimum flow, 2.3 l/min in December, 1972.

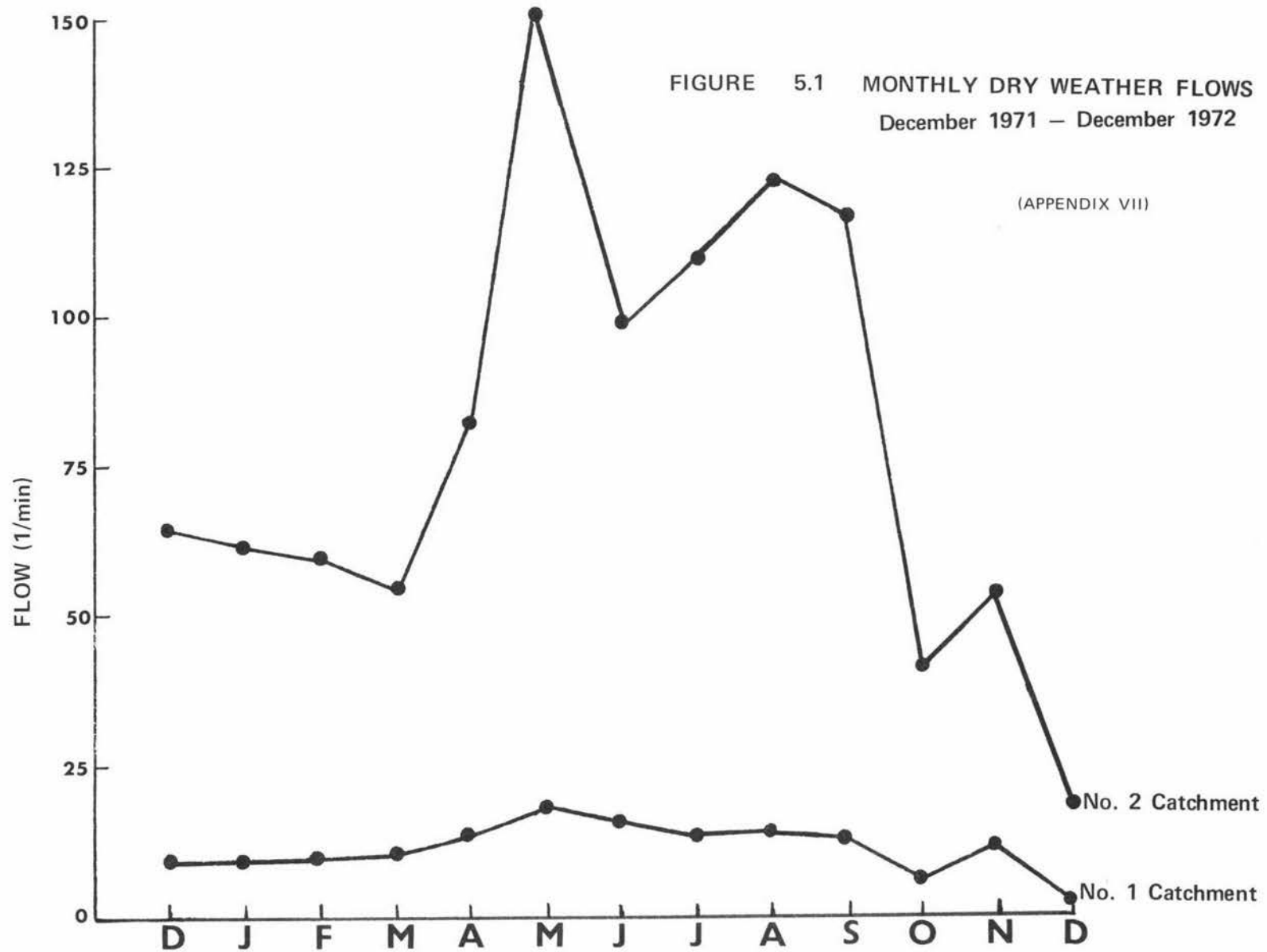
The flows in the Number 2 Catchment were in the order of 5 to 8 times greater than those for Number 1, reaching a maximum of 150 l/min in May and dropping to a minimum of 18 l/min in December, 1972.

5.1.2. Flood Flow Records

These are given Table IV.

When the dry weather readings were taken at the end of the month, the flood level recorders were checked to see whether the floods earlier in the month had risen to levels higher than previously recorded. Thus it was determined whether in fact the flood at the time of sampling was rising or falling.

The float method of measuring velocity was more accurate in Number 2 catchment than in Number 1 catchment, because of the relatively uniform straight stretch of channel directly above the sampling site. In number 1 catchment however, although the channel itself was relatively straight, the actual flow as it approached the



concrete dam was invariably affected by debris in such a way that the flow was extremely turbulent and erratic. Generally it was concentrated in a smaller width than the cross section of the dam and was of varying depths. Thus an alternative method of measuring velocity would have been desirable.

TABLE IV : Measured Flood Flows

Date :	Rainfall (mm)		No. 1 Catchment			No. 2 Catchment		
			Flood Depth	Velocity of Flow	Discharge	Flood Depth	Velocity of Flow	Discharge
	Day 1/Day 2: (cm):		(m /sec):	(l/min.):		(cm):	(m/sec):	(l/min):
March 10/11 (rising - almost at peak)	26	90	12.7	0.896	21,510	40.7 (a)	1.60	48,000
May 14 (falling)		20	-*	-*	54.6	8.9	0.436	1,770
June 15/16 (falling)	50	5	14.0	0.914	24,130	35.6 (b)	1.385	34,080
July 17/18 (rising)	5	23	1.0**	0.554	1,050	11.4	0.585	3,060

* Discharge measured by the method used for dry weather flows

**Equivalent depth across channel - i.e. flow not full width due to debris.

Number 1 Catchment : Channel at measurement site rectangular 3.15 m across.

Number 2 Catchment : Channel at measurement site rectangular, at depths less than 15 cm; calculated as trapezoidal at depths greater than 15 cm and subject to discrepancies. The width of top surface of water was measured in these situations.

(a) Width of flow 1.68 m

(b) Width of flow 1.56 m

Similarly, the depth across the dam cross section was not always uniform due to flood debris and deposition of silt and further debris in the channel beside the flood level recorder.

Thus, these flood flows are guides only to the volume of water that may result from the two catchments during flood events. No correlations can be made relating discharge in volume per unit time, to velocity, rainfall preceding the event, or sediment load, seeing the measurements and samples were all taken at different stages of the hydrograph. The flows illustrate the higher discharges produced by Number 2 catchment at all times. These results are given Table V.

TABLE V : Monthly Water Depth Maxima and Silt Deposition in Number 2 Catchment from Flood Events.

Month :	Previous Maximum Rainfall (mm) 2-day total :	Depth of Silt deposited (cm) :	Maximum Water height at recorder (cm) :	Maximum depth mid channel (cm) :
28/1	36	nil	22.9	33.2
28/2	26	nil	17.8	25.8
28/3	*116	7.6	30.5	44.4
28/4	37	nil	20.3	29.4
28/5	* 30	7.6	22.9	33.2
28/6	55	nil	25.4	36.8
17/17	* 28	8.9	25.4	36.8
28/7	* 28	16.5	27.9	40.6
28/8	* 18	7.0	17.8	25.8
28/9	* 15	7.0	22.9	33.2
28/10	* 24	12.7	22.9	33.2
28/11	8	nil	nil	-
28/12	18	nil	nil	-

* Rainfalls from which Figure 5.3 was derived.

Figure 5.2 shows the relationship between measured water depth and discharge for Number 2 Catchment. From the equation for this line, the discharges for the maximum water heights at the recorder can be calculated. This is the only correlation that can be made. Appendix VIII gives the discharges for the maximum recorded levels. Figure 5.3 shows that there is no relationship between the depth of sediment deposited at the recorder, and the predisposing rainfall.

Note: Where depth of silt deposited is recorded as "nil", this does not necessarily mean that no silt built up as a result of the stated maximum preceding rainfall. On some occasions the silt was washed away before it could be measured.

5.1.3. Flood Sediment Analysis

Table VI gives the sediment loads measured from flood events.

TABLE VI :

Sediment Loads

<u>NO. 1 CATCHMENT</u>					<u>NO. 2 CATCHMENT</u>			
Date of Flood:	Measured Discharge (l/min.):	Load (g/l):	Load (Kg/min.):	Instantaneous Equivalent Erosion Rate (Kg/ha/hr):	Measured Discharge (l/min.):	Load (g/l):	Load (kg/ha/hr):	Instantaneous Equivalent Erosion Rate (Kg/ha/hr):
10/3/72 (rising)	21,510	185.8	4,000	1,000	48,000	16.3	783	235
14/5/72 (falling)	55	3.4	0.185	0.05	1,770	0.4	0.744	0.22
15/6/72 (falling)	21,130	198.0	4,780	1,195	34,080	20.5	699	209.7
17/7/72 (rising)	1,050	15.5	16.3	4.08	3,060	15.1	46.3	13.9

* The figure for the Number 2 Catchment sediment load is disproportionately large due to a slip falling into the stream, several hundred metres upstream from the point of measurement.

FIGURE 5.2 RELATIONSHIP BETWEEN RECORDED WATER
DEPTH AND DISCHARGE FOR NUMBER 2 CATCHMENT

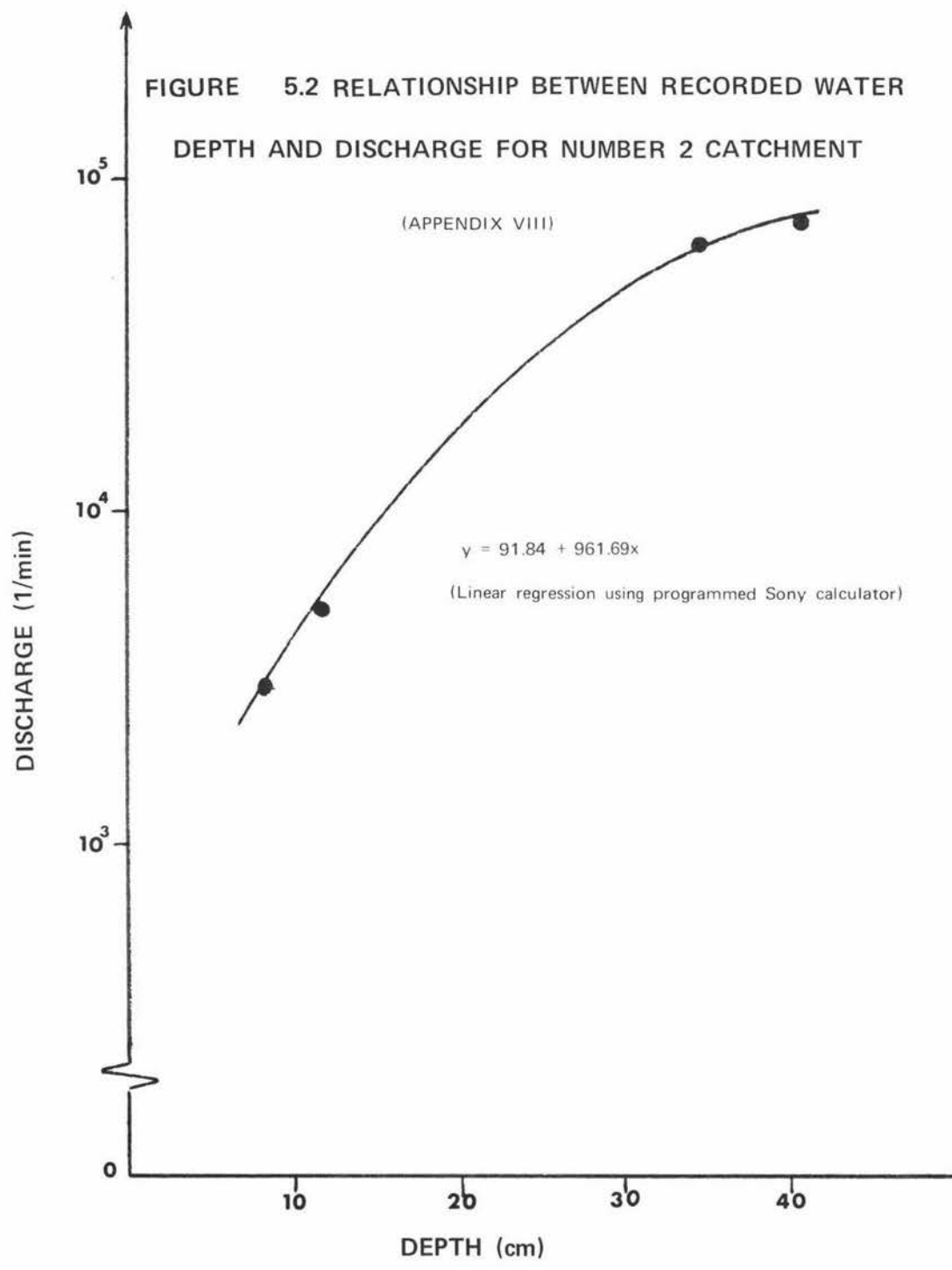
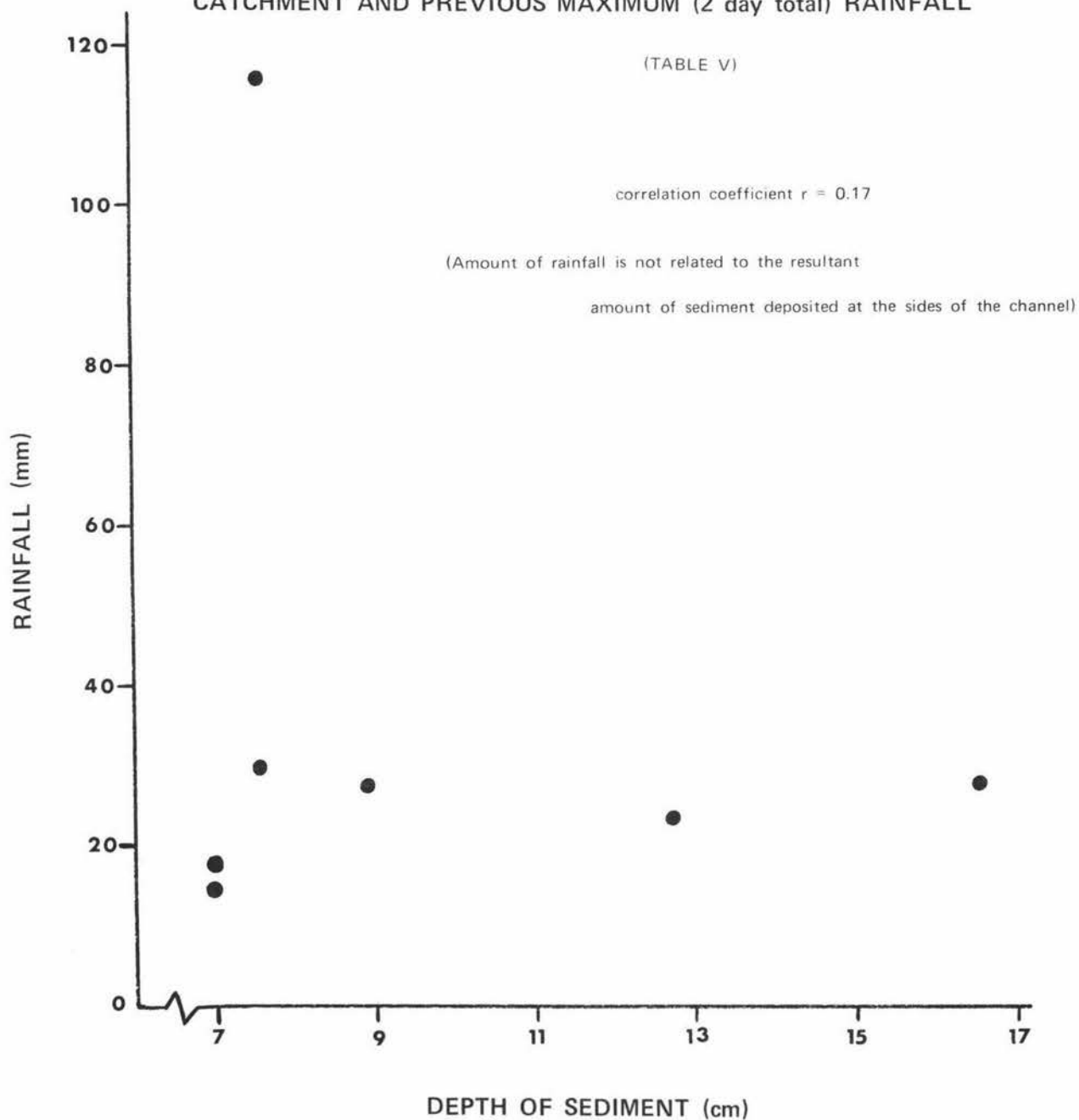


FIGURE 5.3 RELATIONSHIP BETWEEN DEPTH OF SEDIMENT DEPOSITED AT THE FLOOD LEVEL RECORDER IN NUMBER 2 CATCHMENT AND PREVIOUS MAXIMUM (2 day total) RAINFALL



These figures give an indication of the order of magnitude of the sediment loads that are carried by the two streams in times of flood. These loads may only be carried for a very short period of time, as the streams rise and fall extremely rapidly. Nevertheless, loads in the order of 4,000 kg/minute for the Number 1 stream and 700 kg/minute for the Number 2 stream, even for a very short time are contributing enormous quantities of sediment to the river system.

Appendix IX (1) gives the raw data (means and standard errors) for the data on Table VI. The standard errors are generally very small. This shows that the four samples taken were very uniform. Thus, the simple sampling method gave relatively accurate results.

The results of the mechanical analyses performed on the sediment samples are given Table VII.

TABLE VII : Particle Size Distribution in Flood Sediment Loads

Date of flood Event:	NO. 1 CATCHMENT			NO. 2 CATCHMENT		
	10/3/72	15/6/72	17/7/72	10/3/72	15/6/72	17/7/72
	%			%		
CLAY						
0.002 mm	14.1	1.4	12.1	14.7	4.5	*41.3
SILT						
0.02-0.002mm	8.2	2.5	9.7	6.0	14.1	34.5
FINE SAND						
0.2-0.02 mm	80.3	90.6	79.1	79.6	79.2	29.1
COARSE SAND						
2.0-0.2	4.2	10.2	2.2	4.0	3.9	0.2

* An extremely high percentage of clay was obtained from the 17/7 flood samples due to the large amount of topsoil in the slip that temporarily blocked the channel a few hundred metres from the recording site. The colour of the water was a pale yellow-brown. The difference in colour and composition of the sediment loads of the two streams where they met at the confluence was extremely marked, and indicative of the high clay load in the Number 1 stream.

Thus except in the case where a shallow slip dropping into the streams contributes the finer silt and clay material from the topsoil horizons, the major particle size as determined from the above mechanical analyses is fine sand. At least 80 percent of the load falls in the range of fine sand.

Appendix IX (2) gives the raw data with standard errors and means for Table VII. This shows reasonable accuracy and uniformity in the sampling technique. No correlations can be made between the percentages of each particle size in different floods seeing some measurements were made before the flood peak and others after.

5.1.4. Rainfall Records

Appendix X (1) and Figure 5.4 show the daily and monthly rainfall for the study area over 1972. As also recorded at Palmerston North (D.S.I.R.) Ballantrae, Te Awa and the Pohangina Valley Domain, March was the wettest month, due to the heavy rains on and around the 10th March. The maximum daily rainfall experienced during the year occurred at this time over much of the Manawatu, See Appendix X (2).

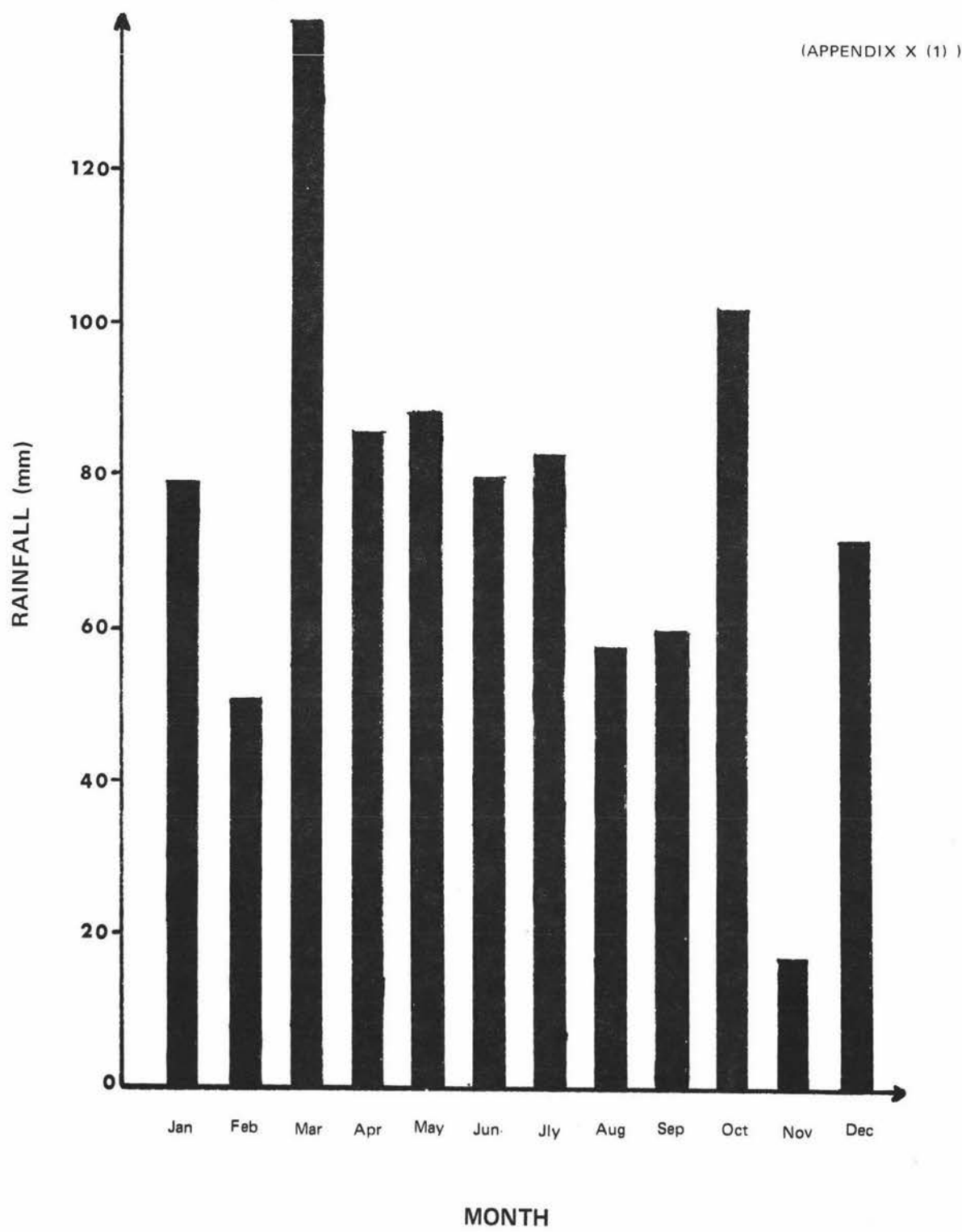
In fact, as recorded by the N.Z. Met Service Rainfall Observations for 1972, March was the wettest for at least 50 years over the North Island. Rainfall was $2\frac{1}{2}$ times the normal March value for the North Island.

November was the driest month over the study area and much of the surrounding district.

Rainfall for 1972 was below normal, mainly by about 15 percent over most of the North Island. (Appendix X (3).

The Palmerston North D.S.I.R. 40-year figures from 1933-1972 give March and September as the driest months, and June and December as the wettest months. This may not necessarily be the case for the study area,

FIGURE 5.4 1972 MONTHLY RAINFALL TOTALS FOR STUDY AREA



but for the southern half of the North Island, the 1972 rainfall was below normal, mainly by 50 percent, for December, and mainly by 25 percent for June.

Appendix X (4) gives the 23-year rainfall figures for Te Awa, which may give some indication of the general situation for the study area over this period of time. However, the 1972 figures for Te Awa recorded 200 mm lower rainfall than Culling's Gully. Thus, how relevant the Te Awa figures are, is questionable.

5.1.5. Other observations

In November, 1971, the farm track from the confluence of the gullies giving access to the better quality Raumai Sandy Loam country between the two streams was subsiding badly, undercutting in places and becoming generally unserviceable. At this stage the young poplar poles were having difficulty establishing on the exposed substrata. During the March 10 flood, small mudflows were observed issuing from the saturated sides of the slopes exposed by the construction of the track. Samples of these were not analysed, but on settling gave 30 cm of solid sand with about 2 cm of water separated out on top. These mudflows caused a number of small runnels to be carved out of the loose materials on the track and on the steep slopes. These were subsequently filled in with debris in the next runoff event.

During the March 10 flood, the Number 2 recorder was silted up to a depth of 35 cm. This silt deposit which extended several metres upstream was removed in the June and July flood events. Further upstream in the Number 1 gully silt deposits up to 1.5 m high were left after the winter.

A number of poplar poles on the sides of the channel were buried up to a metre deep and many were completely uprooted and buried. A number of poles observed in November, 1971, in the first main tributary of Number

1 gully had completely disappeared by the same time the following year. Thus the mortality rate of the vegetative material planted in the gully bottoms, is extremely high. The remaining poles, once past their first two winters, appeared to be growing well. After the spring winds a number of these healthy poles were observed with their tops broken off. This could also be caused by opossums, though generally, opossum damage was not very evident.

Slips were observed in the vicinity of the recorder in Number 1 gully at the end of March, after the 10 March storm, at the end of June, after the June storm, at the end of July, after the flood events during July, and at the end of August. Further silt deposits, this time on the same side as the slipping, were observed at the end of August.

The July runoff events also caused a large surface slip to drop off the hillside into the Number 2 gully causing the extremely high sediment load and clay content in the flood samples taken in the 17/18 July flood. This slip caused a partial blockage of the stream such that the water built up behind. A sudden release then brought down the high sediment load and caused the raised water levels downstream. When the channel was partially blocked the sediment load was also extremely large.

Damage resulting from the action of cattle hooves causing miniature slippages from the gully walls was observed throughout the winter months from June to September. To a smaller extent, sheep tracks down the unconsolidated slopes from the farm track were also causing material to drop down into the gully, exposing the layers underneath. When the soil and substrata was extremely dry in the summer months, sheep and cattle treading also caused material to dislodge.

5.2 COMPARISON OF DIFFERENT FILM TYPES

5.2.1. Qualitative Observations of Different Applications of Aerial Photographs

Plates 5.1, 5.2 and 5.3 depict approximately the same area of Number 1 gully showing the first tributary coming in on the right hand side to join the main channel. Plate 5.3 extends down as far as the confluence of Number 1 and Number 2 gullies.

Plates 5.4, 5.5 and 5.6 show approximately the same area of Number 2 gully.

From these and further photographs that covered the whole of the study catchments the following observations were made.

The most important feature that warranted observation was the degree of gully erosion. As outlined in the following section 5.3, photogrammetric methods gave quantitative measures of headward gully movement and area of gully erosion. Qualitative observations allowed the areas of prime concern to be identified. Feasibility of vehicle access could be determined where conservation measures were warranted.

The extremely steep slopes of the gully sides limited the view into the stream beds. This meant that sites of aggradation could not be determined. In the situation of a broad flat flood plain these would have stood out clearly under stereo and would have been visible with the naked eye because of the textural difference in the photo.

Variations in vegetative cover, especially on the clean pasture areas, enabled wetter and drier areas to be distinguished. Subsequent field checks verified the observation of the predominance of rushes on the damper generally concave slopes and scotch thistles on the drier ridge tops, spurs and convex areas of hillside. Areas

PLATE 5.1

Kodachrome Aerial of the
Main Gully and First
Tributary of No. 1 Catch-
ment.



PLATE 5.2

Infra Red Aerial of the Main
Gully and First Tributary of
No. 1 Catchment.





PLATE 5.3

Black and White 1972 Aerial View of the Lower Part of No. 1 Catchment.

PLATE 5.4

Kodachrome Aerial of
Part of the Main Gully
of No. 2 Catchment

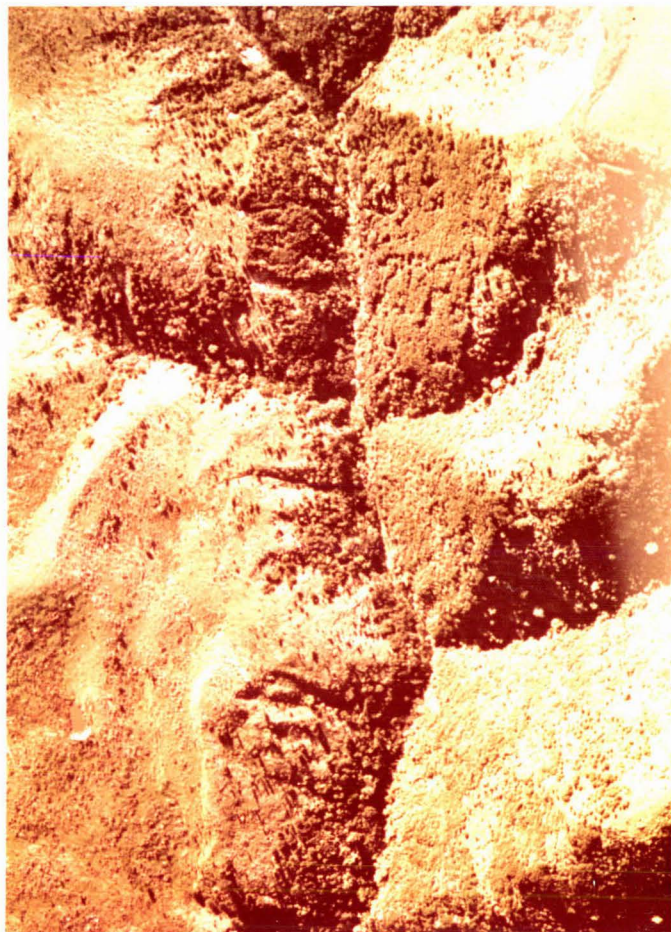


PLATE 5.5

Infra Red Aerial of Part of
the Main Gully of No. 2
Catchment.

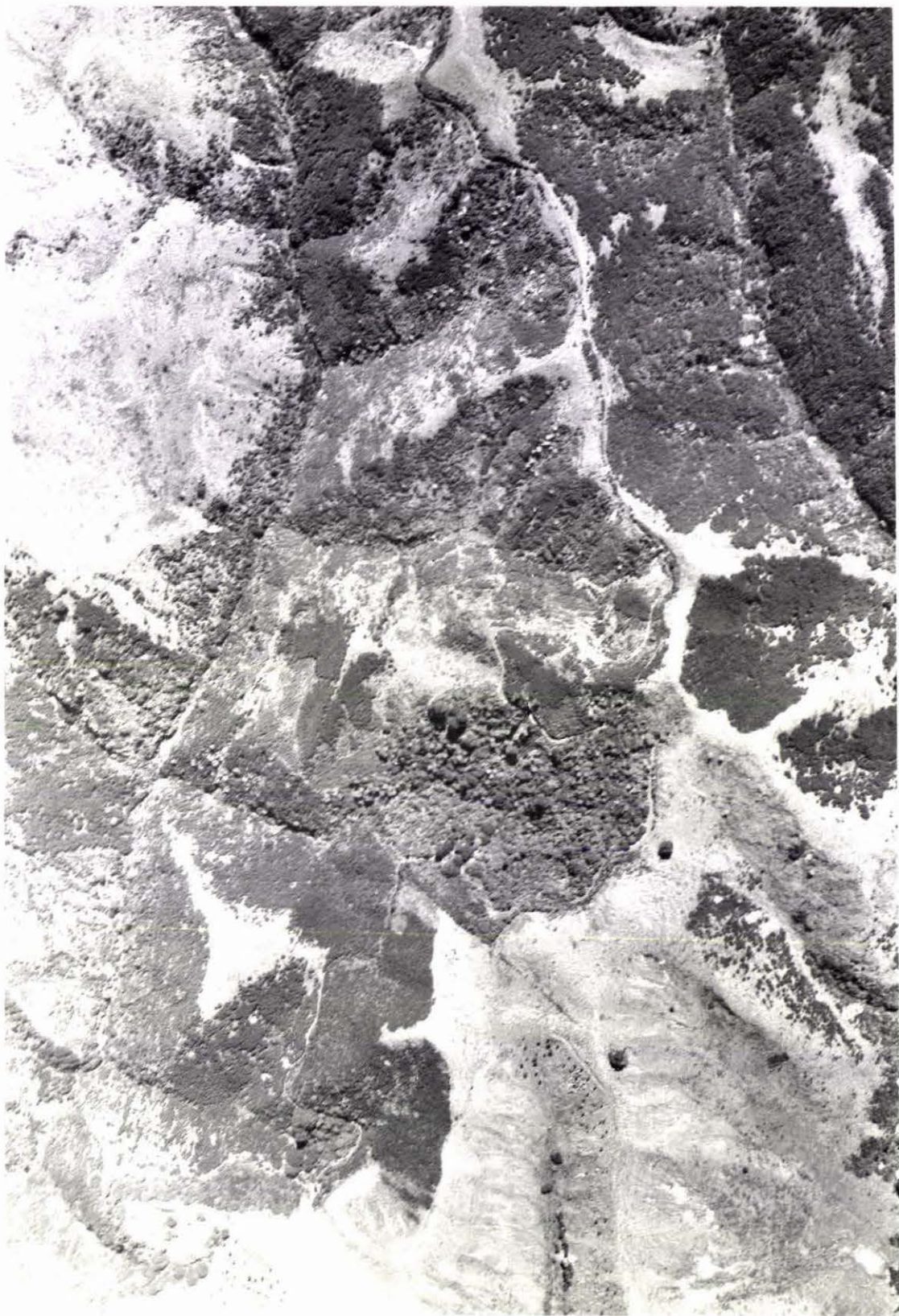


PLATE 5.6

Black and White Aerial View of the Lower Part of No. 2 Catchment.

of poor pasture cover could be noted as incipient sites for sheetwash and shallow slips especially on the steeper slopes.

The steep slopes clothed with regenerating native bush and manuka were seldom the sites of slips, whereas slopes of equivalent slope but with scattered scrub or pasture cover exhibited a far greater degree of instability. This was not so obvious on the more gentle slopes.

Areas of manuka could be distinguished from the areas of mixed scrub and regenerating native bush and in some cases actual species could be distinguished. The residual clumps of black beech on several knobs and drier spurs were easily picked out and verified by field checks. Similarly, in the upper portions of the gullies, tree ferns were readily identified by their distinctive crown shape. Scattered pines, macrocarpas and acacias and lines of poplars were also easily identified. A very limited number of field checks was thus necessary once the crown shapes, texture and tone of the individual species was able to be recognized. Thus the vegetation over a much wider area than the two study catchments could have been characterized.

As the major criterion distinguishing the different soil types over the catchments is slope, it was relatively easy to draw in the soil boundaries from the photographs under stereo. Thus, on Plate 5.3 the flat areas of Ohakea Silt Loam of the terrace country at the bottom and on the middle left hand side, can be readily picked out. Similarly, the areas of Raumai soils on the open tops between the gullies can be outlined, with the areas of Pohangina Steepland Soils separating them. Figure 2.4 showing the distribution of soils over the study area was drawn in this manner from the photographs. Obviously, in an area that was predominantly flat and where soil differences were not related to slope, mapping of the soil types directly from photographs would be a much more difficult task and require a greater number of field checks.

Whereas it is difficult to assess the drainage texture and classification in the field, even a superficial examination of the channel systems on the aerial photographs, gives an indication of the drainage system. Section 5.3 gives the quantitative results from a more thorough analysis of the drainage pattern. In a few places where the gully walls were not too steep and the gully bottoms are not obscured by shadow or vegetation, the light coloured dry sandy channels can be seen.

Stock water dams are readily identified by the darker tones of the more lush vegetation and rushes surrounding them and from the tone and texture of the water surface. Similarly, small seepage points can be determined from the darker tones of the lush vegetation and wet soil, under stereo. Careful examination of the projected slides on the screen also identified these areas, but in this case previous field knowledge was necessary. However, knowing what to look for after one or two field checks is preferable to making a large number of excursions into the field.

Existing fencelines and stockyards provided an indication of the amount of subdivision over the study area. Future fencelines could be more readily planned from the photographs than from maps as the slope and vegetative cover could be more readily appreciated.

Thus, qualitative observations from aerial photographs can provide a considerable amount of information about an area and replace a lot of field work.

5.2.2. Factors Affecting Photo Interpretation

The main limitation to interpretation of the photos was due to the lack of contrasts obtained in printing, especially in the black and white photos. Where there were indefinite ranges of greys, rather than the full range from black to white it was impossible to determine subtle changes in tone. This can be largely remedied in the processing of the prints. Lack of contrast is

still however, a limitation. As mentioned when making observations in the actual gullies, the dark shadows on the steep gully walls limited interpretation. This is, however, unavoidable in this sort of country. Shadows cast by taller vegetation obscured immediate ground conditions but were not important on the scales used.

Ground checks were carried out during the same period of time that the measurements and observations were being carried out on the photos, so there was no problem involved here. In fact, from the amount of ground checking done, a much larger area than the study catchments could have been examined with accurate interpretation.

Resolution of small microtopographical features was not possible on the original 1:41,800 and 1:64,400 photos, but scales of 1:16,300 were adequate for most purposes when magnified under the mirror stereoscope. For observation with the naked eye, larger scales than this were preferable. The scale at which the 1972 black and white prints were used was 1:6,500 and this was optimum for detailed interpretation work. However, with these photos, there was no difficulty in enlarging the prints to whatever size required. (Plates 5.3 and 5.6 are not the exact scale worked with, but merely a convenient size to fit the page.

Although Pena (1970) advocates the use of optical equipment to magnify the images on the photos rather than enlarging the print, the enlarged prints (scale 1:16,300) from the 1:41,800 and 1:64,400 were extremely useful for quantitative measurements using the mirror stereoscope and were able to be directly compared with the 1:16,300 contact prints of the 1946 photos.

Although the transparencies were less convenient to use in that they had to be projected onto a screen and could not be drawn on and labelled, they showed considerably finer detail than the prints partly due to the larger scale viewed at. Qualitative observations only, were made from these, but quantitative measures could readily

have been carried out had these been the only type of photograph available. This would have meant projecting the slides on to white paper and transposing important data on to this from which measurements could then be made. It would then be necessary to compare a known distance on the ground with a distance on the projected image to obtain the scale.

5.2.3. The Merits of Different Film Types

Access to three different types of photographs enabled a greater amount of information to be obtained more readily than had only the black and white photos been available. The black and whites were used for all quantitative measurements because of the convenience of using them under stereo. The Kodachrome and infra red colour slides were however, of greater use for the qualitative observations.

Farm dams stood out extremely clearly on the infra red slides and appeared a bright turquoise colour. On the coloured slides they appeared a muddy greyish colour whereas on the black and white photos one had to look extremely carefully amongst the various textures and tones in the greys to identify these. Thus, the infra red imagery was definitely superior for the rapid identification and positioning of water bodies and wet areas. The damper slopes and more lush vegetation appeared in varying shades of bluish-turquoise, in comparison with the pinker woody and drier vegetation and whitish drier pasture areas.

The penetration into the actual gullies was better on the infra red and colour slides than on the black and white photos where shadows limited the view into the gullies. Penetration of shadows was particularly good on the colour slides as seen in Plates 5.1 and 5.4.

Determination of the different tree species was easier using the infra red slides, once the psychological barrier created by the false colours was overcome. Field checks were a necessity in this respect, but once :

accomplished, the greater diversity of tones and textures enabled a greater number of species to be identified.

On both the infra red and Kodachrome slides, micro-topographical differences were far more apparent than on the black and white photos. This is extremely evident on Plates 5.1 and 5.2 on the area of Raumai soils between the two gully branches, where the small knolls and hillocks are far clearer than on Plate 5.3.

Fencelines and stockyards were more rapidly identified and traced on the colour and infra red slides than on the black and white photos. Sharper contrasts in the vegetative cover due to different stock pressures on opposite sides of fences was more readily picked out on the Kodachrome and infra red slides. On the black and white photos, the difference in tone was apparent but not as clear and distinctive.

Actual areas bared by gullying and slipping were equally readily identified from the three film types due to the high contrast between the white of the exposed substrata and the darker colour of the pasture and normal topsoil.

The greatest limitation with the infra red transparencies was that it was necessary to take several exposures for each photograph at half stop intervals and hope that one of these would give optimum discrimination. Even then some of the results were too dark for good identification of subject matter, as can be observed in some of the regenerated gully sides in Plate 5.2. Part of this limitation could have occurred in the printing process from the slide to the print. Similarly, there is less colour contrast on the Kodachrome print than was present on the original transparency.

Thus, the Kodachrome transparencies were superior for shadow penetration and ready recognition of features as no interpretation step was required. Thus a smaller number of field checks would have been necessary. Once accustomed to the false colours of the infra red slides, these were

undoubtedly superior in vegetative studies and for looking at the drainage system and identifying small seepage areas and other areas of wet topography.

Both the Kodachrome and infra red slides were of greater value for specialized interpretation than the black and white photos, but the latter cannot be excelled for quantitative interpretative purposes and convenience of viewing.

* * * * *

5.3 PHOTOGRAMMETRIC AND MORPHOMETRIC MEASUREMENTS

5.3.1. Areal Analysis

(1) Total Area

Table VIII shows the areas for each catchment calculated from the five different methods. Appendix XI gives the raw data from which these results are derived.

TABLE VIII : Area of the Study Catchments Calculated by Five Different Methods.

Method of Measurement :	<u>No. 1 Catchment :</u>	<u>No. 2 Catchment :</u>
Leaf Area Machine	240	202
Weight Proportion	235	197
Open Grid (Graph paper)	237	200
Planimeter	238	201
Dot Grid Method	235	196
Average value	237	199

Thus the area of Number 1 Catchment could be taken as 240 ha and the area of Number 2 catchment as 200 ha.

Each method of calculation gave very similar results. Thus as far as accuracy is concerned, the method used to measure areas is merely a matter of personal preference and availability of equipment. If a planimeter is available, this is obviously the quickest and least tedious method as it can be done directly on the photo without tracing an outline. Similarly, if a machine is available to calculate the areas, this

is extremely rapid and convenient. The weight proportion method is less tedious and more rapid than the Dot Grid or Open Grid methods for larger areas. However, where the areas to be measured are small and irregular, the Dot Grid or Open Grid methods are the most convenient.

(2) Areas of Erosion and Regeneration in
Sequential Airphotos

Both the Dot Grid and Line Transect methods were used to measure the areas of erosion and regeneration from the four sets of photos. The Dot Grid method was adopted as a matter of personal preference though very similar results were obtained from each. Figures 5.5 and 5.6 show the changes in the amount of erosion and regeneration from 1946, 1958, 1966 to 1972, derived from Appendix XII.

On an areal basis, the greatest area of erosion is when slipping is predominant; gullyng does not show up as a large area, but contributes an enormous volume of sediment to the drainage system, per unit area of gullyng. Thus these figures do NOT imply that erosion over the study area has decreased from the high amounts in 1946 to lesser amounts in 1972. Rather these figures indicate that the amount of slip erosion has been drastically reduced over this time period. As previously discussed, it was impossible to view the gully walls and floors due to the shadows on the photos and the steepness of the slopes. Also, in calculating the areas, slope was not taken into account. Thus the actual areas of the gullies were underestimated.

Thus areal measurements are not an accurate measure of the extent of gully erosion. This is dealt with in a later section on headward gully movement, which gives a better indication of the changes in gully erosion during the period 1946 to 1972.

However, the areas of slips that occur in areas

FIGURE 5.5 CHANGES IN EROSION OVER THE
STUDY AREA FROM SEQUENTIAL AERIAL PHOTOGRAPHS

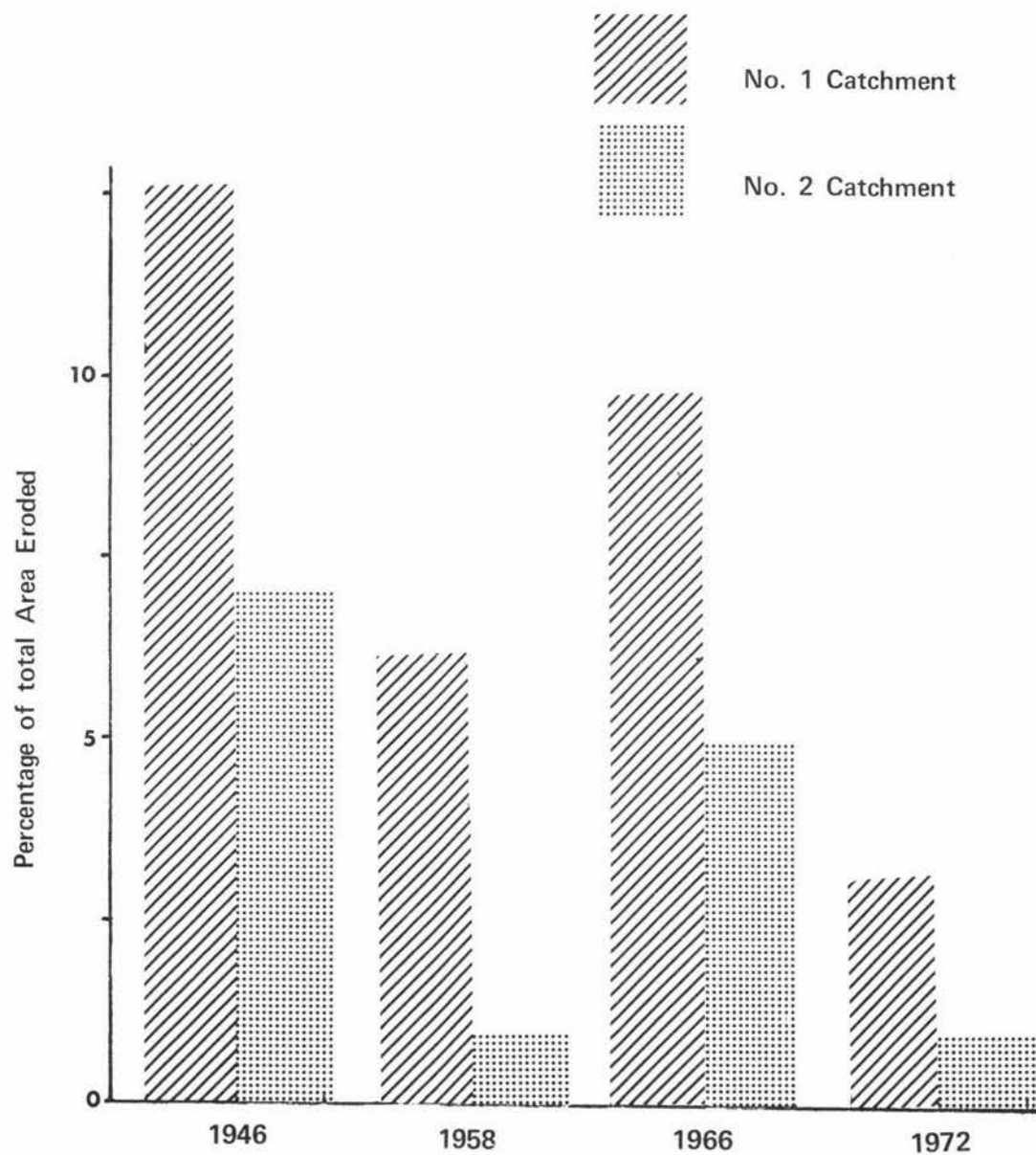
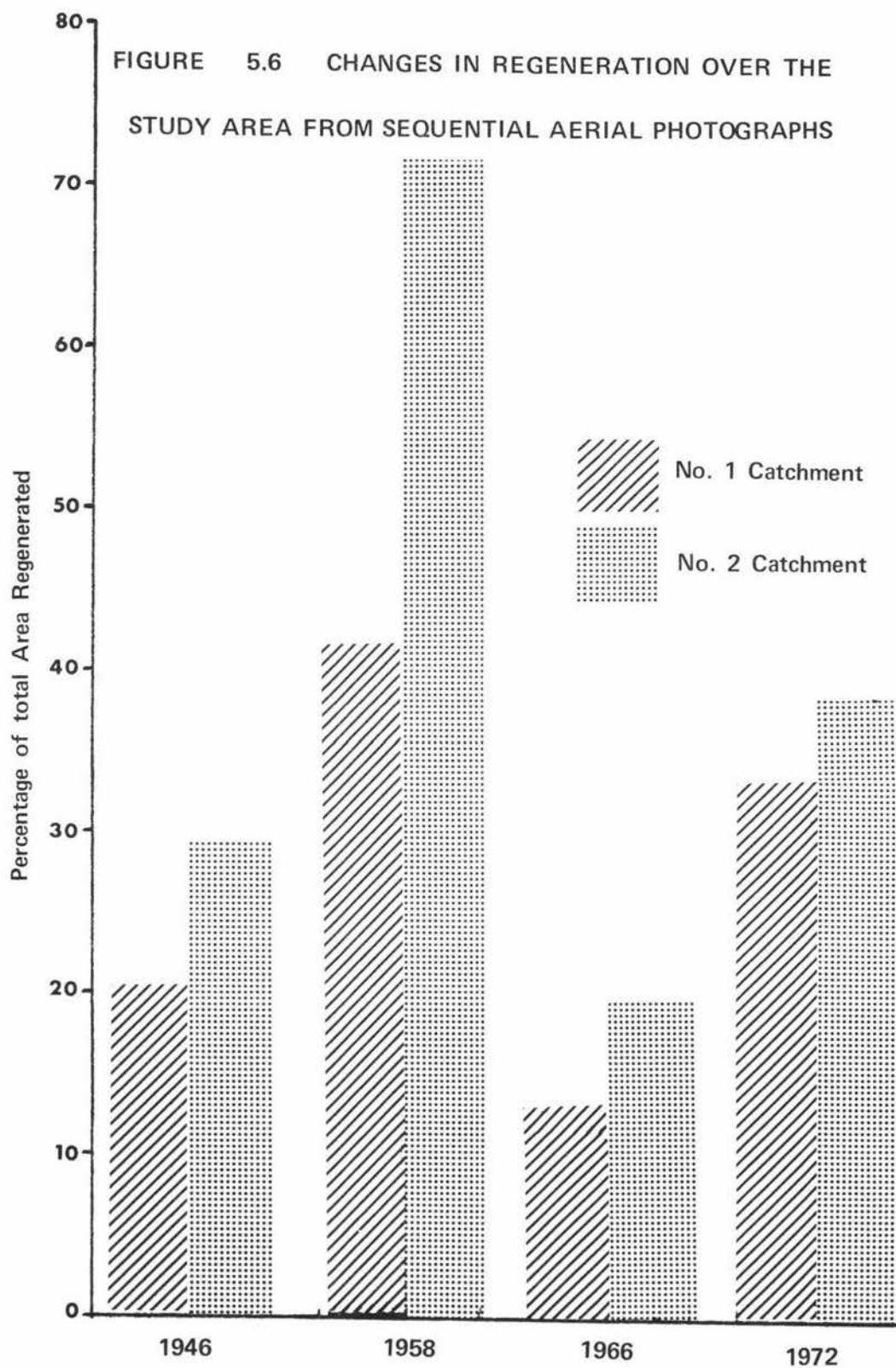


FIGURE 5.6 CHANGES IN REGENERATION OVER THE
STUDY AREA FROM SEQUENTIAL AERIAL PHOTOGRAPHS



not associated with the gullies were readily measured. In 1946, about 7 percent of the ungullied area of Number 1 catchment exhibited slipping. The figure for Number 2 catchment was similar. By 1958 this area had become greatly reduced. Accompanying this change was a dramatic increase in the amount of scrub and regenerating native bush. Then between 1958 and 1966 a large amount of scrub was cleared from both catchments, reducing the regenerated areas to less than a third of their area in 1958. Accompanying this decrease in regenerated areas, was a significant increase in the area of slips over both gullies. By 1972, the scrub had again increased its range and the area of slip erosion had once again decreased. Thus, there was an inverse relationship between the amount of slipping and regeneration.

Throughout the whole of the study period from 1946 to 1972, Number 1 gully exhibited a greater degree of erosion than Number 2 gully. Conversely, Number 2 catchment exhibited a far larger proportion of its total area covered in scrub and regenerating bush. These features can be readily observed from a superficial study of Plates 5.7, 5.8 and 5.9 showing the study area, or parts thereof, in 1946, 1958 and 1966 and from the 1972 photos, Plates 5.3 and 5.6. The frontispiece gives an oblique view of both gully systems and shows clearly the greater amount of gullying in the Number 2 catchment.

(3) Analysis of Subwatershed

Figure 5.7 shows the pattern of subwatersheds over the study area, and the inter-catchment areas. The inter-catchment areas are extremely regular along the length of the main gully of Number 2 catchment. No such regularity is observed in Number 1 catchment.

The regularity of the inter-catchment areas over a number of catchments in the same district as the two study catchments, can possibly be related to the relative stability of the watersheds in question. The shape and size of these areas and the areas of the subwatersheds

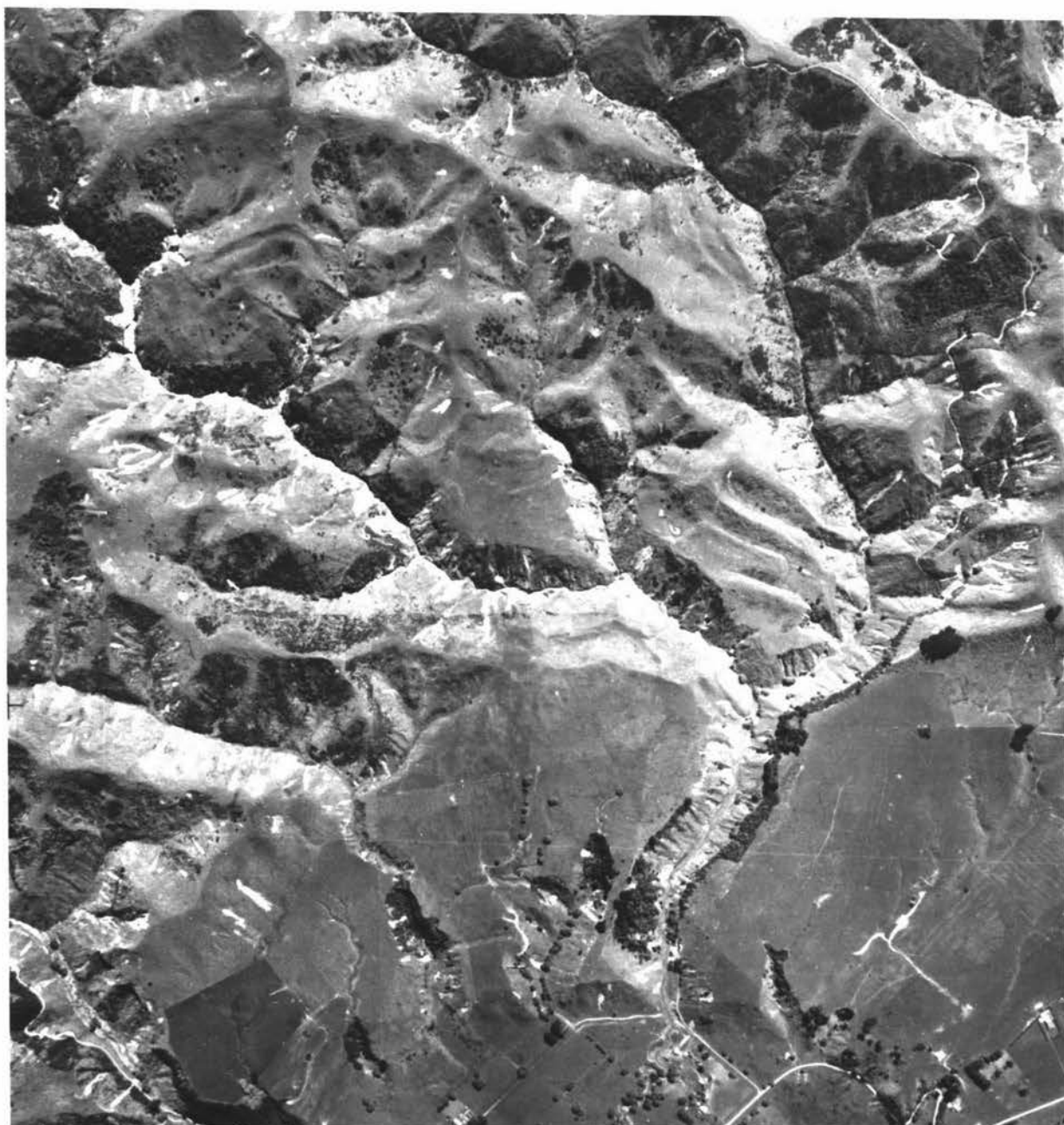


PLATE 5.7

1946 Aerial View of Lower Part of the Study Area Showing High Incidence
of Slipping.

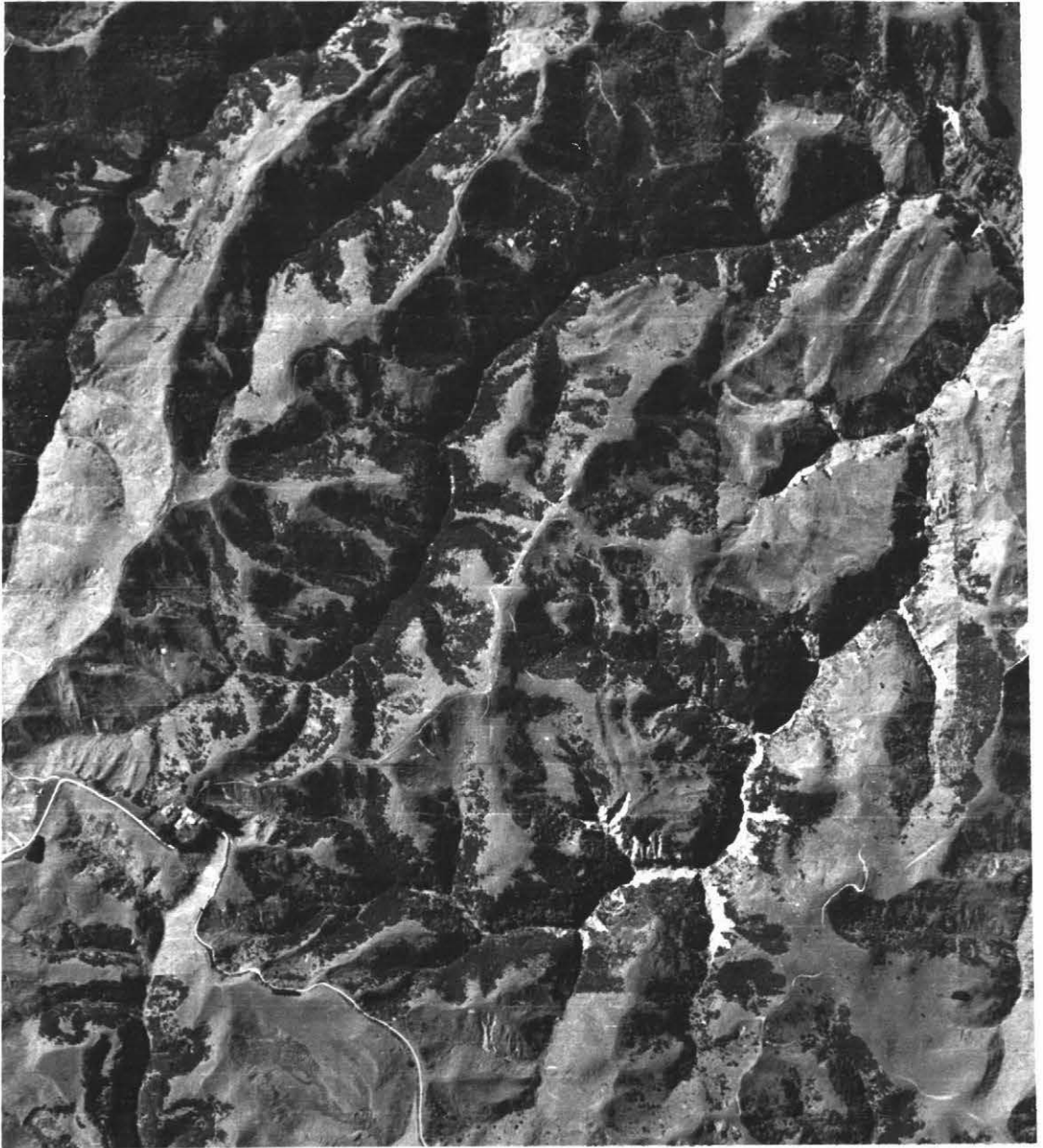


PLATE 5.8

1958 Aerial of Study Area Showing Increased Regenerative Cover.

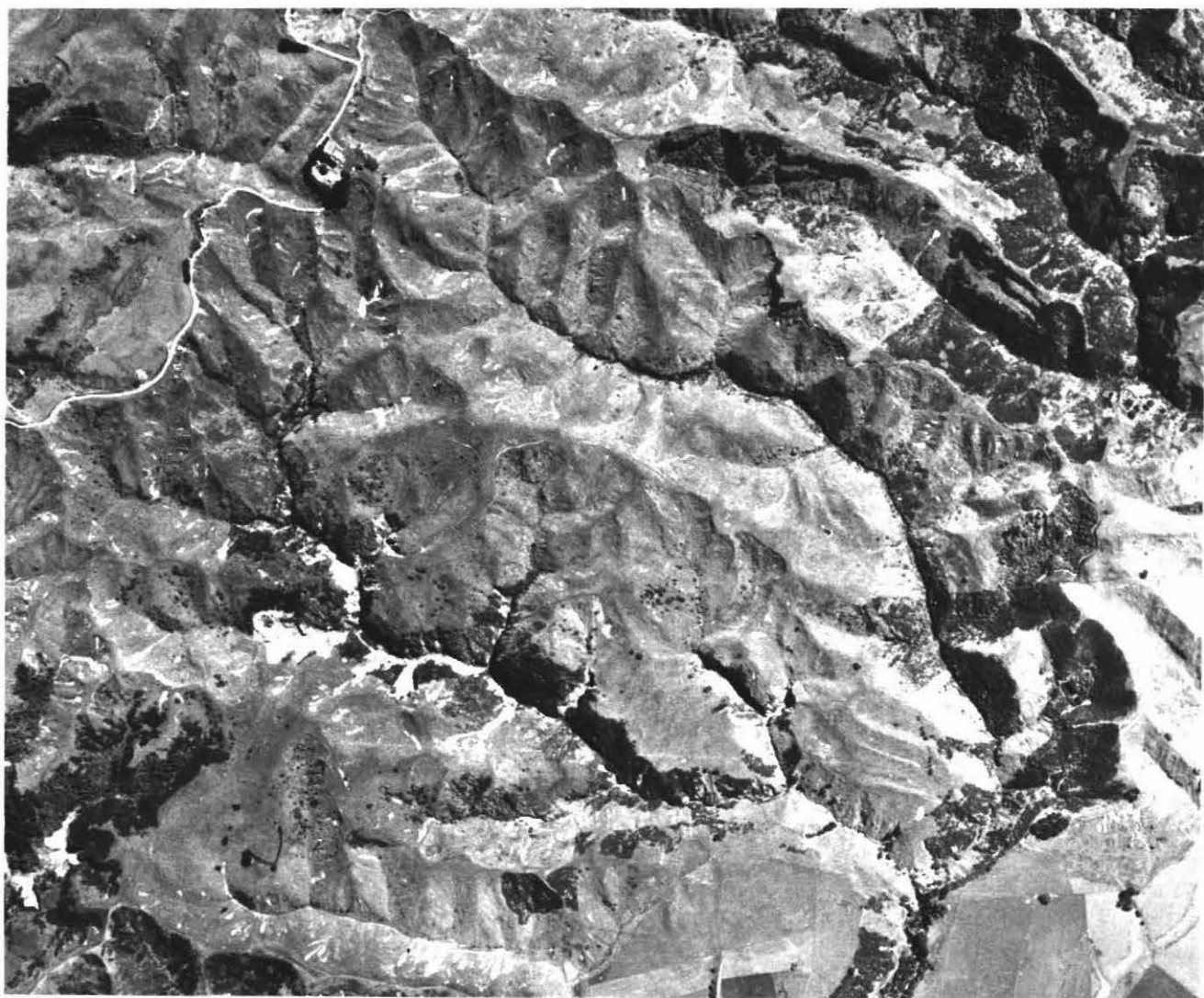


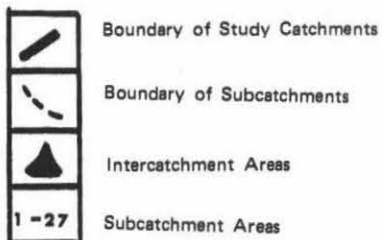
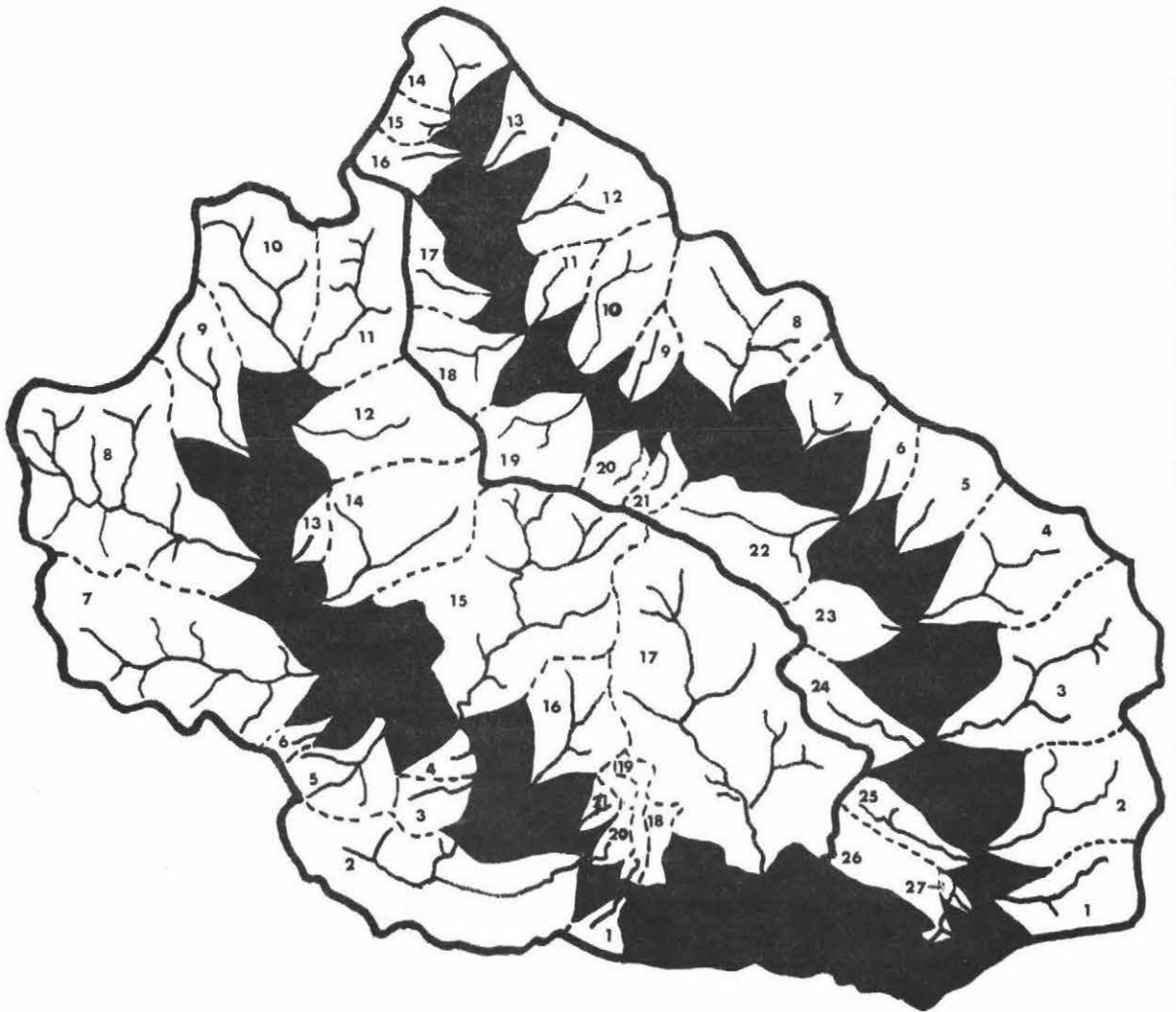
PLATE 5.9

1966 Aerial of Study Area Showing Increased Incidence of Slips

FIGURE 5.7 ANALYSIS OF THE SUBWATERSHEDS

OF THE STUDY WATERSHEDS

SCALE 1:16,300



could have some bearing on time of concentration of floods and runoff in general. Thus an analysis over a larger number of examples could yield some interesting information.

Table IX records the results of measuring the areas of the subwatersheds of the two catchments.

TABLE IX : Analysis of Subwatersheds

Areas of Subwatersheds (ha)		
Subwatershed No.:	No. 1 Catchment :	No. 2 Catchment :
1	1.54	6.55
2	15.85	9.86
3	2.60	15.40
4	1.54	10.45
5	4.21	5.62
6	1.27	2.52
7	1.94	4.14
8	2.20	11.25
9	6.23	2.21
10	10.37	6.55
11	10.58	2.67
12	7.21	7.96
13	1.40	2.87
14	10.85	4.94
15	21.90	1.54
16	6.03	2.53
17	33.50	3.02
18	1.41	4.94
19	1.41	5.68
20	1.74	2.40
21	0.87	1.81
22		8.15
23		4.14
24		4.55
25		2.94
26		4.35
27		4.01
TOTAL ..	184.0	140.0
Average Size ..	8.69	5.16
Total inter-catchment area	56 ha	60 ha
(by difference from total area)	23%	30%

There are a larger number of subwatersheds in Number 2 catchment than in Number 1, and the average size is smaller. Also the inter-catchment areas make up a larger proportion of the whole catchment than in Number 1 catchment. These factors could have an important bearing on the hydrological characteristics of the catchment. However, this sort of analysis would have to be carried out on a larger number of catchments on the same geologic material under the same climatic regime to really be able to make any conclusions from these measurements.

5.3.2. Slope Analysis

(1) Construction of Formlines

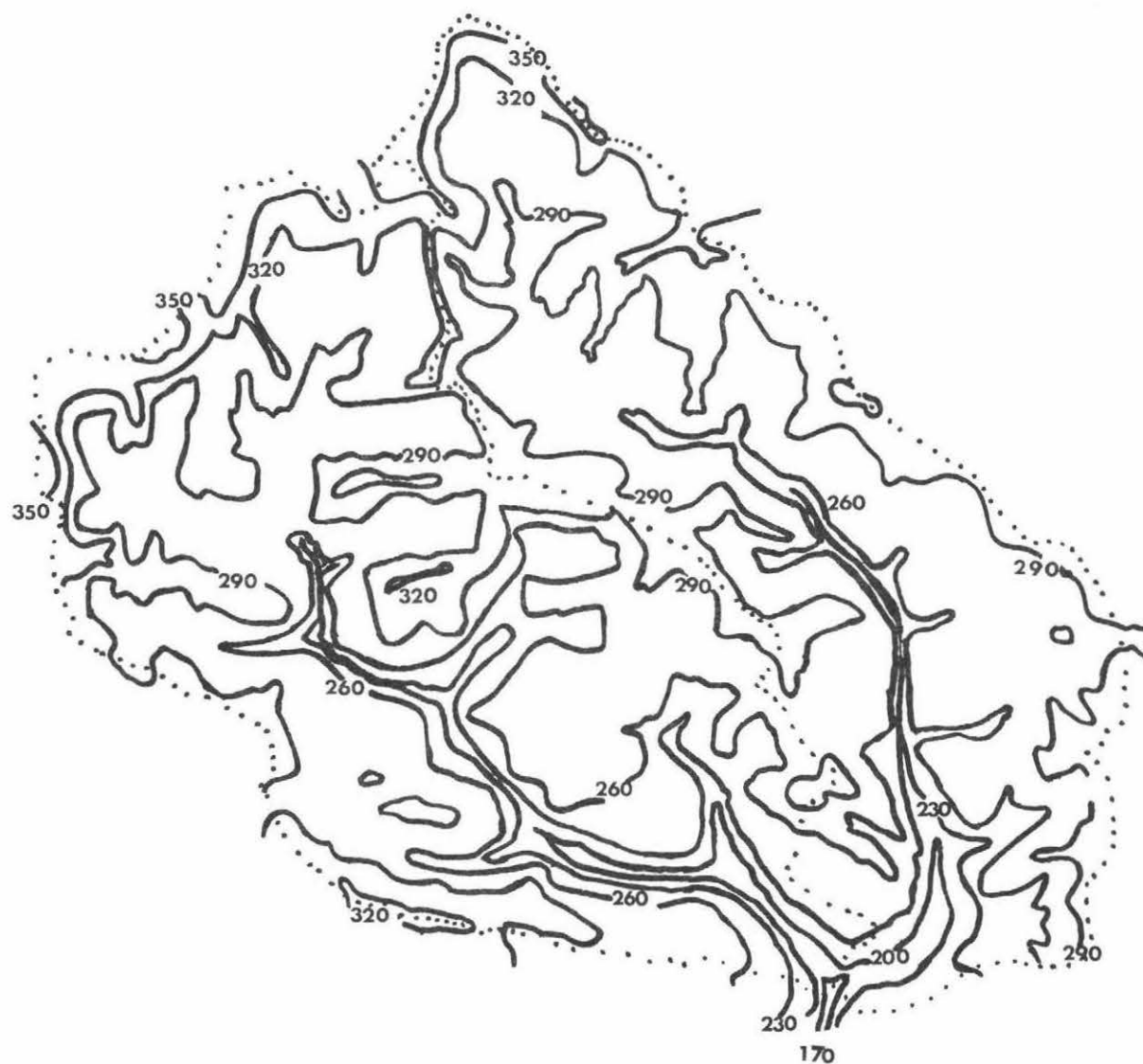
Figure 5.8 shows the resultant formline or contour map of the study area. These were originally constructed in 50 foot and 100 foot contours, but are shown in metres on the final map. The original 50 foot contours were so close together in places, due to the steep slopes, as to be confusing. Thus the 100 foot contours were considered more useful for any calculations that had to be made.

(2) Determination of Average Slope

There was a small difference in the average slope angle obtained depending whether the 50 foot contours or 100 foot contours were used. The result using the 50 foot contours would have been the most accurate, had the contours themselves been more accurate. The average slope angle for Number 1 gully was slightly greater than that measured for Number 2 gully: 22° as compared with 20° , using the 100 foot contours. This is reflected in the higher proportion of erosion prevalent over the Number 1 Catchment.

Appendix XIII gives the results for this exercise.

FIGURE 5.8 CONTOUR MAP



SCALE 1:16,300

Contour Interval 30 m

..... Boundary of Study Catchments

(3) Construction of Generalized Contours

Figure 5.9 shows the distribution of generalized contours over the study area. These show the initial form of the landscape before it was so deeply dissected by the rejuvenating gullies.

(4) Stream Profiles

Figure 5.10 shows the stream profiles of the two catchments. The data from which these are plotted is given in Appendix XIV. This figure clearly shows the greater degree of degradation that has occurred over the lower part of Number 1 catchment as compared with Number 2 catchment, and the steeper nature of the streambed in the upper reaches. Plotting the points at such wide intervals has resulted in the ironing out of all the smaller irregularities in the channel. The construction of the concrete dams in the lower reaches of Number 1 has now resulted in a degree of aggradation in the stream bed over this lower portion. However, there is still a vast difference in the amounts of sediment that have been removed from each gully as seen from the differences in the levels of the two channels.

The slope over the entire Number 2 gully is more uniform than that of the Number 1 gully, and interrupted only by three small waterfalls. From ground observations, these three waterfalls appear to be relatively stable. The waterfall in the Number 1 gully, however, is actively eroding at the bottom and could precipitate a further series of headward gully movement if it should collapse. A vast volume of sediment would then be degraded to achieve a uniform slope up the gully.

(5) Valley Cross Profiles

As suggested when outlining this technique, no results were obtained using this method for reconstructing the original stream profiles. However, this would be a valuable exercise to carry out by ground survey as

FIGURE 5.9

GENERALIZED CONTOURS

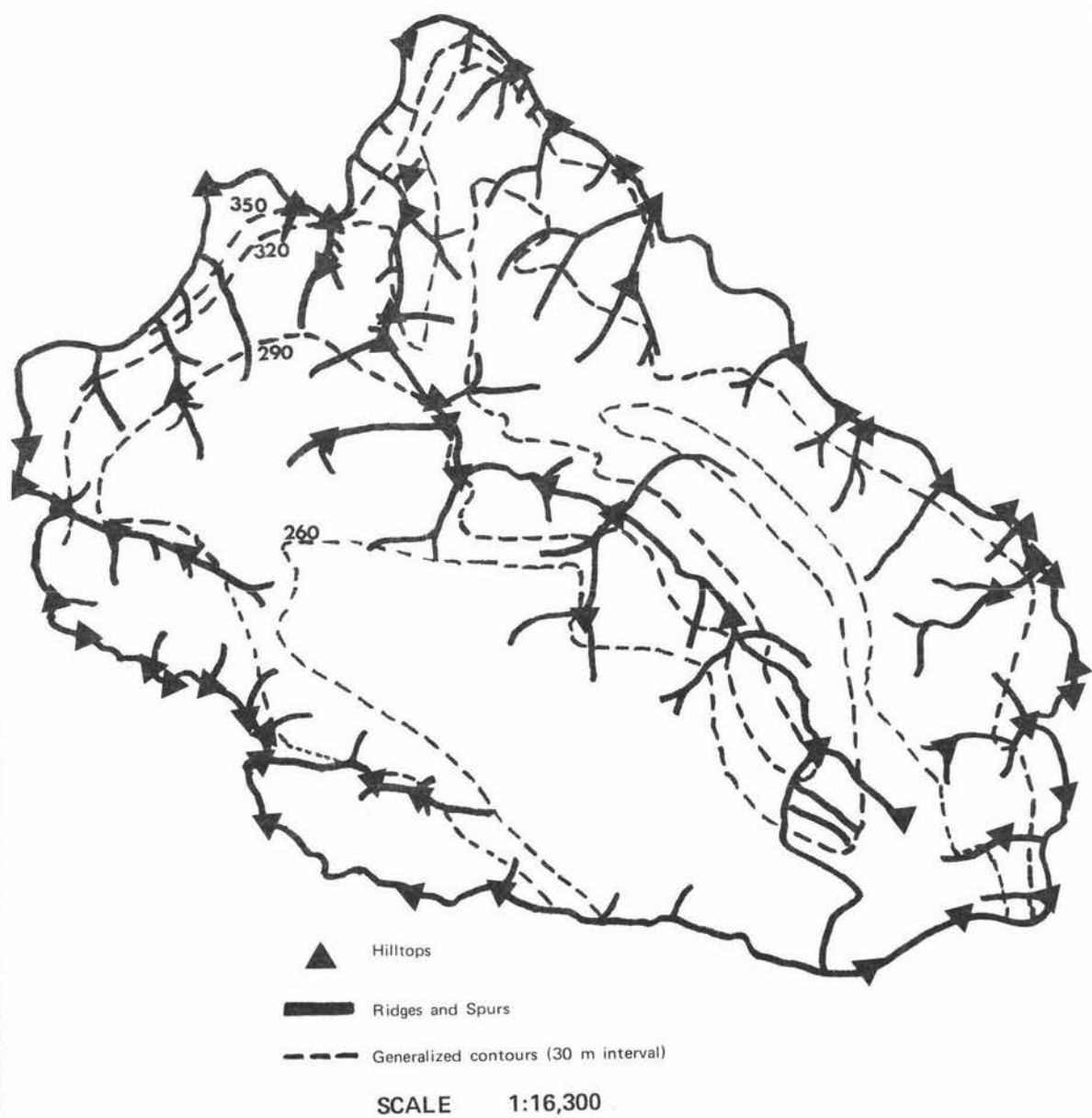
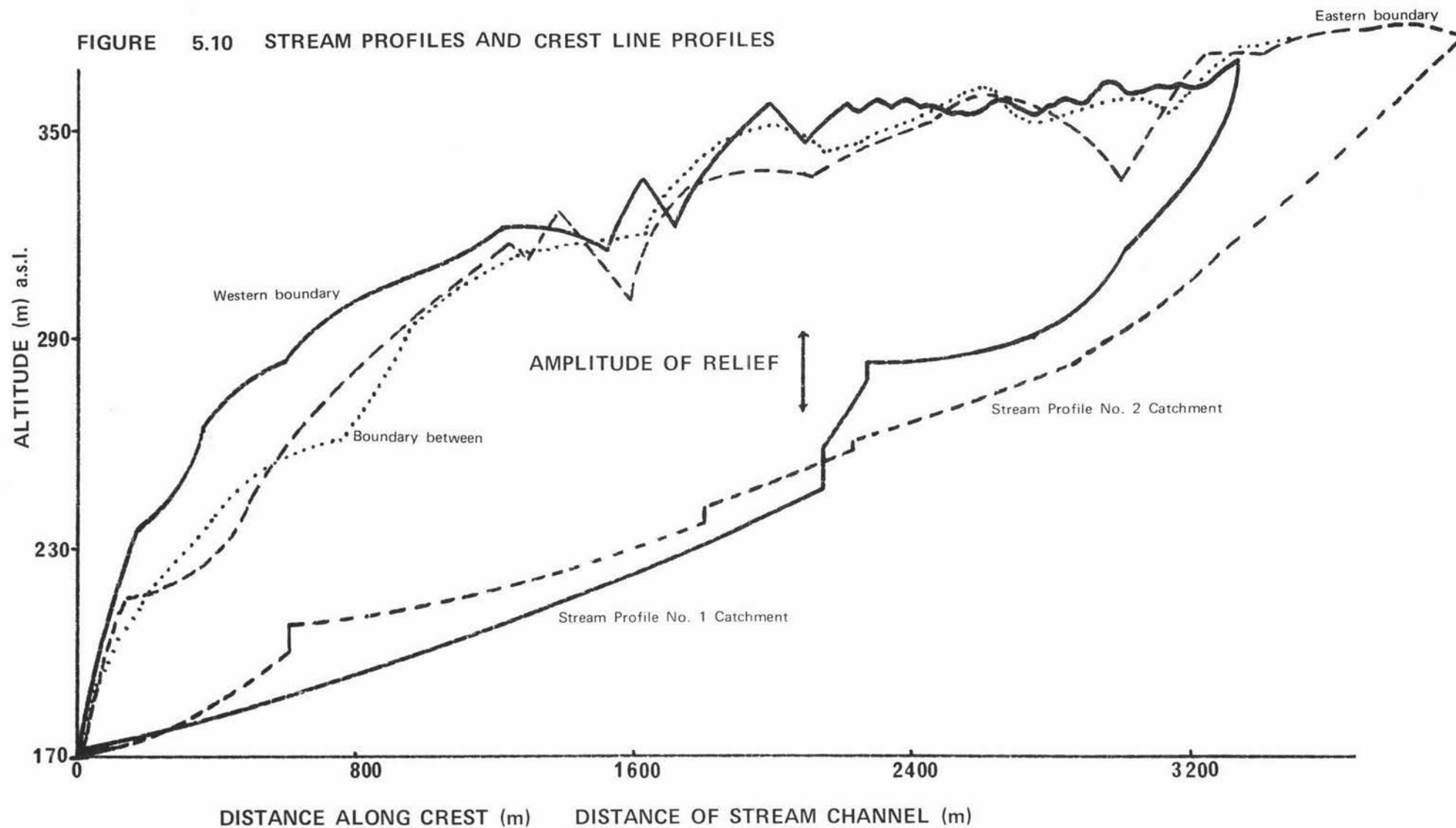


FIGURE 5.10 STREAM PROFILES AND CREST LINE PROFILES



it would enable the amounts of sediment removed during the period between the present and the reconstructed original stream profile, to be calculated, in conjunction with the previous exercise.

(6) Crest-line Profiles

These were drawn and plotted on Figure 5.10 with the stream profiles to give an indication of the amplitude of relief. The raw data from which these were constructed is included in Appendix XIV.

These illustrate the form of the divides between and on either side of the two catchments and reveal the windgaps and other down-sags in the ridges. The amplitude of relief, (the vertical distance between the valley bottom and the hill crests) is also demonstrated. This gives an idea of the elevation of the initial surface before rejuvenation deeply dissected the area.

(7) Projected Profiles

The three projected profiles of the study area are shown in Figure 5.11. As these are merely the foreshortened crest-line profiles, the raw data from which they were constructed is also included in Appendix XIV.

(8) Construction of Area-Height and Hypsometric Curves

These are shown in Figures 5.12 and 5.13. The raw data for their construction is given in Appendix XV.

Both the Area-height and Hypsometric curves are very similar for both catchments. Thus it is not a difference in altitudinal range over the two watersheds that leads to the observed hydrological differences. In other regions however, these techniques could show distinct variations in altitudinal distribution of area for catchments of varying erosion potential.

FIGURE 5.11 MULTIPLE PROJECTED PROFILES

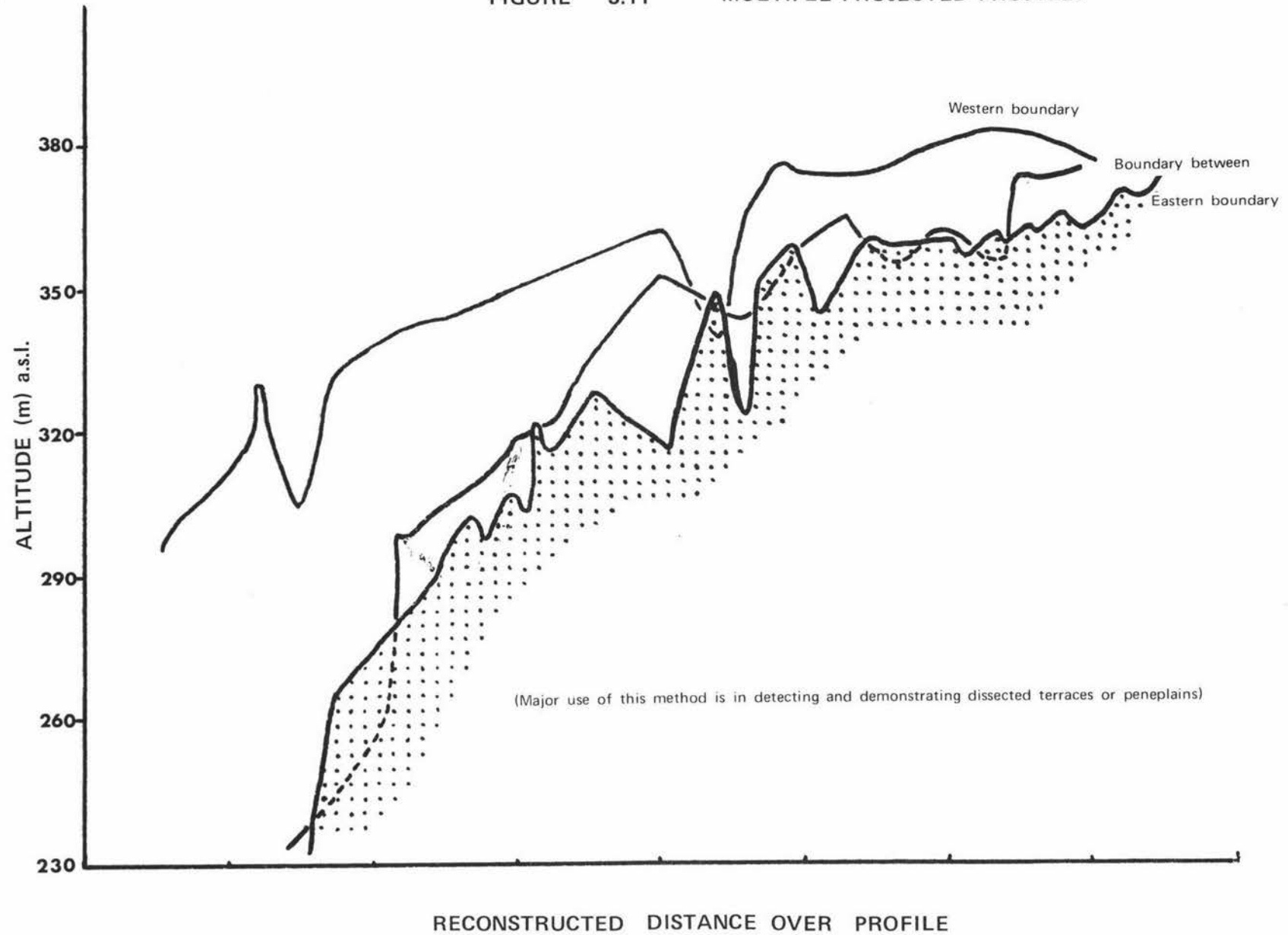


FIGURE 5.12 AREA HEIGHT CURVES

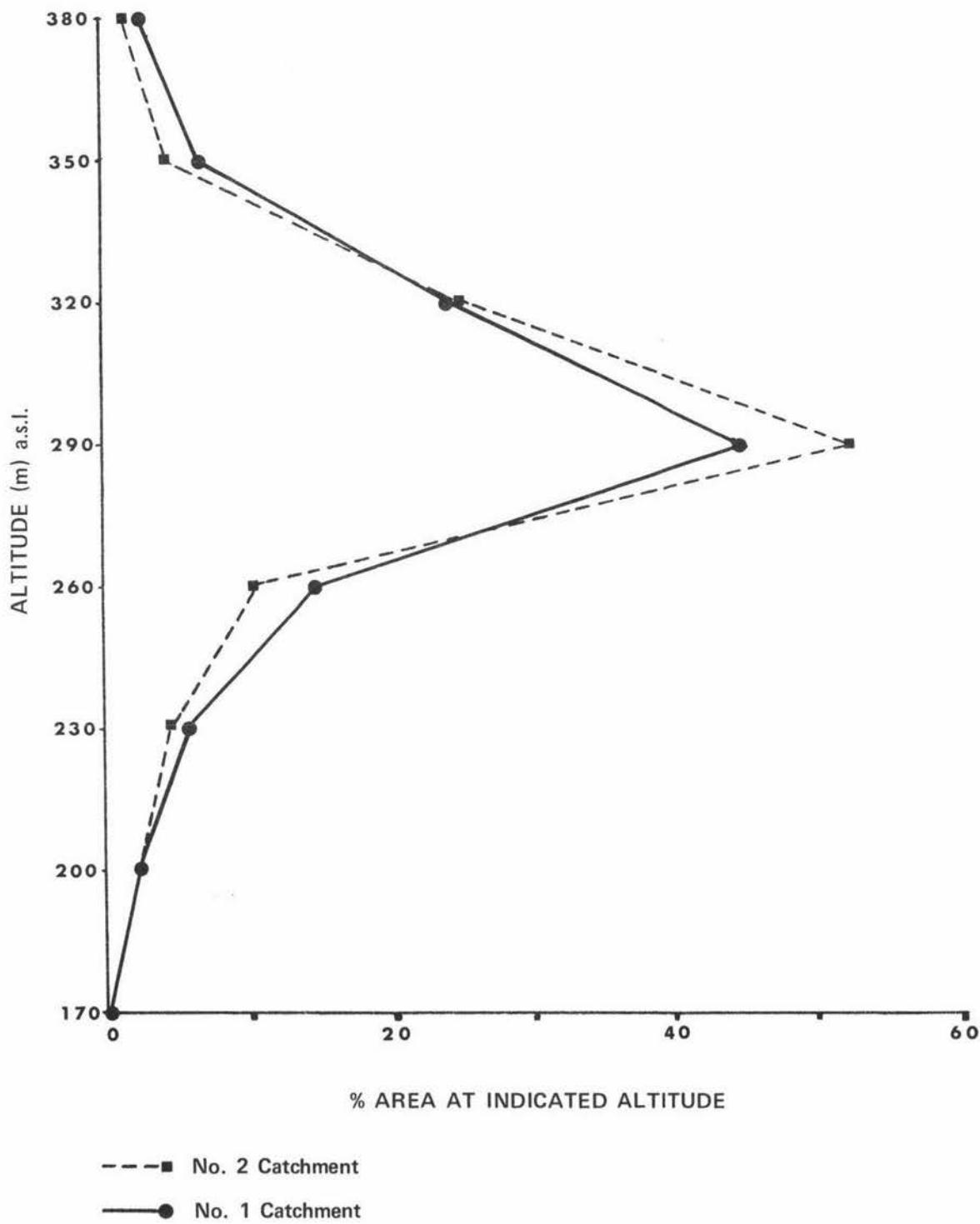
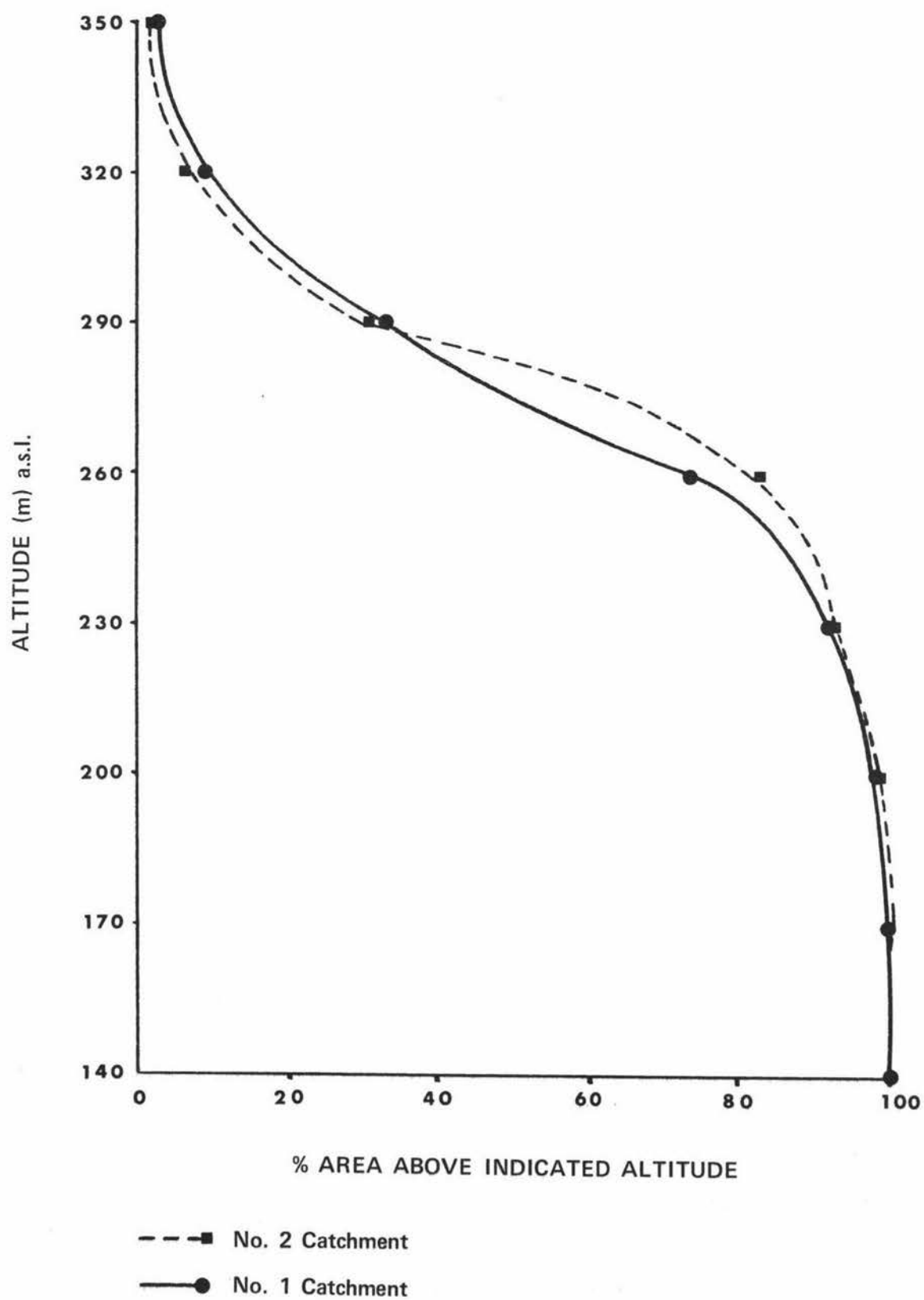


FIGURE 5.13 HYPSONETRIC CURVES



(9) Quantitative Aspect Determination

As suggested when outlining this exercise,, this technique was unsuited to the nature of the study catchments. However, in a region where the dissection is less, and where areas of a similar aspect are larger and not so broken up, this method would be a rapid and simple way of determining the percentage of the total area occupied by the different aspect classes. This could also assist in planning of fencing to separate sunny and shady faces.

5.3.3. Drainage Analysis

(1) Patterns of Drainage

Figure 5.14 shows the drainage network over the study catchments. The surrounding drainage pattern over the adjacent area of the anticline between the Pohangina and Oroua Rivers is shown in Figure 5.15. Reference to Zernitz (1932), Parvis (1950), The American Society of Photogrammetry (1960), and Avery (1970) led to the conclusion that the drainage pattern of the study area is basically subdendritic. Number 1 Catchment tends to be more dendritic; Number 2 catchment is narrower with shorter tributaries. The longer lengths and greater profusion of tributaries on the upslope side of Beehive Creek make the drainage pattern here, somewhat assymetrical.

Dendritic drainage, of which subdendritic drainage is a modification, is the most common type of drainage and is formed where the rock structure does not interfere with the free development of streams. Subdendritic drainage patterns closely resemble the dendritic type but show minor slope control of the second and third order streams and result from streams flowing from a non-resistant material area, through another of slight structural control, according to Parvis (1950).

FIGURE 5.14 DRAINAGE ANALYSIS

SCALE 1:16,300

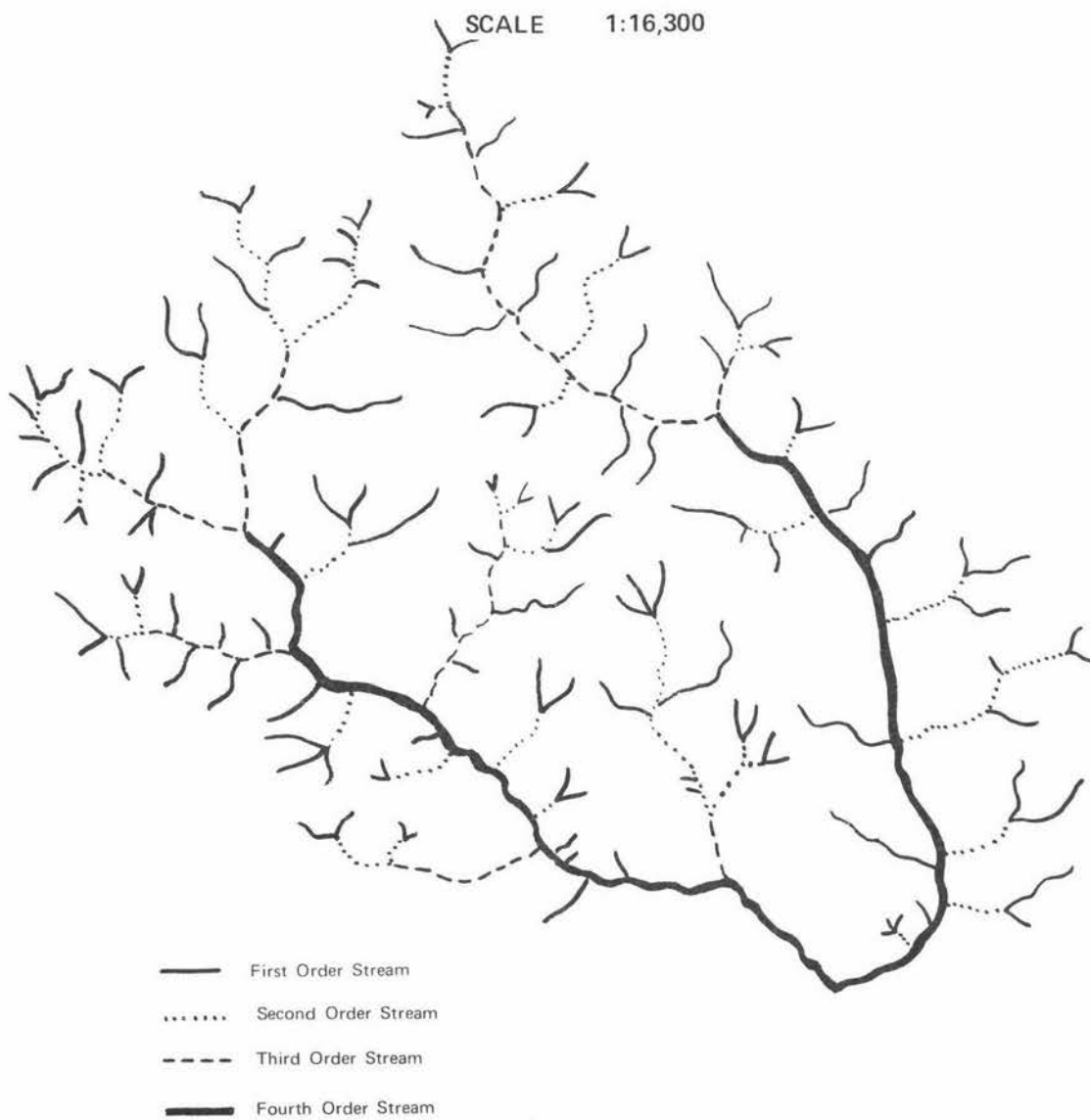
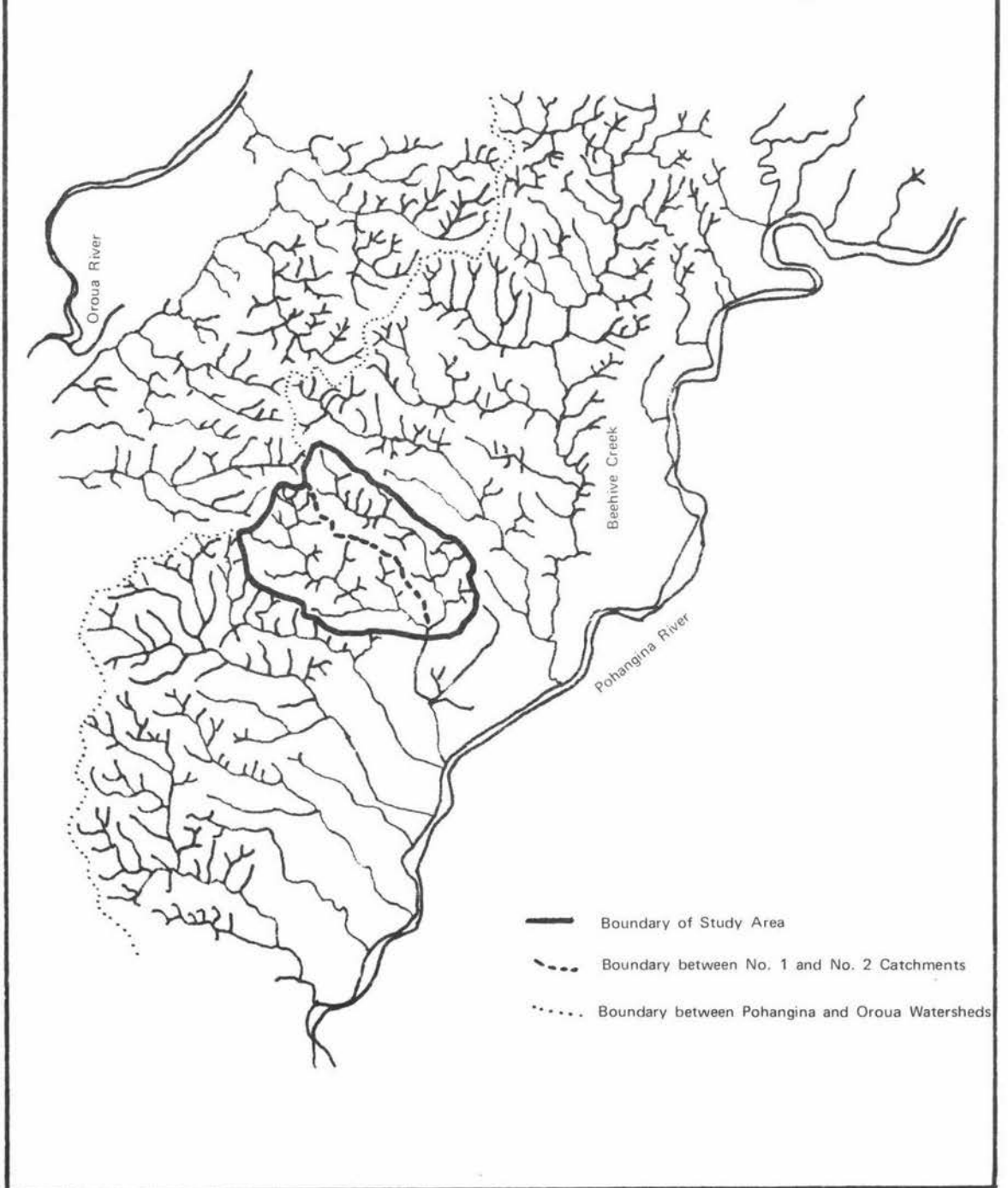


FIGURE 5.15 SURROUNDING DRAINAGE

NETWORK BETWEEN THE POHANGINA AND OROUA RIVERS



(2) Hydrographic Network and Texture
of Drainage

Table X records the measurements made on the drainage patterns. These are all the means of four independent measures.

TABLE X : Analysis of Drainage

	<u>No. 1 Catchment : No. 2. Catchment:</u>	
Total No. of Streams	106	65
No. of Streams per unit Area	0.44/ha	0.33/ha
Total length of Streams	16.7 km*	12.0 km
Length of streams per unit area	69.5 m/ha	60.0 m/ha
(Drainage Density or Texture)		
Total valley length	29.8 km	27.6 km
Total valley length per unit area	125 m/ha	138 m/ha
(Texture of Dissection)		
Ratio of Valley Length to Stream Length (Index of Drying up)	1.8*	2.3
No. of Confluences	75	46
No. of Confluences per unit area	0.31/ha	0.23/ha
Ratio of total length of Tributaries to Main Trunk	7.1	5.6

* misleading values

Firstly, there is both a greater number and length of streams per unit area in Number 1 catchment. However, it must be pointed out that much of the so-called "stream" length in this catchment, is not really water length as such, but dry sandy aggraded channel. Actual total water length is in the order of 0.5 km. Also in the Number 2 channel there is part of the stream length that has no water flowing down it for most of the year.

Thus, the drainage density (or texture) of the Number 1 catchment is slightly greater (or finer), than that of Number 2 catchment. Well developed drainage patterns are usually indicative of relatively low infiltration and relatively impervious materials, Lueder (1959). In the situation of the study area, the unconsolidated parent material is by no means impervious. However, this slightly better developed drainage pattern in the Number 1 catchment may indicate that this catchment is slightly less pervious and has a slightly lower infiltration capacity than the Number 2 catchment. This in turn would lead to an increased amount of runoff and thus a greater degree of potential erosion, as is evident in practice.

Because the total length of streams was misleading in that not all the length was actual streamflow, so are the figures obtained for Texture of Dissection and the Index of Drying up misleading. In both cases the Index of Drying up would in reality be much higher. A more realistic value of this measure would be 59.6, ($29.8/0.5$ from Table X). No such correction has been attempted for the Number 2 catchment, but the figure could also be expected to be many times greater than that in the Table.

Much of the valley length as measured for the Texture of Dissection was not actually "valley length" as such, but small indefinite first order channels and incipient gullies only carrying water in flood events.

The higher ratio of Total Length of Tributaries to Main Trunk in the Number 1 gully, and the greater

number of confluences per unit area relate to the observation that the Number 1 catchment tends to be less subdendritic than the Number 2 catchment.

(3) Channel Orders

Figure 5.14 shows the composition of the drainage for the study catchments. Table XI gives the results of the measured lengths and numbers of the different stream orders.

TABLE XI : Analysis of Drainage Composition

Stream Order :	<u>No. 1 Catchment</u>				<u>No. 2 Catchment</u>			
	1st :	2nd :	3rd :	4th :	1st :	2nd :	3rd :	4th :
No. of Streams	79	20	6	1	48	14	2	1
Total Channel length	8.25	3.76	2.68	2.07	6.17	2.48	1.45	1.82
Average Stream Length (m)	104	188	447	2060	129	177	724	182
Length of Channel per unit area (m/ha)	34.4	15.7	11.2	8.6	25.7	10.3	6.0	7.6
No. of Channels per unit area (per ha)	0.33	0.08	0.03	0.004	0.25	0.07	0.01	0.00
Expressed as % of Total Drainage Length %	49.3	22.4	16.0	12.3	52.0	20.7	12.1	15.1
No. of Channels expressed as % of Total No. of Streams	74.5	18.9	5.7	0.9	73.8	21.5	3.1	1.5

Looking at the lengths of the different stream orders expressed as a percentage of the total drainage length, the values for the two catchments are very much the same. Number 2 catchment has a slightly larger percentage of its total drainage length as fourth order channel. There is much greater channel storage capacity in the higher order streams, especially in the main trunks of the study area streams, due to their infinitely larger cross-sections. This can be an important factor in modulating flood peak intensities. However, whether this difference is sufficiently large to have a significant effect in this respect, is debatable. However, it is a known fact that the flood peaks in Number 1 catchment are more erosive and carry a much greater sediment load than the equivalent flood in Number 2 catchment.

The greater length of first order channels per unit area in Number 1 catchment, could be important as potential sites for incipient gullyng. They would also reduce the distance of overland flow before a drainage channel was reached, thus reducing interception by vegetation and percolation through the soil. As a result, a greater proportion of the precipitation would end up as runoff than in the Number 2 catchment.

(4) Headward Gully Movement

The differences in headward gullyng between 1958 and 1966 are recorded in Table XII.

TABLE XII : Changes in Headward Gullyng from 1958-1966

	<u>No.1 Catchment</u>		<u>No.2 Catchment</u>	
	1958 :	1966	1958 :	1966 :
Headward Gullyng as a percentage of the Total Drainage Length.	35.4	47.5	21.4	21.4

Thus the extent of active gullying had increased by some 12 percent of the total drainage length over the period 1958 to 1966, in the Number 1 gully. This is equivalent to 12 percent of 16.7 km which is a distance of 2 km over the whole of the Number 1 gully system in 8 years.

This is an advancement of the headward gully erosion of 250 m per annum.

The Number 2 gully appeared to have remained static over this time period.

* * * * *

CHAPTER SIX

DISCUSSION AND CONCLUSIONS

6.1. FIELD MEASUREMENTS AND OBSERVATIONS.

6.1.1. Stream and Flood Flows

The main difficulty encountered in trying to compare the dry weather and flood flows from the two catchments was the lack of applicability of the standard methods of measuring stream discharge. This was due to the extremely low dry weather flows, the shallow depth of all flows, the extremely high sediment loads and the non permanent flow over the entire length of the drainage systems.

Current meters are impossible to use in small shallow channels. Radioactive tracers were too expensive and not available anyway, as radioactive isotopes with extremely short half lives are necessary for this type of work to minimize radioactive contamination of the drainage system. Chemicals such as salts and dyes for measuring flow rates and time of concentration of floods were inapplicable for a number of reasons. Firstly, it was impossible to predict the onset of a flood producing rain, let alone travel 35 km at any hour of the day or night to instigate measurements. Secondly, the required detection equipment was not available and thirdly, the streamflows were such that access to their sources was both unpredictable and difficult. This was because the streams were dry for a certain proportion of their lengths and the distance of actual flow varied throughout the year. During actual flood flows access even to the recording sites could be difficult as the channel below the confluence of the two streams had to be crossed a number of times.

Statistical methods for analysing flow data were inapplicable. Had daily discharge been measured,

the conventional methods of hydrograph and base flow analysis could have been carried out. Similarly, lack of long term rainfall records limited the statistical approach to analysing morphometric data and correlating it to stream-flow data.

Thus although rough measurements of flood flows were made, because they were not able to be measured at intervals throughout the flood event, and because it was not known whether they were rising or falling at the actual time of measurement, there was no way of relating discharge to velocity, depth, precipitation or sediment load. However, for the Number 1 catchment a discharge of 21,500 l/min was recorded during the 10 March storm. In comparison, the dry weather flow for the preceding month was only 9 l/min. This tends to emphasize the nature of the flash floods that can occur in this district in small streams. The corresponding flows for the Number 2 catchment were 48,000 l/min and 59 l/min.

Despite the smaller sediment load and less eroded and gullied nature of the Number 2 catchment, the actual water discharge was greater for both dry weather and flood flows for all the measurements made. Whether a sufficiently representative number of measurements were made in times of flood is debatable. Total flood discharge could not be calculated. Rate of rise and fall of flood levels were also unknown. Thus all we can say is that the instantaneous flood flows as measured were higher for the Number 2 catchment than for the Number 1 catchment. There may or may not have been a higher total flood discharge.

Why the dry weather flows were always smaller in the larger area Number 1 catchment can only be explained by suggesting that the interflow and baseflow through the sandy aggraded streambed accounted for most of the flow in this situation.

6.1.2. Sediment Loads

The annual suspended sediment yield of the two catchments could not be calculated due to the lack of continuous flow records and lack of data for constructing a sediment rating curve. As seen from the literature, where sediment rating curves are available, these greatly facilitate predictions of sediment discharge, as standard tables are available for converting suspended sediment concentrations into weight of material eroded from a catchment.

As explained in the previous section, tracer and chemical methods were not applicable to the study area situation. Turbidity measurements for estimating sediment loads are also not applicable because of lack of records for calculating the turbidity/sediment relationship. Bed-load was too difficult to measure. Thus the results obtained can only be taken as giving an indication of the instantaneous sediment load in the particular flood events measured. Some measures were taken on rising floods; some after the flood peak. This means that, as for flood discharge, no correlations could be made with other factors such as rainfall and depth.

The results merely illustrate the magnitude of sediment load that may be carried by the two streams during flood events. For the 10 March flood, the instantaneous erosion rate was 1,000 kg/ha/hr for the Number 1 catchment. A figure for comparison is the value of 130 kg/ha/hr obtained from a 10,250 ha mainly forested catchment as measured at the Piripiri Bridge on the 22 September, 1969, (M.C.B. Files). The corresponding instantaneous erosion rate for the Number 2 catchment was 234 kg/ha/hr. In other words, extremely high amounts of sediment are moved by the two study catchments during flood events. Although the flow in Number 2 catchment is considerably greater than that in Number 1, the suspended sediment load in Number 1 is considerably higher. This is of course reflected in the higher proportion of the Number 1 catchment that is

suffering from gully erosion.

Sediment yield in small catchments was seen to be largely a function of rainfall energy, rainfall intensity and vegetative cover characteristics, (McGuinness et al 1971). As discussed in a later section, the vegetative cover of the two catchments is considerably different and thus possibly accounts for a large proportion of the variation in sediment yields between the two catchments.

Although a number of workers have used aerial photographs to study sediment transportation and deposition, this was not very applicable because of the steep sides of the gully walls and concealing vegetation restricting the view of the gully floors.

6.1.3. Erosion

From the sequential studies using aerial photographs to analyse the changes in erosion from 1946 - 1972, the main change noted was the decreased incidence of slip erosion over both the study catchments. In 1946, there was a high incidence of areas exposed by slips. This had decreased substantially by 1958 and then increased to an intermediate level in 1966. By 1972 slipping had once again decreased in importance. At the same time regeneration had altered in the opposite direction. Thus there was an inverse relation between the incidence of slipping and scrub infestation. It can be suggested here that a vegetative cover of scrub and regenerating bush provides some protection against slipping. This suggestion is backed up by evidence quoted in the literature, as well as the measurements carried out on the photographs.

Throughout the period 1946 - 1972, Number 1 catchment exhibited a higher incidence of total erosion on both an areal basis, and lineal basis (headward gully movement), than Number 2 catchment. Similarly, Number 2 catchment exhibited a far greater proportion of its area under regenerating scrub and bush, throughout this

period. Over the period 1958 - 1966 the headward gully movement in the Number 2 gully appeared to be static. In Number 1 gully there was an extension in the headward erosion of the gully equivalent of 250 m/yr. This was taken over all the tributaries that were actively gullyng as well as the main channel, and thus does not mean that the main gully was eroding at this rate. It is the total figure for the whole watershed.

From the general observations made throughout the study, and supporting evidence in the literature, the following points emerge. Firstly, the erosive nature of the study area is directly related to the geology - i.e. the unconsolidated Castlecliffian Sands, and stage of rejuvenation. Secondly, removal of the original bush vegetation and replacing it with a pasture cover of poor interception qualities, led to a number of complications. The less extensive root systems of the pasture species were not as conducive to a favourable soil structure as the original bush roots; consequently there was a reduction in the proportion of macropores in the soil, (this was further accentuated by trampling and consolidation by stock) and a reduction of storage capacity in the soil. Thus, infiltration and percolation rates were decreased, with the resulting increase in runoff and thus greater likelihood of erosive floods. This was particularly serious on the steeper slopes, as steeper slopes have an increased proportion of rainfall lost as runoff anyway.

Similarly, the decreased interception ability of the pasture meant a larger proportion of the rainfall resulting in runoff.

The geological process of rejuvenation is very active in cutting down the relief to lower levels. Thus, there exists the situation of a high rate of geological erosion as well as accelerated man-induced erosion, because of the nature of the erosive sediments and continuing uplift of the anticline.

However, much of the man-induced damage could have been avoided. Similar gullies in the same district were brought to the attention of the Manawatu Catchment Board before 1950, e.g. Tew's gully. Subsequent erosion control measures have practically stabilized this gully. The two gullies in the study area, however, were not included in a Conservation Farm Plan until 1969, twenty years later, by which time the situation could be described as almost beyond control. Since then, the conservation measures have shown a degree of success. The two concrete dams installed filled up with sediment remarkably rapidly, and are reducing the degree of degradation of the Number 1 gully floor. Many of the poplar poles planted on the gully sides and floors have survived although the mortality rate has been high. However, these are merely minor efforts as evidenced by the active gullying and high sediment loads still produced.

Stock in the gullies are contributing to the instability, by compacting the ground and reducing the infiltration capacity. The action of their hooves also contributes to minor slippages and further exposure of more substrata. Grazing reduces the effectiveness of the vegetative cover in protecting the soil against rain impact. Until more fencing is done to keep these animals out of the gullies, these effects will persist. It is thus suggested to completely retire the gullies and increase the vegetative cover. This means permitting regeneration of native bush and scrub to continue uninhibited. Supplementary planting of conservation species such as poplars and willows, and plants such as lupins, which will establish on the vertical walls, or even converting the gully systems to farm forestry, will also be necessary. Further concrete dams may also be required to assist in stabilizing the streambed.

Perhaps the most serious error was made last century, when the land blocks were surveyed. At this time there was no appreciation of the watershed as a unit. Blocks were surveyed in straight lines regardless of contour or watershed boundaries. This has complicated the

management of individual catchments as entities. What happens in the adjacent property is of little concern to the owner of the rest of the watershed until drastic effects are felt. If on the other hand the headwaters were owned and farmed by the same individual, a greater appreciation of the overall situation would be evident. In the situation of the study area, amalgamation of the two properties that constitute the major part of the two watersheds, would lead to a more economic farming venture, a better appreciation of the gullying problems and hopefully better control measures.

Alternatively, planting a large proportion of the study area in Pinus radiata as has been done with considerable success in Moars' gullies in the same district, would be another means of achieving control. Whichever method is adopted, will mean treating the whole area as a watershed unit.

6.1.4. The Effects of Rainfall and Climate on Erosion

Although Te Awa and Culling's gullies are only a short distance apart, there was nearly 200mm higher rainfall recorded for Culling's gully than for Te Awa in 1972. Also the date and amount of the maximum daily rainfall for that year was considerably different. Thus it is difficult to extrapolate any information from the Te Awa long term rainfall record and relate it to the study area. However, despite the localized differences between the two areas, it was noted from the Te Awa rainfall figures that the rainfall since 1969 has been abnormally low in comparison with the figures for previous years. The normal annual rainfall for Te Awa is quoted as 1016 mm, but the mean for the years 1969-1972 is only 810 mm. Whether the same situation exists for the study area is not known.

It was seen from the literature that the erosion produced as a result of one rainfall event, can seldom

be compared with that produced by another because of the differences existing between antecedent moisture content, soil conditions and vegetative cover. Thus, just because the highest amount of rainfall was experienced during the March 10 storm in 1972, does not necessarily mean that this storm was the most erosive or damaging, even though this appeared to be so.

It is well documented that the most erosive storms are the high intensity short duration events that occur with low frequency. Total annual or monthly rainfall, is not correlated with erosion. It is the variability of the precipitation that is of greatest importance, especially in an area with such a readily erodible substrata, which has undergone such drastic changes in vegetative cover. If such high intensity rains occur at times when the ground cover is least prepared to deal with it, very severe effects may result. For example the major storm in February, 1936, occurred at a time when the vegetative cover was incompetent as a protective cover. The accelerated cycle of most erosion in the Pohangina County can be dated from this storm (Greenall et al, 1951). Other severe storms prior to this date included those of 14/4/1895 and 12/5/1902, which would have occurred very soon after the study area was cleared of bush. These obviously would have major effects in removal of the high fertility resulting from the bush burns. In July, 1926, there was another severe storm which would have occurred at a time when the soil and substrata was saturated and when attempts were being made to clear the scrub and fern from the study area. The autumn 1949 storm is recorded to have deposited up to 1 m of sand on approximately 40 ha of river flats at Te Awa. No doubt severe effects would also have been felt over the study area, adding to the area of slipping measured in the 1946 photographs. Subsequent storms would have had similar effects. For example, 79 mm of rain were recorded at Te Awa on 22 January 1961 and 61 mm on 20 December 1965. These high intensity short duration storms in

conjunction with the clearing of a substantial area of scrub from both catchments, probably contributed to the increased amount of slipping recorded on the 1966 photographs.

Leenards (1971) makes reference to a major flood in May 1971 changing the pattern of meander of the Pohangina River. This flood would have contributed greatly to the build up of sediment behind the newly installed dam in Number 1 catchment.

It is also suggested that as well as short duration high intensity rainfalls contributing greatly to the erosion problem, there may have been long term changes in rainfall and climate that may have had similar effects. It would be an interesting exercise to examine the rainfall records available from the surrounding districts to see whether there have been changes in the pattern of low intensity and high intensity rainfalls over the period since 1890. A high frequency of large falls at times when the land is insufficiently protected by vegetation would have more severe effects than high frequencies of low intensity rainfalls under the same conditions.

Grant (1971) reported that the climate of the North Island has been more variable since the 1930s. It is since then that the erosion problems in the study area have become more apparent. Runoff was reported as being greatest from 1890 - 1910 with higher rainfalls over this period than in subsequent years. These two factors could have had a profound influence on the erosion problem because this was the period when the greatest changes in the vegetative cover were being experienced. The 1890s are also considered the stormiest years since records commenced in 1890. The years 1930 - 1960 were then more stormy than the period from 1901 - 1930. The effect of temperatures having risen from the turn of the century, with a marked increase in the 1940s and 50s could also have had a profound effect on the cycle of erosion.

Thus long term changes in rainfall regimes and temperature can satisfactorily explain many of the problems that have arisen this century. These have generally been attributed to changes due to land development. It is thus suggested that man's cultural activities have merely accentuated the effects resulting from the climatic changes. Possibly the greater storminess in the earlier period paved the way for the drier period to follow, thus resulting in man's influence being more destructive than it would have been.

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6.2 THE QUALITATIVE USE OF AERIAL PHOTOGRAPHS

6.2.1. Applications

Photo interpretation can be defined as the act of examining photographic images for the purpose of identifying objects and judging their significance. In this study photo interpretation permitted the evaluation of a number of features that would have otherwise required a considerable amount of field work to obtain the same information.

Type and amount of erosion and changes over the period 1946 to 1972 were able to be evaluated. Drainage and soils information was obtained. This was especially useful as access over the whole study area is not easy and thus a considerable amount of field work was eliminated. Once the vegetation was determined and species field checked over a small area, extrapolations could be made over a large area with minimum field checking. Keys for identification of tree species could have been constructed if desired. The differential grouping and distribution of pasture weeds such as rushes and thistles could be made according to slope and moisture conditions.

Because less slipping was observed over the completely scrub covered and regenerated areas, this is given as a good reason for not clearing scrub on the steeper slopes as has been the practice only too frequently. This ties in with the observation made in the last section that increased erosion was evident when scrub areas were reduced.

The identification of seepage points enables these points of incipient gullying to be checked in the field so that conservation measures can be taken before they become a problem. Suitable areas for stock water dams can be identified so that once the gullies are fenced off there will be no need for stock to go down into the gullies. Stock water on the higher country appeared adequate for the present.

Topographical factors were readily interpreted; steep slopes could be readily identified and the nature of the gullies observed.

Thus, general observations that can be made from a series of sequential aerial photographs can provide a lot of interesting information and save a lot of field checking.

6.2.2. Limitations

Although many useful observations were able to be made there are still a number of limitations inherent in the use of aerial photographs for studying soil conservation problems. Firstly, it is expensive to fly special runs over areas not photographed or if up to date photographs are required. Thus, economics are the first and major limitation.

Secondly, it is not possible to obtain consistent contrasts if photographs are not taken on the same run at the same time of the year under the same atmospheric conditions. Also, the processing can result in a lack of contrast between desired features. This was especially marked in the black and white photos. However, the lack of contrasts in the black and white photos is offset by the convenience of making measurements on the prints, rather than having to project slides.

Thirdly, the scale of the photographs tends to limit their use. For observations with the naked eye a scale of at least 1:6,500 is necessary. For stereoscopic work, scales 1:20,000 or less are generally satisfactory. The scale used in the study, 1:16,300 was found satisfactory for most observations, though for extremely detailed work, a larger scale would have been desirable.

The actual nature of the study area with its extremely steep sided gully walls, prohibited extensive observation of the channels of the main trunks of

the drainage systems. This was because the gullies were often obscured by shadows. This limited any estimation of costs for control measures, or suggestions for siting of further conservation structures such as dams. However, in an area with broader valleys more information of this nature could be obtained.

6.2.3. Different Film Types

It was concluded from the study of the three different film types, that more information could be obtained more readily from the three, than from any one film type. In effect, the results from one added to those of the others. The Kodachrome transparencies gave better penetration of shadows, whereas the infra red colour transparencies facilitated identification of trees and features associated with water. Both these film types were superior to the black and white photos for penetration of the gullies, microtopographical differences, planning of fencelines and discerning vegetative differences. However, these advantages do not offset the high costs and greater difficulties experienced in using these films. Thus, unless these special purpose films are readily available and finance is no problem, black and white panchromatic film will remain the most widely used, even though the other film types are more valuable for interpretation purposes. Where several film types are available one can help interpret information less discernable on the other, thus increasing the value of each.

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6.3 THE USE OF PHOTOGRAMMETRIC AND MORPHOMETRIC MEASUREMENTS FOR COMPARING AND EVALUATING WATERSHED CHARACTERISTICS AND PROBLEMS

The basic aspects of morphometric analysis were developed by Horton (1945) and modified by Strahler (1945, 1952, 1956, 1957). Numerous workers have utilized their methods for comparing and characterizing different regions and landforms. Those used in this study are merely a selection of the more relevant and simple procedures, which endeavour to show the basic differences between the two catchments. The use of stereo photo pairs facilitated these measurements, enabling more accurate delineations of boundaries to be made.

6.3.1. Areal Measurements.

The areal measurements used in the study were adequate for determining total area of each catchment and the areas of pasture and regeneration of bush cover. The Dot Grid method was adopted as a result of personal preference, though the other methods used were found to be just as accurate, and some of them less time consuming and involving less operator strain. The areal analysis of the subwatersheds of the study catchments revealed a distinct difference between those of the badly eroding Number 1 gully and the Number 2 gully. A greater regularity of the inter-catchment areas in the Number 2 gully could have been related to the greater overall stability of this catchment. However, this sort of analysis would have to be carried out on a large sample of catchments in the same area before any hypotheses of this nature can be suggested. Nevertheless this method served to illustrate the fact that there was a distinct difference between the two gully systems.

The major limitation of areal analysis lay in the fact that the extent of gully erosion was greatly underestimated. Lineal measurements are distinctly

superior in measuring gully erosion. The sequential aerial photos permitted the actual rate of gully erosion to be calculated as discussed in Section 6.1.3.

6.3.2. Slope Analysis

Formlining was a useful exercise in that it permitted average slope, generalised contours and hypsometric analyses to be carried out. However, the extremely steep slopes meant that contour lines closer than 30 m appeared on top of each other and too close together for satisfactory analysis at the scale used. This could be remedied by the use of larger scale photographs. This would then have permitted a more accurate estimate of average slope.

However, as anticipated, the average slope of the Number 1 catchment was slightly greater than that of the Number 2 catchment. This would help account for the greater proportion of erosion over the Number 1 catchment seeing runoff is greater and more erosive over steeper slopes. The literature suggests that heavier soils are found on steeper slopes. However, most of the steepest slopes over the study area are gully walls and as such, have no soil cover. They consist of the exposed unconsolidated substrata on which it is difficult to induce a vegetative cover.

Plotting the various profiles of the two catchments resulted in a number of striking differences being observed. The greater degree of degradation in the Number 1 catchment and steeper more irregular nature of the stream profile means that a considerable amount of erosion is imminent if a uniform profile is to be achieved. Plotting the profiles of a number of ungauged streams could be a most useful technique for determining the erosion potential of each stream bed. The levels can either be obtained by field checking

with an altimeter or by height measurements by parallax differences under stereo.

In the study area, altitude was not a factor predisposing to erosion as shown from the very similar curves obtained in the area-altitude and hypsometric analysis.

Thus although a number of morphometric techniques for the analysis of slope did not show significant differences between the two study catchments, this does not mean that they are not valuable methods, as in other circumstances under a different climatic and geologic regime, they could be most useful.

6.3.3. Drainage Analysis

Analysis of drainage is probably of most use over a large diverse region where it is required to identify differences in the geology and soils of the whole area. On the small scale catchment basis, the techniques used are still valuable in that they served to show distinct differences in the nature of the drainage composition between the badly eroding Number 1 catchment and the more stable Number 2. Extending this analysis over a greater area of the surrounding drainage network could have some interesting results and permit a number of generalizations to be made with respect to how the different measures influenced the erosion potential of the watershed in question.

The slighter greater drainage density in the Number 1 catchment is a result of the greater amount of runoff resulting from the poorer vegetative cover and steeper slopes. It can be suggested that the soils are of a slightly less permeable nature with lower infiltration capacities, but the significance of this is questionable.

6.4 CONCLUSIONS

From the above discussion of the results of this study and the available literature, a number of conclusions and suggestions can be made.

At the beginning of the study it was known that the Number 1 catchment was in a more critical state with regard to erosion than was the Number 2 catchment. Comparing the results of a number of photogrammetric and morphometric measures related to the hydrology of the catchments showed that Number 1 catchment had a steeper average slope, a different pattern of subwatersheds, a different drainage composition, a steeper more irregular stream profile and a greater degree of headward gullying than did the Number 2 catchment. These simple techniques could readily be used in similar catchment comparisons to determine the different predispositions to erosion.

As well as actual quantitative measurements from aerial photos, qualitative observations can also be of value in distinguishing differences in features readily observable from photos but more difficult to discern from ground level. These observations are especially valuable where access is difficult, and eliminate a large amount of time consuming fieldwork. A selection of film types, (economics permitting) yields better and more information than merely using black and white panchromatic prints.

Simple field measurements of flow and sediment yield can be of value in obtaining a rough estimate of the order of discharge and sediment load and thus of the severity of the erosion problem in the area under study. Automatic recording equipment and long term records of rainfall, runoff and other hydrological data would yield more specific information.

From the above measurements and techniques and a study of geologic, soils, climatic and land use aspects

of the study area it was therefore concluded that, if the present system of management is not modified, then the whole of the study area, and especially Number 1 catchment, will continue to undergo the spectacular canyon gully erosion at the accelerated rate now in progress. The only area of non-critical erosion potential is that covered in the Raumai soils. Here the slopes are less steep and the vegetative cover of improved pasture is capable of holding the soil against slipping. These areas lie on the higher country between the gully systems and should thus be fenced off adequately to prevent stock having access to the gullies and steeper areas. Some of the headwater regions where gullying has not yet extended could continue to be grazed if attention to topdressing and oversowing is given. Lax grazing would be preferable to closer grazing. Cattle should be kept out of the gullies at all costs.

It is suggested that the entire area of Pohangina Soils excluding some of the headwater regions, should be retired from grazing altogether and permitted to regenerate in scrub and native bush. Farm forestry would be an alternative, though access for removal of timber could be a problem in some localities.

Management of the whole study area as a watershed unit rather than as two distinct properties would greatly facilitate control measures. Possibly the most economic venture would be to amalgamate the two farms, planting all the gullies in Pinus radiata.

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APPENDIX I : SUMMARY OF THE MAIN CLIMATIC
ELEMENTS IN THE POHANGINA
DISTRICT

The only relevant current data (other than rainfall) available from the N.Z. Met. Service Meteorological Observations Misc. Pub. 109, were the records from the Ballantrae experimental area on Saddle Road 14 km S.S.E. of the study area. These were felt to be far more useful than the records from Ohakea or Palmerston North, but still not close enough to the study area to give an exact indication of the conditions to be expected. Also, these figures have only been kept for the last three years and do not give long term records.

Ballantrae No. 1 (347 m a.s.l.)

(1) Wind

(a) Percentage Frequency of Surface Wind Directions

Observations:	N :	N.E.:	E:	S.E.:	S:	S.W.:	W:	N.W.:	Calm:
1970 (364)	6.2	9.2	12.8	7.3	3.6	1.1	15.2	41.0	3.6
1971 (365)	3.3	13.7	22.1	7.5	3.3	2.7	12.2	30.5	4.7
1972 (364)	2.8	3.0	13.2	9.6	2.5	1.4	20.3	43.6	3.6
Mean %	4.1	8.6	16.0	8.1	3.1	1.7	15.9	38.4	4.0

(b) Daily Run of Wind (km/day) (mean)

Year :	JAN:	FEB:	MAR:	APR:	MAY:	JUN:	JLY:	AUG:	SEP:	OCT:	NOV:	DEC:
1970	-	-	-	-	-	-	-	-	538	664	662	836
1971	-	616	584	554	475	628	513	626	785	918	652	590
1972	774	598	-	786	916	632	598	575	1033	930	679	776

APPENDIX I (Contd.) :(2) Temperatures

(a) Extreme temperatures averaged for 1970 - 1972. (3 year period)

Means of:	JAN:	FEB:	MAR:	APR:	MAY:	JUN:	JLY:	AUG:	SEP:	OCT:	NOV:	DEC:	YEAR
Daily Max.	19.9	19.9	19.3	16.1	12.5	10.6	10.1	10.7	12.3	14.0	16.9	17.3	14.8
Daily Min.	12.5	11.9	12.0	9.4	6.5	5.3	4.7	4.7	6.5	7.8	9.5	10.3	8.7
Daily Means	16.2	15.8	15.7	12.9	9.5	7.9	7.5	7.7	9.5	10.9	13.2	13.6	12.0

(3) Sunshine

Bright Sunshine (hours)

Year:	JAN:	FEB:	MAR:	APR:	MAY:	JUN:	JLY:	AUG:	SEP:	OCT:	NOV:	DEC:	YEAR
1971	143	187	198	170	95	68	101	110	113	142	217	205	1749
1972	207	191	129	117	118	100	96	133	125	153	122	148	1639
Mean	175	189	164	144	107	84	99	122	119	148	170	172	1694

(4) Miscellaneous

Days of :	Fog :	Thunder :	Gale :	Max. daily rainfall for year (mm).	Date :	Total rainfall for year (mm).
1970	23	4	12	58	31 March	1192
1971	44	3	6	71	4 May	1167
1972	21	3	20	85	10 March	987
Mean	29	3	13	71		1115

Twenty-three-year rainfall figures were available from Te Awa.
These are given in Appendix (4).

APPENDIX II : STRATIGRAPHIC TABLE OF THE CASTLECLIFFIAN STAGE

AT WANGANUI

(From Fleming 1953)

Substage:	Group:	Formation :	Member etc.
PUTIKIAN	SHAKESPEARE	Landguard formation	Landguard sand
		Undifferentiated formations	
		Putiki Shellbed	
		Mosstown Sand	Basal Conglomerate
		Karaka Siltstone	Tawera lenticels
		Upper Castlecliff Shellbed	
		Shakespeare Cliff Sand	
			Basal shell conglomerate
		Shakespeare Cliff Siltstone	
		Tainui Shellbed	
OKEHUA	KAIWI	Pinnacle Sand	
		Lower Castlecliff Shellbed	
		Seafield Sand	Toms Conglomerate
		Upper Kaiwi Siltstone	
		Kupe Formation	Pecten layer
			Pelecypod Shellbed member
			Mactra tristis layer
			Gastropod Shellbed member
			Crossbedded Sand member
		Upper Westmere Siltstone	Kaikokopu Shell Grit
	OKEHU	Lower Westmere Siltstone	Basal Sand member
		Omapu Shellbed	
		Lower Kaiwi Siltstone	
		Kaimatira Pumice Sand	Local member
		Upper Okehu Siltstone	Basal Shell Conglomerate
		Okehu Shell Grit	
		Lower Okehu Siltstone	Basal Shell Conglomerate
		Butlers Shell Conglomerate	Ototoko Siltstone tongue
		Makirikiri Tuff	Conglomerate members

APPENDIX III : GEOLOGICAL SECTION DESCRIPTIONS

- (1) Culling's Gully Section measured
westward from axis of anticline at
N144/267597 to waterfall at N144/265601

(Measured with rod and level, June 16, 1973,
 by Mrs. D. Seward, Geology Department,
 Victoria University)

<u>Unit :</u>	<u>Individual</u> <u>Thickness:</u>	<u>Cumulative</u> <u>Thickness:</u>
1 Sand, medium to fine, thinly laminated, slightly tuffaceous - sharp contact -	6.2	6.2
2 Silty sand with lenses of very coarse pumiceous sand and with clasts of carbonaceous silt up to 0.3 m long. - sharp contact -	0.3	6.5
3 Sand, fine to coarse, pumiceous with large convolutions up to 1.0 m high and of irregular form, i.e. no parallelism of axes. Unit has extensive lateral variation, e.g. 100 m upstream there is a lens 4.0 m long of large scale trough cross-bedded medium sands with laminae of magnetite and ilmenite. Each set is separated by a large silt flaser up to 2.0 m long and 0.1 m thick. The flasers have small flame structures, (up to 20 mm high) on their upper surfaces. - sharp contact -	5.0	11.5
4 Sand, medium to coarse, thinly laminated. Some very coarse pumice sand and a few magnetite laminae. Slight decrease in grain size towards the bottom of the unit. - sharp contact -	7.2	18.7

<u>Unit :</u>	<u>Individual Thickness:</u>	<u>Cumulative Thickness:</u>
5 Sand, fine to medium, moderately well sorted, tuffaceous. In lower 0.1 m intraformational breccia with subrounded silt clasts up to 30 mm long; no orientation of clasts apparent. - sharp contact -	0.4	19.1
6 Sand, brown, medium, moderately well sorted, thinly laminated. At 7.5 and 8.7 m are thin beds composed dominantly of magnetite. The lower of these is ripple-drift cross-laminated. - erosion surface with 0.2 m relief -	12.7	31.8
7 Intraformational breccia. Clasts up to 5.0 m long, 0.25 m wide set in very coarse pumiceous sand and gravel with pumice and greywacke pebbles and cobbles up to 0.1 m long. The main clasts are carbonaceous silts showing root structures and palaeosols. Some have been deposited upside down as the soil is on the lower surface. Other clasts include wood fragments up to 0.3 m long.	0.3	32.1
8 Sand, grey, medium, tuffaceous. All with convolute laminae varying from 0.05 m to 0.2 m in height. Most show evidence of water or air expulsion. - sharp contact -	8.5	40.6
9 Sand, light brown, medium, moderately well sorted, slightly tuffaceous, thinly laminated. Very rare beds of ripple-drift cross lamination up to 40 mm thick. - gradational contact -	20.1	60.7
10 Alternating sands and silts. Sands slightly tuffaceous medium, moderately well sorted, thin bedded, with ripple-drift cross-lamination and bipolar orientation of fore-sets. Silts, slightly tuffaceous, thin bedded, with rippled bases, sometimes grading up from the sands.	4.5	65.2

APPENDIX III : (Contd.)

(2) Culling's Gully Section measured eastwards from axis of anticline at N144/267597 to N144/282588.

(Measured with rod and level, June 16, 1973
by Mrs. D. Seward, Geology Department,
Victoria University)

<u>Unit :</u>	<u>Individual Thickness:</u>	<u>Cumulative Thickness:</u>
1 Sand, medium to fine, thinly laminated, slightly tuffaceous.	24.2	24.2
2 Sand, medium to coarse, very pumiceous. Large scale trough cross-stratification grading into convolute laminations with an average height of 1.0 m - erosional surface with 0.1 m relief -	1.4	25.6
3 Intraformational breccia. Clasts up to 0.7 m long, 0.2 m wide, of ash with soil developed on one surface; at least one clast deposited upside-down. Matrix, coarse pumiceous sand. - uneven sharp contact -	0.2	25.8
4 Sand, medium to coarse, very pumiceous. Large scale trough cross stratification up to 0.7 m high. - uneven sharp contact -	2.4	28.2
5 Sand, very coarse, poorly sorted, grey-white, pyroclastic thin to medium bedded, with some laminae and a few horizons of ripple-drift cross lamination. - sharp contact -	3.0	31.2

<u>Unit :</u>	<u>Individual Thickness:</u>	<u>Cumulative Thickness:</u>
6 Sand, brown, medium, moderately well sorted, slightly tuffaceous, thinly laminated. - sharp uneven contact -	35.0	66.2
7 Intraformational breccia. Clasts of silt up to 0.1 m long. Matrix of silty, very fine sand. - sharp contact -	0.9	67.1
8 Sand, light, brown, medium to fine, moderately well sorted, thinly laminated. A few laminae of heavy minerals and some of coarse pumice sand. - sharp contact -	12.5	79.6
9 Intraformational breccia. Clasts up to 0.1 m long of silt set in silty very fine sand. - sharp contact -	0.7	80.3
10 Alternating silts and fine sands, brown. Sands have ripple-drift cross-lamination, while silts have rippled bases. Some wavy bedding, and a few flasers. - sharp contact -	3.1	83.4
11 Sand, brown, generally appears massive, but some incipient lamination. To the south is a channel, 3.0 m deep and at least 15 m wide cutting into the sands. The channel fill is parallel to the bottom surface, becoming less concave upwards to horizontal bedding at the top. The fill is of silt with a few thin beds of medium sand which has ripple-drift cross-laminae. - sharp contact -	3.2	86.6
12 Sand, brown, massive, with some lamination visible. A few <u>Amphidesma</u> . - top of outcrop -	20.0	106.6

APPENDIX IV : SOIL PROFILE DESCRIPTIONS

(1) Raumai Sandy Loam, Profile No. 1

Soil : Raumai Sandy Loam, (No. 1)

Classification : Moderately weathered Yellow Grey Earth-
Yellow Brown Earth Intergrade soil from
unconsolidated Castlecliffian Sand.

Location : Ridge top between Numbers 1 and 2 Gullies
on Mr. J. Culling's property, Pohangina
Valley.

Grid Reference N144/282592.

Topography : Local flat area on ridge top; altitude
280 m a.s.l.

Drainage : Moderately well drained. External drainage,
medium-rapid.

Vegetation : Of site- pasture; ryegrass, white clover,
sweet vernal, browntop, Scotch thistles;
Previous Native Cover- Podocarp-broadleaf
forest, Black Beech on crests of ridges.

Parent Material : Castlecliffian Sand of the Wanganui Series
of the Mid Pleistocene.

Climate : Rainfall, 1145 mm.

Land Use : Hill country sheep farming practised in con-
junction with another block of land in the
same district.

Profile :

- A 18 cm pale brown (10YR 6/3) silt loam; slightly hard;
weakly developed medium crumb structure with very occasional
firm iron nodules; well drained; many roots and remains of
original forest roots; a few worms; pH 5.5; indistinct
wavy boundary.
- B1 12 cm light yellowish brown (2.5Y 6/4) loamy fine sand;
slightly hard; very weakly developed medium blocky structure;
slight compaction showing the beginnings of an incipient

fragipan; well drained; many roots, a few dead roots from the original forest cover; a few worms; pH 5.4; very indistinct diffuse boundary.

B2 18 cm yellow (10YR 7/6) very fine sand; loose; structureless-single grained; well drained; few roots, roots from the original forest cover; pH 5.0; reasonably distinct boundary.

C From 48 cm depth and down, pale yellow (2.5Y 7/4) fine sand; loose; structureless (single grained); well drained; few roots in the upper parts of the horizon; pH 5.5; distinct pumiceous band between 77 and 88 cm depth with indistinct boundaries.

APPENDIX IV : (Contd.)(2) Raumai Sandy Loam, Profile No. 2Soil : Raumai Sandy Loam (No. 2)Location : Low ridge of local spur on ridge between Numbers 1 and 2 Gullies on Mr. J. Culling's property, Pohangina Valley.
Grid Reference N144/282592.Topography : Small flat area on top of spur off crest of ridge, altitude 265 m a.s.l., sloping slightly to the south east.Drainage : Well drained. External drainage, medium-rapid.Vegetation : Of site - pasture, ryegrass, white clover, sweet vernal, browntop, Scotch thistles.
Previous Native Cover - Podocarp-Broadleaf forest, Black Beech on crests of ridges.Profile :

A1 19 cm dark grey brown (10YR 4/2) silt loam; firm; moderately developed medium nutty and fine crumb structure; moderately well drained; many roots, some earth worms; pH 6.0; indistinct boundary.

A2 12 cm of olive brown (2.5Y 4/4) very fine sandy loam with yellowish brown (10YR 5/8) concretions; firm; moderately developed, medium nutty structure with a few small rounded concretions of weathering sandstone; moderately well drained, many roots; some earthworms; pH 6.5; indistinct boundary.

B1 18 cm of light olive brown (2.5Y 5/4) fine sandy loam; friable; very weakly developed crumb structure with a few

sandstone concretions; well drained; a few pasture roots and fine remains of original bush roots; a few earthworms; pH 6.0; indistinct boundary.

B2 32 cm light yellowish brown (2.5Y 6/4)
fine loamy sand; very friable; very weakly developed fine nutty structure with very few concretions; imperfectly drained; pH 6.0; indistinct boundary.

C from 81 cm depth and down light yellowish brown (2.5Y 6/4) fine loamy sand grading down into fine sand; loose; structureless, single grained; well drained, pH 5.5.

APPENDIX IV : (Contd.)(3) Pohangina Steepland Soils
Profile No. 1.Soil : Pohangina Sandy LoamClassification : Moderately weathered Yellow Grey-Yellow Brown Earth intergrade soil from unconsolidated Castlecliffian Sand formed on steep and very steep slopes.Location : Top of spur running off main ridge on eastern boundary of Number 2 gully on Mr. J. J. Culling's property, Pohangina Valley, a few hundred metres from Branch Road. Grid Reference N144/285596.Topography : Moderately well drained. External drainage, medium-rapid.Vegetation : Of site - pasture, - ryegrass, white clover, sweet vernal, browntop, Scotch and Californian thistles, other Asteraceae (Compositae) spp., with manuka and bracken fern closeby, though not actually on the site;Previous Native Cover - Black Beech.Parent Material : Castlecliffian Sand of the Wanganui Series of the Mid Pleistocene.Climate : Rainfall - 1145 mm.Land Use : Hill country sheep farming practised in conjunction with another block of land in the same district.Erosion : On adjacent slope - slipping. Severe gully erosion nearby.

Profile :

- A 11 cm dark brown (10 YR 3/3) fine sandy loam; friable; moderately developed medium crumb structure; well drained; numerous pasture roots and remains of old bush roots; some earthworms; pH 6.0; very distinct regular boundary.
- B1 30 cm light olive brown (2.5Y 5/6) light sandy clay loam with yellow (2.5Y 7/6) mottles; firm; almost compacted; very weakly developed blocky structure, almost structureless, massive; imperfectly drained; numerous roots and remains of old bush roots; a few earthworms; pH 5.5; indistinct boundary.
- B2 21 cm yellow (2.5Y 7/6) sandy loam; firm, almost friable; very weakly developed blocky structure, almost structureless; moderately well drained; some living roots and a few old bush roots; pH 5.5; indistinct boundary.
- C from 62 cm depth and down light yellowish brown (2.5Y 6/4) very fine sand, friable; structureless, single grained; well drained; a few living roots at the top of the horizon; pH 5.5.

APPENDIX IV : (Contd.)(4) Pohangina Steepland Soils.Profile No. 2.

- Soil : Pohangina Sandy Loam
- Location : Steep side of spur running off main ridge on eastern boundary of Number 2 gully on Mr. J. Culling's property, Pohangina Valley, a few hundred metres from Branch Road. Grid Reference N144/285596.
- Topography : 38° slope, E.S.E., not very exposed; altitude 296 m a.s.l.
- Drainage : Moderately well drained. External drainage, rapid.
- Vegetation : Of site -reverting pasture, -bracken fern, manuka, soft fern, with pasture inbetween, - white clover, sweet vernal, browntop, and weeds including foxglove, thistles, rushes, and other Asteraceae (Compositae) weeds; Previous Native Cover - Black Beech.
- Profile :
- A 15 cm dark brown (10YR 3/3) silt loam; firm; weakly developed medium crumb structure; moderately well drained; numerous living pasture roots and bracken rhizomes; some earthworms, small black crickets; pH 6; very distinct irregular boundary giving the horizon an 8 - 21 cm range in depth.
- B1 12 cm olive (5Y 5/3) fine sandy loam, with distinct numerous brownish yellow (10YR 6/8) mottles; firm, well compacted almost like a fragipan; very weakly developed medium nutty structure, almost

structureless; imperfectly drained;
 numerous living roots including bracken
 fern rhizomes, remains of old bush roots;
 a few earthworms; pH 6.0, distinct but
 very irregular boundary.

B2 18 cm pale olive (5Y 6/4) fine sandy loam
 with faint yellow (10YR 7/8) mottles;
 loose; very weakly developed blocky structure,
 almost structureless: imperfectly drained,
 a few living roots, some root remains from
 original forest; pH 5.5 - 6.0; fairly
 regular but indistinct boundary.

C from 40cm depth and down, pale olive very
 fine sand; loose; structureless, single
 grained; well drained; a few living
 roots at top of horizon to 80cm; pH 5.5.

Notes: Incipient fragipan in B1 horizon most obvious
 Pohangina Sandy Loam No. 1 profile where the B1 horizon
 dries out on the top of the spur. Irregularity of No.
 2 profile A horizon may be due to an old slip on the sit.
 In both profiles the influence of the original bush cover
 is still obvious.

APPENDIX V : COMMON AND BOTANICAL NAMES OF PLANTS
REFERRED TO IN THE TEXT

Acacia	<u>Acacia sp.</u>
Black beech	<u>Nothofagus solandri</u>
Bracken fern	<u>Pteridium esculentum</u>
Brown top	<u>Agrostis tenuis</u>
Californian thistle	<u>Cirsium arvense</u>
Climbing ratas	<u>Metrosideros spp.</u>
Cocksfoot	<u>Dactylis glomerata</u>
<u>Coprosma spp.</u>	<u>Coprosma lucida</u> , <u>C. rhamnoides</u>
Crested dogstail	<u>Cynasurus cristatus</u>
Danthonia	<u>Notodanthonia spp.</u>
Fivefinger	<u>Neopanax arboreum</u>
Foxglove	<u>Digitalis purpurea</u>
Hangehange	<u>Geniostoma linguistrifolium</u>
Hardfern	<u>Paesia scaberula</u>
<u>Helichrysum sp.</u>	<u>H. glomeratum</u>
Hinau	<u>Elaeocarpus dentatus</u>
Kawakawa	<u>Macropiper excelsum</u>
Kohukohu	<u>Pittosporum tenuifolium</u>
Kowhai	<u>Sophora microphylla</u>
Lancewood	<u>Pseudopanax crassifolium</u>
Lupin	<u>Lupinus arboreum</u>
Macrocarpa	<u>Macrocarpa sp.</u>
Mahoe	<u>Melicytus ramiflorus</u>
Maires	<u>Olea spp.</u>
Manuka	<u>Leptospermum scoparium</u>
Mapou	<u>Suttonia australis</u>
Mingmingis	<u>Cyathodes acerosa</u> , <u>Leucopogon fasciculatus</u>
Northern rata	<u>Metrosideros robusta</u>
Pines	<u>Pinus radiata</u>
Poplars	<u>Populus spp.</u>
Pukatea	<u>Laurelia novae-zelandiae</u>
Rewarewa	<u>Knightia excelsa</u>
Rimu	<u>Dacrydium cupressinum</u>
Rushes	<u>Juncus spp.</u>

Ryegrass (perennial)	<u>Lolium perenne</u>
Scotch thistle	<u>Cirsium lanceolatum</u>
Soft fern	<u>Histiopteris incisa</u>
Supplejack	<u>Rhipogonium scandens</u>
Sweet vernal	<u>Anthoxanthum odoratum</u>
Tawa	<u>Beilschmiedia tawa</u>
Titoki	<u>Alectryon excelsium</u>
Treeferns	<u>Dicksonia spp.</u>
Tree lupin or Tree lucerne	<u>Cytisus proliferus</u>
White clover	<u>Trifolium repens</u>
Willows	<u>Salix spp.</u>
Wineberry	<u>Aristotelia serrata</u>

APPENDIX VI : LAND CAPABILITY CLASSES USED IN THE
POHANGINA SURVEY

<u>CLASS I</u>	Flat or gently rolling land. Fertile and capable of cultivation in its present state. No special conservation practices required.
<u>CLASS II</u>	Flat to gently rolling land. May require drainage or flood protection, or the like to make it suitable for cultivation. No special conservation practices required, except perhaps on the rolling land if this is frequently cultivated.
<u>CLASS III</u>	Rolling to moderately steep land, not suitable for cultivation but very suitable for permanent high producing pastures. Requires little or no special treatment under present management.
<u>CLASS IV</u>	Moderately steep to steep land suitable for high producing pastures. Intensive special conservation practices required such as open tree planting and gully control measures.
<u>CLASS V</u>	Very steep to precipitous land. Use for pasture is very restricted. Requires more or less urgent treatment.

(From Glass, 1957)

APPENDIX VII : MONTHLY DRY WEATHER FLOWS

(Means of three measurements)

Month :	<u>No. 1 Catchment :</u>	<u>No. 2 Catchment :</u>
	l/min	l/min
December 1971	8.0	63.7
January 1972	8.0	61.4
February	9.1	59.2
March	11.4	54.6
April	13.7	81.9
May	18.2*	150.2*
June	17.1	95.6
July	13.7	109.2
August	14.2	122.9
September	13.7	116.0
October	6.8	41.0
November	9.1	54.6
December	2.3**	18.2**

* maximum flow

** minimum flow

APPENDIX VIII : CORRELATION OF MAXIMUM FLOOD LEVELS
WITH DISCHARGE FOR NUMBER 2 CATCHMENT

(Raw Data for Fig. 5.2)

Measured Depth (D) (cm)	Measured Discharge (Q) (l/min)	Date
40.7	48,000	10/11 Mar
8.9	1,770	14 May
35.6	34,080	15/16 Jun
11.4	3,060	17/18 Jly

Measured Depth : (cm)	Calculated Discharge from linear regression (l/min.) :	Flow occurred prior to this date in month recorded :
33.2	32,020	28 Jan., 28 Sept., 28 Oct.
25.8	24,230	28 Feb., 28 Aug.
44.4	42,790	28 Mar.
29.4	28,370	28 Apr.
33.2	32,020	28 May
36.8	35,480	28 Jun., 17 Jly.
40.6	39,140	28 Jly.

Regression Equation : $y = 91.84 + 961.69x$
 $r = 0.692$

APPENDIX IX : SEDIMENT LOADS

(1) Raw Data- (Means and Standard Errors)
for Table VI

Catchment No.1		Catchment No. 2	
Flood Event	Weights of Sediment in 100 ml sample (g)	:	Weights of Sediment (g) (100 ml sample)
10/3/72	20.50		1.84
	19.06		1.55
	17.10		1.67
	17.66		1.47
	Mean 18.58 ± 0.76		Mean 1.63 ± 0.08
			(500 ml sample)
14/5/72	0.349		0.212
	0.314		0.206
	0.373		0.213
	0.330		0.208
	Mean 0.339 ± 0.01		Mean 0.210 ± 0.005
			(500 ml sample)
15/6/72	20.27		10.30
	18.58		10.09
	19.80		10.08
	19.51		10.20
	Mean 19.84 ± 0.36		Mean 10.25 ± 0.09
			(100 ml sample)
17/7/72	1.57		1.50
	1.71		1.51
	1.54		1.52
	1.38		1.51
	Mean 1.55 ± 0.07		Mean 1.51 ± 0.01

APPENDIX IX : (Contd.)(2) Raw Data- (Means and Standard Errors)
for Table VII

Note: For the calculation of Standard Error, the percentages of each particle size were transformed using arcsin Tables from Snedecor and Cochran (1968).

Flood Event	<u>Mechanical Analysis Percentages</u>			
	Clay	: Silt	: Fine Sand	: Coarse Sand
10/3/72	<u>No. 1 Catchment</u>			
	14.2	7.6	79.5	5.6
	13.1	6.8	81.1	4.3
	14.1	9.4	79.5	3.2
	15.0	9.1	81.1	3.5
Mean	14.1 ± 0.3	8.2 ± 0.7	80.3 ± 0.3	4.2 ± 0.7
	<u>No. 2 Catchment</u>			
	14.9	4.9	79.8	4.5
	15.1	5.4	77.5	3.7
	14.3	7.5	81.0	3.6
	14.5	6.2	80.1	4.1
Mean	14.7 ± 0.1	6.0 ± 0.7	79.6 ± 0.5	4.0 ± 0.3

APPENDIX IX : (Contd.)

Flood Event	Mechanical Analysis Percentages			
	Clay	: Silt	: Fine Sand	: Coarse Sand
<hr/>				
15/6/72	<u>No. 1 Catchment</u>			
	1.6	1.7	88.7	11.2
	1.5	2.5	91.5	9.6
	1.2	2.9	90.0	10.5
	1.3	3.1	92.1	9.5
Mean	<u>1.4</u> \pm 0.2	<u>2.5</u> \pm 0.6	<u>90.6</u> \pm 0.7	<u>10.2</u> \pm 0.4
	<u>No. 2 Catchment</u>			
	14.9	4.9	79.8	4.5
	15.1	5.4	77.5	3.7
	14.3	7.5	81.0	3.6
	14.5	6.2	80.0	4.1
Mean	<u>14.7</u> \pm 0.1	<u>6.0</u> \pm 0.7	<u>79.6</u> \pm 0.5	<u>4.0</u> \pm 0.3
<hr/>				
17/7/72	<u>No. 1 Catchment</u>			
	11.7	10.6	80.5	3.0
	12.5	10.0	78.5	2.9
	12.2	8.6	80.1	1.2
	12.1	9.7	77.4	1.8
Mean	<u>12.1</u> \pm 0.2	<u>9.7</u> \pm 0.4	<u>79.1</u> \pm 0.5	<u>2.2</u> \pm 0.9
	<u>No. 2 Catchment</u>			
	45.3	33.0	30.7	0.22
	43.3	32.2	29.4	0.16
	39.0	35.0	27.8	0.24
	37.5	37.8	88.5	0.18
Mean	<u>41.3</u> \pm 1.0	<u>34.5</u> \pm 0.7	<u>29.1</u> \pm 0.4	<u>0.20</u> \pm 0.1

APPENDIX X : RAINFALL RECORDS

(1) Rainfall Record (mm) for 1972 for
the Study Area

Date :	JAN:	FEB:	MAR:	APR:	MAY:	JUN:	JLY:	AUG:	SEP:	OCT:	NOV:	DEC:
1												
2				2							2	10
3	36						3		3.5			
4									10			
5					13.5							
6		3	7				2					10
7	6		2.5	2.5								
8	6		4.5									
9		6.5		17								
10		1	26				4	8	7.5	14	5	
11	0.5		90				4			10		
12	8	1.5	4				10	4		8		
13				2		3	15					
14					20					17		12
15	6.5					50	15	3	12	2		
16						5		3		20		
17				2.5	30		5	13	4		8	2
18				10		15	23	5				
19						5				14		
20												18
21		9.5							15		2.5	
22		2					2					1
23		2										
24		6		7	9	2						
25		20		22	7							5.5
26	1.5		3	15				6		7		7.5
27								12		10		
28			2.5									6
29	0.5			6					5.5			
30	12							1	2.5			
31	2.5				9			3				
TOTAL	79.5	51.5	139.5	86.0	88.5	80.0	83	58	60	102	17.5	72

TOTAL 917.5 mm

APPENDIX X : (Contd.)From N.Z. Met. Ser. Rainfall Observations for 1972(2) Maximum Daily Rainfall for 1972

	(mm)	Date:
Culling's Gully	90	11 March
Te Awa	49	9 March
Pohangina Valley	71	10 March
Ballantrae	85	10 March
Komako	81	10 March
Feilding	91	10 March
Palmerston North (D.S.I.R.)	84	10 March
Ohakea	84	10 March

(3) 1972 Rainfall for the Study Area and Surrounding Districts. (mm)

*wettest month						
Month:	Culling's:	TeaAwa:	Ballantrae:	Pohangina Valley:	P.N. DSIR:	Feilding:
January	80	38	37	71	64	65
February	52	46	86	58	50	45
March*	140	116	156	138	139	155
April	86	67	121	81	74	87
May	89	74	108	105	97	85
June	80	55	61	90	36	40
July	83	62	89	93	100	94
August	58	50	93	69	80	54
September	60	52	54	73	55	68
October	102	74	95	106	65	62
November	18	24	39	34	29	17
December	72	51	48	63	40	32
TOTAL:	918	709	987	981	829	804
Normal annual rainfall and % departure from it.	-	1016 (-30)	-	-	991 (-16)	950(-15)

APPENDIX X (Contd.) :

(4) TE AWA 23 YEAR RAINFALL FIGURES (mm)

YEAR :	JAN:	FEB:	MAR:	APR:	MAY:	JUN:	JUL:	AUG:	SEPT:	OCT:	NOV:	DEC:	TOTAL:	DAILY MAX:	DATE:
1949	-	-	-	104	70	100	135	100	51	76	81	112	-	-	-
1950	66	128	88	57	18	110	131	157	56	58	41	106	998	69	9 Feb.
1951	71	57	56	105	72	58	108	84	8	158	182	169	1130	46	8 Oct.
1952	75	93	52	52	75	171	47	65	38	49	234	131	1084	32	27 Nov.
1953	121	89	58	96	87	58	58	41	86	144	79	149	1065	46	27 Jan.
1954	19	38	69	113	47	82	119	84	85	44	99	86	850	42	1 Apr.
1955	15	98	43	107	112	104	128	141	51	139	92	45	1076	47	23 Apr.
1956	78	69	30	76	114	127	168	75	68	121	131	141	1206	38	14 Aug.
1957	53	43	50	30	192	104	93	39	57	177	138	138	1113	41	15 May.
1958	75	86	86	69	140	56	82	113	16	111	32	160	1040	60	23 Dec.
1959	96	127	47	85	225	34	53	33	101	98	57	48	1009	66	12 Jan.
1960	23	77	83	36	77	58	104	76	51	58	87	82	813	50	5 Aug.
1961	172	66	45	84	44	88	99	196	113	17	50	47	1017	79	22 Jan.
1962	144	38	72	60	35	171	107	76	60	116	87	128	1096	46	28 Jan.
1963	89	67	54	70	64	82	63	52	75	25	106	47	794	50	9 Jan.
1964	88	28	81	19	75	129	137	126	114	82	29	161	1070	38	24 Nov.
1965	112	120	20	89	40	52	107	66	52	78	110	134	1250	61	20 Dec.
1966	67	111	36	116	46	89	140	85	60	41	110	44	1086	65	26 Dec.
1967	58	-	69	76	75	59	25	130	61	101	95	150	-	-	-
1968	63	39	18	156	119	144	94	72	67	148	34	137	1091	42	18 Jan.
1969	69	72	48	55	89	73	51	72	20	38	39	80	706	33	6 May.
1970	25	21	162	10	79	87	75	48	97	56	44	47	750	57	18 Mar.
1971	120	88	27	18	153	70	33	56	90	116	69	49	889	48	4 May.
1972	38	46	116	67	74	55	62	50	52	74	24	51	709	49	9 Mar.
Monthly Average:	76	73	69	73	89	90	92	86	62	88	86	101	993		

Note : The normal annual rainfall at Te Awa is quoted as 1016 mm.

1969 - 1972 were abnormally low rainfall years.

APPENDIX X : (Contd.)

(5) Maximum Rainfall in Selected Time
Intervals from 10 minutes to 72 hours
during 1972.

	<u>Minutes</u>					<u>Hours</u>					
	10	20	30	60	:	2	6	12	24	48	72
Te Awa	6	8	10	17		23	41	68	90	95	102
Ohakea	7	10	15	25		31	52	83	117	128	135
P.N. (DSIR)	4	6	10	14		24	50	79	105	117	121

APPENDIX XII : ANALYSIS OF EROSION AND REGENERATION

(data for Figures 5.5 and 5.6)

	<u>PERCENTAGE OF TOTAL AREA :</u>							
	<u>No. 1 Catchment</u>				<u>No. 2 Catchment</u>			
	1946:	1958:	1966:	1972:	1946:	1958:	1966:	1972:
Regeneration	20.0	41.0	13.0	33.0	29.0	71.0	19.5	38.0
Pasture	68.5	53.0	76.5	64.0	64.0	28.0	75.5	61.0
Erosion* (total)	11.5	6.0	9.5	3.0	7.0	1.0	5.0	1.0
Gully Erosion*	4.5	5.0	6.5	2.5	0.5	0.5	0.5	0.1
Slip Erosion	7.0	1.0	3.0	0.5	6.5	0.5	4.5	0.9

* Underestimated

These percentages are derived from the mean value of four dot grid surveys over each set of photos, taken as a percentage of the total catchment areas as calculated in the previous section.

APPENDIX XIII : DETERMINATION OF AVERAGE SLOPE
USING 100 FOOT (30 m) CONTOUR
INTERVAL

Grid Reference:	No. of horizontal transects:		Length of Grid Lines: (inches)		No. of vertical transects:		Length of Grid Lines: (inches)	
No:	No. 1 : No. 2:		No. 1 : No. 2:		No. 1 : No. 2:		No. 1 : No. 2:	
1	-	4	-	0.75	-	7	-	2.60
2	-	5	-	1.65	-	10	-	3.10
3	5	5	1.24	1.85	-	14	-	3.70
4	3	9	1.38	2.45	6	6	1.48	3.17
5	9	6	2.20	2.65	7	8	2.25	2.18
6	5	6	2.66	3.11	7	8	2.61	2.30
7	13	8	4.00	2.54	12	8	2.72	2.40
8	13	4	4.42	2.11	14	11	2.78	2.85
9	11	5	3.53	1.88	18	7	4.41	1.52
10	11	7	3.40	1.86	14	-	4.06	-
11	12	6	3.05	1.72	12	-	3.25	-
12	3	1	1.00	0.85	5	-	2.02	-
13	-	-	-	-	10	-	1.70	-
Total:	85	66	26.88	23.42	105	79	27.28	23.82
Total Vertical and Horizontal Transects:			Total length Vertical and Horizontal Grid lines:(in.)			Total length feet on ground:		
No: 1		No: 2	No: 1		No: 2	No: 1		No: 2
190		145	54.16		45.24	7355		61,400

No. of crossings of grid lines per mile x contour interval 3,361

= tan angle of general slope

(Miller, 1966)

Average Slope Angle: No. 1 Catchment 22° 6'
 No. 2 Catchment 20° 22'

(Using the 50 foot contours, the average slope angles were 24° 17' for Number 1 Catchment and 21° 6' for Number 2 Catchment).

APPENDIX XIV : STREAM AND CREST LINE PROFILES

(Raw Data for Figures 5.10 and 5.11)

(1) Stream Profiles

<u>No. 1 Catchment</u>		<u>No. 2 Catchment</u>	
Altitude (m a.s.l.) :	Cumulative Distance on Ground from Con- fluence (m):	Altitude (m a.s.l.)	Cumulative Distance on Ground from Confluence (m) :
170	41	170	41
200	1076	200	621
245	2151	208	621
258	2151	230	1656
280	2306	238	1847
285	2306	241	1847
290	2788	260	2229
320	3198	262	2229
		290	3009
		320	3321

(2) Crest Line Profiles

<u>Eastern Boundary :</u>		<u>Boundary between No. 1 and No. 2 :</u>		<u>Western Boundary :</u>	
Altitude of Points taken (m) :	Cumulative Distance along Crestline: (m)	Altitude of Points taken (m) :	Cumulative Distance along Crestline (m) :	Altitude of Points taken (m) :	Cumulative Distance along Crestline (m) :
200	82	200	124	220	235
206	137	217	268	248	290
222	310	245	745	272	645
282	447	273	880	290	1070
310	945	280	964	306	1255
300	1240	272	1145	298	1535
312	1305	280	1350	318	1660
287	1395	302	1494	305	1750
312	1725	305	1620	342	2010
321	1790	327	1952	328	2090
324	1905	335	2208	343	2270
328	2140	348	2600	342	2340
339	2550	334	2710	343	2510
345	2780	340	2785	340	2570
321	3150	346	2905	343	2615
358	3190	339	3060	344	2720
357	3515	358	3260	343	2760
366	3940	359	3470	344	2870
358	4460			349	3080
				346	3270
				354	3340
				358	3420

APPENDIX XV : RAW DATA FOR CONSTRUCTION OF AREA-HEIGHT
AND HYPSONETRIC CURVES

<u>No. 1 Catchment</u>			<u>No. 2 Catchment</u>	
		<u>Total:</u>		
Contour Interval: (m a.s.l.)	Area Between Contours (%) :	Area Above Indicated: Level : (%)	Area Between Contours: (%)	Area Above Indicated Level : (%)
140 - 170	Less than 0.1	100.0	Less than 0.1	100.0
170 - 200	2.0	100.0	1.8	100.0
200 - 230	5.7	98.0	4.4	98.2
230 - 260	14.8	92.3	10.4	93.8
260 - 290	44.7	77.5	52.6	83.4
290 - 320	24.0	32.8	25.0	30.8
320 - 350	6.6	8.8	4.3	5.8
350 - 380	2.2	2.2	1.5	1.5