THE USE OF FRACTIONAL ACRE PLOTS TO PREDICT SOIL LOSS FROM A MOUNTAIN CATCHMENT

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FOREWORD

Lincoln College, the College of Agriculture of the University of Canterbury, sponsors an active research and teaching programme in hydrology, soil conservation and water resources development. The purpose of these Papers is to communicate research results and new developments in these fields as rapidly as possible and particularly to report the results of projects undertaken in conjunction with the Department of Agricultural Engineering and the New Zealand Agricultural Engineering Institute. From time to time the opportunity will be taken to publish material originating elsewhere in New Zealand with which the College is associated and which could not otherwise be made available.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

For the last 100 years the condition of the New Zealand South Island high country has been the subject of much controversy.

Although there are very few records of the condition of this land at the time of European occupation, one of the first accounts from Canterbury draws attention to spectacular erosion. In 1849 F. Strange climbed to the top of the Torlesse Range and recorded:

> "The sight that met my view was very singular and wild; whole sides of mountains appeared to have slipped into the immense gullies below, whilst immense blocks of rock had been precipitated, cutting their way through the black birch (mountain beech) trees which line the gullies and carrying everything with them."
> (Quoted by Molloy, 1964.)

In the earlier years of pastoral occupation, a few authors expressed concern about the erosion being caused by repeated burning and overgrazing of sheep and rabbits. (Buchanan, 1868; Cockayne, 1919a, b, c; Bathgate, 1922.) However, it was not until the late 1930s that these views received very much public support. In 1939 the Government set up an expert Committee to enquire into the maintenance and improvement of plant cover as a protection against soil erosion. This Committee recommended that: "Statutory and administrative measures should be taken at the earliest opportunity to inaugurate a programme to handle the serious soil erosion, soil conservation and land utilisation problems that now face us ..."

In 1941 the Government passed the Soil Conservation and Rivers Control Act which set up Catchment Boards and Commissions to (inter alia) conserve soil resources and prevent damage by erosion.

During the 1940s and 1950s a number of authors drew attention to the extent and severity of erosion. (Gibbs, Raeside, Dixon and Metson, 1945; Campbell, 1944, 1951; Cumberland, 1944, 1945; Jobberns, 1949; Tussock Grasslands Research Committee, 1954.) In general it was claimed that most, if not all, erosion was a result of pastoral mismanagement. This claim was frequently debated and occasionally denied. (See for example, Morgan, 1960; Relph, 1962.) In 1949 a Royal Commission to enquire into and report upon the sheep farming industry in New Zealand reported:

> "New Zealand as a whole is little threatened by erosion ... (p.42) ... much of what has been written or spoken on the subject of erosion in New Zealand can only be described as misleading propaganda. (p.61) ... We think that Catchment Boards have no essential function to fulfil. We therefore recommend that Catchment Boards should be abolished." (p. 67)

In view of the now accepted extent and severity of erosion, and in the intensity of former debates, it is a matter of some surprise that there were, and still are, no measurements relating to the stability of soils on steep slopes. While this lack of data has been a handicap in the past it will without doubt become a greater barrier to progress in the future.

In recent years a few investigations have been made of materials and techniques for the revegetation of high altitude eroded lands. (O'Connor and Lambrechtsen, 1967; Nordmeyer, pers comm; Dunbar, 1967.) However, before the results from studies such as these can be used in action programmes it will be necessary to know the benefits of such work in terms of reduced soil loss or surface water runoff.

1.2 PURPOSE OF STUDY

It was therefore decided to set up a study which, it was hoped, would determine the extent of soil movement within one mountain catchment, and assess the influence of plant cover and type on soil stability.

1.3 METHOD OF STUDY

To carry out such a study, a number of possible techniques were considered, but the fractional acre runoff plot method appeared to have a number of advantages which could not be overlooked. The most important were that the technique had been used under diverse conditions in the United States for nearly 50 years with apparent success. In addition the plots were inexpensive, easy to install, and could provide information in relatively short time periods.

Elsewhere the author has reviewed the use of runoff plots in erosion research (Hayward, 1967b) and critically discussed some of the major deficiencies of experimental design common to most studies (Hayward 1969). This study attempted to rectify the major deficiencies of design, and use the plots to sample the erosion behaviour of the sub-areas of a small mountain catchment. It was hoped that the erosion behaviour of the sub-areas and the catchment could be predicted from the behaviour of this sample.

CHAPTER 2

THE STUDY AREA

2.1 LOCATION AND AREA

The study area is a 75 acre catchment in the headwaters of Starvation Gully in the Rakaia catchment. (Fig. 1, plate 1.) It is reasonably "representative" of the drier sub-alpine/alpine Canterbury high country and was chosen largely because of its accessibility. (State Highway 73 rises to 3,100 at Porter's Pass and is within half a mile of the catchment.

2.2 GEOLOGY AND TOPOGRAPHY

The basement rocks are greywacke (sandstones) with minor amounts of argillite (siltstone). A distinctive feature of these is their complex fracture system. Diurnal temperature changes and frost action cause an unequal expansion and contraction of the rock mass and angular fragments split off.

Table 1 sets out some of the main topographic features of the catchment as defined by Boughton (1968a).

Although the general catchment aspect is south by south west, approximately one third is south east, one third is south by south west, and one third is north west.

2.3 SOILS

The soils of the catchment have been described by Molloy (1964). Tekoa-like soils are found under the _Dracophyllum_ scrub - _Chionochloa_ grassland on the shady face, and Kaikoura-like soils are found on the sunny face. Above 4,700 feet there is a small area of alpine "soil". A detailed description of these soils is given in Appendix A.

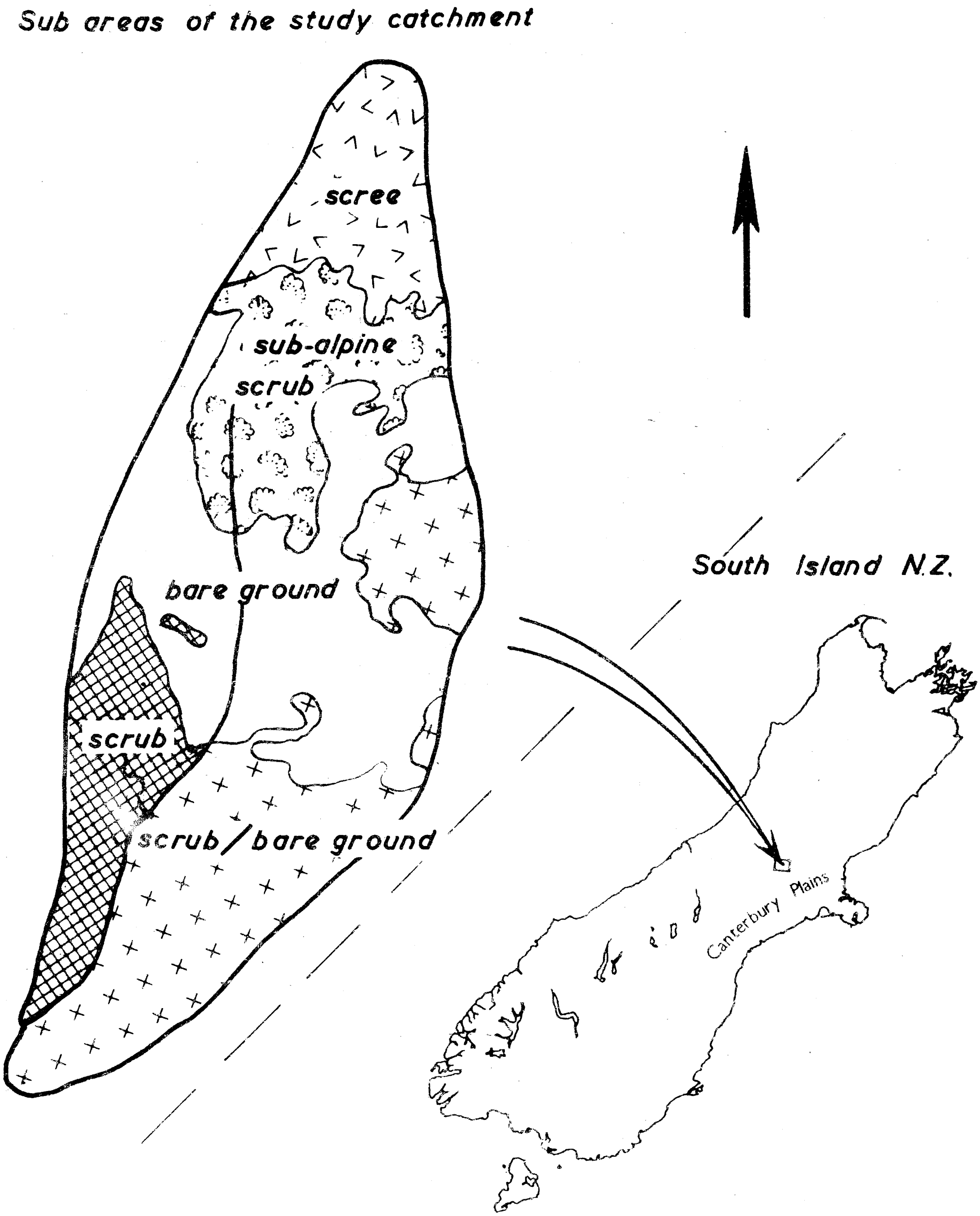


Fig. 1

Location and sub-areas of the study catchment

Plate 1

The study area in the headwaters of the Rakaia catchment. State highway 73 and Porter's Pass in bottom right.

TABLE 1

Some topographic features of the study catchment

Maximum basin relief	2,000 feet
Stream length	40 chains
Catchment area	75 acres
Maximum basin length	55 chains
Average width of catchment	2 chains
Form factor	0.05
Compactness coefficient	4.2
Circularity ratio	0.5
Elongation	0.2
Mean stream slope	1:1.7

Although the broad pattern is fairly simple, the physical factors of the environment and past land use have substantially modified some soils. On exposed north facing slopes almost all the topsoil and some of the subsoil has been eroded. The shallow soil which still remains is usually covered by angular rock fragments. The Tekoa-like soils on the shady face have suffered least erosion.

Despite the differences in profile depth these soils have several common features:

1. They are weakly weathered and strongly leached. In consequence they contain poor reserves of the essential plant nutrients.

2. They are friable, and have weakly developed crumb to nutty structures. Soil aggregates are easily pulverised. Therefore when exposed they are very susceptible to erosion by wind and water.

3. They have low bulk densities and good total porosity and macroporosity values.

2.4 CLIMATE

The climate in the vicinity of the catchment is generally cool and moist. In 1958, Molloy (1963) established four temporary climatological stations in and adjacent to the catchment. Appendix B summarises some of his data for the 11 month period December 1957 to November 1968. He found that on 44 percent of the days in his study the cloud base was below 3,000 feet, and was accompanied by fog, rain or snow.

Wind is the dominant climatic feature. Porter's Pass is a "topographic gap" between the Benmore Range and the Torlesse Range through which north-west and south-west winds are funnelled.

North-westerly winds are usually strong and dry, but may occasionally bring rain, or snow. Easterly winds usually bring mist and drizzle. Southerlies are usually rain or snow bearing. Fig. 2 is a summary of Molloy's wind frequency and direction data for the period of his study.

Snowfalls may occur throughout the year, although even in winter these seldom lie for long. However, during the winter and spring of this study exceptionally heavy falls covered most of the catchment above 3,500 feet.

2.4 VEGETATION

Prior to the Polynesian occupation of New Zealand the catchment was covered by mountain beech forest up to 4,300 feet, and tall tussock grasslands and scrub above this. Between 500 and 1,000 years ago fires destroyed the forest. An indefinite period of instability followed, during which soil was stripped from the upper catchment and the present alpine scree field was formed. The beech forest failed to regenerate and in its place the present cover of _Dracophyllum_ scrub - _Chionochloa_ grassland developed. The condition of the vegetation at the time of European occupation is a matter of speculation. There is little doubt that the pastoral practices of repeated burning and overgrazing by sheep have influenced the present pattern but it is probable that the most striking transformations occurred prior to European occupation. (Molloy, 1963.)

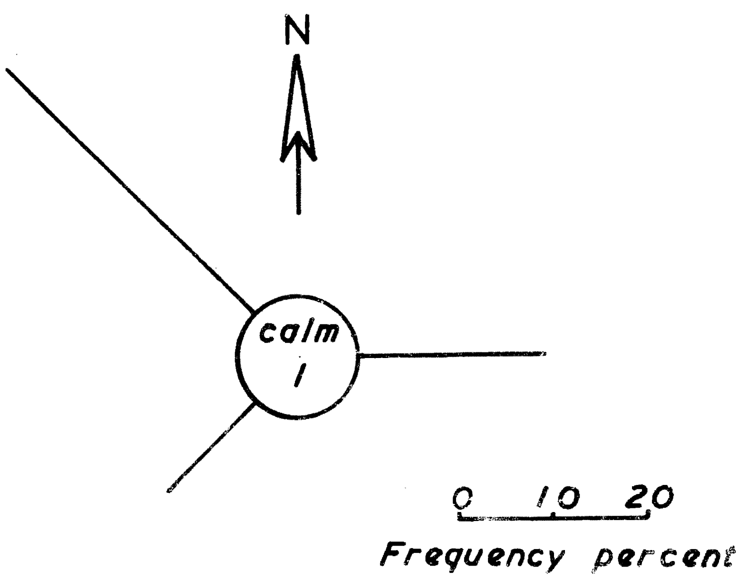


Fig. 2

Wind frequency and direction Porter's Pass
December 1957 - November 1968

(from data presented by Molloy 1963)

Molloy (1959) has described in detail the vegetation of the catchment and adjacent land. The shady face is dominated by the heath Dracophyllum acerosum. It forms a dense scrub from two to five feet high, with a thick carpet of small herbs, bryophytes and leaf litter. The most important associated plants are Chionochloa rigida, Coprosma cheesemanii, C. pseudocuneata, Gaultheria rupestris and Celmisia spectabilis.

On the sunny windward face the plant cover is discontinuous and less dense. "Islands" of vegetation are separated by areas of bare soil or erosion pavement. In addition to the species found on the shady face the sunny face supports Podocarpus nivalis, Hymenanthera alpina and a number of other minor species. A feature of both sunny and shady faces is the absence of exotic sward grasses and herbs.

Between 4,000 feet and 4,300 feet the scrub-tussock cover includes C. pallens in the gully head. The community becomes more open and discontinuous towards the exposed Foggy Peak ridge.

A mobile scree occupies both shady and sunny slopes across the middle of the catchment. A comparatively stable scree occupies the land above c. 4,300 feet. Plant cover is extremely sparse on both areas.

CHAPTER 3

EXPERIMENTAL

3.1 DESIGN OF EQUIPMENT

Plate 2 and Fig. 3 give the layout and dimensions of the plot equipment. Although this equipment is similar to that described by Costin et al (1960), Soons (1966) and the New Zealand Forest Service (C.L. O'Loughlin, pers. comm.) the only basis for its use was the author's belief that it would be most suitable for this study.

Borders

The plot borders were made of 22 gauge galvanised iron and enclose an area of 0.001 acres. Each side was reinforced by a folded upper edge and the sides are sealed and bolted together. They were buried 4 inches to 6 inches into the soil.

Collection Trough

The collection trough was made of 5 inch P.V.C. "Cromac" spouting and fitted with a stop-end and drop-end. To prevent the direct capture of rainfall, the trough was shielded by an inverted length of spouting. (Fig. 4) Each end was bolted to a plot side and the region between the trough and soil was sealed with bitumen.

Conveyance Equipment

Fibre glass reduction unions were made to connect the drop-end of collection trough to the 5 feet to 10 feet of 1¼ inch P.V.C. hose used to carry soil and water to the storage equipment.

Plate 2

Runoff plot equipment

1. Plot sides
2. Shielded collection trough
3. Fibre glass reduction union and conveyance hose
4. Storage drum: sediment trap suspended inside.

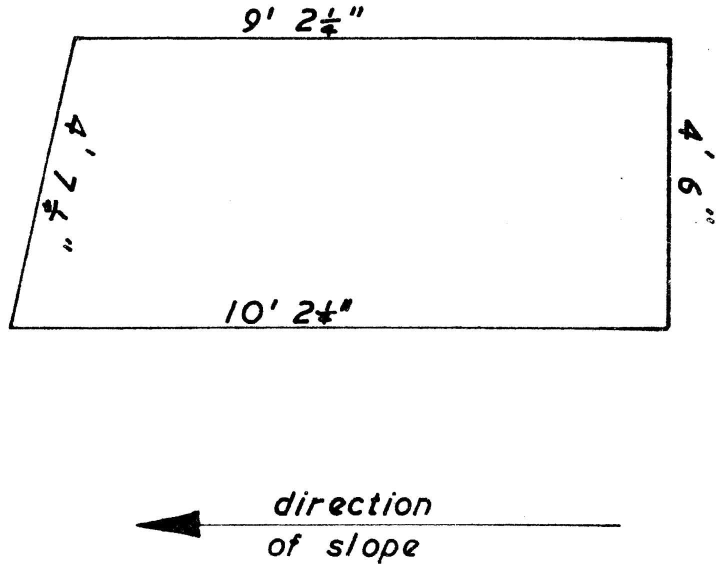


Fig. 3

Dimensions of runoff plots

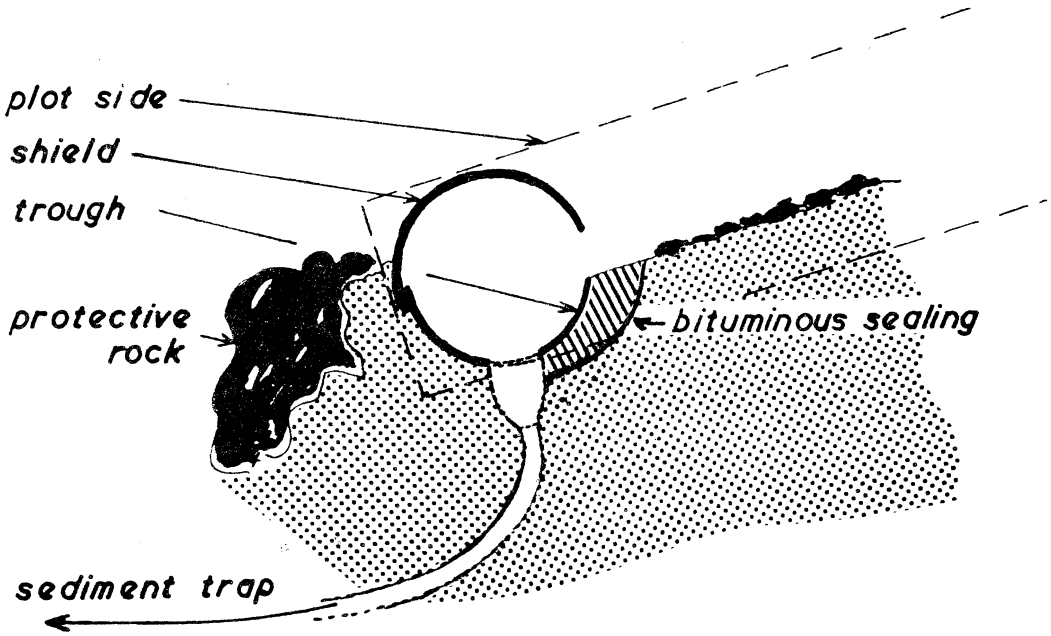


Fig. 4

Cross section through collection trough showing shielding of the trough, and the bituminous sealing between soil and trough.

Storage Equipment

Nine gallon steel grease cartridges were stream cleaned and treated with "Tarmanel" to provide the basic storage unit. Inside each, a wide neck ½ gallon plastic jar was suspended below the hose outlet to act as a simple sediment trap.

Ancillary Equipment

Raingauges - A 4 inch "Marquis" raingauge was installed at each site. Each gauge was set with its orifice parallel to the slope in the belief that this arrangement would give the most reliable information about rainfall at the site. (Hamilton, 1954).

Anemometer - An anemometer was installed on the Foggy Peak ridge at plot 20. This machine was discarded by the New Zealand Meteorological Service, but repaired for this study. It was calibrated with the anemometer at the Lincoln College Meteorological station from July to November 1967. Wind mileage was predicted from the regression equation:

$$y = 13.5 + 1.37\,x \quad (r = 0.97)$$

3.2 EXPERIMENTAL DESIGN

In Boughton's (1968b) classification of hydrological procedures this is an "Observational" study. The objects of study were:

1. To determine total soil lost from the catchment.

2. To quantitatively assess the influence of plant communities on soil loss.

The plots were to be used to sample the behaviour of sub-areas (or communities) of the catchment with respect to their soil loss and surface water runoff behaviour.

The catchment was divided into five regionally homogeneous sub-areas. (Fig. 1, Plate 3.)

Sub-area I was a mosaic of snow tussock, _Dracophyllum_ scrub and bare ground, on the sunny face.

Sub-area II was the mobile scree on both shady and sunny faces in the centre of the catchments.

Sub-area III was the dense _Dracophyllum_ scrub on the shady face. This sub-area was subdivided along an old fire boundary into tall or shorter scrublands.

Sub-area IV was the scrub-tussock grassland community between 4,000 feet and 4,300 feet.

Sub-area V was the comparatively stable alpine scree above 4,300 feet.

It was decided that 20 plots would be the maximum number that could be installed and maintained with the available resources. This would allow four replicates in each of the five "treatments".

Within each sub-area the plot locations were randomly chosen on a map by using grid co-ordinates and a table of random numbers. The position of each plot was determined in the field by theodolite survey. Fig. 5 shows the location of the 20 plots.

The important feature of this method of plot selection was that every point within a sub-area had an equal chance of being chosen to represent the area. This means that the design would provide a valid estimate of the error associated with the mean soil loss from each sub-area. However, random sampling has a number of potential difficulties.

Within each sub-area a reserve site was chosen. This would have been used if a chosen site had, through inaccuracies in mapping, been located in the wrong sub-area, or outside the catchment. Plate 4 shows the rock outcrop chosen as the reserve site for sub-area II. It would almost certainly have been impossible to establish a plot on this site. However, if difficult sites were rejected, the sample could not have been considered to represent the community. Plate 5 shows that at plot 11 it was necessary to construct a dog-leg in one plot side to establish the plot on the selected site.

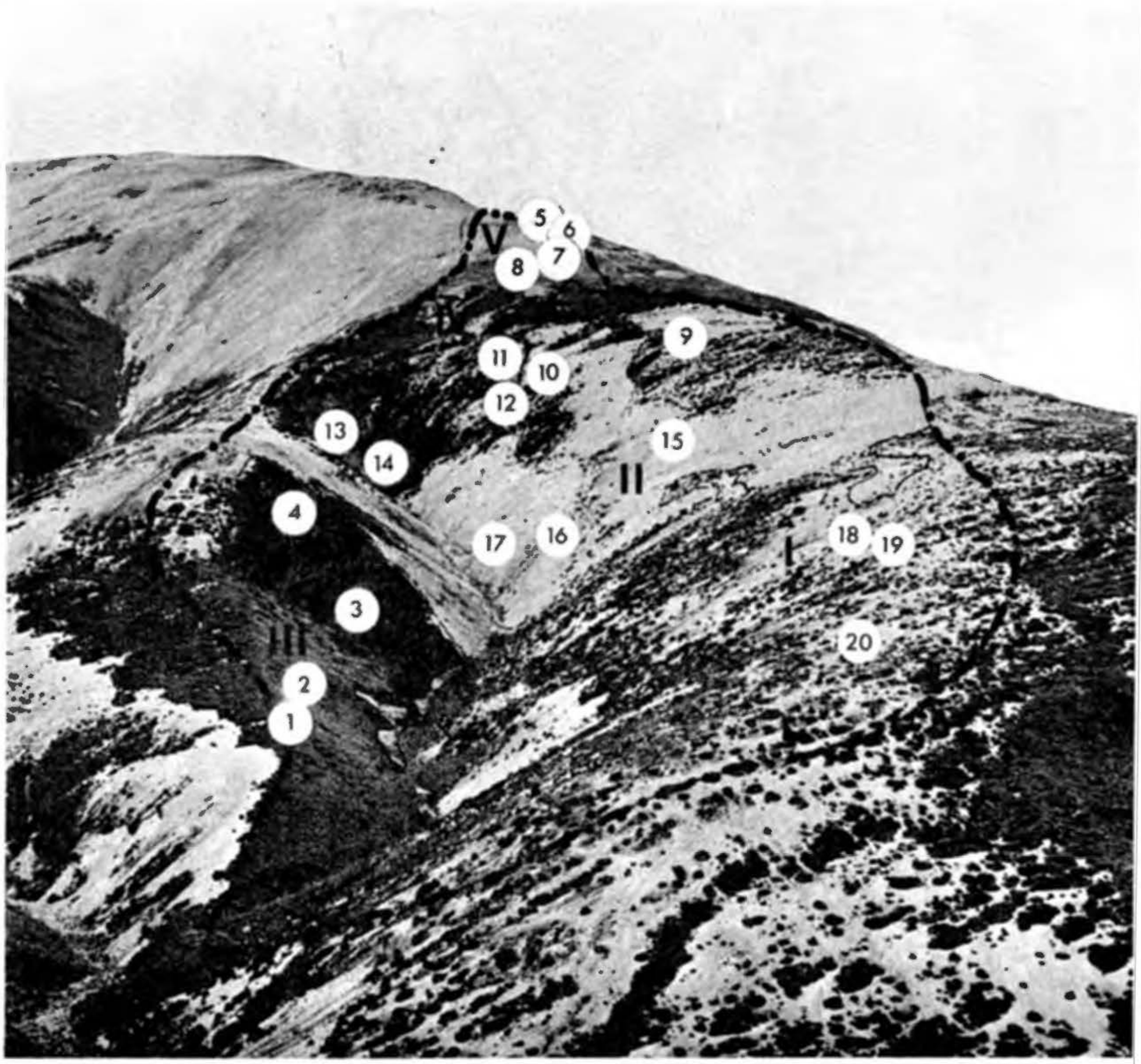


Plate 3

Plot locations and sub-areas within the study catchment (see legend for Fig. 5)

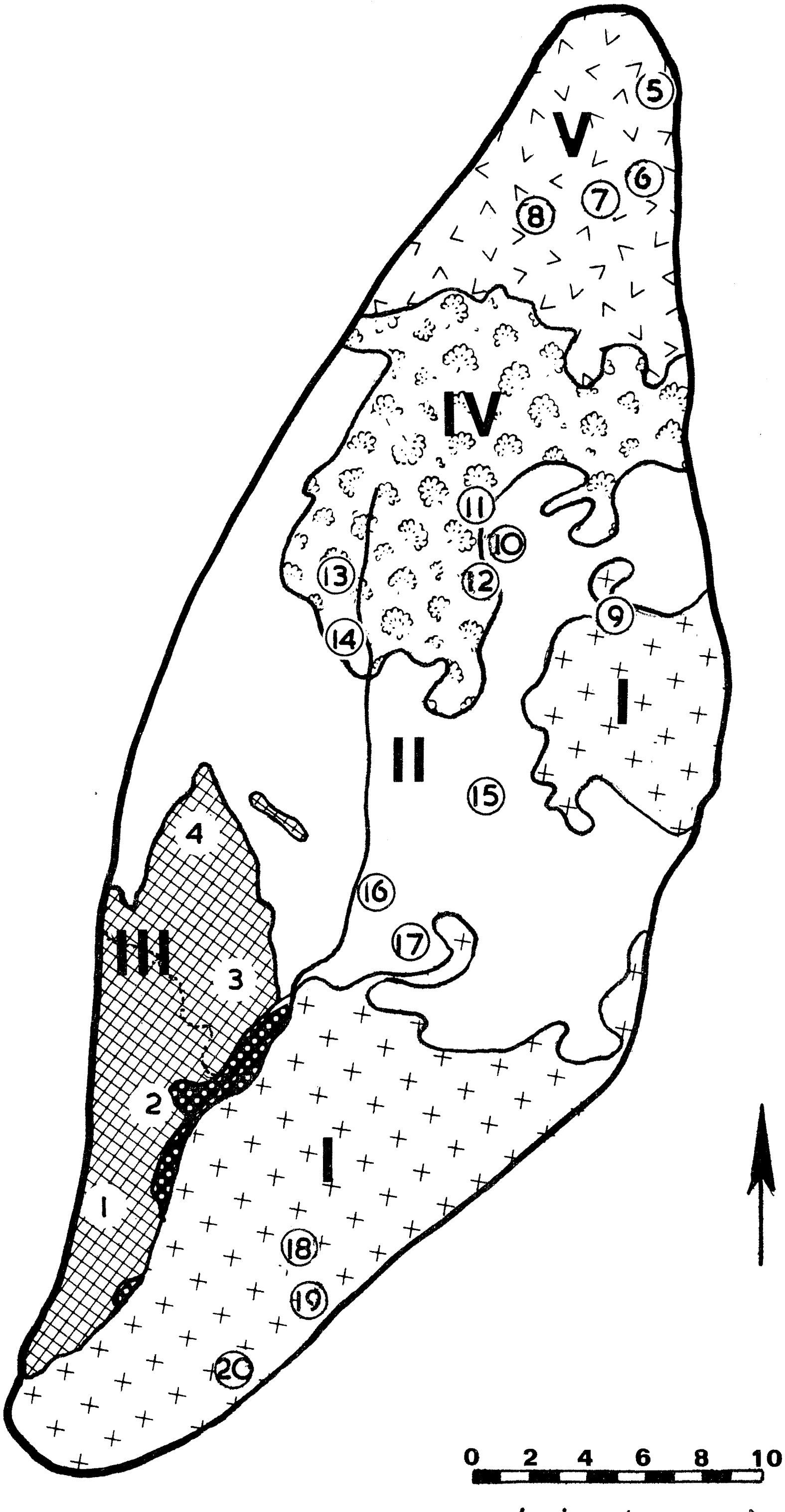
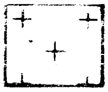


Fig. 5

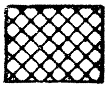
Plot locations and sub-areas within the study catchment

LEGEND FOR FIG. 5



Sub-area I : Discontinuous bare ground and *Dracophyllum* scrub

Plot 20	Raingauge, plotless area, control trough, anemometer
Plot 19	Raingauge, plotless area
Plot 18	Raingauge, plotless area
Plot 9	Raingauge, plotless area, control trough

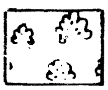


Sub-area II : Bare ground

Plot 10	Raingauge, plotless area
Plot 15	Raingauge, plotless area
Plot 16	Raingauge, plotless area control trough
Plot 17	Raingauge, plotless area, control trough

Sub-area III : *Dracophyllum* scrub

Plot 1	Raingauge, control trough
Plot 2	Raingauge, control trough
Plot 3	Raingauge
Plot 4	Raingauge

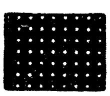


Sub-area IV : Sub-alpine snow tussock grasslands and *Dracophyllum* scrub

Plot 11	Raingauge, plotless area, control trough
Plot 12	Raingauge, plotless area
Plot 13	Raingauge, control trough
Plot 14	Raingauge

Sub-area V : Alpine scree

Plot 5	Raingauge, plotless area
Plot 6	Raingauge, plotless area control trough
Plot 7	Raingauge, plotless area
Plot 8	Raingauge, plotless area, control trough



Riparian land excluded from the study

The only part of the catchment which was excluded from sampling was the small area of riparian land shown in Fig. 5.

Appendix C gives a detailed description of the ground cover of each plot.

3.3 BIAS

Elsewhere (Hayward 1969) the author has noted that former plot studies have paid little attention to the problems of biased data. From intuitive reasoning and observation, a number of sources of bias were identified. Where possible steps were taken to quantitatively assess the importance of each source. Where measurements were not feasible, observations were made to indicate the possible importance of each source.

3.3.1 Bias Caused by Plot Sides Interrupting Overland Flow

Most theories of overland flow hold that the depth and velocity of flow increase with distance. The plot sides therefore interrupt the natural movement of surface water and within each plot a new overland flow film will be set up. Because of this it may be assumed that plots tend to underestimate soil loss. The importance of this bias should depend on plot location. Normally the bias could be expected to become greater with distance from the catchment boundary.

An attempt was made to evaluate this source of bias by comparing rates of surface movement inside and outside those plots with more than 50 percent bare ground. Two lines of graded ½ inch painted gravel were laid inside each plot and two lines were established on the "most comparable site" within 10 yards of the plot. It was realised that stones of this size tend to be unresponsive to overland flow. However, an earlier trial using paint lines on surface soil particles had shown that it was difficult to re-locate fragments smaller than ½ an inch. *

* The principal reason for this appears to be the mixing of surface particles with the soil body by freeze and thaw cycles and the associated soil creep on steep slopes.

Plate 4

The rock outcrop chosen as the reserve site in sub-area II

Plate 5

Plot 11 - In order to establish a plot at this site a "dog-leg" had to be made in one plot side. The straight edge, used to detect changes in slope and ground surface can be seen mounted on the datum pins on the lefthand side of the plot.

3.3.2 Bias Caused by Direct Capture of Rainfall

Within the first weeks of the study it became obvious that despite the shielding of the collection trough a significant proportion of the water collected as "runoff" was in fact rainfall. On several occasions the author observed rainfall being blown into the collection troughs and accumulating in the sediment trap. On these occasions there was no surface runoff.

To assess the significance of this inaccuracy 10 collection units ("control" troughs) were set up adjacent to plots, but mounted two inches above the ground surface. These were randomly assigned, two to each sub-area. Fig. 5 shows their location. Plate 6 shows the control trough at plot 20.

3.3.3 Bias Caused by the Capture of Windblown Sediment

Appendix B shows that these soils are very friable and have weakly developed structures. Their aggregates are easily pulverised. After a frost heave cycle, the surface soil particles on areas of bare ground become loose and detached from the soil body. In this condition they are extremely susceptible to erosion by wind. On many occasions the author observed soil and fine sand being blown into the collection troughs.

The collection troughs set up to measure the amount of direct capture rainfall were also used to assess the significance of wind-borne sediment. However, this could only be a qualitative assessment. The collection troughs were installed about 2 inches above the ground to allow the natural movement of surface material underneath them. It is therefore probable that they would not collect particles moved by creep and only some of the finer particles moved by saltation and suspension.

Nevertheless it was hoped that a comparison of particle sizes and weights of material collected from plots and plotless troughs would indicate the possible significance of this source of bias.

Plate 6

The "control" trough at plot 20. Although this plot was raised two inches above the soil surface it retained 0.12 lbs of soil, or four percent of the yield from plot 20.

3.3.4 Bias Caused by Alteration of Plot Slope

Several authors have compared the behaviour of a single plot or treatment over a period of years. Some have suggested that this replication in time overcomes the objections to a lack of treatment replication.

The author suggests that such comparisons are probably only valid when:

1. There is no change of slope with time, i.e. the collection trough can be lowered to match the lowering of the surface soil caused by erosion.

2. There is no real difference in the composition of the eroding surface soil particles and those of the soil body.

To detect changes in slope with time, three feet long deformed steel datum pegs were established above and below each plot. A straight-edge was placed between these and distance to the soil surface measured at 3 inch intervals down the plot. Two surface profiles were recorded on those plots where surface movement was expected and two were recorded on the adjacent "plotless areas".

3.3.5 Bias Caused by Leakages into and out of the Plot

On most bare ground sites the author was apprehensive about his ability to seal each plot against surface water from adjacent areas. This was caused mainly by the porous and stony nature of the soil. Fig. 6 shows where leakages were anticipated. To provide a qualitative assessment of this source of error the water sc[illegible]le dyes Lanasol Red and Sodium Fluorsene were spread on the soil surface immediately above plots 18, 19 and 20.

3.4 PROCEDURES

3.4.1 Field Procedures

The plot materials and ancillary equipment were transported to Porter's Pass and packed into the catchment. All

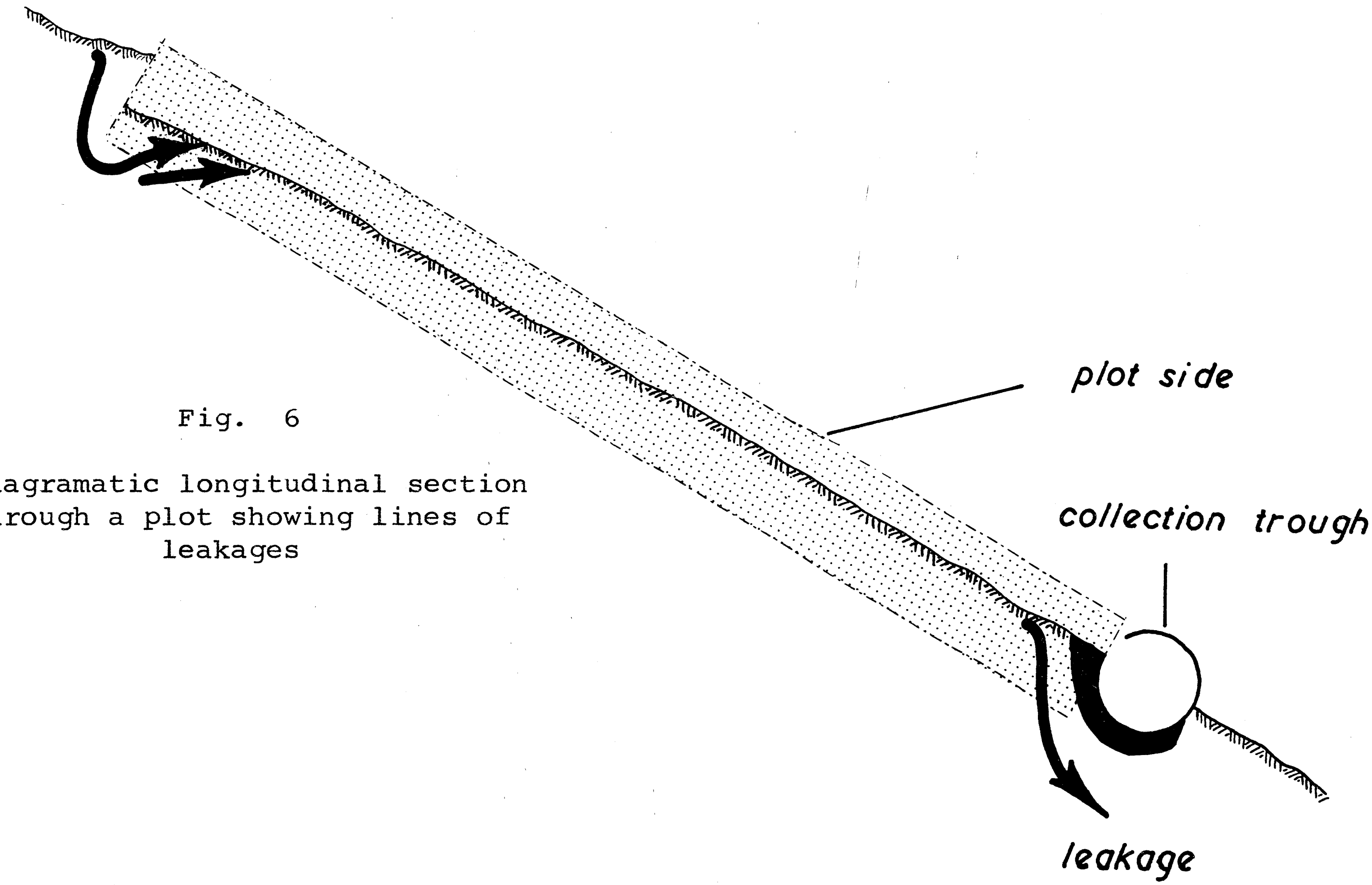


Fig. 6

Diagramatic longitudinal section through a plot showing lines of leakages plots were established between April and June 1967 and allowed to settle in during the winter and spring. Measurement of soil and water losses were started in November 1967.

It was planned to service the plots after each storm event and during severe storms. However, weather conditions in the study area forced many servicing trips to be abandoned. Strong winds made the physical task of climbing between plots extremely difficult and made the accurate measurement of rainfall and runoff an impossibility. During the winter of 1968 exceptionally heavy snowfalls were recorded throughout the South Island high country. From June until early October most plots were under a continuous snow cover. Under these conditions many plots could not be located. This, together with the problem of frozen sediment traps, made winter servicing difficult and unrewarding.

On each servicing trip:

1. Rainfall for the last period was measured.

2. Surplus water in the sediment trap was decanted off and measured, to reduce the weight of each sample.

3. Overflows held in the storage drum were either pumped out or mopped out and measured.

4. Sediment traps were replaced and brought back to the laboratory for an analysis of the eroded soil.

Surface soil and stones retained in the collection trough were collected once every two months. On these occasions sediment was also flushed from the conveyance hose.

The surface profiles were measured in December 1967 and again in November 1968.

The lines of painted gravel used to compare movement inside and outside each plot were to have been measured every two months. However, only one re-measurement was possible. Snow precluded re-measurement during the winter, and frost-lift in the spring destroyed most lines.

Plate 7

Plot 20 August, 1968

Plate 8

Porter's Pass July 1968 looking
towards the study catchment

3.4.2 Laboratory Procedures

These were basically simple. The first stage was to filter the sediment from the sample, using a qualitative filter paper. This retained particles coarser than "fine crystalline" but did not retain colloidal material. The loss of colloidal material was found to be unimportant. Where the filtrate was evaporated to dryness the weight of colloidal material was found to be well within the error value for laboratory weighing. Plate 9 shows the 20 filtering units set up to handle all samples at the same time.

The sediment was then oven dried and weighed. Where necessary, organic matter was floated off and the sample redried and stored.

In November 1968 the accumulated sediment was sieved for particle size determination.

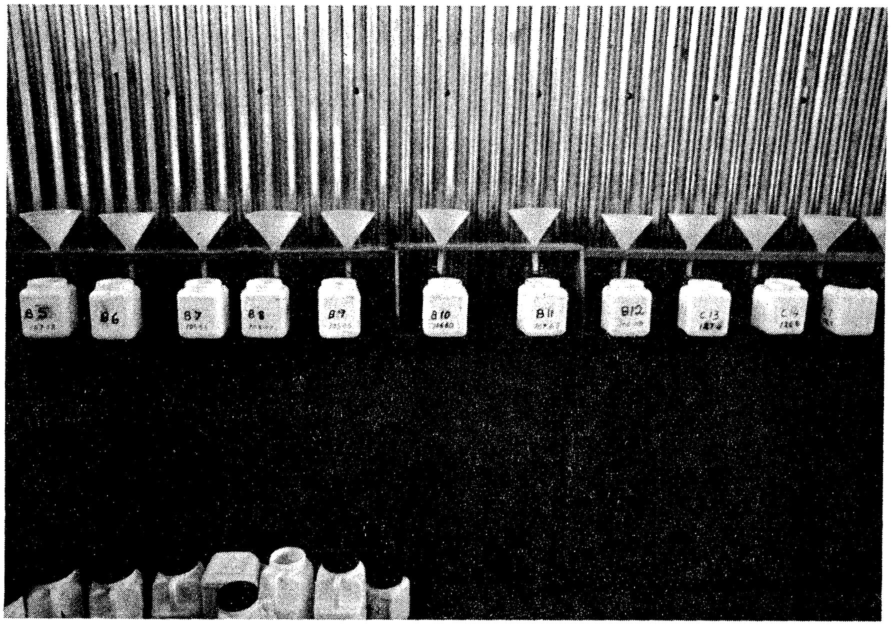


Plate 9

Part of the filtration unit set up in the laboratory. The half gallon plastic jars were suspended inside the storage drums to act as sediment traps.

CHAPTER 4

RESULTS

4.1 SOIL LOSS

It is assumed for the moment that the plot yields were normally distributed throughout each sub-area and that they were not biased.

Table 2 shows the total soil loss from all plots during the period November 1967 to November 1968. It also shows the distribution of particle sizes of the eroded material. These results are also shown diagramatically in Fig. 7.

Table 3 shows the mean value for soil loss from each sub-area and the uncertainty associated with each estimate. These are presented diagramatically in Fig. 8.

The analysis of variance method was used to establish the significance of the differences in soil loss between sub-areas. The null hypothesis adopted was that there were no differences in soil loss between sub-areas and that the measured differences were chance events. The analysis (Appendix D) failed to disprove this hypothesis at the 99%, 95% and 90% probability levels.

4.2 BIAS

4.2.1 <u>Plot Sides Interrupt Overland Flow</u>

The movements of lines of ½ inch stones inside and outside plot 9, 18, 1[illegible] 20, 10, 15, 16, 17 and 12 are shown in Appendix E. Table 4 shows the average movement of stones inside and outside each plot.

On the assumption that these differences were due to the protecting influence of the plot sides, they were examined by:

TABLE 2

Total soil loss from all plots November 1967 - November 1968, and particle size distributions (lbs)

Sub-area	Plot	Soil	Particle Size Distribution					
		Total soil (lbs)	Soil < 2mm	Fine gravel 2mm-3/16"	Medium gravel 3/16" - ½"	Coarse gravel ½" - ¾"	Small stones ¾" - 1½"	Medium stones 1½" +
I	9	2.34	0.61	0.77	0.57	0.16	0.23	
	18	3.90	0.11	0.04	0.73	1.25	1.22	0.55
	19	3.05	0.27	0.08	0.61	0.33	1.33	0.43
	20	2.86	0.25	0.07	0.30	0.35	1.16	0.73
II	10	1.00	0.16	0.23	0.29	0.04	0.28	
	15	2.69	0.16	0.16	0.37	0.22	0.70	1.08
	16	13.70	0.44	1.85	4.93	2.18	3.65	0.65
	17	0.55	0.17	0.14	0.16	0.04	0.04	
III	1	0.08	0.07	0.01				
	2	0.04	0.02	0.01	0.01			
	3	0.01	0.01		trace			
	4	0.03	0.02	0.01	trace			
IV	11	0.39	0.22	0.08	0.04	0.05		
	12	1.59	0.42	0.36	0.33	0.22	0.26	
	13	0.04	0.03	0.01	trace			
	14	0.03	0.02	0.01	trace			
V	5	0.42	0.07	0.05	0.05	0.25		
	6	0.25	0.15	0.06	0.04			
	7	0.31	0.15	0.08	0.06	0.02		
	8	0.08	0.02	0.02	0.02	0.02		

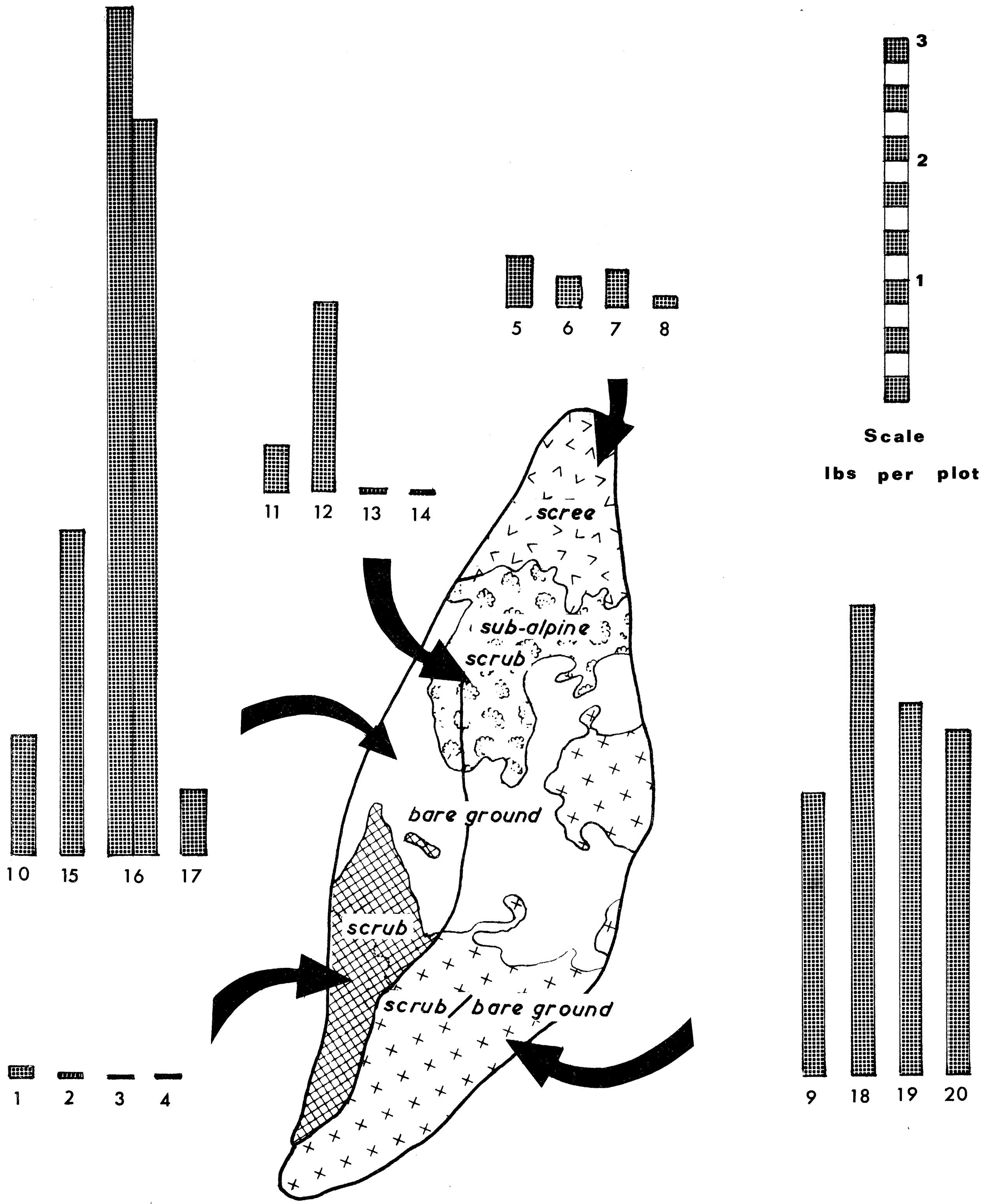


Fig. 7

Diagramatic representation of total soil loss (November 1967 - November 1968) from the four plots in each sub-area.

TABLE 3

Mean value of soil loss from four plots in each sub-area: (lbs)

Sub-area	Mean	Standard error	Confidence interval		Range within which there is a 95% chance a mean will be found
			80%	95%	
I	3.04	± 0.33	± 0.55	± 1.03	2.01 - 4.59
II	4.49	± 3.10	± 5.10	± 9.88	0 - 14.37
III	0.04	± 0.02	± 0.02	± 0.04	0 - 0.08
IV	0.50	± 0.37	± 0.59	± 1.17	0 - 1.67
V	0.26	± 0.07	± 0.11	± 0.22	0.04 - 0.48

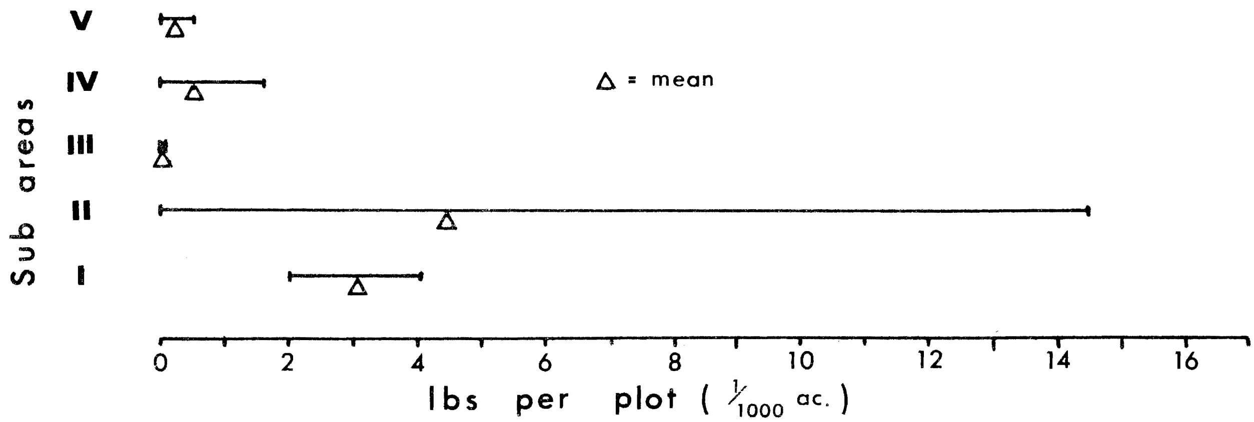


Fig. 8

Diagramatic representation of mean soil loss from each sub-area and range within which mean will be found of 95% of all occasions.

TABLE 4

Average movement of ½ inch gravel lines inside and outside plots.

Sub-area	Plot no.	Average movement per stone (inches)	
		Inside Plot	Outside Plot
I	9	9.4	6.0
	18	6.7	3.6
	19	19.3	16.5
	20	4.9	4.7
II	10	11.0	33.2
	15	11.5	10.3
	16	9.5	9.8
	17	6.2	4.3
IV	12	18.9	24.6

1. Students' t. test.

2. The analysis of variance.

The students' t. test failed to demonstrate significant differences in the mean movement of stones inside and outside each plot. The analysis of variance indicated that there was greater variability of movement within either plots or plotless areas than between them.

4.2.2 <u>Direct Capture of Windblown Sediment</u>

Table 5 shows the yield and particle size distribution of material collected in troughs suspended two inches above the ground. These results are shown diagramatically in Fig. 9.

The total yield from all "control" troughs amounted to 7% of the yield from the associated plots (1.41 lb v. 20.32 lb). However, Table 5 shows that this ranged from 2% (plot 16) to 71% (plot 17).

If the soil fraction is considered by itself, the yield from all "control" troughs was 30% of that from the plots (0.61 lb v. 1.98 lb). The range was from 3% (plot 11) to 88% (plot 17).

4.2.3. <u>Changes in Plot Slope</u>

The re-measurement of a number of profiles on the same day showed that the distance from the straight edge to the soil surface could be measured to:

i. $\pm$ ½ inch on all occasions

ii. $\pm$ 3/8 inch on 96% of all occasions

iii. $\pm$ ¼ inch on 73% of all occasions

iv. $\pm$ 1/8 inch on 30% of all occasions

It was therefore decided to reject differences of less than 3/8 of an inch.

TABLE 5

Soil from "control" troughs two inches above ground surface, March - November 1968; and particle size distribution.

Sub-area	Plot no.	Total yield (lbs)	% of yield from associated plot	Soil, <2mm	% of soil from associated plot	Fine gravel 2mm - 3/16"	Medium gravel 3/16" - ½"	Coarse gravel ½" - ¾"
I	9	0.52	22	0.22	35	0.22	0.08	
	20	0.12	4	0.11	44	0.01	trace	
II	16	0.31	2	0.09	20	0.10	0.09	0.03
	17	0.39	71	0.15	88	0.09	0.11	0.04
III	1	0.02	19	0.02	17	trace		
	2	trace	7	trace	10			
IV	11	0.01	3	0.01	3	trace		
	13	trace	13	trace	8	trace		
V	6	0.02	8	0.02	11	trace		
	8	0.01	8	0.01	27	trace		

Fig.9 - Diagramatic representation of soil collected from "control" troughs (March-November 1968) compared with soil collected from plots (November 1967 to November 1968). (Note: "control" troughs mounted 2 inches above ground surface)

The best indication of slope change is shown in Fig. 10 which records the changes of the soil surface on both lines at plot 16. The first stages of slope change on plots 12, 15, 17, 18, 19 and 20 were observed, but less easily detected by measurement. A distinct alteration in the size of surface material was associated with these changes in plot surface. This was most evident on plot 19, (plate 10) but was also observed on all plots in sub-areas I and II and on plots 11 and 12 in sub-area IV.

In sub-area V (alpine scree), there was some movement of the angular rocks, but general changes in slope could not be detected.

4.3 RUNOFF

The collection of "surface water" runoff was abandoned after the autumn of 1968 when it was found that the data were excessively biased and subject to major errors.

4.3.1 Direct Capture of Rainfall

Table 6 shows the yield of "runoff" from plots and "control" troughs from some storms. On many occasions the storage capacity of the control troughs was exceeded. These events have not been included. For storms in which the "control" trough storage capacity was not exceeded rainfall in the "control" trough accounted for 30 percent of the total runoff from all plots.

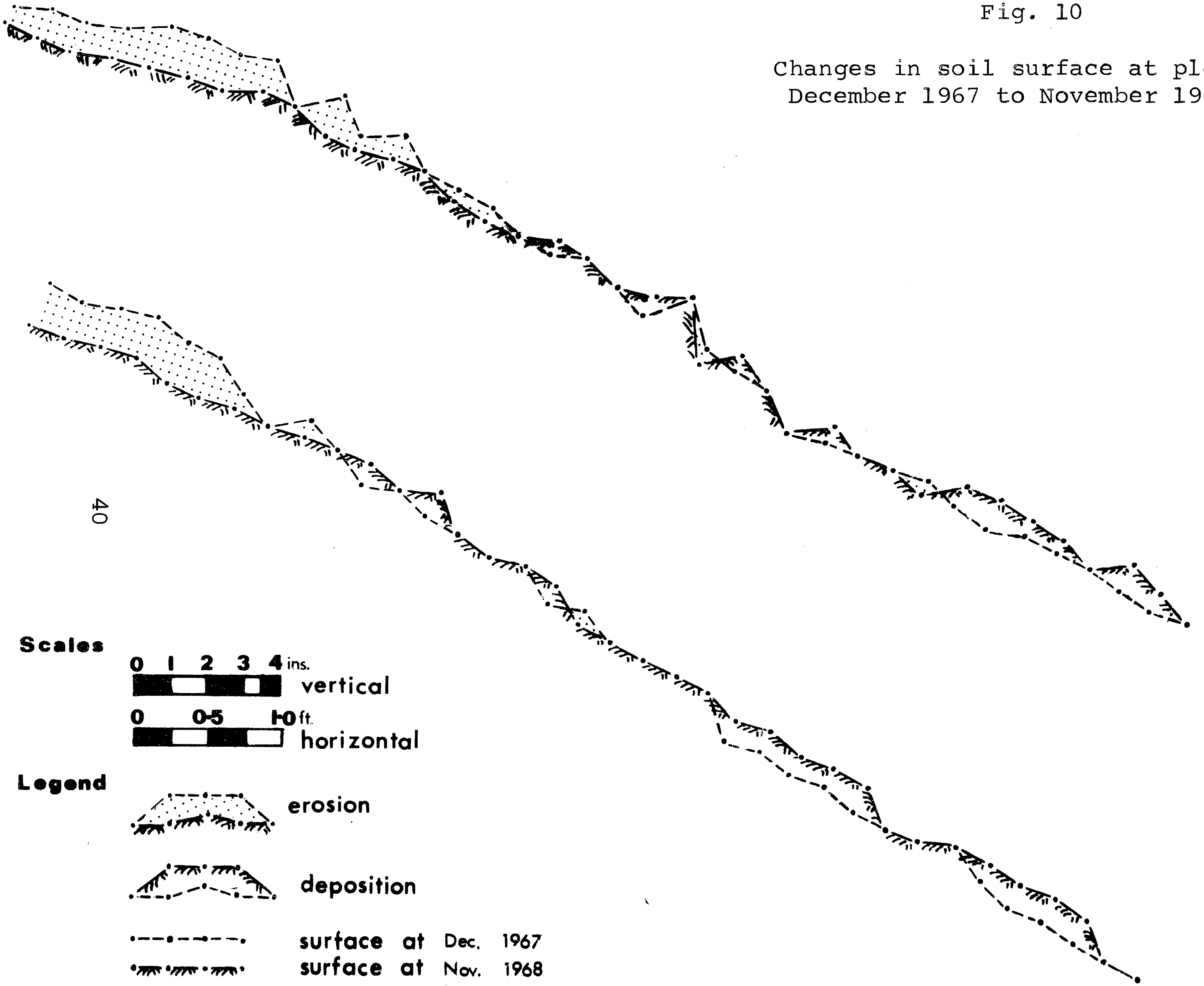
However, this average has little real meaning. Table 6 shows that the average for individual plots varied from 2 percent (plot 11) to 78 percent (plot 8). In addition there was considerable variation between storms on the same plot. For example at plot 13 the yield from the "control" trough varied from 13 percent to 204 percent of that from the associated plot.

4.3.2 Leakages

Clear evidence of leakages into the plot was obtained at plot 18. The water soluble dye Lanasol red (spread on

Fig. 10

Changes in soil surface at plot 16
December 1967 to November 1968



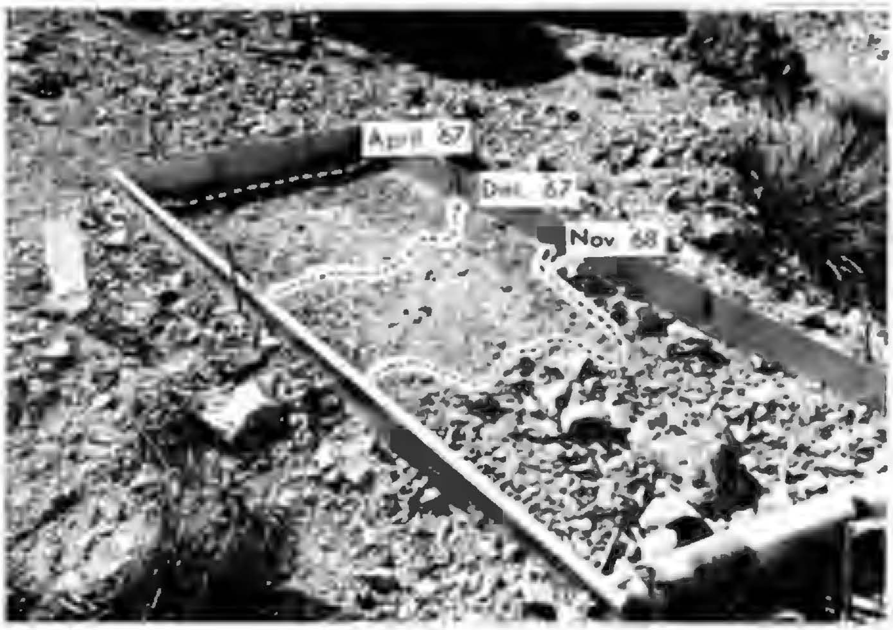


Plate 10

Plot 19 - The dotted lines show the movement of the surface stone pavement.

TABLE 6

Some selected runoff results from plots and "control troughs.

Rainfall measured in inches
Runoff measured in c.c.

% = Control trough yield as % of plot yield for <u>all</u> storms

						Percentage
	9	Rainfall	284	56	95	
		plot	5330	270	3080	
		"control"	3000	1090	1420	68%
I						
	20	Rainfall	322	33	37	
		plot	11850	1120	2770	
		"control"	4390	500	1390	40%
	16	Rainfall	290	42	?	
		plot	5345	690	1310	
		"control"	2040	340	500	40%
II						
	17	Rainfall	46	43	276	
		plot	500	415	6510	
		"control"	430	270	3000	50%
	1	Rainfall	47	42	43	
		plot	715	805	2370	
		"control"	715	470	750	42%
III						
	2	Rainfall	300	97	23	
		plot	5130	1520	725	
		"control"	530	0	755	20%

cont/....

.... Cont.

	11	Rainfall	300	91	42	
		plot	8510	2540	200	
		"control"	0	390	0	2%
IV						
	13	Rainfall	278	104	44	
		plot	5450	980	890	
		"control"	2500	2000	1190	45%
	6	Rainfall	283	56	241	
		plot	7300	300	5580	
		"control"	3670	500	4000	52%
V						
	8	Rainfall	101	37	215	
		plot	2170	1130	3520	
		"control"	1480	1000	3830	78%

the ground above the plot) was found to stain the soil surface for about 18 inches inside the plot. However, neither this nor the sodium fluorescene (spread above plots 19 and 20) could be detected in the "runoff" water.

4.3.3 The Influence of the Plot Sides

The effect of the plot sides on air flow at the ground surface and precipitation was not measured. Nevertheless this was observed at plot 19 (plate 11) as snow accumulation in the lee of the plot side and the adjacent raingauge.

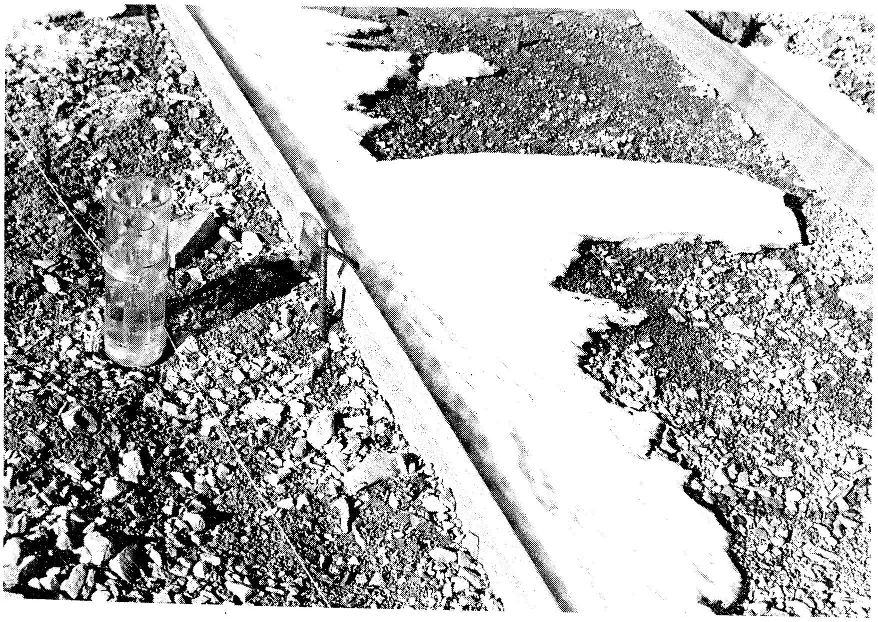


Plate 11

Plot 11 showing the accumulation of snow in the lee of the plot side, and the adjacent raingauge.

CHAPTER 5

DISCUSSION

5.1 SOIL LOSS

5.1.1 Homogeneity and Sample Size

The outstanding feature of this study is the variability in the yields of eroded material from so called homogeneous areas. It was noted that an analysis of variance suggested that there was greater variability of soil loss within sub-areas than there was between them (at 1%, 5% and 10% significance levels).

However, a basic assumption of the analysis of variance is that the variance of each treatment (or sub-area) when taken separately, is the same. Table 3 shows that the standard error for each sub-area ranges from 0.02 lb to 3.10 lb per plot. These differences in standard error mean that there will be comparable differences in variance. It is therefore doubtful if the use of the analysis of variance method as shown in Appendix D(a) is a legitimate one.

In order to legitimately use this method of analysis the data were transformed to "equalise" their variance from each sub-area. As there was a slight suggestion that the standard error was proportionate to the mean from each sub-area, a logarithmic transformation was used. Appendix D(b) shows the analysis of the transformed data and shows the F value to be highly significant (1% significance level). In other words the soil loss yields when logarithmically transformed suggest that the differences between sub-areas are more important than the within sub-area differences.

While this analysis of transformed data may be a statistically valid procedure, the author has a number of reservations about its real worth. A logarithmic transformation is fairly drastic, and has the effect of shortening the long right tail of the distribution and lengthening the short left tail. This means that whereas the yield from, say plot 16, made a very substantial contribution to the total variance of the "raw" data, it has only a slight influence when the data are transformed. Because this transformation lessens the influence of high yields, it also has the effect of altering the ranking order for mean soil loss. Whereas in Appendix D(a) mean losses are ranked II > I > IV > V > III their order in Appendix D(b) is I > II > V > IV > III.

This discounting of large events and promoting of smaller events may be legitimate in studies where size above a critical level is unimportant. For example river flows of 100 or 200 cusecs could be of little importance if all flows exceeding 50 cusecs caused maximum damage.

However, in this study the author believes the wide range of yields to be extremely important. It suggests that these apparently homogeneous areas are in fact highly variable with respect to their soil loss behaviour. Any attempt to minimise the influence of high yields merely to obtain statistical conformity is difficult to justify. Results obtained in this manner would have a doubtful value and could in fact be misleading.

The difficulty with these results is that because there is a wide range of variance between sub-areas they are not suited to analysis by the analysis of variance method. The variance may be equalised by a transformation procedure. However, this technique has the disadvantage of giving results with an uncertain real meaning.

Despite the difficulties of statistically analysing the results, the yields shown in table 2 quite clearly demonstrate the importance of ground cover in reducing rates of erosion. For example plot 14 (a dense cover of snow tussock and <u>Dracophyllum</u> scrub) yielded 0.03 lbs of soil whereas plot 15 (bare ground) yielded 2.69 lbs. This also applies to the sub-areas. Those with most cover, (III and IV) and greatest stability, (V) yielded less soil that the areas of bare ground (I and II). However, many authors have shown that plant cover reduces erosion. The object of this study was not a qualitative demonstration, but a quantitative assessment. The question to be answered was not does plant cover influence erosion, but rather by how much. In this respect the study has been unsatisfactory.

It was explained earlier that in this project the plots were being used to sample the erosion behaviour of the communities which made up the study catchment. From the behaviour of the sample, the behaviour of each sub-area would be inferred and total soil loss for the catchment would be predicted. If it can be assumed for the moment that the results can be extrapolated beyond each plot, estimates can be made for the soil loss for each sub-area and for the catchment (table 7).

TABLE 7

Estimates of soil loss from the catchment and its sub-areas assuming that the soil loss results can be extrapolated beyond each plot.

Sub-area	Area (acres)	"Average" loss (tons)	Range (tons) 95% confidence interval
I	22	30	20 - 45
II	25	50	0 - 160
III	8	0	0 - ½
IV	11	3	0 - 9
V	8	1	0 - 2
Total	74	84	20 - 217

Even under the very doubtful assumption that the data can be extrapolated, table 7 shows that range within which the average loss will be found is extremely wide. In consequence it has little real meaning. To reduce the range of the mean from each sub-area, and therefore the catchment, a very much larger number of plots would be needed.

An indication of sample size can be obtained from the formula

$$n = \frac{t^2 s^2}{e^2}$$

where n = number of replicates ($\pm$ 50 percent)

t = students' t. for the required confidence interval

e = required precision

s^2 = variance

Using this formula, it was estimated that to measure erosion to $\pm$ 0.22 lbs per plot (about 0.1 tons per acre) a total of about 3300 plots would be needed. Of these, 35 would be required in sub-area I, 3200 in sub-area II, 1 in sub-area III, 45 in sub-area IV and 2 in sub-area V.

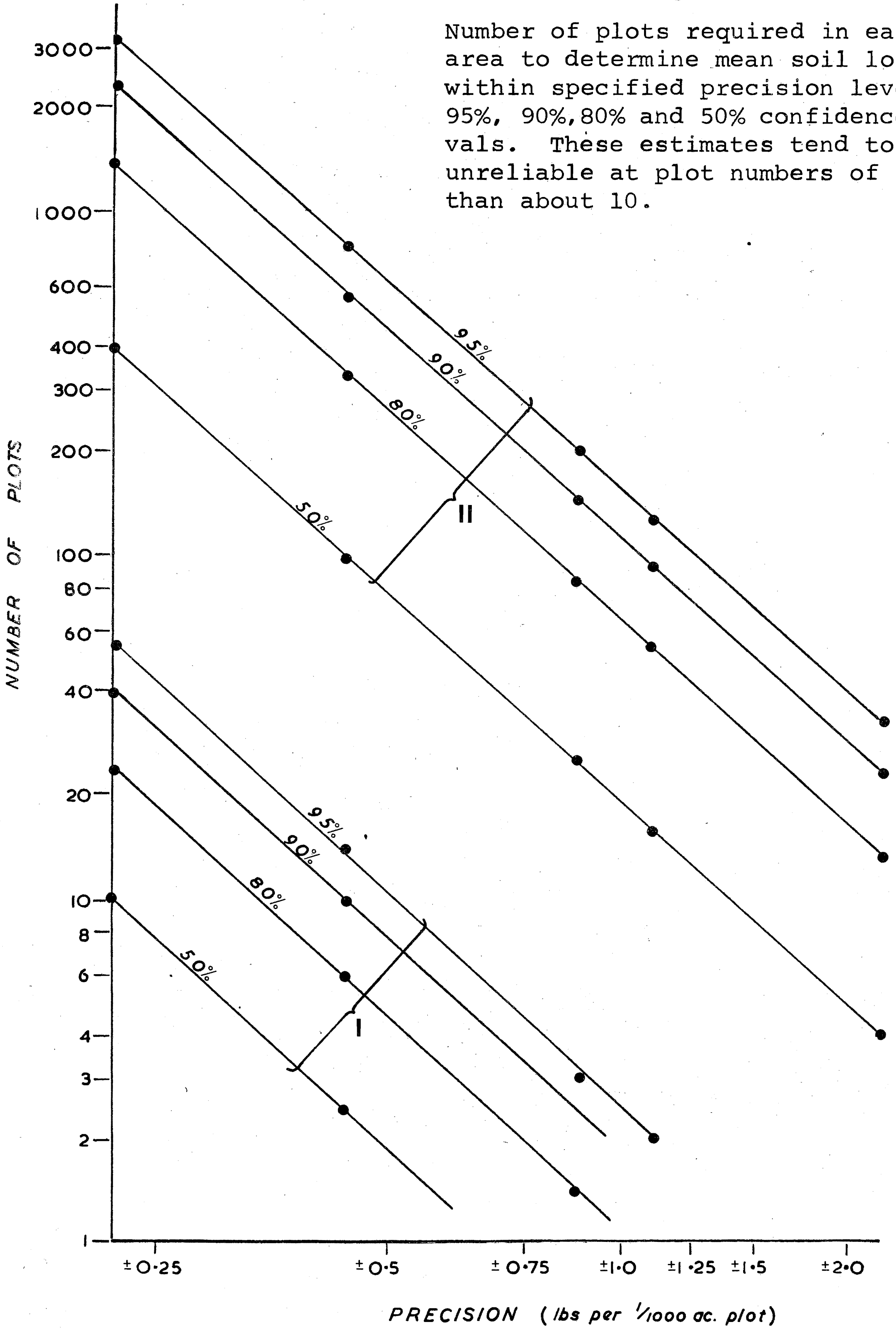
It may be argued that the precision and confidence interval of this estimate are too high. Figs 11 (a and b) show the number of plots needed to estimate soil loss within a range of precision levels and confidence intervals.

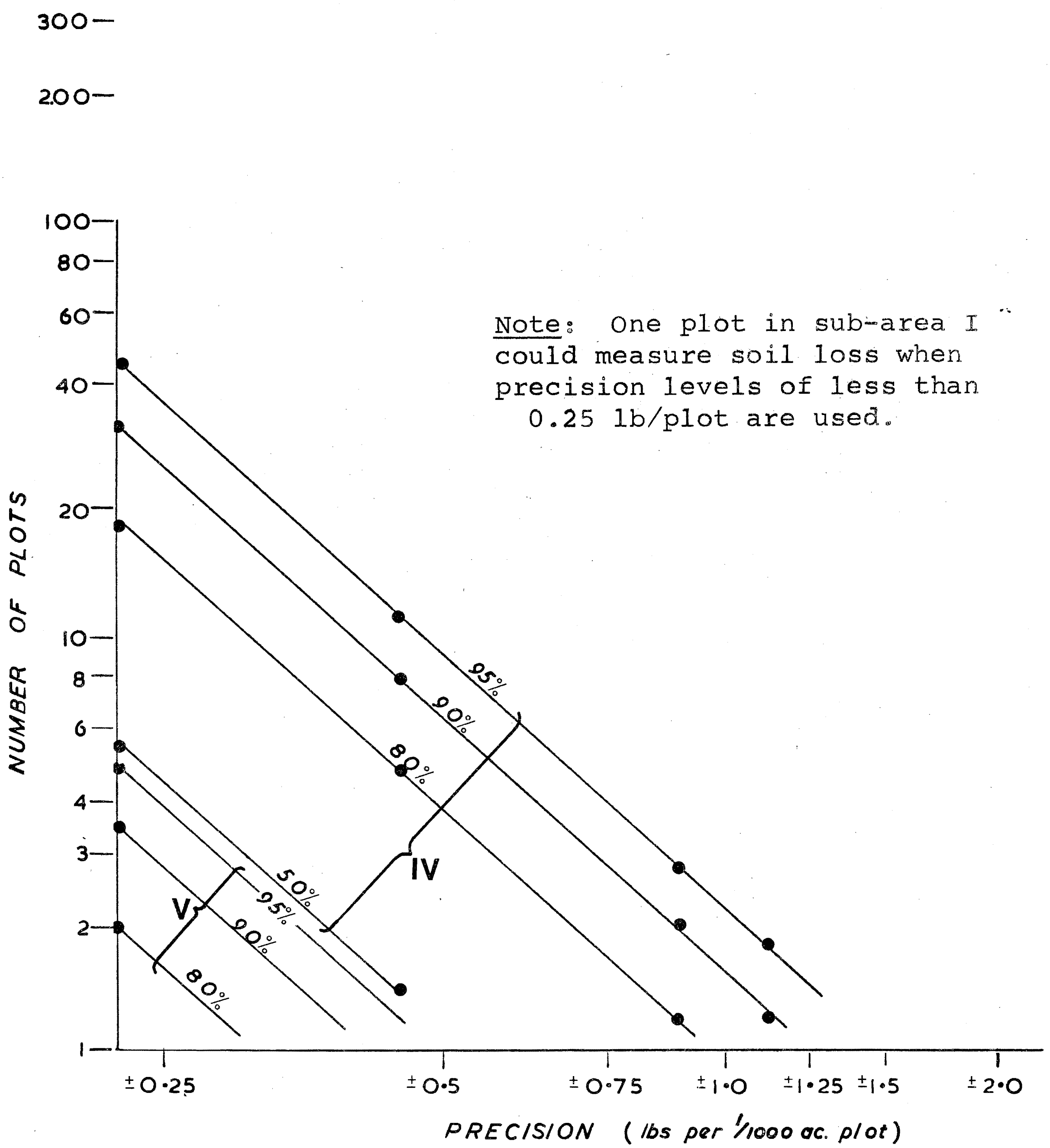
However, if the results of a study such as this are to be extrapolated to larger areas, high levels of precision and certainty are necessary. For example in the Waimakariri catchment there are approximately 100,000 acres of land "similar" to sub-areas I and II. (Hayward, 1967a) An error estimate of only 0.22 lb per plot could amount to an error estimate of about $\pm$ 10,000 tons from the catchment. Although less precise results could be obtained from fewer plots, fig. 11 shows that many more plots would be required than were used in this study.

When the results of a study are inconclusive, there is always the temptation to use the results to show something else. For example it would be possible to regroup the data and present results from well covered plots (e.g. 1, 2, 3, 4, 13, 14) as distinct from bare ground plots (e.g. plots 9, 10, 15, 16, 17, 18, 19, 20). Such a reworking of the data would probably reduce the range for the mean loss. This would enable a better comparison to be made of erosion losses from good plant cover and from bare ground. However, the object of this study was to determine soil loss from several communities (or sub-areas) and from this, to predict total soil loss from the catchment. The study has failed to do this, and no amount of reworking of the data can alter this result.

Fig. 11a

Number of plots required in each sub-area to determine mean soil loss to within specified precision levels at 95%, 90%, 80% and 50% confidence intervals. These estimates tend to be unreliable at plot numbers of less than about 10.





300
200
100
80
60
40
20
10
8
6
4
3
2
1
NUMBER OF PLOTS
Note: One plot in sub-area I could measure soil loss when precision levels of less than 0.25 lb/plot are used.
95%
90%
80%
IV
50%
95%
90%
80%
V
±0.25
±0.5
±0.75
±1.0
±1.25
±1.5
±2.0
PRECISION (lbs per 1/1000 ac. plot)

Fig. 11b

However, it should be noted that the results of this study are substantially influenced by the behaviour of plot 16. The influence of the high yield from this plot (table 1) can be seen in the estimate of standard error for community II and for the catchment (table 3) and the high number of plots required in sub-area II and hence the catchment, to predict soil losses at specified levels of precision. Because this plot gave an extraordinarily high yield, the author considers that it warrants additional comment.

Although community II was regionally "homogeneous" it did include a small number of "non-representative" areas. These were principally rock outcrops and islands of vegetation. However, the random selection of plot sites provided four visually similar sites. Slopes ranged from 27^{o} to 33^{o} (plot 16 was 30^{o}) and all plots were devoid of vegetation. Although there were minor variations in the proportion of bare soil and small stones on the surface of each plot, plot 16 did not appear to be different. Nevertheless, it became apparent during the study that this plot had a more mobile surface than the others. The reason for this is not clear, so that it would not be possible to stratify community II for this characteristic.

There is no way of knowing the proportion of community II which is "represented" by plot 16, therefore the author has no reason for discounting its yield.

This study has shown a fundamental weakness in the suitability of the runoff plot method for "observational" studies in this type of environment. Clearly, useful results are only possible if large numbers of plots are installed or if more homogeneous sub-areas are defined.

In addition, the author believes that these results cast an element of doubt on the concepts of homogeneity and representativeness in hydrological research.

For example Unit Source Watersheds have been described as physically homogeneous areas which are subject to relatively uniform precipitation. (Amerman, 1965; Kincaid, Osborne and Gardiner, 1966). Although the term has usually been restricted to natural drainage areas, Amerman and McGuiness (1966) suggested that it could include runoff and erosion plots, as the hydrological cycle operated within their boundaries in much the same way as it did in larger areas or catchments.

If a complex watershed can be considered as the summation of a number of unit source watersheds then its runoff can be considered as the summation of the runoff from its component unit areas. (Bernard, 1936) Amerman (1965) suggested that at least there should be a constant relationship between runoff from a complex watershed and runoff from its component unit source areas. Therefore if runoff can be predicted from a variety of unit source areas it should be possible to predict runoff (and presumably erosion from either complex ungauged catchments or for proposed changes in land use. (Amerman and McGuiness, 1966)

The validity of this concept is open to question on several grounds. For the moment the author's concern is that apart from any other considerations, this concept will only be valid when the unit source area is representative of another area. In this study the author cannot define with any real confidence any one plot (or unit source area) whose behaviour was "representative" of the community it was supposed to represent.

This difficulty in defining a representative site is the author's main reason for doubting the value of the results from earlier "observational" plot studies (see for example Costin et al, 1960; Gilmore, 1965; Soons, 1966). In these studies plot sites were subjectively chosen on the assumption that they represented a much wider area. This study has shown that, in this catchment at least, "homogeneous" areas can have highly variable rates of erosion. Therefore those studies which have established small numbers of plots at subjectively chosen sites cannot be expected to give useful results.

5.1.2 Influence of Season on Soil Loss

It was planned to clear the collection troughs of eroded soil at regular intervals so as to determine the influence of season on soil loss. However, the almost continual snow cover from late autumn until late spring made this impossible. Nevertheless from observations made during the study period, it is the author's opinion that most erosion takes place in late autumn and again in early spring. This is also the period when frost lift is most active. It is probable that ice needle development and subsequent decay is the most important factor influencing erosion in this catchment. The following example supports this view. A paint line two inches wide was laid across most plots to identify particular stones. Plate 12 shows that where the line covered bare ground, the film of paint gave the soil surface good protection against sheet erosion. However, this protection was lost by one freeze thaw cycle which caused widespread displacement of the surface material.

5.2 BIAS

5.2.1 Influence of Plot Sides

The results shown in Table 4 failed to establish significant differences between the movement of surface stones inside and outside each plot. However it cannot be concluded that the plot has no influence on the rate of erosion.

1. The use of ½ inch gravel to indicate surface movement is a crude technique. Under most conditions overland flow would not be expected to move material of this size. However, as this was the minimum size of particle which could be relocated with confidence these stones were used in the hope that they would indicate the existence of this bias. A negative result could not be interpreted as evidence that bias did not exist.

2. On some sites it appeared that the stability of the surface gravel depended on a mutual support phenomena. At a particular site, the downhill movement of the gravel was impeded by the stones immediately below. However, when the stones on the lower slopes were removed (for example in the collection trough) the stones above were able to move at increased rates. This is thought to be the reason for the increased movement noted inside some plots with respect to their adjacent areas (for example plots 9, 18 and 17).

3. On some sites (for example plots 10,12) there was much greater movement outside the plot than there was inside.

Plate 12

The paint line on plot 12 has protected the soil against sheet erosion. The pencil points to a small scarp which has formed on the downslope edge of the paint line.

In these cases, the plot had been established across a depression or minor debris channel. Here the plot sides interrupted the natural movement of surface material and gave considerable protection to the enclosed soil surface.

These results could not give a quantitative assessment of this bias, but they do suggest that the establishment of a plot will alter the rate of erosion at a site. While this influence may not be great on most sites, the movement at plot 10 suggests that at some sites the results may be significantly biased.

5.2.2 The Direct Capture of Windblown Sediment

The quantities of soil collected from the "control" troughs indicate that quite large stones can be blown across the ground surface.

Although it is not possible to make a quantitative assessment of this bias, it is suggested that because of it little reliance can be placed on the soil loss yields from any plot. It is a matter of speculation as to what the yields may have been had the control gutters been established at ground level. Nevertheless the author believes that the control trough yields cast serious doubts on origin of a large proportion of the eroded soil. For example, it is suggested that most of the soil collected from plots in sub-area III must have been windborne, and did not come from the well-covered plot surfaces. The author has observed the collection of windblown soil in this sub-area. Plate 13 shows the accumulation of soil particles and organic material on a snow pack adjacent to plot 3.

The importance of wind as a means of transporting soil and gravel particles was dramatically demonstrated on several occasions. In April 1967 two recently installed plots were blown out of the ground and the material for a third was blown out of the catchment. In February 1968 the average wind speed during a five hour visit was about 60 miles per hour. (Wind speed in Christchurch during the same period was about six miles per hour.) Winds of this order have been seen to move quite large particles.

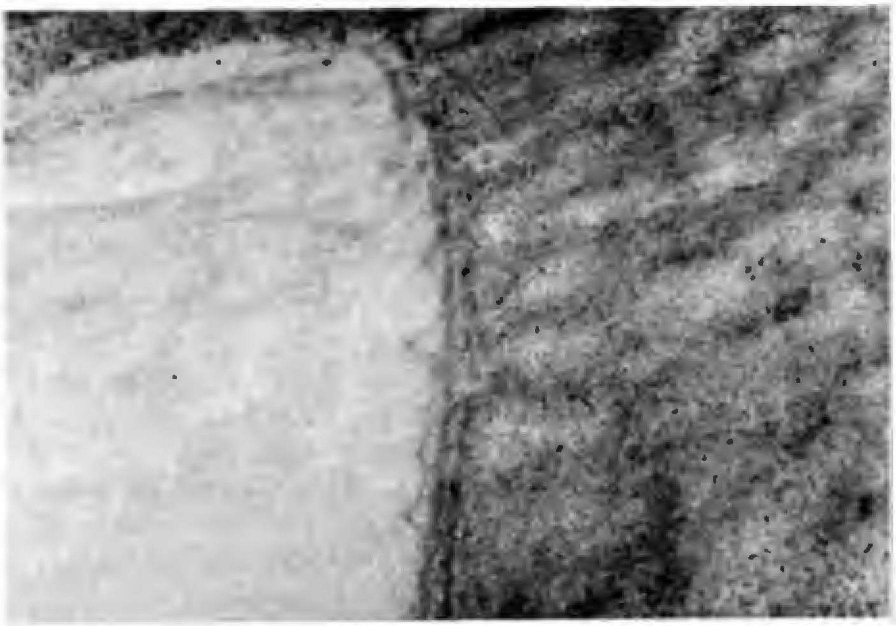


Plate 13

Accumulation of windblown soil on a snow pack adjacent to plot 3, October 1968.

(Debris has been cleared from the snow on the left hand side of the photograph)

Although most of the windblown material was soil and fine gravel, table 5 shows that the "control" troughs at plots 16 and 17 collected stones of up to ¾ inch minimum diameter. It should be noted that the opening to each trough was only about one inch and therefore there was a limited opportunity for larger stones to be caught.

5.2.3 Changes in Plot Slope

The results presented in fig. 10 are thought to show the first stages of real changes in slope. It is possible that the datum pegs were lifted slightly by frost heaving but the measured results support both the expected and observed behaviour of a lessening of slope with time.

5.2.4 Other Sources of Error

The soil loss yields probably contain errors due to frost heaving of the collection troughs. In the spring of 1968 needle ice lifted the collection troughs and left them up to one inch above the ground surface. Soil and gravel were observed to accumulate along the edge of the trough but were unable to gain entry. The plots in sub-areas I and II were the most severely affected by frost lift and it is probably that some of the variability in soil loss from these areas is due to this source of error.

Damage by frost heaving was first noticed during the calibration period. In the repair of this damage the collection troughs were bolted to the plot sides and coarser gravels were placed under each trough in the hope that this would be an unsuitable medium for the growth of ice needles. In addition the plot sides were held down to the soil surface by deformed steel pins. In most cases these were driven down to bedrock. These measures were apparently unsuccessful.

When strong winds swept over the study area, air was forced down the conveyance hose. Soil in the hose was literally blown out and sprayed around the inside of the storage drum instead of being caught in the sediment trap. This was probably a small source of error.

The sediment traps were quite efficient, even when full of water. However, in the low temperatures of winter and spring the water froze and traps, if full, became non-functional. Sediment produced by a thaw could not get into the trap, but overflowed into the storage drum. The amount of soil lost in this way is not known.

5.3 RUNOFF

5.3.1 Runoff Results

Runoff collection and recording were abandoned because the data were found to contain large errors and substantial bias.

5.3.2 Direct Capture of Rainfall

The results in table 6 showed that rainfall caught directly in the collection trough could on occasions form a highly significant part of "runoff". Moreover this addition to runoff was found to be highly variable and lacking any predictable pattern.

The most important factors influencing the amount of rainfall caught directly in the collection troughs appeared to be:

1. Storm direction
2. Wind velocity
3. Amount of protection given to the trough by over-hanging vegetation.

5.3.3 Leakages

Leakages into and out of each plot were another major source of error. From the use of water soluble dyes on three plots it can be assumed that on stony and porous sites, (e.g. sub-area I, II and V) the plots could not be adequately sealed. Leakages into the plot were detected but leakages out of each plot were probably more significant. The bituminous seal between soil surface and trough was broken in the winter/spring either by frost heaving, or by the weight of accumulated snow forcing the collection trough downhill. Although overland flow was not observed at any time during the study, it can be safely assumed that the equipment used in this study would be incapable of measuring this phenomena if it occurred.

5.3.4 Other Errors

The accumulation of snow in the lee of plot sides was not a constant nor predictable event. It appeared to depend on the plot location, the surrounding vegetation, storm direction, wind velocity and type of precipitation. Although this effect was observed only when it snowed, it is assumed to apply to other forms of precipitation. As a source of error this is probably only of importance in small plots such as those used in this study.

Snow falls confused any attempts to attribute "runoff" to particular storm events. For about five months of this study most plots had at least a partial snow cover. Delays in the thaw of each snowfall and fresh additions made it impossible to identify "runoff" from particular storms.

Difficulties were also experienced in measuring precipitation with the four inch diameter gauges. It is possible that these gauges may have given reliable information about rainfall, but they were inadequate in estimating snowfall. Their main failing was that early in a storm, snow bridged across the orifice and occasionally formed a frozen cap.

CHAPTER 6

CONCLUSIONS

6.1 SOIL LOSS

This study has shown the importance of plant cover on minimising soil loss, but it has not given clear evidence of the <u>amounts</u> of soil lost from the sub-areas of the catchment.

The main reason for this failure is thought to be the heterogeneous nature of the so-called "homogeneous" areas. In order to adequately account for the variability in behaviour of these areas very large numbers of plots would be needed. For example it has been estimated that about 150 plots would be needed to measure soil loss from sub-area II (bare ground) to about $\pm$ half a ton/acre, with 95 percent confidence.

However, even if large numbers of plots were used, the estimates of soil loss would incorporate considerable bias. The investigations of sources of bias in this study were unable to give a quantitative assessment of each source but quite clearly demonstrated that the measured yields would need considerable adjustment before they could indicate "true" loss.

The quantity of material caught in troughs two inches above the ground casts real doubt on the origin of a large part of the material collected from each plot. The author believes that if for no other reason, this source of bias makes runoff plots an unsuitable method of estimating erosion losses in the South Island high country.

From the comparisons of surface stone movements inside and outside some plots, the author concludes that by enclosing an area within a plot the rate of erosion at that site will be affected. The significance and direction of this bias will depend on location, type of surface material and erosive force (rain, frost).

Fig. 10 indicated that where the collection trough was fixed and could not be lowered to match the lowering of the ground surface, the plot slope would probably become less steep with time. Plate 10 showed that at some sites there could be a distinct change in the size of the eroding material. These observations lead the author to the general conclusion that in this area at least, valid comparisons of the same plot in different seasons cannot be made. This means that replication in time cannot be used as a substitute for the large number of replicates needed in each treatment. (This consideration is quite apart from the fact that replication in time does not overcome the problem of inadequate sampling.)

The damage caused by frost heaving and weight of snow leads the author to conclude that even if all the other problems could be overcome, the plot method is not suited to the harsh environment of most of the South Island high country.

Had the soil loss results been found to be significant, or nearly so, very much more attention would have had to be paid to the sources of bias. As it was, the method was found to provide inadequate data. The question of the extent to which the data were biased is therefore unimportant to these results.

Even if large numbers of plots were used and these could be protected from damage by frost or snow and their data were either free of bias, or bias could be accounted for, the plot method would only give information about soil movement on the catchment and not soil loss from it.

These points lead the author to the general conclusion that the plot method is totally unsuited for determining soil loss in this catchment and is unlikely to be useful in any area of South Island hill or high country.

6.2 RUNOFF

The plots were even less successful in providing information about runoff than they were in providing information about soil loss. The very real problems of obtaining reliable data showed that the plot method, as used, here, is an extremely crude technique.

It is possible that some sources of bias would be less significant on larger plots. (e.g. the importance of the direct capture of rainfall could be expected to decrease with increasing plot size.) Nevertheless sources of bias and error will always exist and must be accounted for. It is concluded that in the South Island hill and high country, fractional acre plots have no value for runoff determinations.

6.3 FORMER STUDIES

Because of the results of this study, the author has a number of doubts about the validity of the results of many of the studies of the last fifty years. While the general conclusions of most of these studies are probably correct, the quantitative estimates of soil loss may not be. For example Costin et al (1960) presented soil losses (lb/50 sq. ft) for natural forest, regrowth forest and depleted forest. They showed that the losses from natural forest were significantly different to those from regrowth or depleted areas. However, the plot sites were apparently selected as being typical of each community. It is the author's belief that an objective method of site selection would have produced different quantities of eroded soil which may or may not have altered the conclusions.

6.4 THE CONCEPT OF HOMOGENEITY IN CURRENT HYDROLOGIC RESEARCH

This study has shown the difficulties of selecting a site which is representative of a wider area. It has shown that whereas an area may be uniform with respect to soil, vegetation, slope, climate etc. this does not ensure uniformity with respect to its soil and water losses. Because of this the author believes that the Unit Source Watershed concept is unlikely to have any value in the South Island hill and high country. It will only be useful in other areas when it can be shown that the unit source areas do in fact represent the areas they are supposed to represent, both physiognomically and hydrologically.

If small so-called homogeneous areas show considerable variability in behaviour, it is fair to assume that larger areas will also show considerable variations in behaviour. The usefulness of the Representative Basin (see for example Toebes, 1966) is therefore open to question.

CHAPTER 7

SOME THOUGHTS FOR THE FUTURE

Fractional acre plots as used in this study have been shown to be a totally unsuitable technique for measuring soil loss in the South Island high country. The problem now is to find alternative procedures.

A possible solution is to persevere with plot studies and either use very large numbers of plots or seek greater uniformity in the areas under study.

It is doubtful if either of these propositions are feasible. Two of the principal advantages claimed for plots are their cheapness and ease of installation and maintenance. Installing and maintaining more than 1,000 plots would be neither cheap nor easy. In any case it is the author's opinion that the plot method has the major flaw of attempting to measure the effects of a treatment without any understanding of the basic mechanisms of the erosion processes. Rather than attempting to seek greater uniformity and measure effects, future studies should seek to understand the basic mechanisms of erosion. Once these are understood it should be possible to predict the erosion behaviour of a catchment on the basis of measurable properties, rather than assumptions of similarity. In the long run we will need to know the mechanisms of erosion before we can modify these to our advantage.

In this respect the mechanics of frost heaving, wind erosion and sheet erosion are worthy of detailed study as these are thought to be the most important erosion processes in the alpine areas of the South Island.

However, a detailed understanding of erosion processes will not in itself provide a definition of the erosion problem in alpine areas. Other approaches will be needed to do this.

The author advances the hypothesis that erosion of alpine land is not a problem related to pastoral productivity, but rather that it creates problems of water quality, channel aggradation and therefore flood control. One method of testing this hypothesis would be to examine the sources of sediments carried by streams. Suspended sediment and bed-load should be considered in relation to the condition of the catchment and its stream channel. Particular attention should be paid to erosion within the channel.

Future studies should therefore proceed along two main lines. On one hand studies of the sources of sediment in rivers and streams should provide a clearer definition of the problem associated with erosion of high altitude land. On the other hand studies of the mechanisms of the erosion processes should ultimately allow us to make predictions of the erosion behaviour of a catchment and predict its behaviour under a variety of cultural influences.

CHAPTER 8

SUMMARY

1. Although New Zealand has had statutory authority for erosion control since 1942, there is still no quantitative information about soil stability on steep slopes or of the influcence of plant cover in reducing rates of erosion.

2. This study was set up to investigate the erosion losses from the various communities which made up a catchment and from this to predict the losses from the catchment.

3. The fractional acre runoff plot method was chosen because it had been used for 50 years in the United States with apparent success, it was cheap, and it promised to give results quickly.

4. A review of former studies showed a number of weaknesses in their experimental designs. The most important were that little attention had been paid to the problems of uncertainty and bias. Only a few studies had replicated and randomised their treatments. None had considered the possibility that their results may have been biased.

5. In this study four plots were used to sample the erosion behaviour of each of the five communities (or sub-areas) which made up a 70 acre alpine catchment. It was hoped that the erosion behaviour of each community could be inferred from the behaviour of each sample and that from this total soil loss could be predicted for the catchment.

6. Three potential sources of bias of erosion data were investigated and three sources were similarly defined and investigated for the runoff results.

7. The soil loss results from a 12 month period showed great variability between communities and within communities. They quite clearly showed that whereas the sub-areas may have been physiognomically homogeneous they were highly heterogeneous with respect

to their erosion losses. With only four plots in each sub-area the estimates of mean loss were associated with error estimates of ± 34% (sub-area II), ± 100% (sub-area III), ± 230% (sub-area IV), and ± 80% (sub-area V). (At the 95% confidence interval) Whereas the study showed the importance of ground cover in minimising erosion, it failed to show that the absolute values of erosion were significantly different between areas. Statistical analysis indicated that the variability within areas was greater than the variability between areas.

8. More conclusive results could only be obtained from a very much larger sample. For example it was estimated that to measure soil loss to within ± 0.22 lb per plot (about 0.1 tons per acre) a total of about 3,300 plots would be needed.

9. However, the investigations of bias indicated that even if such large numbers of plots were used the data would be of limited usefulness. For example it was concluded that the establishment of a plot influenced the erosion rate at that site. It was not possible to predict the direction or extent of this bias. It was also found that considerable quantities of soil and gravel could be blown into the collection trough, either from the plot or from the surrounding land. Thus the origin of an unknown proportion of the collected material is uncertain. Even within the short period of this study observations suggested that the size of the surface particles had changed and that the slope of some plots was lessening. It will probably not be valid to compare the behaviour of these plots between several seasons.

10. The collection of runoff was abandoned when these results were found to include substantial bias, and large errors. Despite shielding of the collection trough rainfall was caught and added to the runoff. On a number of occasions collection troughs not connected to a plot gave a greater yield of "runoff" than did the adjacent plot. This source

of error was neither constant nor predictable. The runoff results were still further confused by leakages into and out of each plot.

11. The author has concluded that the runoff plot method is a totally unsuitable one for erosion research in the South Island hill and high country. He has suggested that future studies should attempt to understand the mechanisms of the erosion processes rather than measure their effects. In this way it would ultimately be possible to predict erosion on the basis of measurable properties, rather than of assumptions of similarity.

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APPENDIX A

SOIL PROFILES

The terminology for the descriptions of the Kaikoura and Tekoa soils is based on the Soil Survey Manual, (United States Department of Agriculture, 1951). The description of the Alpine profile is taken from Molloy (1964).

The method for the mechanical analysis of the soil fraction has been described by Bouyoucos (1964).

Soil Type:	Kaikoura stony sandy loam (strongly eroded phase)
Soil Set:	Kaikoura steepland soil
Location:	100 yards west of plot 18
Map Sheet:	N.Z.M.S. 1 S74 Grid reference: 860,217
Terrain Class:	Strongly-steeply sloping slope: 25°
Landform:	Upper mid-slope of strongly eroding steep ridge side - with discontinuous patches of scree.
Aspect:	East Elevation: 3,400'
Drainage:	Site: Well drained - shedding site Internal: Moderately well drained
Vegetation:	Present: Scattered <u>Chionochloa</u> and <u>Dracophyllum</u> - no vegetation over site Past: Tall tussock community - previously subalpine Beech
Parent Material:	Colluvial greywacke debris forming active scree

Profile:

(A)	0-2½"	Yellowish brown (10YR5/4) very stony sandy loam, loose (peds friable to very friable) weak fine crumb, few roots, very porous, very stony angular moderately weathered greywacke gravels to large stones, distinct boundary to -
B_2	2½"-7"	Yellow (10YR6.5/6) very stony silt loam, loose (peds very friable), weak fine crumb and some tendency for very weak nutty aggregation, common roots both fine fibrous and decaying medium woody roots, very porous, very stony angular moderately weathered gravels to large stones of greywacke, boundary distinct and merging to -
uB_2	7-12"	Pale yellow (2.5Y6.5/4) very stony sandy silt loam, loose to very friable, very weak fine crumb and single grain, common fine fibrous roots, very porous, very stony angular moderately weathered greywacke gravels to large stones, merging through a lower zone of large (non oriented) stones and common roots to -
uB_3	12-19"	Pale yellow (2.5Y6.5/4) extremely stony sandy loam, friable (peds Loose) very weak fine crumb and single grain, few fine roots, extremely stony angular moderate to weakly weathered gravels to large stones of greywacke, merging to -
uC	19" +	Light yellowish brown (2.5Y6/4) extremely stony sandy loam, loose, very weak fine crumb and single grain, rare roots, extremely stony angular weakly to moderately weathered gravels to boulders of greywacke.

There is only a very weak slow reaction to the allophane field test in the upper and lower horizons, the other horizons give a moderate to weak positive reaction to this test.

Soil Type: Tekoa sandy loam

Soil Set: Tekoa

Location: 100 yards north east of plot 2

Map Sheet:	N.Z.M.S. 1 S74 Grid Reference: 860,214
Terrain Class:	Steeply sloping Slope: 32°
Landform:	Footslope of steeply sloping well covered hillside
Aspect:	S.W. Elevation: 3,300'
Drainage:	Site: well drained - shedding site Internal: moderately well drained
Vegetation:	Present: dense cover of _Dracophyllum_, _Chionochloa rigida_, _Celmisia_ ssp., _Festuca_, _Novae-zelandiae_, _Gaultheria_, and _Helecrysum_ Past: subalpine Beech forest
Parent Material:	Thin deposit of colluvial gravels and large stones over greywacke, with thin greywacke gravel and sand overlying.
Profile:	Very thin almost discontinuous litter of plant fragments.

A_1	0-1"	Dark brown (7.5YR3/2) peaty sandy loam, loose, principally of decomposing fragments of snow grass and _Dracophyllum_.
(A_2)	1-5"	Dark brown (10YR3/3) sandy loam, loose to very friable, moderate fine crumb, many fine roots, very porous, few small soft pieces of charcoal, indistinct boundary to -
ABh	5-8"	Dark brown (7.5YR3/3) sandy loam, loose to very friable moderate fine crumb and some very weak nutty (fine) aggregation, many fine roots, very porous, incorporating thin lenses of peaty material along upper boundary in some places, distinct boundary to -
B_3	8-10"	Dark brown (10YR4/3) silt loam, very friable to friable, (peds very friable), moderate fine crumb and weak fine nutty, common fine roots, very porous, few scattered soft pieces of charcoal, few subangular moderately weathered greywacke stones, boundary indistinct and merging to -

C	10-17"	Brown (10YR4/3 sandy loam, very friable, weak fine crumb and very weak fine nutty, common fine roots, very porous, few scattered soft pieces of charcoal, common subangular moderately weathered greywacke stones, distinct clear boundary to -
uA_1	17-20"	Very dark greyish brown (10YR3/2) humic silt loam, very friable, weak fine crumb and some very weak fine nutty aggregation, common fine roots, very porous, common soft small pieces of charcoal; distinct and irregular boundary to -
uA_2	20-25"	Yellowish brown (10YR5/4) silt loam, friable (peds very friable to friable) weak to moderate fine nutty and weak fine crumb, few roots, common fine pores, few medium roots in various stages of decomposition, rare subangular moderately weathered greywacke stones, indistinct boundary to -
uAB	25-30"	Yellowish brown (10YR5/6) silt loam, friable (peds very friable to friable), weak to moderate fine nutty and weak fine crumb, few fine roots, common fine pores, rare subangular moderately weathered stones, distinct irregular boundary to -
uB_2	30-35"	Strong brown (7.5YR5/6) silt loam - slightly gritty, friable (peds friable to very friable) weak fine nutty and fine crumb, rare fine roots, common fine pores, few angular weakly-moderately weathered greywacke stones, irregular merging boundary to -
uB_3	35-38"	Yellowish brown (10YR5/6) sandy silt loam, friable weak medium and fine nutty and fine crumb, rare fine roots, common fine pores, few angular weakly-moderately weathered greywacke stones, irregular and distinct boundary to -
uC	38" +	Light olive brown (2.5Y5/4) very stony sandy loam, slightly compact (peds very friable), weak fine crumb, very stony angular weakly weathered greywacke gravels and stones.

Soil Type:	Alpine
Location:	About 400 ft below the summit of Foggy Peak
Altitude:	5,300 ft a.s.l.
Slope:	38^{o}
Aspect:	N.E.

Profile:

SA_1	12"	Fresh greyish angular greywacke fragments mixed with weathered and unweathered chips, sands and silts; loose; structureless; boundary distinct.
UB_2	4½"	Yellowish brown (10YR5/4) sandy loam; very friable; weakly developed fine nutty structure breaking down to crumb, few partly decomposed fine roots; boundary distinct.
UC		On coarse angular debris, greywacke fragments, sands and silts; loose; structureless.

	Horizon		"Soil" Composition (% by weight)			Mechanical analysis of soil fraction (%)		
			Soil less than 2 mm	Gravel 2mm - ¾"	Stones more than ¾"	Sand 2.0 - 0.02 mm	Silt 0.02 - 0.002 mm	Clay less than .002mm
Kaikoura soil	A :	0-2"	39	55	6	66	18	16
100 yards west	B_2 :	3-6"	45	55		66	20	14
Plot 18	UB_2 :	8-12"	18	41	41	66	16	18
Tekoa soil	A_2 :	1-5"	96	4		84	10	6
100 yards N.E.	ABh :	5-8"	97	3		80	14	6
Plot 2	B_3 :	8-10"	86	14		68	20	12
	C :	10-17"	69	25	6	64	20	16
	UA_1 :	17-20"	90	10		62	14	14
	UA_2 :	20-25"	73	19	8	54	23	18
	UB_2 :	30-35"	65	15	20	62	26	12
	UC :	38 + "	39	26	35	84	12	4

APPENDIX B

Meteorological Data November 1957 - December 1958
Adapted from Molloy (1959)

Climate Station "A"

Altitude: 3,500 ft

Aspect: S.W.

Slope: 28°

Approx. 300 yards south of plot 20.

Climate Station "C"

Altitude: 4,500 ft

Aspect: S.W.

Slope: 30°

Approx. 150 yards south west of plot 7.

	1957	1958											
	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Total
Precipitation, inches													
"A"	8.3	6.3	1.6	5.1	2.4	6.3	0.8	0.4	5.1	1.2	3.9	2.0	43.4
"C"	11.4	6.3	1.2	7.1	2.4	4.8	0.3	0.3	2.0	1.2	3.4	1.5	41.9
Approximate potential evapotranspiration, inches													
"A"	2.2	3.1	3.5	2.7	1.6	0.7	0.3	-	0.5	0.9	2.1	3.1	20.7
"C"	2.5	3.0	3.3	2.5	1.2	0.5	-	-	-	-	1.5	2.8	17.3
Maximum monthly temperature ^{o}C													
"A"	21	26	27	25	19	15	12	10	11	16	20	29	
"C"	20	26	27	24	17	11	8	7	7	12	18	25	
Minimum monthly temperature ^{o}C													
"A"	1	0	5	0	-2	-7	-6	-10	-8	-8	-4	-5	
"C"	-3	-3	4	-2	-5	-9	-9	-10	-11	-10	-7	-6	
Mean monthly temperature ^{o}C (approx.)													
"A"	9.7	11.5	16.0	12.0	8.5	3.6	3.0	0.0	2.7	4.2	8.2	12.2	
"C"	8.5	10.5	14.5	10.5	5.7	2.2	-0.5	-1.0	-1.5	0.7	5.7	10.2	

APPENDIX C

Ground Cover on all Plots

Ground cover determinations were made in November 1968. The description of each plot is based on the point method of sampling, described by Levy and Madden (1933). A frame held five vertical needles at six inch centres. Each needle was pushed down to the ground and the ground cover at the needle point was recorded.

Strikes on canopy cover were disregarded. One hundred points were recorded on each plot and while this sample may indicate the essential features of each plot, it is not large enough to allow detailed comparisons between plots.

On plots 3, 4, 13 and 14 the canopy of vegetation made it impossible to use the point frame. On these sites the plots were subdivided into eight quadrats and a visual estimate of percentage ground cover was made in each quadrat.

Legend:

B	:	Bare ground (or surface material less than ½" diameter)
S	:	Stones (½" - 4")
R	:	Rock (greater than 4")
DM	:	Dead plant material *in situ*
L	:	Litter
Ac. au.	:	*Aciphylla aurea*
An. od.	:	*Anthoxanthum odoratum*
Bl. pe.	:	*Blechnum penna-marina*
Ce. vi.	:	*Celmesia viscosa*
Ch. ri.	:	*Chionochloa rigida*
Co. sp.	:	*Coprosma*
Cy. fr.	:	*Cyothodes fraseri*

Dr. ac.	:	*Dracophyllum acerosum*
Eu. re.	:	*Euphrasia revoluta*
Fe. no.	:	*Festuca novae-zelandiae*
Ga. ru.	:	*Gaultheria rupestris*
Lu. ca.	:	*Lusula campestris*
M	:	Matt plant
Pi. tr.	:	*Pimelia traversii*
Po. co.	:	*Poa colensoi*
Se. la.	:	*Senecio lagopus*

Plot 1

Ch. ri.	19
Ga. ru.	7
Pi. tr.	1
Dr. ac.	5
Ce. vi.	2
Fe. no.	2
Se. la.	2
Ac. av.	4
Po. co.	2
L	15
DM	40
B	1
	100

Plot 2

Ch. ri.	21
Ac. ri.	2
Po. co.	4
Bl. pe.	3
Ga. ru.	4
An. od.	2
Ce. vi.	2
Cy. fr.	2
M	1
Pi. tr.	1
Co. sp.	5
DM	46
L	7
	100

Plot 3 - 100% plant and litter cover

Plot 4 - 100% plant and litter cover

Plot 5

B	1
S	57
R	42
	100

Plot 6

B	-
S	73
R	27
	100

Plot 7

B	-
S	63
R	37
	100

Plot 8

B	-
S	58
R	42
	100

Plot 9

B	55
S	39
R	5
	100

Plot 10

B	45
S	48
R	7
	100

Plot 11

B	55
S	27
R	-
Ga. ru.	3
Dr. ac.	3
Ce. vi.	2
An. od.	1
DM	7
L	2
	100

Plot 12

B	62
S	17
R	1
Dr. ac.	6
Eu. re.	2
Ce. vi.	3
Se. la.	1
DM	3
L	5
	100

Plot 13 - 100% plant and litter cover

Plot 14 - 100% plant and litter cover

Plot 15

B	32
S	64
R	4
	100

Plot 16

B	34
S	66
	100

Plot 17

B	18
S	82
	100

Plot 18

B	61
S	38
R	1
	100

Plot 19

B	74
S	17
R	9
	100

Plot 20

B	29
S	66
R	5
	100

APPENDIX D

Analysis of Variance Calculations

A. Analysis of Yields Shown in Table 2

Sub-area	Yields from four plots				
I	2.34	3.90	3.05	2.86	12.15
II	1.00	2.69	13.70	0.55	17.94
III	0.08	0.04	0.01	0.03	0.16
IV	0.39	1.59	0.04	0.03	2.05
V	0.42	0.25	0.31	0.08	1.06
					33.36

Correction factor (C.F.) $= \frac{(\Sigma x)^2}{n}$

$= \frac{(33.36)^2}{20}$

$= 55.81$

Total sum of squares $= (2.34)^2 + (3.90)^2 + \ldots.(0.08)^2 - \text{C.F.}$

$= 237.42 - 55.81$

$= 181.61$

Sub-area sum of squares $= \frac{(12.15)^2 + (17.94)^2 + \ldots(1.06)^2}{4} - \text{C.F.}$

$= 118.70 - 55.81$

$= 62.89$

Analysis of Variance Table

Source of Variation	Degree of freedom	Sum of squares	Mean square	Variance ratio (F)
Sub-areas	4	62.89	15.72	1.98
Error	15	118.72	7.91	
Total	19	181.61		

Variance ratio values for 4 d.f. sub-areas and 15 d.f. error

= 2.36 at 10% significance level

= 3.06 at 5% significance level

= 4.89 at 1% significance level

Therefore the null hypothesis cannot be rejected.

B. Analysis of Variance Using a Logarithmic Transformation of the Yields Shown in Table 2

Sub-area	Logarithmic values of soil loss yields				
I	.3692	.5911	.4843	.4564	
II	.0000	.4298	1.1367	$\bar{1}.7404$	
III	$\bar{2}.9031$	$\bar{2}.6021$	$\bar{2}.0000$	$\bar{2}.4771$	
IV	$\bar{1}.5911$	.2014	$\bar{2}.6021$	$\bar{2}.4771$	
V	$\bar{1}.6232$	$\bar{1}.3979$	$\bar{1}.4914$	$\bar{2}.9031$	
=					
I	.3692	.5911	.4843	.4564	1.90
II	.0000	.4298	1.1367	-.2596	1.31
III	-1.1938	-1.3979	-2.0000	-1.5229	-6.11
IV	-.4089	.2014	-1.3979	-1.5229	-3.13
V	-.3768	-.6021	-.5086	-1.0969	-2.58
					-8.61

Correction factor $= \dfrac{(\Sigma x)^2}{n}$

$= \dfrac{(-8.61)^2}{20}$

$= 3.70$

Total sum of squares $= (.3692)^2 + (.5911)^2 + \ldots(-1.0969)^2 - \text{C.F.}$

$= 18.60 - 3.70$

$= 14.90$

Sub-area sum of squares $= \dfrac{(1.90)^2 + \ldots (-2.58)^2}{4} - \text{C.F.}$

$= 14.78 - 3.70$

$= 11.08$

Analysis of Variance Table

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratio
Sub-areas	4	11.08	2.77	11.08
Error	15	3.82	0.25	
Total	19	14.90		

Variance ratio for 4 d.f. sub-areas and 15 d.f. error

= 4.89 at 1% significance level

Therefore the null hypothesis can be rejected.

APPENDIX E

Movement of half inch stones inside and outside some plots from 8th March to 30th May 1968.

In every case lines 1 and 2 were inside the plot, and lines 3 and 4 were on the adjacent plotless areas.

Line no.	Plot	Distance from original line (inches) and number of stones within each distance class											
		0-3"	3-6"	6-9"	9-12"	12-15"	15-18"	18-21"	21-24"	24-27"	27-30"	30-33"	33-36"
1	20	126	10										
2	20	74	35	16	1								
3	20	116	31										
4	20	109	52	1									
1	19	1	19	40	38	24	11	9	10	6	1	1	1
2	19	27	23	25	56	10							
3	19	1	24	48	36	3							
4	19	0	28	30	37	15							
1	18	57	95	17									
2	18	90	63	4									
3	18	133	24										
4	18	117	5	1									
1	17	4	79	9									
2	17	126	0	1									
3	17	104	14	2									
4	17	87	29	0	0	0	1						
1	16	64	32	14	11	6	3	2					
2	16	58	59	11	2	2	2	1					
3	16	52	47	26	6	0	1						
4	16	19	39	42	4	1							
1	15	18	32	24	23	6	4	1	1	0	1	0	2
2	15	70	53	20	3								
3	15	36	52	22	6	1	1						
4	15	35	50	44	10	6	1	2	0	0	0	0	3

Line no.	Plot	Distance from original line (inches) and number of stones within each distance class											
		0-3"	3-6"	6-9"	9-12"	12-15"	15-18"	18-21"	21-24"	24-27"	27-30"	30-33"	33-36"
1	12	16	7	14	33	11	15	6	7	1	1	0	1
2	12	49	35	30	14	7	3	5	4	4	1	1	2
3	12	5	5	9	52	62	21	0	4	3	2		
4	12	0	43	28	32	14	10	43	9	2			
1	10	34	45	43	11	10	1						
2	10	56	18	24	14	6	0	1	1	0	0	0	1
3	10	0	0	0	0	14	15	28	44	24			
4	10	0	0	23	60	21	13	7	2	0	0	0	2
1	9	70	93	28	3	1							
2	9	15	57	41	4	1	0	1					
3	9	44	86	18	1								
4	9	164	25	4									

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